THE ROLE OF BEAM DIAGNOSTICS IN THE RAPID COMMISSIONING OF THE TPS BOOSTER AND STORAGE RING

P. C. Chiu, C.Y. Liao, C. Y. Wu, K. H. Hu, Y.S. Cheng, C. H. Huang, Demi Lee, Jenny Chen, C. H. Kuo, K.T. Hsu
NSRRC, Hsinchu 30076, Taiwan

Abstract

The TPS is a newly constructed 3-GeV third-generation synchrotron light source featuring ultra-high photon brightness with extremely low emittance. After some hardware improvement especially demagnetization of chamber are completed, the commissioning of the beam in the booster ring began on December 12 and attained 3-GeV energy on December 16. The storage ring obtained its first stored beam and delivered synchrotron light on December 31[1][2]. This report summarizes the role of beam diagnostic for hardware improvement and parameter tuning during TPS successful commissioning.

INTRODUCTION

The TPS accelerator complex consists of a 150 MeV S-band linac, linac to booster transfer line (LTB), 0.15–3 GeV booster synchrotron, booster to storage ring transfer line (BTS), and 3 GeV storage ring. The linac was a turn-key system delivery by RI GmbH. The booster and the storage ring share the same tunnel in a concentric fashion. The booster has 6 FODO cells and its circumference is 496.8 meters. The Storage Ring's circumference is 518.4 meters with 24 DBA lattice and 6-fold symmetry [3].

To catch up the delayed schedule due to construction delay, it was decided to perform system test and beam commissioning in parallel just after get operation permission from government authority in mid August. After solved overheating problem of the booster dipole power supply and optimize post-pulse residual field of the booster injection kickers, multi-turn circulating beam was observed in the booster synchrotron in beginning of September. These hardware problems are mostly due to the limited rush time before operation. However, the captured and stored beam intensity is decay exponentially even any kind of efforts were did such as orbit optimization, add extra correctors, chamber and magnet re-alignment and etc. Finally, it was recognized the relative permeability (ranging from 1.2 to 2.0) of the pipes arising from the cold-drawn process of the booster vacuum pipe was too large on November 12. After dismantle vacuum pipe, heat treatment, and re-install again, beam was stored successfully on December 12, energy ramp to 3 GeV on December 16. Later, after improving field leakage of booster extraction DC septum, we had a 5-mA stored beam on Dec. 31 2014. Diagnostic system played a helpful rule to provide beam profile and information to improve or tune subsystem to make progress quickly during beam commissioning. This report will brief about diagnostics for TPS.

SCREEN MONITOR

The screen monitor system is the most import destructive monitor during the TPS beam commissioning. There are 33 screen monitor systems distributed around Linac (5), LTB (5), booster synchrotron (7) , BTS (5), storage ring (4), and frontend (7). The screen monitor is responsible for the beam profile acquisition from fluorescent screen and used to analysis to find the beam characteristic data. The beam profile image has extensive information on beam parameters, including beam center, sigma, tilt angle and etc. The system contains YAG:Ce screen, lens, lighting system, LEDs illuminator, and GigE Vision CCD camera. A pneumatic device is used to move the whole assembly in or out. All of these devices are controlled remotely including the CCD power control, screen in/out control and LED lighting system. The camera timing trigger clock is locked with TPS injection system, which is produced from a local timing IOC (EVR). Based on the area Detector module which provides a general-purpose interface for area (2-D) detectors in EPICS, it is easy to construct a camera control panel by using the EDM, and analysis tool by using the Matlab tool. Figure 1 shows the beam profile observed at booster 1st screen monitor.

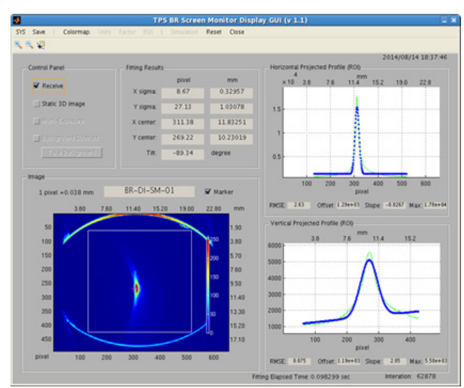


Figure 1: Beam profile at booster 1st screen monitor.

INTENSITY MONITOR

Linac contracted to RI GmbH is provided two Faraday cups and two warm current monitors. Figure 2 shows bunch waveform observed by the wall current monitor just after electron gun. There are two ICTs and two FCTs for LTB, two ICTs and one FCT at BTS where Figure 3 shows ICT waveform at LTB for single bunch beam and

ISBN 978-3-95450-176-2

SNS BEAM DIAGNOSTICS: TEN YEARS AFTER COMMISSIONING

A. Aleksandrov
Oak Ridge National Laboratory, Oak Ridge, TN 37830 USA

Abstract

The Spallation Neutron Source, a neutron scattering user facility based on a 1.4 MW proton accelerator, has been in operation since 2006. The accelerator beam diagnostics were designed, in large degree, with commissioning unknowns in mind. Today we face new challenges to support stable 1 MW beam power operations and an accelerator upgrade for even higher power. The beam instrumentation problems span a range from mitigating obsolescence of many electronics to developing new techniques for measuring beam parameters important for high power operation. This report describes several examples of the ongoing work: development of new electronics for the Beam Position Monitor (BPM) and Beam Loss Monitor (BLM) systems to replace the aging designs; and development of large dynamic range and high precision beam phase space characterization tools to facilitate model based accelerator tuning.

INTRODUCTION

The SNS accelerator complex consists of an H^- injector, capable of producing one-ms-long pulses with 38 mA peak current, chopped with about 70% beam-on duty factor and a repetition rate of 60 Hz to produce 1.6 mA average current; an 87 MeV Drift Tube Linac (DTL); a 186 MeV Coupled Cavity Linac (CCL); a 1 GeV Super Conducting Linac (SCL); a 1 GeV Accumulator Ring (AR); and associated transport lines. A diverse set of diagnostics is used to monitor various parameters of the beam [1] in the accelerator. Results of the initial beam instrumentation commissioning and operation experience can be found in [2]. The Second Target Station Project (STS) [3] aims at doubling the beam power. This will be achieved by increasing the SCL and AR beam energy to 1.3 GeV and the peak current in the linac to 59 mA.

After completion of the initial beam commissioning and gradual power ramp up, the SNS accelerator complex has been delivering proton beam to the neutron target for about 4500 hours per year with availability exceeding 80%. As shown by a historical plot of the beam power on the target in Fig. 1, the beam power has been mostly above 1 MW since 2010 and close to the design level of 1.4 MW lately.

With the SNS entering routine neutron production operations, the roles and requirements for the beam diagnostics are changing as well. Only a limited subset of diagnostics is absolutely required during steady neutron production: the Beam Loss Monitors to ensure accelerator safety, the Beam Current Monitors for beam accounting, and a multi-wire monitor (the Harp) to validate the beam size on the target. Reliability and maintainability are the most important qualities for these systems. Additional diagnostics are needed to tune the machine after long maintenance periods or significant configuration changes (e.g. taking out of service failed superconducting RF cavities): the Beam Position and Phase Monitors (BPM) and some Wire Scanners. The rest of the diagnostics systems provide convenience for operators (e.g. the Target Imaging System) or are used for machine studies. The main thrust of the machine studies is to create a realistic beam dynamics simulation tool to facilitate machine tuning and improve beam transport.

This paper describes the ongoing development work for selected systems from each category.

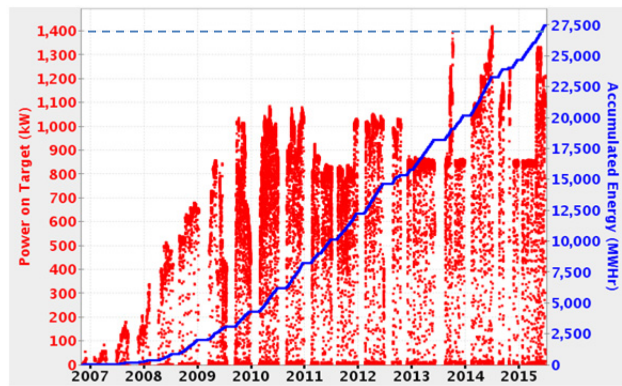


Figure 1: A history of beam power on the target (red points) and accumulated beam energy (blue line). The dashed line shows the design beam power level.

OBSOLESCENCE MITIGATION EFFORTS

The original set of SNS diagnostics was designed about 15 years ago, which is quite a significant time in the electronic components industry. Many of the parts became or are becoming obsolete and many of them do not have a direct replacement suitable for drop in replacement. We have a sufficient amount of spare parts for supporting operations in the short term but replacement electronics need to be developed for long term sustainability. This task is easier in some regards compared to developing the original diagnostics: we know precisely what is needed for operation as all uncertainties of the machine commissioning already have been resolved; there is less schedule pressure; and there is less equipment to install at once. On the other hand, there are additional constraints: the available operational budget and manpower is significantly smaller compared to the construction project. Therefore, we use the following approach to all new electronics design:

ISBN 978-3-95450-176-2

OVERVIEW AND STATUS OF SWISSFEL DIAGNOSTICS

V. Schlott, V. Arsov, M. Baldinger, R. Baldinger, G. Bonderer, M. Dehler, R. Ditter, D. Engeler, F. Frei, S. Hunziker, R. Ischebeck, M. Kaiser, B. Keil, W. Koprek, R. Kramert, F. Marcellini, G. Marinkovic, G.-L. Orlandi, C. Ozkan Loch, P. Pollet, M. Roggli, M. Rohrer, A. Romann, S. Schnabel, M. Stadler, D. Treyer, PSI, Villigen, Switzerland

Abstract

SwissFEL is an X-ray free electron laser user facility presently under construction at the Paul Scherrer Institut (PSI) in Villigen, Switzerland. All diagnostics systems have been developed and successfully tested within the baseline SwissFEL parameters, including a low charge, ultra-short pulse operation mode. The monitor designs have been finished, production is ongoing and most of the components are ready for installation. The paper will give an overview of the SwissFEL diagnostics systems, highlight some of the instrumentation developments, summarize the latest results and report on the installation and commissioning schedule.

SWISSFEL

SwissFEL is a compact free electron laser user facility presently under construction at the Paul Scherrer Institut in Villigen, Switzerland [1]. In its first project stage, which lasts from 2012 – 2017, it will provide hard X-rays with photon energies ranging from 4 to 12 keV to the three ARAMIS user end-stations [2]. In a second project stage, which is scheduled for 2018 – 2020 soft X-ray users will be served by an additional FEL line, called ATHOS [3].

Most of the SwissFEL key accelerator components (e.g. solid state modulators, C-band accelerator structures, in-vacuum undulators, as well as the optical synchronization system and also the beam instrumentation devices) have been developed and successfully tested at the SwissFEL Injector Test Facility (SITF) during the past years. The SwissFEL building is almost ready for occupation and the technical infrastructure is presently being built up, so that installation of accelerator components can start by the end of 2015 and commissioning of the accelerator complex has been scheduled for spring 2016.

The SwissFEL electron beam is generated in a 2½ cell S-band photo-injector RF gun, which provides a 7 MeV, low emittance beam with bunch charges of 10 to 200 pC at a bunch repetition rate of 100 Hz. The S-band injector LINAC, which boosts the beam energy up to 450 MeV, contains a laser heater and two X-band RF structures, located in front of the first magnetic bunch compression stage (BC-1) for linearizing the longitudinal phase space. Further acceleration to 2.1 GeV is achieved by the C-band LINAC-1, before the electron bunches are fully compressed in the second bunch compressor (BC-2) to 2.5 fs (at 10 pC) respectively 20 fs (at 200 pC). The C-band LINAC-2 and LINAC-3 are ramping the beam energy up to its final value of 5.8 GeV before the electron bunches are transferred to the hard X-ray ARAMIS FEL line. For the future ATHOS soft X-ray FEL line, a second bunch will be accelerated at a distance of 28 ns and extracted in a magnetic switchyard at beam energies of 2.4 GeV. All diagnostics components have accounted for this two-bunch option already during their design stage and beam tests have been executed at the SITF [5, 6] in

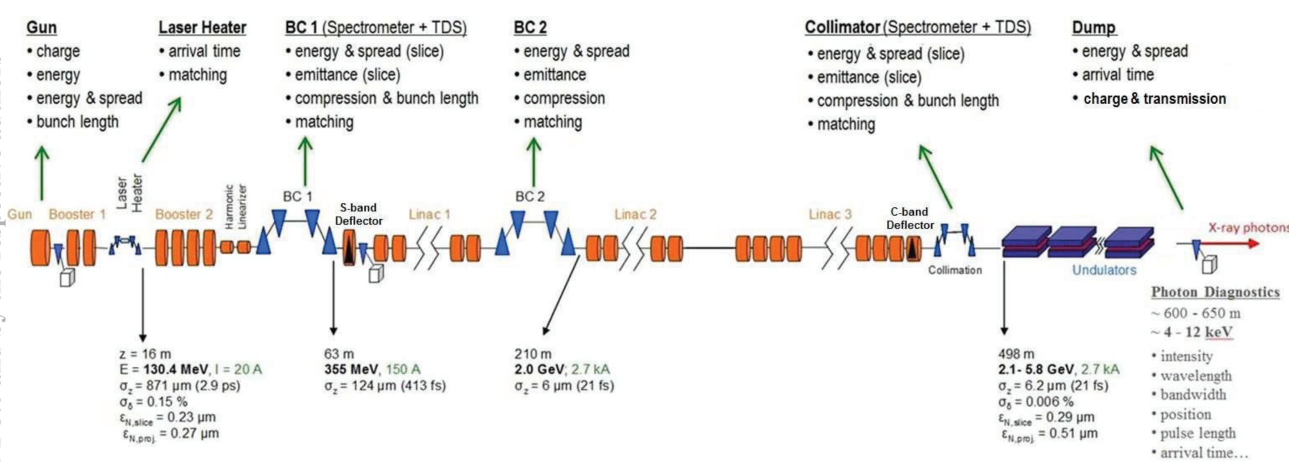


Figure 1: Schematic overview of the SwissFEL hard X-ray ARAMIS line, which will be set-up in the first project phase. Locations are indicated, where the most important beam parameters will be measured during set-up and commissioning and monitored during operation. In addition (not shown here), beam position monitors, loss and charge monitors as well as wire scanners and screens are distributed along the machine to measure transverse beam positions and profiles as well as transmission and losses. Photon diagnostics is set-up in the ARAMIS front end.

ISBN 978-3-95450-176-2

MICROBUNCHING INSTABILITY IN RELATIVISTIC ELECTRON BUNCHES: DIRECT OBSERVATIONS OF THE MICROSTRUCTURES USING ULTRAFAST YBCO DETECTORS

E. Roussel, C. Evain, C. Szwaj, S. Bielawski, PhLAM/CERLA, Villeneuve d'Ascq, France
J. Raasch, P. Thoma, A. Scheuring, M. Hofherr, K. Ilin, S. Wünsch, M. Siegel
KIT, Karlsruhe, Germany
M. Hosaka, N. Yamamoto, and Y. Takashima, Nagoya University, Nagoya, Japan
H. Zen, Kyoto University, Kyoto, Japan
T. Konomi, M. Adachi, S. Kimura, M. Katoh, UVSOR, Okazaki, Japan

Abstract

Relativistic electron bunches circulating in accelerators are subjected to a dynamical instability leading to microstructures at millimeter to centimeter scale. Although this is a well-known fact, direct experimental observations of the structures, or the field that they emit, remained up to now an open problem. Here, we report the direct, shot-by-shot, time-resolved recording of the shapes (including envelope and carrier) of the pulses of coherent synchrotron radiation that are emitted, and that are a "signature" of the electron bunch microstructure. The experiments are performed on the UVSOR-III storage ring, using electrical field sensitive $YBa_2Cu_3O_{7-x}$ thin-film ultrafast detectors. The observed patterns are subjected to permanent drifts, that can be explained from a reasoning in phase space, using macroparticle simulations.

INTRODUCTION

Recent coherent synchrotron radiation (CSR) studies in storage rings have heightened the need for understanding the dynamics of electron bunches during the microbunching instability which is a source of intense emission of THz CSR pulses. This instability is known to lead to the formation of structures at millimeter scale in the longitudinal direction of the electron bunch [1]. However, direct observations of the dynamics of these microstructures were an open challenge up to now. Indeed, this requires to detect CSR pulses of hundreds or tens picoseconds length with internal structures at one to tens of picoseconds. Moreover, high-acquisition rate, typically of the order of tens of megahertz, would be required. Thus far, only indirect measurements were achieved by recording the spontaneously emitted coherent signal with slow detectors (at best with microsecond response time) [2–9] or by perturbating the electron bunch with an external laser [10, 11].

In this paper, we report on the first real time recordings of the pulse shape (envelope and carrier) associated with the CSR emitted during the microbunching instability when the electron bunch exceeds several tens of picoseconds [12]. The measurements have been obtained on the UVSOR-III storage ring [13] and have been possible through a new type of detector based on thin-film YBCO superconductor [14–16]. This detector has been developed at the Karlsruhe Institute of Technology (KIT) in Germany. We performed two types of experiments: the first one aims at studying the spontaneous emission of CSR during the microbunching instability; the second one aims at looking at the response of the electron bunch to a localized laser perturbation [2]. We describe the dynamics of CSR pulses from longitudinal phase-space motion.

EXPERIMENTAL SETUP

UVSOR-III Storage Ring

For the study of the spontaneous CSR emission, the UVSOR-III storage ring is operating in single bunch mode and the injected beam current is initially set above the instability threshold (here, around 53 mA). Under these conditions, the electron bunch emits CSR in the sub-terahertz frequency range which is a feature of the presence of longitudinal microstructures in the electron bunch at the millimeter scale. The CSR electric field (envelope and carrier) is detected through a new type of THz detector (YBCO, see next section for details) connected to an ultra-fast oscilloscope (63 GHz bandwidth, Agilent DSOX96204Q) at the BL6B infrared beamline [17](Fig. 1(a)).

A laser-electrons interaction in condition of slicing with picoseconds laser pulses is also possible and is achieved in the undulators U1 [18] (Fig. 1(b)). The beam current is just set below the instability threshold. The laser pulse is generated by an amplified Ti:Sa laser (Mira oscillator and Legend amplifier from Coherent) coupled with a cryogenic Ti:Sa amplifier (Legend Elite Cryo) which delivers a 800 nm, 10 mJ uncompressed laser pulses with a 300 ps duration at 1 kHz repetition rate. The pulses are compressed in the picoseconds range using an adjustable compressor with gratings [19]. Finally, the laser pulse is focused in the undulators U1 where it interacts with the electron bunch. The emitted coherent terahertz radiation is recorded at the BL6B infrared beamline using the YBCO detector and the same 63 GHz bandwidth oscilloscope.

YBCO Detector

The high-temperature superconductor $YBa_2Cu_3O_{7-x}$ (YBCO) is a new technology developed for the detection of radiation in the terahertz frequency range. The detector is composed of a YBCO superconducting thin-film detector

ISBN 978-3-95450-176-2

DESIGN OF A COMPACT L-BAND TRANSVERSE DEFLECTING CAVITY WITH ARBITRARY POLARIZATIONS FOR THE SACLA INJECTOR

H. Maesaka, T. Asaka, T. Ohshima, H. Tanaka, Y. Otake, RIKEN SPring-8 Center, Kouto, Sayo, Hyogo, 679-5148, Japan
S. Matsubara, Japan Synchrotron Radiation Research Institute, Kouto, Sayo, Hyogo, 679-5198, Japan

Abstract

For the X-ray free electron laser, SACLA, fine-tuning of the injector part of a drive linac is quite important. Since one of the most effective ways for this tuning is to monitor the temporal structure of an electron beam, we designed a compact L-band (1428 MHz) TM110-mode transverse deflecting cavity (TCAV). The TCAV will be installed at the end of the velocity bunching section, where a bunch length ranges from 10 ps to 1 ns, the kinetic energy of the beam is approximately 1 MeV. In order to measure a short bunch as long as 10 ps, the TCAV system was designed to have less than 3 ps time resolution. The TCAV has 2 input ports intersecting at a right angle in order to excite either of linear and circular polarizations, depending on the measurement condition. The linear polarization is suitable for a short bunch measurement with high temporal resolution and the circular one is useful to measure a long bunch comparable to the rf period (700 ps). Thus, the TCAV system has sufficient temporal resolution and wide measurement range required at the SACLA injector and this system is expected to be beneficial for fine-tuning of the injector.

INTRODUCTION

The X-ray free electron laser (XFEL) facility, SACLA [1], has been stably operated for experimental users for more than 3 years. However, we have encountered some problems that we could not always reproduce the best XFEL performance soon after a long shutdown period. One of the reasons for this problem could be that the temporal profile of an electron beam at the injector part of SACLA was slightly changed at each time. Since a thermionic electron gun and a velocity bunching process are used at the injector, the rf phase and amplitude of a buncher cavity should be accurately adjusted to reproduce the appropriate temporal structure. Therefore, a temporal profile measurement system is demanded at the SACLA injector for fine-tuning of the velocity bunching part.

In order to clarify the necessity of the temporal structure measurement, we introduce the bunching scheme of SACLA. Figure 1 shows a schematic layout of the SACLA accelerator. An electron beam is generated by a 500 kV thermionic electron gun and chopped into a 1 ns-long bunch by a high-voltage pulse chopper. A 238 MHz buncher cavity applies a velocity modulation to the beam, which is afterward accelerated by a 476 MHz cavity. An L-band (1428 MHz) correction cavity (L-COR) operated at a deceleration phase linearizes nonlinear energy modulation on the beam generated by the rf curvature of the acceleration field in the 476 MHz cavity. The kinetic energy after the L-COR is approximately 1 MeV. The beam is accelerated by an L-band alternating periodic structure (L-APS) at an off-crest phase in order to give an energy chirp along the beam bunch for bunch compression. A C-band correction cavity again linearizes the rf curvature given by the L-APS, and the first bunch compressor (BC1) compresses the bunch length from approximately 30 ps to 3 ps. Then, S-band (2856 MHz) accelerator units accelerate the beam at an off-crest phase so as to compress the bunch length at the BC2. The same bunch compression mechanism is utilized to the first 12 units of the C-band (5712 MHz) accelerators and the BC3. After the BC3, a C-band transverse deflecting structure (C-TDS) [2] is installed for temporal bunch structure measurement. The beam is finally accelerated to 8 GeV by remained C-band accelerators.

As mentioned above, there are 5 cavities in the injector part before the BC1. Therefore, we have to adjust all the rf phases and amplitudes of these cavities. These parameters are, at first, set to those from a simulation result or those of the previous operation condition. Then, they are fine-tuned so as to maximize the XFEL power. This tuning process is quite time-consuming. Once the injector is tuned to an appropriate condition, since a temporal beam profile after the BC2 or BC3 can be measured by the C-TDS, we can tune the S-band and C-band accelerators by using the temporal profile information. However, we cannot tune the injector part only by using the C-TDS. In the injector components, the velocity bunching instruments are quite important, because they determine the initial condition of the electron beam. Thus, we designed a transverse deflecting cavity (TCAV) for the temporal bunch structure measurement in the velocity bunching section.

Since the bunch length in the velocity bunching section is variable from 10 ps to 1 ns, the TCAV system is required to have wide measurement range. For a short bunch measurement around 10 ps, this system should have a high temporal resolution of a few ps. For the design of the TCAV system, these requirements should be taken into account.

In this article, we describe the conceptual design of a transverse deflector system according to requirements for the temporal profile measurement. The design of the TCAV is then detailed. Some basics of a transverse deflector system is briefly described in the appendix.

maesaka@spring8.or.jp

ISBN 978-3-95450-176-2

DEVELOPMENT OF A BEAM PULSE MONITOR FOR THE HEAVY ION ACCELERATOR FACILITY

D. Tsifakis#, N.R. Lobanov, P. Linardakis, ANU, Canberra, Australia

Abstract

The Australian National University (ANU) Heavy Ion Accelerator Facility (HIAF) comprises of a 15 million volt electrostatic accelerator (NEC 14UD) followed by a superconducting LINAC booster. The pulsing system consists of a low energy, single gap, gridded buncher and two high energy choppers. The buncher and choppers need to be set in phase and amplitude for maximum efficiency. The LINAC encompasses twelve, lead tin-plated Split Loop Resonators (SLR). Each SLR, as well as the superbuncher and time energy lens, needs to be individually tuned in phase and amplitude for correct operation. The HIAF pulsing system is based on a few techniques. The first one utilises a U-bend at the end of the LINAC. One special wide Beam Profile Monitor (BPM) is installed after the 90 degrees magnet. The technique allows to set up correct phase by observing the displacement of beam profile versus phase shift of the last phase locked resonator. The determination of beam pulse characteristics are based on γ-ray detection produced by beam striking a tantalum target. In this paper, the HIAF set up for pulsed beam diagnostics with sub nanosecond time resolution is described. The system has demonstrated simplicity of operation and high reliability.

INTRODUCTION

The ANU Heavy Ion Accelerator Facility consists of a National Electrostatics Corporation 14UD electrostatic tandem accelerator and a superconducting LINAC booster accelerator. The LINAC comprises of four cryostats, each consisting of three, split-ring resonators, operating at a frequency of approximately 150 MHz. When the beam needs to be accelerated in the LINAC or when the beam is required by the accelerator users to be bunched, the facility's buncher systems are utilised. The first buncher is installed at the low energy section of the 14UD accelerator. It is a gridded, room temperature, buncher using one or three frequencies to produce the field required for bunching. The resulting bunch has a typical width of 1.5 ns FWHM and the bunching efficiency is approximately 0.25.

A second buncher, Super Buncher (SB), is installed at the LINAC entrance. SB is a superconducting, quarter-wave resonator with β=0.1, developed at the ANU and can further compress the beam to bunches with, typically, 100 ps FWHM.

All bunchers as well as the LINAC, are synchronised to the facility's master 150 MHz clock. The low energy buncher operates on the sub-harmonic frequency of approximately 9.375 MHz (1/16 of the master clock) and the two high energy choppers on 37.5 MHz and 4.6875 MHz (1/4 and 1/32 of the master clock).

When the buncher systems are in use, it is important to have a monitoring system which allows the accelerator operator to measure the characteristics of the bunch in the time domain, to assist with the tuning. This paper describes the system used by the facility to produce a time profile of the pulsed beam. This technique of measuring the longitudinal profile is used by other facilities such as [1]. The output of the pulse monitor is used together with other measurement and tuning techniques [2, 3] to optimise the LINAC beam.

The development of this system has happened through the years and with the scientific contribution of the researchers of the Department of Nuclear Physics.

METHOD DESCRIPTION

The beam pulse monitoring system, shown in Fig. 1 is based on the time difference between prompt γ-rays produced by the beam striking a tantalum target and the reference RF used to synchronise the rest of the accelerator.

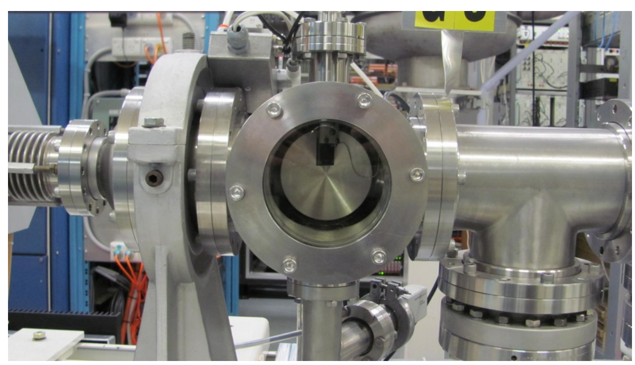


Figure 1: The target station of the beam pulse profile monitor. The target, as seen through the viewing port, can be moved in/out and is rotated by 45 degrees with respect to the beam.

The target is mounted at a 45 degree angle to the beam and it is placed in the path of the beam. This results in prompt γ-rays being produced, which are detected by a barium fluoride (BaF2) scintillation detector. The detector used at the ANU is made by Scionix Holland BV and is model number 38/25B30/2M BaFX2Neg. The BaF_2 detector signal provides the start signal to a time-to-analog converter (TAC) made by Ortec, model 567. The TAC is set to a maximum range of 100 ns. The amplitude signal from the detector is variable as the energy

#Dimitrios.Tsifakis@anu.edu.au

ISBN 978-3-95450-176-2

A COMPACT WEATHER STATION FOR MONITORING ENVIRONMENTAL EFFECTS ON BEAM PROPERTIES AND EQUIPMENT

S. Cunningham#, R. Clarken, A.C. Starritt, Australian Synchrotron, Melbourne, Australia

Abstract

A compact and mobile weather station has been designed and integrated with EPICS (Experimental Physics an Industrial Control System) to assist with environmental monitoring at the Australian Synchrotron. This proved invaluable in correlating the dependence of the Storage Ring RF phase with humidity.

The device is based on Arduino technology and consists entirely of substitutable parts allowing for easy repair and maintenance by people with any degree of technical skill. The project aim is to deploy several of these devices throughout the facility to enhance the understanding of environmental effects on beam properties and equipment.

INTRODUCTION

When considering how to design the weather station, it was essential to try and make it as simple and functional as possible while being low-cost. For this reason the Arduino open-source electronics [1] platform was chosen for the plug and play hardware, simple programming software and pre-existing code available online. The initial prototype utilised an Arduino Uno with an Arduino Ethernet Shield along with a DHT22 temperature-humidity sensor and a digital BMP085, barometric pressure sensor. When choosing these sensors, it was important to take into consideration the operational specifications which are outlined in Table 1 and Table 2 below.

Table 1: BMP085 Technical Data [2]

Variable	Range	Accuracy
Pressure	300-1100 hPa	±2.5 hPa
Temperature	-40°C - +85°C	±2°C

Table 2: DHT22 Technical Data [3]

Variable	Range	Accuracy
Humidity	0 – 100%RH	±5%RH
Temperature	-40°C - +125°C	±0.2°C

Deployment

One practical concern when designing the final weather station device was the capability to isolate and therefore minimise radiation damage. To this end the sensors are housed in their own case separated by a cable from the Arduino and its housing unit. This allows the sensors to be placed near and/or within the plane of radiation of the beam inside the tunnels while potentially minimising the damage to the Arduino itself. Any faulty sensors will therefore be easily replaceable, restoring functionality to the whole module with minimal effort due to the plug and play nature of the device. Figure 1 demonstrates the simplicity of this setup.

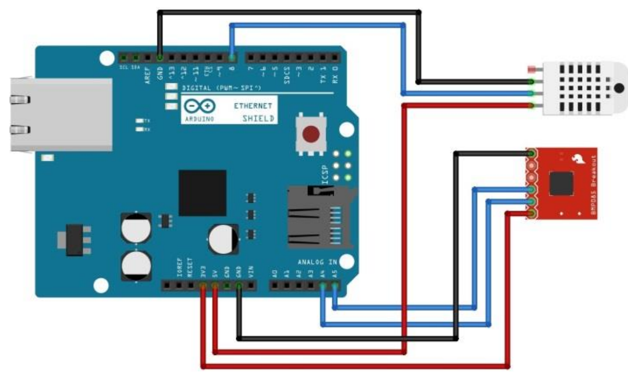


Figure 1: Weather station setup.

To assist with data storage and retrieval, the whole device was hosted on an Input-Output Controller (IOC) to allow integration with EPICS. This removed the need for a real time clock from the device as all data is now saved with a time stamp, as well as enhancing diagnostic capabilities as demonstrated by the correlations in this presentation.

CORRELATIONS DISCOVERED

One of the first correlations discovered was the relationship between beam phase and humidity in the technical hall. It can be clearly seen in Fig. 2 that there is a direct relationship with the humidity leading the phase of the beam.

Another correlation investigated was between the humidity and the vacuum in the linear accelerator (LINAC). Although this has been a known issue for some time, until the development and deployment of the weather station module there has been no way to determine the extent to which this correlation occurs see (Fig. 3).

#Simon.Cunningham@synchrotron.org.au

ISBN 978-3-95450-176-2

ELECTRO-OPTICAL MEASUREMENTS OF THE LONGITUDINAL BUNCH PROFILE IN THE NEAR-FIELD ON A TURN-BY-TURN BASIS AT THE ANKA STORAGE RING*

E. Roussel, C. Evain, S. Szwaj, S. Bielawski (PhLAM/CERLA, Villeneuve d'Ascq, France),
A. Borysenko, N. Hiller, A.-S. Müller, P. Schönfeldt, J.L. Steinmann (KIT, Karlsruhe, Germany)

Abstract

ANKA is the first storage ring worldwide with a near-field single-shot electro-optical bunch profile monitor. Previously, the method of electro-optical spectral decoding (EOSD) was employed to record single-shot longitudinal bunch profiles. The readout rate of the required spectrometer detector system limited the acquisition rate to a few Hz and thus did not allow us to study the evolution of the longitudinal bunch shape on a turn-by-turn basis. The setup at ANKA was combined with the novel method of photonic time-stretch [1] for which the modulated laser pulse is not detected in the spectral domain, but stretched to a few nanoseconds by a long fiber and, subsequently, detected in the time domain. This method allows the sampling of the longitudinal bunch profile on a turn-by-turn basis for several milliseconds, uninterrupted. Here, we present first results obtained with the photonic time-stretch method in the near-field at the ANKA storage ring.

INTRODUCTION

During the low-α_c-operation of the ANKA storage ring at the Karlsruhe Institute of Technology, the momentum compaction factor α_c is reduced to compress the bunches longitudinally and thus generate coherent synchrotron radiation (CSR) in the THz range [2]. Previous streak camera measurements have shown a beam current dependent bunch lengthening and deformation effect at ANKA in this special operation mode [3, 4]. In addition, the emitted CSR exhibits a bursting behavior [5–7], which we believe to be caused by dynamic changes of the longitudinal bunch shape (e. g., microbunching). Our near-field EO setup offers the possibility to obtain direct, single-shot measurements of the electric-field of the bypassing electron bunches which is directly linked to the longitudinal bunch profile. For this, the electric field of the electron bunch is modulated on a long, chirped laser pulse which is then analysed subsequently (Fig. 1). The laser pulses are synchronised to the electron bunch revolutions (f_{rev} = 2.7 MHz at ANKA) and with a fast enough detector, the bunch profile could be measured for every turn. Previously, the laser was detected in the spectral domain with a grating spectrometer housing a commercial line array that allowed for single-shot acquisitions, but only at a rather low readout rate of a few Hz (Fig. 1(a)). These measurements have revealed dynamic substructures on the electron bunches on a sub-ps time scale [8–10], but the dynamic evolution of the longitudinal bunch profile could not be studied on a turn-by-turn basis.

The novel method of photonic time-strech, based on Dispersive Fourier transform (DFT), also known as real-time Fourier transformation [11], is a powerful method that overcomes the speed of classical cameras and enables real-time measurements of fast non-repetitive events using fast detectors. This technique has already been used in optics, photonics, telecommunications and spectroscopy, etc [11–13]. The principle of time-stretch is simple and consists in imprinting the signal containing the information on laser pulses and then stretch these pulses so that the signal is slowed-down enough and can be acquired with classical oscilloscopes (Fig. 1(b)). The combination of the time-stretch with the electro-optic detection has enabled to reach acquisition rate in the tens of megahertz and thus, revealed the evolution of the microbunching instability on a turn-by-turn basis [1].

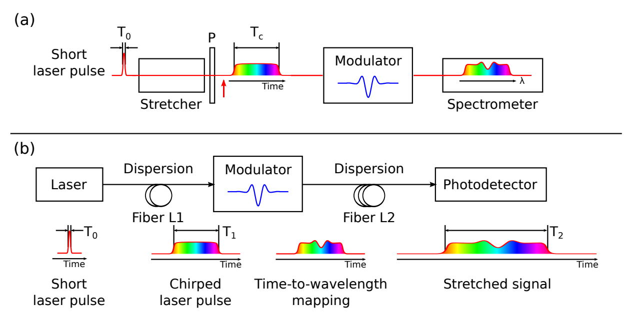


Figure 1: Principle of the detection. The information under inverstigation, here longitudinal bunch profile, is first encoded into a chirped laser pulse, using an electro-optic crystal ("Modulator"). Then the information encoded in the laser pulse is either detected in the spectral domain with a spectrometer (a), or futher stretched by propagation in a long fiber and detected in the time domain with a photodetector (b).

METHODS

Electro-optical bunch length measurement techniques rely on the field-induced Pockels effect to modulate the longitudinal electron bunch profile onto a laser pulse passing through an EO crystal (further reference e. g., [16]).

For the near-field measurements at ANKA, the EO crystal is brought close to the electron beam, so the direct Coulomb field of the bunch induces a time dependent birefringence in the EO crystal and this anisotropy modulates the polarization state of the linearly polarized probe laser pulse. This modu-

* This work is funded by the BMBF contract numbers: 05K10VKC, 05K13VKA.

ISBN 978-3-95450-176-2

SRF GUN CHARACTERIZATION - PHASE SPACE AND DARK CURRENT MEASUREMENTS AT ELBE*

E. Panofski#, A. Jankowiak, T. Kamps, Helmholtz-Zentrum Berlin, Berlin, Germany
P.N. Lu, J. Teichert, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

Abstract

RF photoelectron sources with superconducting cavities provide the potential to generate high quality, high brightness electron beams for future accelerator applications. At Helmholtz-Zentrum Dresden-Rossendorf, such an electron source was operated for many years. The commissioning of an improved SRF Gun with a new high-performance gun cavity with low field emission and a superconducting solenoid inside the gun cryomodule (SRF Gun II) has started in June 2014. First low current measurements as well as studies of unwanted beam transport using SRF Gun II with a Cu photocathode and an acceleration gradient up to 7 MV/m will be presented. First longitudinal beam characterization of the SRF Gun in combination with ELBE, a two-stage superconducting linear accelerator will be discussed.

INTRODUCTION

Helmholtz-Zentrum Dresden-Rossendorf has provided a test stand for SRF gun technology since 2007. Furthermore, this SRF gun can also be used as an electron source for the two-stage superconducting linear accelerator ELBE. In order to reach a higher acceleration field in the cavity and therefore peak electron energy, a new high-performance gun cavity attended by a superconducting solenoid was assembled in the gun cryomodule in May 2014 [1]. For successful application of the new injector commissioning and full beam characterization of SRF Gun II is required. The presented low current measurements focus on longitudinal phase space characterization and first studies about unwanted beam transport.

For future applications, such as driving X-Ray FEL facilities, the longitudinal phase space distribution plays a critical role. Therefore, good understanding of the longitudinal phase space of the photoelectron source is required. The new high-performance gun cavity design of the photoinjector offers low field emission which will be investigated by measuring dark current from SRF Gun II. Unwanted beam transport to the ELBE beamline is determined by the energy acceptance of the dogleg.

This paper starts with a short overview about the design parameters of the SRF gun as well as the relevant operation parameters of the photoinjector in combination with the linear accelerator ELBE. A review of the experimental technique measuring the longitudinal phase space, followed by a description of the data analysis method is given. All experimental results for the longitudinal phase space are presented. The final section of this paper will summarize first studies of the energy acceptance of the dogleg and therefore the transport of dark current, generated by the SRF gun, into the ELBE beamline.

COMMISSIONING OF THE SRF GUN

All beam characterization measurements are done with the SRF Gun II in combination with two-stage linear accelerator ELBE. Figure 1 represents the schematic setup.

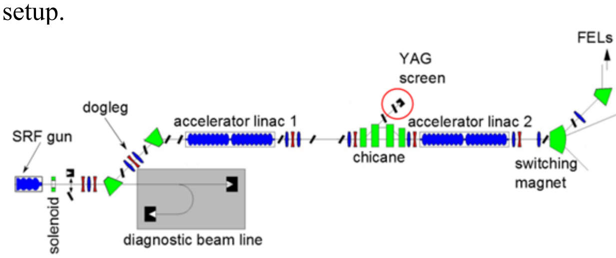


Figure 1: SRF Gun and ELBE beamline at HZDR Dresden [2].

Setup and Operation Parameters

The 1.3 GHz Nb gun cavity consist of 3.5 TESLA cells with a normal conducting Cu photocathode installed in the backplane of the half cell. In order to supress multipacting a DC bias voltage is applied on the photocathode. The cathode is illuminated by 266 nm UV laser light. The drive laser provides 6 ps (rms) long laser pulses with a repetition rate of 100 kHz and an approximately uniform, 2mm transverse profile [1]. Due to the low quantum efficiency of the copper cathode ($\sim 10^{-5}$) only low bunch charges typically smaller than 5 pC are achieved. Therefore, space charge effects can be neglected for all measurements presented in this paper. The generated electron beam is accelerated with maximum gradient (peak field) of 18 MV/m corresponding to a kinetic energy of 3.5 MeV at the gun exit.

Afterwards, the electron beam is guided through the achromatic dogleg to ELBE beamline. The dogleg consists of two bend magnets attended by three quadrupoles which control the horizontal dispersion. The final acceleration up to 19 MeV takes place in the two superconducting cavity modules (C1, C2) of ELBE Linac 1. For all longitudinal phase space measurements presented in this paper the first dipole of the chicane is used to deflect the electron beam with a bend angle of 45° to the YAG screen in the diagnostic beamline.

All relevant measurement conditions and machine settings are summarized in Table 1.

* Work supported by BMBF & Land Berlin
# eva.panofski@helmholtz-berlin.de

ISBN 978-3-95450-176-2

BUNCH COMPRESSION DEPENDENT JITTER ANALYSIS WITH LARGE SPECTRAL RANGE

M. Kuntzsch#, U. Lehnert, R. Schurig, J. Teichert, M. Gensch, P. Michel,
Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

Abstract

At the superconducting continuous wave (CW) accelerator ELBE electron bunch diagnostics have been installed, enabling the investigation of bunch arrival-time jitter for varying bunch compression states [1]. Using these diagnostic systems a comprehensive investigation has been performed that reveals the influence of the bunch compression to spectral noise components up to a frequency of 100 kHz. The contribution describes the measurement results taken for both electron injectors (DC-Gun, SRF-Gun) at the ELBE facility and will give an interpretation of different noise components. Arrival time jitter of the electron bunches is directly transferred into jitter of the secondary radiation generated by the ELBE beam.

INTRODUCTION

Pulse Compression Scheme

The ELBE Accelerator uses two magnetic chicanes to compress the picosecond bunches to the 100 fs regime. The correlated energy spread after the first accelerating module leads in combination with the first chicane to a temporal stretch of the electron bunches. The cavities installed in the second module are operated far off-crest to introduce a large chirp, i.e. a linear correlation between particle energy and longitudinal coordinate. Together with the transport matrix element R56 an energy dependent path deviation in the chicane leads to a longitudinal bunch compression. Figure 1 shows the ELBE accelerators' layout with the two electron injectors and two accelerating modules and illustrates the bunch compression scheme.

Bunch Arrival Time Monitor (BAM)

The bunch arrival time monitor takes advantage of an optical synchronization system that has been installed at ELBE [2]. The stabilized laser pulses provided by that system are used as a timing reference in the BAM. A probe of the electron's electric field passing by is extracted using a broadband electric pickup [3]. The signals are combined in an electro-optic modulator (EOM) which leads to an intensity modulation of single laser pulses according to the phase relation between the reference and pickup signal. Using this technique timing variations are mapped into amplitude modulations of the laser pulses.

The BAM-System installed at ELBE is capable to operate at MHz repetition rates in CW operation and enables arrival time measurements for individual electron bunches with a high resolution [3].

Bunch Compression Monitor (BCM)

The bunch compression monitor uses coherent diffraction radiation or coherent transition radiation generated by the electron pulses passing a boundary of a silicon screen. The intensity of the emitted coherent radiation pulse is dependent on the electron bunch duration [4] and can be used as a qualitative measure for the bunch compression state at the screen position. The shorter the electron bunches the higher the intensity of the coherent radiation pulse. At ELBE the BCMs are used to optimize the compression state of the electron bunches while tuning up the machine. Their application for an active beam-based feedback in order to stabilize the bunch compression state on the target position is currently being evaluated.

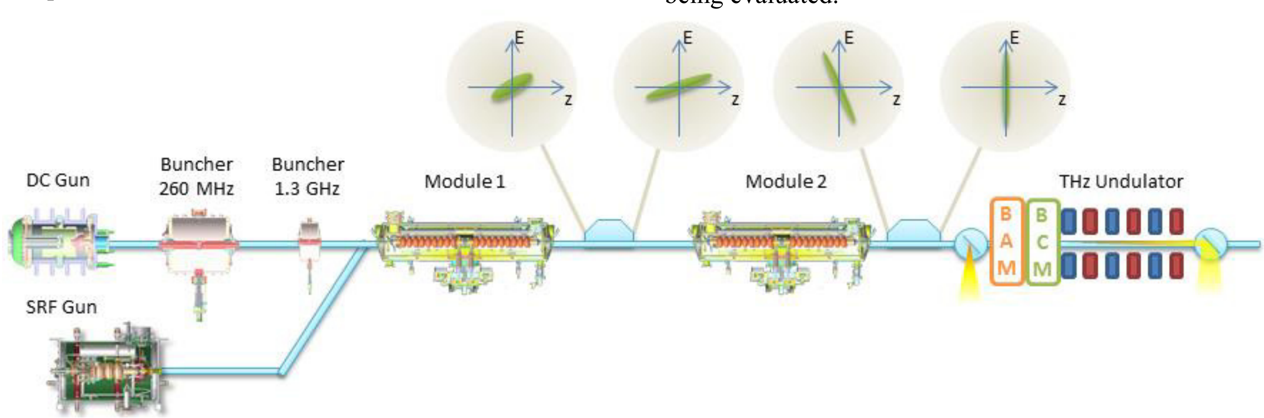


Figure 1: ELBE layout and bunch compression scheme for short pulse operation.

#m.kuntzsch@hzdr.de

ISBN 978-3-95450-176-2

TRIGGER GENERATOR FOR THE SUPERCONDUCTING LINEAR ACCELERATOR ELBE

R. Steinbrück, M. Kuntzsch, M. Justus, Helmholtz-Zentrum Dresden-Rossendorf (HZDR),Dresden
T. Bergmann, Bergmann Messgeräte Entwicklung (BME), Murnau
Alexander Kessler, Helmholtz-Institut Jena (HIJ), Jena

Abstract

The Center for High-Power Radiation Sources ELBE at Helmholtz-Zentrum Dresden-Rossendorf (HZDR) runs a superconducting linear electron accelerator for research applications. A recent machine upgrade enabled new time resolved experiments and made a replacement of the current trigger and clock generation system necessary. The requirements include centralization of trigger generation, improvement of trigger quality, and trigger pattern versatility. To address these needs digital delay generators, developed by Bergmann Messgeräte Entwicklung (BME), have been evaluated. These field programmable gate array (FPGA) based PCI boards have 6 independent trigger channels. Individual PCI modules can be connected by a dedicated trigger bus to extend channel count on demand. The boards are installed in an industrial personal computer (IPC) running Windows 7. Trigger generation runs stand-alone in the FPGA making it independent of operating system timing and ensuring stable phase relation between individual channels. Delay control is possible via C and LabVIEW libraries. A LabVIEW application will offer a graphical user interface (GUI) for local control and an OPC UA interface for control system integration.

INTRODUCTION

The ELBE accelerator is capable of CW operation with a frequency of up to 26 MHz. All timing signals for thermionic injector and superconducting radio-frequency photoinjector (SRF) [1], buncher resonators, macro pulser generator and so on are derived from a 13 MHz master clock oscillator. Currently these signals are generated by independent hardware components. A new structure for the ELBE timing system was proposed that can be seen in Figure 1. This was motivated by:

- a transition to an up to date hardware that is much easier to extend and to maintain,
- an inherent synchronization of all delay channels,
- a precise adjustment of delay channels in reference to each other,
- an increased flexibility of pulse train pattern definition,
- a reduced jitter.

This paper gives an overview of the hard and software structure of the central trigger system currently under development.

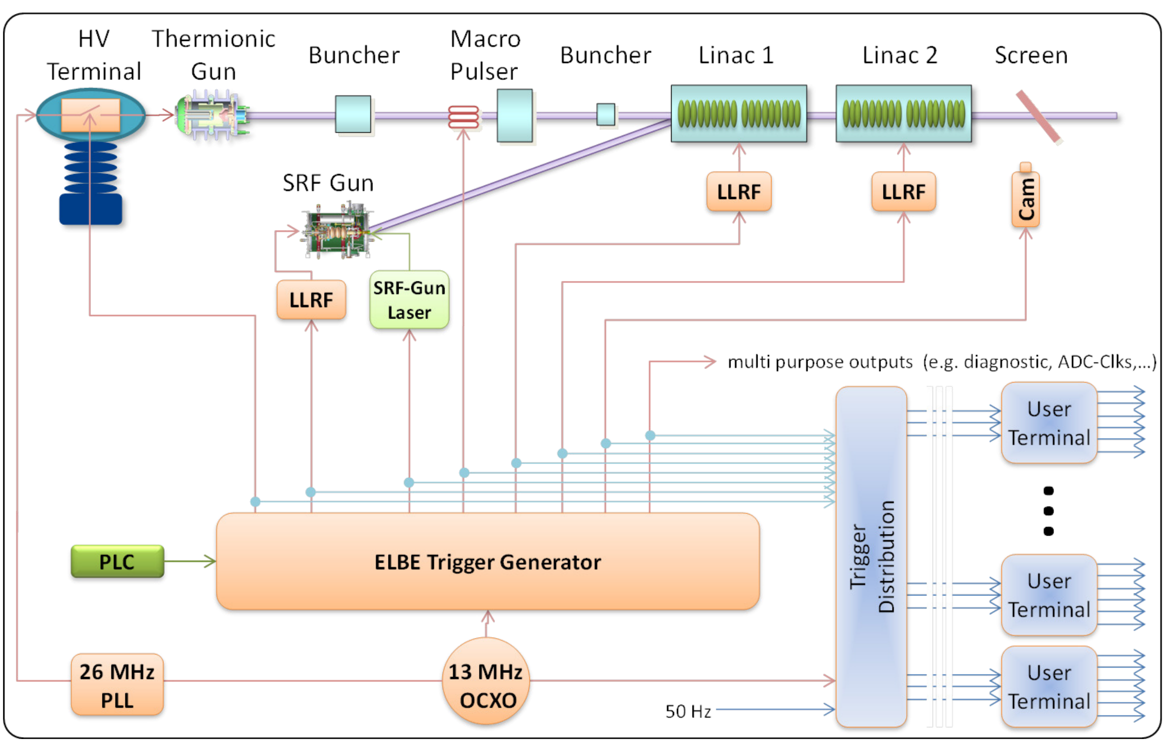


Figure 1: Projected structure of ELBE trigger distribution with central trigger generator. [2]

ISBN 978-3-95450-176-2

VECTOR POLARIMETER FOR PHOTONS IN keV-MeV ENERGY RANGE

V. Gharibyan*, K. Floettmann, G. Kube, K. Wittenburg, DESY, Hamburg, Germany

Abstract

Light's linear and circular polarizations are analyzed simultaneously by vector polarimeters mainly in astrophysics. At higher energies Compton scattering or absorption is applied for linear or circular polarization measurements in satellites and accelerators. Here we propose a Compton scattering only vector polarimeter for monitoring photon beams in a non-invasive way. The setup is adjustable to match the initial photons' energy and can be used for diagnosing electrons' passage through undulators. In perspective the proposed device could also be explored to measure topological charge of the novel vortex photon beams.

INTRODUCTION AND OVERVIEW

As a consequence of the photon spin a beam of photons could possess an average spin which is often described in classical terms as an elliptical polarization [1]. That is a mixture of linear and circular polarizations - similar to transverse and longitudinal polarizations for a massive spinning particle.

Polarization is an important tool for generating and manipulating light in modern lasers as well as in a fast growing field of X-ray or gamma FEL(Free Electron Laser) research and applications. Recently FELs with tunable [2] or fast switching [3] polarizations have been developed for research in biology, chemistry, physics and material sciences.

For controlling the average spin one needs fast and precise measurement of light beam polarization which is increasingly difficult for high energy photon beams. That is why, the polarimeters, at high energies, are specialized for measuring either the linear or the circular polarization of the beam. In a keV-MeV energy range circular Compton polarimeters are designed [4] or used [5] for FEL radiation diagnostic while examples of linear Compton scattering polarimeters are found, apart from the accelerators, in astronomy (see Ref. [6] and references therein).

Advances in the above mentioned elliptical polarization generating FEL undulator devices require vector polarimeters to measure the linear and circular polarizations simultaneously. Such polarimeters are readily available for low frequency or energy photons within visible or near UV or IR parts of the electromagnetic spectrum (a recent example in astrophysics is described in Ref. [7]; for an undulator radiation see Ref. [8]).

Here we propose a high energy vector polarimeter based on Compton scattering.

* vahagn.gharibyan@desy.de

COMPTON KINEMATICS, CROSS SECTION AND SPIN ASYMMETRY

We review briefly some of the basic features of the Compton scattering process.

Definitions:

ω_0 and ω are the initial and final photon energies;
$E_0 = mc^2$ and E are the initial and final energies of the recoil electron;
θ and θ_e are the scattering angles of the photon and the electron.

The energies are related through energy conservation

$$\omega_0 \,+\, mc^2 \;=\; \omega \,+\, E \tag{1}$$

Furthermore, from momentum conservation follows

$$\omega \;=\; \frac{\omega_0}{1 \,+\, (\omega_0/mc^2)\,(1 - cos\,\theta)} \tag{2}$$

The scattered photon and the scattered electron angles relative to the photon beam direction are

$$cos\,\theta \;=\; 1 - \frac{mc^2}{\omega_0}\left(\frac{\omega_0}{\omega} - 1\right) \tag{3}$$

$$tg(\theta_e) \;=\; \frac{ctg(\theta/2)}{1 + \omega/mc^2} \tag{4}$$

The spin-dependent differential Compton cross section is

$$\frac{d\sigma}{d\Omega} \;=\; \frac{d\sigma_0}{d\Omega}\,(1 + P^L_\gamma A_L + P^C_\gamma P_e A_C) \tag{5}$$

with the unpolarized part

$$\frac{d\sigma_0}{d\Omega} \;=\; \frac{{r_0}^2}{2}\left(\frac{\omega}{\omega_0}\right)^2\left(\frac{\omega_0}{\omega} + \frac{\omega}{\omega_0} - sin^2\,\theta\right) \tag{6}$$

where r_0 is the classical electron radius and

$$\frac{r_0^2}{2} \;=\; 39.71\,mb \tag{7}$$

and P^L_γ, P^C_γ and P_e are the linear, circular and longitudinal polarizations of the initial beam photon and the target electron respectively.

ISBN 978-3-95450-176-2

CRYOGENIC CURRENT COMPARATOR FOR STORAGE RINGS AND ACCELERATORS

R. Geithner#, Friedrich-Schiller-Universität Jena, Germany & Helmholtz-Institut Jena, Germany
T. Stöhlker, Helmholtz-Institut Jena, Germany & Friedrich-Schiller-Universität Jena, Germany & Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany
R. Neubert, P. Seidel, Friedrich-Schiller-Universität Jena, Germany
F. Kurian, GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany & Helmholtz-Institut Jena, Germany
H. Reeg, T. Sieber, M. Schwickert, GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany
M. Fernandes, The University of Liverpool, U.K. & CERN, Geneva, Switzerland

Abstract

A Cryogenic Current Comparator (CCC) was developed for a non-destructive, highly sensitive monitoring of nA beams at the planned FAIR accelerator facility at GSI. The sensor part of the CCC was optimized for lowest possible noise-limited current resolution in combination with a high system bandwidth of about 200 kHz. It is foreseen to install the CCC inside the CRYRING, which will act as a well-suited test bench for further optimization of the CCC performance and the cryostat. In the meantime - until the completion of CRYRING - a CCC has been installed and will be tested in the antiproton storage ring (Antiproton Decelerator AD) at CERN. The pulse shape in the AD requires dedicated optimization of the sensor time response. The beam current will increase rapidly during injection from 0 to 12 µA. Since the slew rate of the overall system is limited by the CCC pickup coil, the input signal has to be low-pass filtered to not exceed the slew rate of the CCC system and to ensure a stable operation. For this purpose different low-pass configurations had been tested. In this contribution we present results of the CCC sensor for AD, CRYRING and FAIR, respectively.

INTRODUCTION

The Cryogenic Current Comparator is a well-established device in metrology for current and resistance ratio measurements [1].

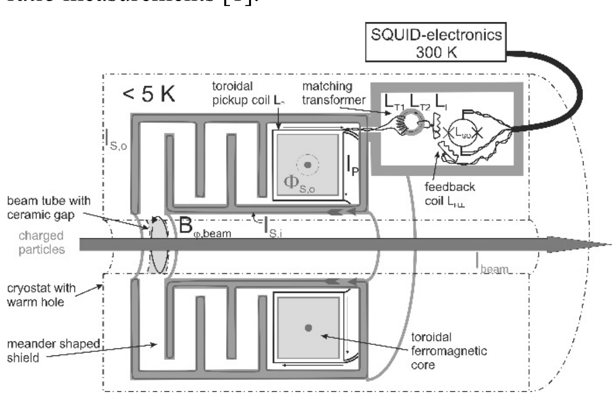


Figure 1: Schematic of the CCC.

Adapting this principle to beam diagnostics it provides a non-intercepting, absolute and precise detection of beam currents in the nA range for continuous as well as bunched beams [2].

The coupling circuit of CCC consists of a superconducting toroidal pick-up coil, a superconducting matching transformer, and a Superconducting QUantum Interference Device (SQUID) and is embedded into a meander-shaped superconducting shielding structure (see Fig. 1). The parts of the coupling circuit are connected by niobium wires and form superconducting closed loops. Due to flux conservation in such superconducting closed loops, it is possible to detect the magnetic field of constant beam currents without modulation techniques like used for DC Current Transformers (DCCT). Using state-of-the-art SQUID systems enables the detection of lowest currents in principle from DC to several MHz, but the overall bandwidth of the CCC is limited by the frequency response characteristic of the coupling circuit, which is specified by the core material embedded in the pick-up coil [3]. All these properties qualify the CCC as a suitable beam charge monitor for storage rings and accelerators.

LEAD-SHIELDED CCC AT GSI

In collaboration between GSI and University of Jena a first version of a CCC working as a beam current monitor was developed in the early 1990's [4]. In this system, the meander-shaped shield was made out of lead, whereas the coupling circuit was made out of niobium. The CCC shows very good results with a current resolution in the nA-range, but the bandwidth was limited by the SQUID-system. Also maintenance issues, like manually refilling of liquid helium prevent the usage as a standard diagnose tool. Therefore for the application in FAIR, a CCC should be developed with lower noise, higher bandwidth having cryostat with automated refilling system. As the existing CCC system at GSI provide a convenient test bench for this development, it has been re-commissioned as a prototype to test new sensor components. The SQUID and the FLL electronics were replaced by state-of-the-art devices. The re-commissioned CCC was then installed in

ISBN 978-3-95450-176-2

BEAM DIAGNOSTICS FOR THE HIGH ENERGY STORAGE RING AT FAIR

C. Böhme, A. Halama, V. Kamerdzhiev, F. Klehr, D. Prasuhn, K. Reimers, S. Srinivasan, D. Temme, R. Tölle, Forschungszentrum Jülich, Germany

Abstract

Numerous beam diagnostics systems, with the BPM system considered the most important one, are envisaged for the High Energy Storage Ring (HESR) within the FAIR Project. The BPM design, the corresponding test bench, HESR BLM studies at COSY, status of the ionization profile monitor and other subsystems are presented.

INTRODUCTION

The HESR, part of the FAIR project in Darmstadt, Germany, is dedicated to the field of antiproton and heavy ion physics. The envisaged momentum range is 1.5 GeV/c to 15 GeV/c. The ring will be 575 m long in a racetrack shape. The planned beam instrumentation within the modularized start version is:

76	Shoebox-style BPMs
118	Beam Loss Monitors
2	Beam Current Transformers
1	Ionization Beam Profile Monitor
1	Wall Current Monitor
1	Schottky Pick-up
1	Dynamical Tune-meter
1	Transverse Feedback System
1	Scraper

BPM SYSTEM

The BPM system is foreseen to measure the beam position throughout the ring. 22 BPMs are located in each arc of the ring and will be co-located to each sextupole magnet. An illustration of the elements between two dipoles in the arc sections is given in Figure 1.

The BPM units consist of two shoebox-style pick-ups rotated by 90° around the beam axis in respect to each other. The setup is shown in Figure 3. The inner diameter of the pick-ups is 89 mm and the length 77 mm with a gap of 3 mm between the electrodes using an angle of 55.5°. The expected signal levels are depending on the ion charge, the amount of ions, and the bunch length and can be calculated using

$$U_{img}(t) = \frac{1}{\beta c C_{el}} \frac{A}{2\pi\alpha} I_{beam}(t) \quad (1)$$

$$= \frac{1}{\beta c C_{el}} \frac{L_{BPM}}{2} I_{beam}(t) \quad (2)$$

The capacitance was calculated using a COMSOL Multiphysics 5.0 simulation. For the lowest case, the first injection of antiprotons with 10^7 particles in the ring, the signal level was calculated to 57 μV. For the highest intensity case, with 10^{11} antiprotons stored, the signal level is 390 mV.

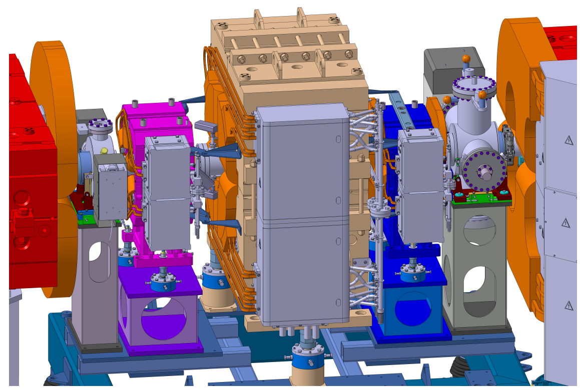


Figure 1: Illustration of the elements between two dipole magnets in the arc. From left to right: Dipole magnet (red), pumping vessel, sextupole magnet (purple), BPM, quadrupole magnet (ocher), steerer (blue), pumping vessel, dipole (red). Magnet coils are in orange.

The achievable resolution ϵ is dependent on the capacity between the pick-ups:

$$\epsilon = \frac{1}{b} = \frac{\alpha}{r_{BPM}} \quad (3)$$

$$\alpha = \frac{1 - \frac{CD}{C_{ges}+CD}}{1 + \frac{CD}{C_{ges}+CD}} \quad (4)$$

with CD the capacity between the pick-ups and C_{ges} the capacitance to ground. The capacity between the pick-ups was determined to 7.8 pF. With this value $\epsilon = 0.0146 mm^{-1}$.

The pick-up design is based upon the COSY BPMs [1]. The length and diameter is shrunk by a common factor in order to keep the length to diameter ratio. As can be seen in Figure 3 the pick-ups themselves are mounted onto a carrier tube which is then mounted within the beam pipe. In order to enhance the signal level, efforts were taken to increase the distance between the electrodes and the grounded carrier tube without changing the inner diameter of the BPM nor the outer diameter of the beam pipe as shown in Figure 2. In detail:

- Increasing the gap between carrier tube and electrodes.
- Shorten all screws to the minimum length.
- Increasing the diameter of holes in the carrier tube for the signal connections.
- Introducing bevels on the small edges of the pick-up cylinder.

ISBN 978-3-95450-176-2

A PATIENT-SPECIFIC QA PROCEDURE FOR MOVING TARGET IRRADIATION IN SCANNED ION THERAPY

Y. Hara#, T. Furukawa, R. Tansho, Y. Saraya, K. Mizushima, N. Saotome, T. Shirai and K. Noda,
National Institute of Radiological Sciences, Chiba, Japan

Abstract

Three-dimensional (3D) pencil-beam scanning technique has been utilized since 2011 in NIRS-HIMAC. Beam delivery system and treatment planning software (TPS) require dosimetric patient-specific QA to check each individual plan. Any change in the scanned beams will result in a significant impact on the irradiation dose. Therefore, patient-specific QA for moving target irradiation requires additional procedure.

In an additional QA for moving target irradiation, we placed 2D ionization chamber on the PMMA plate tilted with respect to the beam axis. The PMMA plate was set on the stage of the moving phantom. The moving phantom was moved according to patient data. We measured the dose distribution for both the static target and the moving target. We compared the results for the moving target with those for the static targets by means of a gamma index analysis.

In the additional patient-specific QA, the gamma analysis between the moving and static targets showed the good agreement. We confirmed that this new technique was a beneficial QA procedure for moving target irradiation.

INTRODUCTION

Heavy-ion beams such as carbon-ion beams have attracted growing interest for cancer treatment due to their high dose localization and high biological effect at the Bragg peak. Since clinical trials using the Heavy-Ion Medical Accelerator in Chiba (HIMAC), operated by the National Institute of Radiological Sciences (NIRS), were started in1994 [1], treatments for more than 7000 patients have been successfully carried out with carbon-ion beams. To make the best use of the characteristics of a carbon-ion beam and provide flexible dose delivery, three-dimensional (3D) pencil-beam scanning is an ideal irradiation technique [2-4]. As part of the efforts to achieve ion-scanning therapy, a new treatment facility equipped with a 3D scanning irradiation system was constructed as an extension to the existing HIMAC. The 3D scanning irradiation system has been utilized for treatment since 2011.

In the scanning irradiation method, since the 3D dose distribution is achieved by superimposing doses of individually weighted pencil beams determined in the treatment planning, any change in the scanned beams will cause a significant impact on the irradiation dose. Therefore, the scanning system and its treatment planning system (TPS) require dosimetric patient-specific QA to check each individual plan and its delivery [5]. This patient-specific QA is usually performed before therapeutic irradiation, as follows. After treatment planning, the dose distribution is measured using ionization chambers set in a water phantom. In this measurement, irradiation is performed in the same manner as in the patient treatment. The measured dose profiles are then compared with the dose distribution obtained by recalculation by the TPS using a homogeneous medium instead of the patient CT data. This method allows the quality of the field to be checked.

One of the aims at the new facility is to realize treatment of a moving target by scanning irradiation. In moving target irradiation with a scanned ion beam, the interplay effect between the target motion and scanned beams is a problem, because this effect cause over or under dosage in the target volume. To overcome this problem, we developed fast scanning irradiation system with gating system for moving target [6]. However, the existing patient-specific QA is performed only in static filed. To ensure the validity of both the delivered dose and the gating system, patient-specific quality assurance (QA) for moving target irradiation requires an additional procedure. In this paper, we describe a new patient-specific QA procedure for moving target irradiation and experience with patient-specific QA.

MATERIALS AND METHODS

Patient-specific QA Procedure

The purpose of the conventional patient-specific QA is to compare the dose distribution calculated by TPS and the measured dose distribution in static field. In the additional QA for moving target irradiation, by comparing static and moving measurements, we confirm that there is no difference between them. Additionally, we check that the gating system and fast scanning system work correctly during irradiation.

Figure 1 shows the schematic workflow of patient-specific QA. In the patient-specific QA in HIMAC, the planned dose distribution is converted to the dose distribution in the water phantom, instead of the patient CT data. After that, we perform the measurement and analysis. In the measurement, a commercial 2D ionization chamber array (Octavius Detector 729 XDR, PTW Freiburg, Germany) is employed. The sensitive volume of each chamber is 5 × 5 × 3 mm, and center to center spacing is 10 mm. In total there are 729 chambers in a matrix of 27 × 27, providing a maximum field size of 27 × 27 cm. This ionization chamber array is used with an accordion-type water phantom, which was developed to

#y-hara@nirs.go.jp

ISBN 978-3-95450-176-2

DEVELOPMENT OF QA SYSTEM FOR THE ROTATING GANTRY FOR CARBON ION THERAPY AT NIRS

N. Saotome#, Y. Hara, K. Mizushima, R. Tansho, Y. Saraya, T. Furukawa, T. Shirai, and K. Noda,
National Institute of Radiological Sciences, Chiba, Japan

Abstract

At the National Institute of Radiological Sciences (NIRS), we have been developing the rotating-gantry system for the carbon-ion radiotherapy. This system is equipped with a three-dimensional pencil beam scanning irradiation system. To ensure the treatment quality, calibration of the primary dose monitor, range check, dose rate check, machine safety check, and some mechanical tests should be performed efficiently. For this purpose, we have developed a measurement system dedicated for quality assurance (QA) of this gantry system. The ion beam's dose output are calibrated by measurement using an ionization chamber. A Farmer type ionization chamber is inserted into the center of a water equivalent phantom. The thickness of the phantom could be changed so that employ both calibration of the output at entrance and output checking at center of the irradiation field. The ranges of beams are verified using a scintillator and a CCD camera system. From the taken images, maximum gradient points are determined by some image processing and compared with reference data. In this paper, we describe consideration of the daily QA for the rotating-gantry.

INTRODUCTION

Since carbon ion deposits most of their energy in the last final millimeters of their trajectory, the accuracy of the beam energy/range is required for carbon ion treatment especially for using scanning method. Physical advantages of carbon ion are not only for the beam direction, but also for the lateral direction compare with conventional photon or proton beam. Although QA procedures are necessary for establishing safe and accurate dose delivery of any radiation therapy treatment modality, much high level of QA procedures are required for carbon-ion therapy. There are few guidelines for QA of the particle radiotherapy. The recommendation of the International Commission on Radiation Units and Measurements ICRU [1] that the uncertainties in the delivered dose to patients be limited to within 5% of the prescribed dose is the fundamental principle of the QA guidelines. To ensure the treatment quality, calibration of the primary dose monitor, range check, machine safety check, and some mechanical tests should be performed efficiently. We made the Daily QA list based on the ICRU 78 [2]. Table 1 indicate the list of the daily QA and tolerances. The new treatment room using the rotating-gantry system will be opened at 2016 in addition to existing 4 fixed beam port. Totally 5 of irradiation port have to be check the condition before the treatment within a limited time. For this purpose, we have developed a measurement system dedicated for quality assurance (QA) of this gantry system. The system includes a dose measurement system, a range measurement system, and a slide rail. The system position can be switched for the purpose of the measurement.

#naosao@nirs.go.jp

Table 1: List of Daily QA and Tolerances

Procedures	Tolerances
Calibration of the primary dose monitor	-
output at center of SOBP	2%
Range	0.5mm
Dose rate and monitor ratios for the pencil beam	5%
Performance of the beam-position monitors	Functional
Interlocks	Functional
Isocenter	0.5mm
Gantry angle	0.2 degree

CALIBRATION OF THE PRIMARY DOSE MONITOR

The dose measurement system is used for the calibration of the primary dose monitor. Fig. 1 is the photograph of the dose measurement system. This calibration is performed for the correction of the dose output from the treatment machine. The Farmer type ionization chamber (30013, PTW Freiburg, Germany) was positioned at a depth of 2.0 cm from top of the front surface of a water equivalent phantom. The depth of 2 cm was chosen to ensure that measurements were made in a low dose gradient region of the pristine Bragg Peak curve. The calibration was performed with 10x10 cm2 field size. By comparison of the dose between reference and measured, daily calibration factor is calculated. This measurement is performed at 0 degree of the gantry angle. From the result of the calibration for the existing fixed beam port, our beam control system is very stable. Almost all of the calibration factor from 2011 were within 1 percent. At this moment, only one energy is measured on a daily basis.

ISBN 978-3-95450-176-2

DEVELOPMENT OF FPGA-BASED TDC WITH WIDE DYNAMIC RANGE FOR MONITORING THE TRIGGER TIMING DISTRIBUTION SYSTEM AT THE KEKB INJECTOR LINAC

Tsuyoshi Suwada*, Kazuro Furukawa, Fusashi Miyahara, KEK, Tsukuba, Japan

Abstract

A new field-programmable gate array (FPGA)-based time-to-digital converter (TDC) with a wide dynamic range greater than 20 ms has been developed to monitor the timing of various pulsed devices in the trigger timing distribution system of the KEKB injector linac. The pulsed devices are driven by feeding regular as well as any irregular (or event-based) timing pulses. For monitoring the timing as precisely as possible, a 16-ch FPGA-based TDC has been developed on a Xilinx Spartan-6 FPGA equipped on VME board with a time resolution of 1 ns. The resolution was achieved by applying a multisampling technique, and the accuracies were 2.6 ns (rms) and less than 1 ns (rms) within the dynamic ranges of 20 ms and 7.5 ms, respectively. The various nonlinear effects were improved by implementing a high-precision external clock with a built-in temperature-compensated crystal oscillator.

INTRODUCTION

Recent advances in FPGA technology have made it possible to apply them to TDCs in which the FPGA is embedded (called FPGA-based TDCs) in high-energy particle and nuclear physics [1] and also in materials science [2]. FPGA-based TDCs are very attractive because of their high performance, high-speed data transfer, and customizability and flexibility in precision timing measurements without any external complex hardware. These excellent features enable high-precision time-duration measurements down to a few picoseconds (see references in [1]). These features also enable the possibility of new applications to precisely monitor various timing pulses with a wide dynamic range in large accelerator complexes, where an accuracy of a few nanoseconds is sufficient.

We have developed a new FPGA-based TDC required for application to the KEKB injector linac. The required specifications of the TDCs are a wide dynamic range greater than 20 ms and an accuracy of 1 nanosecond level, where low-cost fabrication should be also required. The basic design, development, and experimental results of the new FPGA-based TDC for applications to large accelerator complexes are reported in detail.

FPGA-BASED TDC

Required Specifications

All downstream storage rings of the KEKB injector linac [3] will be filled in top-up injections based on a pulse-by-pulse modulation scheme at 50 Hz, which allows the injector linac to perform virtually simultaneous injections [4]. For the virtually simultaneous injections, a new trigger timing distribution system is under development on the basis of the event-based timing and control system [5]. A new additional system is also under development for monitoring all timing pulses generated in the trigger timing distribution system as precisely as possible [6]. The purpose of the introduction of a timing monitoring system is to increase the reliability of the event-based timing and control system. Because the injection beam charges need to be increased to be four to five times greater than those of the previous KEKB, such a timing monitoring system may serve not only the stable operation and complex simultaneous injection but also reliable radiation safety and machine protection of the injector linac.

The fiducial repetition frequency of the injector linac is based on 50 Hz. All pulsed devices are driven by the trigger timing pulses appropriately delayed from the fiducial timing. These trigger timing pulses are fundamentally generated with a frequency of 50 Hz at maximum by obeying the beam injection timing sequences programmed in the control system. However, in a strict sense, the fiducial time duration does not need to be determined exactly to be 20 ms owing to the synchronization condition of the linac and ring RF frequencies on the injection bucket position in the ring.

The allowable width of the fiducial time duration is restricted to the trigger timing condition for the modulators of the high-power klystrons in the injector linac because the modulators should be driven within 20 ± 1 ms to stabilize the applied voltage and to sufficiently allow for stable charging. This specification means that the allowable time duration of the fiducial timing should be monitored to maintain them within 20 ± 1 ms.

The trigger timing for most of other pulsed devices is less than 1 ms delayed from the fiducial timing, and more especially, the trigger timing for the beam-position monitors should be maintained at an accuracy of 1-ns level. Therefore, a resolution of 1 ns and a dynamic range greater than 20 ms are required for the time-duration measurements in the TDC along with a higher accuracy.

Basic Design

The present event-based trigger timing distribution system was constructed in a VME-based system, and accordingly, it was necessary to construct new TDCs (6U VME64x module) in the same VME-based system. The basic specifications required for the VME/FPGA-based TDC are listed in Table 1.

* tsuyoshi.suwada@kek.jp

ISBN 978-3-95450-176-2

DATA ACQUISITION SYSTEM FOR SUPERKEKB BEAM LOSS MONITORS

Makoto Tobiyama#, Hitomi Ikeda and John W. Flanagan,
KEK Accelerator Laboratory, 1-1 Oho, Tsukuba 305-0801, Japan.
Graduate University for Advanced Studies (SOKENDAI), 1-1, Oho, Tsukuba 305-0801, Japan.

Abstract

The monitoring of the beam loss distribution along the accelerator is important to prevent damage do delicate detectors around the collision point and to vacuum components such as collimators, and also to suppress the unnecessary irradiation of the accelerator elements. As it is not convenient to construct the readout system synchronized to fast timing such as beam injection, a new 64-ch ADC system which samples the output of the loss monitor signal integrator at a fairly fast rate and automatically keep the peak, mean, and minimum data has been developed. The performance of the ADC system is shown. The control system configuration which reads and resets the hardware interlock signal from the loss monitor integrator for the machine protection system (MPS) is also shown.

INTRODUCTION

The KEKB collider is now being upgraded to the SuperKEKB collider to obtain 40 times higher luminosity than that of KEKB. To realize such high luminosity, the beam energy is re-optimized to 7 GeV for KEKB-HER (HER, electron) and to 4 GeV for KEKB-LER (LER, positron). The maximum beam currents will be roughly doubled to 2.6A for HER, and to 3.6A for LER with much reduced beam emittances and x-y couplings. The beam size at the collision point will be further squeezed with a larger crossing angle. The first commissioning of the HER and the LER without BelleII detector installed (Phase-I operation) is planned to start early 2016. The main beam parameters of the SuperKEKB rings are shown in Table 1.

With the increase of the beam currents and reduction of the beam sizes, the stable beam loss rate along the rings is anticipated to increase greatly. The simulated beam loss rates with designed luminosity are 10 mA/s and 7.2 mA/s for LER and HER, respectively [1]. Those rates are 50 times higher than that of KEKB. In addition, the much smaller vertical beam size could easily cause disastrous damage to the vacuum components due to higher charge density. It is important to monitor the beam loss and to take necessary actions, such as stopping injection or requesting a beam abort before causing disastrous accidents.

For the main rings (HER and LER), we will use a similar configuration for the beam loss monitor system to that used at the KEKB accelerator [2, 3]. It consists of air ion chambers (ICs) and PIN photo-diodes (PINs) [4]. The lengths of the ICs are 5 m and they are distributed roughly every 30 m around the ring, typically near the focusing sextupole magnets (SFs). They are fixed on the cable rack near the outer wall of the accelerator tunnel where the direct distance from the nearest ring is about 2 m, and about 1 m above the medium plane of the rings. For the new positron damping ring (DR) [5] which will start beam commissioning around late FY2016, we plan to install ICs with lengths of 9 m around the ring.

Table1: Main Parameters of SuperKEKB Rings

	HER/LER	DR
Energy (GeV)	7/4	1.1
Circumference(m)	3016	135.5
Max. Beam current (A)	2.6/3.6	0.07
Number of bunches	2500	4
Single bunch current (mA)	1.04/1.44	18
Bunch separation (ns)	4	>98
Bunch length (mm)	5/6	6
RF frequency (MHz)	508.887	
Harmonic number (h)	5120	230
T. rad. damping time (ms)	58/43	11
L. rad. damping time (ms)	29/22	5.4
x-y coupling (%)	0.27/0.28	5
Natural emittance (nm)	3.2/4.6	42.5
Crossing Angle (mrad)	83	
Horiz. beam size at IP(μm)	10.2/7.75	
Vert. beam size at IP(nm)	59/59	
Beam-Beam Parameter	0.90/0.875	
Peak Luminosity ($cm^{-2}s^{-1}$)	8×10^{35}	
Max. injection rate (Hz)	50/50	50
Number of ICs	105	40
Number of PINs	101	optional

The PIN photo-diodes (PINs) are mainly placed near special vacuum components, such as beam collimators, to directly detect large and fast beam loss. Though the number of ICs is almost the same as that of KEKB, we

#makoto.toibyama@kek.jp

ISBN 978-3-95450-176-2

SIGNAL RESPONSE OF THE BEAM LOSS MONITOR AS A FUNCTION OF THE LOST BEAM ENERGY

K. Yamamoto, J-PARC Center, Tokaimura, Japan

Abstract

The 3 GeV rapid cycling synchrotron of the Japan proton accelerator research complex accelerates a proton beam up to 3 GeV and delivers it to the main ring and the material and life science facility. The injection energy of the synchrotron was 181 MeV since 2013, and it was upgraded to 400 MeV in 2014. The main magnets (dipole and quadrupole magnets) of the synchrotron have large aperture, and thickness of yoke is larger than 200 mm. Considering the stopping power of a proton, a shielding effect of the magnets for beam loss monitor strongly depends on the lost beam energy. When the beam loss occurs during injection, the lost proton cannot penetrate the magnet yoke. But when the beam loss occurs after acceleration, lost beam easily pass the magnet. Therefore the signal response of the beam loss monitor is changed even if the number of lost particles is same. To evaluate the beam loss monitor response by the lost beam, we estimated the signal dependence on the lost energy by the simulation.

