CHERENKOV FIBERS FOR BEAM DIAGNOSTICS AT THE METROLOGY LIGHT SOURCE

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Abstract

After a successful commissioning the Metrology Light Source is in user operation since 2008. Machine studies are still on-going in order to improve the injection efficiency and to minimize the impact of trapped ions. Special operation modes such as a low-alpha optic are implemented. Recently, Cherenkov fibers have been installed along the complete storage ring for diagnostic purposes during commissioning. The Cherenkov system allows for a spatially resolved analysis of electron losses over many turns.

THE METROLOGY LIGHT SOURCE

The Physikalisch-Technische Bundesanstalt (PTB) is the main costumer of the BESSY II facility located in Berlin. To cover the spectral range in the VUV range after the shut down of BESSY I in 1999 the low energy storage ring Metrology Light Source (MLS) has been designed and built by BESSY according to the specifications of the PTB. The new storage ring (SR) is located close to the BESSY II storage ring [1]. It was handed over to the users in April 2008 and is now running in routine operation.

The MLS is a double bend achromat with eight bending magnets and a two-fold symmetry (Fig. 1). One straight section is equipped with an electromagnetic undulator with 180 mm period length. The main parameters of the MLS are summarized in table 1.

The electrons are generated in a 105 MeV microtron and injected into the MLS storage ring through a conventional septum magnet while the stored beam is deflected by a four kicker bump covering nearly all of the injection side of the ring. The main problem in the operation of the MLS is to get a sufficiently high accumulation efficiency (typically 2 mA to 4 mA per shot). As damping times are as low as 8 s the accumulation rate can not run faster than with 1/5 Hz. After accumulating the desired current the storage ring is ramped with full current to the operation energy.

It was found that the injection geometry with the best transmission and largest aperture is not consistent with accumulation, while in order to have best accumulation rates the injection geometry has to be strongly distorted leading to a notably reduced transmission. The situation relaxed after lengthening the septum pulse from 60 µs to 100 µs but the basic mechanism is still unknown by part due to the lack of an appropriate diagnostics tool.

A similar situation occurs in reference to the strength of the injection kicker. The kicker amplitudes where accumulation is at optimum are much lower (by 35%) than the values needed to store the maximum current in a single shot.

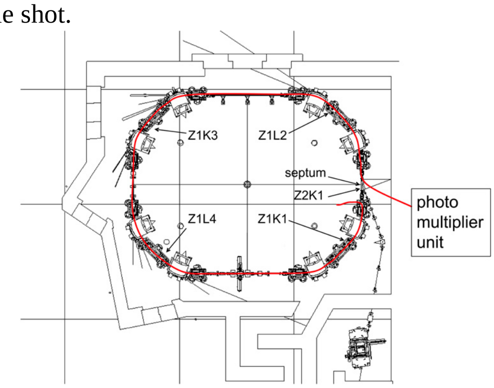

Figure 1: Arrangement of the Cherenkov fibers (red) and the foil monitors at the MLS. The undulator U180 is installed in the straight between Z1L2 and Z1K3.

Table 1: Machine Parameters of the MLS

lattice	double bend achromat
circumference	48 m
revolution time	160 ns
RF frequency microtron	3 GHz
typical length of injected bunch train	500 ns (multi turn injection)
injection energy	105 MeV
RF frequency of SR HF	500 MHz
operational energy	105 MeV to 630 MeV
beam current	1 pA to 200 mA

A detailed understanding of the electron loss mechanisms is required. Further it results that the nonlinear remanent fields of the undulator at the low injection energy also have an impact on the injection performance. This could lead to a severe restriction in the future when additional ID operational modes are required. Recently, a Cherenkov fiber system has been installed at the MLS to provide this information.

THE CHERENKOV FIBER SYSTEM

Cherenkov fibers deliver spatially resolved information of electron losses on a single shot basis [3]. Cherenkov fibers have been installed at linac based light sources such as FLASH [2] and at the HGHG-FEL at MAX-lab [3]. Data of Cherenkov fibers at a storage ring have been reported as well [4]. For single pass machines the conversion of the time axis of the signals into a spatial axis is straightforward. This is also the case in multi turn machines for single bunches or short bunch trains. Losses can be detected over a timescale of many revolutions. For longer bunch trains the signal represents a convolution of the bunch train and the loss pattern along the ring. Furthermore, individual bunches within a bunch train may behave differently shortly after injection due to different energies or phases.

