STATUS OF THE MESA ACCELERATOR *

K. Aulenbacher, J. Diefenbach, R. Heine, F. Schlander
Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, Germany

Abstract

MESA will be operated as a superconducting multi-turn energy recovery linac (ERL), with the option to perform experiments with a windowless target with beam current of 1 mA which is to be increased towards 10 mA in a later stage of the project. Alternatively the machine can be used as a conventional c.w. accelerator with spin-polarized external beam at 150 MeV. We present the status of the design work.

INTRODUCTION

Figure 1 shows the underground areas which are available at our institution in Mainz. The existing accelerator cascade "MAMI-C" is foreseen to drive hadron physics experiments at the areas A1 and A2 for many years to come. On the other hand, the halt of the A4-experiments in autumn 2012 allows to make use of this space (see fig 1) in order to build a small "stand alone" machine, the **M**ainz **E**nergy recovering **S**uperconducting **A**ccelerator, MESA. In June 2012 the project received considerable funding by the German university excellence initiative within the cluster of excellence "PRISMA" (**PR**ecision experiments, fundamental **I**nteractions and **S** tructure of **MA**tter).

The feasibility of the ERL-concept was demonstrated at JLAB [1]. Such machines are widely known as possible drivers for future light sources of "fourth generation". We, however, try to use the ERL for electron scattering experiments, which relieves several of the requirements that plague the designers for light sources, such as operation in excess of 10 pC bunch charge. In this paper we describe the status of the accelerator design.

MESA LAYOUT

MESA will be installed in Hall 3 and in a part of the former MAMI-beamline tunnel (see fig. 1). Hall 4 will be employed for experiments, which gives the advantage that a high power beamdump is already available. The complex will be separated from the MAMI-accelerator and its remaining experiments (A1 and A2) by a 2 m thick heavy-concrete wall, for reasons of radiation protection. In the plane of the MAMI accelerator this shielding is increased additionally with at least 30 radiation length of material to protect against forward directed gamma-showers which could be created due to beam losses in MAMI-operation. MAMI experiments and the construction of MESA can therefore be performed independently. During the time of the conference the area of the beamline tunnel is about to be cleared, we expect the wall to be completed until summer 2014. The wall is a prerequisite to obtain permission from the authorities to work within the MESA Halls during MAMI operation. The main modification of infrastructure will be enlarging of the breakthrough between the beamline tunnel and hall 3.

Figure 2 demonstrates how the machine could be integrated into the existing building. Due to reasons which will be discussed below it is planned to erect the machine in two stages, the parameters for the stages can be found in table 1. If not mentioned otherwise, the discussion in this paper refers to stage-1 parameters.

The R.f.-operating frequency of MESA has still to be defined. A possible choice is 1300 MHz since a great number of superconducting accelerators around the world (e.g. E-XFEL, ALICE, ELBE, C-ERL) use this frequency. Advantages and disadvantages for a lower frequency are discussed below.

The superconducting main linac will allow for an energy gain of 50 MeV. Two recirculations are foreseen in conventional beam mode (external beam, EB-mode), leading to an output energy of the external beam of 150 MeV. This is presently considered as an optimum energy for the 'P2' experiment measuring the weak mixing angle [2]. The current foreseen for P2 is 150 μA with a polarization P≥0.85. The beam power of 30 kW will be released in the beam dump system which was in use for MAMI-C with similar beam powers.

In ERL operation the current is increased to 1 mA (unpolarized), corresponding to a bunch charge of 0.77 pC in c.w. operation. In the second recirculation at 105 MeV the beam orbit is directed towards the experimental hall 4 and passes a windowless target. In contrast to storage ring operation with an internal target the beam particles pass this "pseudo-internal target" (PIT) only once. This allows to achieve stationary beam conditions with minimized multiple and wall-scattering. The high beam power at the target (0.1 MW) allows for a luminosity in excess of $10^{35} cm^{-2} s^{-1}$ in spite of the low target density. Since energy straggling and Coulomb scattering are minimized in this set-up, emittance deterioration is negligible as far as RMS values are concerned. Of course long tails of the distribution exist which have to be collimated before the beam is redirected towards the accelerator. The long recirculation through hall-4 offers enough space for this. After passing the PIT the beam is redirected towards the MESA set-up where it re-enters the recirculation system.

The length of the (second) recirculation in ERL-mode - with PIT - is adjusted to a half integer number of wavelengths so that the electrons get decelerated in the main

* This work was supported by the excellence cluster PRISMA within the German university excellence initiative.

ISBN 978-3-95450-144-1

COMMISSIONING STATUS AND FURTHER DEVELOPMENT OF THE NOVOSIBIRSK MULTITURN ERL*

O.A.Shevchenko#, V.S.Arbuzov, E.N.Dementyev, B.A.Dovzhenko, Ya.V.Getmanov, E.I.Gorniker, B.A.Knyazev, E.I.Kolobanov, A.A.Kondakov, V.R.Kozak, E.V.Kozyrev, S.A.Krutikhin, V.V.Kubarev, G.N.Kulipanov, E.A.Kuper, I.V.Kuptsov, G.Ya.Kurkin, L.E.Medvedev, L.A.Mironenko, V.K.Ovchar, V.M.Petrov, A.M.Pilan, V.M.Popik, V.V.Repkov, T.V.Salikova, M.A.Scheglov, I.K.Sedlyarov, S.S.Serednyakov, A.N.Skrinsky, S.V.Tararyshkin, V.G.Tcheskidov, A.G.Tribendis, N.A.Vinokurov, M.G.Vlasenko, P.D.Vobly, V.N.Volkov, BINP, Novosibirsk, Russia

Abstract

The Novosibirsk ERL is used as a source of electron beams for the powerful Free Electron Laser. It is based on the normal conducting RF structure which operates in CW mode. The third stage of this facility which is the first in the world four-turn ERL has been commissioned recently. More than 90% of electrons were transported to the beam dump, which allowed to increase the average beam current up to 5 mA. The obtained parameters are sufficient to get lasing at the third stage FEL which will be installed at fourth track in the nearest future. In this paper we report the commissioning status and talk about further development of the Novosibirsk ERL and FEL facility.

ACCELERATOR DESIGN

The Novosibirsk FEL facility is based on the multiturn energy recovery linac (ERL) which scheme is shown in Fig. 1. In this scheme the beam goes through the linac several times before it enters undulator. As the result one can increase the final electron energy.

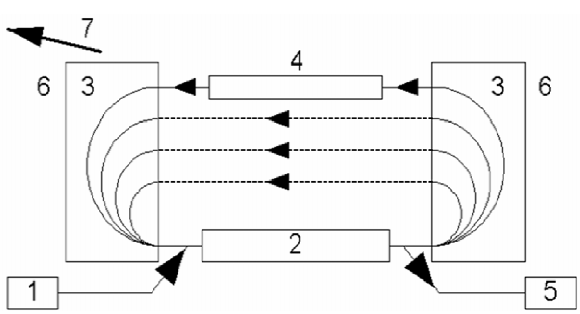


Figure 1: Simplest multiturn ERL scheme: 1 – injector, 2 – linac, 3 – bending magnets, 4 – undulator, 5 – dump.

Multiturn ERLs look very promising for making ERLs less expensive and more flexible, but they have some serious intrinsic problems. Particularly in the simplest scheme shown in Fig.1 one has to use the same tracks for accelerating and decelerating beams which essentially complicates adjustment of the magnetic system. This problem can be solved by using more sophisticated scheme based on two linacs [1].

At present the Novosibirsk ERL is the only one multiturn ERL in the world. It has rather complicated lattice as it can be seen from Fig. 2. The ERL can operate in three modes providing electron beam for three different FELs. The whole facility can be treated as three different ERLs (one-turn, two-turn and four-turn) which use the same injector and the same linac. The one-turn ERL is placed in vertical plane. It works for the THz FEL which undulators are installed at the floor. This part of the facility is called the first stage. It was commissioned in 2003 [2].

The other two ERL orbits are placed in horizontal plane at the ceiling. At the common track there are two round magnets. By switching these magnets on and off one can direct the beam either to horizontal or to vertical beamlines. The 180-degree bending arcs also include small bending magnets with parallel edges and quadrupoles. To reduce sensitivity to the power supply ripples, all magnets on each side are connected in series. The quadrupole gradients are chosen so that all bends are achromatic. The vacuum chambers are made from aluminium. They have water-cooling channels inside.

The second horizontal track has bypass with the second FEL undulator. The bypass provides about 0.7 m lengthening of the second orbit. Therefore when the beam goes through the bypass it returns back to the linac in decelerating phase and after two decelerations it finaly comes to the dump. This part (the second stage) was commissioned in 2009. The final third stage will include full-scale four-turn ERL and FEL installed on the last track.

The basic beam and linac parameters common for all three ERLs are listed in Table 1.

*Work supported by the Ministry of Education and Science of the Russian Federation; RFBR grant 11-02-91320
#O.A.Shevchenko@inp.nsk.su

ISBN 978-3-95450-144-1

PROGRESS OF SRF GUN DEVELOPMENT AND OPERATION AT THE ELBE ACCELERATOR

J. Teichert#, A. Arnold, P. Murcek, R. Xiang, HZDR, Dresden, Germany
P. Lu, H. Vennekate, HZDR & Technische Universität, Dresden, Germany
T. Kamps, J. Rudolph, HZB, Berlin, Germany,
P. Kneisel, TJNL, Newport News, USA,
I. Will, MBI, Berlin, Germany

Abstract

Superconducting RF photo guns are suitable candidates for electron injectors in future free-electron lasers and energy recovery linacs. For the radiation source ELBE an SRF gun was build and put into operation. During long-term tests, the operation of normal-conducting photocathodes in the superconducting cavity has been successfully demonstrated. At moderate average currents of some hundreds of μA the Cs_2Te photocathodes possess long lifetime. The acceleration gradient is the key parameters for emittance and the maximum achievable bunch charge of the gun. Therefore two new cavities with higher performance were developed, built and treated. The final tests of these cavities are ongoing. An upgraded cryomodule with an integrated superconducting solenoid was built.

ELBE SRF PHOTO GUN

The superconducting radio-frequency photoelectron gun (SRF gun) has been developed for the injection of a high-brightness, medium average current (about 1 mA), and continuous wave (CW) beam into the ELBE linac. Due to its potential advantages, consisting in the combination of high-brightness and CW operation, this electron gun type is suitable for future use in energy recovery linacs and next-generation light sources. At ELBE the SRF gun will deliver beam in two operation modes: (a) the FEL mode with 13 MHz repetition rate and up to 80 pC bunch charge, and (b) the high-charge mode with 500 kHz repetition rate and up to 1 nC bunch charge.

The superconducting cavity, the main part of the SRF gun, consists of three TESLA cells and one optimized half-cell. The gun uses normal-conducting Cs_2Te photo cathodes with high quantum efficiency, illuminated with a picosecond ultraviolet laser. The cathode is placed in the cavity half-cell isolated by a 1 mm vacuum gap and cooled with liquid nitrogen. Additionally, a resonant superconducting choke filter surrounds the cathode and serves to prevent RF leakage through the coaxial vacuum gap. Details of the SRF gun design have been published earlier [1].

At ELBE the SRF gun is installed in parallel to the thermionic injector, which is used as injector for user operation most of the time. An extra diagnostic beamline connected to the SRF gun serves for characterization of the electron beam. Furthermore a dogleg-like beamline section with two 45°-bending magnets allows for injection of the SRF gun beam into ELBE (see Fig. 1).

SRF GUN OPERATION

With the present niobium cavity, produced by the company ACCEL (now RI) and surface-treated at DESY, the SRF gun has been in operation since 2007. It turned out that the usual cleaning procedures applied for TESLA cells are hampered for the SRF gun cavity, mainly due to the narrow cathode channel and the presence of the choke filter cell. For that reason, the processing attempts were not as successful as expected. The achieved peak field in the vertical test was limited by field emission to peak field of 23 MV/m at a $Q_0 = 1\times10^{10}$. Details are published in [2]. After commissioning the Q_0 inside the cryomodule revealed an intrinsic quality factor one order of magnitude lower. The achievable peak field is again limited by strong field emission and He consumption. In the following period, various measurements, done under different conditions, have shown that the performance keeps unchanged independent of whether the cathode is inserted or not. The gradient could be improved by applying high power pulsed RF processing To this day, a stable CW operation up to peak field of 18 MV/m is routinely established.

In order to reach higher gradients with the present cavity and simultaneously keep the low load to the liquid helium system, the input RF power can be pulsed. The typical repetition rate varies from 1 Hz to 10 Hz, and the pulse length can be adjusted from 5 to 20 ms. Recently, operation with 22 MV/m peak field was performed in the RF-pulsed mode. Compared with the CW mode, the beam energy reaches higher values up to 4 MeV and the beam emittance becomes also better.

The intrinsic quality factor versus gradient has been regularly measured in the past. Fig. 2 shows the curves measured from the years 2007 until 2013. The practical limitation for the peak field value of the acceleration field in the present cavity is the Q0 decrease and the corresponding increase of the RF heat loss in the cavity surface. For higher fields the source is the strong field emission. The acceptable heat loss is about 30 W.

#j.teichert@hzdr.de

ISBN 978-3-95450-144-1

CONSTRUCTION AND COMMISSIONING OF COMPACT-ERL INJECTOR AT KEK

S. Sakanaka, M. Adachi, S. Adachi, M. Akemoto, D. Arakawa, S. Asaoka, K. Enami, K. Endo, S. Fukuda, T. Furuya, K. Haga, K. Hara, K. Harada, T. Honda, Y. Honda, H. Honma, T. Honma, K. Hosoyama, K. Hozumi, A. Ishii, E. Kako, Y. Kamiya, H. Katagiri, H. Kawata, Y. Kobayashi, Y. Kojima, Y. Kondo, O. A. Konstantinova, T. Kume, T. Matsumoto, H. Matsumura, H. Matsushita, S. Michizono, T. Miura, T. Miyajima, H. Miyauchi, S. Nagahashi, H. Nakai, H. Nakajima, N. Nakamura, K. Nakanishi, K. Nakao, K. Nigorikawa, T. Nogami, S. Noguchi, S. Nozawa, T. Obina, T. Ozaki, F. Qiu, H. Sagehashi, H. Sakai, S. Sasaki, K. Satoh, M. Satoh, Y. Seimiya, T. Shidara, M. Shimada, K. Shinoe, T. Shioya, T. Shishido, M. Tadano, T. Tahara, T. Takahashi, R. Takai, T. Takenaka, Y. Tanimoto, M. Tobiyama, K. Tsuchiya, T. Uchiyama, A. Ueda, K. Umemori, K. Watanabe, M. Yamamoto, Y. Yamamoto, Y. Yano, M. Yoshida,
High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan

E.Cenni, the Graduate University of Advanced Studies (Sokendai), Tsukuba, Ibaraki 305-0801, Japan

R. Hajima, S. Matsuba, R. Nagai, N. Nishimori, M. Sawamura, T. Shizuma,
Japan Atomic Energy Agency (JAEA), Tokai, Naka, Ibaraki 319-1195, Japan

H. Takaki, Institute for Solid State Physics, University of Tokyo, Kashiwa, Chiba 277-8581, Japan

M. Kuriki, H. Iijima, Hiroshima University, Higashihiroshima, Hiroshima 739-8530, Japan

J.-G. Hwang, Kyungpook National University, Daehakro, Bukgu, Daegu 702-701, Korea

Abstract

The Compact Energy-Recovery Linac (cERL) is under construction at KEK in order to demonstrate the technologies that are needed for the future 3-GeV ERL project. In April 2013, the 5-MeV injector of the cERL was completed and commissioned. During April to June in 2013, we tuned up the injector and evaluated its beam performance. From July to November in 2013, we are constructing the entire cERL including its return loop.

