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OPTICAL FIBER BASED BEAM LOSS MONITOR FOR SPS MACHINE

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Abstract

At the Siam Photon Source (SPS) beam loss monitors based on PIN diode have been used. The existing system allows beam loss detection very locally at the monitor position close to the vacuum chamber. For optical fiber, Cherenkov radiation can be detected when a lost particle travels in the fiber. Thus optical fiber based loss monitor with sufficient length can cover parts of the machine conveniently. Fast beam loss event can be detected with more accurate position. In this paper, the design and result of the optical fiber based beam loss monitor system at SPS machine are discussed. The system will be a prototype for the new 3 GeV machine SPS-II.

INTRODUCTION

Siam Photon Source (SPS) has been operating to provide photon beam for users. Beam loss is one of the undesirable events for accelerator operation. It can be irregular major losses or normal losses due to the beam lifetime. The ability to measure beam losses can provide valuable understanding of the machine condition when some components are broken, vacuum has some problems or some obstacle exists in the beam path, for example.

Previously Beam Loss Monitor (BLM) system at SPS is based on Bergoz Instrumentation PIN diodes [1]. However, it is almost impossible to cover all parts of the machine. In addition, in a tight space, the BLM cannot be fitted into the spot. To overcome these limitations, optical fiber beam loss monitor has been investigated. Optical fiber based beam loss monitor uses the generated Cherenkov radiation from a charged particle traveling in a medium with a refractive index (n) with the speed (v_p) greater than the phase velocity of light ($c_o/n < v_p < c_0$).

Optical fiber based beam loss monitor is gaining more popularity due to its flexibility and continuity for losses detection. The system allows good details of the losses event spots and it has been applied in many facilities [2] [3].

SYSTEM DESIGN

There are three main components in the system. Optical fiber plays a role of sensor. Photo Multiplier Tube (PMT) is a data collector. Finally, the collected data can be sent to an oscilloscope for processing.

Optical Fibers

Optical fiber is the main sensor in the beam loss system. To allow sufficient probability to detect beam losses event, the fiber properties has to be taken into account. Core diameter of the fiber is basically the sensor size which cover the path of the secondary particles. Thus larger core is more preferable. Numerical Aperture (NA) is the measure of the angle that light can be accepted and it depends on the refractive index of the fiber. For beam loss application large NA is better. Multimode step-index fibers providing larger NA were used. Transmission of the specific wavelength of light can be affected by water content or Hydroxyl group (OH) in the fiber. Pure Silica providing low OH is suitable for visible light produced by Cherenkov radiation. FC connector was used at both ends in order to conveniently connect the fiber to PMT via FC adapter. Thorslabs's pure silica fibers giving appropriate properties and large NA were selected. The specification for the fibers are described in Table 1. For installation, bend radius has to be carefully taken into account. For larger core diameter, the bend radius is larger at about 80 mm for FP1000ERT (48 mm for FP600ERT).

Table 1: Optical Fiber Specifications [4, 5]

Type	Core Diameter	Core / Cladding Material
FP600ERT	600 μm	Pure Silica / Hard Polymer
FP1000ERT	1000 μm	Pure Silica / Hard Polymer

PMT and Processing

To capture the light from Cherenkov radiation, the cathode spectral response for the PMT H10720-110 ranges from 230 to 700 nm as shown in Fig. 1.

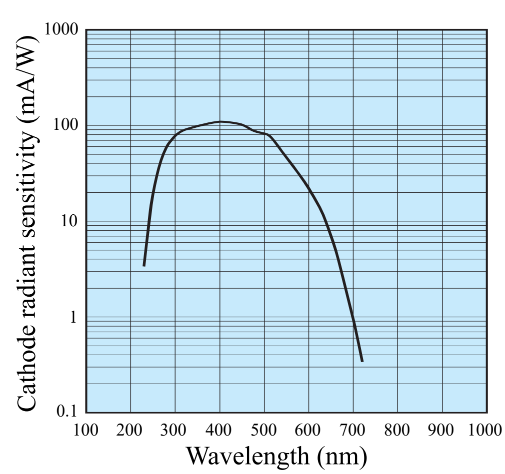

Figure 1: Cathode sensitivity for PMT [6].

