BEAM DIAGNOSTICS SYSTEMS FOR THE DIAMOND SYNCHROTRON LIGHT SOURCE

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Abstract

We present an overview of the diagnostics systems that will be implemented at the Diamond synchrotron light source. The aim of this paper is to give a complete picture of the systems to measure the quality of the electron beam from the injector through to the storage ring. We will show how we intend to measure the dimensions, the position and the time structure of the electron bunches. In addition, the instrumentation to measure the charge, the current and the emittance of the electron beam will be described. Finally, systems to provide accurate measurement of electron losses and the injection efficiency will be detailed.

OVERVIEW

A broad range of diagnostics systems has been included in the design of all parts of the Diamond injector and storage ring. Table 1 gives an overview of the various systems in all locations, starting at the 100 MeV linear accelerator (LINAC) through the LINAC to booster transfer line (LTB), the full energy booster (BST) and the booster to storage ring transfer line (BTS) to the 3 GeV storage ring (SR).

	LINAC	LTB	BST	BTS	SR
Faraday Cup	2	2	-	2	-
WCM	1	1	-	1	-
ICT	-	3	1	3	-
PCT	-	-	1	-	1
OTR/YAG	4	4	3	4	-
SLM	-	2	1	1	1
X-ray Pinhole	-	-	-	-	2
EBPM	-	7	22	7	168
PMT BLM	10	15	-	15	-
PIN BLM	-	-	32	-	192

Table 1: Beam Instrumentation in Diamond (abbreviations are defined in the text)

CHARGE AND CURRENT MEASUREMENT

Faraday cups are a simple but effective way of measuring the charge of the beam. Diamond will have Faraday cups in the LINAC and both transfer lines to allow charge measurements all the way through the injection system. In total there will be five Faraday cups, two in the LINAC, two in the LTB and one in the BTS. The LINAC Faraday cups are based on the SLS design [1] for a 90keV cup but with modifications to allow it to be used at 4MeV as well. The LTB Faraday cups are a new development based on a copper core to capture the charged particles surrounded by a lead shield to absorb the radiation. As they are to be used at a relatively low 100MeV the thermal issues are small and a simple geometry is sufficient. The BTS Faraday cup will have to be able to take the full 3GeV output of the booster and so although a similar copper core / lead shield design is envisaged, heat transport mechanisms have to be closely investigated.

Three SLS design [1] wall current monitors (WCM) will be installed to allow bunch charge measurements with high temporal resolution. The first is just after the gun to allow characterisation of the charge structure entering the LINAC. The second WCM is placed before the first dipole in the LTB to asses the bunch purity of the LINAC output. The third WCM is placed in the BTS to assess the charge structure of the booster output.

To enable non-destructive measurement of the charge during normal operation, integrating current transformers (ICT) connected to integrate and hold electronics are used in several places along each transfer line allowing the transport efficiency of the transfer lines to be optimised.

The transfer lines can be configured so that the beam passes through the ICTs and WCMs and is then captured in a Faraday cup to allow cross calibration between the different systems.

A single parametric current transformer (PCT) in each ring will be used to measure the current in both the booster and storage ring. Due the high demands for stability and accuracy on the current in the storage ring we are planning to use a newly developed PCT from Bergoz Instrumentation [2] for the storage ring location, whereas the lower requirements of the booster allow the existing ”MPCT” design to be used.

In order to characterise the beam current at the injection into the booster an ICT connected to continuous averaging electronics will be installed, which allows the measurement of currents below the noise floor of the ”MPCT”.

SCREENS AND SYNCHROTRON LIGHT MONITORS

Throughout the injector, several screen monitors are installed to image the electron beam. They are mainly used to show the spatial charge distribution and to check focussing. However, in the LINAC they are also used to read the position of the beam, as there are no EBPMs.