INTRODUCYTION

The 3 GeV Rapid Cycling Synchrotron (RCS) of the Japan Proton Accelerator Research Complex (J-PARC) provides more than 500 kW beam to the material and life science facility and the main ring[1]. In such high intensity hadron accelerator, the lost protons that are a fraction of the beam less than 0.1 % cause many problems. Those particles bring about serious radio-activation and malfunction of the accelerator components. Therefore, the beam loss monitor (BLM) is one of the most important equipment to observe the state of the beam during operation, and to keep steady operation. Moreover, if we set operation parameters of BLM adequately, it can detect the beam loss that is 10^{-6} fraction of the beam. Thus it enables fine-tuning of the accelerator.

In order to increase the beam power of the RCS, the injection energy of the RCS was upgraded from 181 MeV to 400 MeV in 2014[2]. The main magnets (dipole and quadrupole magnets) of the RCS have large aperture, and thickness of yoke is larger than 200 mm. Therefore it works as a shielding to the BLM from the secondary radiation by the beam loss, and its shielding effect strongly depends on the lost beam energy. When the beam loss occurs during injection, the lost proton cannot penetrate the magnet yoke. But when the beam loss occurs after acceleration, lost beam easily pass the magnet. Therefore the signal response of the BLM is changed even if the number of lost particles is same. To evaluate the BLM response by the lost beam, we estimated the signal dependence on the lost energy by the simulation.

BEAM LOSS MONITOR IN RCS

In J-PARC RCS, We use two kind of BLM. One is a plastic scintillator connected on a photo multiplier tube and the other is a proportional counter.

The plastic scintillation counter has good time resolution (FWHM is less than 100ns) and its wave form data is used for a comparison between the experiment and simulation.

The proportional counter is mainly used to the interlock system for machine protection. The filling gas of the proportional counter is Ar-Co2 mixture, and it was purchased from Toshiba Electron Tube Co., Ltd [3]. A total of 90 proportional counters are set up all over the accelerator beam line. These proportional counters are connected with the machine protection interlock system and it is always checking that the integration of the proportional counter signal is not over a preset value. Integration values are also archived at all times and we can check it when some interlock alerted. The typical location of the PBLM is shown in Fig. 1. In this paper, we evaluate the response of the proportional counter.

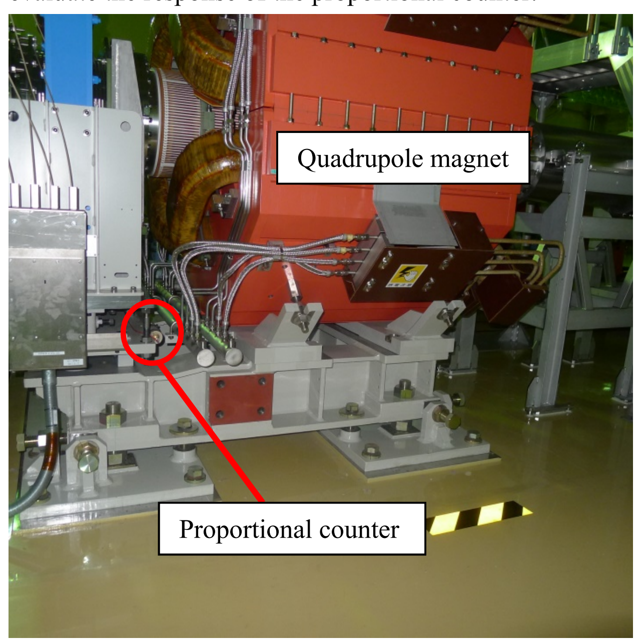


Figure 1: Typical location of the proportional counter.

CALCULATION

The response of BLM would be proportional to the energy deposition by the radiation. Thus we investigated the energy deposition at the monitor as a function of lost beam energy by using the MARS code[4]. The calculation model is shown in Fig. 2. Here, the only quadrupole magnets, proportional counters and vacuum chambers are

ISBN 978-3-95450-176-2

DIAGNOSTICS DURING SESAME BOOSTER COMMISSIONING

H. Al-Mohammad, K. Manukyan, SESAME, Allan, Jordan

Abstract

SESAME* is a 2.5 GeV synchrotron radiation facility under construction at Allan (Jordan), consisting of a 20 MeV Microtron as pre-injector and an 800 MeV Booster Synchrotron. The pre-injector and booster are originally BESSY-I machine with some major changes within power supplies and diagnostics tools. The diagnostic tools are: Fluorescent Screens, BPMs, DCCT, FCT and Synchrotron Radiation Monitor. The Booster had been commissioned in 2014. The installed tools allowed to determine current, orbit, tune, chromaticity and emittance. Set up of the diagnostics and results are presented in this paper.

INTRODUCTION

The SESAME Microtron (MM22) generates an electron beam suitable for injection through Transfer line 1(TL1) into the Booster Synchrotron. The timing system is based on the event generator and receiver system from Micro Research Finland [1], with 1 Hz repetition frequency. The SESAME Booster has a FODO lattice with 38.4 m circumference the main parameters are listed in table 1.

Table 1: Booster Main Parameter

Circumference (m)	38.4
RF frequency (MHz)	499.654
Revolution freq. (MHz)	7.807
Repetition freq.(Hz)	1
Ramping time (ms)	630
Injection/Extraction Energy (MeV)	20/800
Beam Current (mA)	7
H/V Tunes υ_x/υ_y	2.21/1.45
H/V Emittances* ε_x (nm.rad)	180/300
Straight sections β-func.(H/V) (m)	5.2/2.9

*Different optics program give different values (Beta 300 nm, Elegant 180 nm).

In order to properly check the Booster synchrotron performance, the set of diagnostics equipment described in Fig. 1 is installed in the machine. Next, we present the diagnostics elements installed in the Booster and our experience during the commissioning.

* Synchrotron Light for Experimental Science and Applications in the Middle East

FLUORESCENT SCREENS

Fluorescent Screens (FS) are installed in Booster ring which have Aluminium Oxide screens and analog cameras connected to a signal switcher which allows monitoring one camera on the TV monitor in control room. This setup includes manually controlled focus and zoom lenses originally from BESSY-I. All FS are activated pneumatically.

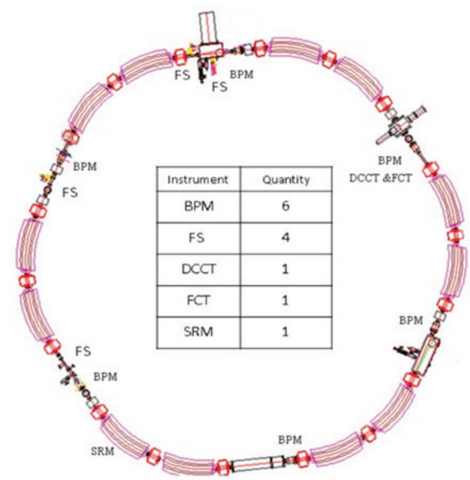


Figure 1: Booster Diagnostics Components.

We placed one FS to monitor the beam path along the Transfer line 1 from the Microtron to Booster (TL1), while 4 more are installed in the Booster to ease the first commissioning goals (injection, first cell, full turn).

Measurements of Microtron emittance were done by Quadruple scan method [2] Fig. 2 shows the results for vertical plane.

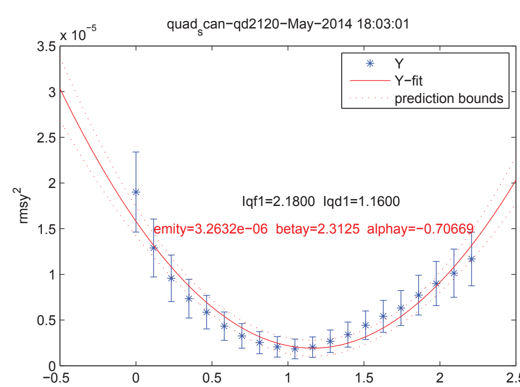


Figure 2: Emittance Measurement of the Microtron in TL1, $\varepsilon_{x/y}$ = 2.6 / 5.2 nmrad.

ISBN 978-3-95450-176-2

A COMPARATIVE STUDY BETWEEN SIMULATED AND MEASURED BEAM'S QUALITY OF 30 MeV CYCLOTRON AT KFSHRC

F. Alrumayan[1], A.Alghaith[1], A. Hendy[1] and M. Dehnel[2]
[1]King Faisal Specialist Hospital and Research Centre, Riyadh 11211, SA
[2] D-Pace, Inc., Nelson BC, Canada

Abstract

At King Faisal Specialist Hospital and Research Centre (KFSHRC), the C-30 Cyclotron (manufactured by IBA) is used to produce radioisotopes for medical purposes. Working with very expensive machine dedicated for patients needs full attention and understanding of how beam can be controlled safely inside beam transport system. Moreover, knowledge of influence of magnetic lenses on charged particles is desired. Therefore, using off-line source such as PC-based beam simulator allows an operator to immediately see the effect of various magnetic lenses attached to the beam line. Initially, the magnetic field of quadruples and steering magnet was recorded using Hall probe Teslameter. The magnetic field values then uploaded into the Beam simulator in which beam quality was recorded and analysed.

INTRODUCTION

Experience gained since the commissioning of the IBA [3] C-30 Cyclotron at the King Faisal Specialist Hospital and Research Centre (KFSHRC) in 2010, has shown this facility to be viable entity. In addition to the C-30 Cyclotron, the facility includes two other Cyclotrons namely; the RDS-111 and the CS30 Cyclotrons. The latter has dual responsibilities; while is kept as a backup for the other Cyclotrons for radioisotopes production, it's used for proton therapy researches and Bragg Peak measurements at that particular energy [1].

Beam transport system is of high importance to carry particles to their final destination, in case of medical Cyclotrons, are isotopes targets. The amount of current that carried out in beamlines could reach up to 250 uA [2]. Hence, working with very expensive machine dedicated for patients needs full attention and understanding of how beam can be controlled safely inside beamlines. Knowledge of influence of magnetic lenses on charged particles is desired.

Therefore, using off -line source such as PC-based beam simulator allows an operator to immediately see the effect of various magnetic lenses attached to the beam line. This
would eliminate strike of beam on the internal wall of beamline.

In this paper, a comparison study is conducted between real beam shape and position with simulated beam. During experiment the beam was completely stopped using destructive beam viewer supplied on the line.

DESIGN PARAMETER

Optical Elements

Figure 1 shows the layout of beamline 2.1 which attached to the C-30 Cyclotron. The main elements of beamline 2.1 are explained as follows. Steering magnets: The thickness between coil and support is made with two "Nomex" layers of 0.12 mm thickness. Each coil is assembled with conductor made by enamelled round copper wire of 1.4 mm diameter. Each coil has 962 turns per coil. Quadrupole Magnets: On the beam line, there two Quadrupoles installed; one inside the Cyclotron vault and the other on the PET target vault. They are made by Scanditronix Magnet. Each of which contains 4 layers of 25 turns and 1 cooling plate.

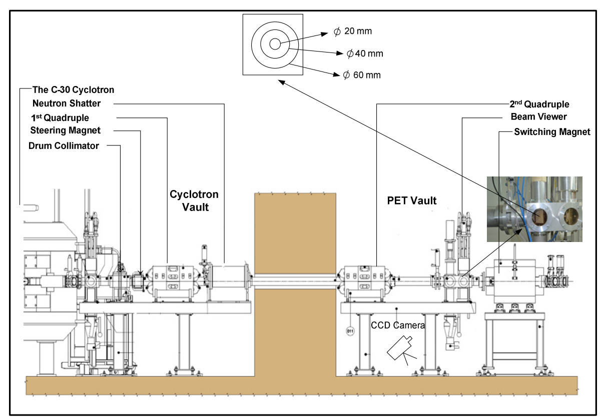


Figure 1: Layout of beamline.

Other Non-magnet elements are installed on the beamline and listed on the figure but outside the scope of simulation of this study.

BEAM MEASUREMENT

On Line Measurement

Real time measurement of beam current was monitored using beam viewer supplied with the C-30 Cyclotron. The Viewer is made of Alumina attached into square piece of copper (the thickness is between 0.2 and 0.3 mm). Within the phosphors screen (figure 1), three indication circles are marked. The diameter of these circles is 20, 40 and 60 mm. A CCD Camera, made by Panasonic, was placed outside the median plane of the Cyclotron. Using very small beam current for short period guarantees the survival of the camera.

Moreover, the beam shape was studied at different beam intensities as shown in Figure 2. The values of the

ISBN 978-3-95450-176-2

HEATING ANALYSIS AND THE SOLUTIONS OF DCCT SYSTEM FOR BEPCII

Y. Zhao, J.S.Cao,J.He,Y.F.Sui,L.Wang

Division for Accelerators, Institute of High Energy Physics, Beijing 100049, China

Abstract

The BEPCII e+ DCCT is damaged due to a high temperature heating. After 8 years operating, it is not working properly in 2014. As the BEPCII is trying to reach high luminosity, the CT will be a defective component with the high beam current, therefore a spare one has replaced it. In order to determine the heating source, some experiments and simulations have been done. A new vacuum chamber structure has been designed to solve the problem. The analysis and result can be also applied to CT designs in the future.

INTRODUCTION

There are two bergoz[1]in air DC current transformers fixed on BEPCII rings on both sides of the interact point(IP). One for positron and another for electron when the machine runs collider mode, both two DCCT can measure the electron current when the machine runs at synchrotron mode. Figure 1 shows the sensor's location. The two DCCT sensors have same parameter and identical mechanical design.

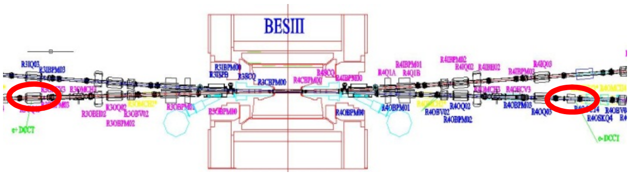


Figure1: Layout of BEPCII DCCT sensor.

Each DCCT has 2 sensors to pick up the temperature. One (e-/e+ T-SU1) is stuck on the DCCT sensor, another (e-/e+ T-SU2) is used to monitor the pipe's temperature. A problem has appeared in e+'s DCCT after once high current operation in 2012: In collider mode ,The e+ DCCT 's temperature is much higher than e- DCCT when the e+,e- beam current is the same. In synchrotron mode, the e+ DCCT's temperature is also slightly higher than e-'s. For the first e+ DCCT sensor was damaged by heating, a spared one with a identical new vacuum chamber made in 2010 has replaced it, but the temperature problem still exist.

The Fig. 2 shows the current and temperature curves when the machine runs at collider mode this year, the peak beam current is 720mA, bunch number is 92, bunch current is 7.9mA for both e+ and e- rings. The e+ T-SU1 is 33°C, 8°C higher than e-'s, the e+ T-SU2 is 50 °C, 10°Chigher than e-'s. The 2 DCCT vacuum chambers have the same water cooling system, they all work normal. The nearby BPMs show the beam position in X,Y direction, no . As the BEPCII will run over 910 mA for collision, and the high temperature will affect the magnetic characters of the DCCT cores [2], the e+ problem should be settled.

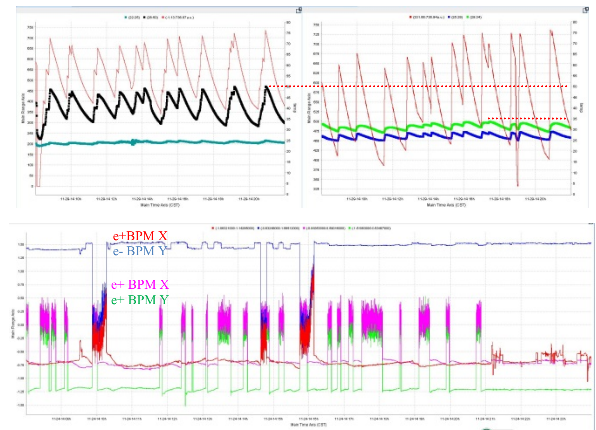


Figure 2: Current and temperature curve for e+ (up left) and e-(up right) DCCT, BPM nearby X,Y position(down).

ANALYSIS AND SIMULATION

For the measurement principle of current transformer, a break is needed in the vacuum chamber to cut off the mirror current. Figure 3 is the structure of DCCT with toroid, bakelite rack and metal shield. The vacuum chamber has a interlayer water cooling. The gap is 2 mm sealed with ceramic ring, kovar alloy is used to weld the ceramic ring to the Steel-316L vacuum pipe. This structure bring a micro vacuum part as a resonate cavity.

BEPCII Bunch length is about 15mm, it means the spectrum of bunch will cover the high frequency part of impedance, which will lead to an enormous heat deposition by the HOM. The HOM power will deposit at places where the wakefield trapped by small discontinuities of the beam duct, such as the ceramic gap. So when charged particles pass through the gap, it loses energy which would transfer into heat power[3].

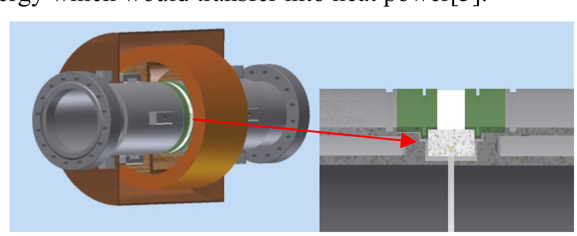


Figure 3: Structure of vacuum chamber.

ISBN 978-3-95450-176-2

PHASE AND ENERGY MEASUREMENT SYSTEM FOR C-ADS INJECTOR I

J.H. Yue, J. Hu, Q.Y. Deng, S.J.Wei, Q.Ye, IHEP, CAS, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

Abstract

For proton linac, phase and energy measurement is very important. Beam phase always can be measured by quadrature sampling [1][2], energy can be calculated by the method of time of flight (TOF), in this way we need to know the beam phase of two points whose distance is given. C-ADS injector I is a 10MeV proton linac with 10mA continuous current. It consists of an ECR (Electron Cyclotron Resonance) ion source, a LEBT (Low Energy Beam Transport), a 3MeV RFQ (Radio-frequency Quadruple) and a superconductivity linac accelerator with 3~10MeV. In the initial phase, the beam energy is about 3MeV. In this paper, phase and beam energy system of C-ADS Injector I have been introduced and some preliminary results have been shown.

INTRODUCTION

The ADS accelerator in China is a Continuous-Wave (CW) proton linac with 1.5 GeV beam energy, 10 mA beam current, and 15 MW beam power [3]. Its main task is to cope with nuclear waste material and produce clean nuclear power. It have two injectors, C-ADS injector I is a 10MeV proton linac with 10mA continuous current made by IHEP. It consists of an ECR (Electron Cyclotron Resonance) ion source, a LEBT (Low Energy Beam Transport), a 3MeV RFQ (Radio-frequency Quadruple) with 325MHz frequency and a superconductivity linac accelerator with 3~10MeV. In the initial phase, the beam energy is about 3MeV. The schematic diagram of C-ADS injector I is shown in Fig.1.

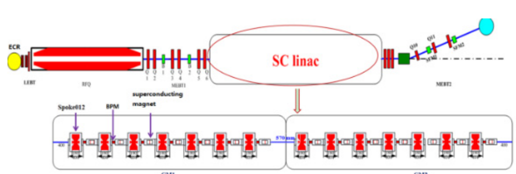


Figure 1: The Schematic diagram of C-ADS injector I.

In order to measure the beam phase and energy, we design the frontend electronics and fast data acquisition system shown in Fig.2. We take the FCT (Fast Current Former) monitors as the pickup, take the quadrature sampling to measure the phase of the FCT1and FCT2 and phase difference between FCTs. We use the method of TOF to get the beam energy.

The phase of sinusoidal signal is can be got by its in-phase and quadrature-phase (I&Q) components. The arctangent of the ratio of I and Q gives the angle of the signal relative to the phase of the sampling clock used to define I and Q.

To get the I and Q components, a signal is sampled at four times its frequency, that means once every 90 degrees. I, Q, -I, and –Q data sequences can be got. I subtract –I produce 2I, Q subtracts –Q makes 2Q, all common-mode errors are consequentially eliminated and low frequency noise is attenuated.

FRONTEND ELECTRONICS

As shown in Fig.2, the pulsed signal from FCT is broadband which comprise 325MHz sine wave. We use a high pass filter and low pass filter to make a narrowband filter. This narrowband signal be sent to DBM (double balanced mixer) to transfer signal to 16.25MHz and to filter again, so here we can get a 16.25MHz sine wave, this signal be input to a 14 bit ADC, the sample frequency is 65MHz, is quadruple of 16.25MHz. 65MHz sample frequency can promise to get a value every 90 degree, so we can get an orthogonal sequence data, the arctangent value of them is phase of the beam. The ADC can receive 325MHz reference signal, then output the 308.75MHz (19/20 of 325MHz) signal as the local signal of DBM.

FPGA CARD AND DAQ

ADC card named 100MAD_DA is selected to sample the waveforms, cope with the data and produce the timing signal. This card has two input tunnels, one is for FCT signal and the other is for reference signal. The analog signals digitize by the ADC, then sent to FPGA, in which we get I/Q data sequence and beam phase, then data are sent to computer by PCI express bus. It also produces the timing signal. The 325MHz reference signal are input to ADC, then 308.75MHz signal are output to send to DBM to down-convert the signal.

PRELIMINARY MEASURE RESULTS

As shown in Fig.3, beam phase of FCT1 and FCT2 have been got. You will find the effective data is not continuous because of two reasons, one is our beam is pulsed mode, not CW mode, the other reason is self-trigger mode. We got the beam phase is -86.98 and 57.66, so the beam phase difference is 144.64 degree. So the time of flight t is (144.64/360)*3.07778ns, equal to 1.237ns, the total flight time is 38.17ns which is 12 high frequency periods plus 1.237ns.

In order to calculate the beam energy, Eq 1, 2, and 3 are needed.

$$V=L/t \qquad (1)$$

ISBN 978-3-95450-176-2

TIME MEASUREMENT METHOD BASED ON CPLD FOR BEAM LOSS POSITION MONITOR*

Yong Yang, Yongbin Leng#, Yingbing Yan
Shanghai Institute of Applied Physics (SINAP), CAS, Shanghai 201204, P. R. China

Abstract

Beam loss position is of great concern at SSRF. Time measurement is one of the key technologies for beam loss position monitor. This paper introduces a time measurement method based on Complex Programmable Logic Device (CPLD). Simulation has been done to verify the performance of this method.

INTRODUCTION

SSRF is the 3.5GeV electron storage ring facility operated at the Pudong New District of Shanghai. During accelerator operation ionising radiation is detected outside the vacuum chamber, mainly caused by electromagnetic cascades, generated by beam loss electrons hitting the chamber. The total dose is predominantly located at only a few positions of the storage ring, especially at the position of transverse feedback system [1-3]. Optical fiber radiation dosimetry from Cherenkov principle offers the possibility to measure the position of beam loss.

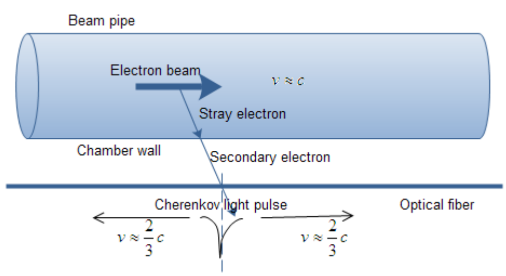


Figure 1: Beam loss position measuring principle.

Figure 1 shows the measuring principle. If some stray electron impact at the vacuum chamber, secondary electron will be excite. The movement of those secondary electron in the optical fiber will bring Cherenkov light pulse. The refractive index of optical fiber (quartz) is 1.5. So the speed of the light pulse in the optical fiber is 0.6666c, where c is the speed of light in vacuum. The Cherenkov light pulse will transmit along the fiber to the both ends [4,5]. The position of the original light pulse can be calculated from the time difference of the light pulse reaching between both ends.

Figure 2 shows an available measurement scheme. The PMT transforms the light pulse to electrical signal, high speed data acquisition card obtains the waveform, and then IOC calculates the time difference by complicated time orientation algorithm from PMT waveform. To measure time accurately, the data acquisition card must be high speed and has enough effective number bits [6,7].

This paper introduces a direct time measurement method to replace the high performance data acquisition card and IOC calculator algorithm.

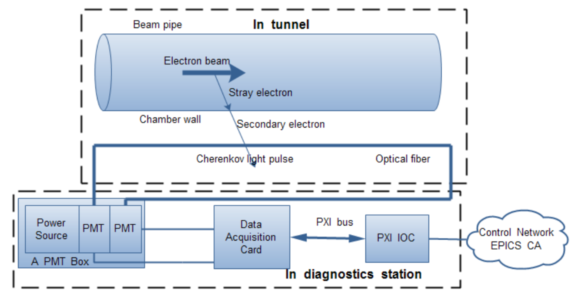


Figure 2: An available measurement scheme for beam loss position.

ARCHITECTURE

In the general purpose CPLD from Altera, there are many dedicated carry lines, which connect adjacent basic logic elements. These dedicated carry lines are normally used to form dedicated carry chains to implement arithmetic functions such as fast adders, counters, and comparators. The delay of each carry line is short and can be considered fixed for a particular physical technology, rail voltage, and temperature range. Using these carry lines as delay cells, a high-resolution time measurement equipment can be implemented in an CPLD [8].

To verify our idea of time interpolation within one clock period using dedicated carry lines, a time measurement equipment based on counter and time interpolation methods was implemented in an CPLD. The block diagram of the time measurement equipment is shown in Figure 3.

Fine Time Measurement

One of the simplest forms used to combine the dedicated carry lines into a carry chain is a multibit adder [9]. The Boolean equations of each adder cell are:

$$Sum = A \oplus B \oplus Ci$$

$$Co = AB + (A + B)Ci$$

where A and B are inputs for the adder, Ci is a carry-in bit, Co is a carry-out bit, and Sum is a sum bit.

*Work supported by National Nature Science Foundation of China (11375255)
#lengyongbin@sinap.ac.cn

ISBN 978-3-95450-176-2

ELECTRON BEAM UNIFORMITY DETECTION DEVICE FOR IRRADIATION ACCELERATOR*

LG Zhang#, Jiang Huang, Kaifeng Liu, Jun Yang, Chen Zuo
Huazhong University of Sicence and Technology, Wuhan, Hubei, China

Abstract

High-voltage electron accelerator is widely used in irradiation processing industry. Beam uniformity of the accelerator has very important impact on the quality of irradiated products. Accurate measurement of beam uniformity helps to improve product quality and production efficiency. In this paper, the electron beam uniformity detection device is designed based on Faraday cup array followed by the signal shaping circuit and the digital signal processing system. Finally, the computer offers friendly interface to help users understand the operating state of the accelerator and the electron beam uniformity information. This device uses DSP technology to process the signal and optical fibre to communicate, which greatly improves noise immunity capability of the system. Through such a high precision, easy to use detection device, user can get the accelerator beam irradiation uniformity information which is very useful to direct the industry radiation process.

INTRODUCTION

Irradiation accelerator is widely used in many areas, such as irradiation processing industry [1], waste gas treatment [1], food preservation [2], and so on. To ensure the quality consistency of the products, beam uniformity of the accelerator is very important. Accurate measurement of beam uniformity helps to improve product quality and production efficiency. The measurement results can also direct the design of the irradiation accelerator.

To measure the beam uniformity is to measure the beam intensity in the scan area of the irradiation accelerator. Faraday cup is a simple and effective device to measure the beam intensity [3]. It converts the beam intensity to a current signal by collecting the charged particles of the beam. In our design, a Faraday cup array is used to measure the distribution of the electron of the beam, which reflects the beam uniformity.

A high-voltage irradiation accelerator is built in Huazhong University of Science and Technology for biological science and materials science. The structure of the accelerator is shown in Fig. 1. The scan coverage of the beam is 1 *m*. The electron beam uniformity detection device is designed to measure the beam uniformity of this accelerator. As for other irradiation accelerators, the structure of the device is similar, the only differences are the parameters of the components in the measurement circuit and the number of the Faraday cup in the Faraday cup array.

*Work supported by the 2011 Project-Hubei Collaboration Innovation Centre of Non-power Nuclear Technology
#zhanglige @hust.edu.cn

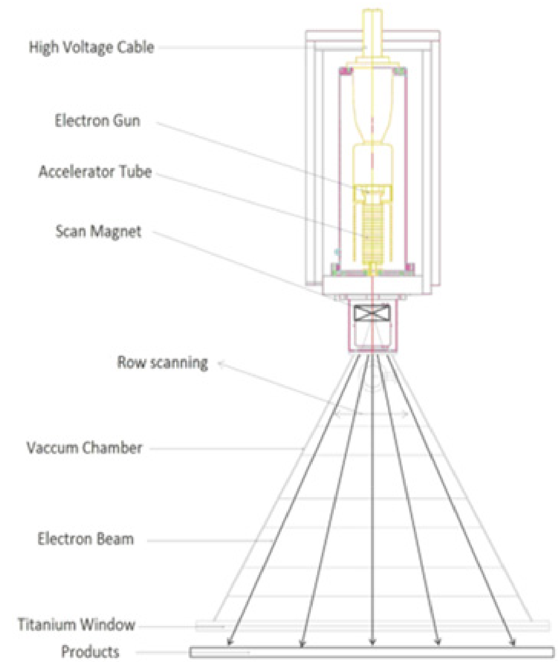


Figure 1: Structure of the high-voltage irradiation accelerator.

SYSTEM DESIGN

The structure of the system is shown in Fig. 2. It consists of four parts: Faraday cup array; measurement circuit; digital processor for optical fibre communication and digital signal processing; and the human-computer interaction interface. Firstly, the Faraday cup array collect the electrons of the beam in the scanning area. The electron current flows from the Faraday cup to the ground, which can reflect the beam density. Then the measurement circuit processes the current signal to reduce the noise and amplify the signal. In order to achieve the remote detection, while reducing EMI noise, a digital processor is used which converts a current signal into a digital signal. Digital filtering method is also used to process signals. In our design the digital filter realised using verilog HDL on the FPGA is a low pass filter. Finally, the beam signal was packaged into data frames and sent to the remote computer, and the graphical interface on a computer written by labVIEW shows the uniformity of the beam, so we can easily achieve the real-time detection of the beam uniformity.

ISBN 978-3-95450-176-2

DESIGN AND ANALYSIS OF A BEAM UNIFORMITY DETECTOR BASED ON FARADAY CUP ARRAY*

C. Zuo†, J. Huang, J. Yang, L G. Zhang
Huazhong University of Science and Technology, Wuhan, Hubei, China

Abstract

Beam uniformity of electron irradiation accelerator has a great impact results for industrial radiation process. In this paper, a beam uniformity detector, based on Faraday cup array, has been designed for a 400KV electron irradiation accelerator in Huazhong University of Science and Technology. Suitable structure has been calculated for the secondary electrons emission. Cooling system is necessary for the detector in the condition of high-intensity ion beams, and it has been designed by thermo-structural analysis. This detector now has been used for experiments successfully.

INTRODUCTION

Electron irradiation accelerator has been widely used in medicine, food, environmental protection and other industrial fields [1]. Uniformity of electron beam has a great influence on the results in the material and life subjects. Measurement of uniformity can provide accurate parameters for experiments, and important evidence for improving the performance of the accelerator.

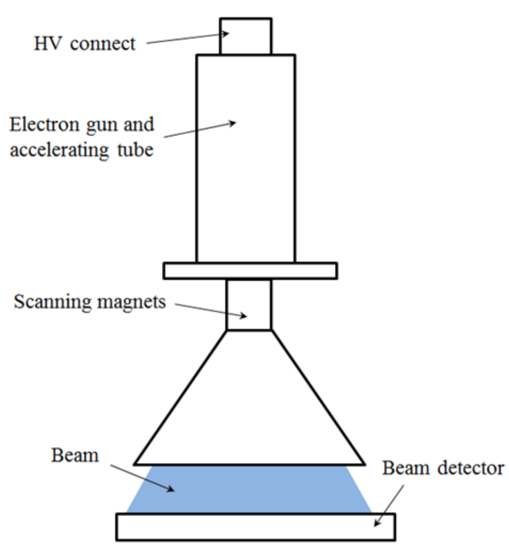


Figure 1: Sketch of a 400kV electron accelerator in HUST.

Faraday cup is a detector designed to measure the intensity of the beam. It is a conductive metal cup hit by a beam of ions or electrons. The metal can then gain a small net charge while the ions are neutralized. By measuring the electrical current in the metal, the number of charges being carried by the ions can be determined. The emission of secondary electrons should been considered, otherwise the result would be less than the actual value. Usually a washer-type metallic electron-suppressor lid, the repeller, is biased at a given voltage to catch the secondary electrons escaped from the metal surface. Faraday cup array is composed of multiple independent Faraday cups arranged in a one (or two) dimension area uniformly. Beam intensity distribution in the area can be obtained by fitting the signals of every Faraday cup. Huazhong University of Science and Technology, HUST, has a 400kV electron irradiation accelerator, as shown in Fig. 1. The length of the beam is about 1000mm. In order to detect the accelerator beam uniformity in the longitudinal direction, a detector based on Faraday cup array has been designed in this paper.

DESIGN DESCRIPTION

Structure

The common structure of Faraday cup is illustrated by Fig. 2 (a). It is composed of a copper cup which collects the electrons and a repeller. The two parts are mounted in an insulated cylinder and they insulate against each other. The metal cup can effectively collect electrons, but the secondary electrons need to be caught again while escaping from the metal surface. For reducing the measurement error, a bias lid mounted on the cup is wildly used. The electric field applied directly on the repeller will reverse and accelerate secondary electrons into the metal cup [2].

As the size of the electron irradiation accelerator's titanium window is 1000mm×100mm, Faraday cup is specially designed to be square, in order to collect more electrons in the beam's longitudinal direction. The inner of the square cup, made up of copper, is 110mm long, 45mm wide and 93mm deep, the surrounding wall is 5mm thick, bottom 7mm thick. The metal square cup is placed into an epoxy square cup with the size of 150mm×75mm× 130mm.The repeller (10mm thick) is mounted on the epoxy cup, so that the distance between bias plate and metal cup is up to 10mm. A square hole (100mm×25mm) is machined in the centre of the lid in order to make the beam enter the Faraday cup directly. A 100V negative bias voltage is given on the electrode.

This beam uniformity detector is composed of a linear array of 10 Faraday cups, as shown in Fig. 2 (b). The distance between each two adjacent is 25mm. Every

*Work supported by the 2011 Project-Hubei Collaboration Innovation Centre of Non-power Nuclear Technology
† cheneyz@hust.edu.cn

ISBN 978-3-95450-176-2

CW LASER BASED PHASE REFERENCE DISTRIBUTION FOR PARTICLE ACCELERATORS

S. Jablonski *, H. Schlarb, C. Sydlo, DESY, Hamburg, Germany

Abstract

We present a cost-effective solution for the synchronization of RF signal sources separated by tens of kilometers with the femtosecond accuracy. For the synchronization a phase reference distribution system (PRDS) is developed, which is comprised of a CW optical transmitter connected via single mode fiber-optic links to remote receivers. This technique enables to use only one transmitter for multiple receivers and removes the necessity of active stabilization units (e.g. piezo-driven fiber stretchers or laser wavelength tuning), which reduces considerably the system cost.

The concept of the new RF reference distribution, parameters of crucial components, phase drift detection and correction techniques are introduced, which lead to low noise and long-term stable PRDS operation. Detrimental effects of various linear and nonlinear fiber impairments are discussed. One of the most important elements is the phase detector, which is based on a direct RF-sampling ADC and it features a femtosecond measurement precision over 2π phase change. Finally, the long-term performance of the designed PRDS is shown, which was evaluated with a 500-m single-mode fiber and an RF signal of 1.3 GHz.

INTRODUCTION

Modern RF linear accelerators to fulfill high requirements in terms of energy gain per meter must be made much more effective. The accelerator performance is considerably affected by the phase reference distribution system (PRDS), which synchronizes various remote subsystems with femtosecond precision.

In this paper, a prototype of a PRDS is presented, which provides the timebase for the spatially distributed devices with the sub-100 fs pk-pk precision at the distance of a few km over several hours. The designed optical distribution makes use of standard components developed for the telecommunication industry and applies a distribution method that avoids complexity or expensive elements, which cause it attractive for a variety of applications.

Optionally, this PRDS can be also used for the transmission of low jitter RF signals to distant locations with the residual phase jitter lower than 10 fs rms. The transmitted RF signals can substitute local high performance RF sources, which leads to the considerable cost reduction.

The PRDS can be implemented in facilities using different reference signal frequencies ranging from about 100 MHz to up to several GHz, and the distance between the synchronized remote devices can reach dozens of km.

NEW CW OPTICAL DISTRIBUTION CONCEPT

The simplified block diagram of the designed PRDS is shown in Fig. 1. The system is comprised of a CW optical transmitter connected via single mode fiber-optic links to multiple receivers (one is shown in the picture). The optical transmitter is a single-mode laser intensity modulated with an RF reference signal using a Mach-Zehnder modulator (MZM). Optical signal linewidth is broadened by applying a phase modulator to mitigate Rayleigh and Brillouin scattering detrimental effects in optical fibers, which is discussed further in the text below. The modulated laser signal is amplified by a high power erbium doped fiber amplifier (EDFA), and then split to dozens of optical fiber links utilizing a multichannel optical splitter. In a receiver a fraction of the modulated light is coupled out to a photodetector "3" and converted into an RF signal, which is further used for the synchronization of a local RF source to the reference oscillator.

Environmental conditions like temperature, humidity, vibrations or air pressure have the considerable influence on the stability of the distribution system. The major phase drift sources are the optical fibers connecting the transmitter with the remote receivers, which experience mechanical tensions and refractive index changes due to environmental variations [1]. The temperature and humidity sensitivity of a standard SMF28e amounts to 40 fs/K/m and 2.5 fs/%RH/m [2], respectively. Hence, time delay variations in a few kilometer optical fiber can equal even a couple of hundreds ps. However, these variations can be measured using the feedback signal reflected by a mirror located at the end-station. Optical signals propagating forward and backward the SMF experience the same conditions and the delay variations are almost symmetrical in both directions.

To measure time delay fluctuations of the optical fiber, a small fraction of the optical beam is reflected back to the transmitter applying e.g. a Faraday rotator mirror (FRM). In the transmitter, the reflected light is separated from the forward propagating light using e.g. a circulator, then converted into an RF signal by a photodector "2". One channel of the optical splitter is directly connected to the photodetector "1" to measure phase drifts of the components in the transmitter, which are not temperature and humidity stabilized, e.g. Mach-Zehnder modulator or EDFA (see Fig. 1).

Phase drifts between the reference oscillator and a remote RF source are determined using three phase detectors denoted as PD1, PD2 and PD3, which measure the relative phase drifts ϕ_1, ϕ_2 and ϕ_3, respectively. The phase of a remote RF source should be shifted by ϕ_{drift} given by

$$\phi_{drift} = \phi_1/2 + \phi_2/2 + \phi_3 \qquad (1)$$

* szymon.jablonski@desy.de

ISBN 978-3-95450-176-2

BEAM PROFILE MEASUREMENTS WITH A SLIT-FARADAY CUP AND A WIRE SCANNER FOR A NEWLY DEVELOPED 18 GHZ SUPERCONDUCTING ECR ION SOURCE AND ITS LEBT*

H. J. You#, S. O. Jang, and W. I. Choo, NFRI, Gunsan, Korea

Abstract

In this presentation we show results of beam profile measurements by a slit-Faraday cup and a wire scanner. Argon 8+ beams were generated in a new liquid helium-free superconducting electron cyclotron resonance ion source (ECRIS). The ECRIS, named SMASHI, was successfully developed at the National Fusion Research Institute in 2014, and in the future it will be dedicated for highly charged ions matter interaction research facility (HIMIRF). Before designing HIMIRF terminals after low energy beam transport (LEBT), it is necessary to characterize the beam properties of the source and its LEBT line. The beam profile measurements have been done after an analyzing dipole magnet (DM). The slit-Faraday cup and the wire scanner were installed at 25 cm and 120 cm from the exit flange of the DM, respectively. Between the two diagnostics an Einzel lens was positioned to control the focusing of diverged beams. Here, with the measurements we checked the present beam alignments in the LEBT, and studied the dependence of beam profile variation on the operations of beam optics such as steering magnets and Einzel lens.

INTRODUCTION

A new superconducting 18 GHz electron cyclotron resonance ion source and its low energy beam transport were developed at the National Fusion Research Institute in South Korea [1]. The source, named SMASHI (Superconducting Multi-Application Source of Highly-charged Ions), will be dedicated for future application of highly charged ions in the area of matter interaction, diagnostic imaging, and probing. In this proceeding, we briefly describe SMASHI and its LEBT. Then, we show preliminary results of beam charge spectra of ^{4}He, ^{16}O, ^{40}Ar, ^{132}Xe ion beams. In order to characterize the beam properties in the LEBT, we also measured beam profiles by a slit-FC system and a wire scanner, by which the beam alignments of the source and the LEBT are checked. Variations of beam profiles are studied with respect to different settings of ion optics in the LEBT.

SOURCE DESCRIPTION

Figure 1 shows the overall section view of SMASHI. As an ECRIS for generating multiply/highly-charged ions, SMASHI has following main features: two-frequency heating(18, 18+Δ GHz), high power-capable plasma chamber, remotely-positional variable gap extraction system, capability to generate a wide range of ion elements from gas to metal, and two diagnostic ports for the extraction region. All these features are highly oriented to the generation of diverse highly charged ions (HCI). Most of all, due to the helium-free SC magnet, SMASHI can be more economically operated with low power consumption, which therefore enabling the full system of ECRIS operated on a high-voltage platform.

Microwave Injection

In Fig. 1, the microwave injection side can be viewed. Normally, the injection electrode is located at the maximum position of the axial magnetic field, and depending on the source condition it can be moved to other optimum positions by adjusting the bellows. In the injection electrode two WR62 waveguide ports, an on-axis sputtering hole, a centered-perforated biased disk, two diagnostic/oven holes, and one gas hole were arranged [1]. The WR62 ports, placed well out of the plasma pattern, are separated by 120◦ from each other. The biased disk is shaped as a triangle with a thru-hole in its center, into which the on-axis sputtering target is inserted. The sputtering target system is remotely positional and designed to easily exchange different materials.

Extraction System

The extraction system, shown in Fig. 1, is a puller-Einzel lens system consisting of 3 electrodes. Each electrode is supported and guided by 4 rods fixed to the extraction chamber. The distance between electrodes can be adjusted when necessary. The whole extraction system is remotely positional by a motor-driven-control, where the gap between the plasma electrode and the puller electrode is adjustable by 20–50 mm. Table 1 summarizes the extraction conditions and beam characteristics. The resulted rms emittance for Ar^{8+} was calculated by using IGUN with the inclusion of the magnetic field and charge state distribution (CSD). The resulting beam radius and the momentum of Ar^{8+} beam are 33 mm and 41 mrad, respectively.

Table 1: Extraction Conditions and Beam Characteristics

Extraction voltage	30 (10-30) kV
Gap distance	33 (20-50) mm
Einzel lens (negative)	30 (10-30) kV
Rms emittance for Ar^{8+} at 500 mm from plasma electrode	48 mm mrad (R_{max}=33 mm, A_{max}=41 mrad)

*This work was supported by R&D Program of 'Plasma Convergence & Fundamental Research' through the National Fusion Research Institute of Korea (NFRI) funded by the Government funds
#hjyou@nfri.re.kr

ISBN 978-3-95450-176-2

PAL-XFEL'S TURBO-ICT FOR BEAM CHARGE MONITORING*

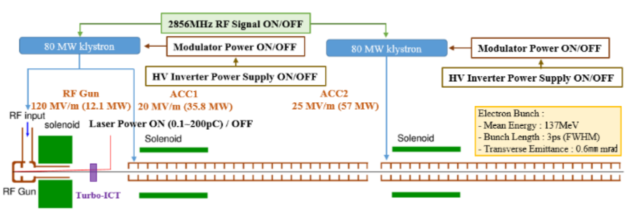
H. Choi†, J.H. Hong, J.H. Han, B.R. Park, S.H. Kim, S.J. Park, H.S. Kang
Department of Accelerator, PAL-XFEL, Pohang, Korea

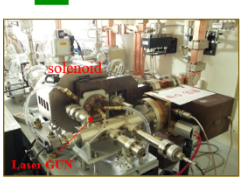
Abstract

The construction of the PAL-XFEL building, which is a fourth-generation synchrotron radiation-light source, was completed in February 2015. Accelerating devices (Cavities, Klystrons, Modulators) and undulators will be installed by December 2015. The installation of the remaining devices will be completed by the start of 2016. A Beamline user service will be started from the middle of 2016 [1]. The installation of PAL-ITF (Injector Test Facility) was completed at the end of 2012 for the production of high-quality electron bunches. Efforts were made to improve the performance of pre-injector system and diagnostic equipments. In this study, details of the performance improvements of PAL-ITF measurements using a Bergoz Turbo-ICT, which is able to measure the amount of bunch charge from 0.1 to 200pC, and the operating plan of Turbo-ICT which will be installed and operated in PAL-XFEL are introduced.

COMPOSITION OF PAL-ITF

PAL-ITF was constructed to produce the same amount of charge in the range of 0.1~200pC as PAL-XFEL and to test the laser cathode RF gun generating the electronic beams (jitter and drift are less 0.5% of set charge) and the pre-injector accelerating the beam preserving shape, emittance length and energy spread. Figure 1 shows the composition diagram of PAL-ITF [2].





Load Type	GUN	1st Accelerator	2nd Accelerator
Peak RF power [MW]	12.1	35.8	57
RF Pulse Length [us]	1.5	1.5	1
Average Power [kW]	1.1	3.2	3.4
Efficiency	35%		40%
HV Pulse Length	> 4us [FWHM]		
Repetition Rate : 1~60Hz			

Figure 1: PAL-ITF composition diagram.

After completing construction of PAL-ITF at the end of 2012, beam charge was first measured using ICT and faraday cup to monitor beam charge. There were various difficulties measuring the exact charge of 0.1~200pC due to the noise of the pulse power klystron modulator. Turbo-ICT was built in 2013 to accurately measure the charge of beams [3]. A charge of 1pC or more could be measured accurately as shown in Figure 2, after measuring the generated charge of the laser gun while changing the half-wave plate angle inside the laser system. However, it was impossible to measure a charge of 1pC or less due to the noise from the pulse power klystron modulator as shown in Figure 3 [4]. The problem of noise from the pulse power klystron modulator is serious enough to create negative effects on not only the measurement of Turbo-ICT charge but also affects the electronic circuits of all diagnostic units and control devices. Measures had to be prepared to prevent the noise from affecting the exact measurement and operation of electronic devices.

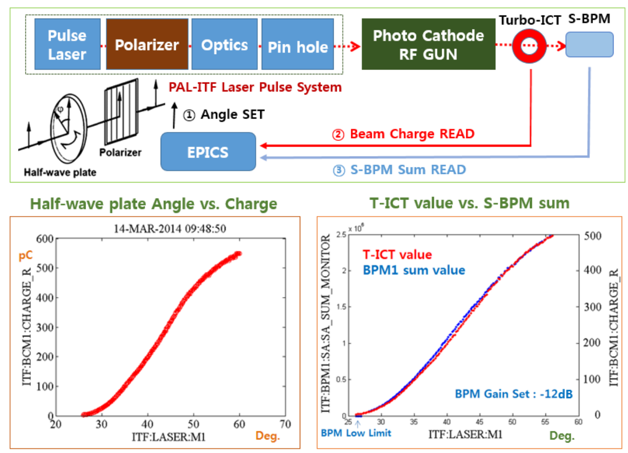


Figure 2: Generation of charge of the laser cathode gun and results of measurement of charge.

PAL-ITF -40-UHV-Turbo1-304-H 180MHz Cable 30M

BCM	Purpose	ICT Size	Turbo-ICT	BCM-RF	Charge [pC]
1	Laser Gun Charge	CF4.5"-ID34.9mm	#3088	#009	$0.015766 \times 10^{BCM\text{-}RF[V] / 0.817896}$

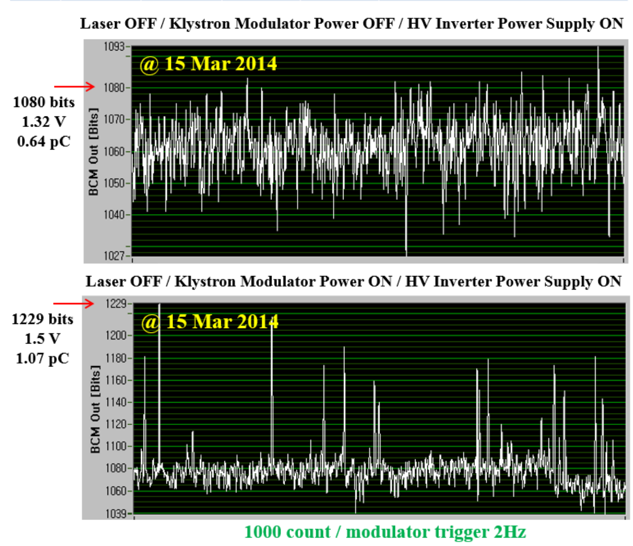


Figure 3: Effects of the klystron modulator noise observed from Turbo-ICT.

*Work supported by Ministry of the Science, ICT and Future Planning
†choihyo@postech.ac.kr

ISBN 978-3-95450-176-2

DEVELOPMENT OF HIGH PRECISION CAPACITIVE BEAM PHASE PROBE FOR KHIMA PROJECT

Ji-Gwang Hwang*, Tae-Keun Yang, SeonYeong Noh
Korea Institute of Radiological and Medical Sciences(KIRAMS), Seoul, South Korea
Peter Forck
GSI, Darmstadt, Germany

Abstract

In the medium energy beam transport (MEBT) line of KHIMA project, a high precision beam phase probe monitor is required for a precise tuning of RF phase and amplitude of RFQ and IH-DTL. It is also used for measuring a kinetic energy of ion beam by time-of-flight (TOF) method using two phase probes. In this paper, we show the electromagnetic design of the high precision phase probe to satisfy the phase resolution of 1 ° (@ 200 MHz), the test result with a wire test bench to estimate a signal strength and phase accuracy, the design of the 0.2 2.0 GHz broad-band electronics for amplifying the signal strength, and the results of beam energy and RF frequency measurement using a proton beam from the cyclotron in KIRAMS.

INTRODUCTION

The Korea Heavy Ion Medical Accelerator (KHIMA) project is launched to construct a heavy-ion therapy machine using carbon and proton beams. It will provide a carbon beam up to 430 MeV/u and proton beam up to 230 MeV which correspond to a water equilibrium range of 3.0 to 27.0 g/cm^2 [1]. The machine consists of an injector included an electron cyclotron resonance ion source (ECR-IS), low energy beam transport(LEBT) line, RFQ and IH-DTL linacs, and medium beam transport (MEBT) line, synchrotron, and high energy beam transport (LEBT) line. The carbon and H_3^+ beam produced by the ECR-IS with the energy of 8 keV/u and the $^{12}C^{4+}$ and H_3^+ beams were separated from the unnecessary beams by using an analyzing dipole magnet and it is transported through the low energy beam transport (LEBT) line. The low energy beam, 8 keV/u, is accelerated up to 7 MeV/u by the RFQ and IH-DTL [2].

By a carbon foil with a thickness of 100 μg/cm^2 in the MEBT line, the $^{12}C^{4+}$ beam is fully stripped and H_3^+ beam is changed to proton beam and injected to the synchrotron. The $^{12}C^{6+}$ and proton beams is accelerated up to 430 MeV/u and 230 MeV, respectively. A high precision beam phase probe monitor is required in the MEBT line of the KHIMA project for a precise tuning of RF phase and amplitude of the RFQ and IH-DTL to achieve the designed performance and high injection efficiency by adjusting longitudinal beam parameters such as a beam energy and bunch length at the exit of the IH-DTL, and to monitor the status of the carbon foil by measuring the variation of the kinetic energy of ion beam by time-of-flight (TOF) method using two phase probes.

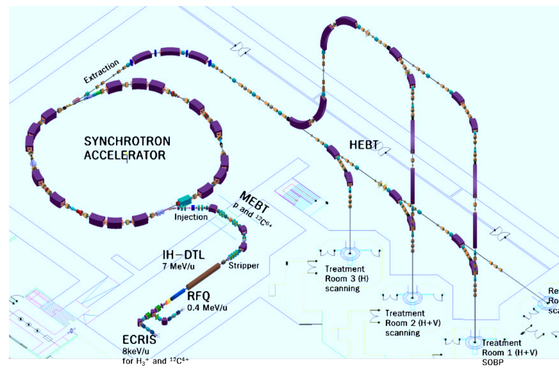


Figure 1: Layout of KHIMA accelerator.

CAPACITIVE PHASE PROBE DESIGN

In the MEBT line, two phase probes are installed to measure the kinetic energy of the ion beams from IH-DTL and to adjust the RF phase and amplitude of IH-DTL by measuring the length of micro-pulses. Since the stripping foil is installed between two phase probes, the status of the stripping foil can be confirmed by the beam energy measurement because the energy loss due to the straggling effects, ~ 16 keV/u, is vanished when the foil is broken. In order to achieve the energy resolution of 10 keV/u, the phase resolution of the phase probe monitor should to be 1° at 200 MHz. Since the beam current is low, ~ 0.1 mA for carbon beam, the capacitive type phase probe monitor is chosen to get the longitudinal distribution without the signal distortion and to get the relatively strong signal. The capacitive pick-up is a stripline bent around the beam pipe axis and then the impedance matching is significant to reduce the ringing effect due to the reflection by the impedance mis-matching. The impedance of the stripline is given by [3]

$$Z_0(l) = \frac{87}{\sqrt{\epsilon_r + 1.4}} \ln\left(\frac{5.98h}{0.8l + d}\right), \quad (1)$$

where ϵ_r is the relative permittivity, h is the distance between the pick-up ring and surroundings, and d and l are the thickness and length of the pick-up ring. In order to determine the length of the pick-up ring, the impedance as a function of the length when the distance between the inner and outer conductor(h) and the thickness (d) are 14 mm and 3 mm, respectively, that is shown in Fig. 2.

* hwang@kirams.re.kr

ISBN 978-3-95450-176-2

STATUS OF BEAM DIAGNOSTICS AT KHIMA FACILITY

Tae-Keun Yang*, Dong Hyun An, Ga Ram Hahn, Heejoong Yim, Ji-Gwang Hwang,
Chang Hyeuk Kim, Seon Yeong Noh, and Chawon Park
Korea Institute of Radiological and Medical Sciences (KIRAMS), Seoul, South Korea

Abstract

The Korea Heavy Ion Medical Accelerator (KHIMA) is the cancer therapy facility based on a synchrotron which can accelerate up to 430 MeV/u for carbon beam and up to 230 MeV/u for proton beam. The facility has 4 sectors Low Energy Beam Transport (LEBT) line from ECR-IS to radio-frequency quadrupole (RFQ) and interdigital H-mode drift-tube-linac (IH-DTL), Medium Energy Beam Transport (MEBT) line from IH-DTL to synchrotron, synchrotron ring, High Energy Beam Transport (HEBT) line from the ring to irradiation rooms, 3 treatment rooms and 1 research room. For the beam diagnostics at the KHIMA, 17 type monitors with total number of 88 are considered and planned including the related instruments such as slit, stopper, stripper and etc. This proceeding introduces specifications of each diagnostic devices and shows test results of several devices.

INTRODUCTION

The Korea Heavy Ion Medical Accelerator (KHIMA) is a project to develop a heavy-ion therapy machine based on a synchrotron. The conceptual design report for each part of the facility has been completed and fabrication of some equipments has been started. The facility can be divided as 4 sectors according to the transferred beam energy; Low Energy Beam Transport (LEBT), Medium Energy Beam Transport (MEBT), synchrotron ring, and High Energy Beam Transport (HEBT) line [1]. A detail information for an ion beam at each sectors are important to transfer well and confirm a beam to a patient with high intensity by minimizing a beam loss. The various monitors are required to measure beam specification such as the beam current, spatial distribution, spill structure, and energy. The beam diagnostic devices can be classified as a destructive or a non-destructive device. The Faraday-cup(FC) is the most famous destructive device and the current transformer(CT) is the most famous non-destructive one to measure the beam current. The DC FCs are installed at the LEBT and AC FCs are the LEBT and MEBT line. The AC current transformers(AC CTs) are installed at the LEBT and MEBT and the DC current transformer (DCCT) is installed at the syncrotron ring. The combination of slit and wire scanner in LEBT line or wire grid monitor in MEBT line, and the pepper-pot device in LEBT line are considered for measuring the beam emittance, which is a significant beam parameter in the accelerator. The transverse beam profile is also measured by the scintillation screen in the synchrotron and HEBT line. Two capacitive pick-up devices are installed in the MEBT line to measure the beam energy by the time-of-flight (TOF) method. Linear-cut beam position monitor, which has the wide linear region, and stripline kicker are adopted to measure the beam position and to use as a RF exciter for tune measurement and RF-KO, respectively. For the interlock, the beam stopper, collimator, and slit is also installed at the each section. In this paper, the beam diagnostics contained at each sectors of the KHIMA facility is introduced.

* ytk@kirams.re.kr

LOW ENERGY BEAM TRANSFER LINE

The LEBT line is the region of ECR-IS to an entrance of radio-frequency quadrupole (RFQ), see Fig. 1. It has two ECR-IS for producing $^{12}C^{4+}$ and H_3^+ beams. The extraction voltage of the ECR-IS is 24 kV and the required maximum current are 285 euA for $^{12}C^{4+}$ and 765euA H_3^+, respectively. The extracted ion beam is bent by 90° analyzing magnet for ion selection and then the selected beam is transferred into RFQ to accelerate the beam up to 7 MeV/u through the optical components, like solenoid, steering magnet, quadrupole magnet, and electrostatic chopper.

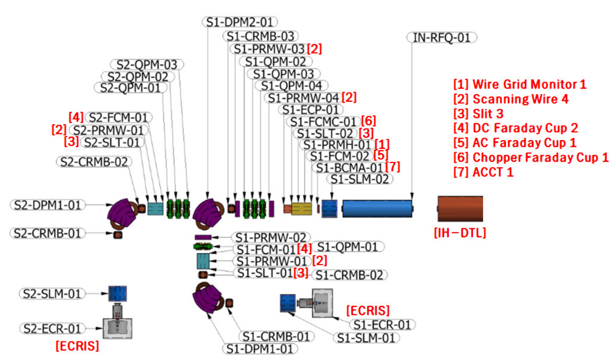


Figure 1: Layout and position of beam diagnostics in LEBT line.

The LEBT line of KIHMA has two emittance measurement systems, which consists of 4 slits with 2 slits at each x- and y-axis, wire scanner with two perpendicular wires, and DC Faraday cup in a vacuum chamber, for measuring the beam emittance after the beam selection by the analyzing magnet and to control the beam optics by measuring the profiles before and after triplet magnets, and an ACCT for measuring beam current after a chopper system. Especially, the Faraday-cup and slit, which is installed in LEBT line, has the cooling channel with the cooling capacitance of 100 W because the beam power of 30 W is fully deposited on

ISBN 978-3-95450-176-2

INSTRUMENTATION IN DESIREE

A. Källberg, G. Eklund, S. Silverstein, A. Simonsson, M. Björkhage, M. Blom, H. Cederqvist, L. Liljeby, P. Löfgren, A. Paál, P. Reinhed, S. Rosén, H. T. Schmidt, R. D. Thomas, Stockholm University, Department of Physics, SE-106 91 Stockholm, Sweden,
H. Danared, European Spallation Source, Box 176, SE-221 00 Lund, Sweden

Abstract

The instrumentation in the double electrostatic storage rings DESIREE is discussed, In particular, we describe the measurements of the stored beam currents, using a fast kick-out of the beam or Schottky signals. For the Schottky signals, the use of the double-peak structure of the signal is described. Also the preparations to implement stochastic cooling in DESIREE are included in this paper.

INTRODUCTION TO DESIREE

DESIREE is a double electrostatic storage ring at the Department of Physics at Stockholm University. The two rings have similar circumferences, 8.7 m, and a common straight section along which stored ions can interact. The ion optics is housed in one single, double walled cryostat and is cooled to around 13 K by four cryocoolers. Two injectors are able to supply both positive and negative ions to both rings.

The optics of DESIREE is shown in Fig. 1 and a picture of the elements mounted on the 20 mm thick aluminium baseplate of the inner box in the cryostat is shown in Fig. 2. Each ring consists of two 160° bends (CD) and four 10° bends (DE) to complete one turn. Two of the 10° bends are common for both rings. For focussing there are four quadrupole doublets (QD) in each ring and there are also several transverse steerers (CC, CV) in each ring. All elements in DESIREE are electrostatic.

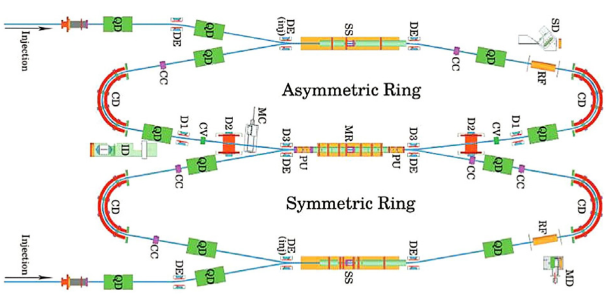


Figure 1: Drawing of the DESIREE optics.

The lattices are similar to the one in ELISA [1]. The main difference is that the injection kicker switches from $+10^{\circ}$ to -10° instead of from 10° to 0°. This difference was made to minimize the amount of infrared radiation reaching the cold interior in the cryostat from the warm surroundings. It also enables the current measurement described later in this paper.

Ring S, the symmetric ring, has a two-fold mirror symmetry while in ring A, the asymmetric ring, two

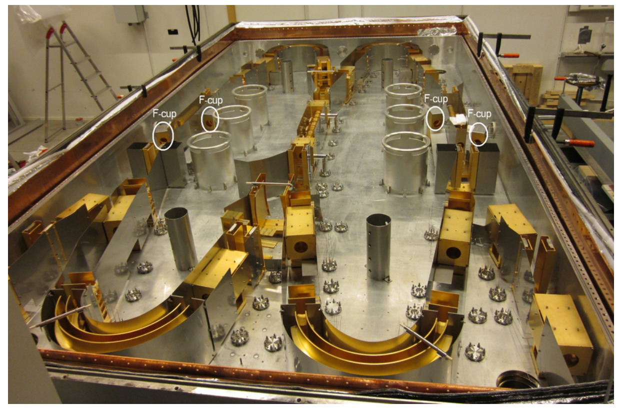


Figure 2: DESIREE inside the cryostat.

quadrupole doublets are displaced to permit the installation of two extra bends (D1, D2) on each side of the common section. These are necessary to simultaneously store ions with different energies. Two bends (D3) are common for both rings, they bend 10° in ring S and 0.5°-10° in ring A, depending on the ion mass and energy in ring A.

Ions can be stored in ring S with lifetimes of several minutes. The lifetimes in ring A are shorter, only in the order of several seconds. This can be expected, since the dynamic aperture in ring A is much smaller than in ring S. For more details about DESIREE see [2] and [3]

MEASUREMENTS OF STORED ION CURRENTS

The most straightforward way to measure the stored ion current would be to use a DC current transformer (DCCT). However, there is no DCCT installed in DESIREE and the stored currents are often weak, often only a few nA or less, so a DCCT would be too noisy to measure such currents. Possibly a squid-based DCCT could be used, but no such device has been incorporated. Instead we are using two other methods.

The Kick-Out Method

Two Faraday cups are available outside and inside of the injection in each ring. These are marked in Fig. 2. The cups on the inside of the rings are used to measure the injected beam when 0 V is applied to the kicker plates (DE (inj)). The outside cups are intended to be used for measurements of the beam after one completed turn. For this measurement the kicker plates are kept at a constant voltage and after having completed one turn, the beam is

ISBN 978-3-95450-176-2

STUDY OF THE TRANSVERSE BEAM EMITTANCE OF THE BERN MEDICAL CYCLOTRON

K. P. Nesteruk[a,*], M. Auger[a], S. Braccini[a], T. S. Carzaniga[a], A. Ereditato[a], P. Scampoli[a,b]
[a]Albert Einstein Center for Fundamental Physics, Laboratory for High Energy Physics, University of Bern, Switzerland
[b]Department of Physics, University of Napoli Federico II, Naples, Italy

Abstract

The cyclotron laboratory for radioisotope production and multi-disciplinary research at the Bern University Hospital (Inselspital) features an IBA Cyclone 18 MeV proton cyclotron equipped with a Beam Transport Line (BTL), ending in a separate bunker. The horizontal and vertical transverse beam emittances were measured for the first time for this kind of accelerator. Two different techniques were used. A measurement based on quadrupole strength variation and beam width assessment after the last focusing section on the BTL was first performed. A second technique was developed employing 4 beam profilers located at successive positions around a beam waist. These novel beam profile detectors were developed by our group and are based on doped silica and optical fibers. For the data analysis, a statistical approach allowing for estimation of the RMS transverse emittance of a beam with an arbitrary density profile was applied. The results obtained with both methods were found to be in good agreement.

INTRODUCTION

A cyclotron laboratory for radioisotope production and multi-disciplinary research is in operation at the Bern University Hospital (Inselspital) [1]. The facility is equipped with an IBA Cyclone 18 MeV proton cyclotron shown in Fig. 1. The cyclotron is supplied with two H^- ion sources, a redundancy aimed at maximizing the efficiency for daily medical radioisotope production. It provides high beam currents up to 150 µA in single or dual beam mode. Extraction is realized by stripping H^- ions in a 5 µm thick pyrolytic carbon foil.

The Bern cyclotron laboratory is equipped with a Beam Transport Line (BTL), which is a unique feature for a hospital based facility. It allows to carry out multi-disciplinary research in parallel with daily radioisotope production. A schematic view of the BTL is presented in Fig. 2. Alternate beam focusing and defocusing is realized by two horizontal-vertical (H-V) quadrupole doublets, the former located in the cyclotron bunker and the latter in that of the BTL. A movable cylindrical neutron shutter is located at the entrance of the BTL bunker to minimize the penetration of neutrons during routine radioisotope production. For scientific activities, experimental equipment such as particle detectors or specific target stations are installed at the end of the 6.5 m long BTL.

* Corresponding author: konrad.nesteruk@lhep.unibe.ch

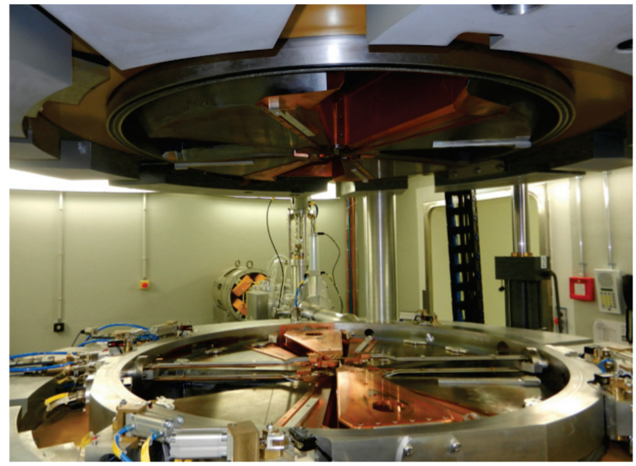


Figure 1: The Bern cyclotron opened during commissioning.

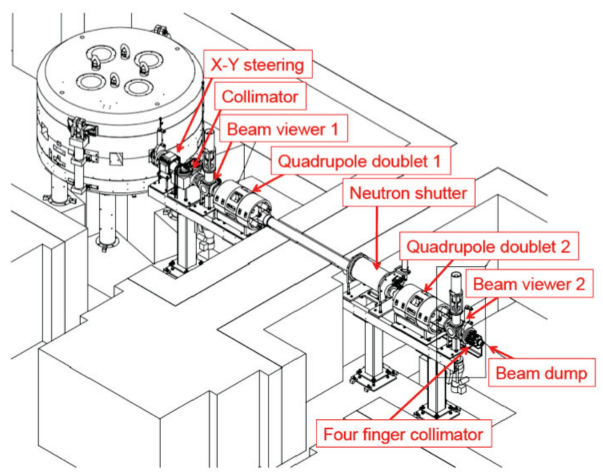


Figure 2: Schematic view of the Bern cyclotron facility, where all the main elements of the BTL are highlighted.

In this paper, we report on the first measurements of the transverse beam emittance of an IBA 18 MeV cyclotron. The measurements were conducted by means of beam profilers developed by our group and named UniBEaM. This detector is a compact device based on doped silica and optical fibers which allows for fully automatized measurements of transverse beam profiles. The first prototype of UniBEaM is described in [2]. For the measurements reported in this paper, a beam current of about 250 nA was used, which is unusual for medical cyclotrons. Such low currents are obtained with the methods described in [3]. This intensity range allows operating the UniBEaM detector in a linear

ISBN 978-3-95450-176-2

BEAM LOSS MONITORS FOR THE CRYOGENIC LHC MAGNETS*

M. R. Bartosik†, B. Dehning, M. Sapinski, A. Alexopoulos, CERN, Geneva, Switzerland
V. Eremin, E. Verbitskaya, IOFFE, St. Petersburg, Russian Federation
E. Griesmayer, CIVIDEC, Vienna, Austria

Abstract

The Beam Loss Monitoring system of the Large Hadron Collider close to the interaction points contains mostly gas ionization chambers working at room temperature, located far from the superconducting coils of the magnets. The system records particles lost from circulating proton beams, but is also sensitive to particles coming from the experimental collisions, which do not contribute significantly to the heat deposition in the superconducting coils. In the future, with beams of higher brightness resulting in higher luminosity, distinguishing between these interaction products and dangerous quench-provoking beam losses from the circulating beams will be difficult. It is proposed to optimise by locating beam loss monitors inside the cold mass of the magnets, housing the superconducting coils, in a superfluid helium environment, at 1.9 K. The dose then measured by such cryogenic beam loss monitors would more precisely correspond to the real dose deposited in the coil. This contribution will present results of radiation hardness test of p^+–n–n^+ silicon detectors which, together with single crystal Chemical Vapour Deposition diamond, are the main candidates for these future cryogenic beam loss monitors.

INTRODUCTION

Motivation

It has been shown with particle shower simulations [1] that with the present configuration of Beam Loss Monitors (BLMs) close to the LHC interaction points (IPs), the ability to measure the energy deposition in the coil is limited because of collision debris masking the real beam loss signal (see Fig. 1).

In the current BLM system layout the particle showers from beam loss are partly shielded by the cryostat and the iron yoke of the magnets. The system can be optimised by locating beam loss monitors as close as possible to the sensitive superconductive coils. For the high luminosity LHC upgrade (HL-LHC) BLMs are therefore foreseen to be located near the superconducting coils inside the cold mass of the magnets in the superfluid helium at a temperature of 1.9 K [2] (see Fig. 2, courtesy of P. Ferracin).

The advantage of this new location is that the dose measured by the Cryogenic BLM will correspond much better to the dose deposited in the superconducting coil [6].

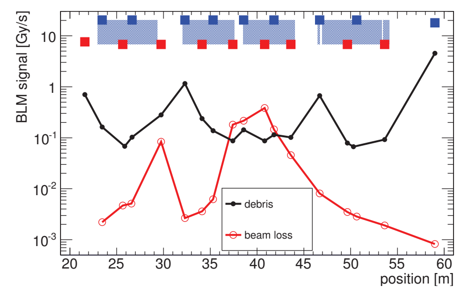


Figure 1: Signal in the coil and in the existing BLMs; Black trace: BLM signal from collision debris (one marker at each BLM location); Red trace: BLM signal from a quench-provoking loss inside the central superconducting quadrupole magnet of the focusing triplet (Q2B).

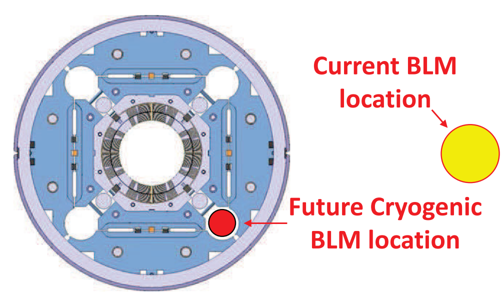


Figure 2: Cross section of a large aperture superconducting insertion magnet (MQXF) foreseen for HL-LHC with the current BLM and the future Cryogenic BLM locations shown.

Cryogenic BLM Requirements

From the electronic point of view the main requirements of the detector are a linear signal relationship with the received dose in the range between 0.1 and 10 mGy/s and a response time faster than 1 ms. The main mechanical challenge of a Cryogenic BLM system is to provide 20 years of maintenance free operation at temperature of 1.9 K [6]. Furthermore the Cryogenic BLM needs to work in a magnetic field of 2 T and be capable of withstanding a fast pressure rise up to 20 bar in case of a magnet quench. The selected detector technologies are based on semiconductor radiation detectors and current readout. The candidates under investigation are single crystal Chemical Vapour Deposition (scCVD) diamond [3] and p^+–n–n^+ silicon [4] detectors.

* This research project has been supported by a Marie Curie Early Initial Training Network Fellowship of the European Communitys Seventh Framework Programme under contract number (PITN-GA-2011-289485-OPAC).

† marcin.bartosik@cern.ch

ISBN 978-3-95450-176-2

A CRYOGENIC CURRENT COMPARATOR FOR THE LOW-ENERGY ANTIPROTON FACILITIES AT CERN

M. Fernandes*, The University of Liverpool, U.K. & CERN, Geneva, Switzerland
J. Tan, CERN, Geneva, Switzerland
C. Welsch, Cockcroft Institute & The University of Liverpool, U.K
R. Geithner, R. Neubert, T. Stöhlker, Friedrich-Schiller-Universität &
Helmholtz Institute Jena, Jena, Germany
M. Schwickert, GSI, Darmstadt, Germany

Abstract

Several laboratories have shown the potential of Cryogenic Current Comparators (CCC) for an absolute measurement of beam intensity down to the nA level. This type of current monitor relies on the use of Superconducting QUantum Interference Device (SQUID) magnetometers and superconductor magnetic shields. CERN, in collaboration with GSI Helmholtz Centre for Heavy Ion Research, Jena University, and the Helmholtz Institute Jena are currently developing an improved version of such a current monitor for the Antiproton Decelerator (AD) and Extra Low ENergy Antiproton (ELENA) rings. The primary goals are a better current measurement accuracy and overall enhanced system availability. This contribution presents the design of the CCC, an estimation of its resolution, dynamic limitations of the SQUID, as well as a description of the modifications to the coupling circuit and cryostat that were required to optimize the monitor for the anticipated beam parameters. First results from beam measurements are also presented. To our knowledge these are the first CCC beam current measurements performed in a synchrotron and the first to be performed with both coasting and bunched beams.

LOW-INTENSITY BEAMS CURRENT MEASUREMENT

Low-intensity charged particle beams present a considerable challenge for existing beam current diagnostics [1]. This is particularly significant for coasting beams with average currents below 1 µA which is the minimum resolution of standard DC Current Transformers. Other monitors, such as AC Current Transformers or Schottky monitors (currently in use in AD) are able to measure low-intensity beam currents, but neither can simultaneously provide an absolute measurement, with a high current and time resolution, which is at the same time independent of the beam profile, trajectory and energy.

At CERN's low-energy antiproton decelerators, the AD and the ELENA (currently under construction) rings, circulate both bunched and coasting beams of antiprotons with average currents ranging from 300 nA to 12 µA. Having a current measurement with the above mentioned characteristics would benefit the machine operation and optimization.

To meet these requirements, a low-temperature SQUID-based Cryogenic Current Comparator (CCC) is currently under development [2,3]. Similar devices have already been developed for electrical metrology [4,5], and have already been used for beam current measurements in particle accelerator [6,7]. The current project, is a collaboration between CERN, GSI, Jena University and Helmholtz Institute Jena to develop this technique further.

The main design specifications for the monitor are: beam current resolution < 10 nA; and measurement bandwidth of 1 kHz.

Overview of the Functioning Principle of the CCC

The CCC (see schematic in Fig. 1) works by measuring the magnetic field induced by the particle beam current. This field is concentrated in a high-permeability ferromagnetic pickup core, from which it is coupled into the SQUID sensor. These are highly sensitive magnetic flux sensors that permit sensing the weak fields created by the beam. A superconducting magnetic shield structure around the pickup-core, as described in [7,8], renders the coupled magnetic field nearly independent of the beam position and makes the system practically immune to external magnetic field perturbations. The unique advantages of the CCC monitor

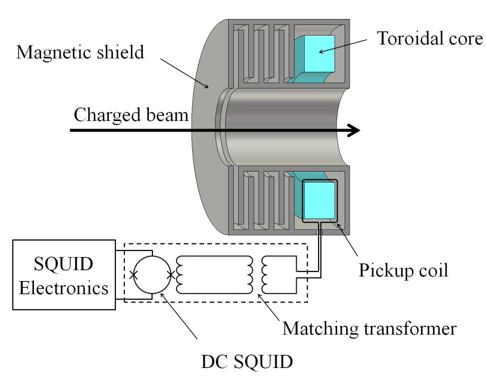


Figure 1: Schematic of the CCC.

are its ability to measure the average current of both coasting and bunched beams with nA resolution, as has been demonstrated by other laboratories. Previous installations of the CCC for beam current measurements were, however, usually

* Funded by the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 289485.

ISBN 978-3-95450-176-2

BLM CROSSTALK STUDIES ON THE CLIC TWO-BEAM MODULE

M. Kastriotou, E. Nebot del Busto, CERN, Geneva, Switzerland; University of Liverpool, UK; Cockroft Institute, Warrington, UK
W. Farabolini, CERN, Geneva, Switzerland; CEA/DSM/IRFU, Saclay, France
S. Doebert, E. Effinger, E.B. Holzer, F.S. Domingues Sousa, W. Viganò, CERN, Geneva, Switzerland
C.P. Welsch, University of Liverpool, UK; Cockroft Institute, Warrington, UK

Abstract

The Compact Linear Collider (CLIC) is a proposal for a future linear e^+-e^- collider that can reach 3 TeV center of mass energy. It is based on a two-beam acceleration scheme, with two accelerators operating in parallel. One of the main elements of CLIC is a 2 m long two-beam module where power from a high intensity, low energy drive beam is extracted through Power Extraction and Transfer Structures (PETS) and transferred as RF power for the acceleration of the low intensity, high energy main beam. One of the potential limitations for a Beam Loss Monitoring (BLM) system in a two-beam accelerator is so-called "crosstalk", i.e signals generated by losses in one beam, but detected by a monitor protecting the other beam. This contribution presents results from comprehensive studies into crosstalk that have been performed on a two-beam module in the CLIC Test Facility (CTF3) at CERN.

INTRODUCTION

The CLIC [1] is a proposal for an electron/positron collider where particles will be boosted to energies up to 1.5 TeV. The required accelerating gradient (100 MV/m) can be achieved via a novel two beam acceleration scheme. RF power from a high intensity (~100 A), low energy (2.37 GeV) Drive Beam (DB) is extracted via Power Extraction and Transfer Structures (PETS), and transferred through a waveguide system to supply the high gradient RF cavities of the high energy, low current (~1 A) Main Beam (MB). The principal constituent of the CLIC linacs is a 2 m long module (the Two Beam Module, TBM), which is a combination of accelerating structures, quadrupoles and PETS. Five different types of TBMs are sufficient for the manufacture of the main CLIC accelerating complex. The simultaneous operation of two parallel accelerators can be challenging for the design of a Beam Loss Monitoring (BLM) system. Losses from one beam line can be detected by the BLMs protecting the other one, reducing the capability of estimating the origin of the losses. This phenomenon is known as crosstalk. In the CLIC Conceptual Design Report the proposed beam loss monitoring system for machine protection is based on ionisation chambers, since they satisfy the requirements in terms of sensitivity and dynamic range. Distributed detectors, such as optical fibres, are also under investigation for their ability to cover the full beam line, preventing potentially dangerous beam losses from going undetected. The present work summarises BLM crosstalk measurements for two different detectors, Little Ionisation Chambers (LICs) and optical fibre BLMs (OBLMs), performed at the prototype TBM hosted at CTF3.