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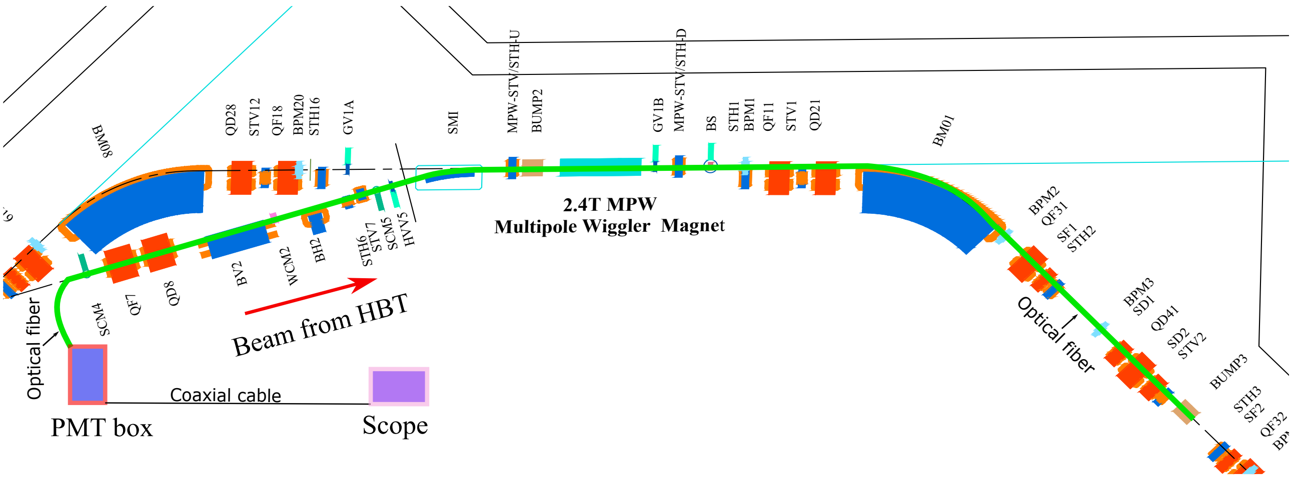

Figure 2: Schematic view of the optical fiber (green line) installation section.

R&S RTO2024 oscilloscope was used to visualize and process the signal from the PMT. A mask can be prepared to capture loss event when it is triggered by the signal from the PMT. During normal operation the beam losses is dominated by the beam injection process. To capture the injected beam losses, an injection trigger signal was connected to the scope.

SYSTEM INSTALLATION

At SPS, the accelerator complex is composed of two main parts: injector and storage ring. The injection begins at the underground injector from an electron gun and linacs to a booster which provide 1.0-1.2 GeV electron beam. The injected beam will be transfer from underground level to the storage ring on the ground floor via High energy Beam Transport line (HBT). This required two vertical bending magnets BV1 and BV2.

Figure 2 shows the schematic view of the optical fiber installation and PMT. Two type of fibers (FP600ERT and FP1000ERT) were installed in parallel as close to each other as possible for comparison as shown in Fig. 3. The optical fibers were attached to the side of the chamber expecting the losses to occur. The starting point is at the end of HBT transferring the beam vertically from underground thus the fibers were attached to the top part of the chamber. Then from Septum Magnet for Injection (SMI) through the total length of the fiber ended at BUMP3, they were attached on the outer side of the chamber.

The PMT was connected to the fiber at the upstream end. This allows the Cherenkov light to travel in the opposite direction to the beam. Then the position of the beam losses can be interpreted more clearly in the time order. As radiation occurs in the storage ring, the PMT was installed together with the power supply in a radiation shielding box. Finally, a coaxial cable will bring the collected signal from PMT to the scope outside of the shielding wall in order to protect the scope from radiation and ease the operation.

