OPTICAL FIBRE BEAM LOSS MONITORS FOR STORAGE RINGS AT DELTA

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Abstract

The Dortmund Electron Accelerator (DELTA) is a 1.5 GeV synchrotron light source. Optimisation of the injection efficiency and understanding lifetime limitations due to chamber aperture limitations was necessary to reduce the injection time during runs for synchrotron radiation users.

To localise beam losses, a monitor system along the vacuum pipe is required. Optical fibre technique developed for linear accelerators at DESY [1,3] seemed suitable and was adapted to the DELTA storage ring [2].

1 MOTIVATION

The DELTA storage ring has a 75 MeV Linac and a ramped injector storage ring (BoDo) as pre-injector (see figure 1).

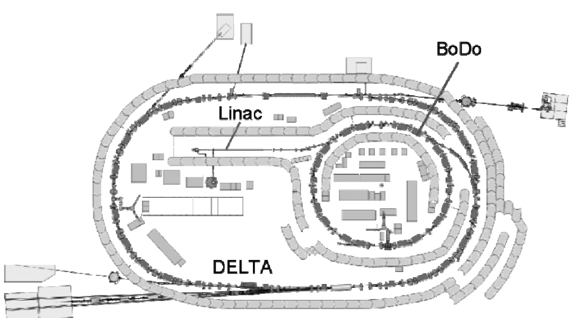

Figure 1: Overview over the DELTA accelerator complex

The transfer efficiency from BoDo to the DELTA storage ring was only in the order of 20 %. Together with a ramping time of BoDo in the range of 10 sec the injection times were up to one hour, which was not acceptable for a synchrotron radiation facility. The most promising way to shorten the injection times was to improve the injection efficiency. To understand the beam loss mechanism during injection a commercial system was searched, allowing to detect and localise beam losses around the complete accelerator system. Interesting questions were especially if the beam loss occurs in the transfer channel between BoDo and Delta and moreover if the beam loss occurs at the expected locations around Delta where the acceptance is at its minimum. The acceptance is given by

$$A = \frac{b}{\sqrt{\varepsilon \cdot \beta + (D \cdot \frac{\Delta p}{p})^2}},$$

b=mechanical or dynamical aperture whichever is smaller, ε=emittance, β=beta-function, D=dispersion, Δp/p=relative momentum spread.

Figure 2 shows the calculated inverse acceptance of Delta. The inverse acceptance allows a direct comparison between aperture limitations and dose deposition in the optical fibre. The main beam losses should be localised at the maxima of the curves in figure 2.

The calculation is based on an optic model of the storage ring fitted to measurement of beta-functions in standard user operation mode. The mechanical aperture was taken at all places. Calculations have shown that the dynamical aperture is larger. Closed orbit offsets reduce the aperture because the orbit deviation reduces the space available for the beam. The closed orbit deviation is only known at the beam position monitors and can be large elsewhere so that this effect has not been taken into account in the calculations.

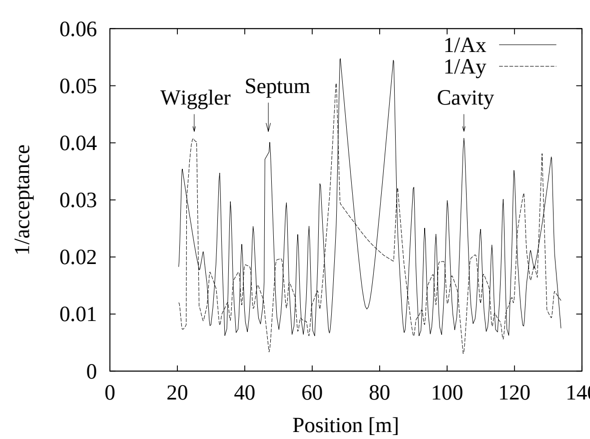

Figure2: Inverse of DELTA acceptance starting from the wiggler (20 m) counter clockwise around DELTA. The maxima of the horizontal and vertical curves show the minimum acceptances at DELTA.