INTRODUCTION

In KEK, we aim to construct a 3-GeV energy recovery linac (ERL) [1,2] that will be used as a super-brilliant and ultra-short-pulse synchrotron light source as well as a driver for an X-ray free-electron-laser oscillator (XFEL-O). This project was recently named the PEARL (Photon Factory Advanced Research Laboratory). To demonstrate the production, acceleration, and recirculation of low-emittance and high-current beams that are need to the 3-GeV ERL, we are constructing the Compact ERL at KEK.

A planned layout of the cERL is shown in Fig. 1. The cERL consists of a 5-MeV injector, a main linac, and a return loop. Low-emittance electron beams are produced in a 500-kV photocathode DC gun, and they are boosted to a beam energy of about 5 MeV in a superconducting (SC) injector cryomodule. The beams are merged to the superconducting main linac where the beams are accelerated to a kinetic energy of 35 MeV, and they are transported through the return loop. The beams are then decelerated through the main linac, and are dumped. The beams from the injector can also be transported to an injector dump through an injector-diagnostic beamline. This allows us to evaluate the various beam properties of the injector. Design parameters of the cERL are given in Table 1.

The cERL injector was completed in April 2013. From 22 April to 28 June in 2013, we commissioned the injector and measured beam properties such as the beam emittance, the bunch length, the momentum spread, and the momentum jitter. During July to November in 2013, we are constructing the return loop [3].

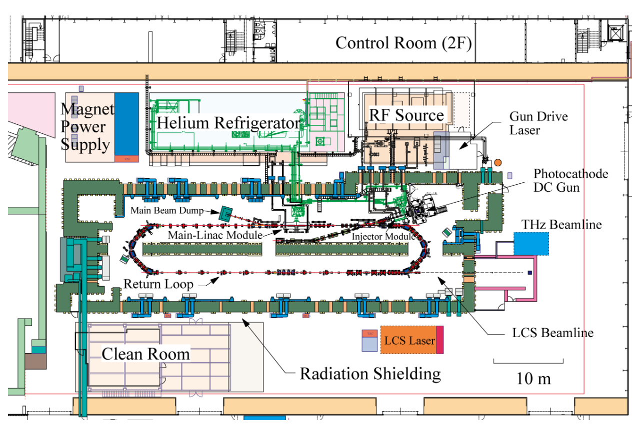


Figure 1: Planned layout of the cERL.

ISBN 978-3-95450-144-1

STUDIES OF NEA-PHOTOCATHODES

V.V. Bakin, D.V. Gorshkov, H.E. Scheibler, S.N. Kosolobov and A.S. Terekhov,
ISP SB RAS, Novosibirsk, Russia

Abstract

Domains of validity for dipole layer and heterojunction models of the (Cs,O) – activation layer for GaAs – photocathode are determined. Two – step photoelectron escape model from NEA-photocathode is proved. Dominated elastic and inelastic scattering processes, which are accompanied the photoelectron escape, are revealed.

INTRODUCTION

In the present work we studied (Cs,O) - activation procedure of p-GaAs/(Cs,O) – photocathode and identified domains of validity for the actual models for p-GaAs/(Cs,O)/vacuum interfaces with Negative Electron Affinity (NEA). To develop photoelectron escape model and to reveal dominated mechanisms of their scattering, we discuss energy distributions of photoelectrons which were measured previously at low temperatures.

EXPERIMENTEL DETAILS

Most of experiments were performed with transmission-mode p-GaAs/(Cs,O) and p-GaN/(Cs,O) photocathodes. Details of surface cleaning and activation procedures were described in [1,2]. To measure NEA – value (χ^*), the retarding field electron energy analyzer was installed within photocathode preparation chamber (PPC). Measurements of $N_e(\varepsilon_{lon})$ were performed during interruption of photocathode activation, when it was transferred to the measuring position below the mesh by rotation of carousel. Measurements of electron distributions $N_e(\varepsilon_{lon})$ and $N_e(\varepsilon,\theta)$ at low temperatures were performed by using of self - made parallel plate photodiodes with homogeneous electric field. Parallel plate image intensifier with microchannel plate (MCP) was used for measurements of $N_e(\varepsilon_{tr})$ at RT.

EXPERIMENTAL RESULTS AND DISCUSSIONS

Determination of Actual Activation Layer Models for p-GaAs / (Cs,O) – Photocathode

At the beginning of activation, when (Cs,O) – layer is thin enough, properties of p-GaAs/(Cs,O)/vacuum interface are obviously described by dipole layer model (DLM)[3], because at this stage of activation both absolute value of NEA and QE of photocathode are increasing along with activation due to the increasing of the dipole moment of the (Cs,O) – layer. Nevertheless, it was not undoubtedly demonstrated that DLM is dominated also at the point of activation, where the absolute maximum of QE for particular photocathode occurs. To clarify this topic, we performed prolonged activation of p-GaAs/(Cs,O) – photocathode, which continued far beyond the absolute maximum of the activation curve. In addition of QE, evolution of NEA-value was monitored along with activation by periodical measurements of $N_e(\varepsilon_{lon})$ – distributions. Shapes of the first (conventional) activation and the second (prolong) activations are shown on fig. 1. One can see that the second activation increase maximal QE from 18% up to 27%. One can see also, that when the absolute maximum of prolonged activation is passed, QE begins to drop down, but the rate of dropping become to be lower little by little. At the last stage of activation, at t_{act} > 300 min, QE drops down linearly with time. One should mention

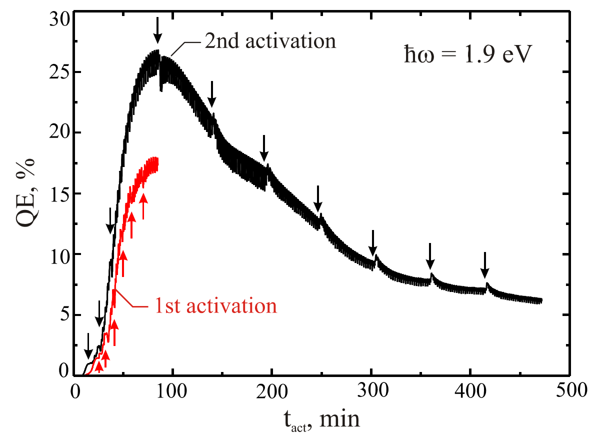


Figure 1: Time dependence of the QE during the activations.

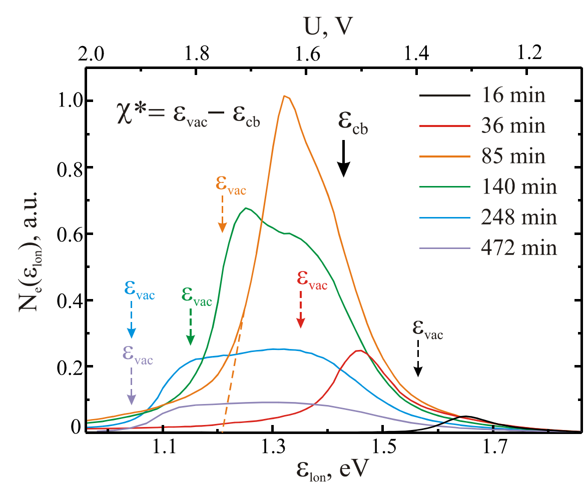


Figure 2: $N_e(\varepsilon_{lon})$ – distributions measured during the 2nd activation.

CONSTRUCTION OF THE SECOND 500 KV PHOTOCATHODE DC-GUN AT KEK

M. Yamamoto[#], T. Miyajima, Y. Honda, T. Uchiyama, M. Kobayashi,
KEK, 1-1 Oho, Tsukuba, Japan 304-0801
N. Nishimori, R. Nagai, S. Matsuba, R. Hajima,
JAEA, 2-4 Shirane Shirakata, Tokai, Naka-gun, Ibaraki, Japan 319-1195
M. Kuriki, Hiroshima Univ., 1-3-1 Kagamiyama, Higashihirosima, Hiroshima, Japan
M. Kuwahara, Nagoya Univ., Furo-cho, Chikusa-ku, Nagoya, Japan 4648603
H. Yoshida, AIST, 1-1-1 Umezono, Tsukuba, Ibaraki, Japan 305-8563
H. Kurisu, Yamaguchi Univ., Ube, Yamaguchi, Japan 755-8611

Abstract

A 500 kV photocathode DC-gun has been developed at KEK since 2009. The gun was almost completed and high voltage conditioning has been carried out up to 500 kV. In addition, we have designed a new quick cathode preparation system for a practical operation of the DC-gun without long interruption. The detail result and status are presented in this paper.

INTRODUCTION

A construction of compact-ERL (cERL) has been started in KEK and a 500 kV photocathode DC-gun (the first DC-gun) developed at JAEA has been installed in October 2012 [1-3]. The second 500 kV photocathode DC-gun has been developed at KEK since 2009 [4] not only for a substitution for the first DC-gun but also for a test machine for continuous R&D's on challenging issues because the second DC-gun can be operated independent of cERL.

Some main parts of the second gun system such as segmented insulator were designed to be compatible with the first gun. However, the second gun system has some new features. We have chosen TA010 (Kyocera) for the insulator, which is different from conventional Al_2O_3 material. Since TA010 is tolerant for surface discharge phenomenon in voltage condition higher than Al_2O_3, we expect the second gun would reach the higher voltage and the higher electric field. In order to investigate a dark current and find a sign of discharge between anode and cathode electrodes in high voltage (HV) conditioning, an isolated anode plate was installed. In addition, a new pump system to generate extreme high vacuum (XHV) will be tested to maintain a long cathode lifetime. A repeller electrode was employed to protect the cathode from ion back bombardment since the electrode can reflect low energy ions which generated at downstream of the gun exit.

A 600 kV oil-impregnation Cockcroft-Walton high voltage power supply (HVPS) was tested up to 580 kV independently. The HVPS and the DC-gun system were connected through a SF_6 vessel (Fig. 1.).

A new cathode preparation system was designed for a practical operation of the DC-gun to compensate short cathode lifetime in high-current electron beam generation. The preparation system can handle plural cathodes in parallel for cleaning, activation and storage.

Figure 1:A photograph of the second DC-gun. The HVPS (left) is connected to the gun chamber (right).

VACUUM SYSTEM

A DC-gun equipped with a photocathode of GaAs having an negative electron affinity (NEA) surface has advantages to generate a beam with low mean transverse energy and a high quantum efficiency. Therefore, a high voltage dc gun using an NEA-GaAs photocathode is one of the candidates for a high brightness electron source of ERL. However, the NEA-GaAs photocathode has disadvantage of a lifetime itself. The cathode QE degradation is dominated by back stream ions which are produced by collision between electron beams and residual molecules during high beam current operations. To improve the cathode lifetime, reduction of the residual molecules is essential. In order to achieve XHV better than 10^{-10} Pa, a chamber of the DC-gun system should have low outgassing property and vacuum pumps with a high effective pumping speed under XHV are indispensable. Generally, a combination of ion pump (IP) and non-evaporable getter (NEG) pumps is employed for

ISBN 978-3-95450-144-1

ANALYSIS OF INJECTION AND RECOVERY SCHEMES FOR A MULTI-TURN ERL BASED LIGHT SOURCE*

Y. Petenev#, T. Atkinson, A.V. Bondarenko, A.N. Matveenko
Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Germany

Abstract

A multi-turn energy recovery linac -based light source is under discussion. Using the superconducting Linac technology, the Femto-Science-Factory(FSF) will provide its users with ultra-bright photon beams of angstrom wavelength. The FSF is intended to be a multi-user facility and offer a variety of operation modes. The driver of the facility is a 6 GeV multiturn energy recovery linac with a split linac.

In this paper we discuss designs of the optic in the linac and compare different schemes of beam acceleration: a direct injection scheme with acceleration in a 6 GeV linac, a two-stage injection with acceleration in a 6 GeV linac, and a multi-turn (3-turn) scheme with a two-stage injection and two main 1 GeV linacs. The key characteristic of comparison is the beam breakup (BBU) instability threshold current.

INTRODUCTION

Our group at Helmholtz Zentrum Berlin is designing a new future multi-turn Energy Recovery Linac (ERL) based light source (LS) with 6 GeV maximum energy of electron beam. This future facility is named Femto-Science Factory (FSF) [1].

One potential weakness of the ERLs is transverse beam breakup (BBU) instability, which may severely limit a beam current. If an electron bunch passes through an accelerating cavity it interacts with dipole modes (e.g. TM_{110}) in the cavity. First, it exchanges energy with the mode; second, it is deflected by the electro-magnetic field of the mode. After recirculation the deflected bunch interacts with the same mode in the cavity again which constitutes the feedback. If net energy transfer from the beam to the mode is larger than energy loss due to the mode damping the beam becomes unstable.

The actuality of this problem was recognized in early experiments with the recirculating SRF accelerators at Stanford [2] and Illinois [3], where threshold current of this instability was occurring at few microamperes of the average beam current. In the works of Rand and Smith in [4] dipole high order modes were identified as a driver of this instability. In late of the 80's the detailed theoretical model and simulation programs had been developed [5, 6]. Nowadays the interest to this problem was renewed. The requirements for more detailed theory and simulation programs [7-9] are given by the needs of high current (~100 mA) ERLs.

* Work supported by German Bundesministerium für Bildung und Forschung, Land Berlin, and grants of Helmholtz Association VH-NG-636 and HRJRG-214.
#yuriy.petenev@helmholtz-berlin.de

In this document we compare different schemes of acceleration for FSF: a direct injection scheme with acceleration in a 6 GeV linac, a two-stage injection with acceleration in a 6 GeV linac, and a multi-turn (3-turn) scheme with a two-stage injection and two main linacs.

DIRECT INJECTION SCHEME

In this part we discuss the simplest scheme of an ERL based LS. In this scheme the beam after an injector section goes directly to the main linac (see Fig. 1), where it accelerated up to 6 GeV and used for the experiments, and after the recirculation turn it arrives to the linac and decelerated there. After the deceleration the beam goes to the dump.

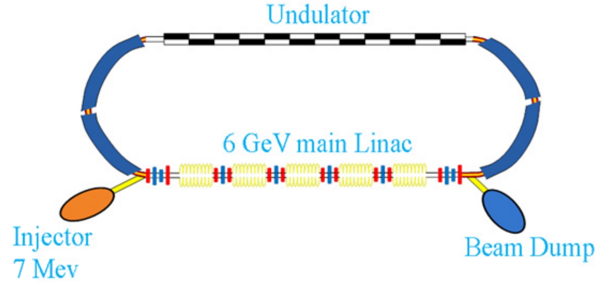


Figure 1: Direct injection scheme.