Three optical fibers have been installed around the MLS storage ring. A fourth fiber is prepared and will be implemented soon (Fig. 2). The symmetric arrangement of the fibers with respect to the electron beam allows for a transverse resolution of the losses [4]. However, for a quantitative analysis the transmissions of the individual fibers and the sensitivities of the multipliers have to be taken into account. The fibers have a length of 80 m each starting at the photomultiplier unit located close to the injection straight running around the complete ring. 2 m downstream of the injection septum they are deflected to the inside of the ring and the remaining length is wound to a coil and put on the floor a radiation safe place. Within the straights a few loops have been added to permit a retraction of the fibers without removing the complete system. To prevent the fibers from braking they have been put into radiation resistant polyamide tubes (TECALAN) with an inner and outer diameter of 4 mm and 6 mm, respectively.

The fibres installed are pure-silica step-index fibres with an F-doped cladding. The core and cladding diameter is 300 µm and 330 µm, respectively. The fibres are coated with acrylate and a black nylon buffer (diameter 800 µm) to reduce the possible influence of ambient light.

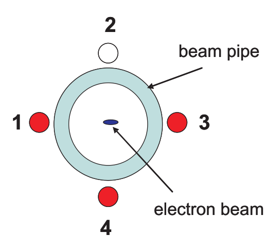

Figure 2: Position of the glass fibers as installed at the MLS. Fiber 1 is located at the inside of the ring. Due to the small vertical aperture the symmetric geometry as depicted in the graph could not be realized within the dipole magnets and the undulator.

After installation the attenuation of the fibers was measured. A highly stable LED light source (wavelength of 650 nm) was connected at the inner end of each fibre. At the end of the fibres around the injection beam line the transmitted light power was measured and compared to the light power emitted by the light source.

The laying of an installed fiber has a significant influence on the transmission which is about 1 dB at 650 nm for a 100 m long straight fiber without any stress. After installation fibers 1, 3, 4 show an attenuation of 1.1 dB, 2.0 dB and 5.9 dB, respectively. The higher attenuation of fiber 4 as compared to fibers 1 and 3 is due to the complicated geometry which requires tighter bends. Fixing the fibers with tape and wire straps increases the attenuation further to 2.7 dB, 2.6 dB and 7.0 dB.

FIRST MEASUREMENTS

In the following we present the data of channel one which shows the highest losses. The asymmetry of the losses will be subject to further studies. The length of the injected bunch train can be varied within a wide range (Fig. 3). Usually, a length of 500 ns is chosen (multi turn injection). The arrival time of the bunch is independent of the bunch length. The sharp spikes at the bunch tail which are always visible may be due to an energy mismatch of the last electrons.

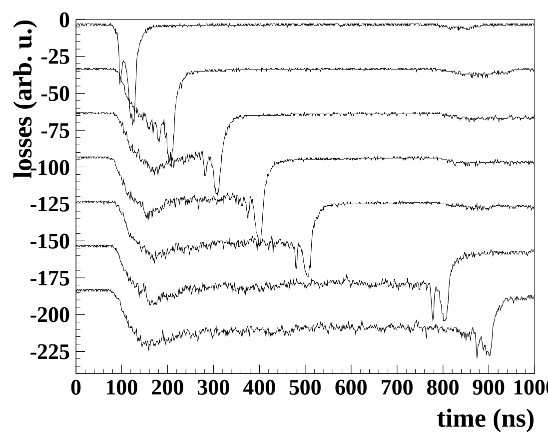

Figure 3: Injection of bunch trains of different lengths. The beam is intentionally dumped with a foil monitor at the septum.

In the following these peaks are used as a reference for the evaluation of the spatial distribution of the losses. Taking into account the reduced speed of light in the fibers of c/1.46 the location of the losses with respect to the septum can be calculated from eq.1 where Δl is the length of the fiber loops in the straights and the additional length due to geometrical constraints.

$$\Delta x = (\Delta t \cdot c - 1.46 \cdot \Delta l) / 2.46 \qquad (1)$$

The losses at various foil monitors with a well known position have been used for a refined calibration (Fig. 4).

The fibers are well suited to study and optimize the injection process. The losses for nominal injection conditions (best accumulation) and for best transmission (but no accumulation) are plotted in figure 5.

The losses at nominal injection geometry are low during the first 150 ns to 200 ns and increase later on. Some electrons get lost at the septum after one revolution (160 ns). Another reason for the increasing losses is the falling kicker amplitude (duration 1 µs). Even after injection of the complete bunch train (marked via the sharp spikes at the tail) losses are visible which indicate that the transmission is reduced by the distorted injection geometry.