TWO BEAM MODULE LAYOUT AT CTF3

The CTF3 complex at CERN was constructed with the aim of studying the feasibility of the CLIC two-beam technology. CALIFES (Concept d'Accélérateur Linéaire pour Faisceau d'Electron Sonde) is a 26 m electron linac with a Cs_2Te photoinjector pulsed by a UV laser. It provides a flexible electron beam with a bunch charge in the range of 0.05 - 0.6 nC and energy up to 200 MeV with a 1.5 GHz bunching frequency. CALIFES aims to mimic the CLIC main beam [2]. To examine the feasibility of the high current beam production and transport, a scaled version of the CLIC Drive Beam providing an electron beam of up to 28 A with a maximum energy of 120 MeV has been built [3].

The first CLIC Two Beam Module prototype was installed in CTF3 in May 2015. It comprises two PETS and two quadrupoles on the Drive Beam side, four accelerating structures (ACS) on the Main Beam, and instrumentation including one Beam Position Monitor (BPM) for each beam and two wakefield monitors on the main beam.

To study the crosstalk of the BLMs at the CTF3 TBM, four LICs and two optical fibres were installed on both sides of the TBM.

THE BLM EXPERIMENTAL SETUP

The LICs installed at the TBM are cylindrical ionisation chambers, with a diameter of 9 cm and a length of 18 cm. They consist of three circular, parallel plate, Al electrodes separated by 0.5 cm and are filled with N_2 at a pressure of 0.4 bar. Four detectors were used to cover the module. Two of them where installed on the main beam, approximately 5 cm downstream of the TBM accelerating structures, and two on the drive beam, around 10 cm downstream of the quadrupoles.

The OBLM systems consist of an optical fibre coupled to a photosensor. High energy particles generated by beam losses produce Cherenkov light in the optical fibre. These photons propagate in the fibre and are detected by the photosensor, giving information on the intensity of the loss and, if the timing is taken into consideration, also its original location [4]. Two high-OH, pure silica optical fibres from Thorlabs [5] were installed, approximately 15 cm above each beam line. On the Main Beam side, the fibre covers both the TBM and a 4 m upstream segment, while on the Drive Beam side the optical fibre extends over the TBM but only

ISBN 978-3-95450-176-2

FIRST K-MODULATION MEASUREMENTS IN THE LHC DURING RUN 2

M. Kuhn[1,2], V. Kain[1], A. Langner[1,2], R. Tomas[1]
[1]CERN, Geneva, Switzerland, [2]University of Hamburg, Hamburg, Germany

Abstract

Several measurement techniques for optics functions have been developed for the LHC. This paper discusses the first results with a new k-modulation measurement tool. A fully automatic and online measurement system has been developed for the LHC. It takes constraints of various systems such as tune measurement precision and powering limits of the LHC superconducting circuits into account. K-modulation with sinusoidal excitation will also be possible. This paper presents the first k-modulation and β^* measurement results in the LHC in 2015. In addition, the measured beta functions will be compared to results from the turn-by-turn phase advance method.

INTRODUCTION

K-modulation is a method for measuring beta functions at locations of individually powered quadrupoles. This method is model independent and often an alternative for locations with a non-optimum phase advance between Beam Position Monitors (BPMs) for the turn-by-turn phase advance measurement [1]. A typical application is the measurement of β^* at the interaction point of a collider or the offset determination of BPMs [2]. Next to β^* measurements, it is also used in the LHC to obtain the beta functions at the transverse profile monitors close to the individually powered quadrupoles in LHC point 4.

K-MODULATION

Changing the strength of a quadruple results in a tune change. The tune change is proportional to the change of strength and the beta function at the location of the quadrupole. If the tune change can be measured accurately, the beta function can be calculated from the change in quadrupole strength following the well-known formula

$$\beta = \frac{2}{l\Delta k}\left[\cot(2\pi Q) - \frac{\cos(2\pi(Q+\Delta Q))}{\sin(2\pi Q)}\right] \quad (1)$$

where l is the length of the quadrupole, Δk the quadrupole strength change in $[m^{-2}]$, ΔQ the tune change and Q the nominal tune. Changing the strength of the quadrupole changes the tune and the beta function itself. For typical tune changes in the range of 10^{-2}, corresponding to a strength change of several 10^{-4} in the LHC, the resulting beta beat at the quadrupole location amounts to 10^{-3} - 10^{-2}. The expected maximum induced beta beat with k-modulation is in the order of 1 %.

This paper will introduce a new custom-made LHC k-modulation application that offers automated measurements and takes care of the particularities of the LHC individually powered quadrupole circuits. In addition, the first k-modulation and β^* measurement results in the LHC in 2015 will be presented. Furthermore the measured beta functions will be compared to results from the turn-by-turn phase advance method.

K-MODULATION IN THE LHC

The LHC is a superconducting hadron collider with an injection energy of 450 GeV and a design collision energy of 7 TeV per charge. The 27 km ring is designed with eight long straight sections. The matching section cells around them contain individually powered superconducting quadrupoles.

No negative voltage can be applied at the unipolar power converters of the individually powered quadrupoles. Thus a decrease in quadrupole current has to follow the slow natural current decay. The upper power converter limits of the modulation amplitude ΔI and frequency f are given by

$$\Delta I = \frac{\Delta U}{Z} = \frac{IR}{2\pi f L} \quad (2)$$

with voltage ΔU, impedance Z, resistance R and inductance L. For example quadrupole MQY.5R4.B1 can be modulated with a maximum amplitude ΔI of 26 A at nominal current and 3 A at injection current at a modulation frequency of 0.1 Hz. This is well sufficient for k-modulation in the LHC. The characteristics are different for all circuits. The new k-modulation application takes care of applying appropriate parameters.

Automatic K-Modulation for LHC Run 2

For k-modulation measurements at the LHC in the past, the tune signal and the quadrupole current measurement have been combined offline. The new k-modulation tool offers simultaneous tune and quadrupole current/strength acquisition and display. It executes k-modulation in two modes: step function, where the current is trimmed to different plateaus and tune data is accumulated, and sinusoidal current modulation. Both modulation methods have been tested and the first results are presented in this paper.

The application is fully integrated into the LHC control system [3] where the circuit characteristics of the quadrupoles chosen by the user are available. The modulation frequencies, amplitudes and time over which current changes are applied are pre-calculated by the application according to the power converter limitations.

LIMITATIONS

The precision of the beta function measurement with k-modulation in the LHC is limited by tune noise. The LHC tune noise level is about 10^{-3}. According to the 2012 experience, with k-modulation in current steps, the typical measurement error on the beta function is about 10 %, mainly due

ISBN 978-3-95450-176-2

DESIGN CONCEPT FOR A THz DRIVEN STREAK CAMERA WITH ULTRA HIGH RESOLUTION

M. Dehler, V. Schlott, F. Frei, R. Ischebeck, PSI, Villigen PSI, Switzerland
T. Feurer, J. Fabianska, M. Hayati, University of Bern, Berne, Switzerland

Abstract

The resolution of streak camera systems strongly depends on the slew rate of the deflecting element, being proportional to the amplitude and the frequency of the deflector. An attractive approach to reach femto and even sub-femto second resolution are THz driven electron streak cameras, which have been only recently proposed. Here, the ultra fast streaking field is generated by exciting a suitable resonant THz antenna, e.g. a split ring resonator with an intense THz pulse [1]. With today's THz sources streak field amplitudes in excess of 1 GV/m are within reach. Here, we present the concept for a proof of principle system. The THz pulse will be generated by rectifying the pulse from an existing 800 nm laser system in a suitable crystal as LiNbO3 [2]. For the source of the electron beam to be streaked, we plan to use an RF photo gun yielding a relativistic 6.5 MeV beam. We describe the setup of the system and present simulations of the beam dynamics.

INTRODUCTION

Pulsed electron sources are capable of emitting electron bunches with durations in the few hundred femto second regime and, using bunch compressor chicanes, these can be further shortened reaching the few femto second regime. Full temporal characterization of such electron bunches is a prerequisite for their use, for example in seeding of X-ray Free Electron Lasers. This issue is complicated by the non negligible pulse-to-pulse fluctuations of such machines requiring single-shot characterization techniques.

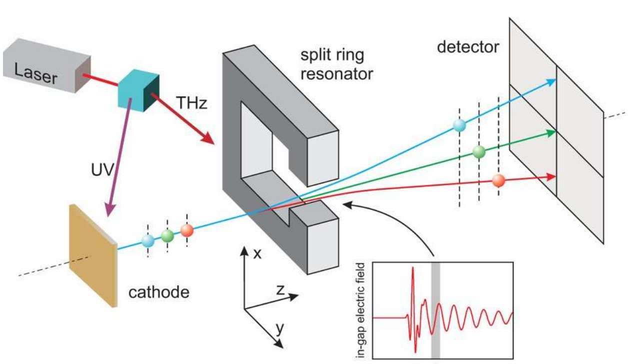


Figure 1: Measurement principle.

In the field of ultra fast electron diffraction, streak cameras have been shown to allow for sub-picosecond bunch duration measurements. Even streak cameras based on deflection mode RF cavities have been demonstrated to operate with sub-100 fs resolution for keV to MeV electron energies [3], yet the issue of phase jitter in RF cavities is a challenge. While obtaining temporal resolutions in the 10-100 fs regime is conceivable with current technologies, few-femtosecond or even sub-femtosecond resolutions seem out of reach. Here, we propose an approach with the potential to achieve a resolution around a femtosecond for electron bunches in the 10 kV to MV energy range [4]. The methodology relies on a resonant THz sub-wavelength structures irradiated with an intense single-cycle THz pulse. The design is reminiscent of a classic streak camera. The deflecting electrodes and the RF streaking field of a standard streak camera are replaced by a split-ring resonator (SRR) and the electric near-field in its gap, respectively. The SRR's resonance frequency can be varied between 100 GHz and several THz simply by changing its geometry, allowing for THz streak field rise times between hundreds of femtoseconds to several picoseconds. The electron bunch passing through the SRR's gap experiences a transverse momentum transfer which sign and magnitude depend on the longitudinal bunch position. Thus, the longitudinal bunch density is mapped onto the transverse axis and can be easily measured with a spatially resolved electron detector. THz-driven streaking should be well adapted to measure ultra short electron bunches, even on a single-shot basis. Ideally, the electron bunches and the THz pulses are generated with the same laser system, that is to say, synchronization between the two is inherently guaranteed.

The planned research builds on the extensive recent work in the field of laser-driven particle acceleration (see e.g. [5]). Particle beams have been accelerated from rest using infrared fields of lasers [6,7]. Due to the small wavelength and corresponding structure size, only low-charge beams could be generated. An acceleration by a field of a few terahertz is described in [8], showing an energy gain of about 7 keV [9]. In the present case, the effective accelerating field is transverse to the direction of motion of the particles, such that particle bunches are streaked rather than accelerated. While the final goal is different, the methods are similar, and we expect to build on the rapid progress made in the field of laser acceleration.

In the following, we describe the principle behind the measurement system, present simulation results for the deflector as well the required electron source and give a first layout of deflector and diagnostics station.

PRINCIPLE

The principle used in the measurement is shown in Figure 1. The photon beam to be measured modulates a photo cathodes and creates an electron beam, which is accelerated

ISBN 978-3-95450-176-2

AN OPTICAL INTRA-BUNCH INSTABILITY MONITOR FOR SHORT ELECTRON BUNCHES

Thomas G. Lucas, Paul J. Giansiracusa
David J. Peake, Roger P. Rassool, University of Melbourne, Melbourne, Australia
Mark J. Boland, Australian Synchrotron, Clayton, Australia
Ralph J. Steinhagen, GSI, Darmstadt, Germany

Abstract

An improved understanding of intra-bunch instabilities in synchrotron light source electron bunches is crucial to overcoming the imposed limitations of the achievable intensity. A Multiband Instability Monitor, designed specifically for the short bunches of a synchrotron light source, has been developed to perform measurements of intra-bunch dynamics. The MIM performs real-time measurements at a diagnostic beamline using optical synchrotron radiation incident on a high speed photodetector. Three frequency bands up to 12 GHz were used to identify characteristic frequency signatures of intra-bunch instabilities. Mixed to baseband using RF detectors, these high frequency measurements can be performed without the need for similarly high frequency digitisers. This paper reports on the performance of the system at the Australian Synchrotron.

INTRODUCTION

Individual bunch currents are limited by intensity dependent instabilities. Typical Synchrotron light sources operate with bunch length in the tens of picosecond regime, making direct digitisation costly and limited in resolution due to thermal noise and clock jitter. The Multiband Instability Monitor (MIM) Principle, first demonstrated on the Super-Proton-Synchrotron (SPS), avoids the limitations of digitisation using a unique frequency domain approach to measure fast beam dynamics [1]. Incoming signals are split into multiple frequency bands which are downmixed and analysed simultaneously. Allowing the measurement of high frequency dynamics, such as the head-tail instability, without the need for a digitiser of equivalent bandwidth.

TRADITIONAL MEASUREMENTS

Head-tail instabilities were first measured by Sacherer on the Proton Synchrotron at CERN. Bunch structures were easily resolvable in the 200 ns bunches given the digitisers available at the time, allowing bunch profiles of the first 3 head-tail instability modes to be measured [2]. Bunch lengths have reduced dramatically in modern synchrotron light sources such that readily available digitisers do not have the necessary bandwidth. Electron bunch wave-forms for the Australian Synchrotron's 23 ps bunches are shown in Figure 1. The four lowest head-tail instability modes are shown, $m = 0$ corresponding to a rigid bunch instability while $m = 1$ to $m = 3$ are the first three modes of the head-tail instability. Referring to frequency domain plot,

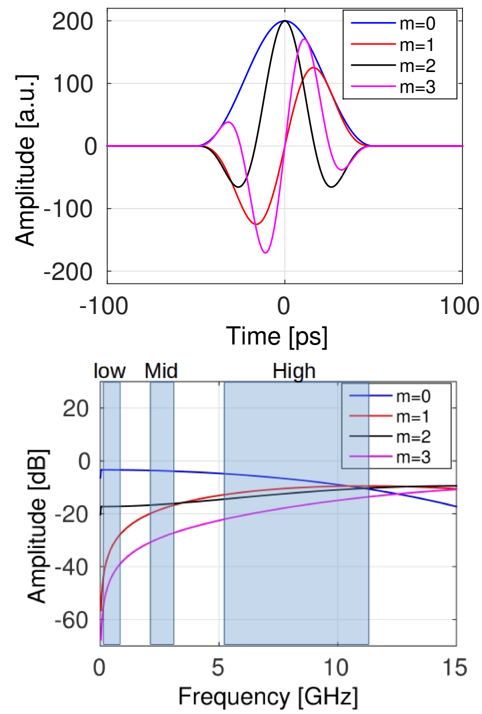


Figure 1: Simulations of the differential BPM signal's waveforms during the lowest four head-tail instabilities modes given the 23 ps bunch lengths seen at the Australian Synchrotron. Displayed in the time and frequency domain, the $m = 0$ represents the shape of the BPM summation signal as well as the differential during rigid bunch motion ($m = 0$). In the frequency domain, a shift in the peak frequency can be seen for the non-zero head-tail instability modes $m = 1$ to $m = 3$. Shading on the frequency plot represents the MIM's frequency bands.

the third mode demonstrates that to measurements would require bandwidths of at least 40 GHz. Such measurements would be limited by the thermal noise, reducing the effective number of bits (ENOB). To resolve the bunch shape bandwidths of hundreds of gigahertz are required, well beyond the capability of digitisers [3]. Thus another technique must be employed to search for these instabilities.

Currently streak cameras are most commonly used to measure intra-bunch dynamics in the picosecond regime. With bandwidths of up to 1 THz these imaging systems are easily capable of resolving intra-bunch structure. Unfortunately

ISBN 978-3-95450-176-2

OVERVIEW OF APPLICATIONS AND SYNERGIES OF A GENERIC FPGA-BASED BEAM DIAGNOSTICS ELECTRONICS PLATFORM AT SwissFEL

W. Koprek, B. Keil, G. Marinkovic, PSI, Villigen, Switzerland

Abstract

For SwissFEL electron beam diagnostics we combine application-specific detectors and front-end electronics with a common solution for digitization, interfacing and FPGA-based digital signal processing. Many key components and standards we use were initially developed by PSI for the European XFEL BPM system, but are equally suited for a broad range of SwissFEL diagnostics systems with little or no modifications. Examples are the FPGA signal processing hardware and firmware/software, ADC and DAC boards, interface boards or peak detection front-end electronics. By following a modular generic hardware and firmware/software design approach, we can cover a larger number of different monitor types with moderate development effort. Applications of our generic platform include BPMs, bunch length monitors, beam arrival time monitors, beam loss monitors. This paper gives an overview of the design, present and future applications of our generic platform, discussing the synergies and differences of the required hardware, firmware and embedded software solutions.

OVERVIEW

In the typical diagnostic system the sensor signals are connected to front-end electronic cards which do analogue signal processing and conditioning. The analogue signals are digitized by analogue to digital converters (ADC) cards and then processed digitally in Field-programmable Gate Array (FPGA) firmware and embedded Central Processing Units (CPU). The processed data is read by control systems over communication interfaces.

Most of the diagnostic systems have this structure therefore one can distinguish in this scheme common and dedicated components. The components may be either hardware modules like an ADC card, can be a firmware component implemented in Very high speed integrated circuit Description Language (VHDL), or software running in embedded processors. The common components - the light grey boxes in Fig. 1 – are present in most applications. The dark grey boxes are specific firmware/software components and are usually different for every application. Having in mind the similarity of various applications we focused on development of common components which can be used by the application developers.

The SwissFEL is a double bunch machine with 28 ns bunch space and 100 Hz repetition rate [1]. In this mode of operation some functions are time critical and have to be implemented in VHDL, but most of the functions can be processed by embedded CPUs between two machine pulses within 10 ms.

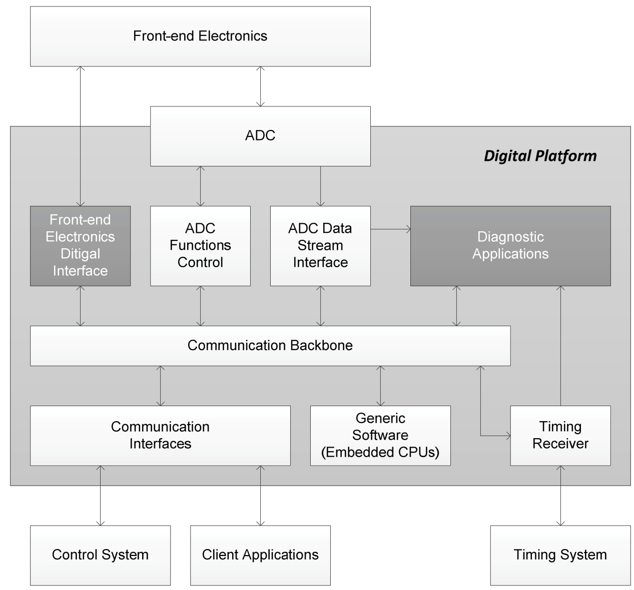


Figure 1: Block diagram of the electronics platform.

The communication backbone is built up of several bus instances and bridges between them and provides access to all components in the system which have bus interface. Communication interfaces block is a set of bridges from communication backbone to other protocols which allow access by control system or various client applications.

Synchronization of the diagnostic systems with the machine is achieved by an embedded timing receiver. This component decodes serial data stream distributed by the timing system over fibre optic links and generates synchronously local triggers and clocks.

HARDWARE PLATFORM

In order to build various systems with common components the system must be modular. Therefore our typical system consists of several hardware cards of various types like carriers, mezzanines or rear transition modules. The hardware platform is based on VERSA Module Eurocard bus (VMEbus) and has been already presented in other publications [2] and the following list gives only brief description:

- General Purpose Analog Carrier (GPAC) is a digital VME card which contains three Virtex-5 FPGA chips, three Spartan3 FPGA chips, and two 500 pin connectors for mezzanine cards. This board is used in every application for digital signal processing - see top left picture in Fig. 2.

ISBN 978-3-95450-176-2

SYSTEM INTEGRATION OF SwissFEL BEAM LOSS MONITORS

C. Ozkan Loch, D. Llorente Sancho, P. Pollet, G. Marinkovic, R. Ischebeck, V. Schlott,
Paul Scherrer Institut, PSI, Switzerland

Abstract

Scintillator-based Beam Loss Monitors will be used at SwissFEL for monitoring the losses, for optimizing beam conditioning, beam measurements with the wire-scanner and Undulator protection. The optical signals from the scintillators will be detected by PMTs which are located outside the accelerator tunnel. The PMT control and signal conditioning is done via a front-end based on the PSI Analogue Carrier board (PAC). The PAC board allows for amplification/attenuation, offsetting and single-ended to differential conversion of the analog signal, while the Generic PSI Carrier (GPAC) board provides digitization and FPGA-based post-processing, along with bridging the communication to EPICs controls. A fast algorithm was developed to process the signals and trigger the machine protection system (MPS) at 100Hz. The system integration of the BLMs will be discussed in this paper.

INTRODUCTION

In SwissFEL, scintillator screens and wire scanners will be used to monitor the electron beam in the charge range 10 - 200 pC and in the energy range 0.007 - 5.8 GeV. In particular, wire-scanner will be used to resolve the 28 ns time structure of a 100 Hz, two-bunches train [1, 2]. Losses caused during beam conditioning and wire-scanner insertions can travel for tens of meters in the machine. Loss monitors have been designed to track these losses for emittance measurements and to prevent radiation-induced demagnetization of the Undulators.

The beam loss monitor systems have been developed based on the following system requirements to detect losses before an appreciable loss level is reached.

Table 1: Beam Loss Monitor Specifications

Parameters	Specifications	Purpose
Charge range	10 - 200 pC	Full beam loss
Minimum detection	0.1 pC	Wire-scanner measurements
Repetition rate	100 Hz	2-bunch resolving capability, shot-to-shot
Machine protection system	Yes	Beam synchro-nous DAQ

There are a total of 48 BLMs, which will be located at fixed distances with respect to the wire-scanner for slice emittance measurements, and between Undulator segments to monitor the losses reaching at these locations. The BLMs will be interfaced to the machine protection system (MPS), leading to either a beam suppression in the machine or to immediately act on the laser shutter.

#cigdem.ozkan@psi.ch

DETECTORS

The BLMs consist of organic scintillator fibers (BCF12, Saint Gobain), which are then connected to clear duplex plastic optical fibers (POF, Avago Tech) that propagate the scintillator's output light from the accelerator into the technical gallery where the light detectors are located. One of the POFs is optically mated to a PMT (Hamamatsu H10720) [3] and the other to a pulsed light emitting diode (Avago Technologies HFBR-1505AZ/2505AZ) [4]. The LED provides a system-live check and observation of light transmission through the connected fibers for radiation damage, during or outside of beam operation.

DAQ SYSTEM OVERVIEW

The PMTs and preamplifiers, which convert the PMT charge pulse into a time-shaped voltage signal, are mounted on the signal conditioning board called the PSI Analog Carrier (PAC) board. All controls of the PMT, preamplifier and LED voltages, and output signal conditioning is done by the PAC. The output signals are digitized and processed with the Generic PSI Carrier (GPAC) board, which was developed at PSI for application in multiple accelerators (European XFEL, SwissFEL and SLS) [5].

PAC Board

Up to four mezzanine-boards, 2 channels per board may be plugged to the PAC carrier board. Each mezzanine board supports one PMT signal conditioning electronic. This means that a single PAC board can house and control 4 BLMs. All mezzanine boards connectors provides low noise standard linear supply voltages (±12 VDC / ±5 VDC and +3.3 VDC), eight remotely controlled DC voltage supplies, eight general purpose digital controls/status signals and four differential digital I/O signals covering a large spectrum of requests. To avoid digital noise production on sensitive signals, the digital control (Oscillators, FPGA) can be set to standby mode when not in use.

The PAC board communicates with remote systems controls over a serial connection, either through specific user I/O on the VME-P2 connector or over a standard RJ45 network connector located on the front panel for

ISBN 978-3-95450-176-2

THE BEAM LOSS MONITORING SYSTEM IN TAIWAN PHOTON SOURCE

C. H. Huang, Demi Lee, Jenny Chen, Y. S. Cheng, K. H. Hu, C. Y. Wu, P. C. Chiu, K. T. Hsu
NSRRC, Hsinchu 30076, Taiwan

Abstract

Taiwan Photon Source is a third generation and 3 GeV synchrotron light source during beam commissioning in NSRRC. Several types of beam loss monitors (BLMs) such as PIN diodes, scintillation detectors, Cherenkov BLMs and RadFETs are installed in the storage ring and booster ring to study the beam loss distribution and mechanism. The installation infrastructure, design of reader units and integrated graphic user interface will be described in this report. The preliminary experimental results will also be summarized here.

INTRODUCTION

Taiwan Photon Source (TPS) is a third-generation light source in NSRRC [1]. The circumference of the storage ring is 518.4 m with 24 double-bend achromat cells. There are 6 long-straight sections and 18 standard-straight sections to accommodate insertion devices. In the first initial phase for the beam-line commissioning, seven beam lines with ten inserting devices are installed in the storage ring. At the same time, two superconducting RF (SRF) cavities are also installed during this stage.

To study the beam loss during the SRF and inserting device commissioning, several types of beam loss monitors (BLMs) are setup in the storage ring and booster ring. The PIN diodes can detector the minimum ionizing particles as an electron hits the wall of the vacuum chamber and produce the electromagnetic shower [2]. Cherenkov detector is sensitive to charged particles. The scintillation detector is a kind of secondary emission monitor which combines a scintillating material and photomultiplier tube and can detect both the charged particles and X ray. A radiation-sensing field-effect transistor (RadFET) is a metal-oxide-semiconductor field-effect transistor (MOSFET) with an aluminium gate and a thick layer of silicon dioxide which can be used as a dosimeter [3]. These installed BLMs provide a tool to investigate the beam loss location, beam lifetime, vacuum conditions, beam loss mechanism, specific beam loss, resonance crossing, energy measurement by mean of spin depolarization method, etc. These may be also useful to fine tune the machine during the commissioning, routine operation and beam physics study.

PIN-DIODE BEAM LOSS MONITOR

Bergoz's PIN-diode BLM is made of two diodes mounted face-to-face [4]. For the coincidence readout of the signals of two channels, the dual PIN-diode BLM detects charge particles rather than synchrotron radiation and reduces the dart counts due to the noise. It is widely used in many facilities [5]. There are many kinds of solutions to integrate this BLM. To simplify the wiring, a custom designed version of Bergoz's BLM was adopted in which the original 10 pin connector is replaced by a RJ-45 connector as shown in the BLM photo of Fig. 1. The output of the BLM is coupled by a pulse transformer. Four pairs of twisted cables are used to connect a BLM to the signal translator. This twisted cable provides power to a BLM and sends the coincident pulse back. An 8-channel LVDS to LVTTL translator is used to convert pulses. The pulse complied with LVTTL level is connected to the scaler input.

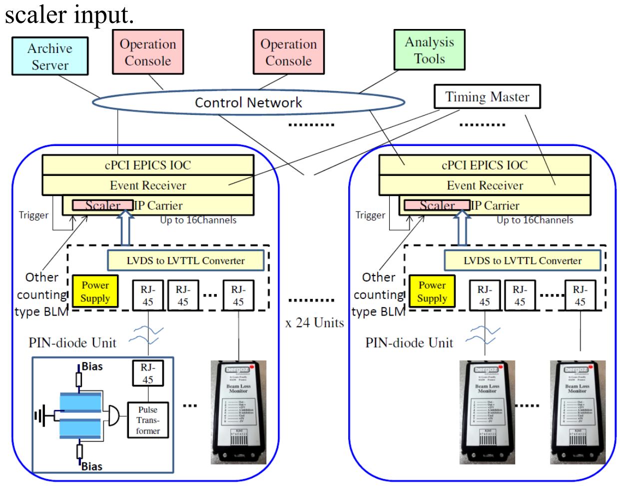


Figure 1: Block diagram of the PIN-diode beam loss monitoring system.

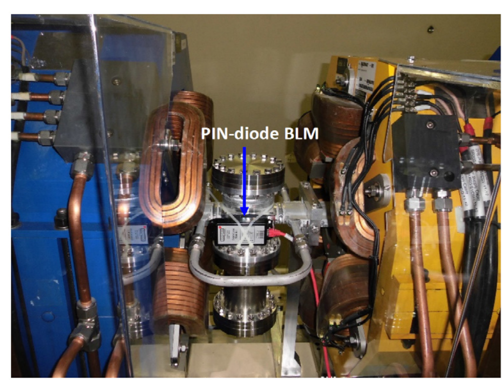


Figure 2: The setup of a PIN-diode BLM.

Data acquisition for BLMs is performed by a 16-channel scaler in an industrial pack (IP) form factor. The IP module is installed on the cPCI carrier board which is located at the cPCI EPICS IOC on the equipment area. All scalers which distributes at 24 IOCs are synchronized by the timing system of the accelerator, shown in Fig. 1. Unused channels of the scalers will be served for another

ISBN 978-3-95450-176-2

THE NSRRC PHOTO-INJECTOR DIAGNOSTIC TOOLS FOR INITIAL BEAM TEST

A.P. Lee , M.C. Chou, N. Y. Huang, J. Y. Hwang, W. K. Lau, C.C. Liang, M.T. Tsou,
NSRRC, Hsinchu 30076 Taiwan.
P. Wang, Department of Engineering and System Science,
National Tsing Hua University, Hsinchu 30013 Taiwan

Abstract

The High brightness injector project at NSRRC aims to develop a100 MeV photo-injector system for light source R&D at NSRRC. This photo-injector system equipped with a photocathode rf gun, a solenoid for emittance compensation, an S-band linac as well as various beamdiagnostic tools is designed for operation in two different modes. One is to generate high brightness electron beams for future free electron laser experiments. The other is to produce ultra-short electron bunches by velocity bunching. It also allows us to perform inverse Compton scattering experiment for generation of fs x-ray. In the beginning of this project, the photocathode rf gun was installed in the booster room of TLS at NSRRC. The normalized beam transverse emittance is 5.5 mm-mrad at ~250 pC with Gaussian laser pulse. Recently, a 100 MeV photo-injector system is being installed in the 38 m by 5 m tunnel of the NSRRC linac test laboratory. The rf gun, the 35 MW high power microwave system and a 5.2 m lina has been set up. The UV driver laser system will be set up in the new temperature controlled clean room in the linac test laboratory. For initial beam test, some beam diagnostic tools are considered. They are presented and discussed in this paper.

INTRODUCTION

The development of high brightness beam produced by a photo-injector has been driven mainly by self -amplified spontaneous emission free-electron laser (SASE FEL) applications. The high brightness electron beam is now an important subject of light source research for developing high gain free electron laser. For high gain FEL, the key issue is to produce an ultra-low emittance beam then compress the beam to higher peak current and to accelerate it to the high energy by the main linac system. Since the injector produces the high brightness electron beams that determine the FEL performance, development of injectors show the strong demand in producing high brightness electron beams.

Photo-injectors that deliver low emittance beams at nC bunch charge are commonly used in high gain FELs worldwide. As a result of the continuing developmentfor high brightness electron beam technology, photo-injectors have now become an essential sub system in many x-ray FEL facilities such as LCLS, European FEL, FLASH, Swiss FEL and SPARC etc. A photo-injector system mainly consists of a photocathode rf gun with a emittance compensation solenoid and a traveling wave S-band linac which accelerates the beam up to ~100 MeV. In the rf gun, electrons are emitted from the cathode surface of the cavity by illuminatingan intense UV laser. These electrons are then accelerated to relativistic energy in a few centimeters by the rf field so that the space charge effect degrading the transverse emittance and the beam energy spread is reduced. An emittance compensation solenoid as well as the three-dimensional laser beam shaping is applied for further reduction of space charge emittance growth.

A THz/VUV free electron laser facility isproposed at National Synchrotron Radiation Research Center (NSRRC) in Taiwan [1, 2]. The FEL complex comprises the following parts. A photo-injector is to generate a bright electron beam with energy ~100 MeV, then a 3 m long linac section to modulating theelectron beam with energy chirp. A double dogleg with linearization optics in the middle section of the dog-leg dipole magnets is used as a bunch compressor. Follow the compressor, two 5.2 m linear accelerators in which the beam is time-compressed and accelerated to 325 MeV, then the system to transport the beam to the undulator which is generate the VUV FEL radiation.

PHOTO-INJECTOR SYSTEM

Before constructing the VUV/THz FEL, the high brightness injector project is proposed to develop the photo-injector capable of producing low emittance sub -100 fs electron beams for the VUV/THz FEL.The 100 MeV high brightness photo-injector of the driver linac system proposed for the VUV FEL facility is under construction in the NSRRC linac test building as shown in Fig. 1. The design of the photo-injector is done by the computer simulation using the particle tracking code, General Particle Tracer (GPT) [3]. A 3.5 MeV low emittance beam with bunch charge of 100 pC is generated from the photocathode rf gun operated at the peak rf accelerating gradient 70 MV/m and optimum laser injection phase23°with respect to rf field. The 5.2 m rf linac with 18 MV/m accelerating gradient is set downstream after the photo-cathode rf gun for boosting beam energy. The optimum location of the linac for getting lowest transverse emittance is according to the Serafini's theory [4]. The linac can be put near the relative local maximum of beam emittance after the solenoid magnet with field strength adjusted correctly for emittance compensation. This optimum location is at 1.35 m from the cathode surface when the solenoid magnet is operated at 1400 Gauss. Beam parameters of the photo-injector in the GTP simulation are summarized in Table 1. Details of hardware components are presented in the following sub sections.

ISBN 978-3-95450-176-2

IMPROVEMENT OF TUNE MEASUREMENT SYSTEM AT SIAM PHOTON SOURCE

S. Kongtawong, P. Sudmuang, S. Krainara, P. Klysubun,
Synchrotron Light Research Institute, 111 University Avenue, Muang District
Nakhon Ratchasima, 30000, Thailand

Abstract

A new tune measurement system was recently developed and implemented at Siam Photon Source (SPS) for both the booster synchrotron and the 1.2 GeV electron storage ring. A new electronic module was installed at the SPS booster for collecting the turn-by-turn signal generated when the beam was excited with white noise and fast kicker. The beam excitation was carefully studied in order to determine the optimum beam response. With this system we observed the variation of the tune during energy ramping. The measurement provides information needed to optimize the working tune and to keep it constant. At the SPS storage ring, the excitation signal was changed from swept frequency signal to frequency modulation (FM) signal to reduce the measurement time. Details of the instrumentation setup and its performance will be presented in this report.

INTRODUCTION

The SPS operates a 1.2 GeV electron storage ring to produce synchrotron radiation in a wide energy range, from infrared to hard X-ray. The SPS booster ramps energy of electrons from 40 MeV to 1 GeV in 660 ms before they are transported to the storage ring. The storage ring then further ramps electron energy up from 1 GeV to 1.2 GeV. The maximum stored beam current is 150 mA. This method of electron beam injection previously took ~ 30 minutes. To cut down the number of steps and reduce the injection time, full energy injection system will be set up. The booster will ramp electron energy from 40 MeV to 1.2 GeV before injecting electrons to the storage ring. Therefore, energy ramping in the storage ring will not be required.

To achieve this, a new ramping pattern needs to be applied. Maximum current of the booster dipole magnets will increase from 1300 A to 1700 A and the current pattern of quadrupole magnets will have to change correspondingly. Since all the booster magnets approaches saturation after reaching the energy of 1 GeV, the current patterns of the quadrupole and dipole magnets are not linearly correlated and cannot be obtained from calculation. Therefore, the betatron tune needs to be measured and kept constant during energy ramping [1-3].

The tune measurement system has been set up at the SPS booster to track the tune shift during commissioning of the new pattern. Libera SPARK module was used to collect the turn-by-turn data from button-type Beam Position Monitors (BPM). At the 1.2 GeV electron storage ring, a new tune measurement system was also developed from the old system that used swept frequency signal to excite the beam. The drawback of this excitation signal was the measurement time which was quite long (10-30 seconds per measurement). The excitation was therefore changed to FM signal for faster measurement.

BOOSTER

Layout of the tune measurement system at the SPS booster is illustrated in Fig.1. The system has two subsystems: the excitation system and the signal detection system, which work together synchronously.

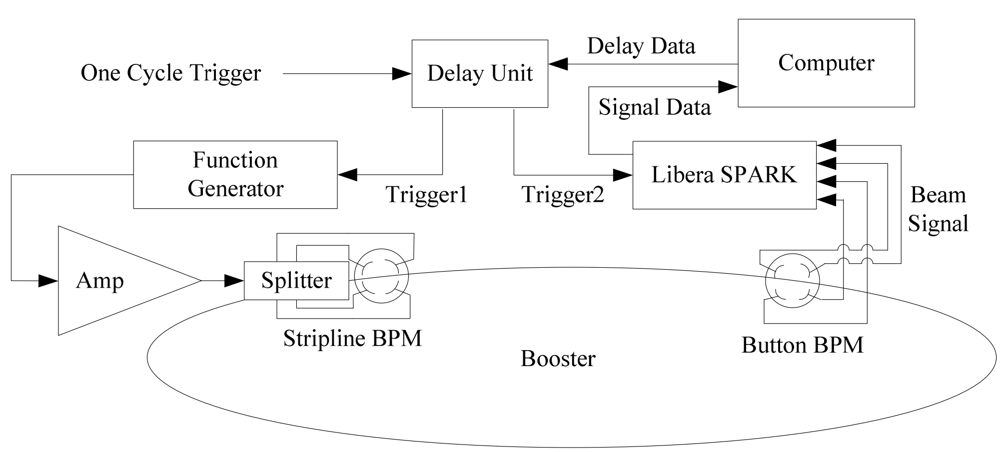


Figure 1: Layout of the tune measurement system at the SPS booster.

ISBN 978-3-95450-176-2

OBSERVATION OF BEAM LOSS SIGNAL AT THE SPS STORAGE RING

S. Krainara, P. Sudmuang, N. Suradet, S. Teawphet, S. Kongtawong, G. G. Hoyes, and P. Klysubun
Synchrotron Light Research Institute 111 University Avenue, Muang District, Nakhon Ratchasima 30000, Thailand

Abstract

Beam Loss Monitoring (BLM) system is an essential tool for observing beam instabilities and hence for machine protection. At the Siam Photon Source (SPS) storage ring, the BLM system is used to check the beam behavior due to optics perturbation, ion trapping, and vacuum leakage. A network of 50 PIN-diode detectors from Bergoz has been installed around the ring at the positions of high particle density. These positions are at the values of large betatron and dispersion functions in the machine lattice. The operational results of tune scanning verses loss rate in the resonance diagram are described. These results will be useful for improving the beam performance in terms of lifetime and beam stability.

INTRODUCTION

Siam Photon Source (SPS) is a synchrotron light source composed of two 20 MeV linacs, a 1.0 GeV Booster Synchrotron (SYN), and a 1.2 GeV electron storage ring. The SPS storage ring contains four Double Bend Achromat (DBA) super periods with four straight sections. Each symmetric period consists of four focusing quadrupole magnets (QF), three defocusing quadrupole magnets (QD), and two bending magnets (BM). The electron beam is filled twice a day to 150 mA. Three insertion devices; Undulator (U60), Superconducting Wavelength Shifter (SWLS), and Multipole Wiggler (MPW), have been installed and commissioned at three of the straight sections [1]. It was observed that loss rate at the SPS storage ring increased due to the insertion devices operation. A BLM system has been used to investigate the beam loss behavior, which can be a result of optics perturbation, vacuum leakage, and ion trapping. The system can provide information needed to improve the performance of the light source such as beam lifetime and stability. This loss detection system was designed and installed at the SPS storage ring in 2005 [2]. However, the detected signal had a relatively large RF interference. The system was then modified in 2014 in order to better observe the beam fluctuation around the ring.

The BLM detectors are two PIN-diodes from Bergoz. They are sensitive to the minimum ionizing particle (MIP) created when a charged particle hits the vacuum chamber. These detectors generate voltage pulses when active area of the PIN-diodes is struck by the MIPs. BLM signal is counted using the coincidence technique. Figure 1 shows schematic diagram of the BLM system. The real-time loss rate at each position of the detectors is recorded every second by the NI-PXIe system and sent to the control room. The hardware and software improvements of the BLM system are described elsewhere [3].

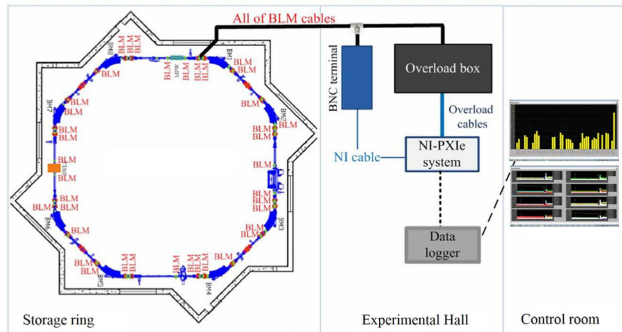


Figure 1: Sketch map of the SPS BLM system.

OPTIMAL BLM LOCATIONS

The loss rate is directly related to the beam lifetime so understanding of all associated mechanisms is necessary for determining appropriate location for BLM installation. In general, the total beam lifetime (τ) is given by three contributions as

$$\frac{1}{\tau} = \frac{1}{\tau_T} + \frac{1}{\tau_q} + \frac{1}{\tau_v} \qquad (1)$$

Touschek lifetime (τ_T) originates from the scattering of electrons within the bunch which leads to longitudinal momentum deviation. If the momentum deviation is higher than the RF acceptance, the electron is lost from the system. The best location for BLM installation is thus the section of largest dispersion function.

Quantum lifetime (τ_q) arises from Gaussian energy distribution of the electron particles. It is a result of quantum fluctuations and radiation damping that lead to the loss of energy. The quantum effect may be neglected if the horizontal aperture (determined by RF voltage) is sufficiently large. Therefore, the BLM detector should be installed at the position that exhibits large betatron function where the aperture is small.

Vacuum lifetime (τ_v) originates from the collision of electrons and residual gases. If the energy loss of an electron exceeds a certain amount, it will hit the inward wall of the vacuum chamber. This is likely to happen when electron beam passing through dipole magnets.

ISBN 978-3-95450-176-2

IMPROVEMENT OF THE SIAM PHOTON SOURCE BEAM LOSS MONITOR SYSTEM

N. Suradet, S. Krainara, P. Sudmuang, S. Taewphet, G. G. Hoyes, P. Klysubun
SLRI, 111 University Avenue, Muang District, Nakhon Ratchasima, 30000, Thailand

Abstract

A description of the newly re-built beam loss monitor (BLM) system at the Siam Photon Source (SPS) is presented. The original BLM system was designed and installed in the 1.2 GeV SPS storage ring in 2005. The main problems of this system were poor performance due to RF electromagnetic interference and the use of now obsolete data acquisition electronics. The beam loss detector used is a PIN-diode type from Bergoz. The new BLM system has been implemented using low-noise coaxial cable and an acquisition system based on NI-PXI. The hardware and software modifications incorporated into the new BLM system are presented.

INTRODUCTION

The Siam Photon Source (SPS) is a second generation synchrotron light source operated by Synchrotron Light Research Institute (SLRI) under the Ministry of Science and Technology, and is located in Nakhon Ratchasima, 250 km northeast of Bangkok, Thailand. The accelerator components consist of a 40 MeV linear accelerator, 1.0 GeV booster synchrotron and a 1.2 GeV electron storage ring. The maximum operating beam current is 150 mA in decay mode. The storage ring circumference is 81.3 meters and contains four super-periods of double bend achromat with a total of 8 bending magnets with 3 insertion devices, a permanent magnet undulator, a superconducting magnet wavelength shifter, and a multipole wiggler, providing synchrotron radiation from infrared to hard x-rays to synchrotron light users.

The existing beam loss monitor system (BLM) was designed and installed in the storage ring in mid-2005. The system was intended for measurement and analysis of the closed orbit distortion (COD) with beam loss rate and beam scraping of the vacuum chamber around the storage ring. It used PIN-diode BLMs from Bergoz. The acquisition and control electronics were based on a conventional PCI interface bus using standalone PCs. The major problems of that system were high RF interference in the BLMs and cables and the non-expandable, now obsolete control electronics.

The new system was implemented and subsequently improved in 2014. The major objectives of this improvement are to reduce and protect from RF electromagnetic interference and to better observe the unstable beam around the ring. This paper is organized as follows. Section 2 describes the hardware improvements, while Section 3 presents software improvements. Finally, the measurement results are presented in Section 4.

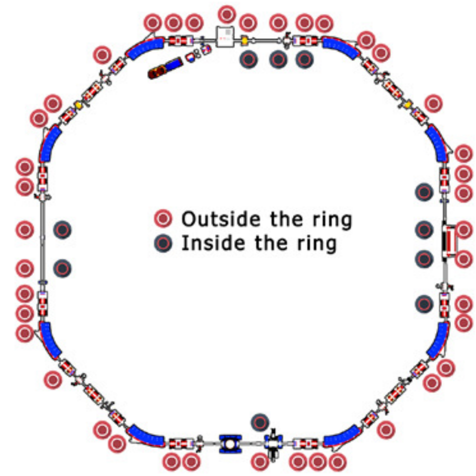


Figure 1: New SPS beam loss monitor positioning layout in storage ring.

HARDWARE IMPROVEMENTS

Sensors and Power Supplies

There are 50 Bergoz's beam loss monitors (Fig. 1), each of which comprises of two pin-photodiodes operating in coincidence mode [1]. The BLMs have been assembled and placed around the vacuum chamber in the storage ring. Regulated low noise power supplies (+5 VDC, -5 VDC, +24 VDC) for up to 10 BLMs is provided from each of 8 transformer units (+12 VDC, -12 VDC, +31.2 VDC) distributed around the ring. The power and signal cables between regulated power supplies and detectors are covered with RF shielding as seen in Figure 2. Also the sources of the RF interference, our bump magnets, were shielded with copper.

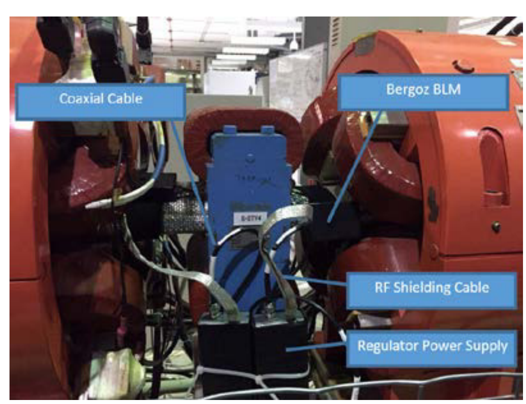


Figure 2: BLMs with RF shielding attached to the vacuum chamber.

ISBN 978-3-95450-176-2

FIRST EXPERIMENTAL RESULTS WITH THE CLIC DRIVE BEAM PHASE FEEDFORWARD PROTOTYPE AT THE CLIC TEST FACILITY CTF3*

G.B. Christian, P.N. Burrows, C. Perry, JAI, Oxford University, UK
J. Roberts, CERN, Geneva, Switzerland; JAI, Oxford, UK
A. Andersson, R. Corsini, P.K. Skowroński, CERN, Geneva, Switzerland
A. Ghigo, F. Marcellini, INFN/LNF Frascati, Italy

Abstract

The two-beam acceleration scheme envisaged for CLIC will require a high degree of phase stability between two beams at the drive beam decelerator sections, to allow efficient acceleration of the main beam. There will be up to 48 such decelerator sections for the full 3 TeV design, and each decelerator section will be instrumented with a feed-forward system to correct the drive beam phase to a precision of 0.2 degrees at 12 GHz relative to the main beam, using a kicker system around a four-bend chicane. A prototype system has been developed and tested at the CLIC Test Facility (CTF3) complex, where the beam phase is measured upstream of the combiner ring and corrected with two kickers in a dog-leg chicane just upstream of the CLEX facility, where the resulting phase change is measured. This prototype is designed to demonstrate correction of a portion of the CTF3 bunch train to the level required for CLIC, with a bandwidth of greater than 30 MHz, and within a latency constraint of 380 ns as set by the beam time-of-flight through the combiner ring complex. A description of the hardware will be given and initial results from the first phase of the experiment will be presented.

INTRODUCTION

The RF power used to accelerate the main beam in the proposed linear collider CLIC is extracted from a second 'drive beam'. To ensure the efficiency of this concept a drive beam 'phase feedforward' system is required to achieve a timing stability of 50 fs rms, or equivalently a phase stability (jitter) of 0.2 degrees of 12 GHz (the CLIC drive beam bunch spacing) [1–3]. This system poses a significant hardware challenge in terms of the bandwidth, resolution and latency of the components and therefore a prototype of the system has been designed, installed and commissioned at the CLIC test facility CTF3 at CERN.

A schematic of the CTF3 phase feedforward (PFF) system is shown in Fig. 1. The phase is corrected utilising two kickers placed prior to the first and last dipole in the pre-existing chicane in the TL2 transfer line. By varying the voltage applied to the kickers the beam can be deflected onto longer or shorter paths through the chicane, thus inducing a phase shift. The goal is to demonstrate a 30 MHz bandwidth phase correction with a resolution of 0.2 degrees of 12 GHz. The required hardware consists of three precise phase monitors [4, 5] and two strip line kickers [5] designed and fabricated by INFN/LNF Frascati, and a kicker amplifier and digital processor [6] from the John Adams Institute at Oxford University. More detailed descriptions can be found in [7].

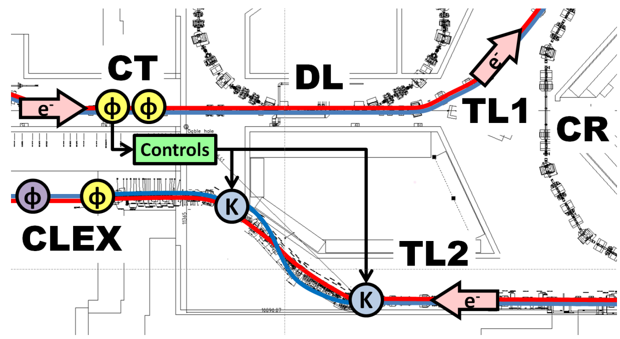


Figure 1: Simplified schematic of the PFF system. Red and blue lines depict orbits for bunches arriving late and early at the first phase monitor, ϕ, respectively. The trajectory through the TL2 chicane is changed using two kickers, K.

The latency of the PFF system, including cable lengths and the latency of each component, is below the 380 ns beam time of flight between the first monitor and the first kicker. This allows the same bunch that was originally measured to be corrected.

COMMISSIONING

The complete PFF system became available in October 2014. Previous results from commissioning of the optics and phase monitors are presented in [8, 9].

The first prototype kicker amplifiers used for the tests presented here provide an output voltage of 340 V. They will be upgraded in stages over the course of 2015, ultimately providing the nominal voltage of 1.2 kV. Constant kick tests demonstrated that applying the maximal 340 V to the PFF kickers resulted in a phase shift of ±3.5°, thus verifying the functionality of the amplifiers, kickers and chicane optics (Fig. 2). The 30 ns rising and falling edges of the response to the kick correspond to 12 MHz amplifier bandwidth when rising from zero to maximum output. This is slew-rate limited and the bandwidth is expected to be 50 MHz for smaller variations.

* Work supported by the European Commission under the FP7 Research Infrastructures project Eu-CARD, grant agreement no. 227579

ISBN 978-3-95450-176-2

INITIAL WORK ON THE DESIGN OF A LONGITUDINAL BUNCH-BY-BUNCH FEEDBACK KICKER AT DIAMOND

A. F. D. Morgan, G. Rehm
Diamond Light Source, Oxfordshire, UK

Abstract

In 2017 it is planned to install some additional normal conducting cavities into the Diamond storage ring. There is some concern that higher order modes in these devices could cause longitudinal instabilities in the beam. In order to deal with this potential problem we have started work on designing a longitudinal bunch-by-bunch feedback system. This paper will concentrate on the design and simulation of the kicker cavity, which is of the overloaded cavity type.

We chose the overloaded cavity type due to its lack of HOMs, and the wide bandwidth.

INITIAL SYSTEM TESTS

In order to investigate the type of instability we would expect to dominate on the Diamond machine, and to test the capability of our existing sampling electronics, we decided to use the already installed stripline kickers which are used for the transverse feedback system. By operating them in common mode rather than the usual differential mode it is possible to make them act as a weak longitudinal kicker. In order to achieve this, we replaced the existing RF output chain of the transverse multibunch feedback system (TMBF) with the arrangement shown in Fig. 1. Also the striplines were driven in the range 1.5-1.75 GHz rather than the 0-250 MHz they were originally designed for.

For this setup we are only using a mixer as a modulator, thus we are exciting both the upper and lower sidebands. In normal operation, due to our momentum compaction factor (α) of 1.7×10^{-4} and our relativistic gamma factor (γ) of 5870, we are operating above transition ($\eta > 0$) in terms of the Robinson criterion, as shown in Eq. (1).

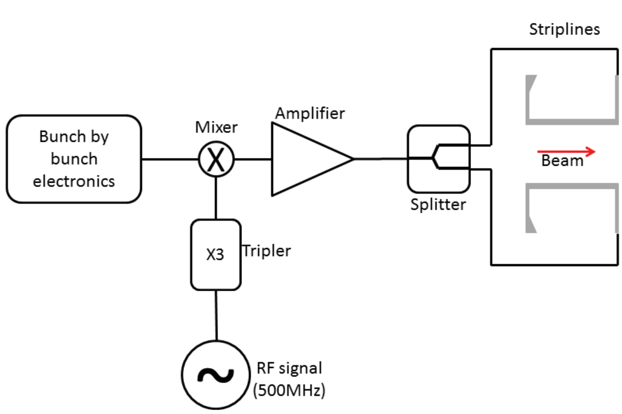


Figure 1: Basic schematic of the modified RF output chain of the TMBF.

$$\eta = \alpha - \frac{1}{\gamma^2} \tag{1}$$

This means that only the upper sidebands are potentially unstable [1, 2]. Correcting the lower sidebandes is unnecessary, however, for these tests the trade off against simplicity was deemed worth it. In the final system we envisage using IQ mixing to drive single sideband only, which is more efficient and means we are only affecting the modes which the machine is driving towards instability.

For the data capture part of the system, we used our existing frontend and our spare transverse data capture system [3]. The frontend timing was adjusted to sample the zero crossing of the bunch signal in order to maximise the phase sensitivity (and thus the longitudinal position) for each bunch.

With this modified setup we proceeded to run grow/damp studies similar to ones we have done previously for transverse measurements [4], where we excited each mode of oscillation of the bunch train individually, turned off the excitation and recorded the decay. By fitting this to an exponential decay we were able to obtain damping rates on a mode by mode basis.

Our results (Figs. 2 and 3) showed that, unsurprisingly, we are currently comfortably far from a longitudinal instability threshold for normal operating conditions. The most unstable mode would require a beam current of ~ 550 mA to move into an unstable regime. There is a large increase in the noise around mode zero. this is due to the fact that our striplines become particularly weak at those frequencies

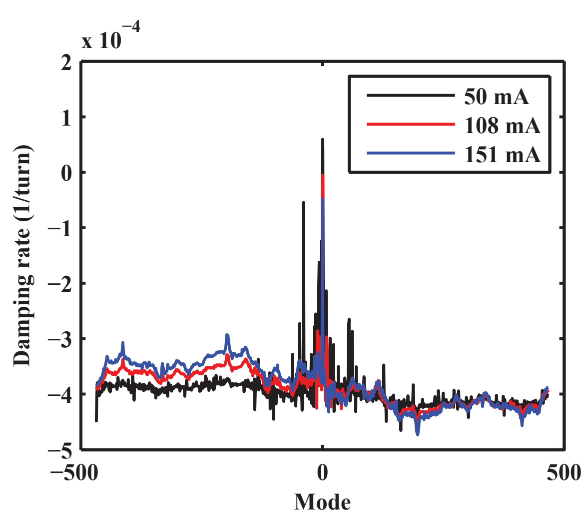


Figure 2: Damping rates for all modes at a range of stored beam currents.

ISBN 978-3-95450-176-2

CONSIDERATIONS AND IMPROVED WORKFLOW FOR SIMULATION OF DISSIPATED POWER FROM WAKE LOSSES

A. F. D. Morgan, G. Rehm
Diamond Light Source, Oxfordshire, UK

Abstract

At Diamond quite some effort has gone into simulating and understanding the dissipation of energy into structures induced by wake losses. Due to changes in the core simulation code we use, it is now possible to extract the dissipated energy information directly from the simulation rather than inferring it from other parts of the simulation output which was, by necessity, our previous method. Various modelled geometries will be used to illustrate the improved approach. Also we will discuss the considerations needed when constructing the model geometries in order to get the most representative results from the simulation.

BASIC WORKFLOW

One of the core principles of our approach is that there should be one core geometry file for each geometry. This can mean some added complexity in the file, but it ensures all the simulations are using the same geometry, and also allows entire simulation sets to be re run for validation. The outline of the approach is shown in Fig. 1

As we are now able to obtain material losses directly from the simulation, only one simulation is required, rather than the N+1 simulations for N materials required by our previous method [1,2]. This gives a large saving in both time and complexity. More importantly it also allows us to remove the assumption that material changes have only a small perturbative effect on the fields in the structure, something we know to be untrue for many of the structures we have studied. Another benefit is that we can now directly compare the total energy lost from the beam to the total energy accounted for from port emission and material heating, giving us an additional valuable check on the self consistency of the simulation.

In order to enable this approach we use a software framework around the core modelling software. The framework (implemented in MatLab [3]) takes the core geometry description and adds any simulation specific information, before running the simulation (CST PS in the past [4], now GdfidL [5]), gathering the results and generating an initial report. As part of the geometry file is programmatically generated it is possible to sweep model parameters (providing the parameters have been set up in the original geometry file). Usually the sweeps involve geometry parameters, however, we have also found it useful to sweep meshing parameters to validate that the model is represented in enough detail to capture all of the resonances and fine structure.

In order to compare the different simulation types, and also to evaluate the effects of geometric changes, we have written high level analysis software in MatLab. This extracts information from the output data of the simulations, and combines results in order to help us extract trends and to pull out the more important information for further study. This work is ongoing as we are often finding new ways to combine and look at the data in order to investigate a new aspect of the structures' behaviour.

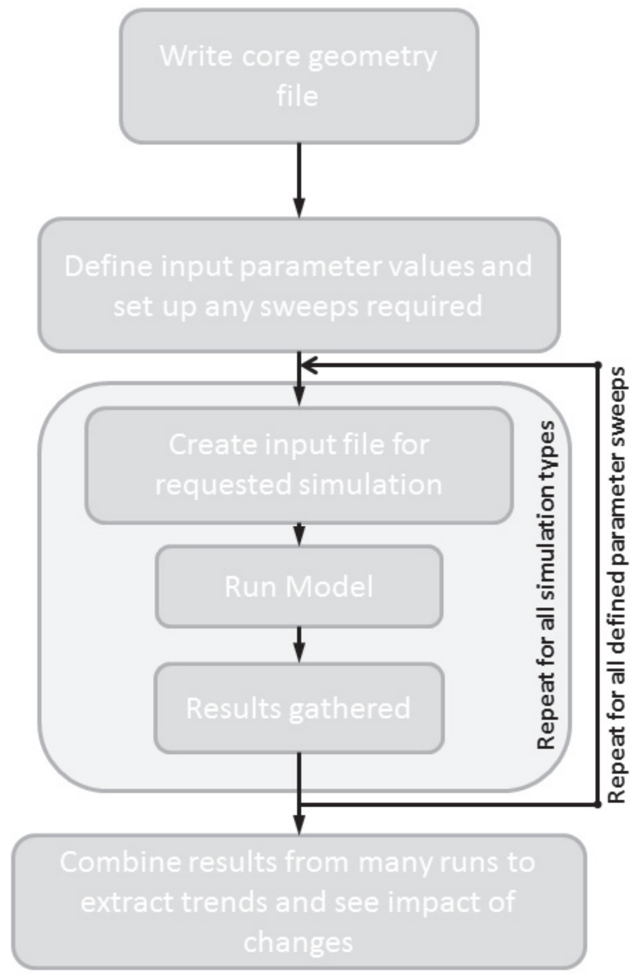


Figure 1: Basic workflow of the simulation process.

Currently, this high level analysis is mainly used to track changes in behaviour in S-parameters or energy losses during design studies. In the latter stages of such studies we can perform sensitivity analysis, in order to help define mechanical tolerancing for manufacture. As well as design work, this sort of analysis can be used to improve our understanding of existing devices. It is also useful to validate that

ISBN 978-3-95450-176-2

STREAK CAMERA PSF OPTIMISATION AND DUAL SWEEP CALIBRATION FOR SUB-ps BUNCH LENGTH MEASUREMENT

L.M. Bobb, A.F.D. Morgan, G. Rehm, Diamond Light Source, Oxfordshire, U.K.

Abstract

Streak cameras are commonly used for bunch length measurement. In normal beam modes, bunch lengths are on the order of 10 ps. For the study of coherent synchrotron radiation, a low alpha single bunch beam mode is implemented with bunch lengths as small as 1 ps and beam current in the tens of μA. In order to reliably measure such a short bunch at low beam currents, the input optics for the streak camera must be optimised for sufficient incident light intensity and high resolution in both sweep directions. This is achieved through the use of reflective input optics in which a pinhole is imaged to provide a small circular PSF. Furthermore, to precisely measure the bunch length the calibration of the dual sweep must be known. Here we describe a calibration method using electrical delays to incorporate calibration information within streak camera images.

INTRODUCTION

Diamond Light Source (DLS) is a third generation synchrotron light source providing high brilliance x-ray beams for user experiments. Nominally a 3 GeV, 300 mA, 900-bunch electron beam is circulated in the storage ring with a revolution period of 1.8 μs. In this normal beam mode the momentum compaction factor α is 1.7×10^{-4} which, given the synchrotron frequency f_s = 2.5 kHz and relative energy spread $\sigma_\epsilon = 10^{-3}$ with Eq. 1, has zero current bunch length $\sigma_{bunch} \approx 10$ ps [1].

$$\sigma_{bunch} = \frac{\alpha}{2\pi f_s}\sigma_\epsilon \qquad (1)$$

In the low alpha beam mode the electron bunch length is reduced to a few picoseconds. Due to the corresponding reduction in x-ray pulse duration, the temporal resolution used for pump-probe or time-of-flight experiments is improved. Furthermore the reduction in bunch length extends the wavelength range in which the electron bunch emits coherently towards the THz/far infrared region of the electromagnetic spectrum [2].

For the low alpha beam mode where $\alpha = 10^{-5}$, f_s = 0.6 kHz and $\sigma_\epsilon = 10^{-3}$ and using Eq. 1, the bunch length $\sigma_{bunch} \approx 2.6$ ps [1, 2].

To measure the longitudinal bunch profile and length, images of the synchrotron radiation (SR) pulses are acquired using a dual sweep streak camera (SC) from Optronis GmbH [3]. The fast deflection unit employs a synchroscan frequency of 250 MHz. This signal is provided to the SC by dividing the 500 MHz master oscillator frequency.

In order for the SC to measure these picosecond bunch lengths at bunch currents of tens of μA, the input optics for the SC must be optimised and the dual sweep calibration must be accurately measured. This report describes the implementation of reflective input optics including a pinhole to ensure maximum light intensity and smallest Point Spread Function (PSF) spot size for high resolution measurements, and presents a method for the dual sweep calibration of the SC using electrical delays.

EXPERIMENTAL SETUP AND ANALYSIS PROCEDURE

The Visible Light Extraction (VLE) system brings visible SR from a bending magnet in the storage to the diagnostics beamline where the SC is located via a series of folding and focussing mirrors. The total path length of the VLE is $\approx$ 25 m, the reader should refer to [4] for further details.

In the diagnostics beamline the visible SR propagates through the input optics and is focussed onto the SC. Inside the SC, visible SR photons are converted to electrons by the photocathode. Electrons are deflected in two directions (horiz. (x) and vert. (y)) within the streak tube. At the end of the streak tube electrons are converted to photons via a phosphor screen. The photons undergo another conversion to electrons as they pass through the intensifier. At the end of the intensifier a second phosphor screen converts the electrons to photons. The readout unit consists of a series of lenses to image the phosphor screen onto the cooled CCD camera for readout. In Figure 1 a schematic overview of the system is illustrated.

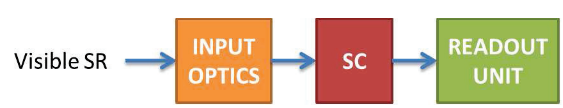


Figure 1: Schematic overview of the streak camera system.

A typical streak camera image with both deflections enabled is shown in Figure 2. The fast 250 MHz sweep and slow sweep run along the horizontal and vertical axes respectively as shown.

To obtain an accurate bunch length measurement the streak image is deconvolved with the PSF (see Figure 3) using the Richardson-Lucy algorithm [5]. The PSF is the measured spot size of the incident light on the SC with both deflections disabled. Next, each row of the deconvolved streak image is fitted with a Gaussian to obtain the r.m.s. bunch length in units of pixels. The bunch length is then converted from units of pixels to picoseconds using the calibration measurement in ps/pixel.

The reader should note that to a first approximation, and assuming the PSF width and bunch profile are Gaussian, the contribution of the PSF width to the bunch length measurement is added in quadrature. The contribution of the PSF to

ISBN 978-3-95450-176-2

OPTICAL DIAGNOSTICS WITHIN LA3NET*

C.P. Welsch#, Cockcroft Institute and The University of Liverpool, UK

Abstract

The Laser Applications at Accelerators network (LA³NET) is a pan-European project that has received 4.6 M€ of funding from the European Union's 7th Framework Programme. It closely links research into lasers and accelerators to develop advanced particle sources, new accelerating schemes, and in particular beyond state-of-the-art beam diagnostics. This contribution summarizes the research achievements in optical beam diagnostics of this 4 year research and training initiative. It presents the achievable resolution of a laser-based velocimeter to measure the velocity of neutral particle beams, results from the measurement of bunch shape using electro-optical crystals with tens of fs resolution, experimental data using a laser wire scanner, and discusses the resolution limits in energy measurements using Compton backscattering at a synchrotron light source. Finally, it also provides a summary of events that have been organized by the LA³NET consortium.

INTRODUCTION

The LA³NET beneficiary partners have recruited 19 Fellows that are hosted by 11 partner institutions all over Europe. Their individual research projects are often carried out within the frame of PhD studies and distributed over the project's different scientific work packages. The largest of these work packages focuses on R&D into advanced beam diagnostics techniques. Furthermore, the consortium organizes a number of international Schools and Topical Workshops, as well as an international conference and numerous outreach events for the wider laser and accelerator communities, as well as the general public.

RESEARCH

Beam diagnostics is one out of the five scientific work packages within the LA³NET project [1]. It is of central importance as the instrumentation developed by the Fellow is crucial in interconnecting research carried out in the other areas of beam generation, acceleration, detectors and power supplies development. The DITANET project [2] pioneered a new approach to researcher training in beam diagnostics and the concepts developed by this consortium have formed the basis also for LA³NET. The following subsection present research results in this work package from individual LA³NET Fellows.

* This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 289191.

carsten.welsch@cockcroft.ac.uk

Electron Bunch Shape Measurements using Electro-Optical Spectral Decoding (EOSD)

FLUTE (Ferninfrarot Linac-Und Test-Experiment – far infrared linac and test experiment) a linac-based light source currently under construction at Karlsruhe Institute of Technology (KIT) is a dedicated accelerator R&D facility. The main R&D goals of FLUTE are to perform systematic bunch compression studies over a wide charge (1 pC - 3 nC) and bunch length (1 fs - 1 ps) range, and to generate THz radiation with high peak fields [3]. The wide range of bunch charges and lengths at a comparatively low energy of 42 MeV requires sophisticated single-shot online-diagnostics. Electro-optical (EO) techniques have proven to be a reliable tool for bunch length measurements at linacs [4, 5]. LA³NET Fellow A. Borysenko had shown previously [6] for a low energy electron beam that longitudinal bunch profile measurements using EO techniques lead to an overestimation of the actual bunch length. This is caused by the electron energy-dependent opening angle of the bunch's Coulomb field that passes the EO crystal during the experiment. The opening angle of the electric field of the bunch is dependent on the electron energy as 1/g due to Lorentz transformation that leads to a longitudinal contraction of the field. Recently, he carried out studies into electro-optical bunch length measurements at beam energies of 40 and 200 MeV at the SwissFEL Injector Test Facility [7], PSI, Switzerland in preparation of measurements at FLUTE.

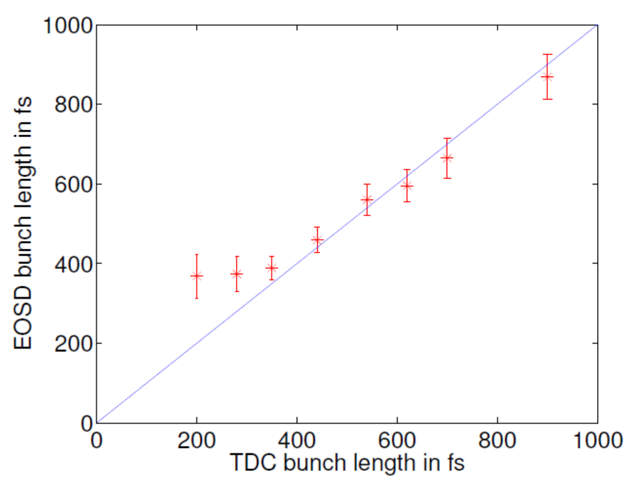


Figure 1: Measurement of bunch profiles using EOSD and a TDC for various electron bunch compressions at a beam energy 200 MeV.

The EO crystal is mounted on a movable arm in a way that the distance to the electron beam can be adjusted during the experiment. The back surface of the crystal has a high reflective coating that reflects the laser pulse. Then it is coupled back into a fibre and transported to the

ISBN 978-3-95450-176-2

ADVANCED BEAM DIAGNOSTICS R&D WITHIN oPAC

C.P. Welsch#
Cockcroft Institute and the University of Liverpool, UK

Abstract

oPAC 'Optimization of Particle Accelerators' is a European research and training network that has received funding within the EU's 7th Framework Program. With a total budget of 6 M€ and 23 Fellows that are employed within the project, it is the largest Marie Curie network that was ever funded by the European Union. oPAC was started in 2011 and would usually come to an end at the end of 2015.

The network currently joins more than 30 partner institutions from all around the world, including research centers, universities and the private sector. One of the project's largest work packages addresses advanced R&D in beam diagnostics. This includes studies into advanced instrumentation for synchrotron light sources and medical accelerators, enhanced beam loss monitoring technologies, ultra-low emittance beam size diagnostics, beam diagnostics for high intensity beams, as well as the development of compact electronics for beam position monitors.

This paper presents the research outcomes of the diagnostics work package and discusses the demonstrated performance of each monitor. A summary of the various events the network has organized for the accelerator community is also given together with an outlook on future opportunities.

INTRODUCTION

An efficient optimization of particle accelerators and light sources requires close collaboration between beam dynamics experts, instrumentation specialists, along with powerful accelerator and electromagnetic field simulations tools. The oPAC network covers all these aspects in its different scientific work packages [1]. The project's Fellows carry out a broad yet closely interconnected R&D program in all these areas. The consortium consists of partners from industry, universities, as well as national and international research centers, such as ALBA, GSI and CERN. Selected associated and adjunct partners contribute to the research activities and complement the network's training program. The primary goals of oPAC are to provide the best possible training to its Fellows thus maximizing their career opportunities, as well as advancing knowledge through a cutting edge research program.

*This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 289485.
#c.p.welsch@liverpool.ac.uk

BEAM DIAGNOSTICS R&D

A versatile beam diagnostics system is crucial for the successful operation and optimization of any particle accelerator or light source. Between 2011-2015 the DITANET consortium [2] set out to define improved training standards in this research area and the development of advanced beam diagnostics is also a key aspect in the oPAC project. Here, a summary of results from Fellows in beam diagnostics R&D is given.

Cavity BPM Electronics

In the last few years the number of projects and applications requiring sub-micrometer resolution for their beam position monitoring systems has increased dramatically. This trend is mainly driven by an increasing number of Free Electron Laser (FEL) projects and by specific applications such as inverse Compton scattering where the high resolution is required in the beam-laser interaction region. Depending on the characteristics of the beam, different cavities and resonant frequencies are used, ranging from single-bunch applications in high-Q cavities to low-Q for long bunch train cavities.

Because of the increased demand in these systems, the requirements for the readout electronics have been collected and extensive simulations run for different scenarios by oPAC Fellow Manuel Cargnelutti, based at Instrumentation Technologies. The idea is to develop a system flexible enough to deliver excellent performance over a broad range of cavities. The compact hard-/software platform on which this instrument will be developed is already in use for other applications [3,4], but several changes will now be introduced in the RF front-end: (1) Down-conversion: A PLL locked to an external reference is used to down-convert the cavity input signal from the cavity resonant frequency to a given intermediate value. (2) Variable attenuators: These are used to adjust the cavity input signal level to the ADC full-scale to maximize the signal-to-noise ratio. (3) ADC: The sampling rate is increased to 500 MS/s. This enables bunch-by-bunch position measurements for low-Q cavities, as well as bunch-train applications. The data acquired is processed by an FPGA of the Xilinx ZYNQ 7045 system-on-chip. Here, a special deconvolution filter and a parametrized time-domain processing of the input signal pulses enable to deliver the beam position for every electron bunch and with sub-micrometer resolution. Fig. 1 presents the simulation of the system position resolution where the internal attenuators setting is parametrized. The cavity used as reference for these simulations is the model BPM16 from the SwissFEL project [5].

ISBN 978-3-95450-176-2

FRIB MACHINE PROTECTION SYSTEM DESIGN AND VALIDATION STUDIES*

S.M. Lidia#, M. Ikegami, Z. Li, Z. Liu, T. Russo, R. Webber, Y. Zhang, Q. Zhao, Facility for Rare Isotope Beams, East Lansing, Michigan, USA 48824

Abstract

The FRIB heavy ion superconducting linac will become the highest peak power heavy ion beam facility, with beams carrying up to 400 kW power with kinetic energy ≥ 200 MeV/u. Fast protection systems are required to detect and remove beam within 35 µs. Detection of beam losses in the low energy linac segment is confounded by two effects: small fluxes of secondary radiation from beam impacts, and large fluxes due to cross-talk from neighboring, higher energy linac sections. We describe a machine protection scheme based on multiple families of diagnostics and diagnostic networks. On-going fault mode studies are utilized to assess risk and to assist in the definition of specific detection networks for high reliability and responsivity.

INTRODUCTION

The Facility for Rare Isotope Beams (FRIB) is a high-power, high-brightness, heavy ion facility under construction at Michigan State University under cooperative agreement with the US DOE [1]. The linac will accelerate ions to energies above 200 MeV/u, with up to 400 kW of beam power on target. The linac facility, shown in Fig. 1, consists of a Front End, three Linac Segments (LSs) connected by two Folding Segments (FSs), and a Beam Delivery System (BDS) leading to the production target. Ion sources are located on the ground level and beam from one of two ion sources is delivered to the linac tunnel through a vertical beam drop. An electrostatic chopper upstream of the vertical beam drop is the primary control of the time structure and duty cycle of the ion beam.

The FRIB linac is designed to support multiple operating modes with varying time structure and peak intensity of the ion beams. These modes can be grouped into four general categories:

- Short pulse (<5 – 50 µs), low duty cycle (< ~1 Hz), varying intensity (50 to 650 µA)
- Moderate pulse length (~0.01 s to s), low duty cycle (< ~1 Hz to 5% duty factor), nominal intensity (3 – 10 pµA)
- Approximately CW (50 µs gap @ 100 Hz), low to nominal intensity (<10 to 400 kW)
- Dynamic ramp to high power (variable intensity, pulse duration, and repetition rate) to slowly increase the target temperature (~10 minutes)

Several additional modes are used for commissioning the front end and fragment separator. These modes exhibit a wide range in intensity: 2–650 eµA for Front End commissioning, and 0.0001–30 pnA for fragment separator commissioning and secondary beam development.

MACHINE PROTECTION SYSTEM

Machine protection systems (MPS) exist to avoid prompt and long-term damage to the accelerator and experimental instrumentation, are required to minimize the number of false trips that limit production, and provide evidence of failures or fault events when interlock systems stop beam operation.

Machine failures can derive from several sources. Hardware failures can include power supply trips, magnet or cavity quench, RF trips and loss of low-level control, loss of vacuum, etc. Control system failures may include incorrect calibrations, improper updates of settings, timing distribution errors or mistimed triggers, and feedback malfunctions. Operator actions may introduce tuning and steering errors that generate errant beams.. Beam instabilities at high current or high brightness might develop quickly and damage components.

The time response for MPS interdiction ranges over many orders of magnitude. Fast protection systems (FPS) serve to protect against prompt damage from beam impacts. Typical FPS response times can vary from several to some hundreds of microseconds, and reflect thermodynamic changes of accelerator materials caused by errant beams. Run permit systems (RPS) operate on a slower time scale, from milliseconds to many seconds, and are used to verify machine state and identify conditions that may lead to unintended damage or long term irradiation effects that limit personnel access. As the FRIB accelerator facility may function in many different operating modes with varying thresholds for beam induced damage, the complete machine protection system must be flexible and configurable.

FRIB Challenges

The challenges for the FRIB MPS derive from multiple sources, including physics of the interaction of heavy ions with the vacuum chamber components and the proximity of high energy to low energy linacs The high power and brightness, and short (< mm) Bragg range of the FRIB heavy ion beam places critical importance on the fast protection system to detect and limit prompt beam losses [2]. The performance and lifetime of sensitive superconducting cavity surfaces can be affected by small losses (< 1 W/m) occurring over long durations.

*This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University.
#lidia@frib.msu.edu

ISBN 978-3-95450-176-2

OVERVIEW OF BEAM DIAGNOSTIC SYSTEMS FOR FRIB*

S.M. Lidia#, S. Cogan, D. Constan-Wahl, J. Crisp, M. Ikegami, Z. Liu, F. Marti, I. Nesterenko, E. Pozdeyev, T. Russo, R. Shane, R.C. Webber, Y. Zhang, Q. Zhao, Facility for Rare Isotope Beams East Lansing, Michigan, USA

Abstract

The Facility for Rare Isotope Beams will extend the intensity frontier of heavy ion linac facilities, with continuous beam power up to 400 kW and beam energy ≧200 MeV/u. Strict demands are placed on the beam diagnostics in the front end, linac, and beam delivery systems to ensure delivery of high quality beams to the target with minimal losses. We describe the design of diagnostic systems in each accelerator sector for commissioning and operations.

INTRODUCTION

Facility for Rare Isotope Beams (FRIB) is a high-power, high-brightness, heavy ion facility under construction at Michigan State University under cooperative agreement with the US DOE [1]. The linac will accelerate ions to energies above 200 MeV/u, with up to 400 kW of beam power on target. The linac facility, shown in Fig. 1, consists of a Front End, three Linac Segments (LSs) connected by two Folding Segments (FSs), and a Beam Delivery System (BDS) leading to the production target [2].

CHALLLENGES FOR BEAM INSTRUMENTATION

FRIB employs a superconducting linac to accelerate the high power, high brightness hadron beam. As such, it shares operational issues with other facilities (SNS, ESS, RHIC, LHC, JPARC, etc.) with regards to power handling, cleanliness of components, restricted access to the beam line, prohibitions against actuated diagnostics near cryomodules, etc. Additional challenges for beam instrumentation presented by FRIB include the low energy of the heavy ion beams, the folded linac geometry, and the plan to transport and accelerate multiple charge states simultaneously.

Low-beta Beam Position Monitoring

The relatively low velocity of the ion beams in the driver linac has implications for accurate beam position monitoring. With low β, the electric field lines spread out resulting in longer, slower image current, and reduced high frequency content. The significance of this effect depends on the proximity to the button and it results in frequency response dependent on position and velocity [3][4][5].

*This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University.
#lidia@frib.msu.edu

Multiple Charge State Beams

The acceleration, transport and delivery of a multiple charge state composite beam presents particular complications to the beam instrumentation design and functionality necessary to establish the machine tune. Representative ion species for FRIB are listed in Table 1, where Q1 is the beam charge state in the Front End and LS1, and Q2 is the beam charge state following the stripper and charge selector in FS1. In the case of Uranium, two charge states are transmitted to the stripper, with five states selected for additional acceleration and target delivery.