The linac is planned to be based on the BERLinPro[12] 7-cell cavities. To reach 6 GeV in the Linac we took 464 cavities with an accelerating gradient *G* about 16 MeV/m and distributed them over 58 cryomodules. The cryomodule is schematically presented in Fig. 2, where λ~0.231 m is the wavelength of the accelerating mode.

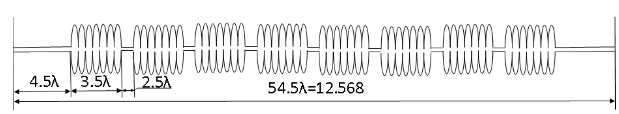


Figure 2: The scheme of FSF cryomodule.

Triplets of quadrupoles are planned to be in between the cryomodules in the linac and were optimized in such a way that the BBU instability will develop similarly for all the cavities in the linac. In this case the highest threshold current might be achieved. The threshold current for the transverse beam breakup may be estimated for the case of a single cavity and single mode for a multipass ERL in the form as [9]:

$$I_{th} \approx I_0 \frac{\lambda\!\!\!^{-2}}{Q_a L_{eff} \sqrt{\sum_{m=1}^{2N-1} \sum_{n=m+1}^{2N} \frac{\beta_m \beta_n}{\gamma_m \gamma_n}}}, \quad (1)$$

ISBN 978-3-95450-144-1

START-TO-END BEAM DYNAMIC SIMULATIONS FOR FEMTO-SCIENCE-FACTORY FEASIBILITY STUDY*

T. Atkinson†, A. Bondarenko, A. Matveenko, Y. Petenev,
Helmholtz-Zentrum Berlin für Materialien und Energie GmbH (HZB), Germany.

Abstract

Design studies for a future multi-turn ERL based light source at HZB are being investigated. The Femto-Science-Factory will provide its users with ultra-bright photons of angstrom wavelength at 6 GeV. The FSF is intended to be a multi-user facility and offer a wide variety of operation modes. A low emittance $\sim 0.1\,\mu$m rad mode will operate in conjunction with a short-pulse $\sim$10 fs mode. This paper reports on the first results of the start-to-end beam dynamic simulations for both modes. Higher order geometric and chromatic aberration terms have been suppressed using both multipole magnets and biased off-crest acceleration. The influence of the collective effects (coherent synchrotron radiation) on the transversal emittance is minimised by adjusting the horizontal phase advance.

INTRODUCTION

This paper continues on from a recent Analysis of Injection and Recovery study[1] for Multi-turn ERL based light sources and highlights the physical limitations when trying to offer interchangeable modes and preserve beam quality.

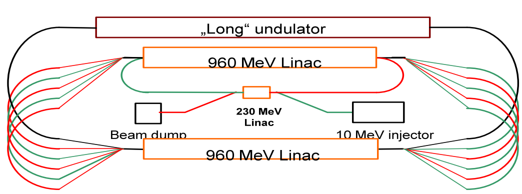


Figure 1: Schematic of the FSF Multi-Turn ERL.

The main design parameters of the FSF are listed in Table 1 and Fig. 1 shows the layout of the light source. In this scheme the acceleration of the whole FSF is constrained to be scalable. This modification relaxes the design of the vertical spreaders, so that if the energy is changed, due to possible upgrades or unforeseen circumstances one would simply adjust the field gradient in the cavity rather than redesign the spreader. Using the scaling formula $E_f = (1+2kN)(E_i+E_{pre})$, an SRF injector based on the design parameters of BERLinPro[2], injects the $E_i = 10\,MeV$ electron beam into a $E_{pre} = 230\,MeV$ preinjector accelerator. From here onwards two equally long linacs are continually traversed each with $N = 3$ passes until the $E_f = 6\,GeV$ final beam energy is reached. Choosing a suitable value $k = 4$ sets the main linacs to both $960\,MeV$.

Table 1: Main design parameters of FSF

Parameter	Low Emittance Mode	Short Pulse Mode
Preinjector (MeV)	230	
Main Linacs (MeV)	960	
Final Energy (GeV)	6	
Charge (pC)	15	4
Emittance (mm mrad)	0.1	0.4
Bunch Length (fs)	2000	10

Each Arc contains straight sections for undulators and in the final energy Arc 3000 period long of 40 mm period length undulators are foreseen.

The higher energy injection into the independent orbit ERL recirculator has naturally modified the beam dynamics from previous studies[3]. The new optic in the linacs has been optimised for the highest Beam Break Up threshold[1]. In this paper the remaining optic with regards to transversal and longitudinal emittance growth are discussed.

TRANSVERSAL EMITTANCE PRESERVATION

The difference in the two modes with regards to the lattice design occurs in the low energy section of the machine. For the Low Emittance Mode (LEM) a beam of higher charge is accelerated on crest in all of the linacs and circulates round isochronous Arcs. The Short Pulse Mode (SPM) however relies on achromatic arcs for the telescopic compression technique[3] removing the correlated energy spread due to the off-crest acceleration. The modes share common high energy arcs where radiation effects play an important role in emittance growth and will be firstly addressed.

High Energy Arcs

Consider the geometrical parameters of Coherent Synchrotron Radiation (CSR) as described in [4]. Taking the

* Work supported by German Bundesministerium für Bildung und Forschung, Land Berlin, and grants of Helmholtz Association VH NG 636 and HRJRG-214.
† terry.atkinson@helmholtz-berlin.de

ISBN 978-3-95450-144-1

LONGITUDINAL STABILITY OF MULTITURN ERL WITH SPLIT ACCELERATING STRUCTURE

Ya. V. Getmanov#, O. A. Shevchenko, Budker INP, Novosibirsk, Russia
N. A. Vinokurov, Budker INP, Novosibirsk, Russia and KAERI, Daejon, Korea

Abstract

Some modern projects of the new generation light sources use the conception of multipass energy recovery linac with split (CEBAF-like) accelerating structures [1 - 5]. One of the advantages of these light sources is the possibility to obtain a small bunch length. To help reduce it, the longitudinal dispersion should be non-zero in some arcs of the accelerator. However small deviations in voltages of the accelerating structures can be enhanced by induced fields from circulating bunches due to the dependence of the flight time on the energy deviation and the high quality factor of the superconducting radio-frequency cavities. Therefore, instabilities caused by interaction of electron bunches and fundamental modes of the cavities can take place. The corresponding stability conditions are discussed in this paper. Numerical simulations were performed for project MARS [4].

INTRODUCTION

The scheme of an ERL with two accelerating structures is shown in Fig. 1.

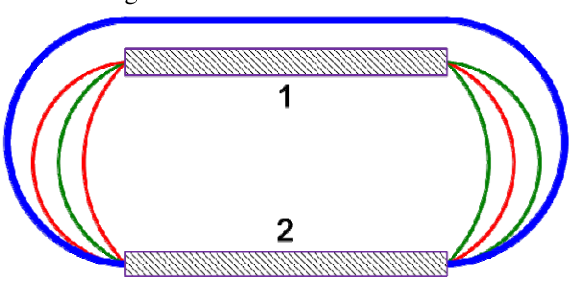


Figure 1: Scheme of ERL with two linacs.

Electrons are injected to the linac 1. After two passes through linac 1 and linac 2 they are used, for example, in undulators. After that electrons are decelerated.

There are four electron beams in each linac simultaneously. Each beam induced large voltage in the linac, but the sum is not so large. If the phases of the beams vary, the sum voltage also varies, and initially small phase deviation may increase due to the dependence of flight times through arcs on the particle energy. This longitudinal instability is considered in our paper.

THEORY

The Voltage Equations

To simplify the picture, consider each linac as one RF cavity. Its equivalent circuit is shown in Fig. 2.

The gap voltage expression $U = L d\left(I_b + I_g - C\, dU/dt - U/R\right)/dt$, I_b and I_g are the currents of the beam and of the RF generator, leads to the standard equation

$$\frac{d^2U}{dt^2} + \frac{1}{RC}\frac{dU}{dt} + \frac{1}{LC}U = \frac{1}{C}\frac{d}{dt}\left(I_b + I_g\right) \qquad (1)$$

Taking the effective voltage on the linac with number α in the form $\mathrm{Re}(U_\alpha e^{-i\omega t})$ (ω is the frequency of the RF generator), one obtains:

$$\frac{2}{\omega}\frac{dU_\alpha}{dt} = \frac{i\xi_\alpha - 1}{Q_\alpha}U_\alpha + \rho_\alpha(I_{b\alpha} + I_{g\alpha}), \quad (2)$$

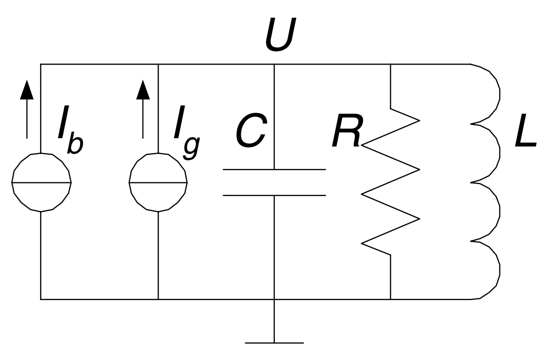


Figure 2: Equivalent circuit of the RF cavity.

where $\omega_\alpha = 1/\sqrt{L_\alpha C_\alpha} = (1 - \xi_\alpha / 2Q_\alpha)\omega$ is the resonant frequency, $Q_\alpha = R_\alpha \big/ \sqrt{L_\alpha / C_\alpha} >> 1$ is the loaded quality of the cavity, $\rho_\alpha = R_\alpha / Q_\alpha = \sqrt{L/C}$ and R_α are the characteristic and the loaded shunt impedances for the fundamental (TM_{010}) mode, and $I_{b\alpha}$ and $I_{g\alpha}$ are the complex amplitudes of the beam and (reduced to the gap) generator currents correspondingly. We are interested in the case of constant $I_{g\alpha}$. The beam currents $I_{b\alpha}$ depend on all U_α due to phase motion. Linearization of Eq. (2) near the stationary solution

$$U_{0\alpha} = \frac{R_\alpha}{1 - i\xi_\alpha}\left[I_{b\alpha}(\mathbf{U}_0) + I_{g\alpha}\right] \qquad (3)$$

gives:

$$\frac{2}{\omega}\frac{d\delta U_\alpha}{dt} = \frac{i\xi_\alpha - 1}{Q_\alpha}\delta U_\alpha + \qquad (4)$$

ISBN 978-3-95450-144-1

NEW WAY TO ACCELERATING HIGH CURRENT BEAM IN ERL*

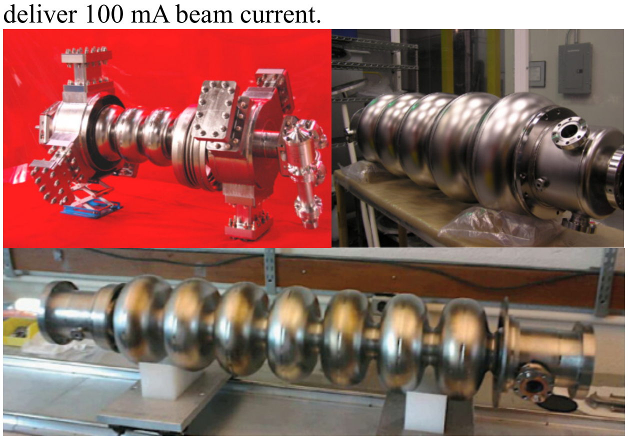
Z.C. Liu#, J. Gao, S. Jin, IHEP, Beijing, 100049, China
F. Wang, PKU, Beijing, 100871, China

Abstract

High beam current is available for the Energy Recovery Linac (ERL). Different methods are adopted to increase the BBU threshold of the cavity to deliver hundreds of milliampere beam current. The key is to absorbing HOMs more efficiently. The BBU threshold of the slotted cavity is much higher than other high current cavities. However, new tuning method is needed and multipacting should be checked. Here we will present a new way to accelerating the high current beam by a highly HOMs damped cavity, the slotted cavity including the tuning method.

INTRODUCTION

In the past 10 years, high current superconducting cavity is developed worldwide. It was designed for the use of ERL, eRHIC, ADS etc.. Various cavity shapes and various HOMs damping methods were developed. A 5-cell superconducting cavity with waveguide HOMs absorber was designed at JLab and several prototypes were fabricated. The cavity reached 22 MV/m and is able to deliver 100 mA beam current [1]. Cornell University has developed a high current cavity for the 5 GeV ERL [2, 3]. A 7-cell superconducting cavity was designed and tested. The cavity was designed in several types with slightly changed cell shapes which can obviously increase the cavity BBU threshold from 100 mA to 450 mA. BNL has developed several types of high current cavity. Now a 5-cell 50 mA superconducting cavity (BNL3) was designed and fabricated [4, 5]. It can deliver 50 mA beam for eRHIC and 300 mA beam for ERL. KEK has developed a 1.3 GHz 9-cell cavity with flute structure to deliver 100 mA beam current for ERL use [6]. The cavity reached 25 MV/m. ANL and PKU has developed a 1.3 GHz 5-cell superconducting cavity in collaboration [7]. The cavity is for the APS upgrade pre-research and can deliver 100 mA beam current.



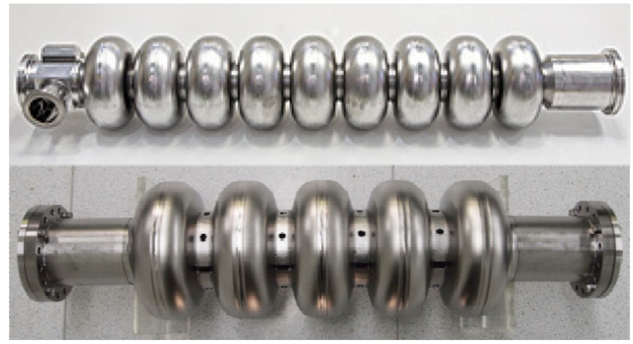


Figure 1: High current cavities around the world. From left to right and top to botom: Jlab, BNL, Cornell universiy, KEK, ANL&PKU [1-7].

To deliver high current beam, cavity is designed following such principles: low cell numbers, large iris and large beam pipe, optimized shape, efficient HOMs damping. Actually, the aim of all these designs is to increase the HOMs' damping.

HOMS DAMPING

The beam current that a cavity can deliver is limited by the BBU threshold of the cavity. For a single high-order mode, the BBU threshold is [8]

$$I_{th} = \frac{2c^2}{e\left(\frac{R}{Q}\right)_\lambda Q_\lambda \omega_\lambda} \frac{1}{T_{12}^* \sin \omega_\lambda t_r} \quad (1)$$

and

$$T_{12}^* = T_{12} \cos^2 \theta_\lambda + \frac{T_{14} + T_{32}}{2} \sin 2\theta_\lambda + T_{34} \sin^2 \theta_\lambda \quad (2)$$

Here, c is the speed of light, e is the elementary charge, λ is the mode number, $(R/Q)_\lambda$ is the shunt impedance (in units of Ω), Q_λ is the quality factor, ω_λ is the HOM frequency, θ_λ is the polarization angle from the x direction, t_r is the bunch return time, and the matrix T describes how a transverse momentum is transported to a transverse displacement after one turn.