The first screens in the LINAC are at relatively low electron energy locations, so a material with a high photon yield needs to be used. We have selected 100 μm thick free standing YAG:Ce which provides a good tradeoff between brightness and blurring [3]. Screen monitors in the LTB are equipped with an additional optical transition radiation (OTR) screen [4] made from 100 nm aluminium deposited on a polished silicon wafer. While these provide a much lower photon yield, the OTR does not saturate and shows no blurring (as it is a surface effect). The OTR screens are thus intended for measurements such as the energy spread measurement after the first dipole in the LTB. In the BTS only OTR screen are used as the photon yield is sufficient at 3 GeV.

All dipole vessels in the transfer paths are equipped with windows to observe synchrotron light. This will allow for a non intercepting monitoring of the electron distribution. However, these monitors are diffraction limited in resolution and the low number of visible photons at 100 MeV. Using a small mirror in one of the dipole vessels, synchrotron light in the booster can also be observed with the same limitations. As soon as the electron energy is ramped up, there should be no difficulty to capture the beam image with a fast CCD camera.

Digital IEEE1394 CCD cameras will be used at all screens and synchrotron light monitors. These do not require a frame grabber for digitisation, offer easy and precise triggering and fully remote controllable gain and shutter settings. Due to their higher resolution compared to TV cameras zoom optics are only required in two locations.

OPTICAL DIAGNOSTICS IN THE SR

Optical diagnostics will be performed in the visible and in the X-Ray domain to characterise the 6-dimensional phase space of the stored electron bunches. In the X-Ray domain, two pinhole camera systems will provide the transverse horizontal and vertical sizes of the electron beam, from which the emittance will be deduced, as well as the relative energy spread. In the visible domain, a CCD camera, a streak camera, and a multichannel analyser will provide static and dynamical information on the beam. The CCD camera images the transverse beam and gives qualitative information on the transverse dynamics. The multichannel analyser will be used to measure the statistical distribution of the electrons in the ring. In particular this tool will measure the purity of the buckets.

X-ray Pinhole Camera System

Two X-Ray pinhole camera systems will measure five of the six dimensions of the electron beam. The basic scheme of each system is presented in figure 1. The X-ray beam is taken from a bending magnet. The two extraction lines are placed tangentially at 0.859 degrees from the entrance of the bending magnet, on the arc made by the electron path. These location of these two dipoles is immediately after the injection straight where they cannot be used for beam lines. The values of the dispersion function are $\eta = 0.9$ cm and $\eta = 3.3$ cm respectively, which, knowing the Twiss parameters, allows to calculate the emittance, the coupling emittance and energy spread [5]. A cooled copper collimator will block most of the hard X-ray beam, so that only a fraction of the radiated power (∼45 W) passes to the aluminium plate, which acts as an exit window from the vacuum. Only the radiation above 15 keV is transmitted through the aluminium (∼3 mm). The pinhole is located in air and as close as possible to the source point (4 m). It is made from tungsten blocks 5 mm thick. The positions of the screens are 8 and 11 m behind the pinhole (Dipole 1 and 2 respectively), which magnifies the images on the screens by a factor 2 and 2.75 respectively. Several screens that transform absorbed X-Ray photons into visible photons, Gd_2O_2S:Tb more commonly known as P43, YAG:Ce, YAP:Ce, $CdWO_4$ have been preselected. They will be tested in order to determine out the screen that gives the best resolution and the best conversion efficiency. The system is expected to measure the horizontal and vertical r.m.s sizes of the beam of the order of 50 and 25 μm at the source within a few percent accuracy.

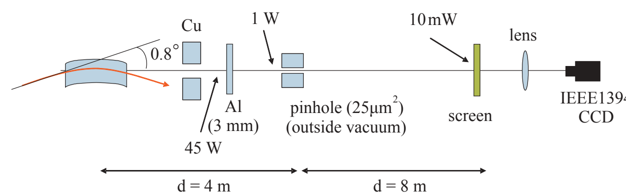

Figure 1: Scheme of the pinhole camera system for measuring the electron beam transverse profile