Table 1: Representative Ion Species in FRIB

Ion Species	A	Emax (MeV/u)	Q1	Q2-center	Q2-spread
U	238	200	33, 34	78	76-80
Xe	136	221	18	49	48-50
Kr	86	257	14	35	35
Ca	48	264	11	20	20
Ar	36	320	8	18	18
O	16	320	6	8	8

In LS1, orbit oscillations in both longitudinal and transverse phase space arise due to charge state dispersion (ΔQ/Q) in neighboring rf buckets. A challenge to beam instrumentation is to spatially resolve the phase dispersion of the charge states so that the oscillation can be monitored, and growth in both longitudinal and transverse emittance be minimized. This may be accomplished by utilizing the network of linac BPMs and incorporating digital sampling techniques to determine the oscillation phase.

Large Dynamic Range of Beam Intensity

The FRIB linac is designed to support multiple operating modes with varying time structure and peak intensity of the ion beams. These modes can be grouped into four general categories:

- Short pulse (<5 – 50 µs), low duty cycle (< ~1 Hz), varying intensity (50 to 650 µA)
- Moderate pulse length (~0.01 s to s), low duty cycle (< ~1 Hz), nominal intensity (~650 µA)
- Approximately CW (50 µs gap @ 100 Hz), low to nominal intensity (<10 to 650 µA)

ISBN 978-3-95450-176-2

CRYOGENIC THERMOMETERS AS SLOW BEAM LOSS DETECTORS*

Z. Zheng#, Z. He, S. Lidia, Z. Liu, R. Shane, Y. Zhang, Facility for Rare Isotope Beams, East Lansing, Michigan, USA 48824

Abstract

Due to the folded geometry of the linac, beam loss monitoring at the Facility for Rare Isotope Beams (FRIB) [1], especially for small losses, is extremely challenging in the low energy section of the linac. Fast detection is not required for slow/small beam losses, and we therefore propose thermometers installed in the cryomodules at potential hot spots, such as the locations upstream of solenoids. Cryogenic thermometry tests were implemented in the ReA6 cryomodule with heaters and RTD thermometers. The preliminary study shows that the 10 mK signal resolution of thermometers corresponds to ~5 mW heat power in 100 seconds, or ~1 W heat power in 10 seconds, which is sufficient to satisfy the requirement for small beam loss at FRIB.

INTRODUCTION

The unique paper-clip geometry of the FRIB linac leads to radiation cross-talk between the low-energy segment and the adjacent high-energy segment. This creates a background which can obscure beam losses, especially small losses in the low-energy segment. Ion chambers, proposed for beam-loss detection in the high-energy sections, are not suitable for the low-energy sections due to this radiation cross-talk and also the x-ray background from field emission in the RF cavities. Neutron detection in these areas is similarly affected.

In this paper, we investigate the suitability of cryogenic thermometers as a tool to measure small beam losses in which prompt detection is not critical (also referred to as "slow" losses). The first section analyzes potential beam-loss hot spots in the FRIB cryomodules. The next section describes the simulation of thermal sensitivity and response time at possible thermometer locations. The final section presents the results of cryogenic thermometry tests implemented in the ReA6 cryomodule.

LOSS HOT SPOTS IN CRYOMODULES

Beam Loss Simulation

The most probable cause of beam loss at FRIB is the failure of solenoids or cavities. Three classes of beam loss were simulated using the code IMPACT [2]:

- 1 of 69 solenoids is tripped (including 69 cases);
- 1 of 332 cavities tripped (including 332 cases);
- 2 of 332 cavities tripped randomly (including 170 cases).

A summary of the beam-loss simulation results is shown in Fig. 1. The largest peaks in power loss occur at positions 284 m and 446 m, corresponding to the second and third Folding Segments of the FRIB linac. The large beam loss in these locations is due to cavity failure. To protect the cryomodules from damage, however, we are more interested in detecting small losses which may occur over a long period time. These occur mainly in the lower-energy Linac Segments 1 and 2, as shown in Fig. 2.

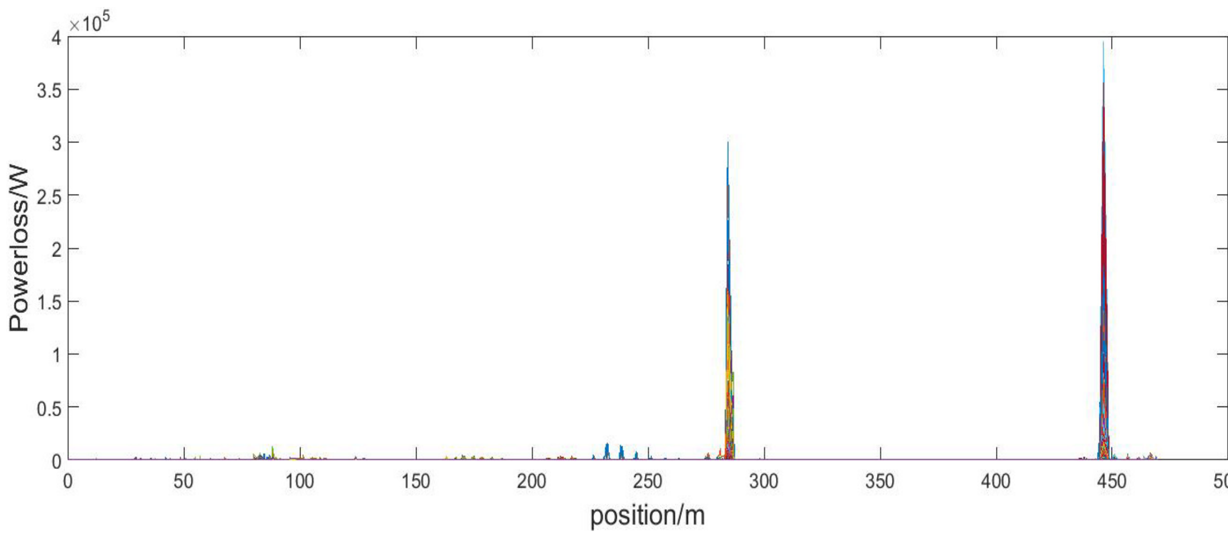


Figure 1: Summary of beam-loss results from IMPACT simulations. The corresponding FRIB linac segments are: Segment 1 = 0 - 126.5, Segment 2 = 136.5 m - 283.3 m, Segment 3 = 301.5 m - 443.7 m.

*Work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661

ISBN 978-3-95450-176-2

REFERENCE SIGNAL DISTRIBUTION FOR BEAM POSITION AND PHASE MONITORS AT LANSCE*

R. C. McCrady, H. A. Watkins, Los Alamos National Laboratory, Los Alamos, NM 87545 U.S.A.

Abstract

The new beam position and phase monitors at LANSCE measure the phase of the beam relative to a reference signal from the master reference oscillator. The distribution of the reference signal along the 800m-long linac is subject to thermal effects, and phase drifts of the reference signal are observed to be greater than 15 degrees. We are investigating stabilization schemes, one of which involves distributing two RF signals of different frequencies. By observing the phase difference between the two signals, the phase drift of the reference signal can be deduced. Initial tests indicate that the reference can be stabilized to within 0.5 degrees using this scheme. In this paper we will present the principles of operation of this stabilization scheme and results from tests of the system.

INTRODUCTION

Deployment of instrumentation for beam position and phase monitors (BPPMs) is imminent at LANSCE, and a 201.25 MHz reference signal is necessary at each of the instrumentation chassis for the phase measurement. Measurement of the beam phase provides time-of-flight information for the tune-up process, as well as diagnostic data for troubleshooting accelerator systems.

The short-term stability requirements for the reference are stringent in order to enable the tune-up process, but long-term stability requirements are fairly relaxed, at about ±1°.

The instrumentation systems are distributed throughout the ~1 km-long klystron gallery, so thermal effects on the reference distribution medium are significant; variations of almost 20° have been observed in tests over the course of a few days, mostly following the diurnal temperature cycles. While this magnitude of variation is not a show-stopper for the system, greater stability would facilitate the use of the phase measurements for long-term monitoring and for troubleshooting.

The original plan for the system had the reference signal tapped off of a thermally-stabilized transmission line that serves as the distribution medium for the accelerator klystrons; this is illustrated in Figure 1. The signal would then have been routed along the same path as the signals from the BPPM electrodes to the instrumentation chassis. This would compensate for thermal effects, as the beam signals and the reference would be subjected to the same environment. This part of the project has been delayed indefinitely, so we are seeking an economical alternative solution.

In an effort to leverage existing infrastructure, we have been exploring the possibility of distributing the reference signal on spare fibres in some recently-installed fibre-optic bundles. In addition to being an economical solution, our experience with analog fibre-optic links gave us confidence that the reference signal could be distributed over long distances with low attenuation, and we were hopeful that we could implement a stabilization scheme. One such scheme is presented in the following sections.

*Work supported by the United States Department of Energy under contract DE-AC52-06NA2596.

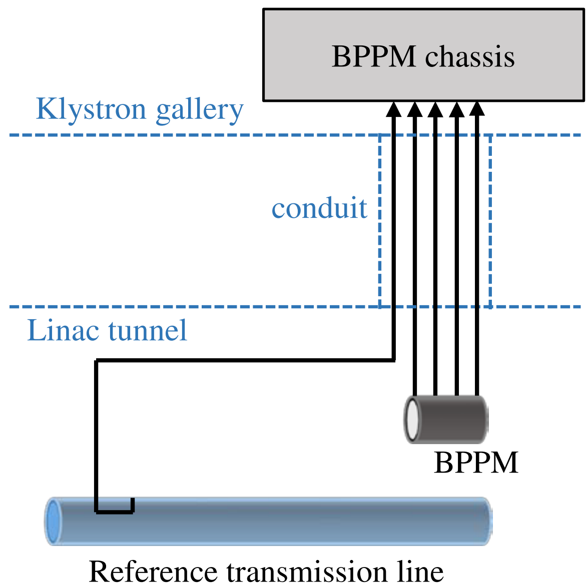


Figure 1: The original plan for distribution of the 201.25MHz reference signal.

THE BPPM SYSTEM

The transducers for the BPPMs are four-electrode, shorted-striplines about 4.8 cm long. These aren't ideally tuned for the 201.25 MHz beam-bunch frequency, as they were designed to replace existing phase-only, single-electrode transducers without modification of the beam pipes.

Coaxial cables transmit the beam-induced signals from the beam tunnel to the instrumentation chassis in the klystron gallery.

The instrumentation has 5 inputs ports, one for each electrode and another for the 201.25 MHz reference signal that serves as a fiducial for the beam phase measurement. Because the input hardware is an off-the-shelf, general-purpose card, additional input ports are available. The significance of this is discussed below.

DISTRIBUTION ON OPTICAL FIBRE

To test the idea of distributing the 201.25 MHz reference signal on optical fibre, we identified a pair of spare fibres in an existing fibre bundle to use in a loop-back

ISBN 978-3-95450-176-2

DIAGNOSTICS CHALLENGES FOR FACET-II*

C. Clarke†, S.Z. Green, C. Hast, M.J. Hogan, N. Lipkowitz, G. White,
V. Yakimenko, G. Yocky, SLAC National Accelerator Laboratory, CA 94025, USA

Abstract

FACET-II is a prospective user facility at SLAC National Accelerator Laboratory. The facility will focus on high energy, high brightness beams and their interaction with plasma and lasers. The accelerator is designed for high energy density electron beams with peak currents of approximately 50 kA (potentially 100 kA) that are focused down to below 10x10 micron transverse spot size at an energy of 10 GeV. Subsequent phases of the facility will provide positron beams above 10 kA peak current to the experiment station. Experiments will require well characterised beams however the high peak current of the electron beam can lead to material failure in wirescanners, optical transition radiation screens and other instruments critical for measurement or delivery. The radiation environment and space constraints also put additional pressure on diagnostic design.

INTRODUCTION

FACET (Facility for Advanced Accelerator Experimental Tests), a User Facility that delivers uniquely high powered multi-GeV electron and positron beams to its experimental program, completes its operations in 2016. FACET-II is a proposed upgrade to FACET currently at the conceptual design stage (Fig. 1). Its primary purpose is to support the development of advanced high-gradient techniques for acceleration (e.g. plasma wakefield acceleration [1,2] (PWFA) and dielectric wakefield acceleration [3] (DWA)). The high power beams, particularly in combination with the facility's multi-terawatt laser system [4], are also in demand by groups developing diagnostics in extreme regimes and studying materials, for example by using terahertz (THz) radiation in THz pump-laser probe experiments.

FACET-II will deliver improved electron beam quality due to advances in technology predominantly the radio frequency (RF) photocathode gun and injection system. It is expected that there will be a factor five longitudinal peak current improvement over FACET and a factor three improvement in transverse area. Though beam energy is 10 GeV (half that of FACET), the tighter bunches will produce much higher peak currents and associated electromagnetic fields (Table 1).

Note that the beam parameters are not independent and configurations are developed for experiments with an understanding for what parameters are most critical and what can be compromised on. Delivering both electrons and positrons adds additional constraint as the two systems are tied together in a shared linac and changing parameters of one may affect the other. Anticipated starting beam parameters are given in Table 2 and are a more relaxed set of beam parameters that can satisfy the requirements for early experiments.

Table 1: Ranges for FACET-II Beam Parameters Considering Design Limits for Electrons and Positrons Delivered to the Experimental Area. Note that the Start-up Beam Configuration will be Relaxed Parameters Shown in Table 2.

Parameter	Electrons	Positrons
Energy [GeV]	4.0-13.7	4.0-13.7
RMS Energy Spread [%]	0.4-1.8	0.5-1.5
Charge per pulse [nC]	0.7-5.0	0.6-2
Bunch Length σ_z	1-20	7-11
Beam size transverse σ_x [μm]	6-20	10-25
Beam size vertical σ_y [μm]	6-10	7-10
Peak Current [kA]	10-100	12-15
Repetition Rate [Hz]	1-30	1-5
Average beam power [kW]	0.1-4.2	0.005-0.14

FACET-II Challenges

The FACET-II injector, linac, chicane and final focus performance has been studied through the 6D particle tracking codes *Impact-T* [5] and *Lucretia* [6] which includes longitudinal and transverse wakefields, coherent synchrotron radiation (CSR), incoherent synchrotron radiation (ISR) and third order optics (e.g. chromatic effects). Dynamic errors from sources of jitter were studied (the dominant sources are phase jitter in the first stage of the linac, timing jitter on the laser used for the injector and position jitter of the laser).

At FACET-II, we expect many of the first experiments to be studies of PWFA with the requirement on the beam parameters that peak current for both the electron bunch and the positron bunch is greater than 10 kA. For this beam configuration, the tracking studies with errors from jitter sources showed that some shots may have a peak current of 80 kA though the average is 30 kA. It cannot be prevented that we achieve sporadic shots of high peak current which can damage intercepting material in a single shot.

The configuration for PWFA does not lead to the highest peak current FACET-II can deliver. Figure 2 shows the variation of peak current and bunch length with electron bunch charge which is controlled through collimation of high and low energy parts of the beam in the bunch compressor chicanes. When the configuration is optimised for high peak currents, peak currents in excess of 100 kA can be achieved.

These extreme beams present challenges for diagnostics just as they create opportunities for experiments.

* This work performed under DOE Contract DE-AC02-76SF00515.
† cclarke@slac.stanford.edu

ISBN 978-3-95450-176-2

SUB-PICOSECOND SHOT-TO-SHOT ELECTRON BEAM AND LASER TIMING USING A PHOTOCONDUCTIVE THz ANTENNA

E. Curry, P. Musumeci, UCLA, Los Angeles, CA 90095, USA
B. T. Jacobson, A. Murokh, RadiaBeam Technologies, Santa Monica, CA 90404, USA

Abstract

Temporal synchronization systems, which measure electron beam time of arrival with respect to a laser pulse, are critical for operation of advanced laser-driven accelerators and light sources. State-of-the-art synchronization tools, relying on electronic e-beam response and photodetector laser response are limited to few GHz bandwidths in most practical configurations. This paper presents a temporal diagnostic instrumentation based upon a photoconductive THz antenna, which could offer an inexpensive and user friendly method to provide shot-to-shot relative time of arrival information with sub-picosecond accuracy. We describe the overall instrument design and proof-of-concept prototype results at the UCLA PEGASUS facility.

INTRODUCTION AND MOTIVATION

Many experiments today involve the careful coordination and synchronization between pulsed laser beams and accelerated charged particle beams. Examples include inverse Compton light generation, laser driven plasma wakefield acceleration, and plasma photocathode injectors. The two most widely used diagnostic systems for measuring synchronization which are capable of providing sub-ps or better timing resolution are BPM pick-ups [1] and fast photodiodes equipped with very high bandwidth oscilloscopes and electro-optical based encoding techniques [2]. The first method requires careful cable trimming and very expensive oscilloscopes. Electro-optic sampling (EOS) methods require careful optical alignment of birefringent crystals and many optical components and relatively high fields to induce non-linear processes.

THz photoconductive antenna (PCA) devices can both detect and produce single-cycle THz fields when used in conjunction with a pulsed laser system (typically < 100 fs pulse widths) [3]. The devices are comprised of a substrate wafer of photoconductive material, such as low-temperature GaAs, which is grown to have modified properties to enhance the carrier mobility in order to respond at ps and sub- ps timescales. Conductive metal is patterned onto the photoconductive substrate in the form of a resonant antenna (dipole, log-spiral, or other geometries) with a small gap left in the antenna structure. When the LT-GaAs in the antenna gap is illuminated with laser radiation with a photon energy above the photoconductive threshold, any incident THz fields will drive current on the antenna which can be measured with a transimpedance amplifier. The device will in this way be "gated" by the laser pulse, the width of which sets a lower limit on the temporal resolution of THz field amplitude detection.

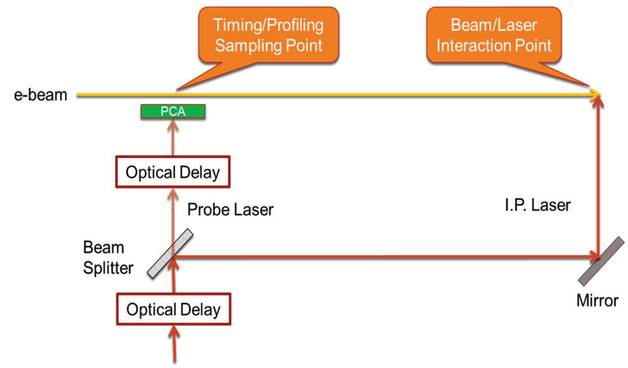


Figure 1: Schematic overview of a THz photoconductive antenna used as a timing synchronization instrument for short pulsed beams. The system could be used for longitudinal profile measurements for beams of longer bunch lengths

BENCH-TOP TESTS

For our proof of concept measurements, we have used the Menlo Systems Tera8-1 photoconductive antenna. The THz pulse used to test the detection capabilities of the PCA was produced through pulse-front-tilted optical rectification [4][5] of a 45 fs Ti:sapphire laser pulse centered at 800 nm with a 30 nm bandwidth. A beam splitter removed a fraction of the initial IR to act as the gating pulse for the PCA. Pulse-front tilting of the remaining IR was accomplished with a grating and then imaged onto stoichiometric lithium niobate to produce a picosecond-scale single-cycle THz pulse. The peak field of the THz pulse was set by the incident IR power and ranged from 300 kV/ m to 4.6 MV/ m. The THz pulse was collimated and then refocused down to a 2 mm spot size at the PCA using a pair of off-axis parabolic mirrors.

Initial measurements with the PCA varied greatly depending on the spot size of the IR pulse that illuminated the antenna. A 50 μm diameter pinhole was placed in front of the PCA to ensure a reproducible IR spot size and limit the IR illumination to the region of the antenna gap. Proper alignment of the pinhole with the antenna gap introduced a substantial challenge to the THz detection set-up, but resulted in significant improvement to the detection sensitivity and timing resolution. The pinhole was incorporated into the antenna mount design and alignment was optimized using the bench-top THz source. With the pinhole locked in place, the antenna mount could then be illuminated with a large (several mm) IR spot size, eliminating the challenge of precise optical alignment.

ISBN 978-3-95450-176-2

NSLS2 FILL PATTERN MONITOR AND CONTROL*

Weixing Cheng#, Bel Bacha, Yong Hu, Guimei Wang, Om Singh
NSLS-II, Brookhaven National Laboratory, Upton, NY 11973

Abstract

NSLS2 storage ring has harmonic number of 1320. Possible fill patterns include multi bunch train(s) followed by ion cleaning gap(s), hybrid fill with single bunch in the ion gap. Storage ring filling pattern can be measured using button BPM sum signal together with high speed digitizer or oscilloscope. Button BPM sum signal typically has dynamic range of 10^-2 to 10^-3. Nonlinearity of BPM sum signal dependence on beam position has been characterized. In preparation for high dynamic single bunch current measurement, a filling pattern monitor system using synchrotron radiation is under development. Besides, the storage ring filling pattern can be controlled using the bunch cleaning function integrated in the bunch-by-bunch feedback system. Results of these two filling pattern monitors and bunch cleaning will be presented.

INTRODUCTION

NSLS2 storage ring has been commissioned recently and it's open for user operation. The ring is using super conducting 500MHz single cell cavity. There are maximum of 1320 bunches that can be filled in the ring. There is one cavity available with RF voltage at 1.78MV. 300mA total beam current were able to be stored with this cavity. Once the second super-conducting cavity is available in the coming months, high storage current can be achieved. NSLS2 storage ring was designed to have weak dipoles and damping wigglers (DW) to further decrease the horizontal emittance to sub-nm level. Depending on RF gap voltage, number of DWs used and bunch lengthening due to broadband impedance, typical bunch lengths at NSLS2 storage ring are between 15-40ns.

Arbitrary fill pattern can be generated in the NSLS2 storage ring. Typical fill pattern includes a long bunch train of about 1000 bunches (80% fill) followed by an ion-clearing gap. Bunches are separated by 2ns in the bunch train. Camshaft single bunch can be added in the ion gap for future time correlated experiments. At the current user operation, a single bunch is filled with similar bunch current to the main train bunches. The single bunch is used to monitoring betatron tune continuously. Even with the ion gap, fast ion instabilities have been observed [1,2] along the long bunch train. With bunch by bunch feedback, ion instabilities can be suppressed well up to 300mA, bare lattice at nominal chromaticity of +2/+2. As the total beam current increasing and machine emittance (especially vertical plane) decreasing like coupling correction, fast-ion effect will be more severe. There is possibility to fill the ring with 4 (or 6) bunch trains. Each train will have ~250 bunch filled followed by a short ion gap of 80 buckets. Camshaft single bunches can be populated in the ion gaps as well.

During top-off operation at 500mA, beam lifetime is expected to be around 3 hours. To keep the total beam current variation within 1% and top off injection period > 1 minute, 7nC charge per shot are required to be delivered to the storage ring. Relative bunch to bunch current variation is specified to be within 20%. It's desired to measure the bunch to bunch current with better than 1% resolution. Fill pattern monitor and control is also important to various machine studies.

Button BPM SUM signal is not only determined by the bunch current, it may depend on the button size and BPM chamber geometry, cable attenuation, electronics attenuations, beam position and bunch lengths. For the fill pattern monitor BPM SUM signal, button geometry, cable and electronics attenuations are fixed once the system is installed. SUM signal nonlinearity dependence on the beam position has been analyzed in [3]. Figure 1 plots the two diagonal buttons SUM signal nonlinearity of the FPM BPM pickup. As can be seen, if the beam orbit is controlled within +/-6mm horizontally and +/- 3mm vertically, BPM SUM signal dependency on beam position is within 1%. With stored beam and orbit corrected, beam position at the FPM pickup is well within 1mm from the BPM geometric center, typically the SUM signal dependency on beam position can be neglected.

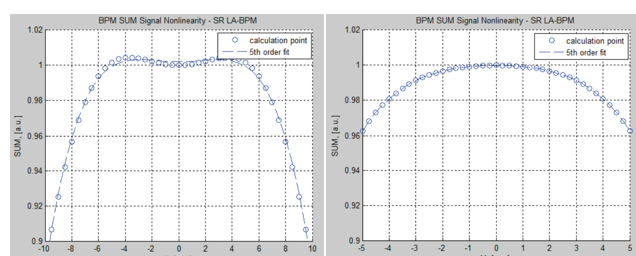


Figure 1: BPM SUM signal nonlinearity of two diagonal buttons. Two diagonal buttons SUM signal is used to measure the NSLS2 storage ring fill pattern.

Reflection of the button signal could lead to inaccurate measurement of the fill pattern, especially when there are high current bunches filled in the ring. As the capactive button is not 50 Ohm matched to the detection electronics, reflection signal is unvoidable. 3 dB attenuators have been added right after the button feedthrough which helped to supress the reflection signal but not able to eliminate it. Reflection signal can come from the HOM of the vacuum chamber structure where BPM pickup is mounted on. Figure 2 shows an example of 0.2mA single bunch filled in the ring, the signal peak amplitude was about 800mV (out of scale), there were

*Work supported by DOE contract No: DE-AC02-98CH10886
chengwx@bnl.gov

ISBN 978-3-95450-176-2

LONGITUDINAL BUNCH PROFILE MEASUREMENT AT NSLS2 STORAGE RING*

Weixing Cheng[#], Bel Bacha, Alexei Blednykh, Yongjun Li, Om Singh
NSLS-II, Brookhaven National Laboratory, Upton, NY 11973

Abstract

Longitudinal bunch profile has been measured at NSLS2 storage ring using streak camera. From the measured profile, bunch lengthening and synchronous phase information can be derived to study the single bunch collective effect. Single bunch lengthening effect has been measured for bare lattice and for other lattices with different insertion devices. The streak camera can also be setup for other beam physics studies, for example to measure the injection beam dynamics and fast ion effects. Y-z imaging was measured using cylindrical lenses. Single bunch y-z profile was measured at threshold current.

INTRODUCTION

Visible synchrotron light monitor (SLM) diagnostic beamline has been constructed and commissioned at NSLS2 storage ring. The diagnostic beamline utilizes the radiation from Cell 30 bending magnet B (BM-B), which is the second dipole magnet after injection straight section. The nominal source point is ~2.75mrad into the dipole. The beamline has acceptance of +/-1.5mrad horizontal and +/-3.5mrad vertical. Visible light from the dipole synchrotron radiation is reflected by in-vacuum mirror through a vacuum window. The visible light is guided into SLM hutch located on the C30 experimental floor. There are various optics setups on the 4'x10' optical table, currently there are four setups: 1) CCD camera for continuous beam profile monitoring, spatial resolution of the CCD camera was analyzed to be around 60 μm, which makes the direct imaging method possible to measure horizontal beam sizes (~100 μm). Vertical beam size at SLM source point is ~10 μm which is not possible to measure with direct x-y imaging. There are methods that can be tested using the CCD camera, such as double slit interferometer and π-mode beam size measurement. Preliminary test of double slit interferometer has been carried out during user operations. 2) Fast gated camera for transient x-y profile measurements. The camera has minimum gate width of 3ns which makes it suitable to measure turn to turn profile of individual bunches. 3) Test branch which is used for Time Correlated Single Photon Counting (TCSPC) system to measure the single bunch purity and fill pattern. 4) Streak camera for various longitudinal beam dynamics studies. Visible light can be directed to different cameras/detectors through beam splitter and flip mirrors. More information on the diagnostic beamline design and the commissioning results can be found at [1, 2].

Streak camera has been used for longitudinal bunch profile measurements. The camera is Hamamatsu C5680 with 2ps resolution and it includes synchroscan module M5675, slow sweep module M5677 and dual sweep module M5679. Synchroscan frequency was chose to be 125MHz, which is 1/4 of the NSLS2 storage ring RF frequency. The sweeping clock signal is getting from master oscillator through long Heliax cables. Phase jitter of the clock signal was measured to be less than 1ps. Small jitter is important for precise bunch length measurements. The long Heliax cable runs inside the NSLS2 buildings where the temperature is well regulated. Phase drift of the streak camera 125MHz synchroscan signal should be small, this is helpful to measure the relative synchronous phase from streak camera profiles.

Depends on the applications, optics setup for streak camera measurement can be different. There is different optical density (OD) filters (OD = 0.5, 1, 2, 3, 4) mounted on a rotation wheel so that different filters can be easily selected according to the beam current. A band-pass filter with center wavelength of 500nm and bandwidth of 10nm is typically used to limit the chromatic aberrations. For a typical bunch length measurement setup, 20x objective lens mounted on a 6-dimesional stage (x/y/z/x'/y'/z') right in front of the streak camera slit. The lens forms a very tight image on the camera slit which is then relayed to photocathode through streak camera input optics.

There are cases to observe the vertical and longitudinal (y-z) profile to understand the single bunch and coupled bunch instabilities. Dove prism was used to rotate the image by 90 deg and cylindrical lenses are used to image on the streak camera slit. Vertical lens has focal distance of 500mm and horizontal lens has focal distance of 50mm to make the beam image tight in horizontal plane and with reasonable magnification vertically. This setup is suitable to detecting the head-tail coupling motions. Fast ion has been observed as the most dominant instability since beginning of NSLS2 commissioning. Using the slow sweep module and y-z imaging setups, streak camera can monitor the bunch motions in vertical plane along the bunch train.

In the following sections, measurement results with different optics setups and streak camera modules will be presented, starts with single bunch profile measurement at different bunch current and RF voltage. Injecting beam longitudinal dynamics has been checked to optimize the phase and energy mis-match of injecting beam. Y-z imaging to study the head-tail coupling due to chromaticity and Transverse Mode Coupling Instability (TMCI) will be followed. Direct observation of fast-ion motions along the bunch train using slow sweep module will be discussed as well.

*Work supported by DOE contract No: DE-AC02-98CH10886
[#]chengwx@bnl.gov

ISBN 978-3-95450-176-2

BEAM ARRIVAL TIME MONITORS

J. Frisch SLAC National Accelerator Laboratory, Stanford CA 94305, USA

Abstract

We provide an overview of beam arrival time measurement techniques for FELs and other accelerators requiring femtosecond timing. This paper will discuss the trade-offs between the various techniques used at different facilities.

ARIVAL TIME MONITORS

Beam timing is only meaningful relative to some reference, and in general what matters is the relative timing of two different systems. Pump / Probe experiments in FELs, UEDs etc. generally have the most critical requirements: down to a few femtoseconds. Proton HEP experiments can require few-picosecond coincidence detection, but bunch lengths are typically long, so precision arrival times are not required.

It should be noted that the thermal expansion of conventional materials, cables, optical fibers etc. is typically on the order of 10^{-5}/°C, corresponding to 30fs/°C. Because of this, most arrival monitors are coupled to some form of stabilized timing transmission system, and the design of that system will influence the monitor technology choice.

As the arrival monitors are typically not the "weak link" in a timing system [1], trade-offs between cost and efficiency should be considered.

Timing System Architecture

A typical timing system includes the beam arrival monitor, a timing distribution system, and an experimental laser system as shown in figure 1:

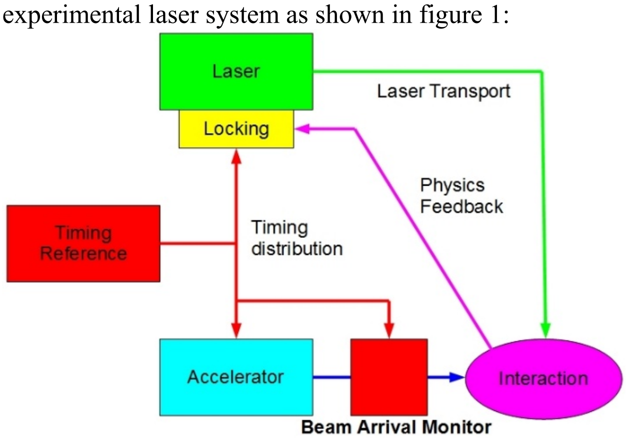


Figure 1: Typical timing system

The information from the beam arrival monitor may be used in a variety of ways:

- Provide feedback to the accelerator timing to reduce timing jitter [2]
- Correct the timing drift in the reference signal from the accelerator to the experiments [1]
- Provide offline correction of experiment data for shot to shot timing jitter [1]

DETECTING BEAM FIELDS

Frequencies

The electric fields from relativistic bunces diverge at an angle of 1/γ so that the fields at the beam pipe radius can contain high frequency components, in most cases above the maximum frequency (~50GHz) of conventional electronics. For high energy machines (γ>~300) the fields at the beam pipe will have frequency components higher than the response time of electro-optical system (~100fs).

Signal Levels

The field probes for arrival time monitors can be described as having a geometric impedance, for accelerator structures this is denoted by "R/Q", and for a cavity is typically 100Ω. The single pulse energy deposition is given by [3]

$$E = q^2\left(\frac{\omega_0}{2}\right)\left(\frac{R}{Q}\right)$$

A 100pC bunch in a 3GHz cavity with 100Ω R/Q will deposit 10nJ. When this is compared to thermal noise of 2×10^{-21}J it corresponds to a timing resolution of 20 attoseconds. Other effects will limit the monitor resolution well before this level, and in most cases thermal noise is not the primary limitation in arrival time monitors.

Other types of beam pickoffs, including "buttons" may have much lower coupling and signal levels can be a performance limit.

Broadband vs. Narrowband Detection

Conventional electronics typically has ~1ps timing resolution for single shot measurements [4]. However if the beam electrical impulse is converted to a narrow band repetitive signal this allows multiple measurements to be averaged on a single pulse. Beamline cavities can perform this narrow-banding for low frequency systems.

Electro-optical systems can have very high bandwidths (100 fs response time) and provide few-femtosecond single shot resolution. These can be used without ringing filters.

Sources of Beam Fields – Working Above Cutoff

Electron beams will emit electromagnetic radiation whenever they encounter a change in beam pipe impedance. Components of this radiation above beam-pipe cutoff of 1.8412C/(2πR). (9GHz for a 1cm radius pipe) will propagate.

ISBN 978-3-95450-176-2

TRANSVERSE PROFILING OF AN INTENSE FEL X-RAY BEAM USING A PROBE ELECTRON BEAM*

P. Krejcik, SLAC National Accelerator Laboratory, Menlo Park, CA 94306, USA

Abstract

Monitoring the pulse by pulse output intensity and profile of an FEL is a critical measurement both for users and for optimizing the accelerator drive beam. The diagnostic challenge is to find a technique that is not susceptible to damage at high output power, is noninvasive and can be performed at high repetition rates. Fluorescent screens are invasive, susceptible to damage and limited in repetition rate by the camera readout. Gas cell monitors are noninvasive but only yield intensity information and suffer from residual ionization at high repetition rates. The technique described here uses the scattering of a beam of low-energy electrons as they are scanned across the photon beam to measure the transverse intensity profile of the photon beam. Two different geometries are compared. One is where a finely focused electron beam is scanned transversely across the photon beam to measure the transverse profile. The second is where the electrons are bent onto the axis of the photon beam and are scattered by the counter propagating beam of photons. Here the electron beam is kept larger in diameter than the photon beam so that the photon pulse intensity can be measured by the scattering.

INTRODUCTION

The pulse by pulse photon energy output of an FEL is a vital parameter for both the experiment users of the photon beam and the operators tuning the electron drive beam to optimize the FEL performance. The energy output varies greatly shot to shot because of the stochastic nature of SASE FELs and experimenters need that information for each shot. The photon output energy depends on many parameters of the electron drive beam such as charge, emittance, bunch length, peak current, energy, energy spread and so on. The pulse energy is therefore the bottom line tuning parameter for optimization of the accelerator. The value is displayed prominently in the LCLS control room on a scrolling display to give an immediate indication of the overall machine performance.

Measurement of the photon beam size is also important in any photon experiment involving focusing of the beam so that knowledge of beam size, beam divergence and the virtual source position can be used to set up the x-ray optics.

The LCLS relies on two main measurement techniques to measure size and intensity. The first is an invasive technique where a fluorescent YAG screen is inserted in the photon beam and the image recorded by a camera[1]. Beam cannot be delivered to user experiments during this measurement process. The size and position of the beam can be measured on the screen with good precision to a few microns. The camera intensity also gives a good measure of the intensity of the x-ray beam at intensities below saturation of the YAG screen.

At high intensities the YAG output saturates, and this is readily observed if the screen is used with small or focused spots. At still higher intensities the YAG screen becomes permanently damaged with reduced light output, and at very high intensities the YAG crystal does not survive a single shot.

Although it can be regarded as a single shot measurement, the repetition rate is limited by the camera read out speed and would not keep up with the high repetition rate of superconducting machines like LCLS-II.

The intensity measurement of the YAG screen needs to be calibrated against an absolute measurement of the x-ray intensity such as with the gas cell monitor.

The gas monitor at LCLS is a low pressure gas cell separated from the photon beam line vacuum by differential pumping. The x-ray photons passing down the axis of the cell ionize the gas and the number of ions is counted by sweeping them to them side with a clearing electrode into a detector [2].

In this way the individual pulse energy of the FEL can be monitored continuously and non-invasively during beam delivery to users, making it a valuable diagnostic tool. No information on beam size or position is available though.

A problem arises when we move to the high repetition rate beams of superconducting machines such as LCLS-II. Ions in the gas monitor move relatively slowly and are not fully cleared by the time the next pulse arrives in a 1 MHz bunch train. There are therefore significant transient effects in the detector response at the beginning of the pulse train compared to later in the train when residual ionization builds up. A diagnostic with a faster response suited to LCLS-II parameters is therefore sought.

ELECTRON PROBE DETECTOR

In its simplest form an electron beam is directed across the beam of x-ray photons so that they scatter off each other, as shown in Figure 1. The interaction can be described by the Compton scattering process, but since the energies considered here are quite low it is in the Thompson elastic scattering regime.

Compton scattering measurements have been routinely performed at high energy accelerators, usually with a laser directed at the high energy electron beam in order to measure the transverse profile of the electron beam. A laser is used when the intensity of the electron beam is so

*This material is based upon work supported by the U.S. Department of Energy, Office of Science under Contract No. DE-AC0276SF00515.
#pkr@slac.stanford.edu

ISBN 978-3-95450-176-2

BEAM BASED CALIBRATION FOR BEAM POSITION MONITORS

M. Tejima, KEK/J-PARC, Tsukuba, Ibaraki, Japan

Abstract

Beam position monitoring is one of the most fundamental diagnostic tools in an accelerator. To get good performance of the BPM system, the beam-based alignment method has been developed and used for more precise BPM alignment and maintaining the performance. The signal from a BPM is transferred by coaxial cable, and processed by signal processing circuit. The beam position is calculated from the relative ratios between the 4 outputs of the BPM head. The circuit gain is calibrated in the beginning on a test bench. But this calibration changes with each passing year. To escape from this problem, a method for calibration of the gain similar to beam-based alignment is a key issue to maintain the good performance of the BPM system. For this propose, a beam-based gain calibration method has been developed and used at KEK. Both beam-based alignment and beam based gain calibration methods are presented using concrete examples.

INTRODUCTION

For high energy accelerators, the measurement of the beam position is one of the basic diagnostics along with the beam intensity and the betatron oscillation frequency. Stability of the closed orbit is very important for stable operations to maintain good performance in an accelerator. Therefore we have prepared a BPM at each quadrupole magnet. For example, there were 186 BPMs in the J-PARC Main Ring. The BPM system requires a high accuracy measurement. In order to satisfy the requirement, we have done careful calibration of the BPM system in three steps before the commissioning. But, in KEKB, we found noticeable errors larger than 0.1 mm in almost all BPM readings.

These errors come from the alignment error of a BPM to its adjacent quadrupole magnet, and the imbalance among 4 output data of the BPM. Beam-based alignment (BBA) is a method for correcting the offset of a BPM head based on beam measurement [1]. The center position of each BPM should be known in terms of offset from the magnetic center of the adjacent quadrupole magnet. The relative gain of the output data may drift due to unpredictable imbalance among output signals from the pickup electrodes, because the output signals must travel through separate paths, such as cables, connectors, attenuators, switches, and then are measured by the signal detectors. For this reason, the gains of every BPM of KEKB have been calibrated by a non-linear least-square method [2]. The same process of gain calibration used in KEKB has been tried with the BPM system in J-PARC Main Ring, however the fitting result gave indefinite solutions.

A new beam-based method to calibrate the gains of BPMs at the J-PARC Main Ring has been developed using the Total Least Square method (TLS) [3].

CALIBRATION DURING INSTALLATION

The output data from a BPM system was usually calibrated in the following three steps on the test bench at KEKB [4].

1. Mapping measurement of BPM system
   The BPM heads were fabricated to within a ± 0.1 mm tolerance. However, variations of frequency response between button electrodes cannot be ignored considering the accuracy requirements. All BPMs were mapped at a test bench with a movable antenna to identify the electrical zero position of each BPM.
2. Alignment of geometrical offset
   Most BPMs (~97%) were aligned in relation to their nearest quadrupole magnet. After installation of BPM heads in the ring, we measured the geometrical offsets of the BPM heads relative to the quadrupole magnet. But the measured offsets were not the offset from the field center of quadrupole magnet.
3. Attenuation ratio of transmission line
   We employed 4 twisted coaxial cables with foamed Polyethylene insulation between BPMs in the tunnel and electronics at a local control room above ground. To measure signal attenuation at the detection frequency, the cables together with the electronics were also calibrated to 50 μm accuracy.

BEAM BASED ALIGNMENT

In order to align a BPM to the field center of a quadrupole magnet, the BPM offset is calibrated by finding the position of the closed orbit at that BPM which is insensitive to a change of the field strength of the adjacent quadrupole magnet. Calibration data are taken for different beam orbits and different field strengths of the quadrupole magnet. The orbit change due to the field gradient change Δk of the quadrupole magnet is proportional to the closed orbit displacement Δx from the magnetic center of the quadrupole magnet. Figure 1 shows an example of BPM offset measurement by BBA in the main ring at J-PARC [5]. A correction coil wound on each pole of a quadrupole magnet was used to change the field strength. The current on the correction coil, I_Q was changed from -4 A to 4 A nominally. To change the

ISBN 978-3-95450-176-2

PROGRESS TOWARDS ELECTRON-BEAM FEEDBACK AT THE NANOMETRE LEVEL AT THE ACCELERATOR TEST FACILITY (ATF2) AT KEK

N. Blaskovic Kraljevic, D. R. Bett, T. Bromwich, P. N. Burrows, G. B. Christian, M. R. Davis, C. Perry, John Adams Institute, Oxford, UK

Abstract

Ultra-low latency beam-based digital feedbacks have been developed by the Feedback On Nanosecond Timescales (FONT) Group and tested at the Accelerator Test Facility (ATF2) at KEK in a programme aimed at beam stabilisation at the nanometre level at the ATF2 final focus. Three prototypes were tested: 1) A feedback system based on high-resolution stripline BPMs was used to stabilise the beam orbit in the beamline region c. 50m upstream of the final focus. 2) Information from this system was used in a feed-forward mode to stabilise the beam locally at the final focus. 3) A final-focus local feedback system utilising cavity BPMs was deployed. In all three cases the degree of beam stabilisation was observed in high-precision cavity BPMs at the ATF2 interaction point. Latest results are reported on stabilising the beam position to approximately 50nm.

INTRODUCTION

A number of fast beam-based feedback systems are required at future single-pass beamlines such as the International Linear Collider (ILC) [1]. For example, at the interaction point (IP) a system operating on nanosecond timescales within each bunch train is required to compensate for residual vibration-induced jitter on the final-focus magnets by steering the electron and positron beams into collision. The deflection of the outgoing beam is measured by a beam position monitor (BPM) and a correcting kick applied to the incoming other beam. In addition, a pulse-to-pulse feedback system is envisaged for optimising the luminosity on timescales corresponding to 5 Hz.

The Feedback on Nanosecond Timescales (FONT) project has developed ILC prototype systems, incorporating digital feedback processors based on Field Programmable Gate Arrays (FPGAs), to provide feedback correction systems for sub-micron-level beam stabilisation at the KEK Accelerator Test Facility (ATF2) [2]. Previous results [3], [4] have demonstrated an upstream closed-loop feedback system that meets the ILC jitter correction and latency requirements. Earlier results demonstrating the propagation of the correction obtained using the upstream stripline BPM feedback system at ATF2 are reported in [5]. The ultimate aim is to attempt vertical beam stabilisation at the nanometre-level at the ATF2 IP [6]. An overview of the extraction and final focus beamlines at the ATF, showing the positions of the FONT5 system components in both the upstream and IP regions, is given in Fig. 1.

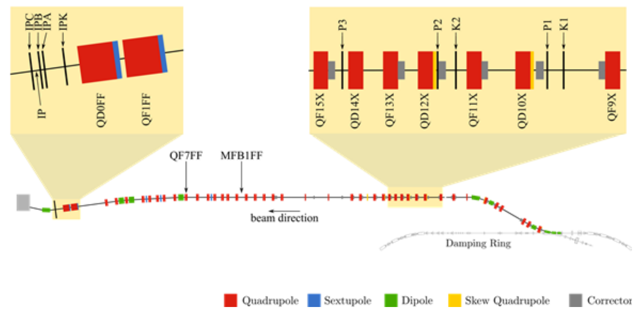


Figure 1: Layout [7] of the ATF extraction and final focus beamline with the FONT regions zoomed in.

We report here the latest developments and beam testing results from the FONT project using both the upstream stripline BPM system as well as near-IP cavity BPMs [8,9] to drive feedbacks for stabilising the beam at the IP.

UPSTREAM FEEDBACK SYSTEM

The upstream feedback system (Fig. 1) comprises 3 stripline BPMs and 2 stripline kickers. The design goal for this system is to stabilize the vertical beam position to the 1 μm level at the entrance to the final-focus system. This requires BPMs capable of resolving bunches separated in time by around 100 ns, and with a position resolution at the submicron level. For tests of the FONT5 system the ATF is operated in a mode whereby a train of two or three bunches is extracted from the damping ring and sent down the ATF2 beam line. The bunch separation is determined by the damping ring fill pattern and typically is chosen to be between 140 ns and either 154 ns (3-bunch mode) or 300 ns (2-bunch mode).

Stripline BPMs (Fig. 2) were used due to their inherently fast, broadband response and capability to resolve bunches with the required time resolution. In the FONT5 system only the vertical plane of the BPMs is routinely instrumented (Fig. 3) with an analogue processor (Fig. 4), which functions [7] so as to deliver the stripline pickoff-pair difference and sum signals in a form that can be easily recorded by the digitizer for calculation of the position-dependent, beam charge-independent ratio of the two. Ten processors were built and are used in beam operations at ATF2. A single BPM processor can be used to process the beam position data in either the horizontal or vertical plane; from here on only the vertical plane is considered.

ISBN 978-3-95450-176-2

DIRECT OBSERVATION OF ULTRALOW VERTICAL EMITTANCE USING A VERTICAL UNDULATOR

K. P. Wootton*,†, The University of Melbourne, Parkville, VIC, 3010, Australia

Abstract

In recent work, the first quantitative measurements of electron beam vertical emittance using a vertical undulator were presented, with particular emphasis given to ultralow vertical emittances [K. P. Wootton, et al., Phys. Rev. ST Accel. Beams, 17, 112802 (2014)]. Using this apparatus, a geometric vertical emittance of 0.9 ± 0.3 pm rad has been observed. A critical analysis is given of measurement approaches that were attempted, with particular emphasis on systematic and statistical uncertainties. The method used is explained, compared to other techniques and the applicability of these results to other scenarios discussed.

INTRODUCTION

The low emittance ring community expects direct observation of beam size as demonstration of ultralow vertical emittance in electron storage rings. In particular, the development of low emittance tuning routines at electron storage rings for proposed linear collider damping rings has motivated the measurement of pm rad vertical emittances. A variety of techniques for measuring vertical emittance have been developed, typically utilising imaging, interferometry or projection of the distribution of spontaneous synchrotron radiation produced by the electron beam.

Recent experiments and simulations have demonstrated that undulator radiation from a vertical insertion device is particularly sensitive to pm rad vertical emittance [1]. However the use of a vertical undulator beamline for direct measurement of pm rad vertical emittance in a storage ring presented several challenges. This work is a critique of several experimental approaches to the measurement of vertical emittance using a vertical undulator.

THEORY

The use of a vertical undulator for measurement of vertical emittance in an electron storage ring was first proposed by S. Takano in 1997 [2]. Using simulations, it was demonstrated that a measurement of the on-axis flux from a short vertical insertion device could be used to evaluate the vertical emittance in the SPring-8 storage ring.

The spectral brilliance of a planar undulator yields a distribution with odd harmonics of high intensity, and null even harmonics. The angular distribution of radiation for the first harmonic illustrated in Fig. 1(a) of Ref. [3] could be approximated by a Gaussian distribution. However, using the first harmonic for a vertical emittance monitor with an opening angle of order $\approx 1/\gamma$ limits the minimum electron beam emittance which can be deconvolved from a measured photon distribution to approximately the same order.

This approximation breaks down at high undulator harmonics. High harmonics yield an angular distribution of undulator radiation which can be described as the fine structure of a narrow interference pattern within the usual cone of undulator radiation. This pattern exhibits minima on axis for even harmonics, and maxima on axis for odd harmonics, and enables measurement of emittances smaller than the undulator radiation opening angle. Employing a narrow interference pattern convolved with the electron beam distribution, this technique is similar to several other emittance diagnostics, such as the π-polarisation technique [4], synchrotron radiation interferometer [5], X-ray Fresnel diffraction [6] and the coded aperture X-ray emittance monitor [7].

PREVIOUS MEASUREMENTS OF ULTRALOW VERTICAL EMITTANCE

Vertical emittance measurements in 2008 at the SLS using the π-polarisation technique demonstrated $\varepsilon_y = 3.2 \pm 0.7$ pm rad [4].

Experiments conducted in 2010 using the AS storage ring demonstrated through indirect measurements a vertical emittance of $\varepsilon_y = 1.2^{+0.3}_{-0.2}$ pm rad [8].

In 2012, a new vertical emittance of $\varepsilon_y = 0.9 \pm 0.4$ pm rad was observed using the direct π-polarisation technique at the SLS storage ring [9].

With the goal of optimising the AS storage ring for lower vertical emittance, a beam-based survey of storage ring magnets was undertaken [10], culminating in 2012 in the mechanical alignment of individual sextupole magnets within vertical tolerances of $\Delta y < \pm 25$ µm [11]. Indirect measurements of the bunch volume by the Touschek lifetime demonstrated vertical emittances below 1 pm rad [11].

The goal of the work presented in [3, 12] was direct measurement of picometre electron beam vertical emittance beams at the AS storage ring.

MEASUREMENT APPROACHES

The flux ratio of the 14$^{\text{th}}$ to 15$^{\text{th}}$ harmonics was measured using the approaches of energy scans, time-averaging and electron beam orbit bumps. These harmonics were selected as they were the highest undulator harmonics (greatest sensitivity to vertical emittance) which were still lower in photon energy than the Au absorption edge cutoff of 2150 eV for the beamline, which arises from Au coatings on the beamline mirrors [13].

* k.wootton@student.unimelb.edu.au
† Present address: SLAC National Accelerator Laboratory, Menlo Park, CA, 94025, USA.

ISBN 978-3-95450-176-2

RECENT PROGRESS IN X-RAY EMITTANCE DIAGNOSTICS AT SPRING-8

S. Takano*, M. Masaki
Japan Synchrotron Radiation Research Institute (JASRI/SPring-8), Hyogo 679-5198, Japan
H. Sumitomo
SPring-8 Service Co. Ltd. (SES), Hyogo 679-5165, Japan

Abstract

At the SPring-8 storage ring, we have recently developed two X-ray instruments for emittance diagnostics. The one for a bending magnet source is the X-ray pinhole camera which directly images the beam profile. A pinhole in the atmosphere is composed of combined narrow X-Y slits made of tungsten. A scintillator crystal is used to convert the X-ray beam image to a visible image. The spatial resolution is about 7 µm. It is operated for continuous emittance diagnostics and coupling correction of user operation of SPring-8. The other for an undulator source is the X-ray Fresnel diffractometry monitor. Monochromatic X-rays are cut out by a single slit, and the vertical beam size is deduced from the depth of the central dip in a double-lobed diffraction pattern. Resolving beam size less than 5 µm is feasible.

INTRODCUTION

Light source rings are competing to achieve lower emittance and emittance coupling ratio for higher brilliance. Serious and elaborate efforts are being paid for upgrade plans of existing synchrotron radiation (SR) rings or new plans of low emittance rings.

X-ray SR is the key diagnostics probe for non-destructive beam emittance [1]. Both direct imaging and interferometric techniques can resolve the micrometer-order transverse beam size. The beam emittance is obtained from the measured beam size with the knowledge of the betatron and dispersion functions and the beam energy spread.

At the SPring-8 storage ring, we have recently developed two X-ray instruments for emittance diagnostics. The one for a bending magnet source is the X-ray pinhole camera which directly images the beam profile. The spatial resolution is about 7 µm. It is operated for continuous emittance diagnostics and coupling correction of user operation of SPring-8. The other for an undulator source is the X-ray Fresnel diffractometry (XFD) monitor [2,3]. Monochromatic X-rays are cut out by a single slit, and the vertical beam size is deduced from the depth of the central dip in a double-lobed diffraction pattern. Resolving beam size less than 5 µm is feasible.

X-RAY PINHOLE CAMERA

The layout of the SPring-8 X-ray pinhole camera is shown in Fig. 1 and the specifications are summarized in Table 1.

The source point is in a dipole magnet (29B2), 1.0 mrad inside from the edge. The magnetic field and the critical photon energy of emitted X-rays is 0.5 T and 21.1 keV, respectively. The X-ray window is located at a distance of 6.2 m from the source point. The window material is aluminium alloy of 3 mm thickness. The window separates the ultra-high vacuum and the atmosphere, and the X-rays emitted in the source dipole magnet go out to the atmosphere.

The pinhole assembly in the atmosphere is located at a distance of 11.4 m from the source. It is composed of

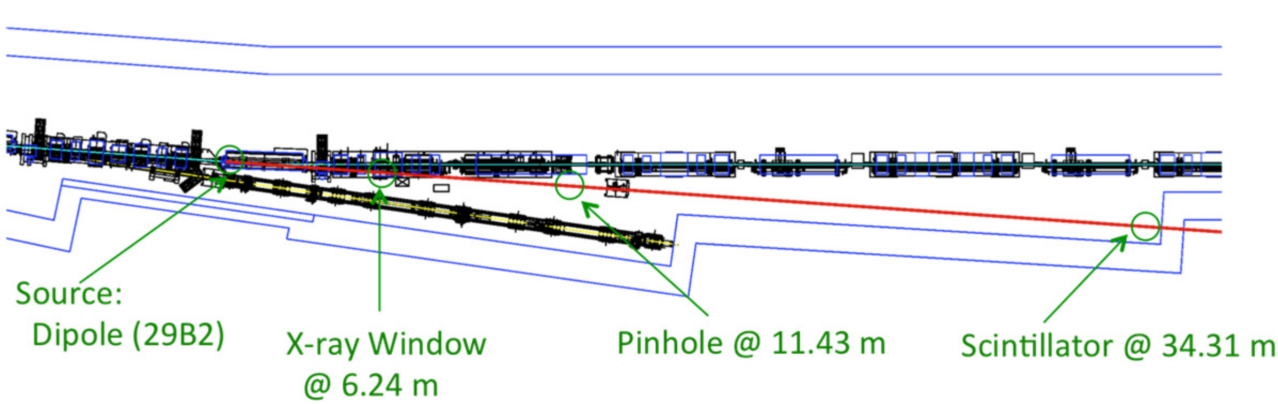


Figure 1: Layout of the X-ray pinhole camera of SPring-8.

*takano@spring8.or.jp

DESIGN OF CORONAGRAPH FOR THE OBSERVATION OF BEAM HALO AT LHC

T. Mitsuhashi#, KEK, Ibaraki, Japan
E. Bravin, R. Jones, F. Roncarolo, H. Schmickler, G. Trad, CERN, Geneva, Switzerland

Abstract

An observation of the beam halo using the coronagraph is planned in LHC in two phases. In the first phase, a coronagraph is designed using some optical components of the coronagraph constructed in KEK in 2005. The diffraction and Mie-scattering backgrounds from optical components near the coronagraph are analysed. Result of this analysis, we can observe a beam halo with a contrast of 10^{-4} range to the peak intensity of beam core. The coronagraph is under construction and will be finished by the end of 2015.

INTRODUCTION

In the LHC, the beam halo can lead to an important beam loss. Measurement of the beam halo distribution is therefore important for understanding and controlling the beam halo. The coronagraph is a spatial telescope to observe the sun-corona by an artificial eclipse [1]. The concept of this apparatus is to block the glare of central image and to observe a hidden image such as the sun-corona. We applied this concept for the observation of the surrounding structure (halo, tail) of the beam core. For this purpose, a coronagraph was constructed at Photon Factory, KEK in 2005 [2]. The project of using the coronagraph for the observation of beam halo image in the LHC will be performed in two phases. We plan an observation test in the first phase where the coronagraph is designed and constructed by modifying the optical design of the KEK coronagraph. This coronagraph is aiming for a halo observation with 10^3 to 10^4 contrast to the beam core, and will be set in B2 optical monitor line. In the second phase an optimum coronagraph will be designed for the LHC, to reach 10^5 to 10^6 contrast. The optical design and diffraction analysis of the coronagraph for phase 1 is described in this paper. Also Mie-scattering from lens surface or optical component in front of the objective lens is discussed and analysed.

THE CORONAGRAPH

The coronagraph was first developed by Lyot for the observation of sun corona without waiting for an eclipse [1]. The optical layout of the coronagraph is illustrated in Fig. 1. The first lens (objective lens) makes a real image of the object (beam image) onto a blocking disk which makes artificial eclipse. The second lens (field lens), located just after the blocking disk, makes a real image of the objective lens pupil onto a mask (Lyot Stop).

The diffraction fringes are re-diffracted by the field lens aperture and transferred to the diffraction fringes on the focal plane of the field lens. The Lyot's genius idea of the coronagraph is to remove the majority of this diffraction fringes by a mask (Lyot stop), and relay the hidden image by a third lens onto final observation plane. By applying a very well polished lens for the objective, we can observe the hidden image with very high contrast (Sun corona has 10^5 contrast to the photosphere). With this coronagraph, we can observe a hidden image surrounding from the bright image of beam core.

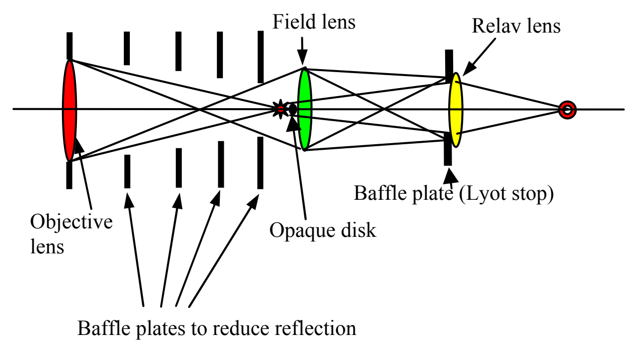


Figure 1: Layout of optical system of the coronagraph.

OPTICAL DESIGN OF CORONAGRAPH FOR PHASE 1

For the first phase, we modified the optical design of coronagraph which was constructed in Photon Factory (PF) in 2005 in KEK [2]. The previous design of the coronagraph is optimized for the conditions at PF as listed in table 1. The same conditions of optical monitor line in B2 of LHC are also listed in table 1.

Table 1: Conditions for Design the Coronagraph at PF and LHC

	PF (BL28)	LHC(B2)
Distance between source point and objective lens	8m	28.5m
Horizontal beam size (1σ of beam core)	263μm	270μm
Vertical beam size (1σ of beam core)	80μm	350μm
Minimum size of opaque disk against beam core	6σ of beam core	5σ of beam core

Modification points of the optical design are 1) the transverse magnification reduction of the objective lens caused by the long distance between the SR source point and the objective lens, 2) Redesigning the re-diffraction system to obtain a larger image of the objective lens for a

toshiyuki.mitsuhashi@kek.jp

FAST ORBIT FEEDBACK SYSTEM AT THE AUSTRALIAN SYNCHROTRON

Y.-R. E. Tan, T. D. Cornall, E. J. Vettoor, A. Michalczyk, N. Basten, SLSA, Clayton, Australia
D. J. Peake, The University of Melbourne, Melbourne, Australia

Abstract

Since the end of commissioning of the facility in 2006, implementing top up (completed 2012) and fast orbit feedback have been top priority upgrades to improve the stability of the light source for users. The fast orbit feedback system is currently being implemented and will be commissioned late 2015. The feedback system has a star topology with an FPGA based feedback processor at its core. The system will utilise the existing 98 Libera Electron beam position processors, with Libera Grouping for data aggregation, as the source of position data at 10 kHz. The corrections are calculated in a Xilinx Vertex 6 FPGA and are transmitted to 14 corrector power supplies in the 14 sectors. These power supplies are six-channel bipolar 1 Ampere and have been developed by a local company. The corrector magnets are tertiary coils on the existing sextupole magnets in the storage ring. This report shall present the design, results of Simulink simulations, the current status of implementation and future plans.

INTRODUCTION

The Australian Synchrotron (AS) is a 3rd generation light what was commissioned in 2006 [1]. The storage ring is a 14 fold symmetric Chasmann-Green lattice with leaked dispersion. In each of the 14 sectors there are 7 beam position monitors (BPMs) giving a total of 98 BPMs [2].

As the technology and techniques on the beamlines mature, their sensitivity to source stability has increased. The stability requirement at the AS is to maintain the transverse beam motion to be less than 10% of the beamsize at the source. The tightest constraint on the beam motion is at the insertion device straights where the beamsize is the smallest. With the nominal configuration (optics) the one sigma beamsize is 320 μm horizontally and 16 μm vertically at 1% emittance coupling and 5 μm for the natural coupling of 0.1%. The integrated motion at the insertion device straights is shown in Figure 1 where in the vertical plane the beam motion exceeds 10% of the vertical beamsize of 16 μm at 100 Hz.

The fundamental requirement for the fast orbit feedback (FOFB) system is to reduce the beam motion to less than 10% of the beamsize up to 100 Hz [3]. To achieve this the system was designed to try and meet a closed loop bandwidth of 300 Hz. However as shall be shown this was always going to be challenging. The second design requirement was to, where possible, reuse the existing infrastructure and equipment. The following sections will introduce the design of the system, the results of simulation studies, the different subsystem and the current state of the project.

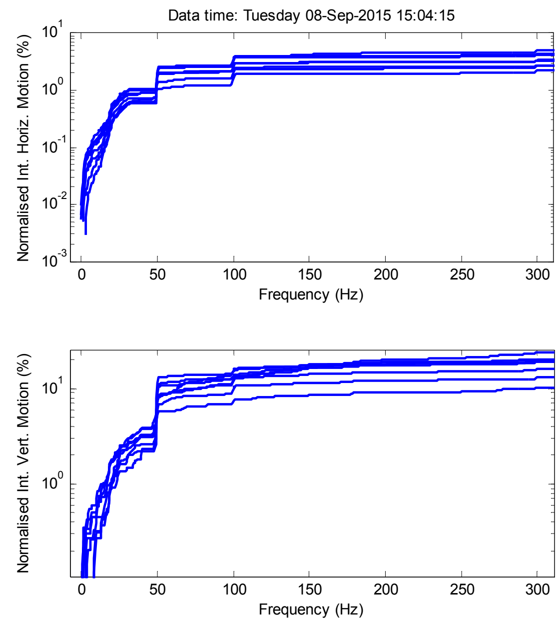


Figure 1: Integrated beam motion at all insertion device straights normalised to the beamsize in percent (320 μm and 16μm). The largest contributor to the perturbation on the beam is the 50 Hz mains frequency. At 100 Hz the integrated beam motion in the vertical plane exceeds 10%.

DESIGN

The design of the system can be broken down into 3 sub-systems as shown in Figure 2: (1) beam position measurement and aggregation, (2) feedback controller and (3) corrector magnets and power supply.

Beam Position Measurement

The beam position in the storage ring is measured using Instrumentation Technologies' Libera Electron beam processor. The processors have a real-time stream of position data at 10 kHz (Fast Acquisition data) and are aggregated across the 98 BPMs by using Libera Grouping [4]. The topology of Libera Grouping implemented here is a single a ring with one level of redundancy. The Libera Electrons transmit 98 horizontal and 98 vertical positions at a rate of 10 kHz via UDP using a GbE link.

Feedback Controller

The feedback controller receives the data, decodes packet information and translates this into corrector current values using an inverted BPM-Corrector response matrix. In the first instance the controller will be a single

ISBN 978-3-95450-176-2

ADVANCEMENTS IN THE MANAGEMENT MEASUREMENTS & VISUALISATION OF NEC BEAM PROFILE MONITORS

D. Button#, D. Garton, M. Mann, ANSTO, Lucas Heights, Australia
S. Yan, National Instruments, Macquarie Park, Australia

Abstract

In DC ion beam tandem accelerator facilities commonly Helix Rotating wire Beam Profile Monitors/scanners (BPM) are used to monitor the shape and location of the ion beam. These BPMs are used in combination with a BPM Selection station which activates and conditions signals visualisation on an Oscilloscope. At ANSTO we have been developing an alternative system to allow firstly the management and operation of concurrent National Electrostatics Corp (NEC) BPMs, secondly to construct a 2D approximation of the particle beam parameters based on programmable hardware and software, and thirdly to give advanced functionality to control systems. This paper will review the current status of the development, and the potential features which can be gained with this technological approach.

BACKGROUND

Beam Profile Monitors BPMs are an important diagnostic device used during the tuning of electrostatic ion beam accelerator particle beams. These provide effectively real-time information back to the operator to indicate the location of the beam and the X and Y intensity profile of the beam. There are generally two types of these monitors/scanners used in DC electrostatic ion beam facilities, the oscillating Y-Shaped wire scanner manufactured by HVEE, and the helix rotating wire scanner manufactured by NEC (see Fig.1). The NEC rotating helix wire scanner is the subject of this paper and development.

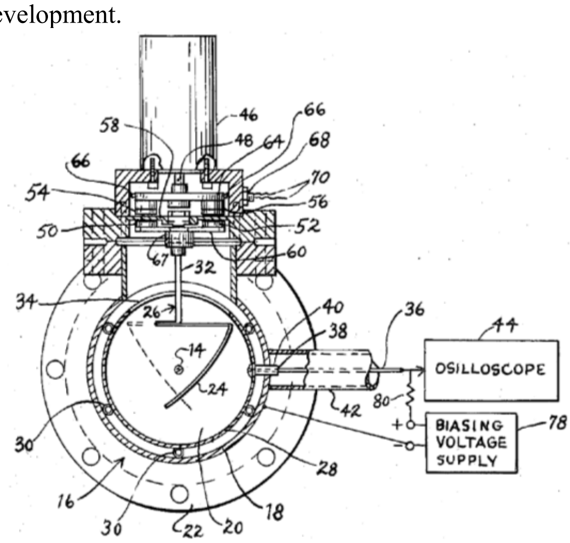
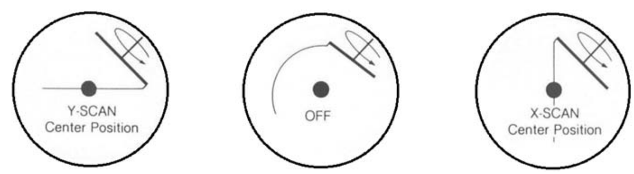


Figure 1: Original general assembly drawing of the NEC BPM taken from the 1971 patent application [1].

dbu@ansto.gov.au

Principle of NEC BPM Operation

The NEC BPM uses a helix shaped wire attached to a rotating disc as shown in Fig. 2, this disc rotates which due to the geometry of the system has a pseudo effect of sweeping the wire through the cross-section of beam firstly in the Y direction, and then the wire sweeps through the X direction, see Fig. 2(a,c). The shaft on the axis of rotation has magnets attached at known positions that a stationary sensor/coil pick-off produces an analogue stream of pulses. These pulses are used to indicate firstly the start of a rotation cycle (Fig. 3(1)), the wire passing the centre of the Y axis (Fig. 3(2)), and the wire passing through the centre of the X axis (Fig. 3(3)), these are referred to as the "Fiducial" markers, see Fig. 3.



(a) (b) (c)

Figure 2: The rotating axis of the helix wire as indicated in (a-c) is setup at an angle of 45° to the horizontal plane. (a) shows the wire "sweeping" through the pseudo Y plane of the beam as the wire is effectively horizontal through this part of the rotation, (b) the wire is free of intersection/interacting with the beam, (c) the "sweeping" motion through the pseudo X plane of the beam as the wires direction is effectively vertical in this part of the rotation [2].

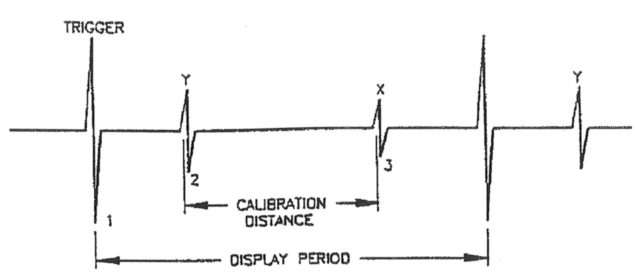


Figure 3: Shows the fiducial markers produced during the rotation of the helix wire shaft (see Fig. 1(26)) [3]. The larger trigger pulse indicates the start of the rotation followed by the Y centre marker, and finally the X centre marker, as the shaft continues to rotate the same pattern continues during operation.

ISBN 978-3-95450-176-2

IMPEDANCE OPTIMIZATION OF SIRIUS STRIPLINE KICKER

H.O.C. Duarte*, S.R. Marques, LNLS, Campinas, Brazil

Abstract

Two approaches to design a transverse feedback (TFB) stripline kicker are well known in the accelerators community: one with bare strips in a tapered cavity and other whose shrouded strips are ended with parallel-plate capacitive gaps. This work presents a comparison between both models in terms of electromagnetic performance, proposes alternative solutions for increasing the gap capacitance and analyzes the performance of a hybrid stripline kicker design.

INTRODUCTION

Studies of collective beam instabilities for Sirius, the 3 GeV light source under construction in Brazil [1], have shown the need of the transverse bunch-by-bunch (BBB) feedback system in the storage ring since day one [2]. For the longitudinal plane, at least for the initial phases, the use of BBB feedback system is not planned since superconducting RF cavities will be used.

The digital signal processing for the BBB system will be performed by the front/back-end and iGp processor units from Dimtel, Inc. [3] and the actuators will be one $\lambda/2$ stripline kicker for each plane. A $\lambda/4$ stripline tune monitor is also planned.

This contribution describes the evolution of the stripline kicker design for Sirius. At first, several concepts were tested regarding their transverse geometric factor and longitudinal coupling impedance. Then the best suited geometry was optimized following the compromise between the reflection parameter at the input coaxial ports and the geometric loss factor of the structure. Shunt impedance was also evaluated and finally the mechanical project and thermal simulation results are shown.

GEOMETRY ALTERNATIVES

The electromagnetic design evolution for Sirius stripline kicker was carried out by analysing three different concepts to further optimize the longitudinal impedance spectrum and the reflection parameters of the chosen one. GdfidL [4] was used for the electromagnetic simulations.

Transverse 2D Analysis

All presented stripline geometries can be grouped in either of these two transverse profiles: Bare Strip and Shrouded Strip designs, whose dimensions are shown in Fig. 1. While solving the 2D Laplace's equation for an electric boundary condition (BC) characterizes the odd mode, which is the kicker operation mode, the solution for a magnetic BC would give the field distribution for the even mode [5]. Both profiles in Fig. 1 had their geometry parameters set to match a 50 Ω characteristic impedance (i.e., 25 Ω for the full structure containing two electrodes). An impedance mismatching can impact the beam coupling impedance [6] and the port signal reflection.

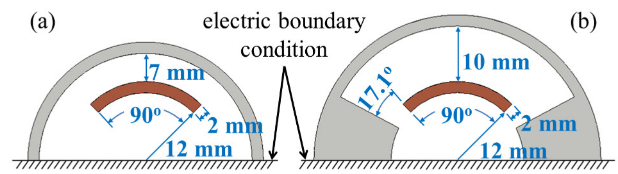


Figure 1: The considered transverse profiles for the vertical striplines: a) Bare Strip and b) Shrouded Strip designs.

From the mentioned 2D electrostatic analysis one can also determine the transverse geometric factor $g_\perp$. For the Bare Strip (Fig. 1a) and Shrouded Strip designs (Fig. 1b), $g_\perp$ is equal to 1.09 and 1.01 respectively. The geometric factor allows determining the transverse beam impedance [5]:

$$Z_\perp(k) = \frac{g_\perp^2 Z_{ch,\perp}}{kr^2}[\sin^2(kL) + j\sin(kL)\cos(kL)] \quad (1)$$

where k is the wave number, $Z_{ch,\perp}$ the full structure characteristic impedance for the odd mode (25 Ω), r the stripline inner radius (12 mm) and L the stripline lenght, which determines the kicker operation bandwidth (BW). Choosing $L = \lambda/2 = 30$ cm provides 250 MHz shunt impedance BW [7], which is enough for correcting Sirius transverse coupled-bunch instabilities (CBMIs) [8] since Sirius RF frequency is ~500 MHz. The shunt impedance can be calculated by [5]

$$R_{sh}^{\perp} = \frac{4 \times \Re e Z_\perp(k)}{k} \quad (2)$$

For a kicker, the shunt impedance is an important parameter since it quantifies its efficiency relating the injected power with the kick energy absorbed by the beam. Given that both transverse profiles in Fig. 1 only differ by the geometric factor, it is straightforward to see in Eq. 1 that a transverse kicker with Bare Strip transverse profile is 16.5% more efficient than one with the Shrouded Strip design type. However, the stripline ends affect other aspects of the kicker and a three-dimensional analysis must be performed for a satisfactory characterization.

Longitudinal 3D Analysis

Figure 2 shows the simplified geometries for the simulation models of three different stripline concepts. The Tapered Cavity Stripline is the design approach considered by NSLS-II [9]. Its adapted model consists of bare strips (see Fig. 1a) placed inside a 1/15 linearly tapered cavity that reaches the 24 mm diameter vacuum chamber profile

* henrique.caiafa@lnls.br

ISBN 978-3-95450-176-2

MULTIFUNCTION INSTRUMENT DESIGNS WITH LOW IMPEDANCE STRUCTURES FOR PROFILE, ENERGY, AND EMITTANCE MEASUREMENTS FOR LEReC AT BNL*

T. Miller†, M. Blaskiewicz, A. Fedotov, D. M. Gassner, D. Kayran, J. Kewisch, M. Minty, I. Pinayev, P. Thieberger, J. Tuozzolo, Collider-Accelerator Dept., BNL, Upton, NY, 11973, U.S.A.

Abstract

The low energy RHIC electron cooling (LEReC) upgrade project [1], being installed over the next two years will require a low impedance beam line so that the soft 1.6MeV electron beam will not be perturbed by induced electromagnetic fields, especially in the instrumentation chambers. Novel designs of the Profile Monitors, Emittance Slit Scanners and BPMs are presented along with Particle Studio simulations of the electron beam wake-field induced electric potentials. The design of a new instrument incorporating a button beam position monitor (BPM) and YAG screen profile monitor in the same measuring plane is presented as part of a method of measuring beam energy with an accuracy of 10^{-3}.

INTRODUCTION

In support of the Beam Energy Scan Phase-II physics program, in search of the QCD critical point and verification of several QCD models [2], a bunched beam electron cooler based on a SRF LINAC is being developed with operation planned for 2018-19. Effective cooling of the low energy Au ion beams below 20 GeV can be accomplished by co-propagating low energy electron beams of 1.6 – 5.0 MeV [2]. With the portion of this new electron machine sharing vacuum space with RHIC, an aggressive design and installation schedule has been set forth to allow the installation of the cooling section components, as shown in Fig. 1, during this year's 2015 shutdown. This has accelerated the design and fabrication of specialized beam instrumentation components for measurements such as profile, position, emittance, energy and energy spread. A key critical requirement of these components is that this instrumentation present minimal impedance to the electron beam; thereby minimizing the effects of longitudinal wake fields to preserve the strict requirements on intrabunch longitudinal beam energy spread An impedance budget of 5.0 V/pC has been set for the entire beamline. As a result, all beam line elements will be evaluated for their impact on this budget.

This low impedance requirement has necessitated the specialized design of the vacuum chambers within which YAG crystals are held for profile measurements, emittance slit masks are scanned for slice emittance measurements, and capacitive pick-up electrodes are mounted for position monitoring. These three chamber types, supporting instruments in the cooling section, were designed to minimize the rate of change of the beam transport aperture; thereby minimizing perturbations in the beam's wake field that can set up oscillating electromagnetic fields and in turn impacting the quality of the beam. Modeling in Particle Studio [3] has led to a refining of the chamber design resulting in a balance of lowest possible induced electric potentials within the chamber against a minimum compromise of the beam aperture to support insertion components and viewing ports.

Finally, the optimized profile monitor design was combined with a newly designed BPM chamber to produce a new hybrid device capable of using optical beam measurement techniques to calibrate integrated BPM pick-ups for better than 50µm absolute position accuracy. This high level of absolute accuracy is provided by the use of BPMs upstream and downstream of and in conjunction with the 180° dipole magnet between cooling sections to make absolute beam energy measurements to an accuracy of 10^{-3}.

Beam Parameters

The electron beam has a nested pulse structure, as previously illustrated [1], so that 120 ps bunches at 705MHz are grouped in macro bunches and positioned to overlap with the RHIC ion beam. These macro bunches (and ion bunches) are spaced at 9.1 MHz and grouped into a train of macro bunches. The train length is one turn around RHIC with a gap between consecutive trains that aligns with the RHIC abort gap. Other key parameters of the electron beam are listed in Table 1.

Table 1: Electron Beam Parameters in the Cooling Section

Parameter	Value
Energy	1.6 – 5 MeV
Bunch Charge	100 – 300 pC
Macro bunch Charge (γ_{ion} = 4.1–10.7)	3 – 5.4 nC
Average beam current	30 – 50 mA
Bunch / Macro bunch Rep Rates	704 / 9.1 MHz
Bunch Length	37 mm
Max. Allowable Energy Spread (Δp/p)	5×10^{-4}
Beam trans. size	σ = 3.84 mm

† tmiller@bnl.gov

*Work supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. DOE

ISBN 978-3-95450-176-2

BEAM DIAGNOSTICS OF THE LIPAC INJECTOR WITH A FOCUS ON THE ALGORITHM DEVELOPED FOR EMITTANCE DATA ANALYSIS OF HIGH BACKGROUND INCLUDING SPECIES FRACTION CALCULATION

B. Bolzon#, N. Chauvin, S. Chel, R. Gobin, F. Senée, M. Valette, CEA, Gif-sur-Yvette, France
K. Shinto, JAEA, Rokkasho Fusion Institute, Rokkasho, Japan
J. Knaster, Y. Okumura, IFMIF/EVEDA Project Team, Rokkasho, Japan

Abstract

To prove the technical feasibility of the IFMIF accelerators concept, the EVEDA phase will commission in Japan the LIPAC accelerator, which will deliver a 125 mA/9 MeV CW deuteron beam. LEDA already managed 100 mA in CW at 6.7 MeV in 2000. The different subsystems of LIPAC have been designed and constructed mainly by European labs with the injector developed by CEA-Saclay. This injector must deliver a 140 mA/100 keV CW deuteron beam at 99% D^+ ratio, which is produced by a 2.45 GHz ECR ion source. The low energy beam transport line (LEBT) is based on a dual solenoid focusing system to transport the beam and to match it into the RFQ. The normalized RMS target emittance at the RFQ entrance is targeted to be within 0.25π mm·mrad. This article describes the diagnostics installed in the LEBT to measure beam parameters such as intensity, profile, emittance, species fraction and degree of space charge compensation. The article also focuses on the algorithm developed to analyze emittance data of high background from an Allison scanner. Species fractions (D^+, D_2^+, D_3^+) using mass separation technique were also calculated during the on-going commissioning campaign with the Allison scanner installed between the two solenoids in a first stage.

INTRODUCTION

The IFMIF project (International Fusion Materials Irradiation Facility) will generate a neutron flux of 10^{18} $m^{-2}s^{-1}$ with a broad energy peak at 14 MeV in order to characterize and study candidate materials for future fusion reactors. To reach such a challenging goal, two parallel deuteron accelerators of 5 MW each will deliver a high intensity D^+ beam of 2 x 125 mA CW (Continous Wave) at 40 MeV against a liquid lithium target [1]. In the present final phase before construction, called EVEDA (Engineering Validation and Engineering Design Activities), a 125 mA/9 MeV CW deuteron demonstrator accelerator called LIPAc (Linear IFMIF Prototype Accelerator) is being assembled, commissioned and will be operated in Rokkasho [2, 3]. LIPAc has been designed and constructed mainly in European labs with participation of JAEA in the RFQ couplers. It is composed of a deuton injector delivered by CEA-Saclay [4], a Radio Frequency Quadrupole (RFQ) [5] to be delivered by INFN, eight superconducting half-wave resonators (SRF Linac) designed by CEA-Saclay [6], Medium and High energy beam transfer lines and a beam dump designed by CIEMAT.