Form equation (1), we know that the BBU threshold is inversely proportional to the cavity intrinsic parameter $(R/Q)_\lambda \cdot Q_\lambda$. The main focus to increase the BBU threshold is to decrease the impedance item $(R/Q)_\lambda \cdot Q_\lambda$.

In 1990, Y. Chen, D. Proch, and J. Sekutowicz experimentally investigated a broadband damping of monopole, dipole, and quadrupole modes by implementing small longitudinal slots near the equatorial region of a single-cell copper cavity [9]. And In 2010 Z. Liu and A. Nassiri proposed a novel rf structure for high current beam transportation [10] (Fig. 2). The structure

*Project 11275226 supported by NSFC
#zcliu@ihep.ac.cn

NOVEL ASTA USERS FACILITY AT FERMILAB : A TESTBED FOR SUPERCONDUCTING RF TECHNOLOGY AND ERL R&D *

V. Shiltsev# for ASTA team, FNAL, Batavia, IL 60510, USA

Abstract

The Advanced Superconducting Test Accelerator (ASTA) currently under commissioning at Fermilab will enable a broad range of beam-based experiments to study fundamental limitations to beam intensity and to develop transformative approaches to particle-beam generation, acceleration and manipulation. ASTA incorporates a superconducting radiofrequency (SRF) linac coupled to a photoinjector and small-circumference storage ring capable of storing electrons or protons. ASTA will establish a unique resource for R&D towards Energy Frontier facilities and a test-bed for SRF accelerators and high- brightness beam applications, including ERLs. The unique features of ASTA include: (1) a high repetition-rate, (2) one of the highest peak and average brightness within the U.S., (3) a GeV-scale beam energy, (4) an extremely stable beam, (5) the availability of SRF and high quality beams together, and (6) a storage ring capable of supporting a broad range of ring-based advanced beam dynamics experiments. These unique features will foster a broad program in advanced accelerator R&D which cannot be carried out elsewhere. Below we describe ASTA and its experimental program, with particular emphasis on the ERL-related accelerator R&D opportunities.

ACCELERATOR OVERVIEW

The backbone of the ASTA facility is a radio-frequency (RF) photoinjector coupled with 1.3-GHz superconducting accelerating cryomodules (CMs); see Fig. 1-(a) [1]. The electron source consists of a 1-1/2 cell 1.3-GHz cylindrical-symmetric RF gun comprising a Cs2Te photocathode illuminated by an ultraviolet (UV, 263 nm) laser pulse obtained from frequency quadrupling of an amplified infrared IR pulse The photocathode drive laser produces a train of bunches repeated at 3 MHz within a 1-ms-duration macropulse; see Fig. 1-(b). The 5-MeV electron bunches exiting the RF gun are then accelerated with two SRF TESLA-type cavities (CAV1 and CAV2) to approximately 50 MeV. Downstream of this accelerating section the beamline includes quadrupole and steering dipole magnets, along with a four-bend magnetic compression chicane (BC1) [2]. The beamline also incorporates a round-to-at-beam transformer former (RTFB) capable of manipulating the beam to generate a high transverse-emittance ratio. In the early stages of operation, the bunches will be compressed in BC1. In this scenario the longitudinal phase space is strongly distorted and the achievable peak current limited to less than 3 kA. Eventually, a third-harmonic cavity (CAV39) operating at 3.9 GHz will be added enabling
the generation of bunches with ~10 kA peak currents by linearizing the longitudinal phase space. In addition CAV39 could also be used to shape the current profile of the electron bunch [4]. The photoinjector was extensively simulated and optimized [3]. The photoinjector also includes an off-axis experimental beamline branching at the second dipole of BC1 that will support beam physics experiments and diagnostics R&D.

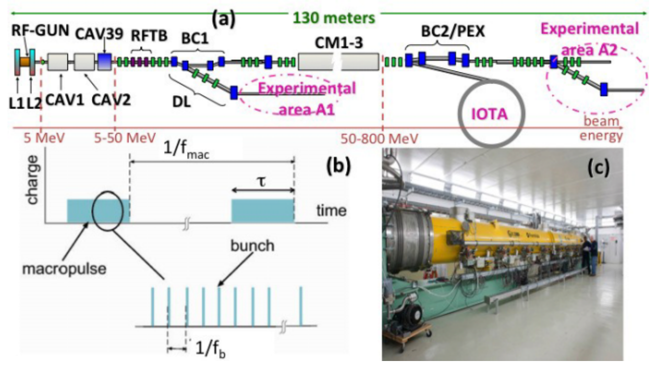


Fig.1: Overview of ASTA (a); "L1" and "L2" stand for solenoids,"CAV1", "CAV2", and "CAV39" correspond to accelerating cavities, "CM1-3" to an ILC cryomodule string, "BC1" and "BC2" to bunch compressors, and "DL" to a dogleg beamline. "EEX" represents a possible reconfiguration of "BC2" to act as a transverse-to-longitudinal phase space exchanger. Electron beam macropulse format (b) and photograph of CM1 module (c).

The 50-MeV beam is injected into the SRF linac, which will eventually consist of three, 12-m long, TESLA/ILC-type CMs. Each CM includes eight 1.3-GHz nine-cell cavities. The first two cryomodules (CM1 and CM2) are a TESLA Type-III+ design, whereas the third (CM3), will be an ILC-Type IV design [5]. Together, these three CM constitute a complete ILC RF Unit. The SRF linac will be capable of generating a beam energy gain of ~750 MeV. The installation of the cryomodules will be staged pending the completion of their construction. The 1st CM has already been tested in the ASTA Facility; see Fig. 1-(c). Downstream of the linac is the test beam line section, which consists of an array of multiple high-energy beam lines that transport the electron beam from the accelerating cryomodules to one of two beam dumps. In addition to testing the accelerator components, the intent of this facility is to also test the support systems required for a future SRF linac. The facility anticipated beam parameters appear in Table I.

*Work supported by DOE contract DE-AC02-07CH11359 to the Fermi Research Alliance LLC.
shiltsev@fnal.gov

ISBN 978-3-95450-144-1

PERFORMANCE OF RF SYSTEM FOR COMPACT ERL INJECTOR IN KEK

Takako Miura#, Mitsuo Akemoto, Dai Arakawa, Hiroaki Katagiri, Tetsuo Shidara, Tateru Takenaka, Katsumi Nakao, Hiromitsu Nakajima, Shigeki Fukuda, Hiroyuki Honma, Hideki Matsushita, Toshihiro Matsumoto, Shinichiro Michizono, Yoshiharu Yano, Feng Qiu, Atuyoshi Akiyama, Takashi Obina, Shogo Sakanaka, Kenta Futatsukawa, Yosuke Honda, Tsukasa Miyajima,
KEK, Tsukuba, 305-0801, Japan

Abstract

The construction of the compact Energy Recovery Linac (cERL) injector in KEK was finished in April 2013, following which the beam commissioning has been performed for 2 months. The cERL injector consists of a normal conducting buncher cavity (BUN) and three superconducting (SC) 2-cell cavities with double couplers. The BUN and the first SC cavity (CAV1) are driven by individual Radio Frequency (RF) power source, respectively. The second and third SC cavities (CAV2 and CAV3) are driven by one klystron using vector-sum control. The low-level RF (LLRF) system is based on I/Q (in-phase, quadrature-phase) digital feedback. RF stabilities of amplitude and phase are, respectively, 0.05%rms and 0.06°rms for BUN and 0.01%rms and 0.02°rms for CAV1, CAV2 and CAV3. Finally, the RF stability was confirmed through the measurement of the beam momentum jitter using a small current and short beam. A momentum jitter of 0.006% was achieved.

INTRODUCTION

The construction of a compact Energy Recovery Linac (cERL) is ongoing as a test facility for the 3-GeV ERL planned for the future. The construction of the injector[1] was finished in April 2013. The construction of the entire cERL will be completed by mid-December 2013. The cERL injector consists of a normal conducting buncher cavity (BUN) and three superconducting (SC) 2-cell cavities with double couplers, as shown in Fig.1. Three RF power sources are used for driving 4 cavities. The phase of the first cavity (CAV1), where the Lorentz β is low, should be changed independently from the second and third cavities (CAV2 and CAV3) in order to suppress the beam dispersion due to the space charge effect. Hence, CAV1 is driven by an independent RF source. CAV2 and CAV3 are driven together by the vector-sum operation. A power distribution system was constructed while taking into consideration the phase matching of top and bottom couplers or phase adjustment between CAV2 and CAV3 for beam transit time. The low-level RF (LLRF) system is based on IQ digital feedback using the FPGA (field-programmable gate array). The requirements of the RF stability for cERL are 0.1% rms in amplitude and 0.1° rms in phase. The requirements for 3GeV ERL are 0.01%rms in amplitude and 0.01° rms in phase. The beam commissioning has been performed for 2 months from the end of April 2013. The beam is accelerated up to 5.5 MeV by the injector. The RF stabilities and the momentum jitter of the beam were measured during this commissioning.

HIGH LEVEL RF SYSTEM

Figure 1 shows the configuration of the RF sources[2] of the injector. RF frequency is 1.3 GHz. The BUN is driven by a 20-kW inductive output tube (IOT), and CAV1 is driven by a 25-kW klystron. Both CAV2 and CAV3 are driven by a 300-kW klystron with vector-sum operation. In order to adjust the phase between CAV2 and CAV3 for the beam, a phase shifter is located in the line of CAV3 at the outside of the shield, as shown in Fig. 2. The circulators are placed for each cavity line. Each SC cavity has two input-couplers symmetrically equipped to the top and bottom. The RF power, therefore, should be fed at the same phase.

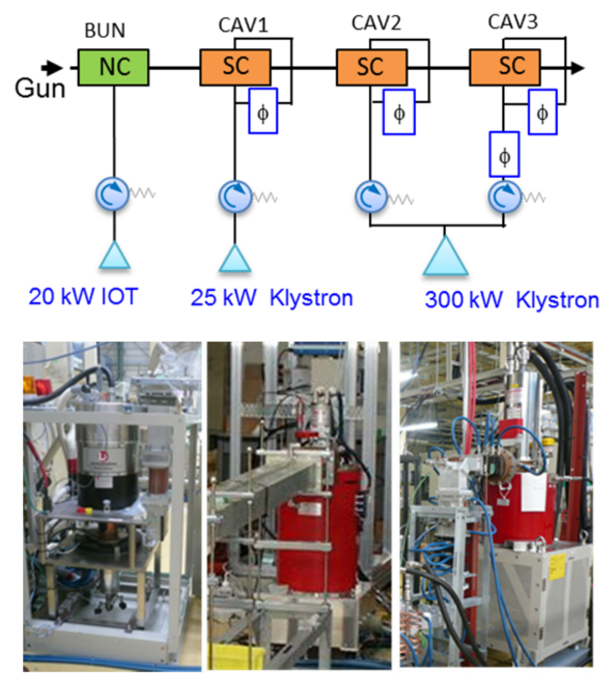


Figure 1: Configuration of RF sources of injector.

Figure 3 shows the power distribution layout feeding the injection cavity on the inside of the shielding-wall. The RF power from the RF-source is divided by the magic-T. The divided power distributed to each coupler. The length of waveguide is designed in advance. The phase shifter,

#takako.miura@kek.jp

ISBN 978-3-95450-144-1

PROGRESS REPORT ON THE INTERNATIONAL CRYOMODULE AT DARESBURY

S. Pattalwar, R. Buckley, M. Cordwell, P. Corlett, P. Goudket, A. Goulden, T. Jones, L. Ma, A. May, A. Moss, P. A. McIntosh, J. Strachan, A.E. Wheelhouse, STFC, Daresbury, UK
S. Belomestnykh, BNL, US
R. Eichhorn, G. Hoffstaetter, M. Liepe, H. Padamsee, P. Quigley, J. Sears, V. Shemelin, CLASSE, Ithaca, US
D. Proch, J. Sekutowicz, DESY, Hamburg, Germany
A. Buechner, F. Gabriel, P. Michel, HZDR, Dresden, Germany
J. Corlett, D. Li, S.M. Lidia, LBNL, Berkeley, US
T. Kimura, T. Smith, Stanford University, Stanford, US
R. Laxdal, TRIUMF, Canada

Abstract

On successful completion of the assembly and preliminary testing of an optimised SRF cryomodule, being developed under international collaboration, for application on ERL accelerators, the cryomodule has now been installed on the 35 MeV ALICE (Accelerators and Lasers in Combined Experiments) Energy Recovery Linac (ERL) facility at STFC Daresbury Laboratory. Existing cryogenic infrastructure has a capacity to deliver approximately 120 W cooling power at 2 K, but the HOM (Higher Order Mode) absorbers, the thermal intercepts for the high power RF couplers and the radiation shields inside the cryomodule are designed to be cooled with gaseous helium instead of liquid nitrogen. As a result, the cryogenic infrastructure for ALICE has been modified to meet these additional requirements. This paper, presents our experience with the integration and cryogenic commissioning with some initial results.

INTRODUCTION

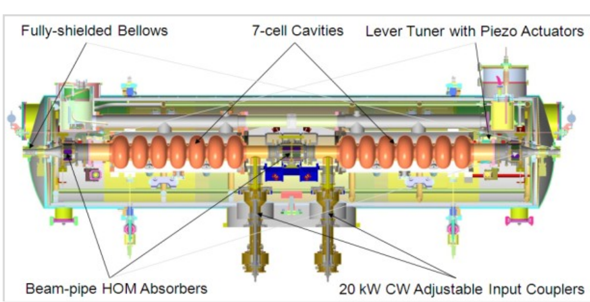


Figure 1: CW-ERL cryomodule under development.

On successful completion of the assembly of the optimised SRF cryomodule (Fig. 1) for CW ERL applications [1], extensive tests were conducted in 2012 to evaluate the cryogenic performance, first with liquid nitrogen and then with liquid helium at 4.2K with the assembled cryomodule (Fig. 2). The main purpose of these offline cold tests were to identify any unforeseen issues that may occur during the installation and commissioning on ALICE Several issues were identified and resolved during the tests, for example - large temperature gradient between the two cavities during cool-down and the lowest temperature reached was only ~8K. Most of these observations could be explained by considering the limitations on the non-ideal test conditions and attributed to the absence of the cooling power at intermediate temperatures for cooling the thermal intercepts on the RF couplers and the HOM absorbers.

Figure 2: Fully assembled cryomodule undergoing Qualification tests.

The cryomodule subsequently passed the offline acceptance tests [2] and was installed on ALICE as shown in Fig. 3 in February 2013. The existing cryogenic infrastructure [3] has a capacity to deliver approximately 120W cooling power at 2K and liquid nitrogen is used as a source for cooling to 80K.