2 OTDR MEASUREMENT

At DELTA a commercial Optical Time Domain Reflectometer OTDR [1] has been applied to identify beam losses caused by aperture limitations along the storage ring and to detect losses during injection.
The system is based on the radiation-induced increase of attenuation of optical fibres. Commercially available fibres of increased radiation sensitivity have been installed along the outer side of the DELTA vacuum chamber of the storage ring, booster synchrotron and transfer channels. The ionising radiation penetrates the fibre and creates additional colour centres inside the fibre material. Light passing through the fibre suffers attenuation. A light pulse coming from a laser will be Rayleigh backscattered at each position along the fibre. Knowing the speed of light inside the fibre, the dose depending on fibre length will be monitored. The height of the induced attenuation step is proportional to the dose. A suitable radiation sensitive core fibre material of Ge-doped Multi-Mode-Gradient-Index (MM-GI) fibres is co-doped with Phosphorus (P). The signal of the weak backscattered Rayleigh light is about –20 dB below the input laser intensity. The OTDR unit repeated automatically several time to monitor the dose distribution. The position resolution of the measurement depends on the wave length of the probe laser (850 nm) and is less than 1 m.

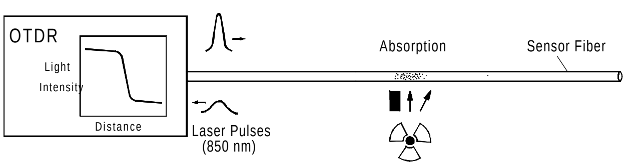

Figure 3: Basic principle of the OTDR measurement [1].

The following aspects concerning beam losses are in the focus point

- Beam losses in the transfer channel.
- Verify the DELTA aperture limits.

The sensitivity of the OTDR measurement system allowed to detect losses after one or two days of beam operation. Due to the bad injection efficiency most of the beam loss is produced during injection. At each new injection the machine and transfer channel was slightly optimised. The OTDR measurement averages over all this different machine tunings. Nevertheless the OTDR measurement detects that the beam gets lost in only a few localised places. Figure 4 shows the dose distribution around Delta. The obtained locations of the maximum beam losses are the expected smallest acceptances.
Not all acceptance limits obtained from the calculation (see figure 2) can be found on the fibre (figure 4). This is due to the fact that the closed orbit in Delta is not known at all positions. At some locations where no beam position monitors are available the closed orbit can have several millimetres offset and therefore influences the acceptance calculation.

Nevertheless, the small horizontal and vertical aperture between 60 m and 90 m limits the flexibility of beam position in the transverse space. A new beam optics for this area is already calculated and will be applied soon to overcome the limitation.
A second measurement with a fibre along the transfer channel between pre-accelerator (BoDo) and Delta has demonstrated that inside the transfer channel no significant beam loss occurs. Only at the end of the transferline, the loss on the septum was measured as seen in figure 4.

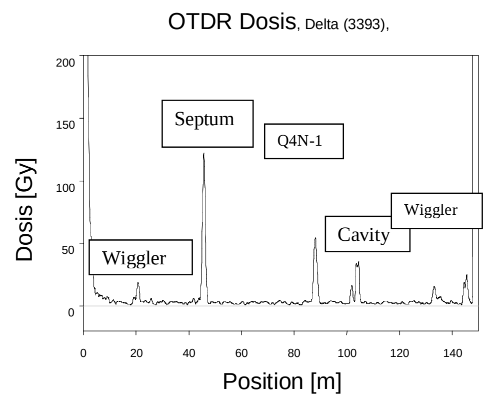

Figure 4: Dose deposited along the optical fibre placed at the outer side of the DELTA storage ring vacuum chamber. The fibre starts and ends at the wiggler. 20 m fibre length are neede to get the fibre out of the shielding wall.

3 CERENKOV LIGHT DETECTOR

A second method adapted for DELTA is based on the Cerenkov light that is produced when energetic charged particles penetrate the fibre. These particles produce cerenkov light inside an optical fibre which is detected with a photo-multiplier at one or both ends of the fibre [3]. The intensity (height) of the pulses is proportional to the dose rate. The time difference of the cerenkov signal and the trigger signal synchronous to the bucket number inside the accelerator can be used to localise the origin of the beam loss. This method allows a real-time measurements with single bunch resolution of 2 ns.