Streak Camera

In the time domain, the structure of the synchrotron radiation is the image of the time structure of the electron beam. Because the r.m.s bunch duration at Diamond will be of the order of 10 ps, very few devices can measure the profile of the electron bunch accurately. One of them is the double sweep streak camera, which has already been used successfully by many different groups on storage rings [6]. A cut of the image along the fast sweep axis gives the longitudinal bunch distribution and the temporal evolution of the distribution can be followed along the slow time scale. The bunch duration is given by the second order moment of the distribution. In our case, a fast synchronous sweep at 250 MHz (half the RF frequency) is important because it allows the streak camera to acquire all consecutive bunches. The slow sweep should cover the range from a few ten nanoseconds to several hundred of milliseconds. This will allow to characterise all the longitudinal instabilities of the beam.

ELECTRON BEAM POSITION MONITORS

A novel digital electron beam position monitor (EBPM) system [7, 8] will be used in all locations. Pickups are strip lines in the transfer paths and buttons in the booster and storage ring. The processing electronics feature direct AD conversion of the input signals and digital signal processing in an FPGA. They combine input multiplexing and four channel parallel processing to achieve sub micron resolution at fast feedback data rates (see table 2) and show hardly any beam current dependance.

beam current range	FFB SR 4 kHz	TBT SR 533 kHz	booster 80 kHz
60-300 mA	0.3 μm	3 μm	-
10-60 mA	0.6 μm	6 μm	-
1-10 mA	1.5 μm	15 μm	-
1-6 mA	-	-	10 μm
0.1-1 mA	-	-	100 μm

Table 2: Specified r.m.s noise on position readings for different sample rates and beam current ranges

Due to the flexible programming of the FPGA the signal processing can be tailored to the needs of a BPM. Position data will be available at several bandwidths and data rates in parallel, e.g. turn by turn (TBT), fast feedback (FFB) and control system display data. A post mortem history buffer will allow to examine TBT data for up to 1 second before a beam loss stopped the acquisition.

The electronics for each BPM are housed in a 1U 19-inch case containing analogue and digital boards, a single board computer for the control system interface, power supplies and fans. On the one hand, it will be connected to the control system network and run an EPICS IOC, on the other hand there are eight fast (2 GBit/s) serial ports for links between the BPM boxes. These will be used to exchange the position data for a fast orbit feedback application.

The precise hardware implementation of the fast orbit feedback is currently under consideration. At the moment, a transfer of the collected orbit information from the BPM electronics through one of the fast serial links into a VME mounted PPC-processor board is favoured. This processor board would be dedicated to the feedback calculations and write the resulting corrector magnet values directly through the VME bus into the power supply controller cards. Alternatively, the feedback calculations could also be done on one of the PPC processors which are included in the BPM electronics' FPGA. The corrector values could then be send through an RS485 interface to the power supplies.

BEAM LOSS MONITORS

Two types of beam loss monitors will be installed in different locations. We will use commercially available PIN-diode based counting modules in the storage ring and booster [2], as these offer low background and easy integration into the control system through scaler cards. This system is ideal for long term monitoring of the loss distribution around the rings. The limitation of these modules is the 100 ns long counting pulse, which means they cannot be used in the LINAC, LTB or BTS where short transient losses will happen only during the passage of a bunch or bunch train of similar duration as one counting pulse.

As an alternative, a combination of scintillators and photomultiplier tubes (PMT) with analogue (not counting) output will be used in these locations. On the one hand, this system has a lot faster response time. On the other hand, there are drawbacks in terms of varying background and linearity. The PMTs will be modules with integrated high voltage supply and the gain of each PMT can be remotely adjusted through a DAC. The PMT output is then read back into the control system through an ADC which will be triggered shortly before a bunch or bunch train is to pass the PMT. The amplitude of the acquired peak will serve as a measure of the amount of lost electrons.

CONCLUSIONS

An overview of the diagnostics systems to be installed in Diamond has been presented. While some systems have already been assembled or delivered (e.g. screen monitors for the LINAC), development is ongoing on many and design of others is in preliminary stages (e.g. fast orbit feedback).

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