However, for the new CW-ERL cryomodule the HOM absorbers, the thermal intercepts for the high power RF couplers and the radiation shields are designed to be cooled with gaseous helium instead of liquid nitrogen. This alternative solution was chosen to allow for investigation of microphonics susceptibility and so a

ISBN 978-3-95450-144-1

ELECTRON POLARIMETRY FOR ERLs*

K. Aulenbacher, Institut für Kernphysik, Universität Mainz, Germany

Abstract

Polarimetry at the planned ERL based linac-ring colliders can rely on similar techniques as have been developed for storage rings such as HERA. However, due to the low energy, operation of polarimetry at the prototype devices such as MESA is shown to be considerably more difficult. The usage of atomic traps which serve as a target of complete electron polarization is discussed for MESA.

INTRODUCTION

In collisions of spin-polarized particles, online analysis of the beam polarization is highly desirable. Usually, a high quality result will also call for a high absolute accuracy $\Delta P/P$ of the polarization measurement. Electron Polarimeters have been operated successfully in ring/ring ep-colliders for instance at HERA [1] and also at LINACs such as SLACs SLC [2]. If we consider the situation in an ERL based linac/ring collider such as eRHIC [3] or LHeC [4] we find that the high beam power at an ERL also requires minimally invasive techniques. In comparison with storage rings several advantages come into play. First, stronger interaction is possible between the beam and the analyzer, since any beam particle makes only a single passage through the interaction region at the experiment and/or the polarimeter. A further advantage lies in the fact that the beam can be analyzed invasively after deceleration in the ERL, i.e. before the beam dump, if the polarimeter can be made compatible with the still high beam power. Due to the rapid deceleration in an ERL the polarization loss between target will usually only lead to negligible depolarization, since depolarizing resonances are crossed very rapidly. Therefore, the information obtained from a dump-polarimeter may still be useful for the interpretation of the experimental data. In the following we will briefly address the issue of the high energy polarimeter for the planned ERL-ring colliders which may be realized in the next decade. In contrast to high energies, new techniques seem necessary for low energy projects like MESA which are going to be realized on a shorter timescale.

POLARIMETRY AT GEV LEPTON ENERGIES

In Laser-Compton polarimeters (LCP) circularly polarized optical photons with an energy $E_{\gamma,0}$ (typical a few eV) are backscattered off the extreme relativistic ($E_{beam} >> m_{lepton}$) lepton beam. The backscattered photons whose energy E_γ is in the many MeV region are concentrated in a small angular region ($\approx 2/\gamma = 2m_{lepton}/E_{beam}$, typically smaller 1 mrad) around the backscattering direction. A beam polarization dependent signal (asymmetry) $A = P_{lepton}P_{\gamma,0} * S_{long,trans}$ can be generated by switching the circular photon-polarization $P_{\gamma,0}$. The character of the analyzing power $S_{long,trans}$ depends on the transverse or longitudinal state of the electron beam polarization. For the transverse case a left/right asymmetry exists, causing a small shift of the center of intensity distribution, the detection of which causes some requirements towards the position resolution of the photon detector. In the longitudinal case an intensity asymmetry occurs, even if the scattered photon-spectrum is integrated over all angles. In this case energy resolution is necessary, since the quantity $S_{long}(E_\gamma)$ varies strongly with the energy of the scattered photon. In the following only the longitudinal case is considered. The largest asymmetry is carried by the photons with the highest energy, i.e. the backscattered photons. The Laser Compton has distinct advantages since the product $S_{eff} = D * P_{\gamma,0} * S(E_\gamma)$, the so-called effective analyzing power, can be determined very accurately. First, $P_{\gamma,0}$, the circular polarization of the photons, which can be considered as a target polarization, is comparatively easy to determine with an accuracy in the per mille range. Second the analyzing power $S_0(E_\gamma)$ can be calculated very accurately for this QED process. The factor D contains all experimental dilutions, like backgrounds or uncertain calibration of the detectors energy-scale. It has been shown that these can be controlled at the sub percent level too.

For electron beam energies of a few GeV or lower the energy of the backscattered photon is still much lower than the incoming beam energy. In this case the approximations in the following paragraph are valid. An exact calculation of the analyzing powers for arbitrary energies can be found in [5].

For 180 degree backscattering the energy of the photon is maximum and it is determined by the relativistic factor γ of the lepton beam: $E_{\gamma,max} \approx 4E_{\gamma,0}\gamma^2$. For a 1 GeV beam and incoming laser Photons of 2.5 eV (typical for frequency doubled high repetition rate laser systems) we obtain $E_{\gamma,max} = 40\,MeV$. On the other hand, the asymmetry is $E_{\gamma,max}/E_{beam}$ which is 0.04 for this example. The averaging over the photon spectrum leads to further reduction of this value in a real experiment.

Small asymmetries ($A < 0.01$) are difficult to measure accurately, not only because the measurement time for a given statistical accuracy increases $\propto 1/A^2$, but also because the contribution of systematic effects - e.g. background from residual gas scattering - becomes increasingly

* This work was supported by BMBF via project 05H12UM6 (Spin Optimierung) and by the European Union through EUCARD-II within FP7.

ISBN 978-3-95450-144-1

MONITORING BEAM POSITION IN THE MULTIBEAM ACCELERATORS*

I. Pinayev#, BNL, Upton, NY 11973, USA

Abstract

In this paper we present the concept of a beam position monitors for the accelerating structures with multiple beams. Both cases with common and separated nominal orbits are considered. For the first case we utilize the phase information, when for the second case additional pick-up electrodes can be utilized.

INTRODUCTION

Most commonly used method for the beam position monitors (BPMs) is based on the evaluation of the signals induced on the pick-up electrodes (PUEs) by a circulating beam. Beam location is calculated from the signal amplitudes using delta over sum [1]. For the vertical plane BPM with two PUEs the equation can be written as

$$y = k\frac{U_{up}-U_{down}}{U_{up}+U_{down}} \quad (1)$$

where U_{up} and U_{down} are the amplitudes, k is a scaling factor, which is determined by the geometry of a vacuum vessel and the electrodes. For a symmetrical system and beam in the center both signals have equal amplitudes and the corresponding position readback is zero.

With two (or more) beams circulating inside the vacuum chamber we need to separate the signals and process them individually. For the colliders with beams moving in the opposite directions this task is solved by utilizing the striplines, which have directional properties. The signals from the different beams appear on the different ports and conventional processing units can be utilized.

This technique is not suitable for energy recovery linacs (ERL) and fixed-field alternating gradient accelerators (FFAG) where two or more beams co-propagate through a vacuum system in the same direction and each beam has its own trajectory.

PROPOSED METHOD

In the energy recovery linacs the beams pass either though an arc where only accelerated and decelerated beams of the same energy are present (on the last pass the only beam is present) or through an accelerating/decelerating section common for the all beams.

For ERL the time delay between accelerated and decelerated bunches is fixed by design and it is possible to employ the phase of the PUE signal to extract information on the position of each bunch. First we consider an arc where only two beams are present. If bunches, separated by a flyby time Δt_{12}, have different positions then each PUE sees different longitudinal "center of gravity" of the two bunches (see Fig. 1) and there is a phase shift between two signals. For a processing unit, utilizing signal processing at frequency ω, and small displacements of the first and the second bunches δ_1 and δ_2 ($S\delta_1, S\delta_2 \ll 1$, where $S=1/k$ is a sensitivity coefficient) we can write the linearized equations:

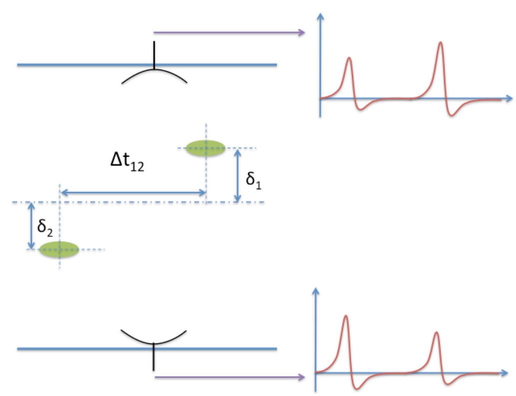


Figure 1: Signals induced on the pick-up electrodes by two bunches with different coordinates. Because of bunches' displacements the amplitudes of the induced voltages differ.

$$\begin{aligned} U_{up} &= U_1(1+S\delta_1)\sin\omega(t+\Delta t_{12}/2) + \\ &\quad U_2(1+S\delta_2)\sin\omega(t-\Delta t_{12}/2) \\ U_{down} &= U_1(1-S\delta_1)\sin\omega(t+\Delta t_{12}/2) + \\ &\quad U_2(1-S\delta_2)\sin\omega(t-\Delta t_{12}/2) \end{aligned} \quad (2)$$

When both bunches have equal charges (a valid assumption for ERL) then we re-write Eq. 2 as

$$\begin{aligned} U_{up} &= U_0\cos\frac{\omega\Delta t_{12}}{2}\left(2+S(\delta_1+\delta_2)\right)\sin\omega t + \\ &\quad U_0 S\sin\frac{\omega\Delta t_{12}}{2}(\delta_1-\delta_2)\cos\omega t \\ U_{down} &= U_0\cos\frac{\omega\Delta t_{12}}{2}\left(2-S(\delta_1+\delta_2)\right)\sin\omega t - \\ &\quad U_0 S\sin\frac{\omega\Delta t_{12}}{2}(\delta_1-\delta_2)\cos\omega t \end{aligned} \quad (3)$$

Neglecting second order terms we can estimate amplitudes ($A=\sqrt{U_{sin}^2+U_{cos}^2}$) of the signals induced on PUE

$$\begin{aligned} A_{up} &\approx 2U_0\left(1+S\frac{\delta_1+\delta_2}{2}\right)\cos\frac{\omega\Delta t_{12}}{2} \\ A_{down} &\approx 2U_0\left(1-S\frac{\delta_1+\delta_2}{2}\right)\cos\frac{\omega\Delta t_{12}}{2} \end{aligned} \quad (4)$$

*Work supported by Brookhaven Science Associates under Contract No. DE-AC02-98CH10886 with the U.S. DoE
#pinayev@bnl.gov

ISBN 978-3-95450-144-1

LONGITUDINAL BEAM HALO IN THE PHOTOEMISSION FROM GaAs-PHOTOCATHODES IN A 100 keV DC GUN

M.A. Dehn, K. Aulenbacher, E. Kirsch, F. Fichtner, V. Tioukine,
Johannes Gutenberg Universität Mainz, Germany

Abstract

At Johannes Gutenberg Universität Mainz measurements of the time response of photocathodes can be performed routinely at the "Testquellenlabor" (source testlab) using a deflector cavity. Short electron bunches are generated using a femtosecond tunable laser system operating at 800 nm for best polarisation/QE if GaAs is used. In our experiment the laser radiation is also frequency-doubled to 400 nm in order to compare the time response at different wavelengths. First measurements show an important modification of the longitudinal beam profile at 400 nm without the trailing electrons which are typically observed at 800 nm.

INTRODUCTION

In addition to a high beam current of 10−100 mA, a long cathode lifetime, low emittance and a low dark current, future accelerator projects (e.g. Mainz Energy-Recovering Superconducting Accelerator (MESA), Berlin Energy Recovery Linac Project (BERLinPro)) require extremely low levels of unwanted beam. To achieve these demands, an analysis of the emitted electron bunches is necessary to determine if the pulse response corresponds to the acceptance of the accelerator.

Emission of electrons which occurs after a certain time may be considered as 'unwanted beam'. In the present paper we extent our old results for GaAs [1] towards excitation with photons in the blue wavelength region. This is typical for an injector into an ERL based light source, where production of polarised electrons (which is only possible with infra-red excitation) is of no importance.

Our measurements indicate that using photons of higher energy leads to a considerable reduction of the unwanted longitudinal beam.

This project is part of joint German-Russian research program and is supported by the German Federal Ministry for Education and Research (Bundesministerium für Bildung und Forschung, BMBF [1]).

PHOTOCATHODES

For high average current machines only two out of the many possible types of photocathodes (see Figure 1) are of interest. Photocathodes of type Cs:GaAs belong to the group of semiconductors with a negative electron affinity (NEA) as opposed to semiconductors with positive electron affinity (PEA) such as K_2CsSb.

[1] FKZ: 05K12UM1 PCHB photocathodes

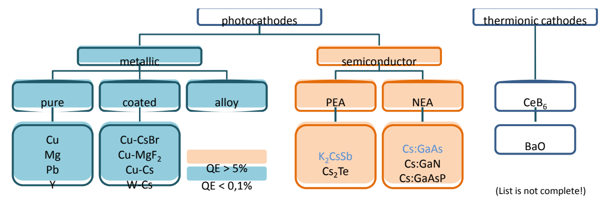


Figure 1: Overview of different cathode types [2]. The semiconducting photocathodes (highlighted) are the most interesting type for this analysis.

Until now, different types of GaAs photocathodes are used at both Mainzer Microtron (MAMI) and source testlab (PKAT) at Johannes Gutenberg University Mainz (JGU). At PKAT, there is the possibility of time response measurements. So, shape and length of electron bunches — generated by laser wavelength λ_{laser} of 800 nm — are well known [1].

Since early 2013 we have the possibility to study the pulse response also for photoexcitation with higher photon energies. Therefore, a direct comparison of the response of NEA-GaAs for excitation with sub-picosecond laser bunches with photon energies of ≈ 1.5 eV (800 nm) and ≈ 3 eV (400 nm) became possible.

EXPERIMENTAL SETUP

The time response of the emission process is encoded within the longitudinal beam profile. A TM_{110} deflector cavity operating at 2.45 GHz of the RF master of MAMI with a maximum input power of 340 W transforms the longitudinal beam profile into a transverse one. The beam spot is observable as an intensity distribution on a fluorescent screen (YAG-screen).

The design of the electron source at PKAT does not allow a bunch charge which is high enough for analysing a single electron bunch. Thus, the analysed image of a beam spot on a YAG-screen is a sample of more than 10^5 electron bunches. If the frequency of electron bunches is synchronised to the radio frequency (RF) of the defector cavity, every bunch is deflected at the same RF phase. Then the resulting intensity distribution represents the time dependency of electrons in one bunch.

Laser System

At PKAT the laser system consists of three components: A DC laser (P_{laser} = 10 W, λ_{laser} = 532 nm) is needed for pumping a modelocked Ti:Sapphire laser. The

ISBN 978-3-95450-144-1

DARK CURRENT IN SUPERCONDUCTING RF PHOTOINJECTORS – MEASUREMENTS AND MITIGATION

J. Teichert#, A. Arnold, P. Murcek, G. Staats, R. Xiang, HZDR, Dresden, Germany
P. Lu, H. Vennekate, HZDR & Technische Universität, Dresden, Germany
R. Barday, T. Kamps, HZB, Berlin, Germany

Abstract

Unwanted beam can cause beam losses and may produce acute or chronic damages of the accelerator. Furthermore it can considerably disturb experiments or increase its back-ground. The operation of the superconducting RF photo gun at the ELBE accelerator has delivered the first experimental information on that topic for this gun type. It was found, that dark current is an important issue, similar to that of normal conducting RF photo injectors. In the presentation the measurement of dark current, its properties and analysis will be shown and we will discuss ways for mitigation, especially the construction of a dark current kicker.