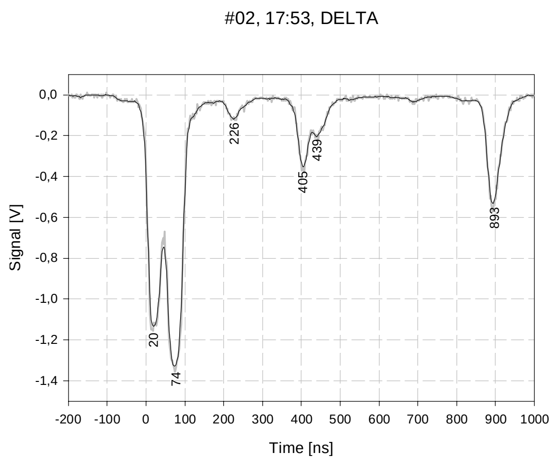

Figure 5: Cerenkov light signal from the photomultiplier. Three turns in DELTA (one turn = 380 ns). Several peaks per turn result from different centres of beam loss.

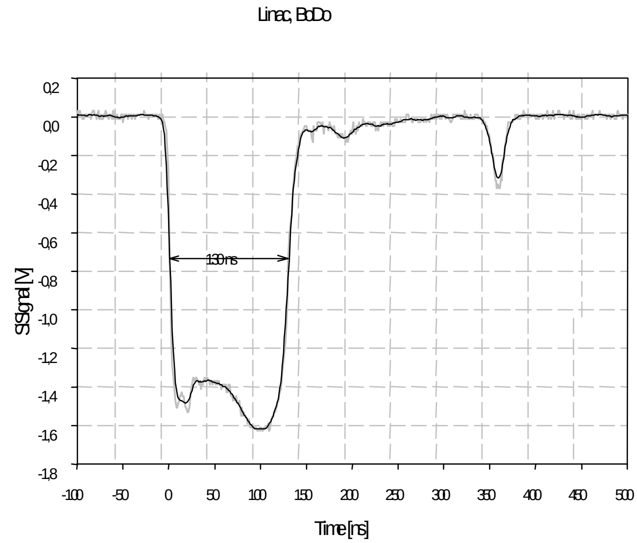

Figure 6: Beam loss in BoDo after injection of a 130 ns long linac pulse. Revolution time of BoDo is 168 ns.

At DELTA a cerenkov light monitor has been used to detect beam losses around the accelerator immediately after injection.

Figure 5 shows a beam loss on the Septum. The main peak every 384 ns corresponds to the loss on the septum. 384 ns is the revolution time of Delta. The other peak can be correlated to acceptance at the wiggler.

One can see that the electrons get lost during several turns after injection. An online optimisation of the injection chain was possible by minimising the loss on the septum.

The width of the loss peak corresponds to the number of buckets filled with electrons. This allows to measure the number of electron bunches and to adjust the DELTA timing system.

Measurements have shown that with stored beam and a beam lifetime of several hours in Delta, the loss rate is to small to be detected with the assembly. This was expected from calculations.

Studies on the ramped storage ring BoDo show that from a 130 ns long linac pulse only ~10 ns are accepted by BoDo. Figure 6 shows the complete loss of the 130 ns linac pulse. The behaviour was well known before and is explained by beam loading from the linac and the small energy acceptance of BoDo.

CONCLUSIONS

The fibre optical radiation sensing systems were successfully installed at the DELTA storage ring. It was possible to understand and to exclude different beam loss mechanisms in the injection chain.

It has demonstrated its ability to localise the areas of beam losses during the injection phase into the storage ring. The main advantage are the acceptable costs for a system which covers the complete length of the accelerator system and the flexibility to measure in nearly inaccessible slits because of the small size of the fibre. The Beam loss measurement based on cerenkov-light allows in addition a real time optimisation of the machine during injection.

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