The injector is composed of a 2.45 GHz ECR ion source based on the CEA-Saclay SILHI source design [7] and a LEBT line that will transport and match the beam into the RFQ. After acceptance tests performed at CEA-Saclay [8, 9], it has been shipped to Japan in 2013 and is currently under commissioning in Rokkasho [10, 11]. According to requirements, the D^+ beam injected into the RFQ must be 140 mA/100 keV CW with a normalized RMS emittance lower than 0.30π mm·mrad (with a target value of 0.25π mm·mrad). Under these conditions, simulations demonstrated that the deuteron beam can be accelerated to 5 MeV by the RFQ with less than 10% losses in order to reach the specified 125 mA CW. This paper details the different beam diagnostics available in the LEBT, not only during this commissioning phase, but also during operation. A particular focus is made on the validation of the algorithm developed to analyze data of high background from an Allison scanner in order to compute emittance and determine species fraction ratio (D^+, D_2^+, D_3^+) extracted from the ion source.

BEAM DIAGNOSTICS IN THE LEBT

The LEBT consists of an accelerator column (containing the ion source extraction system), two solenoids with integrated H/V steerers, a diagnostic box located between the solenoids and an injection cone located just upstream the RFQ. During the injector commissioning, a specific diagnostic box, equipped with a beam stopper designed to handle a 15 kW beam, is placed after the injection cone. To minimize the emittance growth driven by the high beam space charge, the LEBT length has been minimized to 2.05 m from the plasma electrode to the internal face of the RFQ entrance. In such a short line and due to the radiation environment induced by the D-D fusion reactions from beam losses and deuterium adsorbed in the beam pipe walls, only few diagnostics can be installed: Charge Injection Device (CID) cameras, a deported spectrometer beyond the shielding walls via a radiation hardened optical fiber, an Allison scanner, a Four Grid Analyser, an ACCT and a movable beam stopper have been selected to characterize the beam during commissioning and operation.

A 3D view of the LIPAc injector with its dedicated beam diagnostics is shown on Fig. 1.

#benoit.bolzon@cea.fr

ISBN 978-3-95450-176-2

A NEW BEAM ANGLE INTERLOCK AT SOLEIL

N. Hubert#, Y-M. Abiven, L. Cassinari, L. Chapuis, F. Dohou, M. El-Ajjouri, A. Loulergue, L.S. Nadolski, O. Marcouillé, P. Monteiro, D. Pédeau, P. Rommeluere, Synchrotron SOLEIL, Gif-sur-Yvette, France

Abstract

Anatomix and Nanoscopium beamlines are collecting photons generated by two 5.5 mm gap in-vacuum insertion devices installed in a canted straight section. Simultaneous operation of those two beamlines requires particular precautions in terms of alignment of the electron (and photon) beam in the undulators. With the high stored beam current (500 mA), any mis-steering in the upstream undulator could quickly damage the downstream one. Using the classical beam position interlock to guarantee the undulators protection would have constrained too much the operation due to very restrictive position thresholds. Then the machine protection system has been modified to incorporate a new interlock based on the electron beam angle combining two adjacent BPM readings. A description of the system and its performances will be presented.

INTRODUCTION

SOLEIL [1] is the French third generation synchrotron light source located south of Paris. It delivers photon beams to the users since 2008 is shown in Table 1. Today the 2.75 GeV facility has received more than 20,000 users. A total of 27 beamlines (BLs) take beam on a daily basis.

Table 1: Main SOLEIL Storage Ring Parameters

Parameters	Values
Circumference	354 m
Energy	2.75 GeV
Maximum current	500 mA
Revolution period	1.18 µs

Among them two recently constructed long (160 m) beamlines Anatomix and Nanoscopium bring challenges in term of operations. Both BLs use in-vacuum undulators (IVU) as radiation sources that are installed in the same canted straight section. The configuration at SOLEIL is specific since a 12 m long straight section has been transformed and equipped with a strong horizontal chicane for beam separation and a quadrupole triplet for optics adaptation to allow the host of two 5.5 mm minimum gap insertion devices [2]. Their point sources are 6.75 m away (Fig. 1) and make the first undulator a potential hazard for the downstream IVU in term of power deposition. Therefore the radiation angle issued from the upstream insertion has to be precisely and continuously watched for in order to prevent any radiation hitting the NiCu liner sheet of the downstream IVU.

#nicolas.hubert@synchrotron-soleil.fr

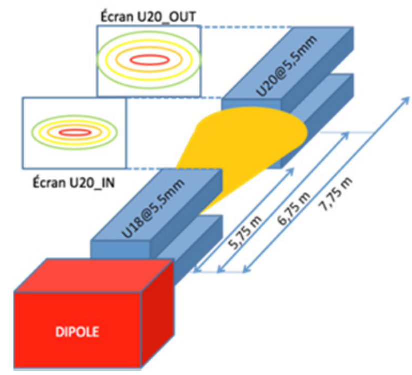


Figure 1: Schematics of the two insertion devices for Anatomix and Nanoscopium beamlines on the same (canted) straight section. In case of mis-steering of the beam in the upstream undulator, radiations may damage the downstream one.

Unfortunately SOLEIL experienced once this issue in 2011: the downstream undulator lower liner sheet was strongly damaged during the first simultaneous gap closing with a 500 mA stored beam leading to the removal of this insertion. Inadvertent mis-steering of the electron beam was aggravated by a wrong vertical offset of the undulator jaws with respect to the beam trajectory. This undulator has then been replaced, and thorough studies were carried out to prevent any such situation to occur again. One of the findings was that the electron beam trajectory in the upstream undulator has to be very carefully aligned and maintained within limits below what was earlier expected so that produced photons pass right into the centre of the downstream one. One of the mandatory steps before allowing again the simultaneous use of the two insertion devices at their minimum gap was an upgrade of the machine protection system (MPS) to protect the device from any accidental beam mis-steering during operation. This will permit simultaneous operation of insertions during the fall of 2015 for an intermediate configuration of the gaps (with gap values respectively 8 and 5.5 mm of the first and second IVUs).

The fastest and easiest way to do that would have been to reduce the vertical position thresholds (currently +/- 300 µm) of the already existing beam position interlock [3] for the two BPMs on each side of the upstream undulator. This would have led to +/-50 µm new threshold values too much constraining for the day-to-day operation (high probability of fake interlocks and strong impact on the beam availability). As a consequence, it has

ISBN 978-3-95450-176-2

DIGITAL PROCESSING OF PICK-UP SIGNALS FOR POSITION AND TUNE DETERMINATION

R. Singh, A. Reiter, P. Forck and P. Kowina, GSI, Darmstadt, Germany

Abstract

With the advent of fast high resolution Analog to Digital Converters (ADCs) and Field Programmable Gate Arrays (FPGAs), "all digital systems" for pick-up data processing to determine position and tune have become commonplace. This contribution compares the frequently used position estimators used in the digital systems in terms of measurement variance, bias and robustness to external interference. An analytical beam model, along with simulated pick-up signal and actual pick-up signal from the SIS-18 synchrotron are used for the comparison. The effect of precise position estimation on the tune spectra is discussed.

INTRODUCTION

High precision position estimation requires the optimization of the beam position measurement system in all the stages of development, which starts from EM simulations to optimize the pick-up design against unwanted resonances, establishing linearity while minimizing the cost of manufacturing [1]. The mechanical construction and installation of pick-ups with respect to the magnetic center of magnets within the specified tolerances is also a challenging task. Finally, the electronics required for acquisition and processing of the pick-up signals demand low noise and high dynamic range as well as periodic and precise calibration. The typical methods for signal processing and calibration are described in [2–4]. In the recent years, the signal processing have completely shifted to digital domain due to availability of fast high resolution ADCs and FPGAs and this contribution will focus on this aspect of position measurement system for circular accelerators.
The concepts of pick-up position sensitivity and offset are presented along with the typical signal spectra for bunched and coasting beams in the next couple of sections. Following that, the frequently used digital position estimation methods are discussed and a new approach to position estimation based on "linear regression model" is introduced. All the presented methods are compared with an analytical beam model, simulated beam data and the pick-up signal from the SIS-18 synchrotron in terms of estimated position bias and variance. The effect of position estimation methods on tune spectra calculated from the turn-by-turn position is discussed.

POSITION SENSITIVITY AND OFFSET

The pick-up position sensitivity and offset estimates are obtained from the EM simulations [5] or on-bench wire based measurements [6, 7]. The uncertainty in the position sensitivity measurement is given by the precision of the measurement equipment used for bench measurements and simulation time/resources which are often < 0.1% of absolute values as shown in [5, 8]. In careful pick-up designs, the pick-up sensitivity is found to be constant within 0.1% of the absolute sensitivity value in the frequency region of interest [5]. Once the pick-up sensitivity and offset are known, the beam center-of-mass can be determined from the difference of the signal induced on opposite pick-up plates. There are two important features of pick-up signal which are relevant for digital position estimation a) Most of the pick-up types are "capacitive" or AC coupled, which leads to rejection of the DC component of the beam signal and b) The signal is sampled with fast ADCs such that many samples are acquired in each time interval for the position measurement. Thus the problem of position estimation is that of an overdetermined system whose low frequency components are significantly suppressed. The lower cut-off is given by the termination impedance of the pick-up [2].

PICK-UP SIGNAL SPECTRUM

The pick-up signal spectrum of a ring accelerator is unique due to the periodic crossing of beam particles through the pick-up. A beam of particles traversing the synchrotron or

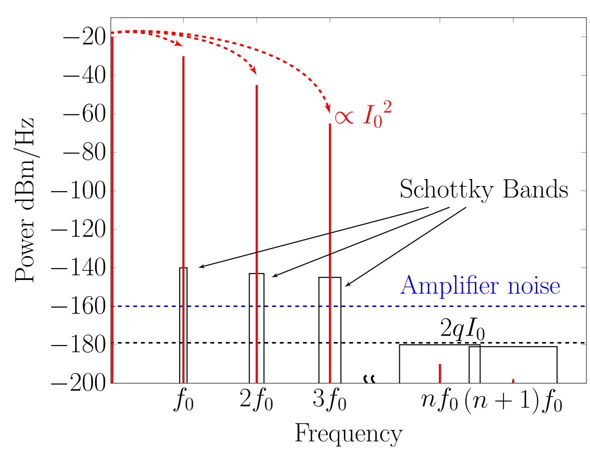


Figure 1: A bunched beam power spectrum of a U^{28+} bunched beam with 10^9 particles at injection energy in SIS-18. $2qI_0$ is the shot noise level while blue dashed line represents the electronics noise. The Schottky bands are shown for reference.

storage ring with a constant energy is referred to as coasting beam. The beam is said to have no coherent longitudinal structure due to absence of any longitudinal focusing. However, due to finite momentum spread, finite number of particles and periodic traversal of particles through the BPM, signals proportional to the square root of number of particles are induced at the revolution frequencies. The power in each revolution band is given by $2qI_0$, where q is the charge

ISBN 978-3-95450-176-2

MICRON-SCALE VERTICAL BEAM SIZE MEASUREMENTS BASED ON TRANSITION RADIATION IMAGING WITH A SCHWARZSCHILD OBJECTIVE

L.G. Sukhikh*, A.P. Potylitsyn, A.V. Vukolov, Tomsk Polytechnic University, Tomsk, Russia
S. Bajt, G. Kube, DESY, Hamburg, Germany
I.A. Artyukov, P.N. Lebedev Physical Institute, Moscow, Russia
W. Lauth, Institute for Nuclear Physics, Johannes Gutenberg University, Mainz, Germany

Abstract

This report presents preliminary results of a measurement of a micron–scale vertical beam size based on imaging of optical transition radiation in the visible region. The visualization of point spread function dominated beam images was carried out using a Schwarzschild objective that provides high magnification and that is free of some of aberrations. According to the preliminary data treatment, a vertical rms beam size of 1.37 ± 0.07 μm was measured at the 855 MeV beam of the Mainz Microtron MAMI (Germany).

INTRODUCTION

Optical Transition Radiation (OTR) is generated when a charged particle crosses the boundary between two media with different optical properties. It is an important tool for beam diagnostics, mainly for transverse profile beam imaging in modern linear accelerators. OTR in backward direction is generated directly at the screen boundary in an instantaneous process with a linear response and a rather high light output. The radiation is emitted in the direction of the specular reflection in a small lobe with an opening angle which is defined by the beam energy. Unfortunately, the diffraction limit of the optical system imposes a limitation that makes the method ineffective for reliable diagnostics of micron–scale beams in modern accelerators.

The point spread function (PSF) defines the minimum beam size that can be resolved using OTR. The PSF was investigated for the first time by M. Castellano and V.A. Verzilov [1] and later in more details by A.P Potylitsyn [2], D. Xiang and W.-H. Huang [3] and by G. Kube [4]. It was shown that the PSF has a double lobe structure which is defined by the observation wavelength and the acceptance of the optical system. The minimum beam size that can be measured using OTR with a wavelength of 400 nm and a reasonable optical system is about 3 μm.

In principle it is possible to overcome the limitation by decreasing the observation wavelength used for the beam imaging. A proof–of–principle experiment that demonstrated the possibility to image beam profiles using backward transition radiation (BTR) in the Extreme Ultraviolet (EUV) region at $\lambda \simeq 20$ nm was published in [5].

In the case of small beams and OTR in the visible region, it is possible to obtain PSF dominated images that at the first glance could be treated as convolution of the PSF with the beam profile. In this situation, beam size information could be extracted as it was shown in [6–8]. In [6, 7], the authors used a thin lens as the main part of the optical system, and in the experiment described in [8] imaging was performed by a spherical mirror. Such optical schemes resulted in a decrease of the resolution because of aberrations, especially due to spherical and chromatical ones. In the present report we describe an experiment devoted to PSF dominated beam imaging using a Schwarzschild objective that is free of this kind of aberrations [9].

* sukhikh@tpu.ru

EXPERIMENTAL SETUP

The experiment was carried out at the 855 MeV electron beam of the Mainz Microtron MAMI (Institute of Nuclear Physics, Johannes–Gutenberg–University, Mainz, Germany). The quasi–continuous beam of the racetrack microtron (mean beam current 52 nA) was operated in macro–pulse mode with a pulse duration of 0.8 s in order to allow CCD frame readout in the gaps in between.

Figure 1 shows a scheme of the experimental setup. A set of targets was mounted onto a motorized stage which allowed rotational and linear motion across the beam axis in horizontal and vertical direction. The target set consisted of Mo and Al single layer targets, a Mo/Si multilayer target which was optimized to generate 20 nm wavelengths, two wire–scanners (10 μm thick and 4 μm thick tungsten wires), and a LYSO:Ce scintillator. The electron beam interacted with the target, generating OTR in a wide spectral range, and the beam spot was imaged using this OTR with

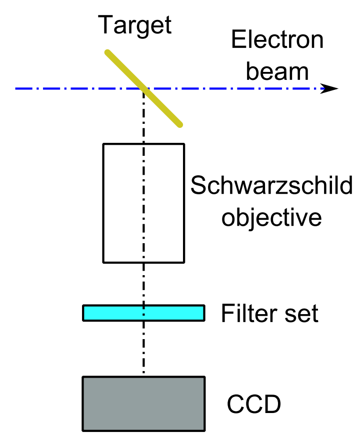


Figure 1: Experimental setup.

ISBN 978-3-95450-176-2

TRANSVERSE BEAM PROFILE IMAGING OF FEW-MICROMETER BEAM SIZES BASED ON A SCINTILLATOR SCREEN

G. Kube, S. Bajt, DESY, Hamburg, Germany
A.P. Potylitsyn, L.G. Sukhikh, A.V. Vukolov, Tomsk Polytechnic University, Tomsk, Russia
I.A. Artyukov, P.N. Lebedev Physics Institute, Moscow, Russia
W. Lauth, Institut für Kernphysik, Mainz, Germany

Abstract

Standard beam profile measurements of high–brightness electron beams based on optical transition radiation (OTR) may be hampered by coherence effects induced by the microbunching instability which render a direct beam imaging impossible. As consequence, for modern linac based 4^{th} generation light sources as the European XFEL which is currently under construction in Hamburg, transverse beam profile measurements are based on scintillating screen monitors. However, the resolution of a scintillator based monitor is limited due to intrinsic material properties and the observation geometry. In this report, a beam size measurement in the order of a few micrometer is presented using a LYSO scintillator, and discussed in view of the possible achievable resolution.

INTRODUCTION

Transverse beam profile diagnostics in electron linacs is widely based on optical transition radiation (OTR) as standard technique which is generated when a charged particle beam crosses the boundary between two media with different dielectric properties. Unfortunately, microbunching instabilities in high–brightness electron beams of modern linac–driven free–electron lasers (FELs) can lead to coherence effects in the emission of OTR, thus rendering it impossible to obtain a direct image of the particle beam. The observation of coherent OTR (COTR) has been reported by several facilities (see e.g. Ref. [1]), and in the meantime the effect of the microbunching instability is well understood [2]. In order to allow beam profile measurements in the presence of the instability, transition radiation based imaging in the EUV spectral region was successfully tested [3,4]. An alternative concept is to use scintillation screens because the emission of the scintillation light is a stochastic process from many atoms which is completely insensitive to the longitudinal bunch structure. A comprehensive overview over scintillating screen applications in particle beam diagnostics is given e.g. in Refs. [5, 6].

In a series of test measurements performed in the past few years, the applicability of inorganic scintillators for high resolution electron beam profile measurements was investigated [7, 8]. Most notably, the dependency of the resolution on the scintillator material and on the observation geometry was studied with respect to resolve beam profiles in the order of several tens of micrometers. Based on these measurements, high resolution screen monitor stations were designed for the European XFEL which is currently under construction at DESY in Hamburg (Germany) [9]. Prototype monitors of this type are successfully in operation since about two years at the FLASH2 undulator beamline of the free-electron laser user facility FLASH at DESY [10]. These monitors use a 200 μm thick LYSO screen as scintillator.

The objective of the present study was to investigate the achievable resolution for micrometer beam sizes. For this purpose, scintillator based beam size measurements were performed at the 855 MeV beam of the Mainz Microtron MAMI (University of Mainz, Germany) which are presented in the following. Based on these measurements, the dependency of the beam size sensitivity on different experimental parameters was studied theoretically using a simple model to describe the scintillator influence.

EXPERIMENT AND DATA TAKING

The experiment was performed at the 855 MeV electron beam of MAMI with a beam current of about 250 pA. Fig. 1 shows a sketch of the experimental setup. The surface of

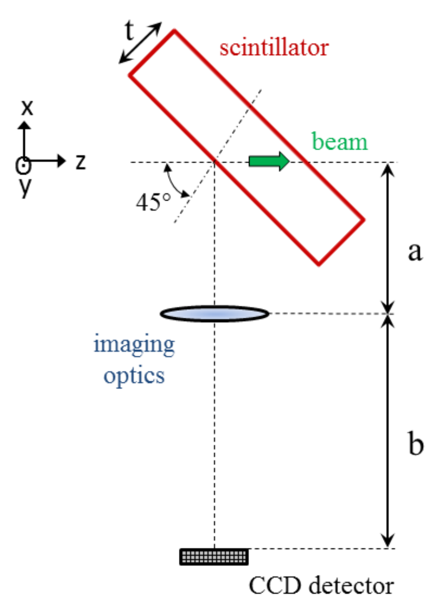


Figure 1: Sketch of the experimental setup (not to scale). The scintillator surface is rotated by 45 deg around the y–axis, observation is performed under 90 deg with respect to the beam axis.

ISBN 978-3-95450-176-2

DEVELOPMENT STATUS AND PERFORMANCE STUDIES OF THE NEW MICROTCA BASED BUTTON AND STRIP-LINE BPM ELECTRONICS AT FLASH 2

Bastian Lorbeer*, Nicoleta Baboi, Hans-Thomas Duhme, Frank Schmidt-Foehre, Kay Wittenburg
DESY, Hamburg, Germany

Abstract

The FLASH (Free Electron Laser in Hamburg) facility at DESY (Deutsches Elektronen-Synchrotron) in Germany has been extended by the new undulator line FLASH 2 providing twice as many experimental stations for users in the future [1] . After the acceleration of the electron bunch train up to 1.2 GeV in FLASH, a part of the beam can be kicked into FLASH 2, while the other is going to the old undulator line of FLASH 1. The commissioning phase started in early 2014 and continues parasitically during user operation in FLASH 1. One key point during first beam commissioning is the availability of standard diagnostic devices such as Beam Position Monitors (BPMs) [2]. In the last couple of years new electronics for button and strip-line BPMs have been developed, based on the MTCA.4 standard [3–6]. This new Low Charge BPM (LCBPM) system is designed to work with bunch charges as small as 100 pC in contrast to the old systems at FLASH initially designed for bunch charges of 1 nC and higher. This paper summarizes the development status of the new BPM system and discusses the results of resolution studies of the BPM system.

INTRODUCTION

The demand for beam time at the user facility FLASH increased substantially in the past. In order to fulfill this need the facility has been extended by a new undulator beam line for SASE generation called FLASH2. The desired charges for FLASH 1 and FLASH 2 can be adjusted separately from two laser systems. FLASH2 has seen the first beam on 4th March 2014 and was able to provide SASE (Self Amplified Spontaneous Emission) for the first time on 20 August 2014 [7, 8]. This was done simultaneously to SASE delivery in FLASH1. The electron beam delivered to FLASH2 is accelerated together with the beam for FLASH 1 within the same RF (Radio Frequency) pulse to up to 1.2 GeV after approximately 150 m from the gun and is then kicked....Part of the diagnostics in FLASH2 are button and strip-line monitors at 16 locations in the machine utilizing new MTCA.4 electronics designed at DESY [3–6]. Challenges in the development of this system are the single-bunch resolution requirement of 50 µm, operation at charges below 100 pC and a high bunch repetition rate of up to 4.5 MHz. These requirements were chosen to be compatible with the requirements for the European XFEL [9]. The development status and resolution studies of the BPM system are summarized in this paper.

* bastian.lorbeer@desy.de

MACHINE AND SYSTEM OVERVIEW

The new FLASH2 undulator beam line runs in parallel to the old FLASH1 undulator beam line as it can be seen in Figure 1. It is divided into several sections namely EXTRACTION, SEED, SASE, BURN, and DUMP. Button and strip-line monitors are installed in different locations.

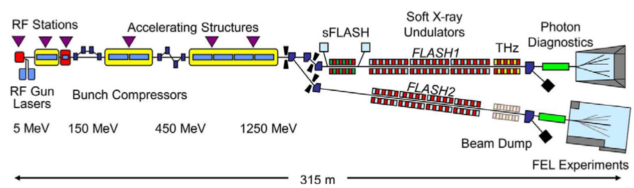


Figure 1: Section overview FLASH.

Most of the LCBPMs are distributed along the EXTRACTION section at the beginning of FLASH2 with nine BPMs. Four BPMs are in the BURN/DUMP section. Due to space limitations in the SASE section three button BPMs have been installed here as well instead of using the more preferable cavity BPMs which offer the required resolution for orbit tuning in the SASE section [10, 11]. A variety of different beam pipe diameters for the button BPMs and a few refurbished strip-line BPMs, with different RF cable lengths ranging from 35 to 58 m, required the development of a very robust but also flexible BPM electronics. Table 1 summarizes all types of BPMs for which the electronics are currently in operation. Electromagnetic field simulations [12] delivered the monitor constants. The button type concept is similar as for the European-XFEL that has been reported in [13], while the strip-line monitors are an old design described in [14].

Table 1: Types of Beam Position Monitors Installed in FLASH2 and Corresponding Monitor Constants

Type	amount	Beam Pipe	Monitor constant
button	2	40 mm	10.6 mm
button	4	34 mm	9.06 mm
button	3	100 mm	23.84 mm
strip-line	4	44 mm	8.678 mm
in-air	1	100 mm	31.25 mm
button	3	10 mm	2.55 mm

An overview of a BPM system can be seen in Figure 2.

The beam excited RF signals in the horizontal and vertical plane respectively are combined after a delay of 100 ns to suppress interference with the next bunch in the train. This so-called Delay Multiplex Single Path Technology (DM-

ISBN 978-3-95450-176-2

DEVELOPMENT OF NEW BEAM POSITION MONITORS AT COSY

F. Hinder*, F. Trinkel, IKP, Forschungszentrum Jülich, 52425 Jülich, Germany
H.-J. Krause, PGI-8, Forschungszentrum Jülich, 52425 Jülich, Germany
H. Soltner, ZEA-1, Forschungszentrum Jülich, 52425 Jülich, Germany
for the JEDI collaboration†

Abstract

The existence of permanent Electric Dipole Moments (EDMs) of fundamental particles would violate parity and time reversal symmetry. Assuming the CPT-theorem, this leads to CP violation, which is necessary to explain the matter over antimatter dominance in the Universe. Thus, a measurement of a non-zero EDM would be a hint to new physics beyond the Standard Model. The JEDI collaboration (Jülich Electric Dipole moment Investigations) has started investigations towards a direct EDM measurement of protons and deuterons at a storage ring. To measure an EDM signal, systematic effects have to be controlled with high precision. One way of studying systematic effects is the use of new Beam Position Monitors (BPMs) based on a Rogowski coil as a magnetic pick-up. The main advantage of such coil is their high response to an RF signal, i.e. the particle bunch frequency, and their compactness. In a first step the BPMs have been benchmarked in a laboratory test system. In the next step the calibrated BPMs have been installed and tested at the storage ring COSY (Cooler Synchrotron) at Forschungszentrum Jülich. First measurement results are presented.

INTRODUCTION

The JEDI collaboration investigates the feasibility of measuring EDMs of charged particles, namely protons and deuterons, in the magnetic storage ring COSY [1, 2]. The method of choice is the usage of an RF Wien Filter to introduce a build-up of the vertical polarization, which is proportional to the EDM of the particle [3, 4]. A measurement of the orbit is necessary to control systematic effects, which contribute to a polarization build-up which is not related to the EDM [5]. The existing orbit control system, including electrostatic BPMs [6, 7], has to be improved to reduce systematic effects. One step of this improvement is an update of the existing BPM readout electronics [8]. In addition, new BPMs are being developed. These BPMs are magnetostatic pick-ups in a Rogowski coil configuration [9]. In industry the Rogowski coil is a well known device to measure alternating currents (ACs). The primary concept of a torus wound with a wire to measure the current, is modified towards a device which measures the centroid of the current. The spatial sensitivity is reached by winding the torus in parts and measuring the induced voltages in these parts. One advantage of the new device is its thickness of 1 cm compared to the length of the existing BPMs of 13 cm. Due to its small dimension the BPM can be installed at various places in the storage ring.

* f.hinder@fz-juelich.de
† http://collaborations.fz-juelich.de/ikp/jedi/index.shtml

DESIGN OF ROGOWSKI PICK-UP COILS

The presented concept is based on the idea of determining the position of the beam by measuring the magnetic field induced by the particle flux. The developed Rogowski coil BPM consists of a torus with the following geometric parameters:

- Radius of the torus $R = 40$ mm
- Radius of the tube $a = 5$ mm.

The tube of the torus is wound with one layer of cooper wire with a diameter of 150 μm. The geometric form of the wiring determines the field of application. A full winding is sensitive to the AC beam current going through the torus. Cutting the wiring into two equal halves leads to a measurement of the beam position in one direction of the transversal plane. Dividing the wiring into four segments allows to determine the beam position in both directions of the transversal plane. Figure 1 shows the Rogowski coil in a halved and a quartered configuration. The depicted coordinate system is used in the following mathematical derivation. The two halves of the coil are labeled R and L. The four quarters are labeled R, U, L and D.

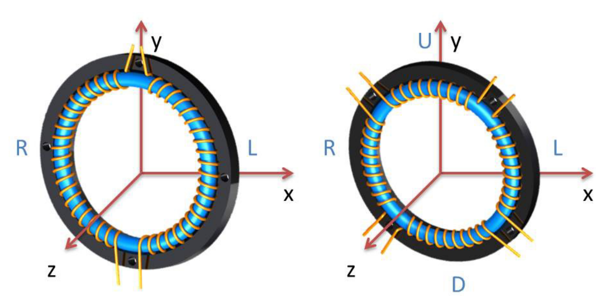


Figure 1: Half and quarter wound Rogowski coils in our coordinate system. The configuration shown on the left hand side permits a position measurement in x-direction. The configuration shown on the right hand side facilitates a measurement of the beam displacement in both directions: x and y.

Magnetic Field of the Particle Beam

The beam current assumed to be a pencil current in z direction perpendicular to the torus. The position with respect

ISBN 978-3-95450-176-2

UPGRADE OF THE BEAM PROFILE MONITORING SYSTEM IN THE INJECTION BEAM LINE OF COSY

K. Reimers, C. Böhme, R. Gebel, A. Halama, V. Kamerdzhiev,
Forschungszentrum Jülich, Germany
J.L. Conradie, M.A. Crombie, H.W. Mostert, iThemba LABS, South Africa

Abstract

The cyclotron Julic is used as an injector for the COSY synchrotron and storage ring of 183 m circumference. The 93 m long injection beam line (IBL) transports polarized and unpolarized H^-/D^- ions which are injected into the ring via multi-turn stripping injection. 8 profile monitoring stations are installed in the IBL. Each station contains two harps having 39 wires at 1mm spacing. Each harp is read out by a multichannel pico-amperemeter module designed by iThemba LABS, South Africa, delivering profile data to the COSY control system. The technical details of the upgrade and recent beam profile measurements are presented.

INTRODUCTION

The cooler synchrotron COSY shown in Fig. 1 is operated at the Nuclear Physics Institute at the Forschungszentrum Jülich. It delivers high precision beams of protons and deuterons for experiments in the momentum range of 290 to 3850 MeV/c.

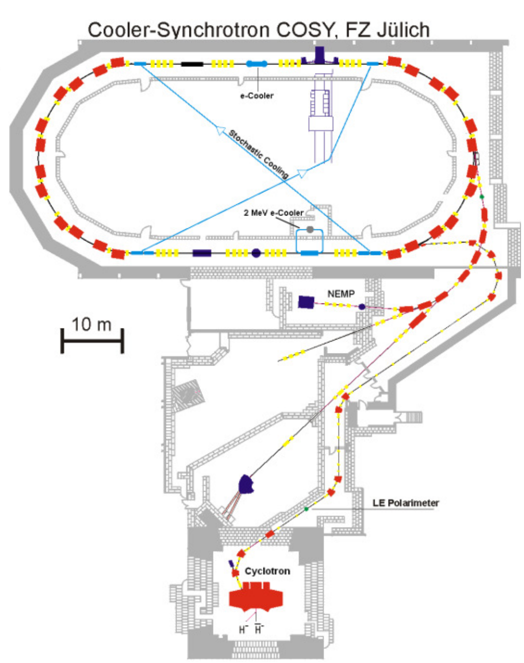


Figure 1: Layout of the COSY accelerator facility. For clarity only a few insertion devices are shown.

Injection and Beam Cycle

A typical COSY machine cycle consists of injection of particles from the cyclotron into the ring, beam acceleration and storage. Injection momentum is 293 MeV/c for H^- and 538 MeV/c for D^- ions. The shortest cycle at COSY is the test cycle with duration of 2 s. This cycle just contains the injection without acceleration. Injection of particles into the COSY ring is gated by the so called macro-pulse of typically 5-20 ms duration. Only during this time interval beam profiles in the IBL are measurable. The macro-pulse signal therefore is used to trigger the beam profile measurement.

IBL Beam Instrumentation

Figure 2 shows the COSY IBL consisting of 4 bent and 4 straight sections with an overall length of 93 m. Phase probes and harps are installed in the IBL for longitudinal and transverse beam diagnostics. This paper deals with transverse beam diagnostics only. The harps allow the detection of beam shape, beam position and intensity.

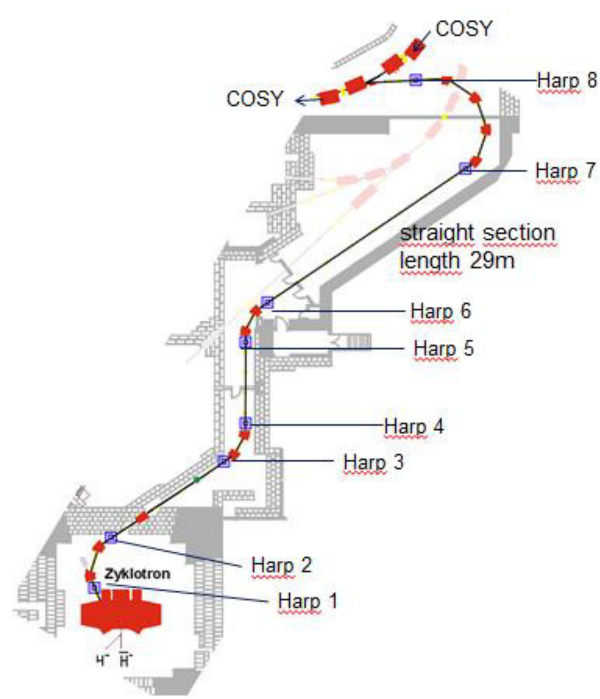


Figure 2: Distribution of harp stations in the IBL.

ISBN 978-3-95450-176-2

STUDIES FOR A BPM UPGRADE AT COSY

C. Böhme, M. Bai, F. Hinder, V. Kamerdzhiev, F.Trinkel
Forschungszentrum Jülich, Germany

Abstract

For the planned Electric Dipole Moment (EDM) precursor experiment at the COoler SYnchrotron (COSY) synchrotron and storage ring an accurate control of the beam orbit is crucial. The required beam position measurement accuracy demands an upgrade of the Beam Position Monitor (BPM) readout electronics. The BPM system currently in operation is described. The required performance and the possible upgrade scenarios are discussed.

INTRODUCTION

The COoler SYnchrotron (COSY) of the Forschungszentrum Jülich is a 184 m long racetrack-shaped synchrotron and storage ring for protons and deuterons from 300 MeV/c (protons) or 300 MeV/c (deuterons) up to 3.65 GeV/c. Built in are devices for stochastic as well as electron cooling. The stored ions can be polarized or unpolarized. Commissioned in 1993, some of the components are not only outdated, but start failing while spare parts for repair are hard to acquire. In addition, for the planned EDM [1] precursor experiment a higher beam position measurement accuracy is needed than can be reached with the used components. Therefore different upgrade scenarios are investigated.

CURRENT STATUS

COSY is equipped with 30 shoebox-style BPMs. During commissioning 27 BPMs of two types were installed, a cylindrical type with 150 mm diameter and a rectangular type 150 mm · 60 mm [2]. The selection was made to fit into the beam pipe, which is round in the straight sections and rectangular in the arcs in order to fit into the dipole magnets. Later on 3 BPMs were added, with special geometries to fit within the beam pipe of a different diameter close to experiments, giving a total number of 30. 2 of them are installed within the recently added 2 MeV electron cooler [3] and use their own electronic for readout, which is different from the others. One of them at the ANKE experiment, which uses a standard readout hardware. All other BPMs are read out by the same type of electronics [4], whose concept is shown in Figure 1. The readout electronic for each BPM, except for the pre-amplifiers, is housed in one VXI crate, consisting of 2 analog modules, 2 digital modules, one CPU, and one timing receiver. The pre-amplifiers are directly connected to the N-type vacuum feedthrough of the pick-ups. This pre-amplifier has a fixed gain of 13.5 dB with an input impedance of 500 $k\Omega$ and a bandwidth of 100 MHz. The gains and offsets of two pre-amplifiers have to be exactly matched for one plane of one BPM in order to avoid incorrect measurements. The preamplified signals are then fed into an analog module, where sum and delta signals are produced

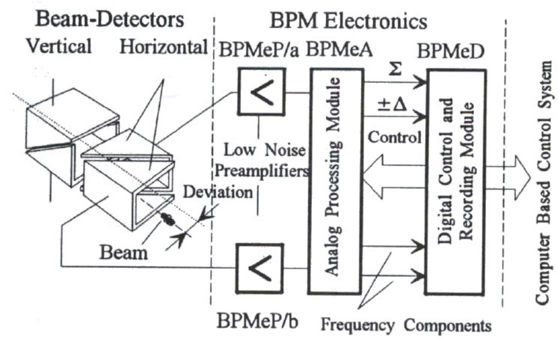


Figure 1: Current Beam Position Monitor electronics assembly [4].

using a hybrid. These signals are then treated separately and can be further amplified in 6 dB steps from 0 dB to 66 dB. Both the sum and the delta branches have two signal paths. A narrowband path features 3 possible filter settings with bandwidths of 10 kHz, 100 kHz, or 300 kHz and an additional amplifier that can be set from 0 dB to 18 dB in 6 dB steps. The broadband path with 10 MHz bandwidth can be used for turn-by-turn measurements while the narrowband signals are used for closed orbit measurements. The analog outputs are unipolar, the sign of the narrowband delta signal is detected separately and the information is transmitted by a separate TTL signal line. After the analog signal processing the signals are digitized in a digital module. This is done using 20 MHz 8 bit ADCs. For the narrowband signal the sampling frequency is lowered to 1 MHz or 100 kHz, depending on the selected analog bandwidth. For the sum signal only 7 of the 8 bits of the ADC are used, the 8th bit is used to indicate the polarity of the delta signal. The digital module generally has the possibility to buffer 4096 data points, while few modules can store up to 32768 data points for turn-by-turn measurements. The CPU of the VXI crate then calculates out of the narrowband signal the beam position using a scaling factor for the specific BPM geometry. It is also possible to transfer the raw data to the control system, display and export it.

LIMITATIONS OF THE CURRENT HARDWARE

First, the position measurement is highly dependent on the pre-amplifiers used for the two pick-up electrodes of one plain having identical characteristics, even better than usual production variations of electronic components. Therefore, at the time of construction, extensive tests have been performed to figure out identical pairs of the produced pre-amplifiers. Recent tests of selected pairs showed that the matching of the pairs is still good, even after years of opera-

ISBN 978-3-95450-176-2

COMPACT AND COMPLETE BEAM DIAGNOSTIC SYSTEM FOR HCI AT IUAC

R.V.Hariwal, [1, 2, #] H.K.Malik, [2] R. Mehta, [1] S.Kedia, [1] and V. Verzilov [3]
[1]Inter-University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi, India
[2]Plasma Waves and Particle Acceleration Lab, Department of Physics, I.I.T Delhi, India
[3]Accelerator Division, TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C., Canada

Abstract

Design efforts result into the fabrication of a compact and complete beam diagnostic system for High Current Injector (HCI) accelerator system [1] at Inter-University Accelerator Centre (IUAC), New Delhi, India. HCI is an upcoming accelerator facility and will be used as an injector to the existing SC-LINAC. It consists of high temperature superconducting Electron Cyclotron Resonance (HTS-ECR) ion source [2], normal temperature Radio Frequency Quadrupole (RFQ), IH-type Drift Tube Linear (DTL) resonators [3] and low beta superconducting quarter wave resonator cavities to accelerate heavy ions having A/q ≤ 6. The diagnostic system is especially designed and fabricated to get the complete beam information like current, profile, position, transverse and longitudinal emittances, bunch length and energy of incident ion beam at the entrance of DTL resonators. The compactness is preferred to minimize the transverse and longitudinal emittance growth at the entrance of DTL resonators. Various beam parameters of heavy ion beams at different energy have been carried out to validate the design and fabrication of the system. Here, the design, fabrication and various test results are presented.

DIAGNOSTIC SYSTEM FABRICATION

Compact Diagnostic System

A compact diagnostic box in Fig.1 is made of 10 mm thick stainless steel material. As the drift space between two DTL cavities is crucial, to accommodate the diagnostic chamber and quadrupole triplet, we need to minimize the drift. A highly compact diagnostic chamber has been designed and fabricated indigenously at IUAC. The diagnostic chamber is of 70 mm longitudinal length. The radial dimension of the box is approximately 160 mm and the beam aperture is 20 mm. The diagnostic box is circular in shape. There are four ports available in the box. Three will be used for Faraday cup, slit scanner and capacitive pick-up. One is left for pumping purpose. The chamber was leak tested at the leak rate of $1x10^{-11}$ mbar.l/s. Without any separate pumping station, the vacuum of $1x10^{-7}$ mbar was achieved, but this can be further improved by adding a separate pumping station.

Faraday Cup

A water cooled Faraday cup (FC) has been fabricated to measure the current. The cup has a beam aperture of 25 mm and its length is 20 mm along the beam direction (Fig. 2). It is made of Oxygen Free High Conductivity (OFHC), copper material. Based on the expected beam power from HCI the FC is designed for few hundred watts of beam power. The suppressor ring, which retains the secondary electrons on the cup, is made of SS 304 material. The FC is completely shielded by the 3 mm thick tantalum sheet. The linear movement of FC is controlled by a pneumatic cylinder, which provides the 60 mm strokes in the diagnostic box.

#hariwal@gmail.com

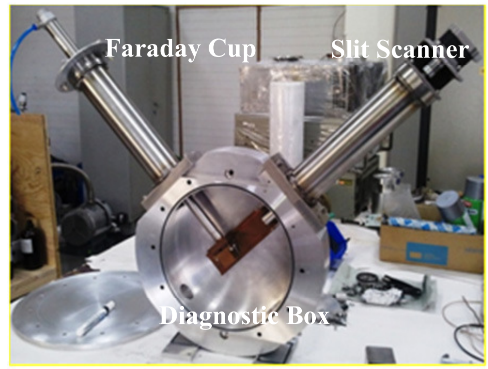


Figure1: Compact diagnostic box.

Figure 2: Faraday cup.

It can be used to measure the current of the order of few nanoamperes to hundreds of microampere current.

Slit Scanner

The slit scanner in Fig. 3 is fabricated indigenously for the measurements of beam positions and beam profiles in HCI beam line. It scans the beam in two transverse directions with the help of two 500 micron slits. The slits are made orthogonal to each other and moves linearly in such a way that they cut the ion beam in x and y directions. The linear motion of the slit scanner is done by a computer controlled stepper motor. The microcontroller programming and data processing have been done with the help of LabVIEW programs. It is possible to see the online beam profiles on the two dimensional graphs of the beam intensity versus the beam positions.

ISBN 978-3-95450-176-2

DESIGN AND DEVELOPMENT OF CONFIGURABLE BPM READOUT SYSTEM FOR ILSF

M. Shafiee[1,2], J.Rahighi, M.Jafarzadeh, [1]ILSF, Tehran, Iran
A.H.Feghhi, [2]Shahid beheshti University, Tehran, Iran

Abstract

A configurable electronic system has been developed for button BPMs readout in the storage ring of Iranian Light Source Facility (ILSF). This system calculates the beam position through the output voltage of BPMs. Output signals of BPMs pass through a 500 MHz and 50ohm front-end for noise filtering and also gain control purposes. Then the signal is digitized based on under sampling method by a 130MHz ADC for further analysis in FPGA. Safe dynamic range of 0dBm to -90 dBm can be covered by this electronic system with white noise measured to be around -110dBm. Trigger for this electronic is 2-10Hz as Slow data acquisition for Slow orbit feedback system and 4-10 KHz as Fast data acquisition for fast orbit feedback system. This paper describes the design, analysis, and measurements of the developed electronic system.

INTRODUCTION

The Iranian Light Source Facility (ILSF) is a 3 GeV third generation synchrotron light source facility which is in design stage [1]. In diagnostics group, we have designed different instrument and fabricated some prototypes. Since Beam Position Monitors (BPMs) are the most frequently used non-interceptive diagnostic in particle accelerators [2], we have designed and developed BPM and its readout system. To monitor closed orbit, It is needed to employ 160 BPMs around the storage ring of ILSF. Important criteria in the design of BPMs are to have the intrinsic resolution of less than *1um*, to have as highest and as flattest transfer impedance as possible, to have less higher-order mode (HOMs) resonances, and excellent impedance matching which will result in well-separated bunch by bunch signals with high signal-to-noise ratio [3]. Fig. 1 shows BPM design and vacuum chamber schematic at ILSF.

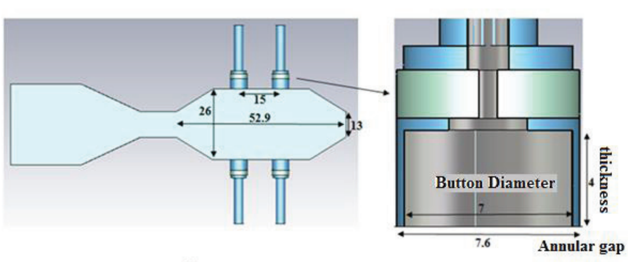


Figure 1: (a) Location of BPMs around vacuum chamber (b) Button BPM structure. All units are in mm.

To simplify BPM parameters calculation, a code was developed in C# [4]. After optimization of BPM design, we have designed and developed a new BPM readout system to improve important parameters of high precision, high speed and high digital processing capability. The developed BPM readout system consists of three parts: the analog front-end, the mixed-signal and the digital circuit. In the analog front-end circuit, each RF input signal is filtered and amplified individually by using two successive accurate IF-band passband filters, and two voltage gain controllers (VGAs) which has been implemented based on combination of attenuators and accurate narrowband amplifiers. Then the four filtered and amplified signals are fed to the mixed-signal section of the circuit to be digitized with high sampling rate and with low noise. Therefore, we used four accurate high speed ADCs and under-sampled the signal using accurate clock signals generated using LVDS clock distributors. Then the digital output and synchronization signals are fed through the FMC connector connected to the main signal processing module (digital circuit). In FPGA (ML605) buffers implemented to transfer raw data to PC by Ethernet for further calculation and analyses in MATLAB [5].

After laboratory tests of this system, final tests were done using the real beam in ALBA. The tests showed precision and resolution of 1 micro meter.

BPM FOR THE ILSF STORAGE RING

As mentioned high sensitivity, high transfer impedance and less parasitic and coupling impedance are the desired features of BPM Design in ILSF. To achieve these features, a code was developed to calculate parameters of BPM such as sensitivity, intrinsic resolution and power dissipation vs bandwidth and current.

It is known that less annular gap causes less parasitic impedance, HOM resonances at higher frequency, and more capacitance. In general more capacitance is equal to less parasitic losses, then increasing it by increasing thickness of button and decreasing annular gap can be helpful. Larger button diameter causes more sensitivity but also increase risk of thermal noise through beam dissipation power on longer button and somehow mechanical deviation at button [6]. Fig. 2,3 shows calculated parameters of designed BPM by using developed code. Fig. 2 shows that BPM sensors supposed to have linear response for almost 10 mm displacement. Fig. 3 also shows induced power on buttons for different

ISBN 978-3-95450-176-2

LONG-TERM STABILITY OF THE BEAM POSITION MONITORS AT SPRING-8

T. Fujita#, H. Dewa, M. Masaki, S. Matsubara, S. Sasaki, S. Takano,
Japan Synchrotron Radiation Research Institute (JASRI/SPring-8), Hyogo, Japan
H. Maesaka, Y. Otake,
RIKEN SPring-8 Center, Hyogo, Japan

Abstract

Stability of the BPM system is critical for synchrotron light source rings to keep the quality of photon beams and to stabilize the photon beam axes. The BPM system of SPring-8 has suffered from fluctuating gain imbalances among 4 electrode channels, which results in variations of offsets for beam position measurement. We recently surveyed the logged data of the BPM and the operating environment, and revealed several features of variations of the offset errors of the BPM. To cure step variations of the offsets, inspections of switch modules of the readout circuit are necessary. For variations correlated with the dew point of the environment, we consider that a possible cause is change of reflection coefficients in the BPM cables damaged by radiation. Further investigations are necessary to find the causes of other variations of the BPM offset errors.

INTRODUCTION

For synchrotron light source rings, accuracy of the BPM system is crucial for the quality of the source electron beam. Elaborate efforts are paid for calibration of BPM offsets including pre-installation bench calibration, survey at installation and beam-based alignment after commencement of operations. Stability of the BPM system is even more important as it is critical to keep the quality of photon beams and to stabilize the photon beam axes as well.

The BPM system of the SPring-8 storage ring has suffered from fluctuating gain imbalances among four 4 electrode channels. A major origin of the imbalances is voltage standing waves in the cables of the BPM caused by reflections at locations with impedance mismatching. While the imbalances are routinely corrected in accordance with a beam-based measurement [1] for several time per year, they fluctuate during the operation periods and result in variations of offsets for beam position measurements. Fluctuating BPM offset errors could degrade stability of the beam orbit and the photon beam axes.

Stability of the BPM system would be affected also by mechanical and electrical stability of the components comprising the BPM system, vacuum chamber and supporting girder of BPM, signal cables and readout electronic circuits. In order to find and cure the causes of variations of offset errors of the SPring-8 BPM system, we recently surveyed extensively the logged data of the BPM and the operating environment, such as the temperature and the dew point (DP).

SPRING-8 BPM SYSTEM

The SPring-8 storage ring consists of 48 cells and six BPMs are regularly placed in each cell. The totals of 288 BPMs are processed at 24 stations of BPM readout circuit. The electrode of the BPM is button-type and four buttons are placed in skew positions. Signal from each button electrode is transferred from the accelerator tunnel to the BPM circuit outside the tunnel through 3 coaxial cables connected; 2.5-m long flexible "a-cable", ~25-m long low loss "b-cable" and 5-m long flexible "c-cable". A block diagram of the BPM circuit is shown in Fig. 1 [2]. The circuit employs multiplexing method. Three BPMs are processed by one common channel comprised of an RF amplifier, a mixer, an IF amplifier and an ADC. A reference signal supplied for the frequency down-converter is delivered from a master oscillator through a phase-stabilized optical fiber cable, which is commonly used for 12 BPMs from two cells.

Beam positions at each BPM are continuously calculated with a repetition of 1 kHz and sent to a ring-buffer on a DSP board. The position data sampled by 1 kHz can be used for analyses of the orbit fluctuations and of error source position at sudden beam loss. Slow position data averaged for 600 ms are sent to a control workstation for routine global orbit correction with 1 Hz repetition [3]. Typical resolution of the averaged position data is 0.1 μm (rms).

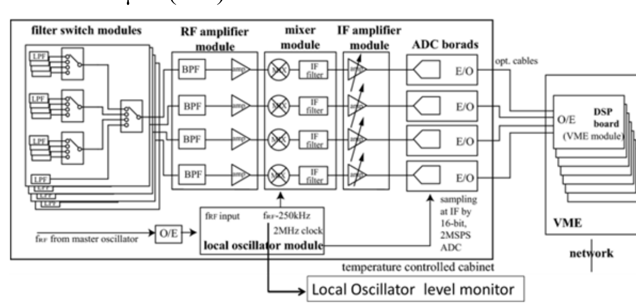


Figure 1: Block diagram of the SPring-8 BPM circuits.

#tfujita@spring8.or.jp

ISBN 978-3-95450-176-2

CHARACTERIZATION OF THE SR VISIBLE BEAM POLARIZATION STATE AT SPEAR3†

Chunlei Li[1], Jeff Corbett[2] and Toshiyuki Mistuhashi[3]
[1]East China University of Science and Technology, Shanghai, China
[2]SLAC National Accelerator Laboratory, Menlo Park, USA
[3]KEK, Tsukuba, Japan

Abstract

Synchrotron radiation has the well-known property of horizontal field polarization in the midplane with increasingly elliptical polarization in the vertical plane. By measuring the beam intensity transmitted through a linear polarizer, it is possible to characterize the beam polarization state, determine the Stokes' parameters and solve for the beam polarization ellipse in the visible portion of the SR spectrum. The results can be compared with Schwinger's equations for synchrotron radiation taking into account the effect of extraction mirrors.

INTRODUCTION

Synchrotron radiation (SR) has both partially-coherent and fully-polarized electromagnetic field properties, each used for a wide range of scientific research. With the advent of high-power, short-pulse free-electron lasers, applications depending on the spatial beam coherence are growing at a rapid rate. Similarly elliptically polarized x-rays have become an increasingly powerful tool to study magnetic dichroism and chirality at both storage rings and FEL facilities [1]. The large vertical opening angle of visible light in the diagnostic beam line at SPEAR3 provides a unique opportunity to study both the transverse spatial coherence [2] and electromagnetic polarization state of the beam [3].

The polarization state in particular can be characterized by measuring beam power transmitted through a polarizer oriented at systematic angles with respect to the x-y beam axis. In this way is it possible to obtain 'slice' measurements of the beam polarization ellipse which can be combined to represent the beam polarization state in terms of the Stokes parameters [3,4].

To cross-check the measurements we compare with Schwinger's equations for the SR field [5]. These 'classical' equations express the horizontal and vertical field intensities $E_x^2(\omega,\psi)$and $E_y^2(\omega,\psi)$ in terms of radiation frequency ω and, conveniently, vertical observation angle ψ. For SR the relative phase difference between E_x and E_y is $\pm\delta=\pi/2$ at all emission angles depending on whether the observer is above (+) or below (-) the midplane, and $E_x \neq E_y$ so the radiation is i general elliptically polarized. Using the SPEAR diagnostic beam line it is possible to measure an calculate the SR polarization state in the visible ligh regime as a function of vertical observation angle.

†Work sponsored by U.S. Department of Energy, Office of Basic Energy Sciences under Contract No. DE-AC02-76SF00515 and the China Scholarship Council.
corbett@slac.stanford.edu

MEASUREMENT SYSTEM

Figure 1 shows a plan view of the SPEAR3 diagnostic beam line. The beam line contains a horizontal 'cold finger' to block the on-axis hard x-ray SR component followed by a rhodium-coated mirror to horizontally reflect visible dipole radiation into the diagnostic laboratory. The cold finger blocks ±0.6 mrad of the beam at the midplane and the surrounding apertures have an acceptance of 3.5 mrad x 6 mrad. A pair of near-incidence Aluminum mirrors is used to reject any stray x-ray Compton scattering and align the SR beam with the optical bench. An image of the 60mm x 100mm unfocused visible SR beam showing the shadow of the cold finger at the measurement station is seen in Fig. 2.

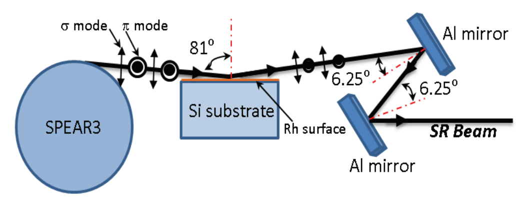


Figure 1: Plan view of the diagnostic beamline.

For the beam polarization measurements, we constructed a remote-controlled scanning system rotatable polarizer, 532nm bandpass filter (BP) and power meter on a continuous-motion vertical stage [6]. An insertable quarter waveplate (QWP) optically matched the bandpass filter is used to determine helicity of the to elliptically polarized light.

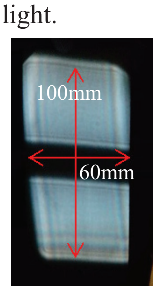


Figure 2: Unfocused visible SR Beam.

As shown in Fig. 3, the polarizer was installed on a computer controlled rotation stage (Newport URS50BPP) to adjust the polarizer axis.

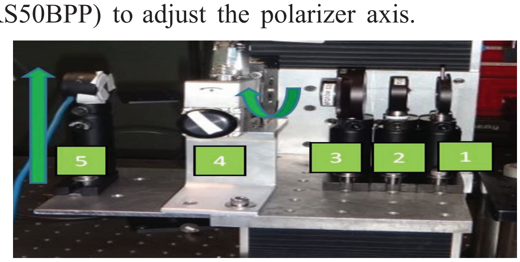


Figure 3: Measurement apparatus: 1-iris, 2-BP filter, 3-quarter wave plate, 4-polarizer, 5- power meter.

ISBN 978-3-95450-176-2

HIGH POSITION RESOLUTION BPM READOUT SYSTEM WITH CALIBRATION PULSE GENERATORS FOR KEK e+/e- LINAC

F. Miyahara#, K. Furukawa, M. Satoh, Y. Seimiya, T. Suwada, KEK, Tsukuba, Ibaraki, Japan
R. Ichimiya, JAEA, Rokkasho, Aomori, Japan
H. Saotome, KIS, Tsuchiura, Ibaraki, Japan

Abstract

The KEK e+/e- injector linac will be operated in multiple modes for the electron beam injection to three independent storage rings, the SuperKEKB HER, Photon Factory (PF) Ring and the PF-AR, and the positron beam injection into the damping ring and the SuperKEKB LER. The beam current ranges between 0.1 and 10 nC/bunch. The beam current depends on the beam mode. The operation modes can be switched every 20 milliseconds. The injector linac is under upgrade for the SuperKEKB, where the required resolution of beam position measurement is less than σ=10 μm. However, the current beam position monitor (BPM) readout system based on oscilloscopes for stripline beam position monitors has the position resolution of 50 μm approximately. Thus, we have developed a new BPM readout board with narrow band pass filter, 16-bit, 250 Msps ADCs and calibration pulse generators. The system is based on VME standard and the beam position is calculated by FPGA on board. The calibration pulse follows every position measurement. The calibration pulse is used for the gain correction and the integrity monitor of the cable connection. We will report details of the system.

INTRODUCTION

In the SuperKEKB, the injector linac is required to inject 5 nC/bunch, 7GeV electron and 4 nC/bunch, 4 GeV positron beams with the emittance less than 20 mm-mrad. The electron beam with emittance of about 10 mm-mrad, is generated by a photocathode RF gun [1]. The initial emittance is low enough for the requirement, but an emittance growth due to the short range transverse wakefield which is caused by misalignment is not negligible. The emittance growth can be suppressed by using the offset injection method [2]. Numerical studies show the emittance at the end of the linac is less than 20 mm-mrad under the condition of alignment error of 0.1 mm [3,4]. To perform the offset injection in the linac, at least resolution of 10 μm is required. However, the resolution of current oscilloscope based BPM readout system [5] is about 50 μm. The beam is also transported to the PF ring. The bunch charge for the PF ring is 0.2 nC/pulse during the top-up operation. By contrast, primary electron beam for positron production will be 10 nC/bunch. Those operation modes are switched every 20 ms. Thus, the wide dynamic range for beam currents is required. The dynamic range can be ensured by setting attenuation of the BPM signal for every beam modes or currents. That means several gain parameter sets and a calibration system to fix those parameters are needed. The calibration system allows the monitoring of a variation of the gain and integrity of the cable connection. The newly developed board was designed to have the high position resolution with dynamic range from 0.1 to 10 nC/bunch and to be equipped calibration pulse generators. A position resolution of σ=3 μm for 0.1 nC/bunch beam was achieved [6]. The board is also designed to have wide dynamic range for the position. The detail of the design is reported in previous studies [6,7]. There are 93 stripline BPMs on the linac, 20 VME crates with 3-8 readout boards are set on klystron gallery. The old system will be replaced with the new one stepwise after this summer. In this paper, we report a whole system of the BPM, calibration scheme and stability of the gain.

#fusashi.miyahara@kek.jp

BPM SYSTEM

The BPM readout system consists of a VME CPU board (MVME5500), a RAS (Reliability, Accessibility, Serviceability) board, an Event Receiver (VME-EVR-230RF) [8] and BPM readout boards. An EPICS IOC [9] runs on the CPU. The RAS board monitor status (such as power, temperature) and control the fan of the VME crate. The event receiver is used for the distinction of the beam mode and the generation of triggers to BPM boards. The readout board has 4 signal input channels for one stripline BPM. The calibration signal is also sent from one of those channels to the corresponding electrode.

BPM Readout Board

The BPM readout board is composed of four RF units which detect the signal from BPM electrodes, 16-bit 250 MSPS ADCs, sub FPGAs for the ADC and a main FPGA. The position and charge of the beam are calculated in the main FPGA. Those results and parameters for the calculation and the operation of the board are recorded in the registers on main FPGA. Figure 1 shows the block diagram of the board and the RF unit. The setting value of the variable attenuator, sum of ATT1A and ATT1B, depends on bunch charge. In particular, the beam is away from BPM center, a nonlinearity of the ADC gain causes a measured position drift. The readout board has a good

ISBN 978-3-95450-176-2

BEAM HALO MEASUREMENT UTILIZING YAG:CE SCREEN

Takashi Naito #, Toshiyuki Mitsuhashi
KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801 Japan

Abstract

We are aiming to produce an extremely small beam having a vertical beam size of 37nm at KEK-ATF2. The beam halo surrounding the beam core will make the background for the beam size measurement using a Laser interferometer beam size monitor. An understanding of beam halo distribution is important for the measurement of the beam size at the final focus point of the KEK-ATF2. In order to measure the beam halo distribution, we developed a beam halo monitor based on fluorescence screen. A YAG:Ce screen, which has 1mm slit in the center is set in the beam line. The image on fluorescence screen is observed by imaging lens system and CCD camera. In this configuration, the beam in the core will pass through the slit. The beam in surrounding halo will hit the fluorescence screen, and we can observe the distribution of beam halo. The intensity contrast of beam halo to the beam core is measured by scanning the beam position for the fixed fluorescence screen position. The results of observation of beam halo are presented.

INTRODUCTION

ATF2 is a test beam line for developing the final focus system for the International Linear Collider (ILC). The very low emittance beam is supplied from the damping ring(DR). The energy is 1.3GeV and the design emittances for the horizontal and vertical are 1.3nm and 10pm, respectively. The final focus optics in the ATF2 beam line generates an extremely small beam. The design vertical beam size is 37nm at the virtual focal point [1]. A laser interferometer beam size monitor is used for the beam size measurement [2]. The collision of the electron beam and the fringe of two laser beams makes the Compton scattered photons. The beam size is estimated from the modulation depth of the Compton signal when scaning the fringe position of the laser beams. A Gussian distribution is assumed for the electron beam in this estimation. The beam halo causes the background of the Compton signal and the measurement error. The beam halo distribution is important for the measurement of the beam size.

The beam-gas scattering, beam-gas bremsstrahlung and intra-beam scattering cause the beam halos in the storage ring. The beam halo distribution in the case of the ATF damping ring was estimated in reference [3]. The vertical beam distribution with different vacuum pressure due to the beam-gas scattering is shown in Fig. 1. The calculation shows some deviation at 10^{-3} of the intensity in the case of 10^{-7}Pa of the vacuum level.

We developed a screen monitor utilizing a YAG:Ce screen, which has both high resolution and high sensitivity[4]. This monitor is also used at the KEK LUCX (Laser Undulator Compton X-ray) facility [5]. The beam halo monitor is an application system of the screen monitor, which can visualize the beam halo distribution.

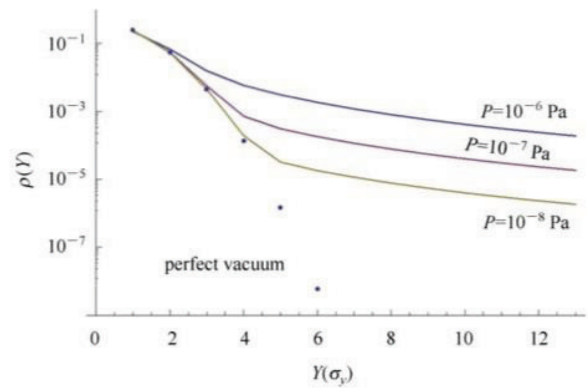


Figure 1: Vertical beam distribution with different vacuum pressure (vertical axis:provability, Horizontal axis : normalized RMS beam size), from Chinese Physics C, Vol. 38, No. 12 (2014) 127003

HARDWARE

The beam halo monitor consists of a YAG:Ce screen held on the air actuator and an imaging system. The YAG:Ce screen has 1mm slit in the center. The size is 10mmϕ and the thickness is 100μm. The picture of the YAG:Ce screen on the actuator holder is shown in Fig. 2.

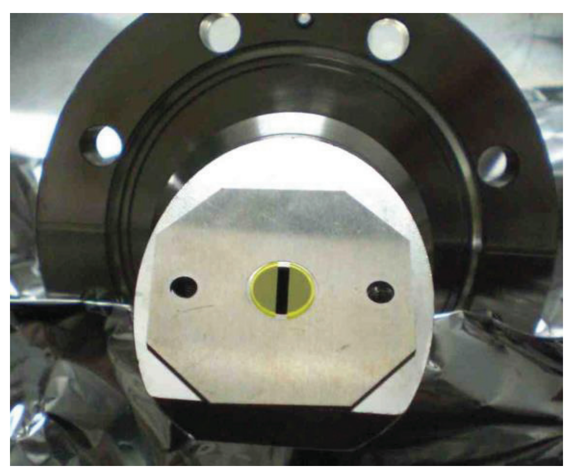


Figure 2: YAG:Ce screen on the actuator holder: The beam core goes through a slit at the center of the screen without any interaction for the scintillator.

In this configuration, the beam in the core passes through the slit and the beam halo hit the screen. The

takashi.naito@kek.jp

ISBN 978-3-95450-176-2

DESIGN OF CODED APERTURE OPTICAL ELEMENTS FOR SUPERKEKB X-RAY BEAM SIZE MONITORS

E. Mulyani, Sokendai, Tsukuba, Ibaraki, Japan
J.W. Flanagan, KEK and Sokendai, Tsukuba, Ibaraki, Japan

Abstract

We describe the design of coded aperture optical elements for the SuperKEKB x-ray beam size monitors. X-ray beam profile monitor are being installed in each ring of SuperKEKB (LER and HER) to provide high resolution bunch-by-bunch, turn-by-turn measurement capability for low emittance tuning, collision tuning and instability measurements[1,2]. We use two types of optical elements, single-slit (pinhole) and multi-slit optical elements (coded apertures, CA). CA imaging offers greater open aperture than a single pinhole, for greater photon throughput and better statistical resolution for single-shot measurements. X-rays produced by a hard-bend magnet pass through a pinhole or CA optical element onto a detector. The resolution is obtained by calculating the differences between the images recorded by the detector for various simulated beam sizes, for a given number of photons. The CA elements that we have designed for use at SuperKEKB are estimated to provide 1.25-2.25 microns resolution for 10-25 microns of vertical beam sizes at 1 mA bunches. We present the design principle and optimizing process used to optimize the resolution at various beam sizes for SuperKEKB.

INTRODUCTION

Precision measurement of vertical bunch size plays an important role in the operation and tuning of electron storage rings [3], including the $e^+ e^-$ collider SuperKEKB[4]. For this machine, luminosity or brightness is directly related with vertical emittance and vertical beam size. To meet bunch-by-bunch beam profile monitoring with high resolution and fast response, we are building an x-ray imaging system based on coded aperture (CA) imaging [5]. The basic concept of CA imaging is shown in Fig. 1. The system consists of a pseudorandom array of pinholes (apertures) that project a mosaic of pinhole images onto a detector. The detector image is then decoded using the known mask pattern to reconstruct the original image. With a single pinhole, the resulting image is relatively easy to understand and analyze, though the usable photon flux is limited.

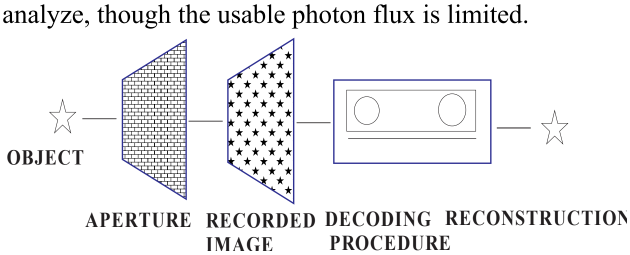


Figure 1: Basic concept of CA imaging [6].

CA imaging offers greater open aperture than a single pinhole, for greater photon throughput and better statistical resolution for single-shot measurements. One traditional example of such a pattern is the Uniformly Redundant Array (URA)[6], which has been tested for beam size measurement at CesrTA[7], Diamond Light Source[8], and the ATF2[9]. Other patterns have also been developed which are optimized for better performance at small beam sizes [10]. At SuperKEKB, x-ray beam monitors will be used primarily for vertical bunch profile measurement, with two types of optical elements, single-slit (pinhole) and multi-slit optical elements (coded apertures, CA). A schematic view of the x-ray beam size monitor line is shown in Fig. 2. Beryllium filters are placed upstream of the optics to reduce heat load, with the whole line being in vacuum up to the 200 µm Be extraction windows at the end. The detector is 128 channels of silicon with 2 mm of sensing depth, and a pixel pitch of 50 µm. SuperKEKB has two rings, the Low Energy Ring (LER) and the High Energy Ring (HER). Parameters for each beam line and the optical elements shown in Table 1.

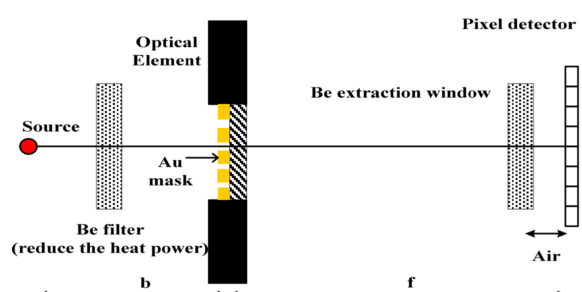


Figure 2: Simplified schematic of x-ray beam size Table monitor (not to scale).

Table 1: Parameter for Beam Lines and Optical Element

Parameter	LER	HER	Unit
Beam energy	4	7	GeV
Source bend radius ρ	31.74	106	m
Distance from source to mask (b)	9.43	10.33	m
Distance from mask to detector (f)	31.38	32.35	m
Au thickness	20	20	µm
Total Be thickness (filter+window)	0.7	16.2	mm
Diamond thickness	600	600	µm
Air gap (window-det.)	10	10	cm

ISBN 978-3-95450-176-2

MACHINE STABILITY ANALYSIS BY PULSE-BASED DATA ARCHIVER OF THE J-PARC RCS

N. Hayashi*, JAEA/J-PARC, Tokai, Ibaraki, Japan

Abstract

The J-PARC RCS runs with a repetition rate of 25 Hz. The beam intensities from current monitor data and beam loss monitors (BLM) data are archived for all pulses and are analyzed to study machine stability. It was found that after replacing ion source, the beam intensity seems to be more stable than before. In addition, beam position monitors (BPM) data are regularly recorded. In this paper we report a few examples of the data recorded by BLM or BPM in the case of magnet power supplies feedback problem or vacuum problem, respectively. In case of the bending magnet problem, not all BLMs show increasing signal, some BLMs' signal were decreasing. In case of the vacuum pump trouble, within a few seconds, the beam losses were quickly increasing. It is described these incidents with various data.

INTRODUCTION

The Japan Proton Accelerator Research Complex (JPARC) has three accelerators and three experimental facilities. The Linac upgrade was upgraded in two stages, namely energy upgrade and intensity upgrade [1]. The energy upgrade from 181 to 400 MeV was performed in the end of 2013 by adding annular-ring coupled structure (ACS) cavities [2]. The intensity upgrade, involving increasing the peak beam current from 30 to 50 mA, was realized by replacing the front-end part of the Linac during the summer shutdown of 2014. The front-end part comprises an RF driven ion source [3] and a 50 mA RFQ [4].

The second accelerator is a Rapid-Cycling Synchrotron (RCS). The RCS injection system, bump magnets power supplies, was also upgraded to adapt the system to higher Linac energy. RF harmonics of the RCS is $h = 2$, and there are two bunches inside the ring. The proton is accelerated up to 3 GeV and is extracted with a 25 Hz repetition rate. The RCS delivers an intensive primary proton beam to the Materials and Life Science Experimental Facility (MLF) and serves as a booster for the Main Ring (MR) proton synchrotron with a period of 2.48 s or 6 s. Four consecutive batches (eight bunches in total) are delivered in every MR cycle. The MR has two beam-extraction modes, fast and slow extraction mode. The first one is for neutrino experiment (NU), and the second one is for hadron experimental facility (HD). By the end of June 2015, nominal beam power of the MR was 330 kW for NU and 33 kW for HD. These are correspond to $4.4{\times}10^13$ protons per pulse (ppp) and 1.010^13 ppp for NU and HD, respectively, at the RCS intensity.

The designed output beam power of the RCS is 1 MW, and the corresponding beam intensity is 8.3×10^13 ppp. Even though it was only pulsed mode, the RCS achieved the design intensity in the beginning of 2015 [5]. It was a successful demonstration, but it revealed several issues pertaining to continuous 1 MW operation. The beam power of the routine user operation has been increased step-by-step. It commenced from 300 kW in fall 2014, increased to 400 kW in March, and reached 500 kW in the spring 2015. Development to achieve 1 MW user operation is underway. In addition, it is required to provide high availability and stable operation. A data-archiving system might be useful for analyzing accelerator stability and investigating the cause of any interruption in accelerator operation. Using these pieces of information, one can improve accelerator stability. In this paper, various examples are presented.

* naoki.hayashi@j-parc.jp

DATA ARCHIVING SYSTEM

The RCS has a threefold symmetric lattice with a circumference of 348 m. The RCS has three straight and three arc sections in the ring. The RCS houses various types of beam instruments [6], and a few important monitor data are continuously recorded and archived. These instruments include 54 beam position monitors (BPM) [7], intensity monitors DCCT and SCT, and beam loss monitors (BLM). The circulating beam current from the raw DCCT data is divided by the revolution frequency to obtain intensity, and the raw BLM signal is integrated in signal processing units. Most of BLMs are proportional chamber type (PBLM), and ninety PBLMs are distributed all over the ring.

The archive system employs reflective memory to read all 25 Hz, 20 ms-long pulses [8]. Although time resolution is limited, these data, BLM and DCCT, are recorded thrice every pulse with a 10 ms interval. BPM data is recorded every 1 ms. Although the system can store all data, 50 consecutive pulses are recorded every minute as archived data.

The Machine Protection System (MPS) is an interlock, triggered by any machine failure or large beam loss detected by BLM. If it is due to a machine failure on the beam, some amount of beam loss is expected. An MPS event triggered by BLM only is an indication of hidden problems.

INTENSITY STABILITY

It is mentioned already that the ion source was replaced in the intensity upgrade stage. The old ion source was of the LaB_6 filament type without cesium. The new one is a cesium feed RF-driven ion source. Figure 1 shows an example of a one-day intensity plot of the new source. The beam destinations were both NU and MLF. Only a few interruptions were observed over the course of a day, and they were caused by MPS. The new ion source seems to be more stable than the old one.

ISBN 978-3-95450-176-2

BUNCH LENGTH ANALYSIS OF NEGATIVE HYDROGEN ION BEAM IN J-PARC LINAC *

A. Miura#, N. Hayashi
J-PARC Center, Japan Atomic Energy Agency, Tokai, Ibaraki, JAPAN
T. Maruta, Y. Liu, T. Miyao,
J-PARC Center, High Energy Accelerator Research Organization, Oho, Tsukuba, JAPAN
S. Fukuoka
Graduate School of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Ibaraki, JAPAN

Abstract

We used bunch shape monitors (BSMs) to measure the longitudinal bunch length of a negative hydrogen ion beam in the J-PARC linac. Because we experienced a vacuum degradation to suspend a beam operation during the BSM operations, BSMs were once dismounted for vacuum conditioning. We installed one BSM again in the beam line with additional vacuum equipment. We stared to measure the 191-MeV beam again to tune the buncher amplitude after checking a functioning BSM by comparing its results with those of a simulation. To evaluate the measurement errors with peak beam current increasing, we observed waveforms with various beam currents. Therefore, the RMS bunch length depends on the peak beam current and the bending at the pulse head grows with the peak beam current. Furthermore, to avoid the thermal stress, we compared the data taken at an off-center beam with the ones taken at an on-center beam, because a target wire will be exposed to a higher peak beam current. In this study, we introduced the peak beam current dependence of the bunch length waveforms, and an effect of on-/off-centering of the wire position. Finally, the new buncher tuning method using one BSM is discussed.

INTRODUCTION

In the 1-MW upgrade project at the J-PARC at the experimental laboratories connected to the downstream of the linac and the rapid cycling synchrotron (RCS), we have two big projects, particularly, the energy upgrade from the 181-MeV linac to the 400-MeV linac and the front-end improvement using a new RF ion source and replacing it with the upgraded radio frequency quadrupole (RFQ) linac cavity. To meet with the 400 MeV of the linac, 21 ACS cavities have been developed and installed in the beam line; we have developed the beam monitors for the ACS cavity tuning. Because the acceleration frequency of ACS cavities is 972 MHz, which is three-fold higher than that of upstream RF cavities, we need to take longitudinal matching at the upstream part of the new ACS beam line.

We started the development of a bunch shape monitor (BSM) for the J-PARC linac. Three years into the project, three BSMs were fabricated. In the summer of 2012, prior to the installation of ACS cavities, we installed all three BSMs at the upstream of the new ACS section to conduct some test measurements using 181-MeV beams [1]. During the BSM measurements, a problem with the degradation in vacuum conditions was found. A major reason for this problem was outgassing from materials when the high voltage and RF power were supplied. To mitigate this problem, BSMs were dismounted from the beam line and the off-line conditioning with outgas analysis was performed. The impacts of the bias voltage to the target wire and static lens and the RF power to the deflector were examined in the vacuum test [2].

The improved arrangement of the vacuum system for installing the BSM was also proposed. We installed a BSM in at the upstream of the ACS again in the summer of 2014 with the additional vacuum arrangement. We started to use the BSM to conduct the buncher amplitude tuning. In the study on space-charge driven transverse–longitudinal coupling resonance, we measured the longitudinal emittance with the BSM. The results are expected to contribute to the design of the beam operational parameters for the energy-upgraded linac. The high-intensity linac design follows the equipartitioning (EP) condition. Fortunately, J-PARC linac could find its EP solution as the baseline design without sacrificing hardware efficiency. It also has the applicability for a wide range of off-EP conditions, offering opportunities not only for investigating the basic beam physics principles but also for further optimizing the machine operation [3].

To evaluate the measurement errors in the high-intensity beam operation, we observed waveforms with various beam currents. We discuss the longitudinal bunch length taken at an off-center position to avoid the thermal stress from the higher peak beam current. Finally, we introduce a proposal for the new buncher tuning method with one BSM.

STRUCTURE OF BSM

A BSM comprises the body, RF deflector, steering magnet, actuator, and electron detector as shown in Fig. 1. An RF deflector and an actuator which holds a target wire are vertically installed against the beam axis on the body. Secondary electrons that pass through the collimators on the RF deflector travel to the pipe connected to the electron detector [4]. Finally, secondary electrons pass

* amiura@post.j-parc.jp

ISBN 978-3-95450-176-2

STATUS OF BPMS IN THE FIRST STAGE OF COMMISSIONING AT CADS INJECTOR I*

H.Z. Ma#, J.S. Cao, Y.F. Sui, Q. Ye, IHEP, 100049, China
Key Laboratory of Particle Acceleration Physics and Technology,
IHEP, Chinese Academy of Science

Abstract

The paper will introduce the status for BPMs in the first stage of commissioning at CADS (China Accelerator Driven Subcritical System) Injector I. The measurement principles and results of BPM at injector I are presented. The measurement of BPM is rigorous in the first medium energy beam transport line of CADS Injector I. To ensure the safety of test cryomodule, beam orbit should be corrected to the minimized region. The third order fitting way is used to calculate the position of beam for BPM non-linearity. And the average of data in the single pass window should improve the resolution. Then BBA of BPM can help tracking beam position accurately. Finally the interlock circuit of BPM is tested with the beam.

INTRODUCTION

China Accelerator Driven Subcritical system (CADS) is a strategic plan to solve the nuclear waste problem and the resource problem for nuclear power plants in China[1]. CADS has two injector linacs named Injector I and II to ensure its high reliability, which are respectively built by Institute of High Energy of Physics (IHEP) and the Institute of Modern Physics (IMP).

With the energy of about 3.4MeV in the first stage of commissioning, the injector I in IHEP is composed of ECR ion source, Low Energy Beam Transport line (LEBT), Radio Frequency Quadrupole (RFQ), Test Cryomodule (TCM), Medium Energy Beam Transport line (MEBT) and beam dump. The layout of BPMs for the ADS Injector I at the first stage of commissioning is illustrated in Figure. 1.

The injector I linac at the test stage includes total 10 BPM detectors of three types, which are strip line, capacitive and button. Two of BPMs are cryogenic mechanical structure. The rest of them are designed to work in the normal temperature environment. Here are the parameters of BPMs and beam characteristics as Table 1.