INTRODUCTION

ELBE is a user facility with a superconducting electron linear accelerator based on TESLA-type RF cavities and operates in continuous wave (CW) mode with original design values of maximum beam energy of 40 MeV and average beam current of 1 mA. In 2012 an upgrade in beam current to 1.6 mA was realized. The facility serves for manifold applications of electromagnetic radiation and particle beams ranging from the operation of two free-electron lasers (FEL) for infrared light, the production of gamma rays for nuclear astrophysics, positrons for material science, neutrons for transmutation studies, and beams for oncological radiations. For high-current applications like FELs or gamma ray production, small fractions of beam loss of 0.1 % or less can damage accelerator components. For the other low-current applications like radiation treatment of cells, tests of new particle detectors, or Compton backscattering experiments unwanted beam produces irradiation dose errors or additional measurement background. A thermionic electron gun has served as injector since the commissioning of the accelerator in 2001. Unwanted beam derives from field emission in the acceleration cavities and beam halo due to jitter or other instabilities.

A new superconducting RF photo-injector (SRF gun) has been developed and installed at ELBE which produces beams of higher brightness and allows for higher bunch charges than the thermionic injector. The design of the SRF gun and its present status and properties are presented elsewhere [1, 2]. The SRF gun will replace step by step the thermionic injector.

Normal-conducting RF photo-injectors are known to produce a high amount of dark current due to field emission [3, 4]. Especially for RF photo-injectors with long bunch trains like at FLASH or the future European XFEL, dark current is a serious problem and requires counter measures as the installation of a dark current kicker [5]. Dark current might be also a problem for SRF guns, especially due to their CW operation. For the SRF gun at ELBE we therefore performed dark current measurements.

SRF GUN DESCRIPTION

The SRF gun at ELBE comprises a 3½-cell niobium cavity for 1.3 GHz with a 12 mm hole in the half-cell back wall for the insertion of the photo cathode as it is shown in Fig 1. The photo cathode is hold by the cathode cooler and its 10 mm diameter stem extends through the choke filter cell into the hole of the half-cell. There is a 1 mm circular gap between the cathode stem and cavity. Thus the cathode is electrically and thermally insolated off the cavity. The front part (plug) of the cathode stem consists of Mo whereas the other part is Cu. The Cs_2Te photo layer is deposited on the front surface of the Mo plug. Usually the cathode is about 2.5 mm retracted with respect to the half-cell wall resulting in a lower cathode surface field.

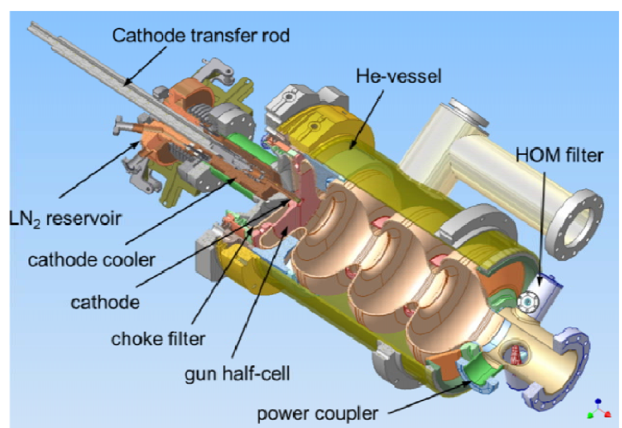


Figure 1: SRF gun cavity with liquid He vessel and cathode cooling system.

The on-axis acceleration field of the cavity is presented in Fig. 2a and the corresponding surface electric field is shown in Fig. 2b. The calculation was carried for the design value of 50 MV/m peak field but the relative field distributions are true also for the lower field values used in the measurements. Compared to the peak field in the three TESLA cells, the maximum on-axis field in the half-cell is 60 %, and at the cathode the value is 40 % caused by the retracted cathode. The details of the geometry near the cathode are shown in Fig. 3. For high-field areas, significant for field emission, the simulation delivers 80 % of the peak value at the cathode boring

ISBN 978-3-95450-144-1

FEASIBILITY STUDY OF MULTI-TURN ERL-BASED SYNCHROTRON LIGHT FACILITY

A.N. Matveenko*, T. Atkinson, A.V. Bondarenko, Y. Petenev, Helmholtz-Zentrum Berlin, Germany

Abstract

Energy Recovery Linacs (ERL) have been discussed as drivers for synchrotron radiation facilities in X-ray region for over a decade. The first proposal for a multi-turn ERL as a next generation synchrotron light facility was in 1997 [1]. Since then great advances in ERL technology and high brightness electron source development were achieved [2], ERL-based high power free electron infrared laser at JLab (e.g. [3]) and the demonstration of multi-turn energy recovery at BINP [4]. The feasibility of an X-ray ERL-based light source seems more and more realistic.

An overview of the design of a multi-turn ERL under development at Helmholtz Zentrum Berlin (FSF – Femto-Science Factory) is given in this paper.

LAYOUT

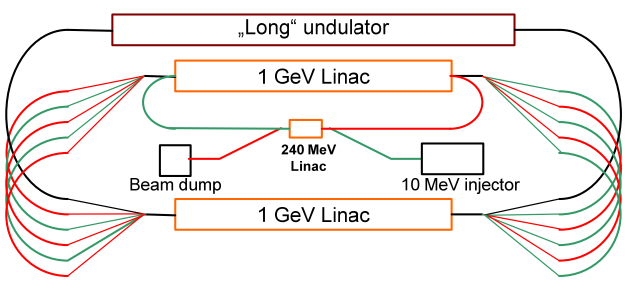


Figure 1: General layout of the FSF. Green lines – beam at acceleration, red – at deceleration, black – 6 GeV beam.

The accelerator layout is shown in the Fig. 1. It consists of a 10 MeV high brightness photo injector, medium energy (240 MeV in the picture) second stage injector, main linac, which is split into 2 1-GeV linacs (similar to CEBAF design). Each of the 1 GeV linacs is passed 3 times by the beam to gain 6 GeV, deceleration takes place in the reverse order. Undulators with user stations can be installed in (emittance optimized) arcs at all energies (see Fig. 4). Additionally, there is a possibility to have a long undulator at the maximal beam energy.

The beam and accelerator parameters are summarized in the following Table 1.

In following chapters we summarize specific features of this design.

*Work supported by grants of Helmholtz Association VH-NG-636 and HRJRG-214
#aleksandr.matveenko@helmholtz-berlin.de

Table 1: Main Parameters of the Multi-Turn ERL

Accelerator/beam parameters	High brilliance mode	Short pulse mode
E, GeV	6	6
$<I>$, mA	20	5
Q, pC	15	4
$\varepsilon_{\perp n}$, mm	0.1	~0.5
$\varepsilon_{\parallel}$, keV·mm	~3	~3
τ, fs	200-1000	~10
$<B>$, $\frac{Ph}{s \cdot mm^2 mrad^2 0.1\%}$	$8 \cdot 10^{22}$	$\sim 4 \cdot 10^{21}$
B_{peak}, $\frac{Ph}{s \cdot mm^2 mrad^2 0.1\%}$	10^{26}	$\sim 10^{26}$

Two-Stage Injection and Split Linac Geometry

The cascade injection drastically improves the low to high energy ratio in the first 1 GeV linac, which allows for reasonable focusing along the linac for all energies and improves TBBU stability of the installation. On the other hand, 250 MeV arcs can be used for the longitudinal bunch compression (additional compression stage) on acceleration, to reduce the energy spread during deceleration by decompression, and to compensate for the average energy loss of the beam due to radiation. Finally, if one has concerns of even higher energy spreads at deceleration (consider SASE FEL), beam scrapers (or an additional beam dump for a reasonable average current) at 250 MeV can be thought of.

Split linac geometry allows to separate beams in the arcs, (i.e. the beam on accelerating path have different energy compared to the beam on the decelerating path) so that they are transported in separate vacuum chambers. This way all the beams can be steered separately, and users see only one beam type in every undulator.

Operation Modes

As shown in the Table 1, two main operational modes of the accelerator are considered. The high brilliance mode is optimized for the maximum average brilliance. Low transverse emittance and high flux are important for this mode. A long bunch is preferable in this mode to maximize the flux keeping transversal emittance low. No bunch compression is necessary, the linacs operate at phase 90° (maximal acceleration) of the RF, longitudinal dispersion (R_{56}) of all arcs are zero.

The short pulse mode is designed to provide short pulses of X-ray radiation with high peak brilliance. The bunch length in undulators is limited by collective effects in this case and will vary depending on the bunch charge.

ISBN 978-3-95450-144-1

OVERVIEW OF THE LHEC DESIGN STUDY AT CERN

O. Brüning, CERN, Geneva, Switzerland

Abstract

The Large Hadron electron Collider (LHeC) offers the unique possibility of exploring lepton-proton collisions in the TeV Center of Mass (CM) range by further utilizing the existing LHC infrastructure. This paper summarizes the Linac-Ring option for the LHeC project and outlines the next developments for the study.

INTRODUCTION

Lepton-proton collisions in the TeV CM energy range provide a unique tool for studying new phenomena in the partonic structure of protons and nuclei, for precision Higgs physics and the search for physics beyond the Standard Model of particle physics [1,2]. The LHeC may become the first electron-ion collider ever built. The LHeC is designed to use one of the hadron beams of the LHC in a synchronous operation mode in parallel with the HL-LHC exploitation. It therefore represents an important opportunity for a further exploitation of the existing LHC infrastructure and its massive infrastructure investment already taken and to come. Achieving ep CM collision energies in the TeV range with a 7 TeV energy proton beam demands lepton beam energies above about 50 GeV. The LHeC Conceptual Design Report (CDR) [1] is based on a lepton beam energy of 60 GeV. But it also addresses the option of a much higher lepton energy (140 GeV) for exploring the high energy CM regime. The CDR was developed under the auspices of CERN, ECFA and NuPECC who sponsored around four dedicated LHeC workshops between 2008 and 2012.

The CDR explored two distinctly different design approaches for the LHeC collider: one design for a Ring-Ring option and one for a Linac-Ring option with Energy Recovery operation. Beam transfer aspects for both options are given in [3]. The last LHeC workshop in 2012 focused on the presentation of the CDR and concluded with a CERN mandate to develop the required technical R&D work over the next 4 years (2013 to 2016), focusing on the technologies required for the ERL option of the LHeC project, so that a decision on the project could be taken when the LHC starts its second run period at full energy.

LINAC-RING OPTION

The Linac-Ring [L-R] option requires a new linear accelerator for the electron beam that intersects in one location with the existing LHC machine. Several options have been considered for the linear accelerator (pulsed, re-circulating and Energy Recovery Linac configurations). These provide a range of energy and luminosity combinations. The baseline option for the LHeC CDR is a recirculating 60 GeV Energy Recovery Linac (ERL) which allows for high luminosity operation. A pulsed linac option provides still an interesting option for maximizing the energy reach of the LHeC (at the cost of a reduced peak luminosity performance) as could be demanded by findings at the LHC. Table 1 summarizes key parameters for both options. The 60 GeV ERL version is capable of reaching a luminosity as high as the Ring-Ring option (O(10^{33} $cm^{-2}s^{-1}$)). First considerations have been made as to further increase the luminosity reach of the LHeC Linac-Ring (L-R) option and to possibly reach a luminosity level of 10^{34} $cm^{-2}s^{-1}$, which would enhance the potential of the LHeC for precision Higgs measurements [2].

The 60 GeV ERL version features two 1km long superconducting RF sections and two return arcs that house magnets for three passages at different energies. Each linac section provides an energy gain of 10 GeV and the machine requires in total three recirculations through the two SC linacs to reach an energy of 60 GeV. The minimum acceptable bending radius of the return arcs is determined by the maximum acceptable energy loss through synchrotron radiation and the requirement of having a total circumference that is an integer fraction of the LHC circumference. For the 60 GeV ERL option these considerations lead to a radius of curvature of 1km for the two return arcs and a total machine circumference of ca. 9km (1/3 of the LHC circumference). Figure 1 shows a schematic layout of the 60 GeV ERL option and Figure 2 shows a schematic view of the resulting underground installation. The overall LHeC complex would have approximately the same size as the existing SPS machine.

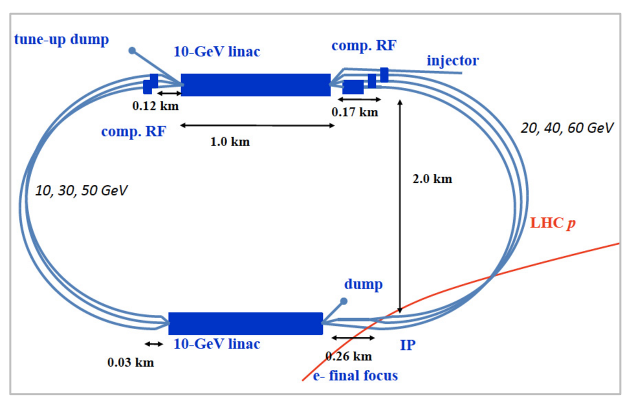


Figure 1: Schematic layout of the 60 GeV ERL option.

The L-R option has the advantage over the R-R option that all civil engineering and installation work can be done parallel to the LHC operation and thus independently of the LHC shutdown schedule. Furthermore, it is notable, as was recently pointed out [5],

ISBN 978-3-95450-144-1

BEAM DYNAMICS STUDIES ON THE INJECTOR OF THE IHEP ERL TEST FACILITY*

Y. Jiao#, O.Z. Xiao, J.Q. Wang, S.H. Wang, IHEP, Beijing 100049, China

Abstract

In this paper we present the beam dynamics studies with the Impact-T program on the injector of the ERL test facility in the Institute of High Energy Physics, Beijing. Variable parameters, including driven-laser beam size, solenoid strengths and positions, RF cavity strengths, positions and phases, are varied to optimize the beam quality at the end of the injector.

INTRODUCTION

The energy recovery linac (ERL) and free electron laser (FEL) are considered to be candidates of the fourth generation light sources, and have received much attention worldwide. Since both of them are based on linac technologies, it is possible to combine FEL into an ERL facility, resulting in a compact two-purpose light source. A test facility, named energy recovery linac test facility (ERL-TF), was proposed at the Institute of High Energy Physics (IHEP), Beijing, to verify this principle [1]. Physical design of the ERL-TF started a few years ago and is well in progress [2-4]. It is worth mentioning that we thoroughly studied the beam breakup effect in such a two-purpose machine. It is found that two effects emerge as a result of the introduction of FEL beams: a reduction in the threshold current and a central orbit fluctuation for ERL current under threshold. Due to the fact that the repetition rate of FEL bunches is much smaller than that of ERL, the introduction of FEL beam does not have a fatal effect on the threshold current. As for the orbit fluctuation, we gave a simple model and found a resonance relation between the voltage spread and the ratio of HOM frequency to the FEL repetition rate. By choosing an appropriate FEL frequency, the amplitude of the orbit fluctuation can be kept small [4].