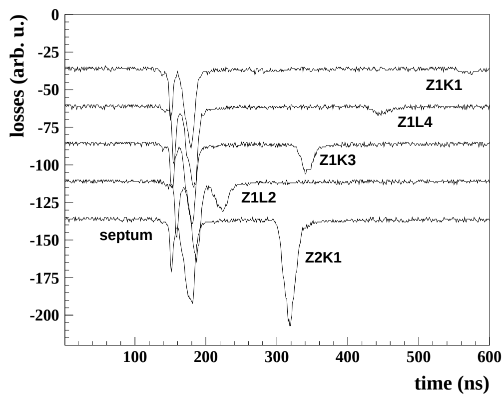

Figure 4: Losses of a short bunch at various foil monitors. The shower at FOM Z2K1 (upstream of the injection straight) does not hit the end of the fiber since it is already bent to the inside of the ring but the fiber part at the septum.

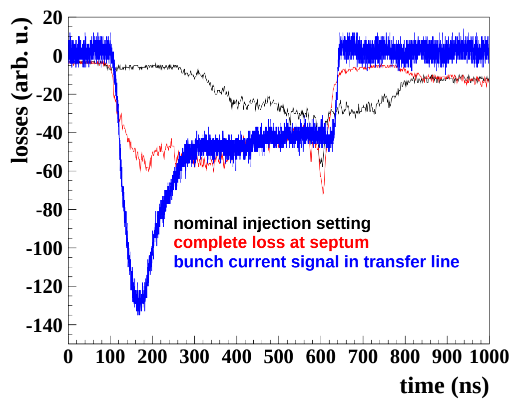

Figure 5: Losses for nominal injection conditions (black) and best transmission (red). For comparison the charge distribution as measured with a stripline upstream of the septum is plotted (blue).

The charge distribution as measured with the striplines in the transfer line shows a high peak at the train head which does not show up in the losses at the septum.

In another experiment the higher than normal settings of the kicker bump used to store the highest current in a single shot was applied to slow accumulation. After injection of 20 mA into the SR the microtron has been switched off and the kickers at the "high store" settings where triggered at a frequency of 0.2 Hz. The losses of the stored beam after each kick have been measured (Fig. 6).

Losses occur immediately after powering the kickers and additionally after more than four revolutions around the SR. The excited bunch moves around the horizontal phase space and losses occur after one revolution in the horizontal phase space. Figure 7 demonstrates the dependency of the revolution speed in the horizontal phase space on the horizontal tune. Detailed studies of these loss mechanisms will be done in the future.

The data presented demonstrate the sensitivity of the system and the potential help for a machine parameter optimization. The data acquisition software permits the definition of time windows where the signals are integrated online. These integrated values can be written into EPICS variables and are available for correlated measurements with other parameters.

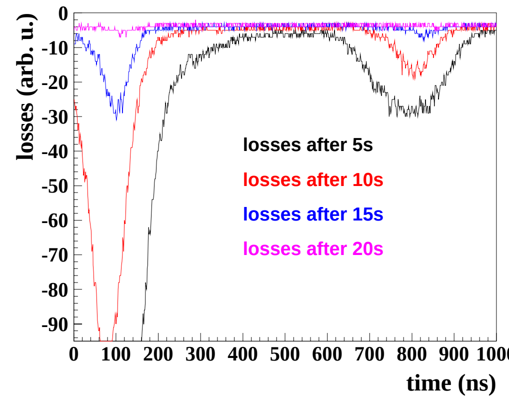

Figure 6: Losses of the accumulated and damped beam when powering the kickers with a frequency of 0.2 Hz. All data correspond to a single filling.

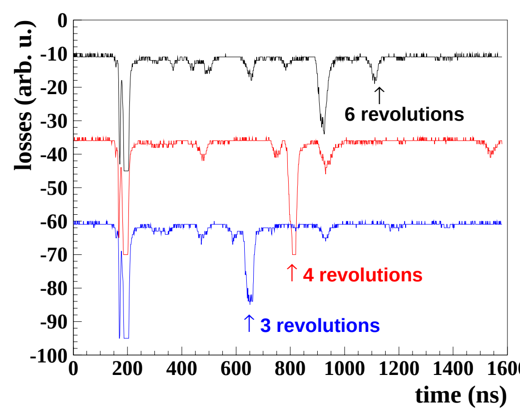

Figure 7: Electron losses at the septum after 6, 4 and 3 revolutions in the storage ring for horizontal tunes of 0.185 (black), 0.256 (red) and 0.320 (blue).

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