Table 1: The Parameters of BPM and Beam Characteristics of 3.4 MeV C-ADS Injector I

Parameter	Value
Electrode type	Strip Line /Capacitive/Button
Beam pipe diameter	30/50/35 mm
Beam max displacement (with ref. to beam pipe)	50%
Position accuracy	±100um
Position resolution	30um
Beam energy	3.4MeV
Bunch repetition rate	325MHz
Beam pulse length	30us-CW
Pulse repetition rate	5Hz/10Hz
Peak current	10mA

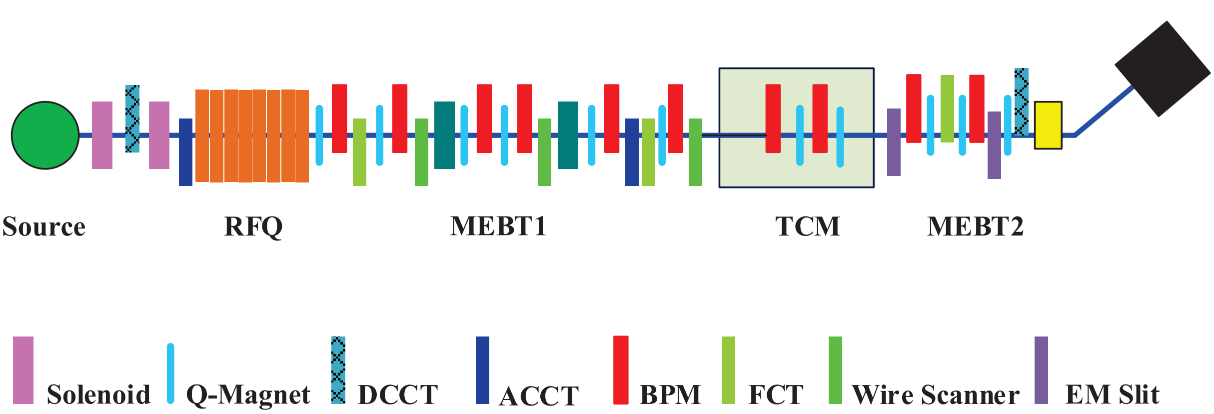


Figure 1:The layout of BPMs of the ADS Injector I.

*Work supported by China ADS Project (XDA03020000)
#mahz@ihep.ac.cn

ISBN 978-3-95450-176-2

MEASUREMENTS OF BEAM HALO BY WIRE SCANNER MONITOR*

Hongping Jiang#, Key Laboratory of Particle & Radiation Imaging (Tsinghua University), Ministry of Education, Beijing 100084, China
Peng li, Taoguang Xu, Institute of High Energy Physic, Chinese Academy of Sciences, Beijing 100049, China

Abstract

A wire scanner is used in the beam halo experiment at the Institute of High Energy Physics (IHEP) to measure the beam halo for the study of beam halo dynamics. The beam energy in the FODO transport line is 3.5 MeV and the peak current is 24 mA. Firstly we get the emittance value for the vertical and the horizontal plane respectively by measuring the matched beam. Then we measure the beam halo of the mismatched beam.

INTRODUCTION

The beam halo formation is an important characteristic of high intensity beams. Beam halo particles are more easily lost on the walls and increase unwanted radioactivity [1]. The experimental study of beam halo formation is very important and necessary. So we built a 28-quadrupole beam transport line after the IHEP RFQ [2]. We have designed a beam profile and halo measurement system and have installed the system in the transport line [3]. In the experiments we used the measured beam profile data to character the proton beam with quadrupole scans method, firstly [4]. Then we measured the RMS matched beam profiles. We also measured the mismatched beam profiles and beam halos, lastly.

In this paper, we introduce the beam profile and halo measurement system and the beam halo experiments. Then we present the measured RMS matched beam profiles with beam halo and the measured mismatched beam profiles with beam halo.

THE BEAM PROFILE MEASUREMENT SYSTEM

We have designed a wire scanner system to measure the transverse beam profile and the emittance. The schematic view of the wire scanner is shown in Fig. 1. The wire scanner will be mounted at 45 ° to the horizontal plane. The outer assembly that resides outside the vacuum consists of a stepper motor, a linear encoder and an electric control platform. The inner consists of a movable frame that carries a sensing wire. And the 32micron diameter carbon wire is selected for use.

* Work supported by National Natural Science Foundation of China (Major Research Plan Grant No. 91126003)
#Jianghp@ihep.ac.cn

Figure 1: The Schematic view of the wire scanner.

BEAM HALO EXPERIMENT

The 28-quadrupole beam transport line is installed at the end of the IHEP RFQ, which accelerates the proton beam to 3.5MeV and operates at the frequency of 352MHz [2]. The block diagram of this transport lattice is shown in Fig. 2.

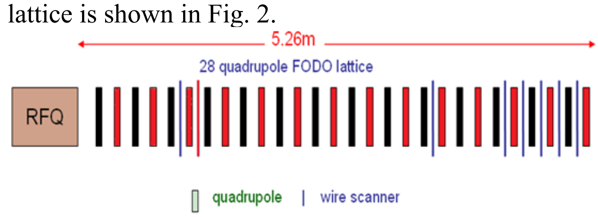


Figure 2: Block diagram of beam halo experiment transport line.

The squares mean quadrupoles, and we change the focusing strength of the FODO channel to obtain the different zero current phase advances. The lines mean wire-scanners. The red line is used to measure the vertical beam profile; the blues are used to measure the horizontal beam profiles at the different locations. Quadrupole scans method is used to charactering the beam, firstly. And the results are presented in Table 1.

Table 1: The Beam rms Parameters

Direction	Alpha	Beta	Emittance (RMS Normalized)
Horizontal (x)	3.287	0.4466 (mm/mrad)	0.29 (mm-mrad)
Vertical (y)	-0.165	0.1005 (mm/mrad)	0.47 (mm-mrad)

ISBN 978-3-95450-176-2

BUNCH-BY-BUNCH STUDY OF THE TRANSIENT STATE OF INJECTION AT THE SSRF*

Zhichu Chen, Yongbin Leng, SSRF, Shanghai, China

Abstract

High current and stable beams are preferred to a light source, so the suppression of the oscillations due to the frequent injections during top-off operations get the attention at the Shanghai Synchrotron Radiation Facility (SSRF). To evaluate the possibility of further optimizations, a bunch-by-bunch position monitor is used to study the behavior of the injected bunch. The injected part is isolated from the stored one by decomposing the position matrix of all the bunches in the storage ring. Frequency feature, motion lifetime and other characteristic parameters of the injection mode have been compared with those of the stored mode.

INTRODUCTION

The SSRF is a third generation light source aiming to provide stable and brilliant synchrotron radiation. The high brilliance target was achieved by operating under top-off mode. But the frequent injections required by the top-off mode will decrease the stability of the beams. The behavior of the injected bunch has to be studied before finding a solution to minimize the effect of the injection.

BUNCH SEPARATION

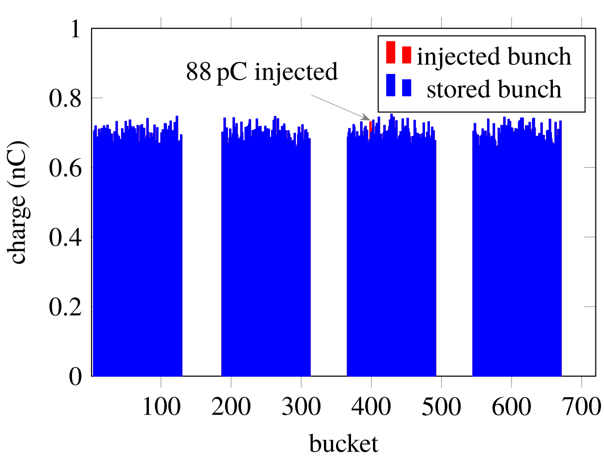


Figure 1: Filling patterns before and after an injection.

The goal of the study is to build an on-line feedback system to stabilize the injected bunch, so it's better to leave the beam undisturbed while getting its information. Signals from the electrodes of the bunch-by-bunch position monitor can easily be used to get the positions as well as the filling pattern of the bunch train. The data succeeded the injection were saved for further study.

* Work supported by National Natural Science Foundation of China (No. 11305253)

The injected bunch can be found by using the filling patterns (as shown in Figure 1). The adjacent bunches are used to interpolate the orbit of the stored bunch and the position of the injected bunch can be obtained by deducting the weighted stored part from the raw position data. The injected bunch can also be separated by decomposing the motion matrix of all bunches by using the singular value decomposition (SVD) [1]. Both methods gave the same—or extremely close—results.

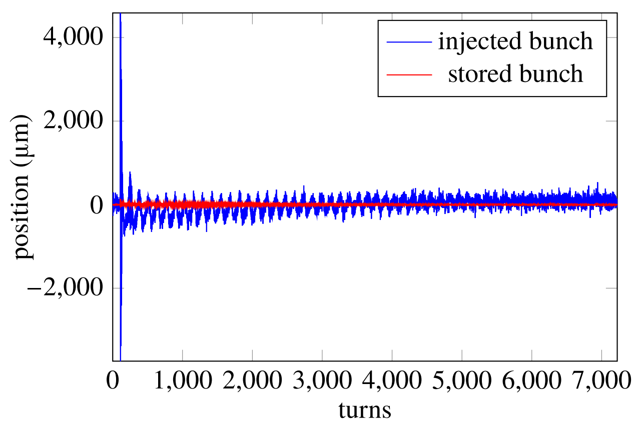


Figure 2: Horizontal positions of the injected bunch separated from the stored one.

The behavior of the stored bunch (red line in Fig. 2) is considered trivial, while the motion of the injected one (blue line in Fig. 2) shows the potential to give more information at the first glance.

A motion matrix was constructed to decompose the source signals. The columns of the matrix are shifted segments of the total waveform, so that the sources (the five major sources are shown in Fig. 3) can be separated after the independent component analysis (ICA) [2, 3]. The waveforms and the spectra (as shown in Fig. 4) of the sources indicates that the motion is dominated by the energy oscillation and its harmonics. The signal source 5 is pure horizontal betatron oscillation, and the rest sources are mixtures of horizontal and vertical betatron oscillations, judged by their characteristic frequencies.

The ICA is a time-consuming and semi-automatic method which requires human interference. Considering the on-line processing requirement in the future, the SVD method would be used and the ICA results would serve as a reference.

The singular values of the aforementioned motion matrix show that only the first ten modes make sense and the rest modes can just be considered as random noise (as shown in Fig. 5). The singular values and the spectra of the left-singular vectors implies that the modes are in pairs and the

ISBN 978-3-95450-176-2

PROGRESS OF CAVITY BEAM POSITION MONITOR AT SXFEL

L.W. Lai , Y.B. Leng, L.Y. Yu, R.X. Yuan, W.M. Zhou, Z.C. Chen, Y.B. Yan
SSRF, SINAP, Shanghai, China

Abstract

Shanghai Soft X-ray FEL Test Facility (SXFEL) has started the infrastructure construction in 2015. All beam diagnostic systems are under processing and measurement, including C-band Low-Q cavity BPMs. This paper presents the progress of the cavity BPM system, including design and the measurements on a lab platform. Measurements shown that the cavity BPM frequency is 4.7GHz ± 8MHz, and the complete test platform verify that the cavity BPM system, which including signal processing electronics can work as expected.

INTRODUCTION

The SXFEL project at the Shanghai Synchrotron Radiation Facility (SSRF) campus serves as a test facility of China's future hard X-ray FEL user facility, while it can be easily upgraded to a FEL user facility at "water-window" spectral region for scientific investigations with high brilliance X-ray pulses of ultra-fast and ultra-high resolution processes in material science and physical biosciences.

The construction of the SXFEL has started since April 2015, and the first X-ray FEL light is planned to be delivered to the beam line in 2017.

The SXFEL consists of following parts:

1. A photo-injector generating a bright electron beam and accelerating it to ~ 130 MeV.
2. The main linear accelerator, where the electron beam is longitudinally compressed and accelerated to ~ 840 MeV.
3. The FEL undulator complex where X-ray radiation is generated.
4. The photon beam transport & diagnostic line.

To achieve the physical design of SXFEL, the diagnostic system need to achieve requirements listed in Table 1, and the dynamic is 0.1nC~0.5nC.

CAVITY BPM SYSTEM

The cavity BPMs have been chosen for the real time measurements of the electron beams positions along the undulator of the SXFEL. The layout is shown in Fig. 1.

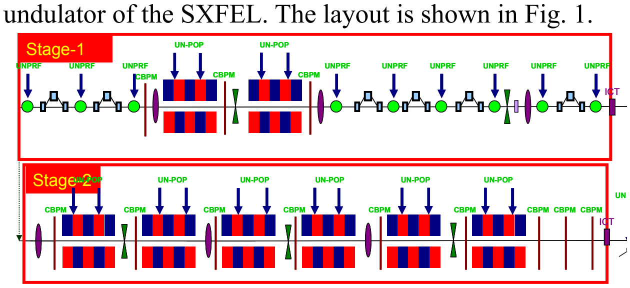


Figure 1: Layout of cavity BPM along undulator.

Table 1: Beam Diagnostics System Specification

Parameter	Main technical specifications
Position	Stripline BPM, Resolution: 10μm@0.5nC
	Cavity BPM, Resolution: 1μm@0.5nC
Size	YAG/OTR, Resolution:30μm@1nC, Repeatablity:50μm
Charge	ICT, Resolution:1%
Length	CSR, Resolution:100fs
Arrive time	Phase cavity, Resolution:200 fs

Cavity BPM Pickups

The cavity BPM system consists of the cavity BPM probes, the RF front-end and data acquisition (DAQ) electronics is shown in Table 2. The working frequency of the position mode and the reference cavity of the CBPM are designed to be 4.7GHz preliminary to avoid the interference of the dark current caused by the frequency multiplication of the RF. The signals will be lead out through the 50Ω load and the system quality factor will be mainly determined by the external quality factor.

Table 2: The Cavity BPM Design Parameter

Parameter	TM110	TM010
Frequency	4.7GHz	4.7GHz
Q	~60	~60
Ports number	4	2
Signal amplitude@50Ω	12mV/μm/nC (peak)	100V/nC (peak)

CBPM responses with a series of simulated electron beams passing the CBPM at different positions have been modeled with MAFIA. The output signal and the corresponding spectrum at the electrode of the CBPM are shown here in Fig. 2.

ISBN 978-3-95450-176-2

INTERFEROMETER DATA ANALYZING USING THE PCA METHOD AT SSRF *

Y.B. Leng#, H. J. Chen, J. Chen, Z. C. Chen, Y.B. Yan, SSRF, SINAP, Shanghai, China.

Abstract

An SR interferometer, which was used to monitor the transverse beam size in the SSRF ring, had been implemented and put into operation since 2009. The direct projection and curve fitting was adopted for raw image data processing. Any CCD alignment error could introduce some beam size measurement error in this case. Using primary component analyzing (PCA) method to process raw image data, the horizontal and vertical distribution information can be decoupled and the misalignment information of CCD can be derived. Beam experiment results will be discussed in this paper.

INTRODUCTION

Shanghai Synchrotron Radiation Facility (SSRF) is the 3.5GeV third generation light source with the emittance of 3.9nm.rad. The typical transverse beam sizes are 53μm in horizontal plane and 22μm in vertical plane with 1% vertical coupling. To monitor such small transverse beam dimension and motion, a set of interferometer was implemented since 2009 [1].

The source point of SRM is inside the second bending magnet of the cell#2. The synchrotron light is extracted by a water-cooled beryllium mirror. Then three mirrors guide the light to the dark room.

Two Harsherian-type reflective SR interferometers are installed to measure the both of vertical and horizontal beam sizes. The double slit is set at 18 meter apart from source point. A focusing mirror, f=2000mm, is used as an objective mirror. A small off axis diagonal mirror is set for the convenience of the observation. A band-pass filter, which has 50nm or 80nm bandwidth at 550nm, is used to limit the wavelength of input light. The σ-polarization of SR is selected by dichroic polarization filter.

The 800Mb/s interface enables full frame rate and even more cameras on the same bus. The IEEE-1394b cable with jack screws allows a more secure connection to the camera. 12-bit A/D converter, Via external trigger, software trigger (on same bus), This equipment has been tested and found to comply with the limits for a Class A digital device, have good linearity It provide reasonable protection against harmful interference when the equipment is operated in experimental environment. After all environments and system calibration, Interferometer is good enough for the measurement of a few μm small beam size. [2]

Figure 1 shows a set of typical interference image data and corresponding data processing method. In order to minimize measurement uncertainty, CCD exposure time was set to a large number (for example 200ms) to get strong visible light signal. Meantime the edge part of raw image with poor SNR was cut and only central part was reserved to get interference flange profile using direct projection method.

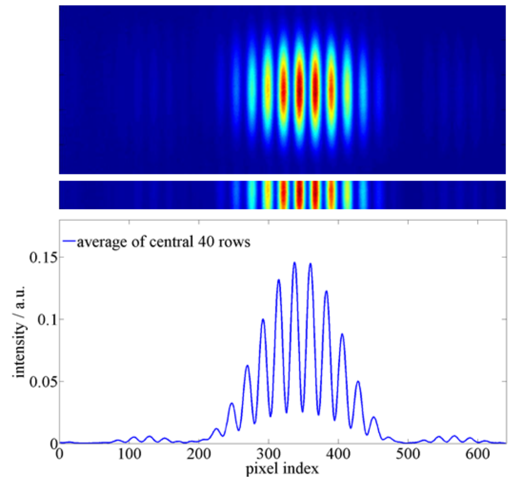


Figure 1: Typical interference image (top), central slice of 40 rows (middle) and projected interference flange (bottom).

The SNR of the final profile can be guaranteed with above CCD configuration and data processing method. But two disadvantages were introduced into the system at the same time. The first, not all information of the raw image was used. The second, any misalignment between the double slit and CCD will contribute measurement error and this contribution is hard to find and fix with direct projection method.

So we propose to use PCA method to process raw image data, reduce random noise, detect misalignment angle and decouple the horizontal and vertical profile.

IMAGE PROCESSING USING PCA

PCA method is originally used in image processing filed to reduce data dimensions and now widely used in accelerator field to do BPM turn-by-turn data analyse. [3]

The interference image matrix can be decomposed into three terms by using SVD:

$$IMG=USV \tag{1}$$

where U and V are unitary square matrices and S is a diagonal matrix. U is the matrix of the eigenvectors of the covariance matrix IMG and each column of U corresponds to the horizontal distribution pattern of a specified mode; V is the matrix of the eigenvectors of the covariance matrix IMG and each column of V corresponds to the vertical distribution of a specified mode; Each element of S is nonnegative and real, and it corresponds to the intensity of a specified mode.

*Work supported by National Nature Science Foundation of China (11375255)
#lengyongbin@sinap.ac.cn

DEVELOPMENT OF CAPACITIVE LINEAR-CUT BEAM POSITION MONITOR FOR HEAVY-ION SYNCHROTRON OF KHIMA PROJECT

Ji-Gwang Hwang *, Tae-Keun Yang, Seon Yeong Noh
Korea Institute of Radiological and Medical Sciences, Seoul, Korea
Peter Forck, GSI, Darmstadt, Germany
Changbum Kim, Pohang Accelerator Laboratory, Pohang, Kyungbuk, Korea

Abstract

Since the beam intensity after the injection and capturing process in the KHIMA synchrotron is $\sim 7.4 \times 10^8$ particles for the carbon beams and $\sim 2.07 \times 10^{10}$ for the proton beams, the linear-cut beam position monitor is adopted to satisfy the position resolution of 100 μm and accuracy of 200 μm with the linearity within the wide range. In this paper, we show the electromagnetic design of the electrode and surroundings to satisfy the resolution of 100 μm, the criteria for mechanical aspect to satisfy the position accuracy of 200 μm, the measurement results of position accuracy and calibration by using a wire test-bench, and the beam-test results with long ($\sim$ 1.6 μs) electron beam in Pohang accelerator laboratory (PAL).

INTRODUCTION

Main purpose of the Korea Heavy Ion Medical Accelerator(KHIMA) project is to construct a proton and carbon therapy accelerator based on a synchrotron and it is currently under construction in Korea [1]. A low intensity proton and carbon beam with an energy in the range of 110 to 430 MeV/u for a carbon beam and 60 to 230 MeV for a proton, which corresponds to a water equilibrium beam range of 3.0 to 27.0 g/cm^2, is produced by the accelerator for a cancer therapy [2]. The accelerator consists of the low energy beam transport (LEBT) line, radio-frequency quadrupole (RFQ) linear accelerator (linac), interdigital H-mode drift-tube-linac (IH-DTL), medium beam transport (MEBT) line, synchrotron, and high energy beam transport (HEBT) line [3]. In the KHIMA synchrotron, a high precision beam position monitor, which has a position resolution and accuracy of 100 μm and 200 μm, respectively, is required to match and control the beam trajectory for the beam injection and closed orbit [4]. It is also used for measuring Twiss parameters, betatron tunes, and chromaticity in the synchrotron. Since the bunch length in the heavy ion synchrotron is relatively long, a few meters, and the intensity of the beam is low, a box-like device with long plates of typically 20 cm is used to enhance the signal strength and to obtain a precise linear dependence with respect to the beam displacement [5]. The number of the horizontal and vertical beam position monitors in the synchrotron are 10 and 7, respectively. The position of the monitor is determined based on the amplitude of the betatron oscillation. It is shown in Fig. 1.

* hwang@kirams.re.kr

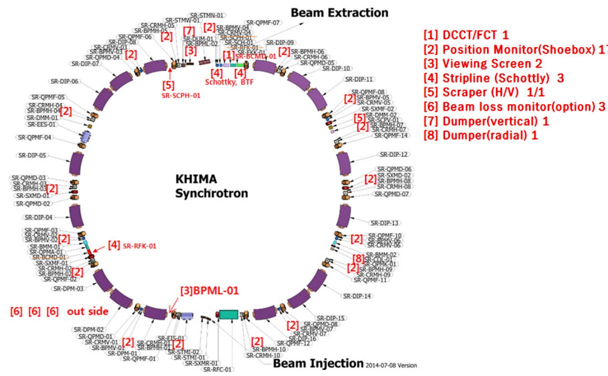


Figure 1: Layout and position of beam diagnostics in KHIMA synchrotron.

LINEAR-CUT BEAM POSITION MONITOR

The linear-cut beam position monitor consists of two electrodes with the width of 136 mm and the thickness of 2 mm, 5 mm thick body, insulator, holder and vacuum chamber. The distance between the body and electrode is maintained to be 8 mm to increase the induced signal by reducing the capacitance. The designed beam position monitor is shown in Fig. 2.

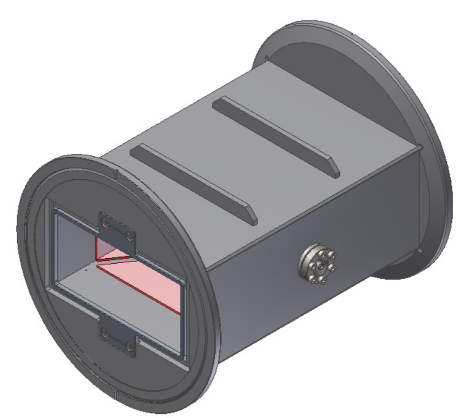


Figure 2: Linear-cut beam position monitor in KHIMA synchrotron.

The transverse and longitudinal dimensions of the beam position monitor is restricted because the beam position monitor would be installed inside the steering magnet yoke. The length of horizontal and vertical monitor are 290 mm and 244 mm, respectively. The transverse dimension of

ISBN 978-3-95450-176-2

DEVELOPMENT OF A SCINTILLATION SCREEN MONITOR FOR TRANSVERSE ION BEAM PROFILE MEASURMENT AT THE KHIMA PROJECT*

Seon Yeong Noh#, Se Duk Chang, Tae-Keun Yang Ji-Gwang Hwang, and Ga Ram Hahn
Korea Institute of Radiological and Medical Sciences
75 Nowon-gil, Nowon-gu, Seoul, 01812, Korea

Abstract

The scintillation screen monitor measures transverse profile of ion beam in beam transport line. The Korea Heavy Ion Medical Accelerator Project (KHIMA) has developed a scintillation screen monitor in the high energy beam transport (HEBT) line. The images of each beam pulse were recorded by CCD camera and evaluated the beam properties by the LabVIEW®-based in-house program in real time. We designed a scintillation screen monitor using phosphor screen, P43. In order to investigate the limits of scintillating screen during beam profile monitoring at low intensity, we designed a remote control device of iris for the incoming light adjustment to the CCD camera. In this paper, we present details of the image processing system using the LabVIEW® and the beam profile measurement results from the in-beam test.

INTRODUCTION

In the Korea Heavy Ion Medical Accelerator (KHIMA) project at the Korea Institute of Radiological And Medical Sciences (KIRAMS), to measure the beam properties i.e. position, size and intensity, we have studied using scintillating screen monitor and the imaging analysis method. The beam properties can be inferred by measuring the visible light from the scintillation screen when the charged particle passing through. The resulting photon emission represents the two-dimensional beam distribution and can be recorded by a standard optical device, a charge-coupled-device (CCD) camera. The scintillating screen provides many advantages, such as a high resolution of beam profile,a direct intercepting method to observe beam profiles, and a simple structure etc. For the high energy beam transport (HEBT) line of KHIMA, a prototype beam profile monitoring system was manufactured and tested in MC50 cyclotron facility at KIRAMS. Through the preliminary experimental results, we checked and evaluated the beam position, size and intensity by using a developed image analysis program.

FABRICATION OF SCINTILLATION SCREEN MONITOR

Hardware

As shown in Fig. 1, the scintillation screen monitoring system consists of a very thin phosphor screen and CCD camera. The prototype system used a gadolinium sulphate oxide doped with Terbium (Gd_2O_2S:Tb) phosphor screen for convert the proton beam path to visible light [1]. And, a high spatial resolution CCD camera (type: 659 × 494 pixels, H:0.169mm/pixel, V:0.14mm/pixel, model: acA640-90gm, Basler, Germany) was adopted to record the emitted light the scintillation screen.

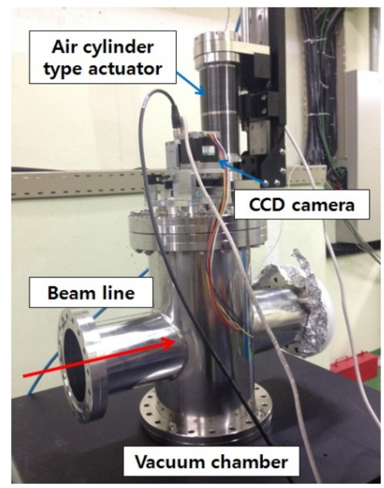


Figure 1: Photograph of the 2D beam imaging system.

The CCD camera was located perpendicularly to the beam axis, and the 100 mm diameter scintillation screen was mounted on the holder 45 degree tilted with respect to the beam axis. The 2 dimensional beam profiles display on the computer screen, and can be stored by the LabVIEW®-based data acquisition program [2,3]. The schematic drawing of the 2D beam imaging system is shown in Fig. 2.

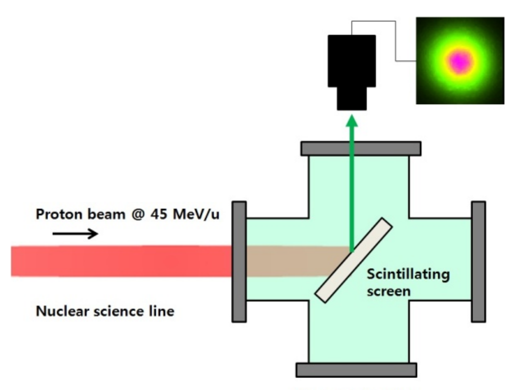


Figure 2: Experimental setup of 2D beam imaging.

*Work supported by KIRAMS
#synoh@kirams.re.kr

INTEGRATION OF THE DIAMOND TRANSVERSE MULTIBUNCH FEEDBACK SYSTEM AT ALBA

A. Olmos, U. Iriso, J. Moldes, F. Pérez, ALBA-CELLS, Cerdanyola, Spain
M. Abbott, G. Rehm, I. Uzun, Diamond Light Source, Oxfordshire, UK

Abstract

A Transverse Multi-Bunch Feedback system (TMBF) has been commissioned at the ALBA storage ring for stabilization of the beam instabilities. The system is based on the Libera Bunch-By-Bunch electronics, controlled using a specific software developed at Diamond Light Source. This system refurbishes the existing FPGA code to include several features for machine studies, like fast and precise tune measurements using a Phase Locked Loop, sequences of grow-damp experiments that allow measuring damping rates on a mode-by-mode basis, and precise bunch cleaning. We describe the TMBF system and the integration of the control software into the ALBA machine. We show examples of beam stabilization and machine studies using this system.

INTRODUCTION

Transverse betatron oscillations associated with coupled-bunch instabilities limit the machine performance in current synchrotron light sources. The TMBF system is designed to cure these instabilities by using an active feedback system based on sensors capable of detecting the beam motion, fast FPGA processors to calculate the motion correction, and actuators that apply the correction to the beam.

At ALBA, we have commissioned a TMBF system based on the Libera Bunch-By-Bunch electronics [1] provided by Instrumentation Technologies (ITech), controlled using the firmware and software developed at Diamond Light Source (DLS) [2]. Since 2007, DLS has been developing functionality beyond the pure feedback action, and ALBA decided to profit from this experience.

This paper describes the ALBA TMBF system, the integration of the control system from DLS to ALBA, and the performance and first results with it.

SYSTEM OVERVIEW

The block diagram of the ALBA TMBF is shown in Fig. 1. The signal coming from the BPM buttons is sent to the in-house Hybrid combiner designed to work around 1.5 GHz (3rd harmonic of the RF frequency) to maximize the transfer function. The Hybrid combines the four BPM signals to obtain the Horizontal, Vertical and Longitudinal (not used for the time being) components. Following to the Hybrid module, the RF FrontEnd, also by ITech, performs an amplitude and phase demodulation of the wideband components to the required working frequency of the following electronics.

The Libera Bunch-by-Bunch unit is in charge of the detection of beam instabilities and the calculation of the corresponding correcting action (kick). Correct synchronization with bunches is accomplished by proper locking to 500 MHz RF clock, usage of timing signals from ALBA timing Event Receivers (EVR) and phase matching of all critical cables down to the picosecond range. Following to the Libera electronics, 180° splitters provide the drive for the 100 W / 50 dB / 250 MHz amplifiers by IFI. Signals from the amplifiers are sent through phase-matched cables to the feedback kickers (FFK) to act on the corresponding bunches. Forward signals out of the kickers are sent out of the tunnel for diagnostics purposes.

We have faced a problem on the amplifiers' phase response. While their 50 dB gain stays quite flat up to their higher working frequency (250 MHz), the amplifiers phase response starts degrading around 200 MHz, as it is shown in Fig. 2 and Fig. 3. The effect of such amplifier imperfection is that when the system attempts to act on a particular bunch (while running the feedback, doing bunch cleaning etc.), it can happen that it also affects the neighbor bunches. In the future, we plan to change our amplifiers.

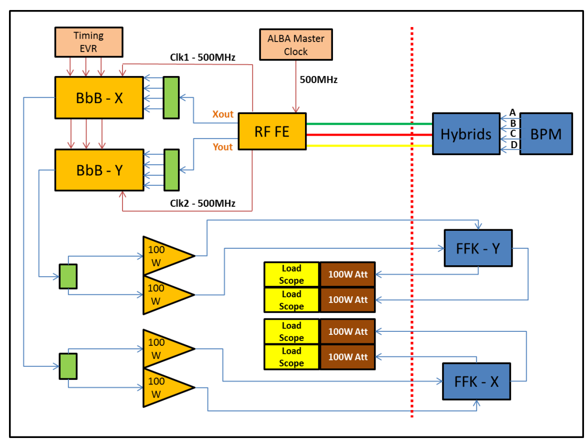


Figure 1: Schematic of the TMBF.

CONTROL SOFTWARE

DLS developed its own FPGA implementation to be run in the Libera Bunch-by-Bunch, replacing the one provided by factory. DLS also developed an EPICS driver for controlling the system, including an EPICS IOC meant to be run inside the unit, a user interface based on Extensible Display Manager (EDM) together with python and Matlab scripts and some other software utilities [2–4]. Since ALBA uses Tango as machine control system, we installed EPICS Base on some selected machines for running the user EDM. Great effort has been done by DLS to prepare a working software infrastructure to adapt all EPICS developments to the ALBA environment, including also the migration of the whole FPGA code from System Verilog to VHDL languages.

ISBN 978-3-95450-176-2

ELECTROSTATIC FINITE-ELEMENT CODE TO STUDY GEOMETRICAL NONLINEAR EFFECTS OF BPMS IN 2D

A. A. Nosych, U. Iriso, ALBA-CELLS, Barcelona, Spain
J. Olle, UAB, Barcelona, Spain

Abstract

We have developed a 2D finite element-based software for Matlab to study non-resonant effects in BPMs of arbitrary geometry, in particular the geometric nonlinearities. The developed code called *BpmLab* utilizes an open-source tetrahedral mesh generator *DistMesh*, combined with a short implementation of FEM with linear basis functions to find the electrostatic field distribution for boundary electric potential excitation. The BPM response as a function of beam position is calculated in a single simulation for all beam positions using the potential ratios, according to the Green's reciprocity theorem. The code offers ways to correct the geometrical nonlinear distortion, either by polynomials or by direct inversion of the electrode signals through numerical optimization. This work is an overview of the *BpmLab* capabilities to date, including its extensive benchmarking and validation against other methods.

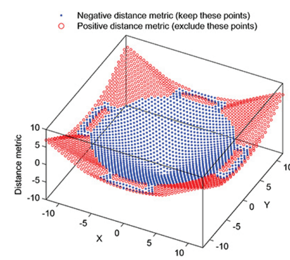
INTRODUCTION

At the initial design stage of any beam position monitor (BPM) lies its numerical characterization and optimization to fit the machine requirements. The common nowadays tools for electromagnetic (EM) simulations are usually an overkill for BPM simulations: they are either expensive (CST, Ansys, GdfidL), or free but complex (ACE3P, POISSON), requiring users to possess specific knowledge of geometrical modeling in 2D/3D and the tool itself. However, BPMs used in accelerators with ultra-relativistic beams are usually designed to be resonance-free and their position characteristic to be independent from the accelerator's operating frequency. Hence, the numerical characterization of a BPM does not need to be complicated and 2D approximations can be made to simulate the behavior of most BPM types and provide their optimization.

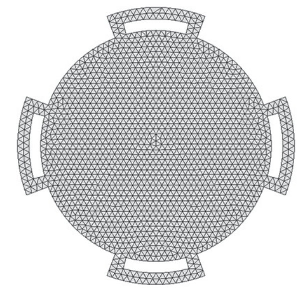
At ALBA, characterization of storage ring and booster BPMs has previously been done with the 2D boundary element method (BEM) [1, 2], and lately cross-checked with ACE3P [3]. However, though sufficient for ALBA's needs, the BEM code was limited to only two simple BPM geometries, while using the 3D time domain solver of ACE3P is rather complicated for such tasks.

The electrostatic (ES) approach to numerical BPM characterization is not new and has been used for over a decade in various accelerator laboratories, e.g. SLAC [4], CESR [5] and FNPL [6]. However, together with post-processing, this approach usually requires extra effort of additional software to get the final results.

Matlab is, perhaps, the most common tool for mathematics and data analysis in the accelerator community, with its



(a) Modeling the BPM geometry by metric functions prior to triangular meshing.



(b) Optimized equilateral Delaunay mesh of the BPM's vacuum interior, generated by *DistMesh*.

Figure 1: Modeling the pilot-BPM in *BpmLab* by combining a circle with arcs as functions of radii and internal/orientation angles.

mighty Middle Layer [7] used in the control systems of a number of accelerators, including ALBA. Thanks to a vast amount of built-in and open-source code solutions offered by Matlab, we have developed *BpmLab*: a simplistic yet powerful code for electrostatic analysis of BPMs of arbitrary geometry and free electrode arrangement in 2D.

METHODOLOGY

Some functionality, mentioned in this work, already exists in Matlab to some extent as parts of paid toolboxes. Our intention, however, is to create a free and easy to use tool, while bringing some novelty to the table.

FEM to Solve Laplace's Equation

In order to solve Poisson's equation we have used a short numerical implementation of Laplace's equation solver in 2D with mixed (Dirichlet + Neumann) boundary conditions for unstructured grids with linear triangular or quadrilateral elements [8]. Here, the problem is solved employing the finite element method (FEM) using the standard Galerkin discretization scheme. The FEM solver calculates the electrostatic potential value in each mesh node based on the boundary conditions and any volume forces, if they exist.

Meshing

For meshing we are using *DistMesh* [9], which is a simple Matlab code for generating constrained equilateral Delaunay meshes with node coordinates optimization by a force-based smoothing procedure. Here the geometry specification is done by *signed distance functions*, which give the shortest distance from every node to the boundary of the domain. The sign is negative inside the region and positive outside,

ISBN 978-3-95450-176-2

MEASUREMENTS AND CALIBRATION OF THE STRIPLINE BPM FOR THE ELI-NP FACILITY WITH THE STRETCHED WIRE METHOD

A. A. Nosych, U. Iriso, A. Olmos, A. Crisol, C. Colldelram, ALBA-CELLS, Barcelona, Spain
F. Cioeta, A. Falone, A. Ghigo, M. Serio, A. Stella, INFN/LNF, Frascati, Italy
A. Mostacci, Rome University, Rome, Italy

Abstract

A methodology has been developed to perform electrical characterization of the stripline BPMs for the future Gamma Beam System of ELI Nuclear Physics facility in Romania. Several prototype units are extensively benchmarked and the results are presented in this paper. The BPM sensitivity function is determined using a uniquely designed motorized test bench with a stretched wire to measure the BPM response map. Here, the BPM feedthroughs are connected to Libera Brilliance electronics and the wire is fed by continuous wave signal, while the two software-controlled motors provide horizontal and vertical motion of the BPM around the wire. The electrical offset is obtained using S-parameter measurements with a Network Analyzer (via the "Lambertson" method) and is referenced to the mechanical offset.

INTRODUCTION

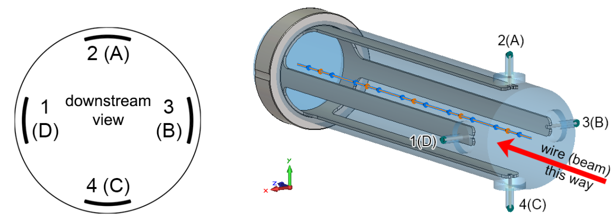
The future Extreme Light Infrastructure Nuclear Physics (ELI-NP) facility will be located in Bucharest (Romania), and will be dedicated to the study of secondary light sources and attosecond pulses. This will be done by the Gamma Beam System (GBS) consisting of a 90 m long Linac producing a 700 MeV electron beam, whose main characteristics are listed in Table 1.

Table 1: Main Characteristics of the ELI-NP Linac

Number of bunches	32
Bunch spacing	16 ns
Charge/bunch	[25–400] pC
Bunch size, σ_x	100-200 µm
Bunch size, σ_y	100-200 µm
Bunch length, σ_z	3–4 ps

The stripline BPMs for the GBS of ELI-NP have been originally designed by the Accelerator division of INFN/LNF in Frascati (Rome), and are being manufactured by the company *Comeb*. After production, the BPM units are shipped to ALBA for electrical characterization and alignment measurements. In total there will be 32 BPM units, all of them $\lambda/4$ stripline type working at ~500 MHz, shorted on the downstream port. Figure 1 shows a schematic drawing and a model of the stripline, including the port naming convention used throughout all measurements.

This document describes the methodology followed to characterize the stripline BPMs. This is done in two ways: first, the so-called electrical offset is obtained (x_e, y_e) using the well-known Lambertson method [1, 2], which is used to analyze the asymmetries among BPM electrodes.



(a) cross-section. (b) 3D BPM Model.

Figure 1: Naming convention and 3D BPM Model.

Next, we emulate the wire scan by scanning the BPM transversely around the stretched wire, Fig. 2, to obtain the sensitivity factors k_x, k_y and the mechanical offset (x_w, y_w). These offsets, referenced with respect to BPM's fiducial points, are due to all possible mechanical effects and they will be taken into account when installing the BPM units in the GBS Linac oF ELI-NP facility.

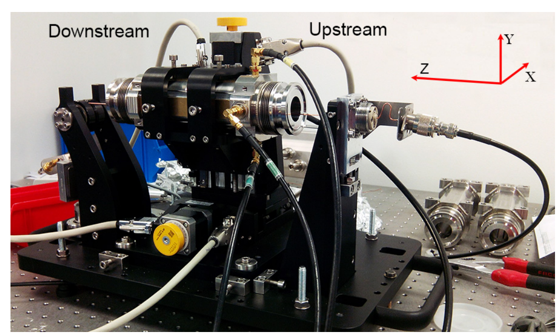


Figure 2: Photo of the BPM and the test bench in the lab.

ELECTRICAL CHARACTERIZATION

The beam position (x_b, y_b) in a symmetric BPM mounted in a circular chamber is obtained from the classical difference over sum (DOS) expression for the electrode signals $V_{1..4}$ with removed offset:

$$x_b = k_x \times \frac{V_3 - V_1}{V_3 + V_1} - x_{\text{offset}} \tag{1}$$

$$y_b = k_y \times \frac{V_2 - V_4}{V_2 + V_4} - y_{\text{offset}} \tag{2}$$

Lambertson Method

The BPM electrical center is defined as the position where $V_3 - V_1 = V_2 - V_4 = 0$, and it corresponds to the deviation (x_e, y_e) from the BPM geometrical origin (mechanical center). Its measurement does not require a BPM precisely

ISBN 978-3-95450-176-2

LIMITATIONS AND SOLUTIONS OF BEAM SIZE MEASUREMENTS VIA INTERFEROMETRY AT ALBA

L. Torino, U. Iriso, ALBA-CELLS, Cerdanyola del Vallès, Spain

Abstract

The interferometry beamline at ALBA had several limitations which have been overcome over the past years until currently, beam size measurements are successfully performed using this technique. The main limitation has been related to vibrations in the light wavefront transportation along the beamline. Several counter-measures have been taken to overcome these limitations, related both to the software analysis and the mechanical setup, where the conventional double slit system is substituted by a double pinhole in order to obtain more light and a better interferogram. This report describes the current interferometry setup at ALBA, and show some results.

INTRODUCTION

After two years, interferometry is a reliable technique to measure the beam size at the ALBA storage ring. The diagnostic beamline Xanadu has been updated, analyzed and optimized to achieve good horizontal and vertical results using the this technique [1].

The main parameters related with the beam size and the synchrotron radiation characteristics are listed in Table 1.

Table 1: ALBA Lattice Parameters

	x	y
β	0.299 m	25.08 m
Dispersion	0.04 m	0 m
Energy spread	0.001 01	
Emittance	4.6 nm	0.023 nm
Beam size	53.6 µm	23.9 µm

Several limitations due to the beamline layout have been overcome theoretically and practically. In this report the limitations and the solutions applied are described, and the results for both horizontal and vertical beam size measurements are presented.

MAIN LIMITATIONS

ALBA diagnostic beamline, Xanadu [2], takes the synchrotron radiation from a bending magnet. The light is selected by a photon shutter located at 1.684 m from the source point with an aperture of ±3.2 mm in the horizontal plane and ±5.5 mm in the vertical. After the shutter the light travels for roughly 7 m where a $\frac{\lambda}{8}$ mirror extracts only the upper lobe of the visible radiation. The mirror is motorized and approaches the orbit plane (where the majority of the x-rays are concentrated) up to a distance of 7 mm, in order to maintain the heat load low. The radiation is extracted through a vacuum window $\left(\frac{\lambda}{10}\right)$ and transported outside the tunnel in the experimental hutch through an optical path of 7 mirrors (Thorlabs, 4 ", $\frac{\lambda}{10}$). The mirrors are located "in-air".

The full beamline had been updated in 2014. The improvements of the quality of the in-vacuum mirror, of the extraction window and of all the mirrors of the optical path, already gave the possibility to obtain some preliminary results, as presented in [3].

In any case, the layout of the beamline still presents two mayor limitations.

Diffraction

The footprint of the light reaching Xanadu is strongly affected from Fraunhofer diffraction [4]. The effect is due to the first horizontal cut of the light performed from the photon shutter (vertical strips), and the vertical one due to the extraction mirror (horizontal strips). An SRW [5] simulation of the footprint is shown in Fig. 1.

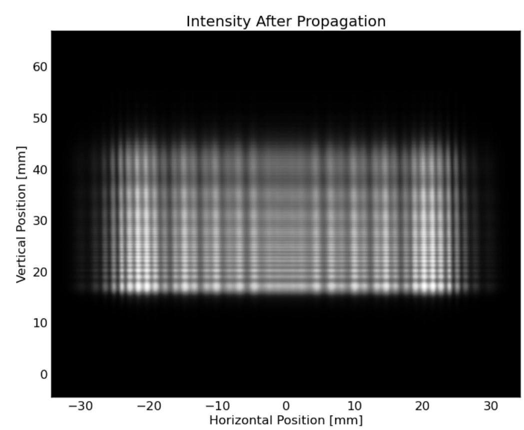


Figure 1: SRW simulation of the footprint reaching Xanadu diagnostic beamline.

When trying to perform interferometry, the use of long rectangular slits allows the selection of a large number of Fraunhofer fringes. The relative phase of these fringes is not necessarily the same and this provokes a modification in the interferogram that leads to a loss of contrast. A solution to this problem was found by using pinholes instead of slits, and adapting the theoretical formula describing the interferogram for this setup.

Vibrations

The second limitation is due to the fact that almost the whole beamline is in-air. This originates vibration in the optical components, which are sensible to air turbulence. This effect provokes changes in the interferogram characteristics and a rigid displacement of the centroid of the image.

ISBN 978-3-95450-176-2

DESIGN OF A NEW SUPER-HETERODYNE MICROTCA.4 BPM AND LLRF REAR TRANSITION MODULE (RTM) FOR THE EUROPEAN SPALLATION SOURCE

A. Young, SLAC, California, USA
H. Hassanzadegan, ESS, Lund, Sweden

Abstract

The 5 MW European Spallation Source (ESS) is a long pulsed source based on a high power superconducting LINAC. In order to achieve this high level of performance, the beam position measurement system needs to measure the beam position, phase and intensity in all foreseen beam modes with a pulse rate of 14 Hz, duration of 2.86 ms and amplitude ranging from 5 mA to 62.5 mA. We have designed a general purpose Beam Position Monitor (BPM) front-end electronics that has a dynamic range of 70dB. The front-end uses the MicroTCA (Micro Telecommunication Computing Architecture) for physics platform that consists of a 16-bit 125 MSPS ADC module (SIS8300L/2 from Struck) that uses the Zone 3 A1.1 classification for the RTM. This paper will discuss the design of this new RTM that includes eight channels of super-heterodyne receivers, two channels of DC-coupled inputs to measure klystron voltage and current, one vector modulator that modulates the LLRF output. The RTM communicates with the AMC FPGA using a QSPI interface over the zone 3 connection.

INTRODUCTION

The Beam Position Monitor (BPM) system of the ESS linac will use BPM sensors of different sizes and types. It is planned to use small-aperture stripline BPMs in the low-energy linac including the Medium Energy Beam Transport (MEBT) and Drift Tube Linac (DTL) sections. The BPMs of the cold linac including the Spoke, Elliptical and the downstream sections such as LogLeg, Dumpline and Accelerator-to-Target (A2T) may be of electrostatic button or stripline type. These two types are currently being studied in terms of performance, cost, space requirements etc. before a decision will be eventually taken on which type to use.

Most of the BPMs will belong to the Linac Warm Units (LWUs) that will be installed in between each two successive cryomodules. The LWU will include two quadrupoles, and in the current design, there is a BPM close to each quadrupole [1]. The BPM number per LWU may however be decreased to one in the next revisions that is mainly due to space limitations. The other alternative would be to use two longitudinally-short BPMs with welded feedthroughs to resolve the space limitation issue.

In order to minimize potential disturbances from nearby RF sources, BPM signal processing will be done at opposite frequency with respect to RF. This means the second harmonic (i.e. 704.42 MHz) of the BPM signal will be processed in the Spoke and upstream sections while the fundamental harmonic (i.e. 352.21 MHz) will be processed in the sections downstream to the Spokes. A direct consequence of this is that for beam phase measurements, the BPM and Low Level Radio Frequency (LLRF) systems will need phase reference signals with opposite frequencies.

The BPMs need to have an overall accuracy of +/-200 um and a resolution of 20 um with the nominal beam current of 62.5 mA and pulse width of 2.86 ms. The BPMs also need to successfully measure the beam position (possibly with a lower S/N ratio) under off-optimal conditions such as with a debunched [2] and low-current beam of 6.25 mA and pulse width of 10 us that is foreseen for linac commissioning. Calculations show that under the worst-case scenario, the BPM voltage with the off-optimal beam can be lower than the nominal voltage by three orders of magnitude.

The BPM button voltage is expected to decrease to less than one-half from the beginning to the end of the linac [1]. This is due to the beam velocity increase and the changes in the BPM size and type. Despite these voltage level variations, the electronics of all the BPMs will be based on the “ESS centralized design”. The BPM electronics and firmware of the low-energy linac will however be slightly different from those of the high-energy linac because of the RF frequency jump at the end of the Spoke section.

The BPMs will also be used to measure the absolute and relative beam phase. The phase information will be needed for RF tuning as well as beam energy measurements based on the beam Time Of Flight (TOF).

As the LLRF and BPM systems have somewhat similar requirements, an effort is being made to maximize synergy by using same/similar electronics and firmware for both systems.

ESS BPM/LLRF FRONT-END REQUIREMENTS

Both the BPM and LLRF front-end designs are based on down-mixing to Intermediate Frequency (IF) and sampling in In-phase / Quadrature-phase (I/Q) or near-IQ to measure the amplitude and phase of the RF input signal. These signals will then be FPGA processed to calculate the beam position, phase and intensity (BPM system) or to control/regulate the cavity voltage (LLRF system). A clock frequency of 88.0525 MHz (this is one-

ISBN 978-3-95450-176-2

WIRE SCANNERS AND VIBRATIONS – MODELS AND MEASUREMENTS

Juan Herranz[123], Bernd Dehning[1], Ewald Effinger[1], Jonathan Emery[1], Ana Guerrero[1]
Carlos Pereira[1], Ana Barjau[2]
[1]CERN, Geneva, Switzerland
[2]Universitat Politécnica de Catalunya, Barcelona, Spain
[3]Proactive Research and Development, Barcelona, Spain

Abstract

The new fast wire scanner foreseen to measure small emittance beams throughout the LHC injector chain will have a wire travelling at a speed of up to 20 m.s^{-1}, with a requested wire position measurement accuracy in the order of a few microns. The vibration of the thin carbon wires used has been identified as one of the major error sources on the wire position accuracy. One of the most challenging and innovative developments in this project has been the work to quantify the effect of wire vibrations and fork deformation. The measurement strategy for the former is based on the piezo resistive effect of the wire itself, while the deflection of the fork supporting the wire has been measured by semiconductor strain gauges. Dynamic models of the wire and fork have been created to predict the behaviour of the fork-wire assembly and will be used for its optimisation. This contribution will discuss the measurement setup and the model development as well as their comparison. In addition it will show that this technology can easily be implemented in current operating devices without major modifications.

INTRODUCTION

A wire scanner is an electro-mechanical device which measures the transverse beam profile in a particle accelerator by means of a thin wire moving rapidly across the beam [1]. The intersection of the wire and the beam generates a cascade of secondary particles. Those particles are intercepted by a scintillator, coupled with a photomultiplier, which measures the intensity of the light generated by the crossing particles (Fig. 1). The wire position is typically measured with a precision rotary potentiometer. By synchronising the digitised potentiometer and the scintillator photomultiplier signals it is then possible to reconstruct the transverse beam profile.

In order for the wire to reach a suitable speed when it crosses the beam, the actuator has to provide a motion which consists of an acceleration phase, a constant speed plateau and a deceleration phase (Fig. 2).

The peak acceleration values will vary depending on the peak speed required, the length of the fork, the angular travel available for the complete motion and the motion pattern parameters.

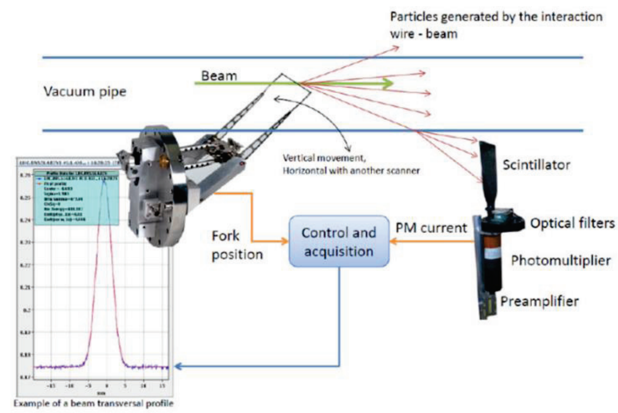


Figure 1: Schematic of the wire scanner instrument.

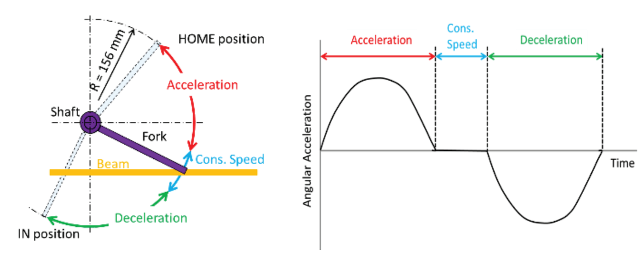


Figure 2: Typical scan cycle (left) and motion pattern (right).

The strong initial acceleration required induces deflections and vibrations in the mechanics (shaft, fork and wire), which result in discrepancies between the true position of the wire midpoint (P) and the position measured by the angular sensor (R) (Fig. 3) [2]. Due to the variation in the acceleration, these deflections cause oscillations, thus increasing the uncertainty of the wire position even further [3].

ISBN 978-3-95450-176-2

HIGH DYNAMIC RANGE DIAMOND DETECTOR READOUT SYSTEM FOR THE CERN'S BEAM WIRE SCANNERS UPGRADE PROGRAM

J.L. Sirvent#, B. Dehning, J. Emery, CERN, Geneva, Switzerland
A. Dieguez, Universitat de Barcelona, Barcelona, Spain

Abstract

A secondary particle shower acquisition system is under design for the upgrade of CERN's beam wire scanners. The system needs to be capable of performing bunch by bunch synchronous measurements with an integration time of 25 ns and to cope with signal variations of up to 6 orders of magnitude. The whole dynamic range should be covered by the acquisition system with a single configuration and should have no tuneable parameters. The secondary particles are detected using a polycrystalline diamond detector with the signal digitization performed nearby with a custom front-end system, designed to resist a total ionising radiation dose up to 1 kGy in 10 years. The digital data transmission, front-end synchronization and control are performed through a bidirectional optical link operating at 4.8 Gbps using CERN's GBT protocol. For the digitization, two radiation tolerant integrator ASICs (ICECAL and QIE10) are under study.

INTRODUCTION

A beam wire scan is an interceptive method for transverse beam profile measurements. The working principle of wire scanners consists on the passage of a very thin carbon wire (~30um) through the particle beam. The secondary particle shower generated by the beam/wire interaction, is detected outside of the beam pipe and transformed into an electrical current proportional to the loss intensity. The beam profile is reconstructed by plotting the loss intensity versus the wire position. Using the measurements from these devices the beam is determined, allowing calculation of the beam emittance, an important parameter for optimising collider's luminosity.

The Beam Wire Scanners Upgrade Program

The CERN accelerator complex currently has 32 installed beam wire scanner systems of different architectures located along the injector chain and in the Large Hadron Collider (LHC) itself. In terms of mechanics, these systems share some common characteristics, such as the transfer of the motor movement from air to vacuum through bellows. These bellows have a limited lifetime and have compromised accelerator operation in the past trough the appearance of vacuum leaks. In addition, the use of complex mechanics leads to mechanical play that reduces the systems accuracy and hence measurement performance. The current scan speeds are also limited and do not allow the measurement of high intensity beams due to wire sublimation [1].

jsirvent@cern.ch

The development of a new scanner type is motivated by all the above mentioned issues and the need to measure smaller beam sizes at higher beam intensities in the future. The basic concept is to combine a high scan velocity, nominally $20ms^{-1}$ to avoid wire damage, with an accurate and direct wire position determination avoiding bellows and any lever arm mechanism. The specified beam profile measurement accuracy is set to 2µm. The upgraded system, common for the CERN PSB, PS, SPS and LHC, is therefore based on an in-vacuum motor rotor, with the stator outside, avoiding the use of bellows, and incorporating an optical position sensor for accurate position determination [2] (see Figure 1).

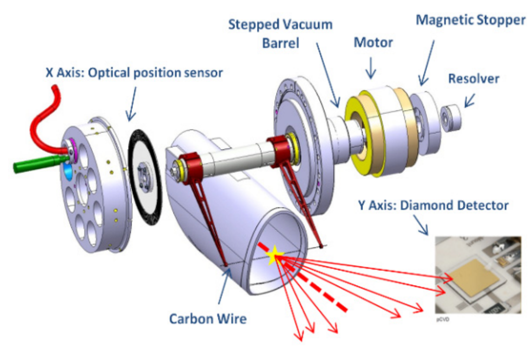


Figure 1: Upgraded Beam Wire Scanner Design.

Secondary Shower Acquisition System Upgrade

Presently, the secondary particle showers from operational beam wire scanners are detected by a scintillator. The light produced transits a wheel of selectable optical filters, after, it is detected using a photo multiplier tube (PMT) that transforms the optical signal into a current. A current-to-voltage, transimpedance, amplifier is used to drive this signal over CK50 coaxial cables of up to 250m, to surface buildings where the digitization is performed. To reach a suitable resolution, this architecture obliges the accelerator operators to set-up the system, selecting a suitable combination of PMT gain and optical filter, according to the beam characteristics. On these systems the dynamic range is limited by the pre-amplifier, sometimes the Gaussian tails of the beam profile are too much shadowed by noise, and in some cases PMT saturation effect can lead to incorrect measurements [3].

The upgraded secondary shower acquisition system aims to use 500um thick polycrystalline chemical vapour deposition (pCVD) diamond as detector. This requires new acquisition electronics which need to cover the high dynamic range of the diamond detector without tuneable parameters, while also providing very low noise

ISBN 978-3-95450-176-2

ELECTROMAGNETIC FIELD PRE-ALIGNMENT OF THE COMPACT LINEAR COLLIDER (CLIC) ACCELERATING STRUCTURE WITH HELP OF WAKEFIELD MONITOR SIGNALS

N. Galindo Munoz, N. Catalan Lasheras, S. Zorzetti, M. Wendt, CERN, Geneva, Switzerland
A. Faus Golfe, IFIC, Valencia, Spain;
V. Boria Esbert, Polytechnical University of Valencia, Valencia, Spain

Abstract

The CLIC project, currently under study at CERN is an electron-positron collider at 3 TeV centre-of-mass energy and luminosity of $2*10^{34}$ $cm^{-2}s^{-1}$. Achieving such luminosity requires a beam dimension of 1 nm in the vertical plane and high beam stability. The TD24 is a traveling wave structure operating at 12 GHz designed to reach 100 MV/m at constant gradient. It consists of two coupling cells and 24 disks. The RF is coupled from cell to cell though an iris of 5.5 mm. To minimize the occurrence of wake-fields and minimize the emittance growth $\Delta\varepsilon_y$ below 5%, the pre-alignment precision of the electrical centre of the accelerating structure (AS) on its support has to be better than 7 µm. Following, the AS is actively aligned with beam using the wakefield monitor (WFM) signals, with a resolution of 3.5 µm. A test bench for laboratory measurements has been designed and exploits the asymmetry created by RF scattering parameters by an off-centre conductive wire, stretched to locate the electromagnetic centre of the AS. Simulations and preliminary measurement results are presented.

INTRODUCTION

The study that concerns this paper is part of a project founded by the European Commission under the name of PACMAN* [1] (Particle Accelerator Component's Metrology and Alignment in the Nanometre scale). The status of this project is presented in these proceedings [2].

The CLIC (Compact Linear Collider) [3] [4] accelerator currently under study at CERN, aims to collide electrons and positrons with vertical beam sizes of 1 nm and an emittance growth budget $\Delta\varepsilon_y$ of less than 5%. To preserve the emittance at the main linac at CLIC, very tight micrometric tolerances are required concerning the position of the components focusing (Quadrupole), accelerating (Accelerating Structure, AS) and detecting (Beam Position Monitor, BPM) the beam over a distance of several hundreds of meters, all along the accelerator.

The accelerating structure TD24 shown in Figure 1 is a traveling wave structure designed for high constant gradient of 100MV/m for compact acceleration required at CLIC. It consists of two coupling cells and twenty-four accelerating cells (see Figure 2) whose iris dimensions decrease gradually in order to compensate the energy given to the beam and ensure constant accelerating gradient. Very precise machining and nanometric tolerances are achieved and demonstrated during the fabrication process of the disks forming the structure. These disks are stacked and assembled by diffusion bonding. The full assembly and bonding process may lead to a geometric deformation of the structure whose tolerances have been established to be less than 1 µm in the case of errors of the iris shape, 5 µm for disk-to-disk misalignment, and a maximum tilt error of 140 µrad.

Figure 1: The TD24 accelerating structure.

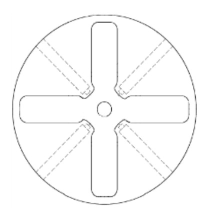


Figure 2: One of the disks of the AS.

The AS is feed in the first coupling cell with a 12 GHz radiofrequency (RF) signal that is coupled from cell to cell through an iris with a mean aperture of approximately 5.5 mm. With such small apertures, the alignment of the electrical centre of each cell in the accelerating structure with respect to the beam axis is extremely important to avoid the excitation of wake-fields. In particular transverse wake-fields might lead to beam instabilities, incoherent transverse kicks in following bunches, and an effective increase of the emittance, which results in a decrease of the luminosity of the collider.

Four waveguides with a cut-off frequency of 15 GHz are installed at the end of every cell in order to extract the high order modes (HOM) without distorting the

*The PACMAN project is funded by the European Union's 7th Framework Programme under Grant Agreement no. 606839

ISBN 978-3-95450-176-2

DESIGN OF A LASER-BASED PROFILE MONITOR FOR LINAC4 COMMISSIONING AT 50 MeV AND 100 MeV

T. Hofmann*, E. Bravin, U. Raich, F. Roncarolo, CERN, Geneva, Switzerland
S. Gibson, A. Bosco, G. Boorman
John Adams Institute at Royal Holloway, University of London, Egham, United Kingdom
E. Griesmayer, CIVIDEC Instrumentation, Vienna

Abstract

A laser-based profile monitor has been designed for commissioning of CERN's LINAC4 accelerator at 50 MeV and 100 MeV, as part of the development of a non-destructive profile and emittance monitor foreseen for the final 160 MeV beam. The system is based on a low power laser which is scanned through the H^- beam. Electrons, which are photo-detached from the ions by the laser, are deflected by a steerer magnet and measured by a diamond detector. The custom designed diamond detector is tailored to minimize the disturbance due to the electromagnetic field of the passing main beam. The laser source will be installed in the LINAC4 Klystron gallery located 75 m away from the profile station and an optical fiber will transport the laser to the tunnel. The laser propagation for different pulse length and peak power values was characterized with laboratory tests with such a long fiber. In this paper we describe the overall design, focusing on key elements such as the fiber-based laser transport and the electron detection with the diamond detector.

INTRODUCTION

As the LINAC4 construction advances, its commissioning is taking place in stages at different beam energies, as indicated in Fig. 1. So far, all the accelerator's equipment and the beam parameters have been validated up to the exit of the first DTL tank (12 MeV).

The conventional techniques which are foreseen to measure the beam profile and transverse emittance, like SEM-grids or wire-scanners, are all destructive or at least invasive with respect to the ion beam.

During the 3 MeV and 12 MeV commissioning, a non-invasive laser system was successfully operated to measure the vertical emittance of the H^- beam, by collecting the neutralized H^0 atoms [1–3].

The next two stages of the LINAC4 commissioning will be used to check the performance of a modified version of the laser-based instrument. The system will be part of a diagnostics test bench that will be temporarily installed after the last DTL cavity (50 MeV) and then moved after last CCDTL cavity (100 MeV).

For these development stages, the system will be setup for measurements in the vertical plane only, with the aim of demonstrating the ion beam profile reconstruction by collecting the electrons that are photo-detached during the laser scan [4].

* thomas.hofmann@cern.ch

The main novelty of our system with respect to those in other facilities [5,6] will be the use of a relatively low power laser and of a fast diamond detector as electron collector.

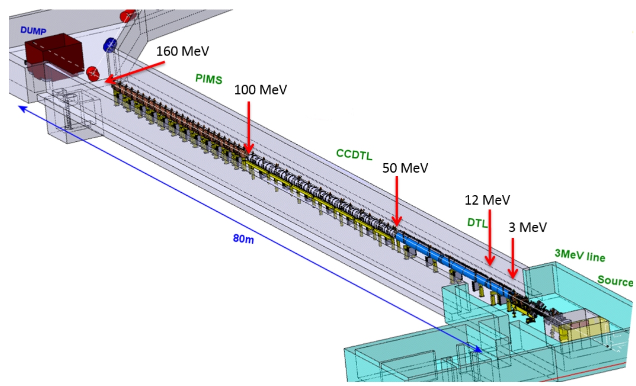


Figure 1: LINAC4 facility indicating the beam energy that will be reached during the different commissioning stages. The laser stripping system has already been tested at 3 MeV and 12 MeV periods and is presently setup for 50 MeV and 100 MeV before being permanently installed at 160 MeV.

CONCEPTUAL DESIGN

The conceptual and mechanical design of the system is shown in Fig. 2. Since in our application the laser beam is relatively small with respect to the H^- beam size, the vertical position of the liberated electrons is well defined and counting the stripped electrons as function of the laser position during a scan allows the beam profile to be reconstructed. A dipole magnet located just after the laser interaction point (IP) is used to extract the electrons toward the diamond detector designed to integrate the electron signal. Due to the much lower energy of the stripped electrons with respect to the H^- ions, the magnetic field necessary to extract the electrons has a very weak effect on the main beam.

As the detachment cross section is small and during a linac pulse only a tiny H^- beamlet is traversed by the laser, less than 10^8 H^- ions per linac pulse are neutralized (i.e. lost). Compared with the total pulse charge of 10^{14} for the nominal beam current (40 mA), this technique can therefore be considered as non-invasive.

LASER DELIVERY, TRANSPORT AND FOCUSING

The selected fiber-laser (V-Gen VPFL-ISP-1-40-50) operates at a wavelength of 1064 nm, with kilowatt peak powers

ISBN 978-3-95450-176-2

TRANSVERSE RIGID DIPOLE AND INTRA-BUNCH OSCILLATION DETECTION USING THE TRANSVERSE FEEDBACK BEAM POSITION DETECTION SCHEME IN SPS AND LHC

W. Hofle, G. Kotzian, D. Valuch, CERN, Geneva, Switzerland

Abstract

The LHC and SPS transverse dampers use beam position electronics with I,Q detection at 400 MHz and 200 MHz, of the sum and difference signals from a strip-line pick-up. Digitization is performed to give synchronous bunch-by-bunch data at the rate of 40 MHz corresponding to the bunch spacing of 25 ns. A performance in the μm range is achieved with beams in LHC and has contributed to the high performance of the essential transverse feedback during the LHC run 1. In the present paper we review the systems deployed and their performance as well as the potential of the I,Q detection to also detect intra-bunch motion. The principle is illustrated using data from LHC injection tests in which intra-bunch motion is expected and has been observed due to electron cloud instabilities. The potential use of this signal to drive a transverse intra-bunch feedback system is outlined.

INTRODUCTION

The CERN LHC transverse feedback system, fully commissioned in 2010 [1] uses strip-line beam position monitors to detect bunch oscillations [2] around the closed orbit and provides feedback to damp these oscillations and keep the beam stable. Kickers operate in baseband and cover betatron frequencies up to 20 MHz, half the bunch repetition frequency to be able to damp all coupled bunch dipole oscillations. The power system of the LHC transverse feedback system uses the same technology as used in the CERN SPS transverse feedback system having operated for many years. Kickers use the electric field only with kicker plates ranging from 1.5 m length to 2.4 m length (1.5 m for the LHC and the SPS vertical systems and 2.4 m for the SPS horizontal systems) driven by tetrode tube amplifiers directly installed in the accelerator tunnel under the kicker structure. The SPS transverse feedback system has been upgraded during the long shutdown 1 (LS1, 2013-2014) as part of the LHC Injector Upgrade Project (LIU) [3] to use the same analogue and digital signal processing techniques as already used successfully since 2010 in the LHC.

In the following we describe the signal processing, analogue and digital, used to compute the bunch position (symmetric mode component) as well as the headtail oscillation amplitude (asymmetric mode component).

POSITION DETECTION IN THE SPS AND LHC TRANSVERSE DAMPERS

The stripline pick-ups are optimized in length to have the maximum response around the RF frequency of the main RF system in these accelerators, 400 MHz in case of the LHC and 200 MHz in the SPS case. The SPS system also includes a variant of hardware for the doublet scrubbing beam, a beam that is split at SPS injection to form two bunches spaced 5 ns every 25 ns [3]. The hardware dedicated to this type of beam takes the beam-pick-up signal at a band centered around 40 MHz directly sampling it with 120 MS/s without analogue down conversion. This ensures proper operation during the splitting process.

LHC Transverse Damper (ADT)

The LHC pick-up signal processing scheme [2] is depicted in Fig. 1. The signals from the strip-line pick-up plates pass through a hybrid and both the sum signal (proportional to bunch intensity) and the delta signal (difference of PU plates, proportional to bunch intensity and position) are taken into account in the further processing. A band-pass filter selects the frequency components around the RF frequency of 400 MHz. The filter is shaped to give in time domain a burst of nine pulses from each bunch, at 400 MHz. Each of the signal bursts from the individual bunches is then separated by one RF period, 2.5 ns , for the canonical bunch spacing of 25 ns. After analogue down conversion a 15 ns to 20 ns wide pulse is obtained that is sampled synchronously using a 40 MHz sampling clock. Digitization is done with a 16 bit ADC and four numerical values are obtained for each bunch, the in-phase (I) and quadrature components (Q) — with respect to the RF frequency — of the Σ and Δ signals.

Within an FPGA the absolute value of the bunch position can be calculated by division of the magnitude of the (I, Q) vector of the Δ and Σ signals

$$x = \frac{\sqrt{\Delta_\mathrm{I}^2 + \Delta_\mathrm{Q}^2}}{\sqrt{\Sigma_\mathrm{I}^2 + \Sigma_\mathrm{Q}^2}} c_\mathrm{cal} \,. \tag{1}$$

The sign for the beam position has to be correctly chosen and depends on the exact phasing of the beam RF signal with the 400 MHz reference RF used for the demodulation. A calibration factor ($\mathrm{mm}/\mathrm{counts}_\mathrm{ADC}$) is determined when the damper is set-up using the orbit measurement system and making closed orbit bumps at the location of the damper pick-ups. In practice, on the FPGA in the damper feedback system, a different algorithm is used to compute the normalised position which takes into account the measured angle between sum and delta signal with respect to the (I,Q) coordinates defined by the 400 MHz RF. This algorithm is using the relation

$$\frac{\Delta_\mathrm{I}\Sigma_\mathrm{I} + \Delta_\mathrm{Q}\Sigma_\mathrm{Q}}{\Sigma_\mathrm{I}^2 + \Sigma_\mathrm{Q}^2} = \frac{|\Delta|}{|\Sigma|} \cos(\phi_\Delta - \phi_\Sigma) \tag{2}$$

ISBN 978-3-95450-176-2

DEVELOPMENT OF A VERSATILE OTR-ODR STATION FOR FUTURE LINEAR COLLIDERS.

R. Kieffer, T. Lefevre, S. Mazzoni, CERN, Geneva, Switzerland
L. Bobb, Diamond Light Source, Oxfordshire, UK
M. Bergamaschi, P. Karataev, T. Aumeyr, JAI, Egham, Royal Holloway, Univ. of London, Surrey, UK
M. Billing, J. Conway, J. Shanks, Cornell University, CLASSE, Ithaca, NY, USA
N. Terunuma, KEK, Tsukuba, Japan

Abstract

In order to study the feasibility of Optical Transition (OTR) and Diffraction (ODR) Radiation based profile measurement for the future electron-positron linear colliders (ILC, CLIC) a new dedicated instrument is under development at CERN to be installed in the Accelerator Test Facility 2 (ATF2) at KEK in fall 2015. To optimize sensitivity to micron and sub-micron beam sizes, we plan to observe ODR/OTR in the visible-UV wavelength range, down to approximately 150 nm. In this paper, we will present the status of the project with a focus on the target development which is one of the most critical aspects of the design.

INTRODUCTION

OTR beam imaging systems are widely used to measure the transverse properties of a particle beam. Recently, sub-micron beam size measurements have been reported on the ATF2 extraction beam line by measuring the visibility of the OTR point spread function [1–3]. However, as OTR occurs where a particle beam crosses a boundary between two different dielectric media, e.g. a Si target, the measurement is strongly invasive. An OTR target will withstand a single bunch but will get quickly damaged when using longer bunch trains as foreseen in linear colliders. A non-interceptive alternative for high power beams would be to replace the solid target by a slit, which will emit ODR. The Coulomb field induced by the beam generates polarisation currents on the slit edges that in turn give rise to radiation [4]. Similarly to OTR, Diffraction radiation will be emitted both in the backward (BDR) and forward (FDR) direction. Beam size information is retrieved from the far-field angular distribution of ODR. Experiments using ODR were performed in 2004 [5] measuring beam sizes as small as 14 microns. Since then ODR has been developed further [6] to provide online transverse beam size monitoring. Further improvements in resolution can be achieved by a careful optical design as well as the observation of DR at smaller wavelength down to 150 nm. In 2010, an experimental test program [7] was initiated aiming at developing the DR slit technology and possibly demonstrating resolution down to few microns.

In this paper, a combined Optical Transition Radiation (OTR) and Diffraction Radiation (ODR) monitor is being proposed to measure the ultra-small emittance of beams generated in damping rings. The latest results on slit development tested at Cornell are also discussed.

THE ODR/OTR STATION FOR ATF2

The Accelerator Test Facility 2 (ATF2) at KEK extracts a 1.28 GeV electron beam from the low-emittance damping ring of ATF, which can be focussed to a sub-micron vertical beam size [8], making it an ideal test facility for high resolution beam size studies. The first phase of the experiment will be dedicated to the OTR Point Spread Function (PSF) and ODR/OTR angular measurements in the visible range. At a later time, the setup will be upgraded with a UV ODR line to further improve optical resolution.

Description of the Setup

The station, as depicted in Fig. 1, will be composed of a mirrored target and a set of two masks (horizontal, vertical) in order to shield the target from synchrotron radiation. Mask and targets can be inserted and removed one by one with micrometer precision actuators. Two UV-compatible view ports sitting at 40 and 90 degrees with respect to the beam axis will be used to extract the light from the tank.

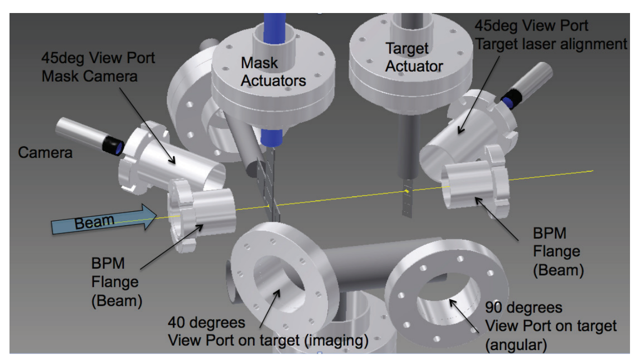


Figure 1: Sketch of the ODR-OTR station.

The OTR Optical Line

OTR will be used to measure single bunch, sub-micron beam size using the PSF visibility technique [2]. The optical line has been designed with the help of optical simulations performed with ZEMAX. [9] A two-lens system has been adopted, with a short (f = 15 mm) focal objective lens installed on the target holder producing an intermediate image that is conjugated to the camera sensor plane by means of a relay lens. This configuration allows a high magnification factor of up to M = 12 with a 4.6 mm PSF

ISBN 978-3-95450-176-2

A NEW ORBIT SYSTEM FOR THE CERN ANTIPROTON DECELERATOR

R. Marco-Hernández, M.E Angoletta, M. Ludwig, J.C. Molendijk, F. Pedersen, R. Ruffieux, J. Sánchez-Quesada, L. Søby, CERN, Geneva, Switzerland

Abstract

This contribution will describe the new orbit system foreseen for the Antiproton Decelerator (AD) located at CERN. The AD decelerates antiprotons from 3.57 GeV/c down to 100 MeV/c, with an intensity ranging from 1×10^7 to 5×10^7 particles. The orbit system developed is based on 34 horizontal and 29 vertical electrostatic beam position monitors (BPMs) fitted with existing low noise front-end amplifiers. After amplification, the BPM signals will be digitized and down-mixed to baseband, decimated and filtered before computation to extract the position. The digital acquisition part of the orbit measurement system is based on the VME Switched Serial (VXS) enhancement of the VME64x standard and includes VITA57 standard FPGA Mezzanine Cards (FMC). The system is foreseen to measure complete orbits every 2.5 ms with a resolution of 0.1 mm.

INTRODUCTION

The AD ring [1] is a synchrotron where ~$3\text{x}10^7$ antiprotons produced from a production target are injected at 3.57 GeV/c. After RF manipulation and stochastic cooling, the beam is decelerated in several stages involving additional stochastic cooling, electron cooling and RF manipulation, before the antiprotons are extracted at 100 MeV/c. The AD revolution frequency varies from 1.59 MHz down to 174.5 kHz during the deceleration cycle. Fig. 1 shows a schematic view of the AD deceleration cycle and the essentials of its operation.

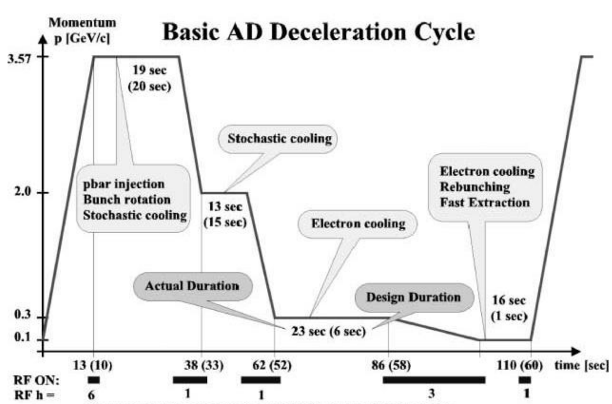


Figure 1: Basic AD deceleration cycle.

The present AD orbit system [2] has a limited performance in terms of time resolution since it is a multiplexed system acquiring signals from one BPM at a time. This allows for a complete orbit measurement only every 1.2 seconds. The new requirement of orbit measurements on the deceleration ramps involves moving to a parallel system where each BPM signal has its own analogue to digital converter (ADC) channel.

The new beam position system will use the same 63 BPMs as well as the head amplifiers of the present system, but with the reception amplifiers, the digital acquisition system as well as the front-end software totally updated.

The aim for the new system is to measure complete orbits every 2.5 ms with a resolution of 0.1 mm.

FRONT-END ELECTRONICS

Beam Position Monitors

The new orbit system acquires the signals from 34 horizonal and 29 vertical electrostatic BPMs. The sigma (Σ) signal is provided by a specific annular electrode while the delta (Δ) signals are derived from two semi-sinusoidal electrodes. The Δ signal level in the electrodes for $1\text{x}10^7$ particles is 4.2 µVp with a BPM differential sensitivity of 0.1 µVp/mm.

Head Amplifiers

The existing head amplifiers [2], placed close to the BPMs around the AD ring, will be also used in the AD new orbit system. These amplifiers have an equivalent input noise of 0.6 nV/√Hz for the Δ inputs, which is low enough to fulfil the 0.1 mm resolution requirement. In order to have this low input noise level, they feature a differential amplifier of 2 times 6 parallel Junction Field Effect Transistors (JFETs). The gain for the Δ outputs can be selected (47 dB or 20 dB) by means of a Transitor-Transistor Logic (TTL) digital control signal. The bandwidth for the high gain setting, which will be used in the new system, is 10 kHz – 20 MHz and the CMRR is better than 66 dB below 10 MHz. The head amplifiers have differential delta and sigma outputs which are transmitted from the AD ring to the AD control room. An analogue calibration input signal and two TTL digital control signals are implemented to simulate the maximum positive/negative beam displacement as well as a centred beam for calibration purposes.