The layout of the facility is presented in Fig. 1. The nominal energy of the electron beam in the radiator is 35 MeV and beam current is 10 mA. Among the components of the facility, one extremely important device dominating the machine performance is the photo-injector. The injector, including a 500-kV photocathode direct-current (DC) gun equipped with a GaAs cathode, a 1.3 GHz normal conducting RF buncher, two solenoids, and two 2-cell superconducting RF cavities, was designed for the ERL-TF [2], with the layout shown in Fig. 2 and main parameters listed in Table 1. Preliminary optimization of the beam dynamics has been performed, and finally an electron beam with normalized emittance $\varepsilon_{n,x(y)}$ of 1.49 mm.mrad was obtained. In this paper, we optimize the beam dynamics of the injector in both the low-charge operation mode (bunch charge 7.7 pC, rep. rate 1.3 GHz) and the high-charge operation mode (bunch charge 77 pC, rep. rate 130 MHz) using the Impact-T program [5], a fully 3D program to track relativistic particles taking into account space charge force and short-range longitudinal and transverse wake-fields. Study shows that it is feasible to achieve a better beam quality at the end of the injector.

*Work supported by the special fund for the R&D of ERL in IHEP
#jiaoyi@ihep.ac.cn

Figure 1: Layout of the ERL test facility.

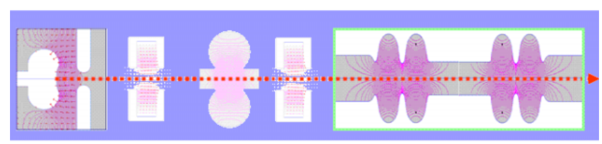


Figure 2: Layout of the ERL-TF injector.

Table 1: IHEP ERL-TF Injector Main Parameters

Parameter	Value	Unit
DC-gun voltage	300-500	kV
Laser power and wavelength	2.3/532	W/nm
Laser rep. rate	130 (or 1300)	MHz
Laser rms trans. size	0.3~1.2	Mm
Laser length	20	Ps
E- ave. kinetic energy	0.2	eV

OPTIMIZATION FOR THE LOW-CHARGE OPERATION MODE

For the low-charge operation mode, a parameter iterative scan program is developed with Matlab which starts several runs of tracking simultaneously. This code can finish the multi-variable scans, which usually contains a few hundred of runs, within an acceptable period of time (e.g. in 2 hours) on a desktop computer.

As the start of the simulation, initial beam distribution is generated according to initial laser parameters listed in Table 1. The normalized emittance $\varepsilon_{n,x(y)}$ is given by

$$\varepsilon_{n,x(y)} = \sigma_{x(y)} \sqrt{\frac{k_B T_\perp}{m_e c^2}}, \qquad (1)$$

ISBN 978-3-95450-144-1

PROGRESS ON THE CONSTRUCTION OF IHEP 500KV PHOTOCATHODE DC GUN SYSTEM

X.P. Li#, J.Q. Wang, S.Y. Chen, Y.L .Chi, S.H. Wang, G.W. Wang, J.S. Cao, J.Q. Xu, O.Z. Xiao, K. Lv，D.R. Sun, Z.S. Zhou, X.H. Peng, T. Zhang, J.R. Zhang
Institute of High Energy Physics, CAS, Beijing 100049, China

Abstract

As one of the most important key technologies for future advanced light source based on the Energy Recovery Linac (ERL), a 500kV photocathode DC gun was supported by IHEP in September of 2011. Up to now, the schematic design of all DC gun subsystems including drive laser, photocathode preparation system, electron gun body and ceramic insulator, high voltage power supply and beam diagnosis system has been finished. The detailed parameters of each subsystem are presented in this paper.

INTRODUCTION

The linac based Free Electron Laser (FEL), and the Energy Recovery Linac (ERL) based light source are the two major types of the 4th generation light source. FEL has higher brightness, shorter pulse length and higher coherent features, but with a minor number of photon beam lines. ERL combines the good beam performance of the linac and good operation efficiency of the storage ring machine, although its brightness and coherent degree not as higher as FEL, but with many photon beam lines. Hence, both FEL and ERL cannot be replaced each other, we really need both of them. Based on this point, IHEP has proposed the suggestion of “one machine two purposes”, both FEL and ERL will share a same super-conducting (SC) linac for having a high efficiency [1].

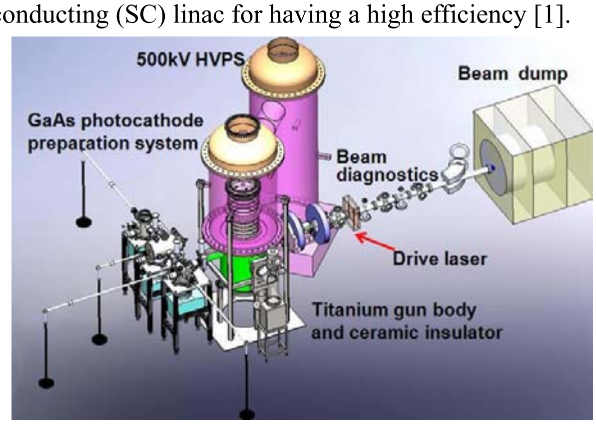


Figure 1: Overall design of the photocathode DC gun.

There are lots of technical challenges on ERL presently, especially on the electron sources which can deliver a high brightness electron beam with a low emittance and high current up to 100 mA are being developed for ERL worldwide [2]. The recent experimental results from JLab and Cornell demonstrated that a photocathode DC gun with a GaAs or multi alkali photocathode is one of the most promising candidate [3][4]. Since September of 2011, a 500kV photocathode DC gun has been supported by IHEP as an innovative project. The overall design of the photocathode DC gun is shown in Figure 1, which consists of the drive laser system, the cathode preparation system, titanium gun body and ceramic insulator, high voltage power supply system and beam diagnosis system. Table 1 shows the main parameters of the DC gun. Up to now, each subsystem has a smooth progress.

#lxp@ihep.ac.cn

Table 1: Main parameters of the DC gun

Parameter	Design value
High voltage	350 ~ 500 kV
Cathode material	GaAs:Cs/O
Quantum efficiency	5-7% (initial), 1%
Live time	20 h
Drive laser	2.3W，530nm
Repetition rate	100MHz，1.3GHz*
Nor. emittance	(1~2)mm.mrad@77pC (0.1~0.2)mm.mrad@7.7pC
Bunch length	20ps
Beam current	(5~10) mA

* Two operation modes:
(1) 100MHz-7.7mA-77pC, (2) 1300MHz-10mA-7.7pC

DESIGN AND CONSTRUCTION PROGRESS

Drive Laser System

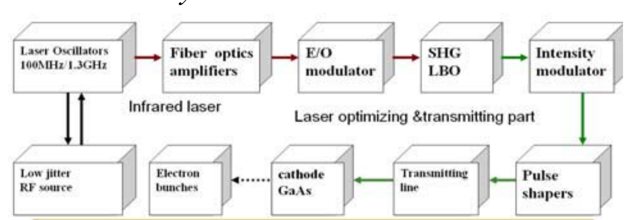


Figure 2: Schematic design of drive laser system.

Drive laser system, as shown in Figure 2, takes a fiber laser technology solution, which is among the most advanced drive laser system so far. Two laser oscillators, one is working at 1.3GHz (PriTel Inc) and the other is 100MHz (Menlosystems Inc) are used in this system,

ISBN 978-3-95450-144-1

UPCOMING MEASUREMENTS OF TRANSVERSE BEAM BREAK UP AT THE SUPERCONDUCTING RECIRCULATING ELECTRON ACCELERATOR S-DALINAC*

F. Hug#, T. Kürzeder, N. Pietralla, TU Darmstadt, Darmstadt, Germany

Abstract

The superconducting accelerator S-DALINAC provides electron beams of up to 130 MeV for nuclear physics experiments at the university of Darmstadt since 1991. It consists of a 10 MeV injector and a 40 MeV main linac and reaches its final energy using up to two recirculation paths. The superconducting main linac houses eight 20-cell SRF cavities operated at 3 GHz and 2 K. Due to transverse beam break up the design beam current of 20 μA could not be reached in recirculating operation mode yet, the highest stable beam current obtained so far accounts for 5 μA, which is sufficient for the nuclear physics experiments carried out at Darmstadt [1].

On the other hand the very low threshold current for the occurance of beam break up in addition with the recirculating linac design gives a unique opportunity to the ERL community for testing different strategies of avoiding beam break up experimentally and to benchmark beam dynamics simulations concerning this topic. We will report on upcoming experiments which will be carried out at the S-DALINAC for that purpose.

INTRODUCTION

The Superconducting DArmstadt LINear Accelerator (S-DALINAC) is operating since 1987 as a source for nuclear- and astrophysical experiments at the university of Darmstadt [2]. It is designed for producing beams of either unpolarized or polarized electrons [3] up to energies of 1 up to 130 MeV with beam currents from several pA up to 60 μA in single pass mode or 20 μA in recirculating mode using two recirculations. The layout of the S-DALINAC is shown in Fig. 1.

For acceleration of the beam ten 20 cell superconducting elliptical cavities (see fig. 2) with a quality factor of $Q_0 \approx 10^9$ are used. The operation frequency of the cavities is 3 GHz while the maximum accelerating gradient of each cavity accounts for 5 MV/m. As the main linac consists of 8 standard 20-cell cavities it can provide an energy gain of 40 MeV. By recirculating

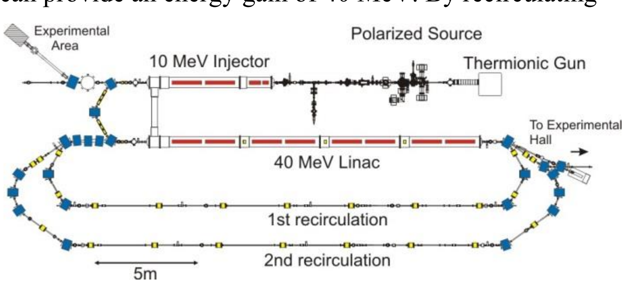


Figure 1: Floor plan of the S-DALINAC.

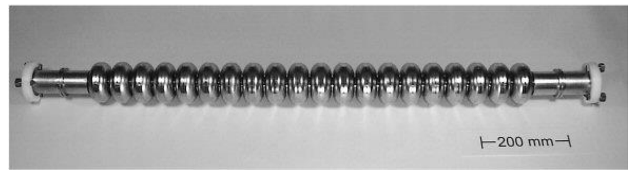


Figure 2: S-DALINAC 20 cell cavity.

the beam up to two times the maximum energy of 130 MeV can be achieved. In the adjacent experimental hall this beam can be used for different experiments such as electron scattering in two electron spectrometers or experiments with tagged photons. For these experiments an energy spread (rms) of $1 \cdot 10^{-4}$ as well as a very low γ-ray background are required.

OPERATIONAL EXPERIENCE

The S-DALINAC is the first superconducting and recirculating cw accelerator for electrons which has been put into operation in Europe [2]. After setting up the injector in 1987 the complete accelerator started operation in 1991 and has been used for experiments in nuclear, astro- and radiation physics since then. In 1996 a first infrared laser beam at the free electron laser (FEL) could be observed [4]. For the FEL operation the peak current of the electron beam was up to 2.7 A at a pulse length of some ps and an operation frequency of 600 MHz [4]. Originally it was planned to operate the S-DALINAC as an ERL as well when using the FEL but the challenges of operating this first European FEL had been big enough even without trying the ERL mode. One reason has been the occurance of instabilities due to the high peak current of the electron bunches – a first observation of transverse beam break up at the S-DALINAC which occurs at a relative low threshold current of some μA due to the design of the 20-cell accelerating cavities which haven't been optimized for suppressing any higher order modes (HOMs).

The beam break up also limits the maximum achievable beam current in recirculating operation of the S-DALINAC. Operational experience obtained during many years of beam time for nuclear physics showed that a stable operation in the twice recirculating mode is possible only up to some μA. The highest stable current achieved so far accounts for 5 μA [1], which is well below the design value of 20 μA but adequate for the experiments carried out. On the other hand this low threshold current gives an opportunity of investigating transverse beam break up experimentally.

*Work supported by BMBF through 05K13RDA
#hug@ikp.tu-darmstadt.de

ISBN 978-3-95450-144-1

STATUS OF THE BNL ERL INSTRUMENTATION*

D. M. Gassner [#], D. Kayran, V. Litvinenko, C. Liu, G. Mahler, R. Michnoff, T. Miller, M. Minty, M. Wilinski Collider-Accelerator Department, BNL, Upton, NY, 11973, USA

Abstract

The Energy Recovery Linac (ERL) project is currently under construction at the Brookhaven National Laboratory. Energy recovery operations are expected with high intensity beams that have current up to a few hundred milliamps, while preserving the emittance of bunches with a charge of a few nC produced by a high current SRF gun. To successfully accomplish this task the machine will include beam diagnostics that will be used for accurate characterization of the beam phase space at the injection and recirculation energies, transverse and longitudinal beam matching, orbit alignment, beam current measurement, and machine protection [1]. This paper describes the recent progress and present status of the systems that will be used to meet these goals.

INTRODUCTION

The diagnostics requirements have been described in several previously published papers [2,3,4]. There is a progression of ERL facility stages planned in order to advance towards achieving full energy recovery. The diagnostics system configurations vary for each stage. The initial stage for beam testing includes the 2MeV SCRF gun, a straight beam transport to an in-flange ICT, then to an isolated blank CF flange acting as a Faraday Cup. After gun testing with different cathodes we will extend the straight transport to include a pepper pot emittance station. When the beam parameters are acceptable we will connect the transport to the injection zig-zag [5] and deliver beam to a low power dump after the 5-cell Linac. The early commissioning stages are limited to 70W operation by the relatively small temporary beam dumps. The full complement of all of the ERL planned instrumentation subsystems, including devices in the energy recovery loop and high power beam dump, are shown in Figures 1 and 2.

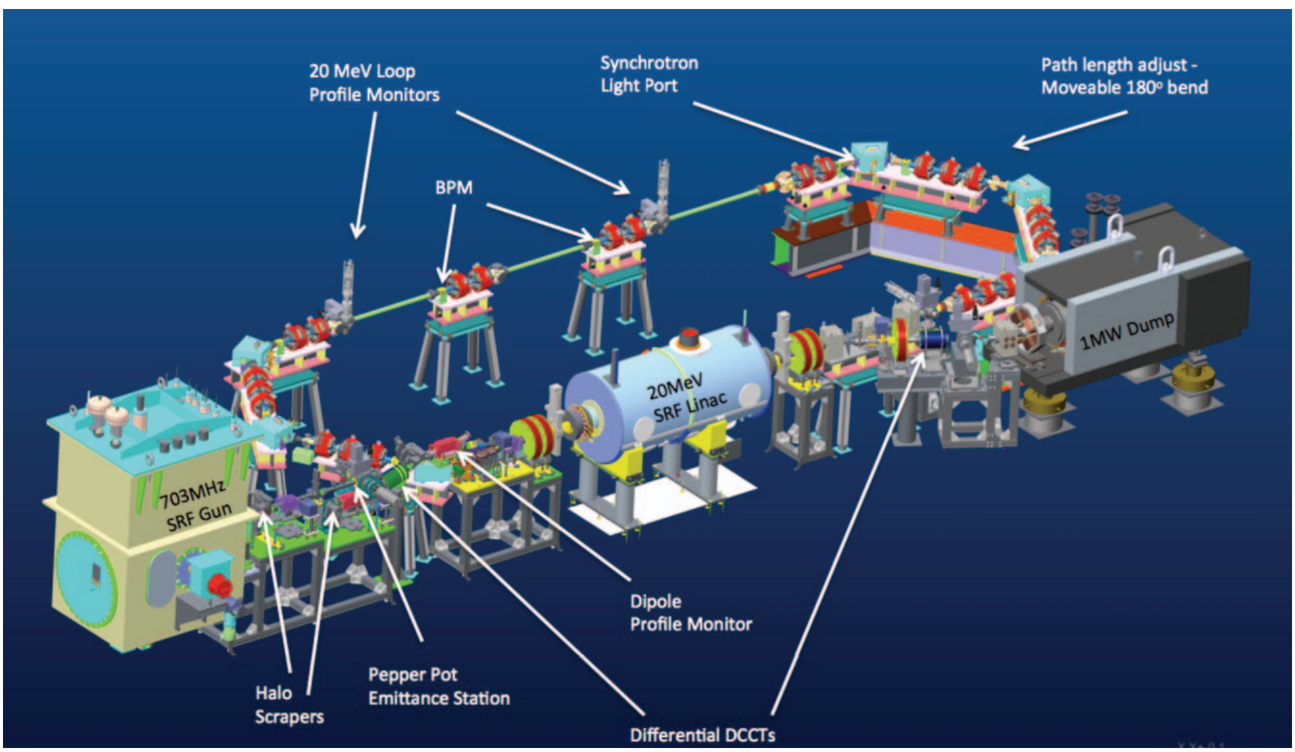


Figure 1: A 3D rendering of the ERL facility showing the SCRF Gun, zig-zag injection transport, 5-cell SCRF Linac, recovery loop, high power dump, and location details of some of the instrumentation detectors.