Reception Amplifiers

New reception amplifiers, placed close to the digital acquisition system in the AD control room, have been designed to transform the differential signals coming from the head amplifiers to single ended signals and transmit them to the ADCs of the digital acquisition system. Two differential amplifiers with a 0 dB gain and a bandwidth of 560 Hz-80 MHz have been implemented for the sigma and delta signals.

ISBN 978-3-95450-176-2

DEVELOPMENT OF AN IONIZATION PROFILE MONITOR BASED ON A PIXEL DETECTOR FOR THE CERN PROTON SYNCHROTRON

D. Bodart[1], B. Dehning[1], S. Levasseur[1], P. Pacholek[1], A. Rakai[1], M. Sapinski[1], K. Satou[1,2], G. Schneider[1], D. Steyart[1], and J.W. Storey[1]

[1]CERN, Geneva, Switzerland
[2]Accelerator Laboratory, KEK, Oho, Tsukuba, Ibaaraki, Japan

Abstract

The transverse emittance measurement in the CERN Proton Synchrotron (CPS) is currently performed using fast rotational wire scanners. These scanners cannot provide continuous bunch-by-bunch measurements and the expected future increase of the beam brightness will lead to an accelerated sublimation of the wire. A novel Ionization Profile Monitor (IPM) is currently under development to cope with these challenges. The readout of this device will be based on a hybrid silicon pixel detector with a Timepix3 readout chip. Pixel detectors are sensitive to single electrons therefore eliminating the need for traditional Multi-Channel Plates, which suffer from aging phenomena. The early digitization of the signal will reduce the susceptibility of the readout system to electromagnetic interference, while the time resolution of the Timepix3 allows for bunch-by-bunch measurements. Due to the small length of the detector a new simplified ion trap has been designed. The guiding field will be provided by a new self-compensating magnet. It is foreseen to test a prototype version of the device with beam in 2016.

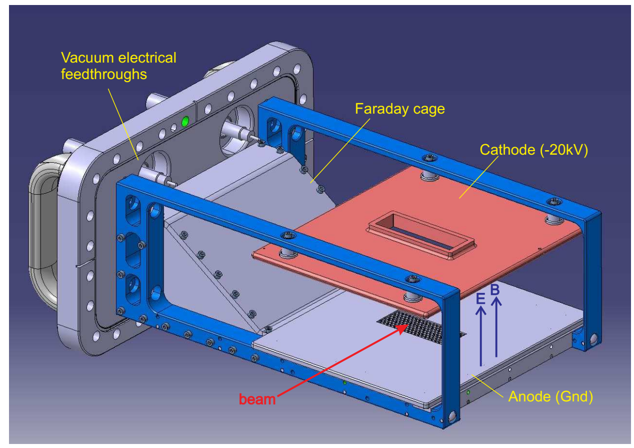


Figure 1: Design of the new non-destructive transverse beam profile monitor for the CPS. Ionization electrons are accelerated by a 270 kV/m electric field towards the pixel detector, which is located at the ground electrode just beneath a honeycomb shield. To suppress any beam induced electromagnetic effects the pixel detector and readout electronics are located in a Faraday cage.

INTRODUCTION

A fast non-destructive transverse profile monitor is currently under development for the CERN Proton Synchrotron (CPS) which is based on the ionization of rest gas molecules by high energy beam particles. The transverse beam profile is inferred from the distribution of ionization electrons which is measured by accelerating the electrons onto an imaging detector consisting of a pixelated p-on-n silicon sensor bonded to a Timepix3 readout chip. The fast sampling and readout speed of the Timepix3 will facilitate bunch-by-bunch measurement of the beam profile. A 0.2 T magnetic field parallel to the electric field will maintain the transverse position of the ionization electrons during the passage of the electrons to the imaging detector. The main elements of the design are shown in Fig. 1. Initial studies of the electron rates for various types of beams expected in the PS together with proposed modes of data acquisition are presented in [1]. Here the final design of the prototype device is presented.

HYBRID PIXEL DETECTOR

Ionization profile monitors typically amplify the ionization signal electrons or ions by means of Micro Channel Plates (MCPs). Charge from the MCP is then either readout optically by means of a phosphor screen and camera [2, 3] or directly using arrays of narrow anodes [4, 5]. A common problem for MCP based systems is the inhomogeneous degradation of the MCP gain and limited lifetime. In recent years hybrid pixel detectors, which consist of a pixelated silicon sensor bump bonded to a pixelated readout chip, have become widely used in many high energy physics and medical imaging applications. By removing the metalization usually applied to the surface of a silicon sensor, hybrid pixel detectors become sensitive to single electrons with an energy of at least 3.6 keV. As an imaging detector for IPMs hybrid pixel detectors offer a number of advantages, namely: trigger-less readout, high spatial and time resolution, early digitization, radiation hardness and removing the requirement for additional amplification stages.

The imaging detector for the CPS IPM is based on the Timepix3 hybrid pixel detector readout chip, which has been developed in the framework of the Medipix3 collaboration [6, 7]. Timepix3 consists of a pixel matrix of 256×256 square pixels with a pitch of 55 µm, covering an area of $14 \times 14\ \mathrm{mm}^2$. The trigger-less readout allows for a sustained hit-rate of up to 40 Mhits/cm^2/s and has a minimum time resolution of 1.562 ns. To detect electrons the Timepix3 will

ISBN 978-3-95450-176-2

DEVELOPMENT AND TEST OF HIGH RESOLUTION CAVITY BPMS FOR THE CLIC MAIN BEAM LINAC*

J. R. Towler†, T. Lefevre, M. Wendt, CERN, Geneva, Switzerland
S. T. Boogert, A. Lyapin, JAI, Egham, UK
B. Fellenz, Fermilab, Batavia, USA

Abstract

The main beam of the Compact LInear Collider (CLIC) requires the beam trajectory to be measured with 50 nm spatial resolution. It also requires a time resolution capable of making position measurements of the head and tail of the 156 ns long CLIC bunch train, for use in dispersion free steering based on an energy chirp applied along the train. For this purpose, a stainless steel 15 GHz cavity BPM prototype has been manufactured, installed at the CLIC Test Facility (CTF3) and tested with beam. An improved design has been fabricated from copper. We discuss results from the two types of the prototype pickups, both from laboratory tests and from beam tests. We also cover the development of the new downconverter electronics.

INTRODUCTION

CLIC is a proposed next generation linear collider which will have a center of mass energy of 3 TeV. The main linac is 40 km long and the beam delivery system (BDS) is 10 km long in total. Over this distance, a precise, reproducible measurement of the beam trajectory is mandatory with almost 4800 BPMs will be needed to achieve this goal [1]. The BPMs are required to have a spatial resolution of 50 nm and are also required to make multiple measurements along the 156 ns bunch train. This is necessary to distinguish the beam displacement along the energy-chirped bunch train on a dispersive trajectory.

A new system of three prototype copper cavity BPMs have been manufactured and installed in the main beam of the Two Beam Test Stand (TBTS) at the CLIC Test Facility (CTF3). One of these BPMs is shown in Figure 1. The BPMs consist of a cylindrical pillbox position cavity with waveguides which strongly coupled to the two polarisations of the first order dipole mode (TM_{110}). The BPM is also equipped with a reentrant reference cav- ity, for coupling to the first order monopole mode (TM_{010}). These modes are excited at 15 GHz, as this is a harmonic of the 1.5 GHz bunching frequency allowing signals from each bunch to add constructively and dominate signals from other modes. The chosen harmonic frequency is sufficiently high, to ensure a high shunt impedance, i.e. high position sensitivity, while staying well below the fundamental TM_{01} beampipe cutoff frequency of 29 GHz. The bunch spacing used at CTF3 differs from that proposed for CLIC where the final bunch spacing frequency will be 2 GHz. A cavity with a dipole frequency of 14 GHz is therefore foreseen to be used.

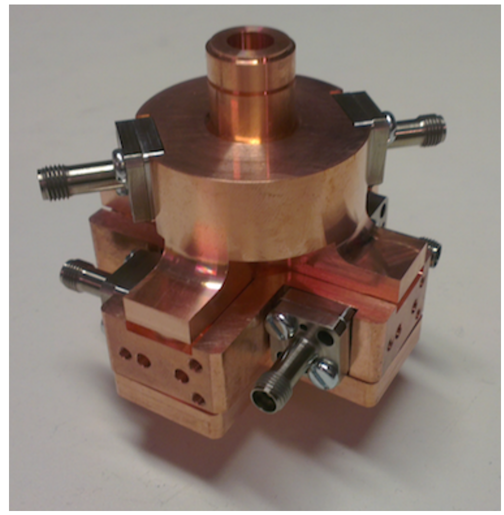


Figure 1: Prototype copper CLIC cavity BPM.

The signal amplitude of the TM_{110} dipole mode, excited in the position cavity by a displaced beam, is directly proportional to beam offset and charge for small offsets [2]while the amplitude of the (TM_{010}) monopole mode is directly proportional to the beam charge, but independent of the beam offset. The (TM_{010}) monopole mode can therefore be used to normalise signals from the position cavity, and used as a phase reference to indicate the sign of the beam position and for rejection of the trajectory and bunch tilt signals.

BPM OVERVIEW

During 2013 and 2014, a stainless steel cavity BPM was tested at CTF3 which performed well, but could benefit from a few im- provements [3]. These improvements were taken into account and incorporated into a new design [4]. The old design had a low Q factor of 250, which gave a higher time resolution than required but the position resolution suffered as a result. To improve this, simulations were performed to optimise the Q value. Copper was finally chosen as the material for the new design, to give the best position resolution while maintaining a temporal resolution within the specification. New feedthrough antennas were also designed to remove the necessity of tuning the distance between the antenna and the opposite waveguide wall. The geometry of the reference cavity then had to be slightly modified to compensate the change in resonant frequency and Q value caused by the new feedthroughs. The geometry of the position cavity remained unchanged.

* Computing time with ACE3P provided by US DOE at NERSC
† jack.towler@cern.ch

ISBN 978-3-95450-176-2

EXPERIENCE FROM THE CONSTRUCTION OF A NEW FAST WIRE SCANNER PROTOTYPE FOR THE CERN- SPS AND ITS OPTIMISATION FOR INSTALLATION IN THE CERN-PS BOOSTER

R.Veness, W.Andreazza, N.Chritin, B.Dehning, J.Emery, D.Gudkov, J.Herranz Alvarez, P.Magagnin, E.Piselli, CERN, Geneva, Switzerland
S.Samuelsson, CERN, Geneva, Switzerland, on secondment from Chalmers University of Technology, Gothenburg, Sweden

Abstract

A new design of wire scanner is under development for the LHC Injector Upgrade project at CERN. A prototype has been designed, built and installed in the SPS accelerator to test the concept in an operational environment. New technology has been developed and qualified for in-vacuum motor and structural components using 3D metal additive machining. This paper will describe the technology developed for this scanner and the test results to date.

This prototype has recently been re-optimised to fit in the limited space available in the PS Booster rings. This design will also be presented.

INTRODUCTION

The LHC Injector Upgrades (LIU) project at CERN [1] covers a wide range of changes to the LHC pre-injectors (LINAC, PS Booster, PS and SPS) to optimise beam emittance and intensity for the future upgrade of the LHC. These improvements will require new beam instrumentation, including transverse profile monitoring for the smaller, brighter beams in all injectors. LIU is scheduled for completion during the next long machine shutdown in 2019-20.

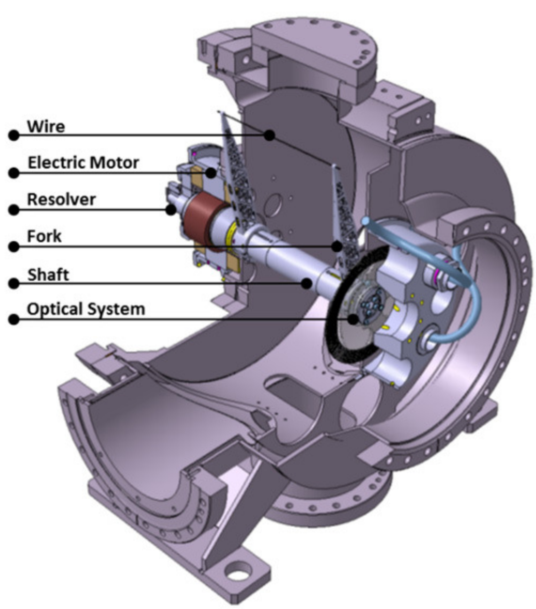


Figure 1: Beam wire scanner for SPS, general view.

A new wire scanner concept, based around an in-vacuum motor rotor is under development [2] to fulfil the LIU requirements. Prototypes have been built, with one installed in the SPS to test performance in an accelerator and the other used for laboratory development and testing. Figure 1 shows a cut away view of the scanner and vacuum tank with the main components labelled.

The PS Booster (PSB) presents the greatest challenge for integration as beams circulate in 4 superimposed concentric rings, with only 360 mm between their centres. The next step in the development is therefore to adapt the SPS prototype concept such that it can be installed in the PSB.

MOTOR SELECTION

Requirements

The conceptual design of the beam wire scanner (BWS) uses a frameless electrical motor with the rotor operating in vacuum and stator at atmosphere pressure. The most appropriate type for such applications is a frameless permanent magnet synchronous motor [1].

The device should provide sufficient torque to accelerate the wire to 20 ms^{-1} following the accelerating profile shown in Fig. 2 [3].

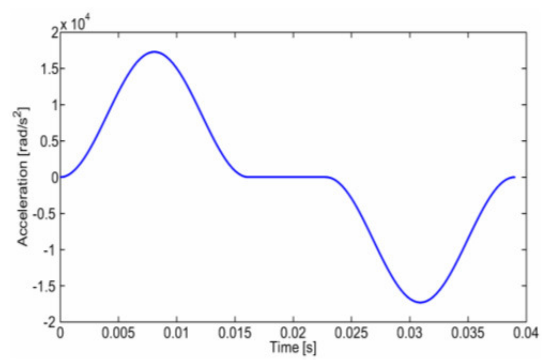


Figure 2: Acceleration profile.

The maximum value of the acceleration is α = 15711 $rad.s^{-2}$ from which the required torque can be calculated using Newton's 2nd law:

$$T = J_{total} \times \alpha.$$

where J_{total} is the sum of moments of inertia of the load and rotor:

$$J_{total} = J_{load} + J_{rotor}$$

ISBN 978-3-95450-176-2

STATUS OF THE PACMAN PROJECT

K. Artoos, M. Buzio, D. Caiazza, N. Catalan Lasheras, A. Cherif, I. Doytchinov, J-F. Fuchs, A. Gaddi, N. Galindo Munoz, J-C. Gayde, S. W. Kamugasa, H. Mainaud Durand, M. Modena, P. Novotny, S. Russenschuck, C. Sanz, G. Severino, D. Tshilumba, V. Vlachakis, M. Wendt, S. Zorzetti, CERN, Geneva, Switzerland

Abstract

PACMAN*, a study on Particle Accelerator Components' Metrology and Alignment to the Nanometre scale, is an Innovative Doctoral Programme, funded by the European Commission, hosted by CERN, providing a high quality training to 10 Early Stage Researchers (ESR) working towards a PhD. It is a multi-disciplinary project covering diverse fields such as beam instrumentation, magnetic measurements, metrology, high accuracy alignment and high precision mechanics. The objective of the PACMAN project is to propose new methods allowing the determination of the reference axis of accelerator components w.r.t. external alignment targets (fiducialisation process). A test bench, using components of the Compact LInear Collider (CLIC) study, will demonstrate the feasibility of the solutions developed and that a micrometric accuracy of their fiducialisation process can be reached. The results of this study, which has started in September 2013, are detailed. They concern the methods developed using a stretched wire to determine: the magnetic axis of small aperture magnets, the electrical centre of a 15 GHz Radio Frequency-Beam Position Monitor (RF-BPM) and the electro-magnetic axis of an accelerating cavity. They integrate also the solutions carried out to measure the position of the wire w.r.t. the external alignment targets. Other systems developed in the frame of the project are also taken into account: a nano-positioning system to validate the nanometric resolution of the BPM and a dedicated seismic sensor to characterize the environment during the measurements.

INTRODUCTION

The preservation of the emittance is a key issue for the next generation of linear colliders, and more particularly for CLIC [1], that will have nanometric beams size at the collision point. To reach such objectives, a strategy of alignment was proposed in the Conceptual Design Report of the CLIC study edited 3 years ago, consisting among others of a high accuracy and active pre-alignment of the components [2]. The aim of the PACMAN project [3] is to improve the pre-alignment accuracy of the major components of the CLIC main linac: 15 GHz RF-BPM, Accelerating Structures (AS) and quadrupole magnets along the main beam. This will be achieved by developing new methods and tools addressing several steps of pre-alignment simultaneously, using a stretched wire acting as a reference to fiducialise the components in the accurate environment of a 3D Coordinate Measuring Machine (CMM) [4].

*The PACMAN project is funded by the European Union's 7th Framework Programme under Grant Agreement no. 606839

The tools and methods developed will be then validated on a final bench to demonstrate their feasibility, before being extrapolated on other projects.

This paper reviews first the requirements concerning the pre-alignment of the CLIC study and the improvements in term of accuracy targeted by the PACMAN project. It then presents the objectives and first results obtained, concerning the determination of the reference axis of components using a stretched wire, the means to determine the position of this wire acting as a reference of alignment, and the alternative studies undertaken to achieve such a goal.

CLIC PRE-ALIGNMENT REQUIREMENTS AND PACMAN

The requirements concerning the pre-alignment of the three types of main component: BPM, AS and quadrupoles, are beyond the actual state-of-the-art. For a sliding window of 200 m, the standard deviations of the transverse position of the reference axis of each component (magnetic axis for a quadrupole, electric axis for a BPM and electro-magnetic axis for an AS) w.r.t. a straight line fit must be less than 14 μm for AS and BPM and less than 17 μm for quadrupoles [2].

Taking into account the number of components to be pre-aligned (more than 4000 BPM and quadrupoles, more than 60000 AS) and the very tight tolerances required, an active pre-alignment will be implemented. The position of the components, more precisely the position of their supports, will be determined continuously by alignment sensors, and re-adjusted by actuators. To ease the process, several components will be assembled on the same support: 4 AS per girder support, 1 BPM coupled with 1 quadrupole. This assembly step will occur after the determination of the reference axis of the components w.r.t. external alignment targets (fiducialisation). Then, the position of the pre-alignment sensors interface will be determined in the referential frame of the assembly support. Once the assembly support is installed in the tunnel, the pre-alignment sensors are plugged on their interface; measurements w.r.t. a straight reference line are carried out. Combining all the above-cited measurements, the position of the reference axis of each component can finally be deduced in the global coordinate system of the tunnel

The PACMAN project aims at combining at the same time the fiducialisation and the assembly steps, in the

ISBN 978-3-95450-176-2

STRETCHED-WIRE TECHNIQUES AND MEASUREMENTS FOR THE ALIGNMENT OF A 15GHz RF-BPM FOR CLIC*

S. Zorzetti†, N. Galindo Munoz, M. Wendt, CERN, Geneva, Switzerland
L. Fanucci, Universitá di Pisa, Pisa, Italy

Abstract

For the Compact LInear Collider (CLIC) project at CERN, maintaining low emittance beams, as they are transported along the two independent 10-20 km long main linacs, is crucial. The beam trajectory therefore has to be very well aligned to the magnetic centre of the quadrupole magnets. A series of microwave cavity beam position monitors (BPM) is foreseen to detect the position of the beam along the main linacs to precisely monitor the beam trajectory in the circular beam pipe of only 8 mm diameter. The PACMAN project aims to demonstrate the pre-alignment of the magnetic field of a main CLIC quadrupole with the electro-magnetic centre of a 15 GHz RF-BPM to the required sub-micron accuracy. This paper focuses on stretched-wire measurements of a CLIC Test Facility (CTF) cavity BPM, to locate its electrical centre. Details of two measurement methods are discussed: RF signal excitation of the wire and analysis of RF signal transfer through the slot-coupled waveguides of the cavity, using the stretched wire as a passive target. This contribution will present the theory behind these measurements, their electromagnetic analysis and first, preliminary experimental results.

INTRODUCTION

To preserve the transverse emittance along the CLIC main linacs, the beam orbit needs to be steered with sub-μm accuracy and reproducibility along an optimal trajectory close to the electromagnetic center of the quadrupole magnets. This trajectory is foreseen to be measured using approximately 4800 high resolution cavity BPMs [1], located at each quadrupole along the beamline. At the CLIC Test Facility (CTF) a set of three cavity BPMs are currently under investigation. The PACMAN project [2] focuses on the study of the pre-alignment between the Main Beam Quadrupole (MBQ) and the resonant cavity Beam Position Monitor (RF-BPM). The pre-alignment methodology consist of characterizing the single components on separate test benches, integrating them on a dedicated support, aligning their respective electro-magnetic centres with stretched-wire measurement techniques.This paper summarizes the current status of the dedicated test stand and measurement setup for the cavity BPM.

* The PACMAN project is funded by the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no. 606839.

† silvia.zorzetti@cern.ch

CLIC RF-BPM

The CLIC RF-BPM consist of a resonant cavity coupled to four lateral waveguide slots with the signal picked up through coaxial connectors (*Fig. 1*) [3].

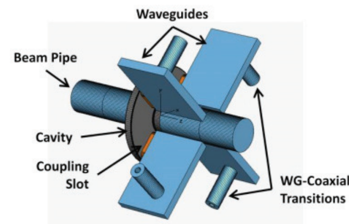


Figure 1: CLIC RF-BPM.

The fundamental mode of the cavity is a TM monopole mode at $\sim 11GHz$, with the TM dipole mode at $\sim 15GHz$. The lateral waveguides act as a high pass filter, suppressing the monopole mode while allowing the dipole mode to pass. Ideally, when the particle beam is centred into the RF cavity, the signal is zero, as the electric field of the dipole mode vanishes. In reality, because of mechanical imperfections, the electrical centre may not match the geometrical centre. The main task of the BPM test bench is therefore to accurately locate the electrical center.

MEASUREMENT METHODS

Two measurements methods have been identified, both using a conductive stretched-wire[1].

Signal Excitation

By means of a coaxial line the signal is propagated from the signal launcher to the BPM cavity. The wire is excited with a continuous sinewave at 15GHz and the BPM signal picked up through the lateral waveguides. With this method we are able to simulate the BPM behaviour as if it were excited by a particle beam (*Fig.*2).

To ensure a good transmission coefficient and to minimize reflections a hybrid PCB-coaxial transformer, operating at 15GHz, has been designed to launch the RF signal and to terminate the coaxial line configuration (*Fig.*3).

As the wire is excited and moved in the transverse plane of the BPM cavity, the signal picked up by one of the slot coupled waveguides is proportional to the electric field of the dipole eigenmode. When the wire is located in the centre of the cavity, the output signal is at a minimum.
The Slater theorem describes the dipole eigenfrequency shift in an RF cavity due to a metallic or dielectric perturbation,

[1] Cu-Be wire, $0.1mm$ diameter.

ISBN 978-3-95450-176-2

STATUS OF THE EUROPEAN XFEL TRANSVERSE INTRA BUNCH TRAIN FEEDBACK SYSTEM

Boris Keil, Raphael Baldinger, Robin Ditter, Mathias Gloor, Waldemar Koprek, Fabio Marcellini, Goran Marinkovic, Markus Roggli, Martin Rohrer, Markus Stadler, Daniel Marco Treyer (Paul Scherrer Institute, Villigen, Switzerland)*

Abstract

The European XFEL (E-XFEL) will have a transverse intra bunch train feedback system (IBFB) that is capable of correcting the beam position of individual bunches in the ~650us long bunch train, with a minimal bunch spacing of 222ns. The IBFB measures the beam positions with high-resolution cavity BPMs, and corrects the position of each bunch via stripline kicker magnets driven by class AB solid-state RF power amplifiers. The production of the IBFB BPM pickups is finished, and a pre-series version of the low-latency BPM electronics, including firmware and software, has been successfully tested with beam. After successful production and tests of prototypes, the series production of IBFB kicker magnets and RF power amplifiers is in progress. The IBFB feedback electronics hardware development is mainly finished, while firmware and software development is still ongoing. This report summarizes the latest design status and test results of the different IBFB system components.

IBFB SYSTEM OVERVIEW

Figure 1 shows the layout of the IBFB. The core of the system is located just upstream of the E-XFEL beam distribution kicker system and downstream of the collimation area. Four cavity BPMs (CBPMs) downstream of the IBFB ("downstream BPMs") are used to implement a fast feedback loop, where two vertical and two horizontal stripline kickers can apply individual kicks to each bunch in order to correct the beam trajectory at the downstream BPMs to the desired position. A feedback loop latency of ~1µs is expected to be sufficient to damp all relevant perturbations.

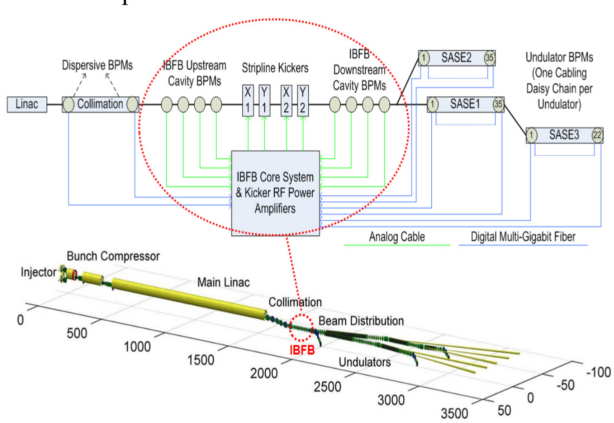


Figure 1: IBFB System.

* This work was partially funded by the Swiss State Secretariat for Education, Research and Innovation SERI.

The necessary kick amplitudes are calculated by an FPGA board that receives the beam position data from the CBPM electronics via fast fiber optic links. The FPGA board applies the kicks via two digital-to-analog converter (DAC) mezzanines with four 16-bit 500MSPS DACs each. In order to apply corrective kicks to each bunch, the DAC mezzanines generate suitable output waveforms that are amplified by pulsed solid-state RF power amplifiers driving the stripline kicker magnets. Each stripline kicker has two amplifiers for driving its two opposite strips in push-pull mode, i.e. with opposite voltages.

Four CBPMs upstream of the kickers ("upstream BPMs") are used by the IBFB to predict the beam position at the downstream BPMs from the upstream BPM readings and DAC set values. This enables the IBFB e.g. to detect failures or drifts of the RF power amplifiers, variations of the beam energy, or to check and adjust the IBFB timing.

The IBFB also receives the data of a dispersive CBPM in the collimator section (for beam energy measurement and kicker scaling factor adjustment) as well as data from all undulator CBPMs via digital multi-gigabit fiber optic links. In order to reduce the amount of cables, the undulator CBPMs of each of the three initial undulators (SASE1, SASE2, SASE3) are connected in a daisy chain, where only the first and last CBPM electronics of each chain is connected to the IBFB core system via single-mode fiber optic cables up to 1km length. When the first bunches of the E-XFEL bunch train (with up to 650µs train length and down to 222ns bunch spacing) arrive at the IBFB, it first corrects the trajectory using only downstream BPM data. As soon as the first undulator CBPM data is received by the IBFB, it fine-tunes the beam trajectory (if necessary), such that the following bunches reach the desired beam position in the undulators. Due to the long distance from IBFB to undulator CBPMs, the resulting latency of this correction is 4 to 10µs, depending on undulator and BPM location. However, the beam trajectory perturbations that occur between IBFB and undulators are expected to be either low-frequent (e.g. quadrupole magnet vibrations) or predictable, therefore it is sufficient to do this fine-tuning of the undulator beam trajectory once at the beginning of the bunch train, and then with a low correction bandwidth for the remaining part of the bunch train, in combination with the above mentioned fast (low-latency) feedback loop based on BPMs near the IBFB. In addition to this feedback-based correction, the IBFB will also perform an

ISBN 978-3-95450-176-2

STATUS OF THE SwissFEL BPM SYSTEM

Boris Keil, Raphael Baldinger, Robin Ditter, Daniel Engeler, Waldemar Koprek, Reinhold Kramert, Alessandro Malatesta, Fabio Marcellini, Goran Marinkovic, Markus Roggli, Martin Rohrer, Markus Stadler, Paul Scherrer Institute, Villigen, Switzerland

Abstract

SwissFEL is a 5.8GeV free electron laser facility presently under construction at PSI. The electron beam position will be measured by three types of cavity beam position monitors (CBPMs). For the injector, linac and beam transfer lines, low-Q 3.3GHz cavity BPMs with 38mm and 16mm aperture (CBPM38 and CBPM16) will be used to measure the position and charge of two bunches with 28ns spacing individually. A fast kicker system distributes each bunch to a different undulator line, where 4.9GHz high-Q cavity BPMs with 8mm aperture (CBPM8) are used in the undulator intersections. The production of the CBPM38 pickups is finished, while the CBPM16 production is in progress. For CBPM8, a prototype pickup has been successfully tested, and a 2nd pre-series prototype with reduced dark-current sensitivity is currently in production. The development of the common 3.3GHz CBPM electronics for CBPM38 and CBPM16 is finished, while the CBPM8 electronics is currently in the prototyping phase. This paper gives an overview of the present pickup, electronics, firmware and software design and production status, including test results and methods to control and maintain the quality during series production.

INTRODUCTION

Table 1 lists the quantities and requirements for the SwissFEL BPMs [1]. CBPM38 pickups [2] are only installed at a few locations where a larger aperture is needed, e.g. at the beam distribution kicker, in beam dumps, or bunch compressor arms. The CBPM16 pickups [2] are used in most parts of the accelerator, except for the undulator intersections where the high-Q CBPM8 pickups [3] will provide higher (sub-micron) resolution and drift as required for the alignment and control of the electron-photon beam overlap in the undulators.

Table 1: SwissFEL BPM Quantities and Requirements

	CBPM38	CBPM16	CBPM8
Quantity*	7	114	51
Usage	Linac, Transfer Lines		Undulat.
Aperture	38mm	16m	8mm
Position Range	±10mm	±5mm	±1mm
Position Noise	<10µm*	<5µm*	<1µm**
Pos. Drift/Week	<10µm	<5µm	<1µm
Charge Noise	<0.1%***		
Charge Range	10-200pC		
#Bunches/Train	1-3		1
Bunch Spacing	28ns		10ms

* Within 30% of the position range
** Within 50% of the position range
*** Or 30fC, whatever is larger

Beam Energy Measurement

The CBPM16 and CBPM38 are also used at dispersive locations for beam energy measurement, e.g. in the arms of the bunch compressors between 1st and 2nd (as well as 3rd and 4th) dipole, or downstream of beam dump dipoles. For an expected position resolution of <1µm, the corresponding energy resolution is typically <2E-5.

Bunch Charge and Beam Loss Measurement

Like in the SwissFEL injector test facility (SITF), high-resolution charge measurements in SwissFEL will mainly rely on CBPMs since they provide higher resolution than dedicated charge monitors (ICTs, wall current monitors, etc.). CBPM16 prototypes achieved <0.07% relative resolution at high charge and <8fC absolute resolution at very low charge [1]. Since the pre-calibration of the CBPMs in the lab only provides ~10% scaling factor error for the charge, the CBPMs will be cross-calibrated with beam against dedicated charge monitors to achieve better absolute accuracy of ~1%.

BPM PICKUP DESIGN

All SwissFEL BPMs are cavity BPMs with two resonators. The so-called reference resonator has one (CBPM16, CBPM8) or two (CBPM38) standard couplers to measure the charge using the TM_{010} mode, while the position resonator has four couplers, using TM_{010} mode-suppressing waveguides to obtain the product of position and charge via the TM_{110} mode. By using the same working mode frequency for both resonators, undesired frequency-dependent drifts of the symmetrically designed BPM electronics are minimized. Both resonators also have the same loaded quality factor Q_L to obtain symmetric waveforms for minimal arrival time dependency of the CBPM electronics.

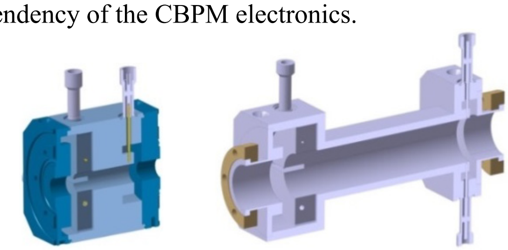


Figure 1: SwissFEL CBPM16 pickup (left) and CBPM38 pickup (right).

The CBPM16 and CBPM38 pickups are based on a SACLA design [4] that was also adopted for the E-XFEL [5][6]. For SwissFEL we did systematic simulation scans of all relevant pickup dimensions in order to achieve high resolution at low charge, and we also optimized the

ISBN 978-3-95450-176-2

PRELIMINARY TEST OF THE BUNCH-BY-BUNCH TRANSVERSE FEEDBACK SYSTEM FOR TPS STORAGE RING

Y.S. Cheng, H.P. Hsueh, K.H. Hu, C.Y. Liao, S.Y. Hsu, P.C. Chiu, K.T. Hsu#
NSRRC, Hsinchu 30076, Taiwan

Abstract

Commissioning of the Taiwan Photon Source (TPS) is in progress and divided into two phases. The storage ring equips with two five-cell PETRA RF cavities and without insertion devices installed for Phase-I commission to confirm correctness of everything, to do preliminary vacuum clearing, and wait available of cryogenic system available. After finished the Phase-I commissioning in March, 2015, installation of two superconducting RF cavities and 10 sets of insertion devices are ongoing. The commissioning is planned to start around in August. There is a prototype vertical stripline kicker installed in 2014. One horizontal stripline kicker and two vertical stripline kickers were installed in May. Commercial available feedback processor was selected for the feedback system integration. Preliminary feedback loop closed have been tested during Phase-I beam commissioning in early 2015 with prototype vertical kicker. Beam commissioning with new kickers is scheduled when beam stored in Phase-II beam commissioning which will started soon. Final check before beam test is under way.

INTRODUCTION

The NSRRC campus host two synchrotron light source, one is a 1.5 GeV Taiwan Light Source (TLS), and the other is 3 GeV TPS. The TPS was started Phase-I commissioning without IDs and superconducting RF system recently [1]. Phase-II commissioning is started from mid September 2015 with 10 sets of IDs and two KEKB-type superconducting RF modules. Analogue type transverse feedback system for TLS is operated since 1996 [2]. The system convert to FPGA based feedback system in during 2004~2005 for transverse as well as longitudinal planes by using SPring-8 feedback processors [3]. Transverse coupled-bunch instability, caused by the resistive wall impedance and fast ion will deteriorate beam quality. Bunch-by-bunch feedback will suppress various transverse instabilities to ensure TPS will achieve its design goals. The TPS project adopts EPICS toolkits as control system frameworks. To simplify system integration, it was decided to adopt EPICS embedded feedback processor iGp/iGp12 from Dimtel [4] for BBF system for TLS and TPS. First system by use iGp was put into operation in 2009 [5] at TLS. Two transverse loops and one longitudinal feedback loop were convert to iGP12 based system around 2010~2011 at TLS [6]. The TPS system are commissioning in 2015 by using latest revision gateware (FPGA code).

Stored beam current reach more than 100 mA in multi-bunch operation with two five-cell PETRA cavities are expected. Strong synchrotron dipole motion is onset around 30 mA. This strong motion limit maximum stored beam current less than 50 mA. RF experts found that the bandwidth of the RF amplitude feedback loop is too large such that a synchrotron sideband entered the loop in March 26. After cure the problem and increasing the chromaticity, beam stored more than 100 mA soon just before April shutdown. Threshold current for the longitudinal instability appeared at 82 mA. Longitudinal instability will be not a problem after replacement of the five-cell PETRA cavities with SRF in Phase-II commissioning.

Phase-I commissioning of the vertical loop with prototype kicker is performed in mid January 2015. Beam commissioning with new kickers is scheduled when beam stored in Phase-II beam commissioning is scheduled in the last quarter of 2015.

TRANSVERSE KICKERS

In order to suppress coupled-bunch instabilities effectively, transverse kickers with higher shunt impedance are desirable especially in vertical plane. However, due to limited manpower available during the final phase of installation, one simple prototype kicker was implemented and installed at diagnostics straight in June 2004. Only this kicker was available for Phase-I commissioning. Shunt impedance of this kicker at lower frequency is less than 5 k. Drawing and installation photo of this prototype vertical kicker is shown in Fig. 1.

Two new vertical kickers and one new horizontal kicker were designed, fabricated, and installed during April to July, 2015 shutdown. Concept of these kickers is derives from the design of PSI/SLS [7] and adapt to fit vacuum duct of TPS at ID straight. Optimization of geometry and shunt impedance was done by SUPERFISH 2D codes. Length of the electrode is 300 mm. Shunt impedance at low frequency is about more than 50 k for vertical and horizontal kicker respectively. Detailed analysis of the impedance, absorption power is underway. About 10 time large than the prototype, and almost factor of 3 times kick voltage will produce than the prototype when the same driven power level. Perspective drawing and installation at the storage ring are shown in Fig. 2. Original, all transverse kickers were planned to install at one dedicated diagnostics straight. However, to save space to accommodate one more insertion devices, decision was made in March 2015 that all kickers install at upstream of in-vacuum undulator (IU22) at three 7 m

#kuotung@nsrrc.org.tw

ISBN 978-3-95450-176-2

SYNCHROTRON RADIATION MEASUREMENT AT TAIWAN PHOTON SOURCE

C.Y. Liao#, C.Y. Wu, Y.S. Chen, P.C. Chiu, C.K. Kuan, H.P. Hsueh, S.Y. Hsu, K.H. Hu, K.T. Hsu
NSRRC, Hsinchu 30076, Taiwan

Abstract

The synchrotron radiation light produced from a dipole magnet is widely used to characterize beam parameters in synchrotron light source (photon synchrotron). The synchrotron radiation monitor (SRM) systems were implemented for the booster synchrotron and the storage ring at Taiwan Photon Source (TPS). The beam parameters of the booster were recorded during the energy ramping process through the CCD camera and streak camera. The beam size measurement and beam behavior observed of the storage ring were performed by X-ray pinhole camera and streak camera respectability. The results are summarized in this report.

INTRODUCTION

The Taiwan Photon Source (TPS) with low emittance and high photon brightness is a state-of-the-art synchrotron radiation facility. The TPS accelerator consists of a 150 MeV S-band linear accelerator (LINAC) system, linac to booster transfer line (LTB), 0.15–3 GeV booster synchrotron, booster to storage ring transfer line (BTS), and 3 GeV storage ring. The storage ring consists of 518.4 m circumference and 24 DBA lattice cells with 6-fold symmetry [1]. The TPS commissioning is divide into two phases. Phase-I commissioning, two 5-cells Petra cavities without insertion device was done in the first quarter of 2015. Phase-II commissioning will start in the third quarter of 2015 with two superconducting RF cavities and 10 sets of insertion devices.

The SRM play an important role during the Phase-I beam commissioning, which is designed for the booster synchrotron and storage ring of the TPS. Synchrotron radiation generated from a dipole bending magnet serves to characterize energy ramping process for the booster synchrotron. In the storage ring, SRM is used to characterize beam size by x-ray pinhole camera, bunch length and longitudinal dynamics by streak camera, and fill pattern by photon counting technique. The outline of design and preliminary beam test results are presented in this report.

SYSTEM DESIGN

Synchrotron Radiation Monitor for Booster

Synchrotron radiation light from a bending magnet is guided to outside of shield wall via a four-piece adjustable mirror. The light is focus by a lens with 1 m focal length. A band-pass filter is insert before the GigE Vision camera. The camera trigger is synchronized with the booster ramping trigger; change delay time will change the energy point of observation. This synchrotron radiation diagnostic port is located at downstream of the booster injection section, so it can used to observe linac beam and booster stored beam with streak camera. Setup for the CCD camera and streak camera is shown in Fig. 1.

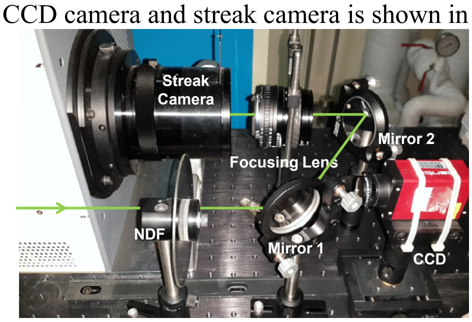


Figure 1: Optical layout of SRM measurement for booster synchrotron. The synchrotron light leads to the wall via a four-piece adjustable mirror and a lens (which are not shown here) then through a band-pass filter and additional two mirrors and focusing lens, finally to the streak camera system. Without the mirror 1, the synchrotron light is guided to the CCD camera.

Diagnostics Beamline for Storage Ring

There is a dedicated beamline for photon diagnostics at the TPS storage ring utilized visible light and X-ray of the synchrotron radiation. The diagnostics devices and its functionality are summary in Table 1. The X-ray pinhole camera is used for imaging the electron beam from bending magnet for the beam size and emittance measurements. It offers the required resolution and the dynamic range to measure the electron beam size accurately at all beam currents. The visible light of synchrotron radiation coming out of the tunnel was design for streak camera, interferometer and fill pattern measurements, as shown in Fig. 2.

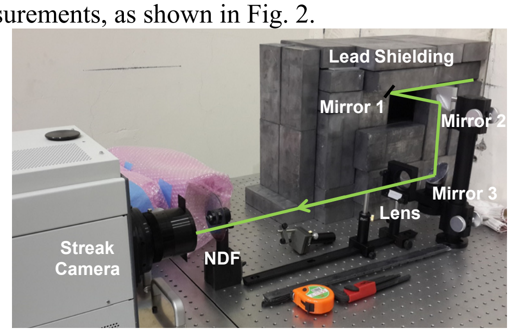


Figure 2: Temporary optical layout of SRM measurement for storage ring. The visible light of synchrotron radiation leads out of the tunnel, then through three mirrors, Lens, and band-pass filter, finally to the streak camera system.

#liao.cy@nsrrc.org.tw

ISBN 978-3-95450-176-2

COMMISSIONING OF BPM SYSTEM FOR THE TPS PROJECT

P. C. Chiu, K. H. Hu, C. H. Kuo, C. H. Huang, Demi Lee, Y. S. Cheng, K. T. Hsu
NSRRC, Hsinchu 30076, Taiwan

Abstract

Taiwan Photon Source (TPS) is a newly constructed 3-GeV synchrotron light source which ground breaking began February 2010. Its Booster beam commissioning and hardware improvement started at August 2014 and ramped to 3 GeV successfully in December 16 2014. Soon the stored beam in the storage ring had achieved 5 mA in December 31[1][2]. The BPM electronics Libera Brilliance+ [3][4] are adopted for booster and storage ring of TPS. The provided BPM data is useful for beam commissioning where it can be used to measure beam position, rough beam intensity along the longitudinal position and also for tune measurement. This report summarizes BPM commissioning and measurement during beam commissioning.

INTRODUCTION

The TPS is a state-of-the-art synchrotron radiation facility featuring ultra-high photon brightness with extremely low emittance [5]. The TPS accelerator complex consists of a 150 MeV S-band linac, linac to booster transfer line (LTB), 0.15–3 GeV booster synchrotron, booster to storage ring transfer line (BTS), and 3 GeV storage ring. The Storage Ring's circumference is 518.4 meters with 24 DBA lattice and 6-fold symmetry; the booster has 6 FODO cells and its circumference is 496.8 meters. The booster and the storage ring share the same tunnel in a concentric fashion. During 4 years of construction period, civil constructions had been completed in early 2013.

At September 2014, booster BPM commissioning had committed with beam commissioning. After some hardware improvement such as power supply tuning, chamber and magnet re-alignment, demagnetization of chamber, kicker and septum improving and etc., booster had achieved beam ramped to 3 GeV at December 16 2014. Later, after improving field leakage of Booster extraction DC septum, we had a 5-mA stored beam on Dec. 31 2014. Diagnostic system played a helpful role to provided beam profile and information to improve or tune subsystem to make progress quickly during beam commissioning. This report will focus on the BPM related environment, functionalities and measurement.

BPM FUNCTIONALITIES AND COMMISSIONING

The TPS storage ring is divided into 24 cells and there are 7 BPMs per cell; the booster ring has six cells where each cell is equipped with 10 BPMs. Booster button BPM shapes 35x20 mm elliptical and button diameter 10.7 mm. The calibration factor Kx and Ky is 8.25 and 9.66 mm respectively. There are two kinds of BPM for storage ring as Fig. 1 shown: one is standard button BPM shapes 68x30 mm elliptical and diameter 7.4 mm at arc section; the other is primary BPM shapes 64x16 mm racetrack and diameter 7.4 mm at straight line. The calibration factor Kx/Ky is 13.8/12.73 and 6.58/8.89 mm for standard and primary BPM respectively.

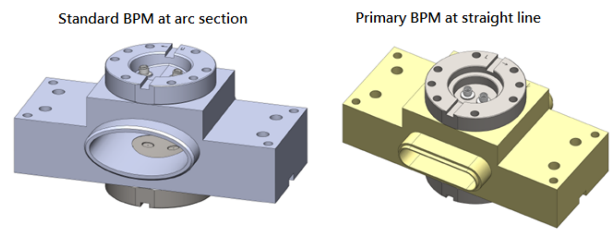


Figure 1: Mechanical drawings of standard type and primary type BPM for TPS storage ring.

The conceptual functional block diagram of the BPM electronics is shown in Fig. 2. It will provide several data type for different application. ADC and TBT data is acquired on demand by trigger; 10 Hz slow data is for DC average orbit and 10 kHz fast data could be applied for booster ramping orbit or fast orbit feedback application. It is also embedded with EPICS IOC for control, monitor and configuration. The timing AMC module would provide functionalities of synchronization, trigger, interlock and post-mortem. To support operation of the BPM electronics, functionalities like cold start, shutdown, housing, control system interface should meet the requirements. The delivered units also had been performed functionality and performance test to ensure compliance with this specification.

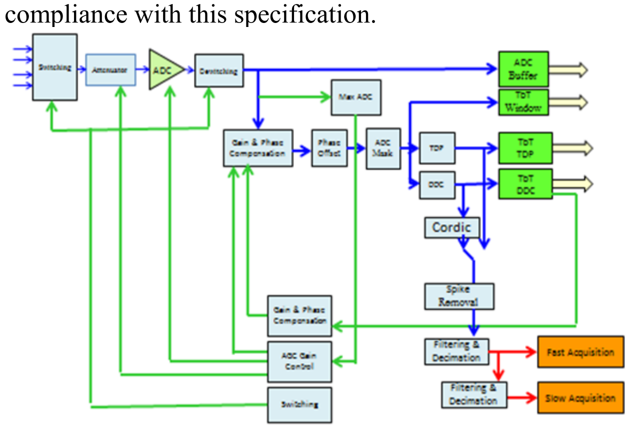


Figure 2: BPM platform functional block diagram.

At September, the first turn of the booster beam had achieved soon after correctors steering. There are only

ISBN 978-3-95450-176-2

BEAM CHARACTERISATION USING LASER SELF-MIXING*

A.S. Alexandrova[#], C.P. Welsch, Cockcroft Institute and The University of Liverpool, UK

Abstract

Non-destructive beam diagnostics are highly desirable for essentially any accelerator or storage ring. This concerns the characterization of the primary beam itself, but also for example of atom and molecular jets that are crossed with the primary beam as experimental targets or for diagnostics purposes. A laser feedback interferometer based on the optical self-mixing effect provides a low - cost, robust, compact and non-invasive sensor for velocity, displacement and density measurements of various targets. This contribution presents results from theoretical and experimental studies into the factors influencing the performance and accuracy of this sensor. Parameters that have been assessed include the target velocity, the size of scattering particles, their density, type and scattering properties.

INTRODUCTION

Gaseous targets and gas jets have many applications in different fields of accelerator physics. A curtain shaped gas-jet is used as a non-destructive beam profile monitor for various types of the particle beams [1-2]. The beam profile monitor is based on the ionisation of the gas jet when it interacts with the beam resulting in 2-dimensional profile picture. Gas jets are used as a source of a laser induced plasma in laser-plasma acceleration experiments [3]. Supersonic gas jets in various configurations are used for the production and spectroscopy of radioactive isotopes [4]. The increasing importance of gas jets means that their characterisation is essential and a sensor is required to obtain information about the velocity, the density and the temperature. The laser self-mixing (SM) sensor is proposed as easy integratable, compact and cheap device for such purposes [5-7].

A laser velocimeter is under development in the QUASAR Group at the Cockcroft Institute/University of Liverpool, UK for the purposes of measuring the velocities of gas jets. The gas jet consists of neutral molecules, such as argon, nitrogen or helium, and forms a curtain of 1-20 mm diameter. Molecules move uniformly with a velocity which can vary from 100 m/s to 2000 m/s. The density of the gas jet depends on the pressure in the vacuum chamber and is expected to be in the range of 10^9–10^{12} particles/cm^3 [1-2]. An SM sensor is expected to measure the flow of gas jets with these parameters. It has been successfully used for characterising velocities of solid targets up to 100 m/s [8], and for some fluids up to 1 m/s [9]. The scattering of light off gas jets and off the seeding particles, which are added to improve the SM signal, directly influences the performance and accuracy of the results.

*Work supported by the European Commission: GA-ITN-2011-289191
#a.alexandrova@liverpool.ac.

THEORY AND METHODOLOGY

The self-mixing phenomenon is based on the coupling of laser light reflected or scattered off a moving target back into the cavity and interacting with the light inside the laser cavity. The backscattered light's wavelength is shifted due to the Doppler effect and the intensity of the backscattered light depends on the particulars of the target i.e. optical properties etc. The here-presented sensor is based on the SM effect in semiconductor lasers. The detection system includes a photodiode (PD), which is part of the commercially available laser diode. The SM phenomenon influences both the wavelength of the light and its power fluctuation. The interaction within the cavity causes backscattered light to be amplified, so the sensor doesn't require powerful light and there is no need for a complex optical system.

Scattering Theory of Light off Various Targets: Expected Spectrum

The distribution function of an electro-magnetic field scattering off a target is expected to be Gaussian [10], independent on the properties of the scattering media and the character of its motion. However, if the amount of illuminated scatters is large enough and their movements are correlated, the resulting function depends on the type of motion of the scatters. For example, the spectrum of scattered light is a Lorentzian function when a large amount of particles undergoes Brownian motion [11]. The process of scattering off a target or group of particles is a complicated process which requires different considerations depending on the nature of the particle.

1. If the light scatters from density fluctuations in a medium, there is a finite correlation between different coherent volumes [12].
2. If the light scatters form a rotating target, the motion of the scatters can vary from fully correlated to completely uncorrelated. It can be assumed that different parts of the rotating target are indifferent from each other. At the same time, the motion of the scatters can be characterised by the distribution of the velocities of the delta-function with the velocity of the centre of the light focus point [13].
3. If the light scatters off a moving flow with a specific velocity, the scatters are independent from each other. However, the flow can be characterised with a velocity distribution within an illuminated volume. Hence, the spectrum should be similar to the second case taking into account the velocity distribution.

The spectrum is to be calculated first for the rotating target with the velocity distribution of delta-function, and to be modified in more difficult case. The theoretical spectrum of the light scattered off a rotating ground glass has been analysed [14]. Assuming the size of the light

ISBN 978-3-95450-176-2

SIMULATIONS OF THE FETS LASER DIAGNOSTIC

A. Kurup, J. Pozimski, P. Savage, Imperial College London, UK
S. M. Gibson, K. Kruchinin, Royal Holloway, University of London, UK
A. Letchford, Science and Technology Facilities Council, Rutherford Appleton Laboratory, UK

Abstract

The Front-End Test Stand (FETS) aims to demonstrate clean chopping of a 60mA, 3MeV H- ion beam. Such high beam intensities require unconventional emittance and profile measuring devices such as the laserwire system that will be used on FETS.

A laser is used to neutralise part of the H- ion beam. The main beam is then separated from the stripped beam by using a dipole magnet. This paper presents tracking results of the laser diagnostic lattice using a simulated field map of an existing dipole magnet and investigates the possibility of laser stripping upstream of the dipole.

INTRODUCTION

The Front End Test Stand is an R&D project at the Rutherford Appleton Laboratory (RAL) with the aim to demonstrate a high power (60 mA, 3 MeV with 50 pps and 10 % duty cycle), fast chopped H- ion beam [1]. FETS consists of a high brightness ion source [2] and a magnetic three solenoid LEBT [3], both of which are operational, see Figure 1. The 4-vane 324MHz radio frequency quadrupole [4],

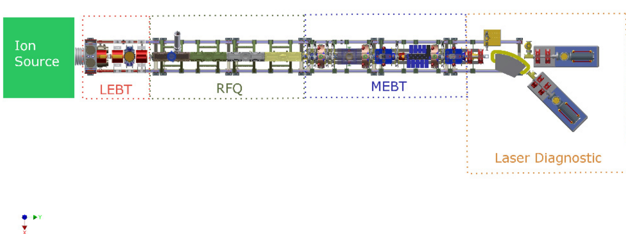


Figure 1: Layout of the Front End Test Stand.

which accelerates the beam from 65KeV to 3 MeV is manufactured and will be assembled and tested in the following months. Downstream of the RFQ is the medium energy beam transport (MEBT) [5], containing a high speed beam chopper [6] and non-destructive photo-detachment diagnostics. The MEBT is in the design phase; with the particle dynamics design finished and the transition to the mechanical design started. The diagnostics of high power particle beams is difficult, due to the power deposition on diagnostics elements by the beam, so non-invasive instrumentation is highly desirable. The laserwire emittance scanner is based on a photo-detachment process, utilizing the neutralized particles produced in the interaction between laser and H- beam for beam diagnostics purposes. The principle is appropriate to determine the transversal beam density distribution, as well as the transversal and longitudinal beam emittance downstream of the RFQ.

Previous studies of the FETS laserwire, see [7] and [8], were done with the laser stripping taking place within the dipole magnet to provide separation between neutrals within the beam and the H^0 particles produced by the laser interaction. The plan was to use a custom-built large aperture magnet and a vacuum vessel with three exit ports to allow scanning the laser over a distance of 40 mm to provide good emittance resolution. Since then it has been decided to use an existing dipole magnet and vacuum vessel and to investigate the possibility of stripping outside of the dipole magnet.

A model of the magnet was made to generate a field map which was then used to perform particle tracking simulations, including space charge effects, using General Particle Tracer (GPT) [9]. The aim was to adjust the optics of the laserwire quadrupoles to transport the beam but keeping the beam size large (around ±20 mm) at the stripping location in order to get good resolution at the detector and to have as large a beam size as possible on the dumps to keep the power density in the dumps as low as possible. The following sections give details of the magnet simulation and the tracking results for the quadrupole configuration that gives the required beam parameters at the stripping location and the subsequent transport of the stripped and unstripped beams to their respective dumps.

DIPOLE FIELD SIMULATION

The existing dipole magnet, see Figure 2, was modelled using CST Studio [10] to produce a magnetic field map that was used in the particle tracking simulations. Measurements of the yoke and coils were made and a 3D model of the magnet, see Figure 3. Here the magnet requires flipping to get a bend in the negative direction and will require mounting the existing magnet upside down. However, for the purposes of these simulations, this will not have any effect on the outcomes of the simulation results so the magnet was used in its current orientation. A 3D field map was generated using 100 A excitation current in the coils which gave 0.2475 T in the centre of the magnet. Figure 4 is a plot of the on-axis vertical field and shows that the fringe fields extend up to 300 mm from the entrance and exit faces of the magnet. Tracking a 3 MeV H^- ion, and ensuring it is on-axis at the entrance and exit faces, requires scaling the field by 0.894 to take into account the longer effective magnetic length due to the fringe fields.

The full 3D field map from this simulation was used in the tracking simulations described in the following section.

ISBN 978-3-95450-176-2

CHARACTERISING THE SIGNAL PROCESSING SYSTEM FOR BEAM POSITION MONITORS AT THE FRONT END TEST STAND*

G. Boorman#, S.M. Gibson, N. Rajaeifar, RHUL, London, UK
J. Pozimski, Imperial College, London, UK
S. Jolly, University College, London, UK
S.R. Lawrie, A.P. Letchford, STFC/RAL, Oxfordshire, UK
J.D. Gale, University of Sussex, UK

Abstract

A number of beam position monitors (BPM) are being installed at the Front End Test Stand (FETS) H^- ion source at the Rutherford Appleton Laboratory, UK, as part of the 3 MeV medium energy beam transport. The FETS ion source delivers pulses up to 2 ms long at a rate up to 50 Hz and a maximum current of 60 mA, with a 324 MHz micro-bunch structure imposed by the frequency of the FETS RF acceleration cavity. The response of an in-house designed button BPM has been simulated and then characterised on a wire-based test-rig and the results are presented. The output from a custom algorithm running on a commercial PXI-based FPGA signal processing system is evaluated using test signals from both a function generator and the BPM in the test-rig, to verify the speed and precision of the processing algorithm. The processing system can determine the beam position in eight BPMs, with a precision of better than 20 µm, within one microsecond of the signal sampling being completed.

FETS BPMS

Eight BPMs are being installed in the FETS medium energy beam transport (MEBT) after the radio-frequency quadrupole (RFQ). Six of the BPMs are in-house designed button BPMs that have been described previously, along with a description of the wire-rig [1]. The remaining two BPMs are strip-line types that are manufactured to a design from the LINAC4 group at CERN, Geneva [2]. The prototype button BPM was originally tested using a wire-rig (Fig. 1), with the output from the electrodes being acquired by a four-channel oscilloscope, the data then being read and analysed to produce a wire position in the *x* and *y* axes.

The beam (or wire) position in X and Y is given by Eqn. 1 and 2, where V_{right}, V_{left}, V_{up} and V_{down} are the voltages as measured on the right, left, up and down electrodes respectively. The constants S_x and S_y are the sensitivities for the relevant axes, d_x and d_y are the relevant position offsets.

$$Position_x = \frac{1}{S_x} * \frac{V_{right} - V_{left}}{V_{right} + V_{left}} + d_x \qquad (1)$$

$$Position_y = \frac{1}{S_y} * \frac{V_{up} - V_{down}}{V_{up} + V_{down}} + d_y \qquad (2)$$

G.Boorman@rhul.ac.uk

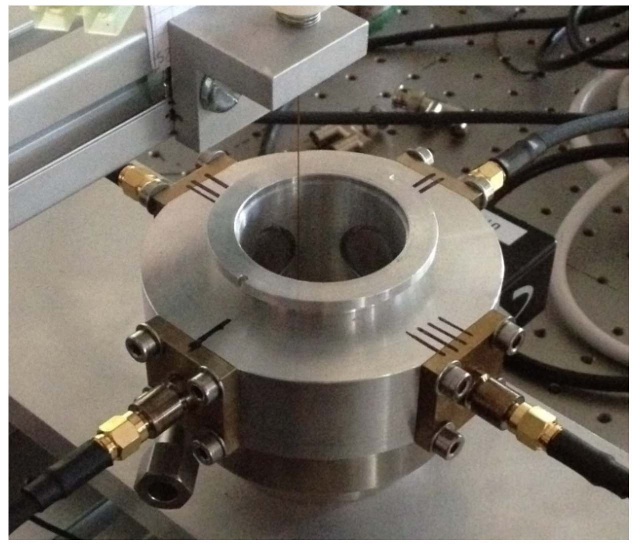


Figure 1: Prototype button BPM on the wire-rig system.

Beam Position Requirements

The ion beam rms width varies as it traverses the MEBT, varying from around 1 mm to about 20 mm. The beam position is required to be known to a precision of better than 100 µm. The beam position during the rising edge of the macro-pulse moves around, due to the stabilisation time of both the pulsed ion source extraction voltage and the space charge compensation, so several position samples of the beam must be taken during this 50 µs period [3]. The position calculation must be completed within 1 µs to avoid result pile-up in the FPGA position-calculation section. The BPM is tested on the wire-rig, and the position calculated using the FPGA, to establish the constants S_x and S_y and the accuracy of each constant.

BEAM POSITION MEASUREMENT

The signal from each BPM electrode is down-mixed, using a single stage mixer, from 324 MHz to 10.125 MHz intermediate frequency (IF), using a local oscillator (LO) frequency of 313.875 MHz. The electronics used is based on a design used by the BPM development group working on the LINAC4 H^- accelerator at CERN. The output filter has been adjusted to take into account the different IF values.

Wire-rig and Ion Beam Signal Levels

The electronics has digitally-controlled amplifiers and attenuators before the mixer, and again after the low-pass

ISBN 978-3-95450-176-2

DEVELOPMENT OF A SUPERSONIC GAS JET BEAM PROFILE MONITOR

H. Zhang[1,#], V. Tzoganis[1,2], A. Jeff[1,3], C.P. Welsch[1]
[1]Cockcroft Institute and The University of Liverpool, Warrington, WA44AD, UK
[2]RIKEN, Nishina center, Wako-chi, Japan
[3]CERN, Geneva, Switzerland

Abstract

A supersonic gas jet beam profile monitor has been developed by the QUASAR Group at the Cockcroft Institute, UK. It creates a 45 degree supersonic gas curtain to interact with the primary beam, and then collect the generated ions to measure the transverse profiles of the primary beam. The gas curtain functions as a non-interceptive screen, which allows us to insert it into high energy, high luminosity and high power beams without worrying about the damage that normal screen would suffer.

Recently, a new movable gauge module has been implemented in the test stand. The purpose is to investigate the gas curtain density distribution in order to understand the jet better. In this contribution, we will briefly discuss the monitor and focus on the gas curtain measurement with the newly installed movable gauge module.

INTRODUCTION

For almost every particle accelerator used contemporarily, beam profile monitors are an essential tool to diagnose the characteristics of the particle beam such as beam centroids, sizes and emittance. Many methods have been widely used for many years, for example scintillating screens, wire scanners, optical transition radiation, synchrotron radiation and laser wire. Each method has its own benefits and specific parameter space over which it can be applied. Nowadays, for the next generation of high energy, high brightness and high power beams such as the High Luminosity Large Hadron Collider upgrade [1] and the European Spallation Source [2], new methods are required in order to survive the destructive nature of the beams. In addition, low-energy, low-intensity beams of exotic particles such as the proposed Facility for Antiproton and Ion Research (FAIR) [3] require new non-interceptive methods to minimize the influence of monitoring on the beam.

Previously, residual gas Ionization Profile Monitors (IPM) [4] and Beam Induced Fluorescence profile monitors (BIF) [5] have been used in these situations due to their non-invasive properties. However, for both methods, the measurement is usually in one dimension, which means two monitors are required for horizontal and vertical profile measurement. Since both methods rely on the residual gas density or pressure, accelerators operating in ultra-high vacuum will require a stable beam for long periods of time to accumulate sufficient signal. Normally, the BIF method requires much more time for integration under the same vacuum condition than the IPM method, but the latter can have poorer spatial resolution due to the ionization and collecting process; about 1.0 mm rms for positive ions and 4.0 mm rms for electrons has been reported by J. Krider [4] in one of the setup in Fermi National Accelerator Laboratory. A hydrogen jet [6] was also used to create a pressure bump in Brookhaven National Laboratory to diagnose their proton beam but the measurement was still limited to one dimension due to the large thickness of the jet.

Based on these gas-based methods, at the Cockcroft Institute we have developed a beam profile monitor using a thin supersonic gas jet [7,8]. In this paper, we will give a brief overview of the experimental setup and measurement principle. Together with the newly installed moveable gauge module, we will discuss the supersonic gas jet properties and the related resolution for this monitor.

EXPERIMENTAL SETUP

The whole setup of this monitor is shown in Fig. 1. In order to produce a supersonic gas jet, a 30 μm diameter nozzle was used in the nozzle chamber. Using a differential pumping technique, gas can flow through the nozzle from the gas cylinder with a high stagnation pressure (1-10 bars) to the low pressure area, the nozzle chamber (about 10^{-3} to 10^{-4} mbar in the pulsed operation). With such a large pressure decline, the gas enters the nozzle chamber without the sense of boundary condition and expands freely until a Mach disk is formed [9]. In this process, gas flow reaches a supersonic speed inside the Mach disk and then returns to a subsonic speed very quickly after the Mach disk. A conical skimmer (180 μm in diameter) is placed a short distance after the nozzle to accept the supersonic flow and collimate the flow. From the formula in [10], the distance between the nozzle exit and the Mach disk is proportional to the square root of the ratio of this stagnation pressure and nozzle chamber pressure. For our case it can be in the range of several tens mm. A 3D translation stage is attached to the nozzle to align the nozzle with skimmer as well as modifying the nozzle-skimmer distance to make sure the gas flow expands to supersonic speed and the Mach disk is not

#hao.zhang@cockcroft.ac.uk

ISBN 978-3-95450-176-2

INSTALLATION STATUS OF THE ELECTRON BEAM PROFILER FOR THE FERMILAB MAIN INJECTOR*

R. Thurman-Keup#, M. Alvarez, J. Fitzgerald, C. Lundberg, P. Prieto, M. Roberts, J. Zagel, FNAL, Batavia, IL 60510, USA
W. Blokland, ORNL, Oak Ridge, TN 37831, USA

Abstract

The planned neutrino program at Fermilab requires large proton beam intensities in excess of 2 MW. Measuring the transverse profiles of these high intensity beams is challenging and often depends on non-invasive techniques. One such technique involves measuring the deflection of a probe beam of electrons with a trajectory perpendicular to the proton beam. A device such as this is already in use at the Spallation Neutron Source at ORNL and the installation of a similar device is underway in the Main Injector at Fermilab. The present installation status of the electron beam profiler for the Main Injector will be discussed together with some simulations and test stand results.

INTRODUCTION

Traditional techniques for measuring the transverse profile of proton beams typically involve the insertion of a physical object into the path of the proton beam. Flying wires for instance in the case of circulating beams, or secondary emission devices for single pass beamlines. With increasing intensities, these techniques become difficult, if not impossible. A number of alternatives exist including ionization profile monitors, gas fluorescence monitors, and the subject of this report, electron beam profile monitors.

The use of a probe beam of charged particles to determine a charge distribution has been around since at least the early 1970's (see [1] for references to previous devices). The most recent incarnation of this technique is a profile monitor in the accumulator ring at SNS [2].

An Electron Beam Profiler (EBP) has been constructed at Fermilab and has been installed in the Main Injector (MI). The MI is a proton synchrotron that can accelerate protons from 8 GeV to 120 GeV for use by a number of neutrino experiments, and eventually several muon-based experiments. The protons are bunched at 53 MHz with a typical rms bunch length of 1-2 ns. In this report we discuss the design and installation of the EBP and present some studies of the electron beam and simulation results for the anticipated measurement technique.

THEORY

The principle behind the EBP is electromagnetic deflection of the probe beam by the target beam under study (Fig. 1).

*Operated by Fermi Research Alliance, LLC under Contract No. De-AC02-07CH11359 with the United States Department of Energy.
#keup@fnal.gov

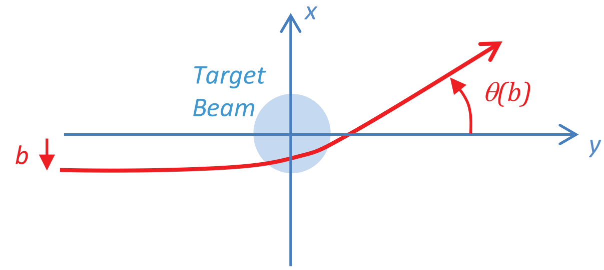


Figure 1: Probe beam deflection (red) for some impact parameter b.

If one assumes a target beam with $\gamma \gg 1$, no magnetic field, and $\rho \neq f(z)$, then the force on a probe particle is

$$\vec{F}(\vec{r}) \propto \int d^2\vec{r}'\rho(\vec{r}')\frac{(\vec{r}-\vec{r}')}{|\vec{r}-\vec{r}'|^2}$$

and the change in momentum is

$$\Delta\vec{p} = \int_{-\infty}^{\infty} dt\ \vec{F}\big(\vec{r}(t)\big)$$

For small deflections, $\vec{r} \approx \{b, vt\}$, and the change in momentum is

$$\Delta\vec{p} \propto \int_{-\infty}^{\infty} dx' \int_{-\infty}^{\infty} dy'\ \rho(x',y') \cdot \int_{-\infty}^{\infty} dt\ \frac{\{b-x', vt-y'\}}{(b-x')^2+(vt-y')^2}$$

where $\{\}$ indicates a vector. For small deflections, $\vec{p} \approx \{0,p\}$ and the deflection is $\theta \approx \frac{|\Delta\vec{p}|}{|\vec{p}|}$. The integral over time can be written as $\mathrm{sgn}(b - x')$ leading to an equation for the deflection

$$\theta(b) \propto \int_{-\infty}^{\infty} dx' \int_{-\infty}^{\infty} dy'\,\rho(x',y')\,\mathrm{sgn}(b-x')$$

where $\mathrm{sgn}(x) = -1$ for $x < 0$ and $+1$ for $x \geq 0$.

If one takes the derivative of $\theta(b)$ with respect to b, the sgn function becomes $\delta(b-x')$ leading to

$$\frac{d\theta(b)}{db} \propto \int_{-\infty}^{\infty} dy'\,\rho(b,y')$$

which is the profile of the charge distribution of the beam. Thus for a Gaussian beam, this would be a Gaussian distribution and the original deflection angle would be the error function, $\mathrm{erf}(b)$. This of course is true only to the extent that the above assumptions are valid.

EXPERIMENTAL PROCEDURE

There are a number of techniques for obtaining $\theta(b)$. A fast scan of the electron beam diagonally through the

ISBN 978-3-95450-176-2

SIGNAL PROCESSING ALGORITHM FOR BEAM POSITION AND PHASE MONITORS AT LANSCE

R. C. McCrady, H. A. Watkins, Los Alamos National Laboratory, Los Alamos, NM 87545 U.S.A

Abstract

The new beam position and phase monitors at LANSCE measure the phase of the beam relative to a reference signal from the master reference oscillator. Because of the various beam pulse formats used at LANSCE the algorithm needs to be flexible and to work well with short bursts of signals. We have developed an algorithm that provides phase resolution of better than 0.25 degrees with signal bursts one microsecond long, and also allows measurement of bursts as short as 100 nanoseconds. For beam position measurements flexibility took priority over precision; the processing scheme provides precision of less than 0.1 mm. In this paper we will present the principles of the algorithm and results of measurements.

INTRODUCTION

We are preparing to install beam position and Phase Monitors (BPPMs) in the linac at the Los Alamos Neutron Science Center (LANSCE.) The transducers are 4-electrode shorted-stripline detectors; the 201.25MHz signals from the electrodes are sampled at 240 Msamples/second, along with a 201.25MHz reference signal. These sample streams are processed using a custom algorithm in a field-programmable gate array (FPGA) to provide both the position of the beam and the phase (arrival time) with respect to the reference signal.

The signal-processing algorithm was developed to provide good precision for the phase measurement, as this is used for the Δt turn-on process [1] for the linac, where the energy of the proton beam can be inferred using phase measurements at two BPPMs. Another feature of the algorithm is its ability to provide good measurements using short bursts of beam signals. This is important because the LANSCE linac provides beams with various pulse formats to several user facilities.

In the following sections the algorithm is described.

THE ALGORITHM

The algorithm can be thought of as a fit of a sinusoid to the data. That is, an amplitude, phase, and DC offset that best fit the data are determined using a linear fitting process.

The i^{th} data sample of an electrode signal is:

$$y_i = A\cos(wi + \phi) + y_{DC} \tag{1}$$

A and ϕ are the signal amplitude and phase, y_{DC} is the DC offset, and w is the phase advance of the RF waveform per sample interval:

$$w = 2\pi f_{RF} \div f_{sample}.$$

In order to make the fit linear in the fit parameters, Eq. 1 can be written as:

$$y_i = a\cos(wi) + b\sin(wi) + y_{DC}$$
$$\text{where } A^2 = a^2 + b^2 \text{ and } \tan\phi = b/a \tag{2}$$

To keep the notation compact, the series of N samples to be analyzed can be denoted by:

$$\vec{y} = a\vec{c} + b\vec{s} + y_{DC}\vec{u} \tag{3}$$

where $\vec{c}$ is the series of values of cos(wi), $\vec{s}$ is the series of values of sin(wi), and all elements of $\vec{u}$ are one. Each of these vectors has N elements.

Now equation 3 can be multiplied by each vector, $\vec{c}$, $\vec{s}$ and $\vec{u}$:

$$\begin{aligned}\vec{c}\cdot\vec{y} &= a\vec{c}\cdot\vec{c} + b\vec{c}\cdot\vec{s} + y_{DC}\vec{c}\cdot\vec{u}\\ \vec{s}\cdot\vec{y} &= a\vec{s}\cdot\vec{c} + b\vec{s}\cdot\vec{s} + y_{DC}\vec{s}\cdot\vec{u}\\ \vec{u}\cdot\vec{y} &= a\vec{u}\cdot\vec{c} + b\vec{u}\cdot\vec{s} + y_{DC}\vec{u}\cdot\vec{u}\end{aligned} \tag{4}$$

Note that each vector dot product is a scalar number. The entire data series to analyse is now represented by 9 numbers (because some of the dot products appear twice in Eq. 4.) Equations 4 can be written in matrix form:

$$\begin{pmatrix}\vec{c}\cdot\vec{y}\\ \vec{s}\cdot\vec{y}\\ \vec{u}\cdot\vec{y}\end{pmatrix} = \begin{pmatrix}\vec{c}\cdot\vec{c} & \vec{c}\cdot\vec{s} & \vec{c}\cdot\vec{u}\\ \vec{s}\cdot\vec{c} & \vec{s}\cdot\vec{s} & \vec{s}\cdot\vec{u}\\ \vec{u}\cdot\vec{c} & \vec{u}\cdot\vec{s} & \vec{u}\cdot\vec{u}\end{pmatrix}\begin{pmatrix}a\\ b\\ y_{DC}\end{pmatrix} \tag{5}$$

Now all that needs to be done is to invert the matrix in Eq. 5 and multiply the inverse onto the vector on the left-hand side. This will determine the 3 quantities to be fit.

The Vectors of Sines and Cosines

Because the frequencies of the RF and sampling are known, one could in principle compute $\vec{c}$ and $\vec{s}$. We found, however, that slight drifts of the sampling frequency caused problems with the stability of the phase

ISBN 978-3-95450-176-2

LANSCE 1L HARP DATA ACQUISITION SYSTEM UPGRADE: FIRST RESULTS*

J. Sedillo, D. Martinez, J. Nguyen, LANL, Los Alamos, NM 87545 USA

Abstract

Efforts applied toward the upgrade of the LANSCE 1L harp beam diagnostic data acquisition system have completed with the system's successful deployment in late December 2014. Leveraging the principle of secondary electron emission, the data acquisition system measures the particle beam-induced, negative charge-loss response of a statically-located, harp-style, beam diagnostic sensor. The harp's sense wires span two orthogonal planes, transversely oriented with the beam's direction of travel resulting in two orthogonal profiles. The profile data provided by this beam diagnostic system allows LANSCE operators to measure the particle beam's transverse properties prior to reaching its final destination: the 1L target. Details will be provided with respect to the system's final hardware architecture, the system's theoretical beam response model, and the system's measured beam response.

INTRODUCTION

Shown in Fig. 1, the 1L harp is a fixed-position beam diagnostic sensor for measurement of the beam's transverse profiles immediately prior to impingement on the 1L target. The sensor is composed of three planes of silicon-carbide (SiC) fibers; two sense planes for measuring horizontal and vertical beam profiles, and a bias plane for absorption of secondary electrons. Each sense plane is composed of seventeen sense fibers spaced at 6 mm intervals. All fibers connect to individual 10 pF capacitors at one end and a cable plant at the other end for signal transmission to the data acquisition system [1].

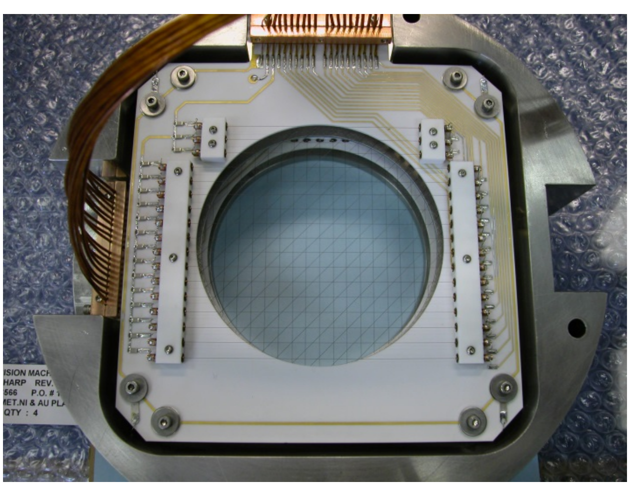


Figure1: 1L harp sensor.

*Funded under the auspices of the US Department of Energy. Contract DE-AC52-06NA25396.

PRINCIPLE OF OPERATION

The 1L harp operates on the principle of secondary electron emission resulting from the interaction of the particle beam with the harp's sense fibers. As the high-energy (800 MeV) H+ particle beam passes through the fiber, electrons from the material are forcefully removed from the fiber's surface into free space, leaving a positive charge gain within the fiber. The positive voltage resulting from the fiber's loss of electrons attracts a flow of electron current from the signal conditioning circuit to the fiber, neutralizing the charge difference. This current and its associated net charge are transformed by the signal conditioning circuitry into a voltage signal proportionally related to the charge. Since the particle beam's transverse particle density is generally Gaussian, each fiber in the plane receives a different amount of beam flux. This beam flux translates into secondary electron emission differences resulting in charge differences at the signal conditioning circuitry and finally a voltage difference at the analog-to-digital converter (ADC) dedicated to each fiber. Plotting the resulting voltages as a function of the fiber's relative position creates a Gaussian profile corresponding to the beam's transverse particle density. General beam and 1L harp parameters are listed in Table 1.

Table 1: 1L Harp and Beam Properties

Beam Property	Value
Beam species	H+
Beam energy	800 MeV
Longitudinal current profile	Triangular
Pulse duration	300 ns
Peak current	33.3 A
Bunch charge	5 μCoulombs
Beam Transverse σ	12.5 mm
Sensor Material	Silicon-Carbide Fiber (SiC)
Sensor Diameter	0.079 mm

BEAM RESPONSE MODEL

In order to model the particle beam's electrical effect on the fibers, the following mathematical tools and theories were employed:

- The Bethe-Bloch stopping power formula [2].

ISBN 978-3-95450-176-2

PERFORMANCE OF THE NEW FAST WIRE SCANNER AT THE LCLS*

P. Krejcik#, M. Campell, M. D'Ewart, H. Loos, K. Luchini, SLAC, Menlo Park, CA 94306, USA

Abstract

A new fast wire scanner based on a linear dc servo motor acting through dual bellows has been developed at SLAC. After successful beam testing at LCLS we are now replacing all the old style stepping motor driven scanners with the new type. The fast scanner design allows full emittance scans to be completed in seconds rather than minutes as before, facilitating speedier tuning of the accelerator. The low vibration design allows for wire speeds up to 1 m/s, making it also suitable for use in the new LCLS-II machine where high wire speeds are essential to prevent wire breakage from the high power electron beam with a 1 MHz repetition rate. The wire scanner design is presented along with beam measurements demonstrating its performance.

INTRODUCTION

The measurement and optimization of transverse emittances in the Linac Coherent Light Source (LCLS) accelerator relies on beam size measurements performed throughout the machine using wire scanners[1]. Beam profile monitors using OTR screens have proved to be unreliable because of the dominance of COTR effects arising from the very short bunches employed at LCLS. The original SLAC wire scanners, originally intended as a backup measurement for the profile monitors, are fairly slow in operation so that a complete emittance measurement may take several minutes of beam time. This early design is based on a stepper motor and ball screw system driving a cantilevered fork at 45° through the beam[2]. The motor speed must be intentionally kept low for measurements of the LCLS beam in order to minimize vibration.

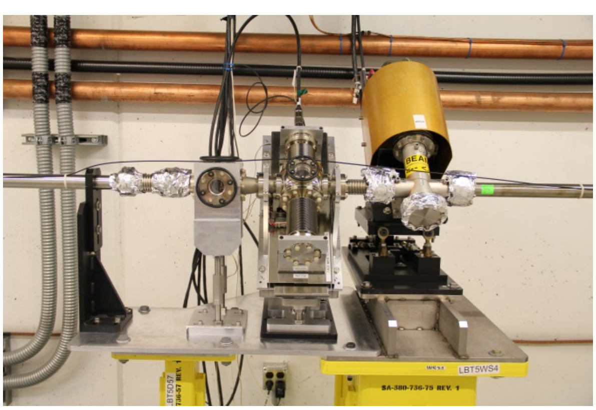


Figure 1: A section of the linac-to-undulator beam line in the LCLS with the new Fast Wire Scanner (middle) installed next to an old style scanner (right).

* This work was supported by Department of Energy Contract No. DE-AC0276SF00515

#pkr@slac.stanford.edu

The need to reduce the accelerator tuning time has motivated us to develop a new wire scanner with higher speeds and minimum vibration. The first of the new fast wire scanners was installed in the linac-to-undulator beam line of the LCLS, shown in Fig. 1, where it could be tested alongside the old style wire scanner.

The advent of the LCLS-II project at SLAC has also resulted in the need for a wire scanner that can move at speeds sufficient to prevent wire destruction during CW beam operation.

For the nominal LCLS-II beam parameters of 100 pC charge per bunch, a transverse emittance of 0.5 μm, and a bunch repetition rate of 0.6 MHz the minimum wire speed to avoid damage is calculated to be 0.34 ms^{-1}.

DESIGN FEATURES

The wires themselves are mounted on an interchangeable card that typically holds an x, y and u (at 45° to the beam axes) wire. The card is moved by a carriage assembly at 45° to the beam axis so that the horizontal, vertical and skew transverse profiles of the beam are measured sequentially. The carriage acts through dual vacuum bellows so that there is no opposing vacuum force for the motor. The carriage moves smoothly on a linear slide that is integrated into the commercially supplied dc linear servo motor assembly [3].

Vibration is minimized in this design since little force is required to move the carriage and the wire card is held at both ends rather than cantilevered as in the old design.

The motor servo control uses an integrated position encoder that allows the motion to be accelerated smoothly to scanning speed and slowed down again within across the total range of travel of 50 mm.

A second external position encoder reads the exact position of the wire with sub-micron resolution at the time of each beam trigger. With this approach the exact position of the wire does not have to be programmed during the scan since we can correlate the signal with the actual measured wire position. This external position encoder is connected to the Beam Synchronous Acquisition (BSA) system in the LCLS controls to seamlessly integrate the data collection during measurements.

The wire scanner assembly mounted on its 45° motion stage is shown in Fig. 2. The at-rest position is down most, against the stops, where no motor holding current is required. A scan of all 3 wire planes can be done in a single upward motion of the scanner before returning to the downward rest position and takes just a couple of seconds. The peak motor current during acceleration for such a scan is of the order of 10 amperes.

The magnetic field generated by the motor drawing this peak current can perturb the electron beam so we placed mu-metal shielding around the motor stage to virtually

ISBN 978-3-95450-176-2

CHERENKOV CONVERTER FOR LARGE DYNAMIC RANGE, HIGH SENSITIVITY DETECTORS FOR USE ON WIRE-SCANNERS*

J. F. Gubeli, P. Evtushenko
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA

Abstract

We are developing a wire-scanner with a dynamic range of 1e+6 or larger. In addition to the large dynamic range (LDR), high sensitivity is very desirable so that measurements can be made with a small amount of beam or small duty cycle beam. This high sensitivity requirement makes photo multiplier tubes (PMT) the preferred detector. Low dark current PMTs have maximum quantum efficiency in the visible wavelength range. We describe a converter where Cherenkov radiation (CR) is used to generate visible photons from electrons and positrons that are present due to wire-beam interaction. Also described is an optical system that collects and couples the CR into an optical fiber that delivers the visible photons to the PMT outside of the accelerator area, reducing background. The high directivity of the CR is used in a way that, when CR in the radiating medium is generated by particles not directed from the wire-beam interaction point to the converter, the CR is not coupled into the optical fiber and therefore does not create background for the wire-scanner measurements. Sensitivities to the refractive index of the radiating medium, alignment and mechanical tolerances are also presented.

INTRODUCTION

Particle accelerators have been using wire scanners as a valuable diagnostic tool to measure the spatial extent of their beam for many years. Several methods of determining the beam profile have been used, including measuring the induced current on the wires [1], by collecting the optical transition radiation [2] or by the use of scintillators [3]. We are developing a wire scanner that utilizes the shower of charged particles generated by the scattered electrons from the wire-beam interaction that impinge on the beam tube. We describe a method of converting these particles to photons by use of Cherenkov radiation and measuring the photons with a photomultiplier tube.

CHERENKOV RADIATION

Cherenkov radiation is electromagnetic radiation created when charged particles travel through an electrically polarizable medium faster than phase velocity of light in that medium. The threshold velocity of a particle to generate Cherenkov radiation is $\nu_n < \nu_p$ where ν_n is the phase velocity of light in a medium ($\nu_n = c/n$) and ν_p is the velocity of the charged particle. The velocity of an electron can be derived from the relativistic kinetic energy equation $E_k = (\gamma - 1)\, mc^2$ where $\gamma = (1 - \beta^2)^{-0.5}$ and $\beta = \nu_p/c$.

*Work supported by US DOE Office of Basic Energy Sciences early career program; DOE award number FWP#JLAB-BES11-05

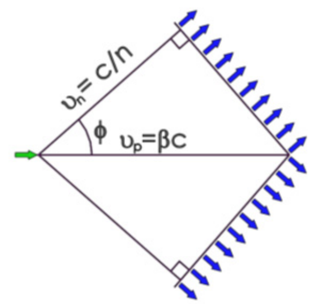


Figure 1: Cherenkov radiation geometry.

Cherenkov radiation is emitted in a cone where the angle is related to the velocities as $\cos\phi = (n\beta)^{-1}$ (Fig. 1). By solving for β in the relativistic kinetic energy equation, we can describe the emitted center wavelength angle as a function of n and E_k (MeV), equation 1.

$$\phi(E_k, n) := \mathrm{acos}\left(\frac{1}{n \cdot \frac{\sqrt{E_k^2 + 2 \cdot E_o \cdot E_k}}{E_k + E_o}}\right) \tag{1}$$

The Frank-Tamm formula describes the number of Cherenkov photons generated per angle and per wavelength of the generated photon [4], equation 2. The right side of this equation S_{CR} is a measure of the spectral distribution of the emitted photons.

$$\frac{d^2N}{d\Omega d\lambda} = S_{CR} = \left(\frac{\alpha \cdot n(\lambda) \cdot L^2}{\lambda^3}\right) \cdot \sin(\theta)^2 \cdot \left(\frac{\sin(k \cdot \pi)}{k \cdot \pi}\right)^2 \tag{2}$$

$$k = \frac{L}{\beta \cdot \lambda} \cdot (1 - \beta \cdot n(\lambda) \cdot \cos(\theta)) \tag{3}$$

CHERENKOV GENERATION CELL

The Cherenkov generation cell for this experiment consists of a 100 mm long water cell with a thin aluminium input window and a quartz output window (Fig. 2). For an index of refraction of 1.337, the phase velocity of light in water is $\nu_n = 0.748c$. To generate Cherenkov radiation, the minimum energy of an electron/positron traveling in water must be greater than 0.259 MeV.

ISBN 978-3-95450-176-2

MULTI-DIAGNOSTIC TRANSVERSE PROFILE MONITOR CHAMBER FOR EXTREME ULTRAVIOLET LITHOGRAPHY*

T. Campese#, R. Agustsson, M. A. Harrison, B. Jacobson, A. Murokh, A. Ovodenko, M. Ruelas, H. L. To, RadiaBeam Technologies, Santa Monica, CA 90404, USA
M. Fedurin, I. Pogorelsky, T. Shaftan, Brookhaven National Lab, Upton, NY 11973, USA

Abstract

RadiaBeam Technologies has developed a compact transverse beam profile measurement system for the Extreme Ultraviolet Lithography (EUL) experiment at the Brookhaven National Laboratory-Accelerator Test Facility (BNL-ATF). The EUL experiment requires fine e-beam and laser alignment across multiple passes. To accomplish this, the system consists of four profile monitor diagnostics: Interaction Point (IP), upstream, downstream, and a sub-micron resolution diagnostic 11.5 mm downstream of the IP. Care was taken in the design to minimize footprint, avoid possible diagnostic collisions, and maximize ease of assembly and alignment. This paper will review the requirements for the dimensional and optical constraints and solutions for this experiment.

INTRODUCTION

Extreme ultraviolet sources in the 7-15 nm range are needed for next-generation integrated circuit fabrication [1]. High quality sources in this range are large and cumbersome and therefore difficult to implement in an industrial setting. Inverse Compton Scattering (ICS) sources, such as the proof-of-concept EUL experiment at BNL-ATF, promise a smaller footprint per photon. In this scheme, a recirculated pulsed CO_2 laser is collided head-on with a 60-MeV electron beam, producing a higher-energy 13-nm photon. Both the laser and electron beam are focused to 50 µm or less at the IP with a minimized electron beam spot size of 22 µm measured.

CHAMBER DESIGN

Four different beam diagnostics are needed to monitor a 50-µm RMS beam size at the IP. They need to fit between two opposing, off-axis parabolic mirrors arranged equidistant from the IP focus which are used to focus and re-collimate the laser. The required separation distance is 120 cm, which caused a particularly challenging limitation for fitting in so many diagnostics. The parabolic mirrors are placed inside larger chambers upstream and downstream of the multi-diagnostic assembly. These three chambers are kept separate for ease of installation and serviceability in the experimental hall (see Figure 1).

Dual Position Profile Monitors

To monitor the transverse profile of the beam, both cerium-doped yttrium aluminum garnet (YAG:Ce) crystals and aluminum-coated silicon wafers are used as optical transition radiation (OTR) screens and are placed in the upstream and downstream profile monitors. Both the OTR and YAG screens are 100 µm thick and placed perpendicular to the electron beam on a multi-position pneumatic actuator. Each screen is backed by a 45° turning mirror (an aluminized silicon water) and viewed by CCD cameras through viewports, allowing for uniform magnification across the screen surface. These upstream and downstream profile monitors are mounted on pneumatic actuators to allow for high (25 µm) repeatability and fast extraction from the beam path (see Figure 2 and Table 1).

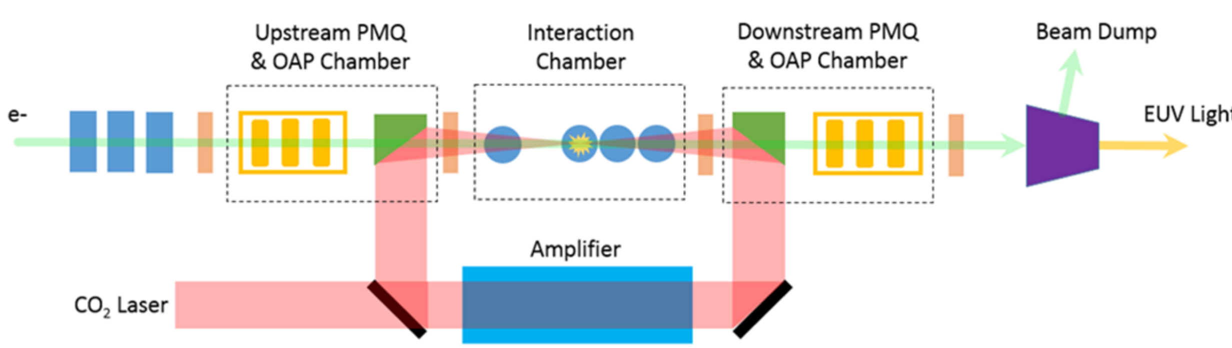


Figure 1: Full EUL Experiment including upstream quadrupole triplet (blue) and steering magnets (Orange).

*Work supported by DOE SBIR Grant No DE-SC0007703
#campese@radiabeam.com

Observation of Ion-induced Instabilities at NSLS2 Storage Ring*

Weixing Cheng#, Yongjun Li, Boris Podobedov
NSLS-II, Brookhaven National Laboratory, Upton, NY 11973

Abstract

NSLS2 storage ring has been commissioned and is open for user operations. At relatively low beam current (~ 25mA) multi-bunch fills, ion-induced instabilities have been observed. For the present user operations, 150mA of total beam current is filled in ~1000 bunches, fast ion is the dominant instability at the NSLS2 storage ring. Although the ion-induced dipole motions can be suppressed using bunch by bunch (BxB) feedback system and it is expected to decrease in severity as the vacuum conditioning progresses further, a thorough understanding and characterization of this effect is still important, especially in preparation to the future 500mA operations. A number of ion instability related studies, mostly parasitic to other machine activities, have been carried out at various fill patterns and beam currents. Preliminary measurement results are reported in this paper.

INTRODUCTION

Residual gas in the vacuum chamber will be ionized by high energy beam. Ions will be trapped by the beam potential and cause ion related instabilities. Conventional ion trapping can be easily cured with empty buckets. However fast-ion instability during the single pass of bunch train will be strong in the low-emittance high current ring like NSLS2. NSLS2 is an advanced third generation light source recently constructed at Brookhaven National Laboratory. Weak dipoles and three damping wigglers are used to decrease the horizontal emittance from 2nm.rad (bare lattice, no insertion devices) to < 1nm.rad (with 3 DWs). Vertical emittance has been measured to be less than 8pm.rad [1].

Even with ion-clean gap, another kind of ion instabilities could happen in small emittance high current storage rings, called “Fast” ion instability. Fast ion instability has been considered to be important for the NSLS2 storage ring and was investigated at design stage of the machine [2]. Transverse BxB feedback has been designed, constructed and commissioned to cure the fast ion and other coupled bunch instabilities [3].

Theory of fast-ion instability and early observations were reported almost 20-years ago [4-6]. As the recent machine development push to lower emittance and high current, fast-ion instability is getting severe for modern light sources and colliders. More recent observations on newly constructed light sources can be found, for example [7-9].

Fast ion instability will be affected by vacuum pressure, chromaticity and coupling. As vertical beam sizes are smaller than horizontal sizes, ion instability is usual dominant in vertical plane and it’s expected to be worse at improved coupling. With three DWs, NSLS2 storage ring horizontal emittance is half of bare lattice, this may change the fast ion growth rate. Close the IVUs may have elevated localized vacuum pressure which will in turn makes the fast ion easier to accumulate. Unfortunately, there was not much machine study time allocated to investigate fast ion behaviors at various machine conditions. Most of the observations reported here were parasitic to other studies, not insertion devices were closed and chromaticity was at nominal value of +2/+2 if not specified. We would like to have further systematic study of the issue in the future, to understand the fast ion behavior with different vacuum condition, chromaticity, coupling and insertion devices.

*Work supported by DOE contract No: DE-AC02-98CH10886

#chengwx@bnl.gov

FAST ION INSTABILITY OBSERVATION

During early commissioning stage of NSLS2 storage ring, fast ion instability was first observed at about 10mA filled in 500 bunches during BxB feedback commissioning. Preliminary observations have been reported in [3].

More recently a study was done at fixed, 1000-bunch and approximately uniform fill pattern while varying the total beam current. Specifically, there were 17mA, 31mA, 46mA, 100mA and higher total beam current evenly distributed in ~1000 bunches. Fill patterns of the first three data sets (17mA, 31mA and 46mA) were well controlled to minimize the bunch to bunch current variation. Rising/falling edges of the bunch train were trimmed to have a uniform bunch train. Figure 1 gives the measured bunch to bunch current at 46mA. Details on how to measure the bunch to bunch fill pattern can be found in [10]. 100mA and other higher current fill patterns had somewhat larger bunch to bunch current variation, edge bunches were not trimmed as these observations were parasitic to other studies.

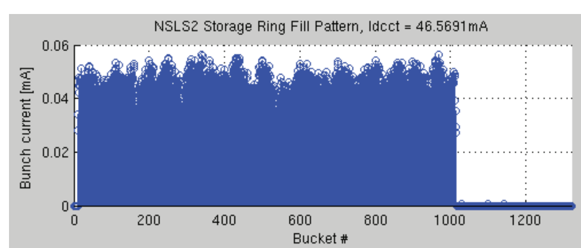


Figure 1: Bunch to bunch current measured at 46mA, machine was filled from bucket #1 to #1020. Rise/falling edge buckets were trimmed, only bunches #11 to #1005 were kept.

With injector set to multi-bunch fill with 20 bunch-train, storage ring was filled with 50% overlap (10 buckets) from shot to shot. After knocking out the head/tail bunches, bunch to bunch current variation shown in Fig 1 was ~ 3.7uA RMS with mean bunch current at 46.4uA. Relative bunch to bunch current

ISBN 978-3-95450-176-2

FIRST LHC EMITTANCE MEASUREMENTS AT 6.5 TeV

M. Kuhn[1,2], F. Antoniou[1], E. Bravin[1], B. Dehning[1], J. Emery[1], V. Kain[1], A. Langner[1,2], Y. Papaphilippou[1], E. Piselli[1], G. Trad[1]
[1]CERN, Geneva, Switzerland [2]University of Hamburg, Germany

Abstract

During LHC Run 1 significant transverse emittance growth through the LHC cycle was observed. Measurements indicated most of the blow-up to occur during the injection plateau and the ramp. Intra beam scattering was one of the main drivers of emittance growth. However, finding a good wire scanner working point was difficult. Photomultiplier saturation added uncertainty on all measurements. A large discrepancy between emittances from wire scanners and luminosity was discovered but not solved. During Long Shutdown 1 the wire scanner system was upgraded with new photomultipliers. In April 2015 the LHC re-started with collision energy of 6.5 TeV per beam. This paper presents the first transverse emittance measurements through the LHC Run 2 cycle with low beam intensity. Comparisons with data from the synchrotron light monitors and the LHC experiments will be discussed and results summarized. In addition, a thorough study of wire scanner photomultiplier saturation will be presented. Finally, the emittance growth results will be compared to intra beam scattering simulations.

INTRODUCTION

In 2012 the LHC was operated with high brightness beams with beam parameters pushed to their limits for outstanding luminosity production. With a bunch spacing of 50 ns the LHC was filled for physics with 1374 bunches per ring, containing up to $1.7{\times}10^{11}$ protons per bunch (ppb) with transverse emittances as small as 1.5 µm at injection. However, the high brightness could not be preserved during the LHC cycle. Measurements in 2012 revealed a transverse emittance blow-up of about 0.4 to 0.9 µm from injection into the LHC to the start of collisions [1].

At the start of Run 2 in 2015 the LHC is operated with beams of reduced brightness. The beam parameters of the 2015 early physics beams as well as the nominal parameters are listed in Table 1. During the first phase of commissioning and intensity ramp-up measurements indicate less total blow-up than in 2015. This paper summarizes the results of beam size measurement accuracy with the LHC wire scanners and emittance growth through the LHC cycle.

LHC Wire Scanner Intensity Limitations

The LHC wire scanners are equipped with a 36 µm thick carbon wire attached to a linearly moving fork [2]. The wire crosses the beam at a constant speed of 1 m/s. For each measurement the beam profile is scanned twice as the wire passes through the beam with in and out scan. In this paper only the average beam size obtained from in and out scan is used and the error from averaging is included in the results.

Table 1: LHC Design and Early 2015 Run Configurations

	Design	Early 2015
Total number bunches per beam	2808	3 – 458
Bunch spacing [ns]	25	25 and 50
Mean bunch length [ns]	1.3	1.2
Bunch intensity [10^{11} protons]	1.15	1.0 – 1.2
Injection energy [GeV]	450	450
Emittance at injection [µm]	3.5	1.5 – 3.0
Collision energy per beam [TeV]	7	6.5
Emittance at collision [µm]	3.75	1.5 – 4.0
β^* at ATLAS/CMS [m]	0.55	0.8

The LHC wire scanners can only be used with a small fraction of the total nominal intensity per ring due to wire heating. The carbon wire should be able to take 2–3×10^{13} charges/mm before sublimating. The close-by LHC superconducting magnets limit the maximum scan intensity further, to 5×10^{12} charges/mm [2], because the particle showers produced by the wire passing through the beam can quench the magnets. This limit corresponds to about 240 bunches per beam ($2.7\times10^{13}p$), less than one injected nominal batch (288 bunches). At 6.5 TeV flattop energy scans were possible with up to two nominal bunches ($2.3\times10^{11}p$). The flattop limit has recently been redefined to $1.6\times10^{12}p$ after the first experience at 6.5 TeV.

The emittance evolution of high intensity physics fills cannot be measured with the LHC wire scanners. The synchrotron light telescope (BSRT) is used for that purpose. The BSRT absolute beam size measurement is obtained from a cross-calibration with wire scanners. Also, the wire scanner is currently the only operational device that can accurately measure beam sizes through the LHC energy ramp. Low intensity test fills during the commissioning phase are used for the calibration of the emittance measuring instruments and emittance preservation studies.

RUN 2 LHC WIRE SCANNER ACCURACY

The obtainable emittance measurement accuracy for a wire scanner at location with no dispersion depends on the accuracy of the optics knowledge (β) and measurement error ($\Delta\beta$) as well as on the beam size measurement accuracy ($\Delta\sigma$) of the given device:

$$\frac{\Delta\varepsilon}{\varepsilon} = \sqrt{\left(2\frac{\Delta\sigma}{\sigma}\right)^2 + \left(\frac{\Delta\beta}{\beta}\right)^2} \tag{1}$$

A large contribution to the wire scanner beam size accuracy derives from the wire position measurement precision and the position measurement calibration. The precision

ISBN 978-3-95450-176-2

BEAM LOSS MONITORING FOR DEMANDING ENVIRONMENTS

E. B. Holzer*, CERN, Geneva, Switzerland

Abstract

Beam Loss Monitoring (BLM) is a key protection system for machines using beams with damage potential and is an essential beam diagnostic tool for any machine. All BLM systems are based on the observation of secondary particle showers originating from escaping beam particles. With ever higher beam energies and intensities, the loss of even a tiny fraction of the beam can lead to damage or, in the case of superconducting machines, quenches. Losses also lead to material aging and activation and should therefore be well controlled and reduced to a minimum. The ideal BLM system would have full machine coverage and the capability to accurately quantify the number of lost beam particles from the measured secondary shower. Position and time resolution, dynamic range, noise levels and radiation hardness all have to be considered, while at the same time optimizing the system for reliability, availability and maintainability. This contribution will focus on design choices for BLM systems operating in demanding environments, with a special emphasis on measuring particle losses in the presence of synchrotron radiation and other background sources.

INTRODUCTION

A Beam Loss Monitoring (BLM) system has three main roles: provide protection against beam induced damage or quench, provide a diagnostics tool for the operation and commissioning of the machine, and keep the activation levels low. When beam particles in an accelerator or a transfer line deviate from the ideal trajectory, they eventually hit the vacuum chamber walls or beamline components and generate secondary particle showers. If their energy is high enough to penetrate, these secondaries can be measured outside of the machine by a BLM system. Hence, for all but the very lowest energy machines, beam loss monitoring is an essential beam diagnostics tool. It applications include: beam steering in linear machines, by minimizing the losses along the line; diagnostic of failure scenarios; search for aperture restrictions or erroneous machine elements causing local losses.

It is important to minimize beam losses even if they are not immediately compromising the machine structure, as they lead to aging of the materials and to activation. Radiation levels have to be kept as low as possible to limit human exposure during maintenance and repair work and to reduce the amount and activation levels of radioactive material at the end of the machine life-cycle. Collimation systems play an important role in this respect. They concentrate the unavoidable losses in comparatively short regions and, in the ideal case, can keep the rest of the machine virtually loss free. The importance of beam collimation increases at very high beam intensities and energies, where uncontrolled losses of even the beam halo have to be avoided.

The first part of the paper will discuss general design considerations for a BLM system with a focus on machines with damage potential, on regions of high radiation levels and on physically large machines. Machine protection, the coverage of loss scenarios and the system dependability will be discussed, as well as the possibility to resolve the position, the magnitude and the time structure of the losses. The second part of the paper discusses background sources to the beam loss measurement. These can limit the sensitivity, reduce the dynamic range and even compromise the machine protection functionality. Showers from distant beam losses, radiation from accelerating structures and background due to synchrotron radiation are reviewed. Throughout the paper examples will be given mostly of recent and current developments to cope with the challenges of future machines.

BLM FOR MACHINE PROTECTION

Where the beam has the potential to damage accelerator structures or to cause quenches in superconductive machines, by far the most demanding role of the BLM system is machine protection. On October 9, 2015 the record level of 200 MJ of stored energy per beam was surpassed with 6.5 TeV beams in the LHC as part of the intensity ramp-up. 362 MJ per beam is envisaged at the design beam energy of 7 TeV and nominal beam intensity. Already one LHC pilot bunch of 5×10^9 protons is close to the damage limit at 7 TeV. At HL-LHC (High Luminosity LHC), a major upgrade of the LHC planned for 2023, it is foreseen that the energy of one beam will reach 694 MJ, and even 8 GJ is envisaged for FCC-hh (Future Circular hadron Collider). Besides the beams, the enormous amount of 10 GJ will be contained in the LHC magnets at 7 TeV. This corresponds to 2.4 ton of TNT. If even a small fraction of this energy is released in an uncontrolled way massive damage could result.

In the design of the CLIC (Compact Linear Collider) two beam module, a low energy (2.4 GeV) and high current (100 A) electron drive beam is decelerated and the extracted power is transferred to a high energy (1.5 TeV) and low current (1.2 A) electron or positron main beam. The nominal beam power is large, 72 MW and 14 MW for the drive and the main beam respectively. Losses from either beam can have severe consequences. The most critical beam quantities are the high intensity for the drive beam and the high energy and small emittance for the main beam.

A powerful machine protection system is vital for all machines with damage potential and constitutes an integral part of the machine design. The BLM system is one of its key components. When losses exceed threshold values on any one of the 3600 loss detectors at the LHC, the beam is safely aborted. The thresholds depend on the detector location, the

* barbara.holzer@cern.ch

ISBN 978-3-95450-176-2

DEVELOPMENT OF THE BEAM LOSS MONITOR FOR BEAM HALO MEASUREMENT IN THE J-PARC RCS

M. Yoshimoto#, H. Harada, K. Okabe, M. Kinsho,
J-PARC, JAEA, Tokai, Ibaraki, 319-1195, Japan

Abstract

In the J-PARC RCS, transverse beam profiles including both the beam core and halo at extraction beam transport line (3NBT) were measured by using a combination with a wire scanner type beam scraper and some beam loss monitors (BLMs). Our final goal of this halo monitor is to measure the intra-bunch beam halo of extracted two bunches from the RCS. Thus the plastic scintillator and photomultiplier (PMT) assemblages were adopted as the BLMs with quick time response. However, we found that the BLMs detected not only the radiation from the wire but also reflected one from other devices and wall. Therefore we tried to develop new-type BLMs, which are scintillation-type BLM of lead glass and Cherenkov-type BLM of quartz or UV acrylic. In this presentation, we will report on the overview and experimental results of the new-type BLMs together with the outline of halo monitor system.

INTRODUCTION

The 3-GeV Rapid Cycling Synchrotron (RCS) of the Japan Proton Accelerator Research Complex (J-PARC) is a MW class of high intensity proton accelerator [1]. In addition, the RCS has two functions as a proton driver for neutron/muon production at the Material and Life science experimental Facility (MLF) and as a booster of the 50-GeV Main Ring synchrotron (MR) injection. To provide such a high power proton beam for the MR with small injection beam loss or for the MLF with broad range and uniformity irradiation to the target using the octupole magnet [2], it is required to improve the extraction beam quality, namely to achieve the Low-Halo and High-Intensity beam by finer beam tuning in the RCS [3]. Therefore the measurement of the transverse beam profile including both of the beam core and the beam halo is one of the key issues for the high power beam operation in the RCS. Thus a new beam halo monitor was developed and installed at the 3GeV-RCS to Neutron source Beam Transport (3NBT) line as shown in Fig. 1 and Fig. 2 [4]. This new beam halo monitor was constructed by combining a wire scanner type beam scraper and some beam loss monitors (BLMs). The transverse beam profile including the beam core and beam halo can be reconstructed with the halo monitor. On the other hand, our final goal of the halo monitor is to measure not only the transverse beam halo but also the intra-bunch beam halo of the extracted two bunches from the RCS. However the beam experiments made clear that there are some issues for the intra-bunch beam halo measurement.

In this paper, we report the transverse beam halo measurement with the new beam halo monitor. In addition, we introduce the new BLMs which were developed for intra-bunch beam halo measurement.

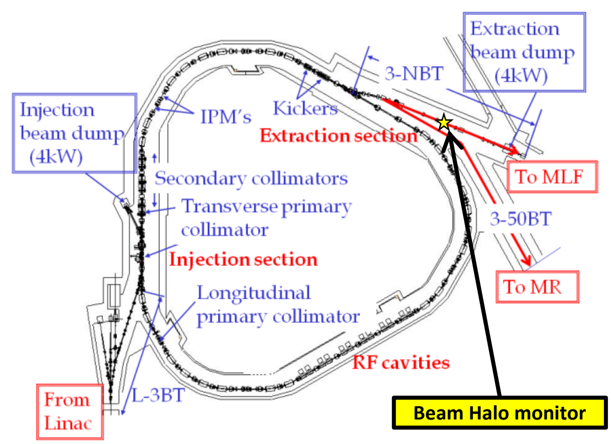


Figure 1: Top view of the RCS and location of the beam halo monitor installation.

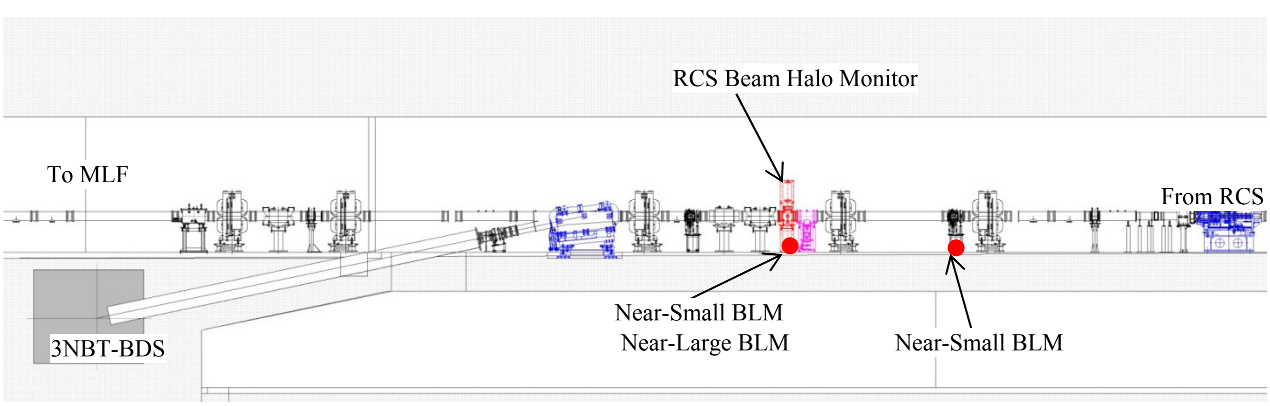


Figure 2: Side view of the 3NBT line and location of the beam halo monitor installation.

ISBN 978-3-95450-176-2

POSITION RESOLUTION OF OPTICAL FIBRE-BASED BEAM LOSS MONITORS USING LONG ELECTRON PULSES

E. Nebot del Busto, M. Kastriotou, CERN, Geneva, Switzerland & University of Liverpool, UK
M.J. Boland, ASCo, Clayton & The University of Melbourne, Australia
R.P. Rasool, The University of Melbourne, Australia
W. Farabolini, CERN, Geneva, Switzerland & CEA/DSM/IRFU, Saclay, France
S. Doerbert, E. Effinger, E. B. Holzer, F.S. Domingues, W. Viganò, CERN, Geneva, Switzerland
C.P. Welsch Cockcroft Institute, Warrington; University of Liverpool, UK

Abstract

Beam loss monitoring systems based on optical fibres (oBLM), have been under consideration for future colliders for several years. To distinguish losses between consecutive quadrupoles, the position resolution of detected losses is required to be less than 1 m. A resolution of better than 0.5 m has been achieved in machines with single, short pulses of the order of a nanosecond. In the case of longer beam pulses with 150 ns duration, as they would be in the Compact LInear Collider (CLIC), the longitudinal length of signals in the fibre is close to the duration of the beam pulse which makes loss reconstruction very challenging. In this contribution results from experiments into the position resolution of an oBLM system based on long beam pulses are presented. These measurements have been performed at the CLIC Test Facility (CTF3) at CERN and the Australian Synchrotron Light Source (ASLS). In the former, controlled beam losses were created in a 22.5 m long decelerating Test Beam Line (TBL) LINAC. In the latter, loss localization was studied by comparing that from single bunches with those from longer bunch trains. In both cases the losses were detected using a 200 µm core pure silica fibre coupled to a Silicon Photomultiplier (SiPM) photon detector.

INTRODUCTION

The operation of particle accelerators would not be possible without the use of instruments and diagnostics systems that allow the main properties of the beam to be characterized. Beam Loss Monitors (BLM), particle detectors installed outside of the vacuum chamber to detect beam induced showers, are a powerful tool for the optimization of the performance of a machine as well as for protecting it against damage. Over the past ten years, optical fibre based BLM (oBLM) systems have been studied and implemented in several accelerator facilities [1] due to the various advantages that they bring with respect to standard BLM techniques. The prompt nature of the Cherenkov light generated in the fibre by the crossing of a high energy charged particle provides a very fast detection technique, with the main limitation coming from dispersive effects in the fibre core. Moreover, only photons with energies above the electron-positron generation threshold would (indirectly) generate light. This is particularly interesting in synchrotron light sources where the large number of low energy photons can limit the sensitivity of BLM systems. From a machine protection perspective, an optical fibre may provide coverage of a full beam line preventing any potentially dangerous beam losses from going undetected. In this contribution, the determination of the original location of beam losses via the time of flight of photons in the fibre core of oBLM systems is discussed. Several experiments conducted at the Australian Synchrotron Light Source (ASLS) and the CLIC Test Facility at CERN (CTF3) with single electron bunches and long multi-bunch pulses are presented.

THE MACHINES

This section describes the most important features of the two facilities where the presented studies were conducted.

The Australian Synchrotron Light Source

The Australian Synchrotron [2] can be schematically seen on the right side of Figure 1. A thermionic gun injects electrons into a 14 m LINAC equipped with two 3 GHz normal conducting RF cavities that accelerate electrons up to 100 MeV. The particle energies are increased up to 3 GeV in a 130 m Booster ring equipped with 500 MHz RF cavities. Electrons are finally injected into a 216 m storage ring, also equipped with 500 MHz normal conducting cavities. The storage ring is subdivided into 14 sectors, each one of them containing a double bend achromat cell and a straight section. In Vacuum Undulators (IVU) are installed in the straight sections of sectors 3, 5 and 13, and the RF cavities in sectors 6 and 7. Sector 11 is equipped with beam scrapers to protect the insertion devices by concentrating beam losses at this location. The machine provides a flexibility to tune the beam conditions used for these experiments. The bunch charge can be varied from $10^{+5} - 10^{+9}$ [4], the bucket in which a single bunch will be injected can be chosen and injection of up to 75 bunches is possible.

The Test Beam Line at CTF3

CTF3 was designed and constructed to verify the feasibility of the novel two-beam acceleration concept of the Compact LInear Collider (CLIC) [3]. A thermionic gun and a bunching system provide an electron pulse with a peak current of 3.0 A and a length that can vary from 0.1 to 1.4 µm. Four normal conducting RF structures boost the electron energies up to 120 MeV. Particles are then driven towards a small delay loop and a storage ring that may be used for

ISBN 978-3-95450-176-2

COMMISSIONING OF THE NEW ONLINE-RADIATION-MONITORING-SYSTEM AT THE NEW EUROPEAN XFEL INJECTOR WITH FIRST TESTS OF THE HIGH-SENSITIVITY-MODE FOR INTRA-TUNNEL RACK SURVEILLANCE

Frank Schmidt-Foehre, Lars Fröhlich, Dirk Noelle, Rainer Susen, Kay Wittenburg, DESY, Hamburg, Germany

Abstract

The new Embedded Online-Radiation-Monitoring-System, developed for the 17.5 GeV superconducting European XFEL (E-XFEL) that is currently being built between the DESY campus at Hamburg and Schenefeld at Schleswig-Holstein [1,2], has been commissioned in a first system test setup at the E-XFEL Injector. As most of the electronic systems for machine control, diagnostics and safety of the E-XFEL will be located in cabinets inside the accelerator tunnel, the test setup incorporates all system parts like cabinet-internal and -external monitor electronics, infrastructure interface boards, firmware, software, cabling and sensors. Hence the commissioning system setup gives the possibility for first operation of the complete online radiation monitoring system under realistic environmental conditions in terms of irradiation, electro-magnetic interference (EMI) inside the injector tunnel, as well as operational and control system aspects. Commissioning results and measurements based on different internal and external sensor channels will be presented here, together with recent measurements done at different radiation sources using the high-sensibility mode for intra-rack radiation monitoring.

INTRODUCTION

The European XFEL that is currently being built between the DESY campus at Hamburg and Schenefeld at Schleswig-Holstein [1,2], will provide high duty cycle, ultra short X-Ray beams at wavelength about 0.5 Å with extreme brilliance. 27000 pulses per second are possible due to the super conducting 17.5 GeV linac, providing an electron beam with the corresponding time structure. The beam can be distributed into 3 undulator sections of about 200 m length, each consisting of about 30 undulators. Due to the overall length of the facility of about 3.4 km located in the city area of Hamburg, the installation of all parts including the electronics was chosen to be inside of a single tunnel system.

Due to the environmental conditions of the installation in a single tunnel, the control of beam losses and radiation damage is essential. Hence a new Embedded Radiation-Monitor-System (DosiMon) has been developed. The DosiMon system has been designed for measurement of γ-radiation at various appropriate electronics-internal and rack-external measurement points and dose levels. For future extension, the system design already incorporates provisions for measurement of Neutron-radiation in similar measurement point setups.

Most of the electronic systems cabinets for machine control, diagnostics and safety of the E-XFEL located in the accelerator tunnel are shielded, based on pre-estimated radiation levels and the expected damage threshold for standard non radiation hard electronics [3]. The current expansion state of the DosiMon system provides an online γ-radiation dose measurement inside those cabinets for this task.

External radiation detection sensors will also be used in addition to monitor e. g. the dose rates in the SASE undulator regions. Lifecycle estimates for the electronics and the sensitive undulators will trigger alarms, before significant radiation damage occurs. Furthermore, the online data from the dosimetry network allow correlating dose rates with machine settings, and thus to detect and to avoid dangerous operation modes.

A complete new modular system architecture has been designed for the DosiMon as shown in Fig. 1 and Fig. 2. The basic readout principle is similar to the reader design developed for undulator radiation measurements at the Fermi accelerator at Elettra-Sincrotrone Trieste(Italy) [4]. Corresponding orienting tests at the DESY Linac II [5] have demonstrated operation with zero-biased RadFets at DosiMon-comparable prototype testboards for a high dynamic range of ~1 Gy to >1000 Gy (e. g. for lifetime surveillance of the undulators in the XFEL SASE sections) at reduced sensitivity. Further calibration measurements have been taken at Fermi at Elettra [6] in a similar dose range, which can be used for start of commissioning at the XFEL. In addition to the zero-bias mode for enhanced dynamic range at a reduced sensitivity, the system also enables a high-sensitivity +18V bias-mode of the RadFet sensors, working in a reduced dynamic range.

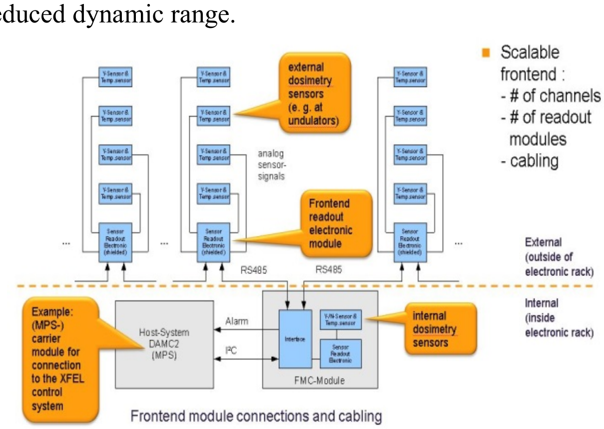


Figure 1: XFEL DosiMon basic system architecture.

ISBN 978-3-95450-176-2

HTc-SQUID BEAM CURRENT MONITOR AT THE RIBF*

T. Watanabe†, N. Fukunishi, M. Kase, RIKEN, Wako, Japan
S. Inamori, K. Kon, TEP CorporationI, Katsushika, Japan

Abstract

For the purpose of measuring the DC current of heavy-ion beams non-destructively at high resolution, we have developed a high critical temperature (HTc) superconducting quantum interference device (SQUID) beam current monitor for use in the radioactive isotope beam factory (RIBF) at RIKEN in Japan. Because of its low vibration, a pulse-tube refrigerator cools the HTc fabrications that include the SQUID in such a way that the size and the operational costs of the system are reduced. Last year,we significantly reinforced the magnetic shielding system. The new strong magnetic shielding system can attenuate the external AC magnetic noise by 10^{-10}. With the aim of practical use in acceleration operation, we disassembled the prototype high-Tc SQUID current monitor (SQUID monitor), installed improved parts, and re-assembled it. Beginning this year, we have installed the SQUID monitor in the beam transport line in the RIBF. Here we describe the present details of the developed SQUID monitor system and the results of beam measurements.

INTRODUCTION

The reason for using a superconducting quantum interference device (SQUID) as a beam current monitor is that it has a very high magnetic sensitivity. For example, SQUIDs are used in studies of the neural activity inside brains and to diagnosis heart conditions in clinical environments. The magnetic fields induced by the brain and heart are very faint in the range of from 10^{-10} to 10^{-14} T. This extreme sensitivity allows a SQUID to measure a beam current nondestructively. Furthermore, we aim to downsize the system and reduce running costs by using high critical temperature (HTc) materials including the SQUIDs. Schematic drawings of the SQUID monitor and the cryostat inside the SQUID monitor are shown in Fig. 1. Both the HTc magnetic shield and the HTc current sensor were fabricated by dip-coating a thin Bi_2-Sr_2-Ca_2-Cu_3-O_x (Bi-2223) layer on a 99.7% MgO ceramic substrate [1]. The Bi-2223 layer is approximately 500 μm thick. When a charged particle (ion or electron) beam passes along the axis of the HTc current sensor, a shielding current produced by the Meissner effect flows in the opposite direction along the wall of the HTc current sensor. The shielding current acts so as to eliminate the magnetic field produced by the beam. Since the outer surface of the HTc current sensor is designed to have a bridge circuit [1], the current generated by the charged particle beam is concentrated in the bridge circuit and forms an azimuthal magnetic field around it. The HTc SQUID is set close to the bridge circuit and can detect the azimuthal magnetic field with a high S/N ratio. The beam current can be precisely obtained by previously calibrating the HTc SQUID output voltage with a known reference current. As shown in Fig. 1-(b), the HTc SQUID monitor consists of two vacuum chambers completely separate from each other. One chamber contains a cryostat in which the HTc SQUID, HTc magnetic shield, and HTc current sensor are cooled. The other is the chamber through which the beam passes. All the fabricated HTc devices are cooled to around 70 K by a low-vibration pulse-tube refrigerator with a refrigeration power of 11 W at a temperature of 77 K. Eight vibration rubbers dampen the vibration caused by the pulse-tube refrigerator. Figure 2 shows a bird's-eye view schematic of the RIBF facility indicating the positions of the SQUID monitor. The research activities of the RIBF project make extensive use of the heavy-ion accelerator complex, which consists of two linacs and five ring cyclotrons, i.e., two RIKEN heavy-ion linacs (RILAC I, II), the AVF cyclotron, the RIKEN ring cyclotron (RRC), the fixed-frequency ring cyclotron (fRC), the intermediate-stage ring cyclotron (IRC), and the superconducting ring cyclotron (SRC). Energetic heavy-ion beams are converted into intense RI beams via the projectile fragmentation of stable ions or the in-flight fission of uranium ions by using the superconducting isotope separator BigRIPS.

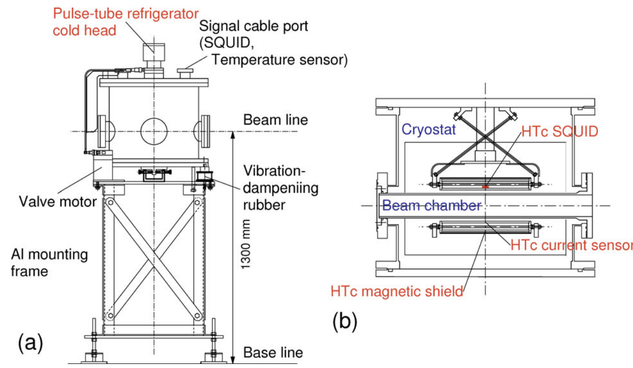


Figure 1: Schematic drawing of the (a) high-Tc SQUID current monitor (SQUID monitor) and (b) the cryostat inside the SQUID monitor.

Beginning this year, we have installed the SQUID monitor in the beam transport line in the RIBF (Fig. 2). We are presently using the SQUID monitor in practice for measurement of the current of beams of heavy-ions such as uranium.

* Work supported by JSPS KAKENHI (Grants-in-Aid for Scientific Research) Grant Number 15K04749
† wtamaki@riken.jp

ISBN 978-3-95450-176-2

WIDEBAND VERTICAL INTRA-BUNCH FEEDBACK AT THE SPS – TECHNOLOGY DEVELOPMENT, RECENT ACCELERATOR MEASUREMENTS AND NEXT STEPS*

J. Fox, J. Dusatko, C. Rivetta, O. Turgut
Stanford Linear Accelerator Center Stanford, CA, USA
H. Bartosik, W. Hofle, B. Salvant, U. Wehrle, CERN, Geneva, Switzerland
S. De Santis, LBL Berkeley, CA, USA

Abstract

A wideband vertical intra-bunch feedback system is in development at the CERN SPS for use to control potential Ecloud and TMCI instabilities. The work is motivated by planned intensity increases from the LIU and HL-LHC upgrade programs. System technical features include pickups, upgraded kickers and related RF power amplifiers, 1 GHz bandwidth analog processing used in conjunction with a 4 GS/sec reconfigurable digital signal processing system. Recent results include driven beam experiments and beam simulation methods to verify the damping provided by the wideband system, and validate reduced MIMO models and model-based controllers. Noise effects and uncertainties in the model are evaluated via SPS measurements to predict the limits of control techniques applied to stabilize the intrabunch dynamics. We present data showing the excitation and damping of unstable modes. The plans for the next year, including experimental measurements, hardware upgrades and future control developments are described.

INTRODUCTION - CONTROL OF INTRA-BUNCH INSTABILITIES

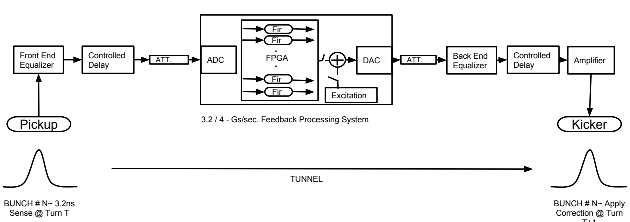


Figure 1: System diagram for the demonstration intra-bunch signal processing

Instability control via feedback at light sources and accelerators requires techniques to sense beam motion, compute correction signals and apply these corrections to the beam. This intra-bunch feedback system follows the same principles, but acts on modes of beam motion within a single bunch as well as coupled bunch modes between bunches. The basic formalism uses digital processing techniques to remove noise and DC orbit offsets from the bunch signals, apply gain at the oscillation frequency with a tailored phase shift to apply a net damping signal at a kicker structure. An intra-bunch feedback system using digital processing formalism has been demonstrated at JPARC [1, 2] for 150 ns long bunches and at the CERN PS for 60 ns bunches [3]. The challenge in our work directed at the CERN SPS is the necessary bandwidth, as the SPS bunch 4σ is roughly 1.7 ns, so our systems sample at 3.2 or 4 GS/sec (Fig. 2). The kicker and pickup elements then require roughly a GHz of bandwidth, and all the processing elements within the loop require careful attention to deviations from linear phase response to allow high closed loop gain without causing oscillations or instabilities.

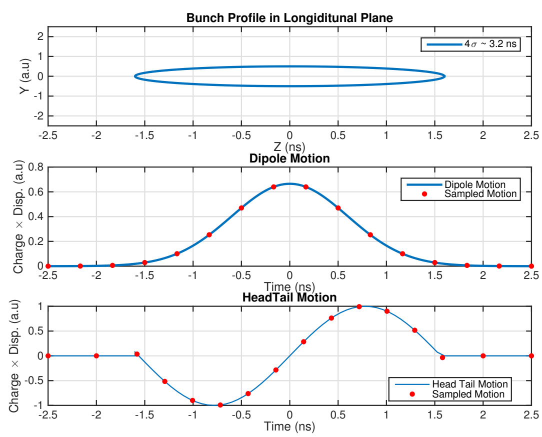


Figure 2: The intra-bunch system samples 16 vertical coordinates across each bunch, and computes correction signals in a processing filter to be applied on later turns.

The high-current operation of the SPS for HL-LHC injection will require mitigation of possible Ecloud and TMCI effects [4]. These intensity-limiting instabilities can be controlled through several measures, including special coatings of the vacuum chamber, tailored machine optics [5] or wideband feedback techniques [6]. A single-bunch wideband digital feedback system was initially tested at the CERN SPS in November 2012 [7, 8]. The project is part of a larger LHC injector upgrade [6]. In 2014, during the shutdown interval this system has been expanded with installation of wideband kickers and associated RF amplifiers [9]. While the original bandwidth-limited system achieved control of mode 0 and mode 1 unstable beams, we must explore the new wideband kicker performance, and understand necessary capabilities to control beams anticipated in the HL operating scenario.

* Work supported by the U.S. Department of Energy under contract # DE-AC02-76SF00515 and the US LHC Accelerator Research Program (LARP).

ISBN 978-3-95450-176-2

FIRST RESULTS OF SOLARIS SYNCHROTRON COMMISSIONING*

A.I. Wawrzyniak#, C.J. Bocchetta, P. Borowiec, P. Bulira, P.P. Goryl, A. Kisiel, M. Kopeć, A. Marendziak, M.J. Stankiewicz, M. Zając, Ł. Żytniak, Solaris NSRC, Krakow, Poland
R. Nietubyć, Solaris NSRC, Krakow and NCNR, Otwock, Poland

Abstract

Solaris is a third generation light source recently constructed at the Jagiellonian University in Krakow. The installation of the 600 MeV S-band linear accelerator with thermionic RF gun and transfer line as well as the 1.5 GeV storage ring is now complete. In November 2014 subsystem tests and conditioning of the Solaris linac were started. A 300 MeV electron beam at the end of the linac was observed for the first time in February 2015 after which the machine was shut down for 2.5 months to complete transfer line and storage ring installation. In May the commissioning of the linac together with the transfer line and storage ring began. The beam was soon observed on the YAG screen monitor, installed at the injection straight in the storage ring. The beam current measured with the fast current transformer in the transfer line was 8 mA over 180 ns, at 360 MeV. The commissioning of the machine is still in progress and preliminary results of Solaris are presented.

INTRODUCTION

Solaris is a third generation light source constructed at the Jagiellonian University (JU) in Krakow, Poland. The project was started in 2010 with a unique cooperation between JU and Lund University/MAX-Lab in Lund, Sweden. Within this framework two twin 1.5 GeV storage rings were designed and built.

The installation of the Solaris accelerators started on May 2014 and was completed one year later. In November 2014 subsystem tests and conditioning of the linac started and by the end of February 2015 a 300 MeV electron beam at the end of the linac was observed for the first time. After this achievement the machine was shut down for 2.5 months to complete the transfer line and storage ring installation. In May 2015 the commissioning of the linac together with the transfer line and storage ring began. In June first turns were observed and then beam was accumulated and stored with the single kicker and RF system. On the 19th of June a 7 µA current was stored at 360 MeV and the first synchrotron light from the dipole was detected at the fluorescent screen in the front end of the PEEM beamline. In August the machine was shut down for a month to allow installation of an aluminium vacuum chamber and an elliptically polarized undulator (EPU) in the 5th straight section of the storage ring.

MACHINE DESCRIPTION

The Solaris injector is designed to efficiently fill the storage ring. Since the RF linac structures and waveguides are not completely conditioned yet, injection into the storage ring takes place at the energy of 490 MeV. After accumulation of the electron beam, the energy will be ramped in the storage ring to 1.5 GeV and RF power is provided by two 100 MHz RF cavities fed by two 60 kW solid state amplifiers.

Injector

The Solaris injector consists of a 0.6 GeV S-band linac with a thermionic RF gun and a vertical dog-leg beam transfer line (TL) [1,2]. The electron source is a thermionic RF gun with a BaO cathode that has been chosen for simplicity of operation. This gun was designed and manufactured at MAX IV Laboratory. The energy of the electron beam exiting the gun is 2.8 MeV and the average current of the bunch train right after the gun is 200 mA. To focus the bunches two solenoid magnets are installed after the gun. The beam is transported through the chopper section and an energy filter in order to compress and clean the beam.

Storage Ring

The Solaris 1.5 GeV storage ring is composed of twelve double bend achromat (DBA) cells [3-5]. Most of the magnets in the DBA are multifunction:

- Bending magnets with defocusing gradient and pole face strips;
- Focusing quadrupoles with focusing sextupole content;
- Defocusing sextupoles with trim coils for skew quads;
- Correction sextupoles magnets with additional coils of steering magnets.

All the magnets within one DBA cell are shaped in one Armco block. This innovative approach allows the mutual alignment of magnets within the DBA cell to be within a 25 µm tolerance range and makes the cell short - 4.2 m. This implementation however comes at a cost of challenging manufacturing of magnets and vacuum chambers and their assembly.

*Work supported by the European Regional Development Fund within the frame of the Innovative Economy Operational Program:
POIG.02.01.00-12-213/09
#adriana.wawrzyniak@uj.edu.pl

ISBN 978-3-95450-176-2

HIGH FREQUENCY ELECTRO-OPTIC BEAM POSITION MONITORS FOR INTRA-BUNCH DIAGNOSTICS AT THE LHC

S. M. Gibson*, A. Arteche, G. E. Boorman, A. Bosco, Royal Holloway, University of London, UK
P. Y. Darmedru, T. Lefèvre, T. Levens, CERN, Geneva, Switzerland

Abstract

At the HL-LHC, proton bunches will be rotated by crab-cavities close to the interaction regions to maximize the luminosity. A method to rapidly monitor the transverse position of particles within each 1 ns bunch is required. A novel, compact beam diagnostic to measure the bunch rotation is under development, based on electro-optic crystals, which have sufficient time resolution (< 50ps) to monitor intra-bunch perturbations. The electro-optic beam position monitor uses two pairs of crystals, mounted on opposite sides of the beam pipe, whose birefringence is modified by the electric field of the passing charged particle beam. The change of birefringence depends on the electric field which itself depends on the beam position, and is measured using polarized laser beams. The electro-optic response of the crystal to the passing bunch has been simulated for HL-LHC bunch scenarios. An electro-optical test stand including a high voltage modulator has been developed to characterize $LiTaO_3$ and $LiNiO_3$ crystals. Tests to validate the different optical configurations will be reviewed. The opto-mechanical design of an electro-optic prototype that will be installed in the CERN SPS will be presented.

MOTIVATION

HL-LHC Crab-Cavity Bunch Rotation

An ambitious High Luminosity upgrade of the Large Hadron Collider will increase the luminosity by a factor of ten. The proton bunches will be rotated by crab-cavities placed before and after the interaction regions, so that the bunches collide head-on to reduce the overlap area and maximize the luminosity. Optimising the performance of the crab-cavities at the HL-LHC requires new instrumentation that can perform intra-bunch measurements of the transverse position of particles within a 1 ns bunch. Conventional electrostatic stripline BPMs are fundamentally limited to a few GHz bandwidth and take up valuable space close to the interaction region. A novel, compact beam diagnostic to measure the bunch rotation is under development, based on electro-optic crystals, which have sufficient time resolution (<50 ps) to monitor intra-bunch perturbations.

Head-tail Instability Monitors

A high-frequency monitor is also necessary to detect intra-bunch instabilities on a turn by turn basis. At the SPS and LHC, *head-tail* (HT) monitors are the main instruments to visualise and study beam instabilities as they occur [1]. The present HT monitors are based on stripline beam position monitors and fast sampling oscilloscopes [2]. Recent measurements reveal low order modes as shown in Figure 1. However the HT monitors only offer a bandwidth up to few GHz limited by the pick-up, cables and acquisition system. Novel pick-ups based on electro-optical crystals and laser pulses [3, 4] have already demonstrated response times in the picosecond range [5], making this technique a promising candidate to achieve higher resolutions to improve the HT monitors capacity to solve bunch shapes and instabilities.

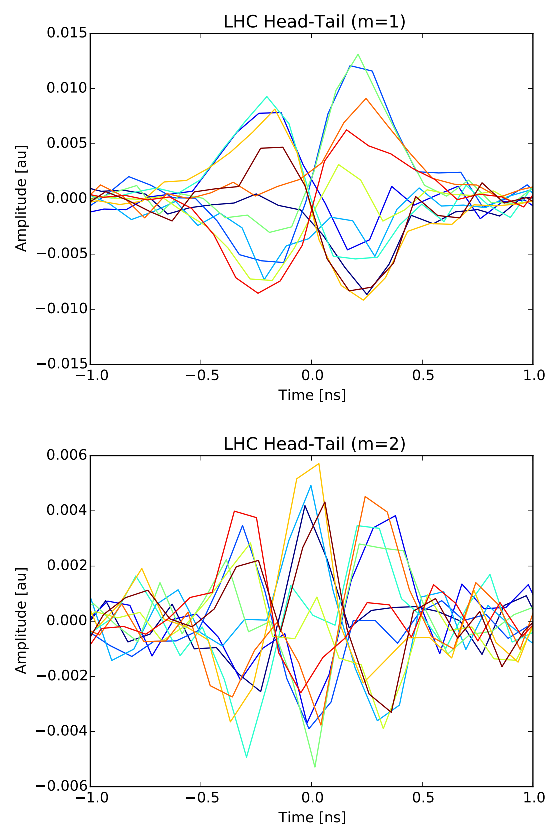


Figure 1: Mode 1 and 2 bunch instabilities recorded with a stripline BPM HT monitor in August 2015 at the LHC.

EO-BPM Project Aims

The above considerations have stimulated a collaboration between the CERN Beam Instrumentation group and Royal Holloway, University of London (RHUL) to develop novel beam diagnostics based on electro-optical crystals, which have sufficient time resolution to monitor intra-bunch perturbations. The aim is to develop a prototype electro-optic Beam Position Monitor (EO-BPM) that will be initially tested to monitor intra-bunch instabilities in the CERN SPS. Success would validate their use as a future diagnostic tool for the HL-LHC to monitor crab rotation of the bunches.

* stephen.gibson@rhul.ac.uk

ISBN 978-3-95450-176-2

BEAM PROFILE MONITOR AT THE 1 MW SPALLATION NEUTRON SOURCE

Shin-ichiro Meigo*, Motoki Ooi, Kiyomi Ikezaki, Tomoyuki Kawasaki, Hidetaka Kinoshita, Atsushi Akutsu, Masaaki Nishikawa and Shinpei Fukuta, J-PARC center, JAEA, 319-1195, Japan
Hiroshi Fujimori, J-PARC center, KEK, 305-0801, Japan

Abstract

Since 2008, the Japanese Spallation Neutron Source (JSNS) of J-PARC has produced a high-power proton beam of 300 kW. In order to operate with high intensity beam such as 1 MW, a reliable profile monitor system is required. Beam profile monitor system was developed by using SiC sensor wires. Since pitting erosion was found at the vessel of the spallation neutron target at other facility of SNS, the beam current density at the target should be kept as low as possible. In order to decrease the beam density, a beam flattering system based on a non-linear optics with octupole magnets was developed. It was found that the beam profile at the target obtained with the Multi Wire Profile Monitor (MWPM) showed flat distribution and showed good agreement with the design calculation. Furthermore, the present status of the development of the profile monitor is also described.

INTRODUCTION

In the Japan Proton Accelerator Research Complex (J-PARC) [1], a MW-class pulsed neutron source, the Japan Spallation Neutron Source (JSNS) [2], and the Muon Science facility (MUSE) [3] will be installed in the Materials and Life Science Experimental Facility (MLF) shown in Fig. 1. Since 2008, this source has produced a high-power proton beam of 300 kW. In 2015, we successfully ramped up beam power to 500 kW and delivered the 1-MW beam to the targets. To produce a neutron source, a 3 GeV proton beam collides with a mercury target, and to produce a muon source, the 3 GeV proton beam collides with a 2-cm-thick carbon graphite target. To efficiently use the proton beam for particle production, both targets are aligned in a cascade scheme, with the graphite target placed 33 m upstream of the neutron target. For both sources, the 3 GeV proton beam is delivered from a rapid cycling synchrotron (RCS) to the targets by the 3NBT (3 GeV RCS to Neutron facility Beam Transport) [4–6]. Before injection into the RCS, the proton beam is accelerated up to 0.4 GeV by a LINAC. The beam is accumulated in two short bunches and accelerated up to 3 GeV in the RCS. The extracted 3 GeV proton beam, with a 150 ns bunch width and a spacing of 600 ns, is transferred to the muon production target and the spallation neutron source.

Recently, pitting damage became evident in the mercury target container [7], and the extent of the damage is proportional to the fourth power of the peak current density of the proton beam. After operating the beam at high power, significant pitting damage was observed at the spent mercury target vessel at JSNS and at the Spallation Neutron Source in Oak Ridge National Laboratory [8, 9]. Using linear optics (i.e., quadrupole magnets) for beam transport, the peak current density can be reduced by expanding the beam at the target. However, beam expansion increases heat in the vicinity of the target, where shielding and the neutron reflector are located. Therefore, the peak current density is limited by the heat induced in the vicinity of the target. At the JSNS, the minimum peak current density is expected to be 9 μA/cm^2, which gives a thermal energy density at the target of 14 J/cm^3/pulse [10]. Because the pitting damage goes as the fourth power of the peak density, scanning the beam with a deflecting magnetic field will not mitigate the pitting damage.

Beam profile monitoring plays an important role in comprehending the damage to the target. Therefore it is very important to watch continuously the status of the beam at the target at the JSNS especially for the peak current density. We have developed a reliable beam profile monitor for the target by using Multi Wire Profile Monitor (MWPM). In order to watch the two dimensional profile on the target, we have also developed the profile monitor based on the imaging of radiation of the target vessel after beam irradiation. In this paper, the present status of the beam monitor at the spallation neutron source is described.

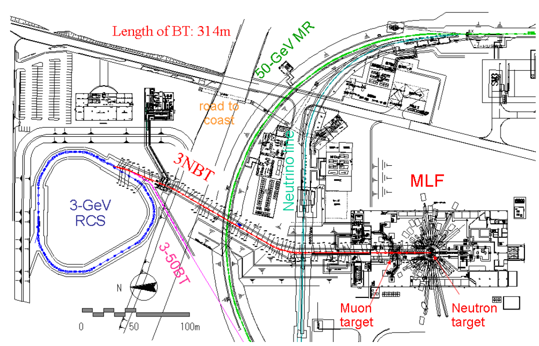


Figure 1: Plan of rapid cycling synchrotron (RCS) at the Materials and Life Science Experimental Facility (MLF) at J-PARC.

BEAM MONITOR SYSTEM AT THE BEAM TRANSPORT TO THE TARGET

Silicon Carbide Sensor Wire

In order to obtain the characteristics of the proton beam, diagnostic system based on a Multi Wire Profile Monitor

* meigo.shinichiro@jaea.go.jp

ISBN 978-3-95450-176-2

BEAM POSITION MEASUREMENT SYSTEM DESIGN

H. Schmickler, CERN, Geneva, Switzerland

Abstract

For newcomers, but also with interesting details for oldies, all components of a modern beam position measurement system are reviewed and explained. From specifications, sensor types, analogue and digital electronics over calibration methods the whole field will be covered.

INTRODUCTION

The Beam Position Monitor (BPM) can be found in every accelerator. Its role is to provide information on the position of the beam in the vacuum chamber at the monitor location. For linacs and transfer lines the BPMs are used to measure and correct beam trajectories, while for synchrotrons such monitors are distributed around the ring and used to calculate the closed orbit. In circular machines, their location is usually chosen close to the main quadrupole magnets where the β-functions are largest and so any orbit distortion a maximum. For 90° lattices a typical layout involves placing horizontal monitors near the focusing quadrupoles (where the horizontal β-function is large) and the vertical monitors near the defocusing quadrupoles (where the vertical β-function is large). Apart from closed orbit measurements, the BPMs are also used for trajectory measurements (the first turn trajectory is particularly important for closing the orbit on itself) and for accelerator physics experiments, where turn-by-turn data, and even bunch-to-bunch data is often required.

In the early days a BPM monitoring system simply consisted of an oscilloscope linked directly to the pick-up signals. Since then, enormous advances in the acquisition and processing electronics have been made, turning beam position monitors into very complex systems. Modern BPMs are capable of digitising individual bunches separated by a few nanoseconds, with a spatial resolution of a micrometre or less, while the resulting orbit or trajectory collected from several hundred pick-ups can be displayed in a fraction of a second.

In the next chapter the mostly used sensors will be described (Pick-ups), followed by a detailed description on the acquisition electronics. Other important aspects, like calibration, timing and synchronization, large scale maintenance and component obsolescence are not treated.

PICK-UPS

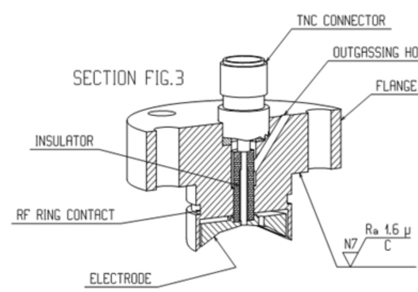
The measurement of beam position relies on processing the information from pick-up electrodes located in the beam pipe. Here we treat the three most commonly employed:

- Electrostatic – including so-called 'button' and 'shoe-box' pick-ups
- Electromagnetic – stripline couplers
- Resonant cavity – especially suited for high frequency linacs

An excellent in depth analysis of most of these pick-ups is presented in Ref. [1]. Here we will briefly describe the three most commonly used, namely the electrostatic, electromagnetic and cavity pick-up.

Electrostatic (Capacitive)

The electrostatic or capacitive pick-up is the most widely used in circular accelerators. It consists of metallic electrodes situated on opposite sides of the vacuum chamber at the location where the beam is to be measured. As the beam passes through, electric charges are induced on the electrodes, with more induced on the side which is closer to the beam than the one furthest from the beam. By measuring the difference in the charge induced, the position can be calculated.



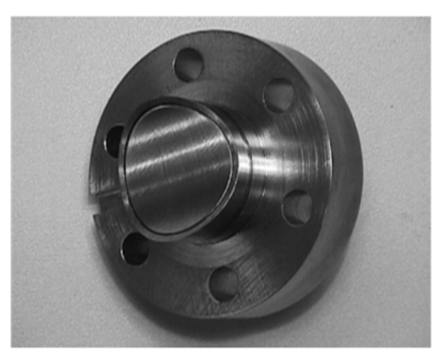


Figure 1: Cross-section and photo of an LHC button.

ISBN 978-3-95450-176-2

CHARACTERIZATION OF NSLS2 STORAGE RING BEAM ORBIT STABILITY*

Weixing Cheng#, Kiman Ha, Joe Mead, Boris Podobedov, Om Singh, Yuke Tian, Li-hua Yu
NSLS-II, Brookhaven National Laboratory, Upton, NY 11973

Abstract

Similar to other advanced third generation light sources, NSLS2 storage ring has stringent requirements on beam orbit stability. NSLS2 BPMs can be synchronously triggered to record turn by turn or fast acquisition 10kHz data. Spectrum of these data reveals various beam motion frequencies and it has been characterized at various machine conditions. Compared to the ground motion and utility system vibration spectra, beam motion introduced by the vibrations can be identified. An algorithm to locate possible noise sources from the measured spectrum has been developed. Preliminary results of locating orbit sources will be discussed in this paper as well.

INTRODUCTION

NSLS2 is an advanced third generation light source recently constructed at Brookhaven National Laboratory. The 3GeV storage ring generates ultra-low emittance of less than 1nm.rad horizontally and 8pm.rad vertically. Machine commissioning has been finished with six beamlines early this year and it's open for user experiments. With one super-conducting cavity, average beam current of 300mA has been achieved. Typical user operation current has been increased in steps, now it operates at 150mA and refills at every three hours. Top off operation will start soon.

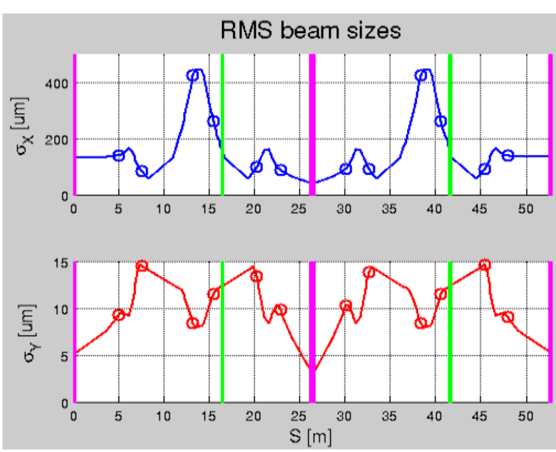


Figure 1: Horizontal and vertical RMS beam sizes in one super cell, calculated using emittance of $\varepsilon_x/\varepsilon_y$ = 0.9/0.008 nm.rad and energy spread of 0.09%.

NSLS2 storage ring has 30 DBA cells. 15 high beta (long) and 15 low beta (short) straight sections are available for insertion devices. Three damping wigglers are installed at long straight sections in C08,C18 and C28. These damping wigglers decrease the bare lattice horizontal emittance of 2nm.rad down to 0.9nm.rad. Figure 1 plots the RMS beam sizes in one super cell (high beta cell + low beta cell). Beam sizes at various beamline source points are marked with vertical lines. Smallest beam sizes of 3 μm are found to be at the center of short straight sections. With 10% beam stability requirement, the orbit needs to be controlled within 300nm at these source points. There are 6 BPMs in each cell to monitor the beam trajectory/orbit. BPM locations are marked as circles in Fig. 1. These BPM readings are used for orbit correction and fast orbit feedback control. There are 6 slow correctors and 3 fast correctors per cell to maintain the beam in desired reference orbit. In addition to the normal BPMs in the cell, there are 2 (or 3 for canted ID straights) ID BPMs on both end of the insertion devices. These BPMs are typically mounted on high stability stands and configured to have better vertical sensitivity. ID BPMs are used to monitor the orbit at the insertion devices. This information is used to ensure that the beam stays within the pre-defined active interlock envelope, as required for machine protection. More information of the NSLS2 button BPM design and performance can be found at [1,2].

In-house developed BPM electronics are used in NSLS2 complex, including the LINAC, transport lines, Booster and Storage ring. Button signals feed to the pilot tone combiner (PTC) box inside the tunnel, where beam signal is filtered. PTC includes a coupler to allow the pilot tone signal be injected into the signal processing chain. This pilot tone signal was designed to dynamically calibrate the BPM electronics drift. It turned out that this kind of dynamic pilot tone calibration is not needed as BPM electronics reside in temperature stabilized racks (+/- 0.1 degC). BPM processing electronics are assembled in a 1-U chassis, analog front end (AFE) first conditions the button signal with band pass filter, variable attenuators and amplifiers. Button signal is sampled by 16-bit ADC sampling rate of 117MHz. Sampled data is then processed in the digital front end (DFE) board, in which ADC/TbT/FA/SA data are available. NSLS2 storage ring BPMs can provide to the user in 4 switchable modes, ADC, TbT (Turn-by-Turn, up to 1M samples, on-demand), FA (Fast Acquisition, 10 kHz, up to 1M samples, on-demand) , and SA (Slow Acquisition, 10 Hz, continuous). 10kHz FA data is shared around the ring through SDI fiber link network, these data are used for fast orbit feedback and active interlock system. Details of the BPM electronics development are reported in previous conferences [3-6]. We report the measured beam orbit stability using these advanced BPMs.

*Work supported by DOE contract No: DE-AC02-98CH10886
#chengwx@bnl.gov

ISBN 978-3-95450-176-2

SUMMARY OF THE 2014 BEAM-HALO MONITORING WORKSHOP*

Alan S. Fisher#, SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA

Abstract

Understanding and controlling beam halo is important for high-intensity hadron accelerators, for high-brightness electron linacs, and for low-emittance light sources. This can only be achieved by developing suitable diagnostics. The main challenge faced by such instrumentation is the high dynamic range needed to observe the halo in the presence of an intense core. In addition, measurements must often be made non-invasively.

This talk summarizes the one-day workshop on Beam-Halo Monitoring that was held at SLAC on September 19 last year, immediately following IBIC 2014 in Monterey. Workshop presentations described invasive techniques using wires, screens, or crystal collimators, and non-invasive measurements with gas or scattered electrons. Talks on optical methods showed the close links between observing halo and astronomical problems like observing the solar corona or directly observing a planet orbiting another star.

INTRODUCTION

There were 39 participants [1] in the workshop on beam-halo monitoring [2]. This paper summarizes the 11 talks and draws from the slides, which are posted on-line [3], without additional reference numbers. Each contributor's name appears in **boldface** when first cited below, and appears again in figure captions.

The subject of beam halo was introduced by **Kay Wittenburg** (DESY). Although a broad definition is difficult, "halo is low density and therefore difficult to measure." Charge near the core of a bunched beam, with a density of 10^{-1} to 10^{-4} of the peak, is commonly considered a "tail". Halo has even lower densities and is often further from the core, although there are no clear boundaries (Figure 1). The dynamic range required for measurement can span 5 to perhaps 8 orders of magnitude, depending on the number of poorly bunched, high-energy particles needed to damage the machine.

Halo has a variety of sources, including space-charge or beam-beam forces; poorly matched, misaligned or non-linear accelerator optics; instabilities and resonances; RF noise; scattering (intra-beam, residual gas, macroparticles, photons, obstacles, stripping foil, screens, etc.); electron clouds; beam-energy tails from uncaptured particles; or transverse-longitudinal coupling in the RF field.

Quantifying halo is made more difficult by varying definitions. Also, oscillations in phase space may cause measurements using projections into real space to vary with position along the machine. The techniques fall into three broad groupings: invasive measurements (wire scanners, scrapers); non-invasive, non-optical methods (gas jets, electrons); and optical measurements. Workshop talks presented many of these approaches.

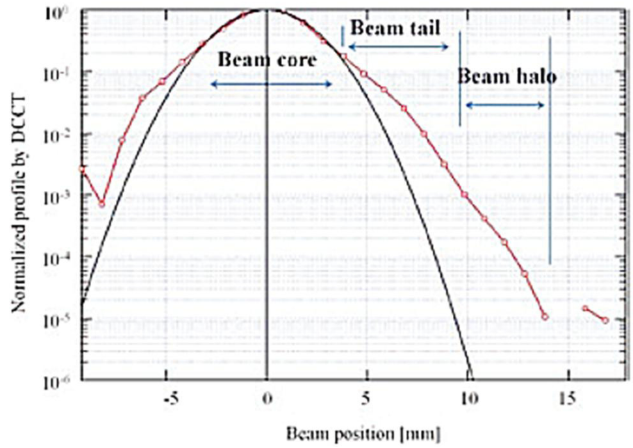


Figure 1: A beam profile showing core, tail, and halo (log scale). (K. Wittenburg, from M. Yoshimoto [4])

INVASIVE TECHNIQUES

Wire Scanners

Pavel Evtushenko (Jefferson Lab) stressed the need to protect electron linacs with continuous RF and MW beams from damage due to beam loss from tails and halos. Even in idealized Parmela simulations, the JLab FEL injector forms a tail at the level of 3×10^{-3}. Images using optical transition radiation (OTR) and YAG:Ce

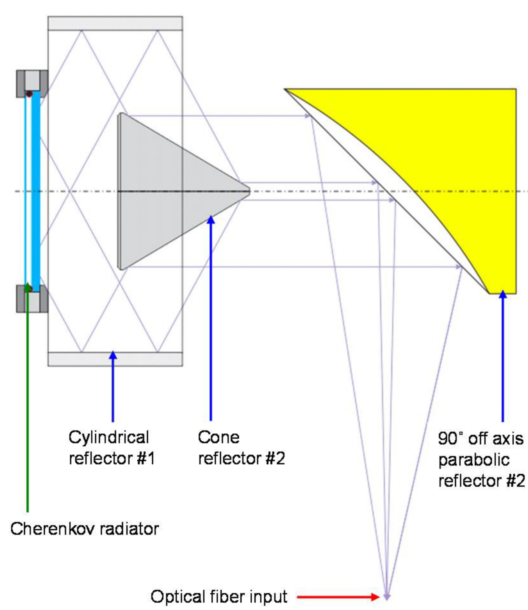


Figure 2: A loss shower emits light in a Cherenkov radiator. The light couples to an optical fibre leading to a PMT outside the tunnel. (P. Evtushenko)

---
*SLAC is supported by the U.S. Department of Energy under Contract DE-AC02-76SF00515.
#afisher@slac.stanford.edu

ISBN 978-3-95450-176-2

IBIC 2014 SCIENTIFIC HIGHLIGHTS

Stephen R. Smith, SLAC National Accelerator Lab, Menlo Park, CA 94025, USA

Abstract

The SLAC National Accelerator Lab hosted the 3rd International Beam Instrumentation Conference (IBIC 2014) at the Portola Hotel in Monterey, California September 14-18, 2014. The four day scientific program consisted of tutorials, invited talks, contributed talks, poster sessions and industrial sponsor exhibits.

PARTICIPANTS

Conference attendance included 181 participants. Notably less than one third of the participants were from the host continent. Two-thirds of the participants travelled from Asia, South America, and Europe which alone was responsible for half of the attendees. This likely reflects the vibrancy of the European accelerator scene with projects such as the European XFEL, the European Spallation Source, FAIR, and LHC underway.

Table 1: Participation

Country	People	Continent
Japan	13	Asia 23
People's Republic of China	1	
Republic of Korea	8	
Taiwan	1	
Armenia	1	Europe 96
Belgium	1	
France	8	
Germany	37	
Italy	8	
Poland	1	
Slovenia	2	
Spain	4	
Sweden	3	
Switzerland	16	
United Kingdom	15	
United States	57	North America 57
Brazil	2	South America 3
Columbia	1	
Total	181	

PROGRAM

Tutorials

Both tutorials were very well received. Mike Gruchalla's (Los Alamos National Labs) tutorial "Managing Electromagnetic Interference in Large Instrumentation Environments"[1] provides very useful advice on understanding EMI with many subtle (and not so subtle) examples. He emphasized starting by understanding exactly what you are trying to measure, and then understanding what is not to be included in that measurement and understanding the coupling of both, with a frequent refrain of "draw a picture."

Thomas H. Lee of Stanford University presented "Dark (and Bright) Secrets of RF Design"[2] including some ancient history of RF technology and its ties to accelerators. He says "RF design is a mystery to many engineers" and that "… arcane incantations are needed to make oscillators oscillate and amplifiers amplify (and not vice-versa). Part of the mystery has to do with the many ways that ever-present parasitics undergo surprising impedance transformations, as well as the sometimes counterintuitive ways that nonlinear and time-varying processes can affect noise in amplifiers, oscillators and mixers." Lee starts with a short list of why RF design is hard: parasitics, limited device power gain, tough noise and nonlinearity requirements, and poor device models. A nice overview of relevant topics such as amplifier matching, noise sources, and some odd effects were explained, and many examples followed.

Superconducting Detector Technology

Kent Irwin[3] (SLAC and Stanford University) presented an exciting talk on arrays of superconducting detectors spanning their applications from X-ray beamlines to the recent announcement of detection of evidence for gravitational waves in the early universe. The detectors are arrays of superconducting transition-edge sensors (TES), sensitive to anything which can deposit energy. The signal is amplified by superconducting quantum-interference devices (SQUID), potentially with frequency-division multiplexing based on superconducting resonators whose frequency is shifted by the energy deposited in the TES. These technologies may well be more broadly useful to our community.

Lab Talks and Posters

LHC Beam Instrumentation was presented by Rhodri Jones (CERN). He pointed out the great challenges due to relative inaccessibility and high stored energies in the machine[4]. Weixing Cheng (Brookhaven National Lab) presented "NSLS2 Diagnostic Systems Commissioning

ISBN 978-3-95450-176-2