*Work supported by the auspices of the US Department of Energy
#gassner@bnl.gov

RADIATION MONITORING AT NOVOSIBIRSK FEL

T.V.Salikova, M.V.Petrichenkov, A.V.Repkov, O.A.Shevchenko, N.A.Vinokurov
Budker Institute of Nuclear Physics, Novosibirsk, Russia

Abstract

The radiation diagnostics system controls the levels of radiation in the accelerator hall and in the adjacent rooms where the FEL personnel works. The system provides radiation safety for the personnel. The software performs data visualization and records measurement results in the database. There are special ionization chambers installed in the accelerator hall. They track beam losses in the vacuum chamber; this information is used for beam orbit correction. These sensors detect induced radioactivity. Based on these data, we can trace the degradation of the material of the construction under the action of radiation.

FEL PARAMETERS

Novosibirsk high-power FEL is based on the multiturn energy recovery linac (ERL), see Fig. 1. The FEL parameters are listed in Table 1.

Table 1: Parameters of FEL

Number of orbits	1	2	4
Electron energy, MeV	12	22	42
Average beam current, mA	10	10	10
FEL wavelength, micron	120 - 240	40 - 120	5 - 40
Max output power, kW	1	10	10

The accelerator hall is shown in Fig 2; the thickness of its concrete walls is 3 meters. This thickness provides radiation protection for the 1 GeV accelerator.

Current losses:

Injector $\delta I/I < 5\%$

Microtron $\delta I/I < 0.5\%$

Higher dose rates are observed in the area of the RF resonators, bending magnets and dump, where radiation sensors are installed.

HARDWARE AND SOFTWARE OF THE RADIATION DOSIMETRY SYSTEM

Our institute has developed a radiation monitoring system using two types of radiation detectors based on ionization chambers. The first-type detectors register radiation at the natural background level of 0.01 – 0.02 µSv/h. They are located in the rooms where people work.

The second-type detectors register radiation of about 10 Sv/h. These twenty gas-filled detectors are located in the accelerator hall and control photon radiation there.

The spherical ionization chamber is filled with air at a pressure of 4 atm. The chamber is made of polyamide with a thin layer of colloidal graphite; its wall thickness is 1.1 mm (Fig. 3.).

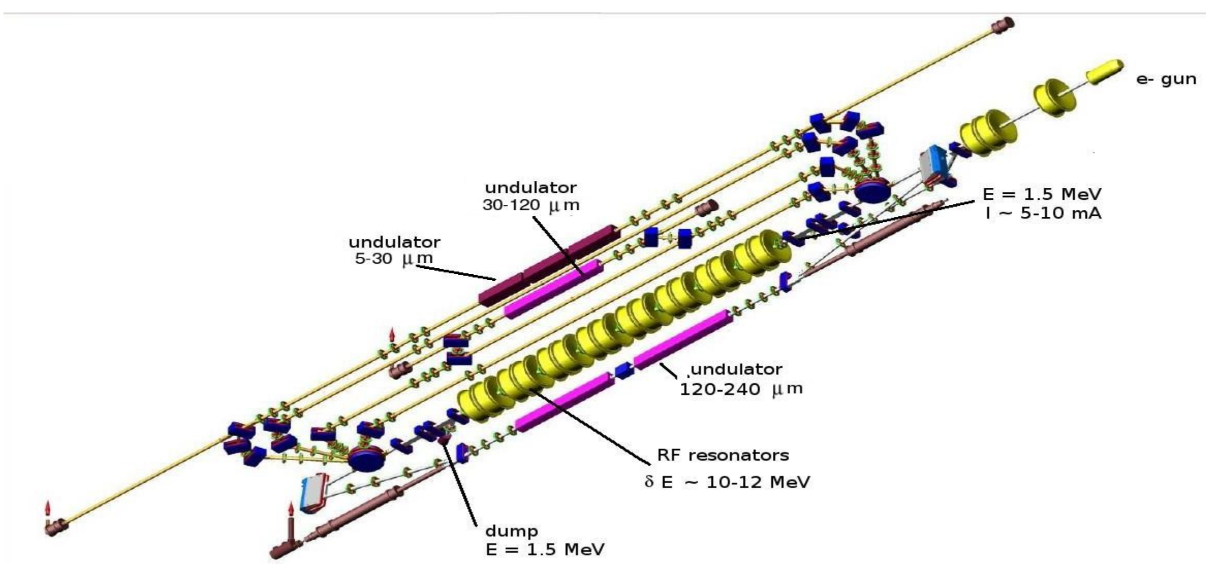


Figure 1: Novosibirsk ERL with the three FELs.

ISBN 978-3-95450-144-1

INSTRUMENTATION DESIGNS FOR BEAM DISTRIBUTION MEASUREMENTS IN THE ERL BEAM DUMP AT BNL *

T. Miller #, S. Bellavia, I. Ben-Zvi, J. Fite, D. Gassner, D. Kayran
Brookhaven National Lab, Upton, NY, USA

Abstract

The R & D Energy Recover LINAC (ERL) at Brookhaven National Laboratory is undergoing continued development in parallel with piece-wise commissioning efforts as installation of each subsystem is completed. While the machine is planned to operate at low intensity with short, low frequency pulses during the commissioning phases, on going design efforts continue to provide a solution to measure the beam distribution inside the high power electron beam dump using several parallel methods. For low power measurements, this includes a new rad-hard version of long 7/8 in. Heliax ion chambers [1,2] that encage the dump both in circular and axial directions. For high power measurements, this includes both "pinhole" like multipoint imaging of the dump with ion chamber beam loss monitors [3] positioned over an array of holes drilled in the shielding around the beam dump as well as an infrared imaging system to peer through an upstream dipole chamber in the extraction line to monitor the temperature distribution on the target surface inside the dump. This paper presents the design details of these three systems that work to ensure the proper distribution of the high power electron beam on the target in an effort to avoid reaching the thermal limit of the water cooled beam dump [4].

INTRODUCTION

The ERL produces an electron beam of short bunches and is designed to operate over a wide range of pulse structures with the ultimate goal of 1MW CW operation. The machine parameters are summarized in Table 1.

Table 1: Machine Parameters

BEAM PARAMETERS	(low charge / high current)
Inj. Energy:	2.0 MeV
Max Energy:	20.0 MeV
Bunch Frequency:	9.383 MHz/ 351, 703 MHz
Bunch Charge:	0.050 – 1.4 nC / 1.4, 0.7 nC
Beam Current:	14 / 500 mA
Bunch Length (rms)	60 – 120 ps / 2 – 40 ps

The ERL has had a long history of R&D efforts at BNL. Its design includes a wide variety of instrumentation [5,6], markedly the three systems described here, to monitor the high power beam dump. Fig. 1 shows the layout and relative size of the machine.

*Work supported by U.S. DOE under contract No DE-AC02-98CH10886 with the U.S. DOE
#tmiller@bnl.gov

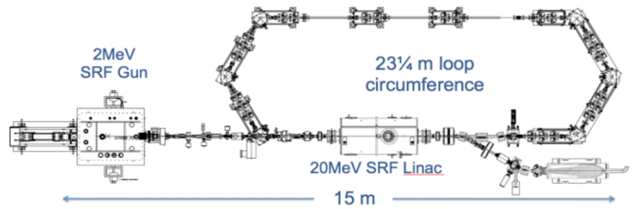


Figure 1: Layout of the ERL.

Electron Beam Distribution

In order to properly fit the beam dump with instrumentation, a simulation of the beam distribution inside the dump was made. Fig. 2 shows the simulated beam function in the X-Z plane. The distribution favors the rear of the dump where most of the energy is deposited on the cone. The predicted beam envelope is outlined in red.

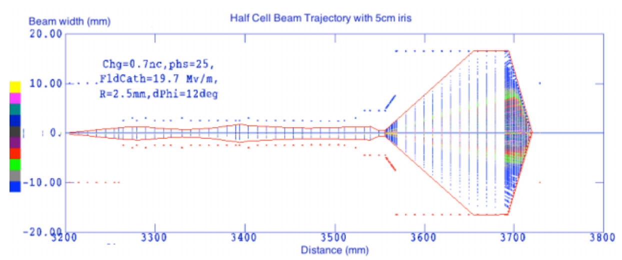


Figure 2: Simulated Beam Trajectory in the extraction line and beam dump.

Beam Dump Design

The design of this water-cooled beam dump is an adaptation of a design for a 1 MW klystron and was built to BNL specifications by CPI, a klystron manufacturer in Palo Alto, CA [7]. Figure 3 shows a drawing of the dump with the beam distribution from Fig. 2 scaled to fit. Before the beam enters the dump it is defocused by a quadrupole to have an opening angle of about 18° and drifts just over a meter before contacting the dump's internal surface. It is important to spread the beam over a large area to distribute the power. The goal of these instrumentation efforts is to continuously confirm an even distribution. When operating at full current, the dump will have to absorb nearly 1 MW of energy from the 2.0 MeV extracted decelerated beam. Simulations predict that when properly defocused, the power density of the absorbed beam will be 600 W/cm^2. However, if the defocusing were lost, a power density of 33 kW/cm^2 would destroy the beam dump. In order to take away the heat, a water jacket is formed around the inner copper dump material that channels cooling water at a flow rate

ISBN 978-3-95450-144-1

THE DEVELOPMENT OF CRYOMODULE FOR C-ERL AT MHI

Hiroshi Hara, Haruki Hitomi, Fumiake Inoue, Katsuya Sennyu, Kohei Kanaoka, Takeshi Yanagisawa
Mitsubishi Heavy Industries, Ltd., Mihara, 729-0393, Japan

Abstract

Mitsubishi Heavy Industries, Ltd. (MHI) manufactured the Superconducting Accelerator Cavity Module of the Injector and the Main Linac of the c-ERL facility being constructed by the High Energy Accelerator Research Organization (KEK). This report provides status of the development.

INTRODUCTION

For the realization of nest generation synchrotron radiation light source ERL (Energy Recovery Linac), a small size ERL "Compact ERL" is under development at KEK (Fig. 1).

MHI manufactured Superconducting Cavities and Cryomodule for mounting Cavities as a high frequency acceleration device to accelerate electrons in the high electric field required as its nucleus technology, and completed installation and delivery of one (1) Injector Cryomodule and one (1) Main linac cryomodule [1].

At present, the beam acceleration test of the Injector Cryomodule is underway at KEK after having been through the High power test.

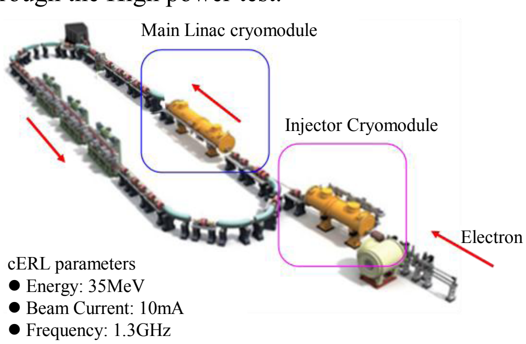


Fig. 1: Outline of the Compact ERL

INJECTOR CRYOMODULE

Configuration of the Cryomodule

The Container enclosing the whole assembly is made of stainless steel, inside of which Aluminum Shield cooled down to 80K is lined to shield radiant heat. Inside of the 80K Shield, the Helium Panels which can store helium of 5K are contained. The thermal anchor is led from the piping connecting two panels to the Input Coupler. Three (3) Cavities welded to the Jacket made of titanium are arranged in the middle of these components (See Fig. 2) [2]. Further, the Magnetic Shield is installed inside the Jacket to cover the Cell. Helium Panels and Piping to supply and recover liquid helium and liquid nitrogen are made of stainless steel, and they passed inspection of High Pressure Gas Safety Inst. of Japan.

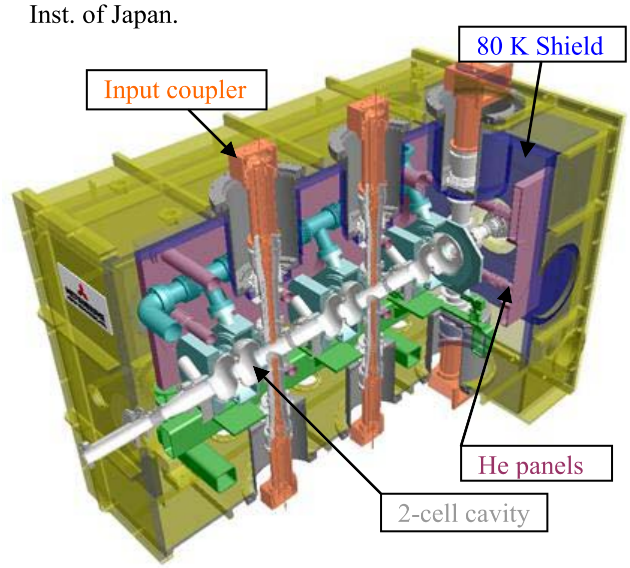


Fig. 2: Overall configuration of Injector Cryomodule

Fig. 3: Examples of component parts, (a) Thermal Shield and piping, (b) Helium Panel.

Superconducting Cavities

The construction is such that the Jacket made of titanium is installed outside of the 2 cells type Superconducting Cavities made of niobium so that the Cavities are held under the superconducting condition by storing liquid helium between the Jacket and the Cavities. The Jacket is designed to be compact so that the Slide Jack Tuner for frequency adjustment can be installed. The design specifications of the Cavities are as shown below, and they passed inspection of the High Pressure Gas Safety Inst. of Japan. The performance of subject three (3) Cavities are confirmed individually at KEK [3].

ISBN 978-3-95450-144-1