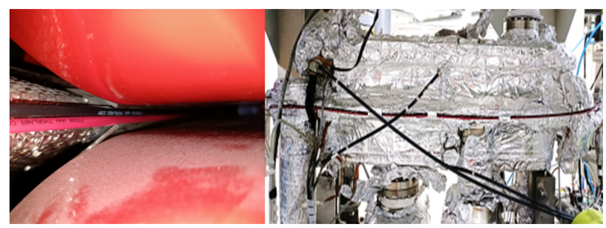

Figure 3: Optical fiber attached on the side of chamber through a quadrupole (left) and on a septum (right). Black and red cables are FP1000ERT and FP600ERT fiber respectively.

MEASUREMENT RESULTS

Fiber Comparison

Ten samples of the beam losses during the beam injection with the same condition were measured for each fiber. In Fig. 4, each measurement was plotted in the light shadow and the average was plotted in red and blue for FP1000ERT and FP600ERT respectively. It is obvious that FP1000ERT can provide better sensitivity which was expected due to its larger core.

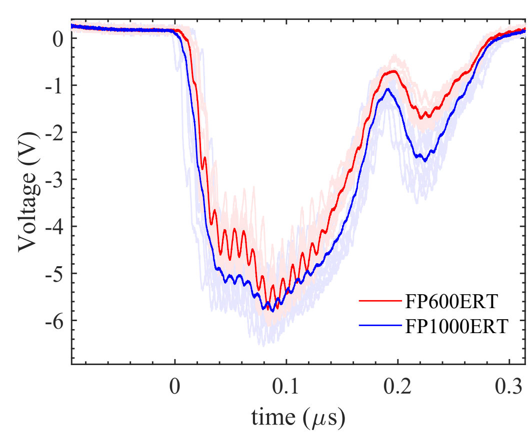

Figure 4: Signal comparison between different fiber types.

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The choice of the fibers has to also consider the cost of the whole system. Larger core fiber giving better sensitivity is unavoidably more expensive. For a larger machine like SPS-II, longer optical fiber will be used and the total cost will be much higher.

Losses Scenarios

To simulate injected beam losses scenarios for detection by the BLM, the injected beam was intentionally forced to be lost in three different places. From Fig. 2, the first case is at the screen monitor SCM4 which is the closest to the PMT. The screen was closed to cut the beam path and caused injected beam losses. The second case is at the vertical bending magnet BV2 which is used to kick the beam to be on the storage ring plane at the end of the HBT. By turning the BV2 off, the beam will directly hit the chamber at the BV2. And at SMI, similar to BV2 case, the SMI power was turned off then the injected be will hit the components and chamber in the SMI.

The time structure of the measured signal from PMT shows clearly the sequence of element from SCM4, BV2 and septum as depicted in Fig. 5. The signals also demonstrate the characteristic of the losses events. The BV2 case reflects clearly the structure of the injected beam bunch train as shown in Fig. 6 which was measured by wall current monitors. For SCM4, the loss occurred when the beam hit directly at the screen then one large chunk of signal was observed rather than the bunch train structure. At the SMI septum, the peaks seem to have two regions which can be explained clearly from the structure inside the septum which has two copper frames at the beginning and the end. The losses signals originated from the injected beam hitting the first frame partially.

For normal beam injection, the signal pattern as shown in Fig. 4 was observed. This indeed indicates the dominant losses spot at the SMI. The fixed copper frames were used for commissioning and will be changed to YAG screen with pneumatic driver in the coming year.

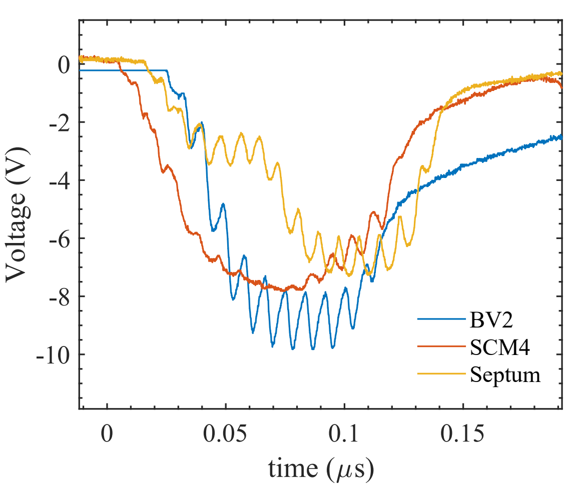

Figure 5: Beam loss measured at different places.

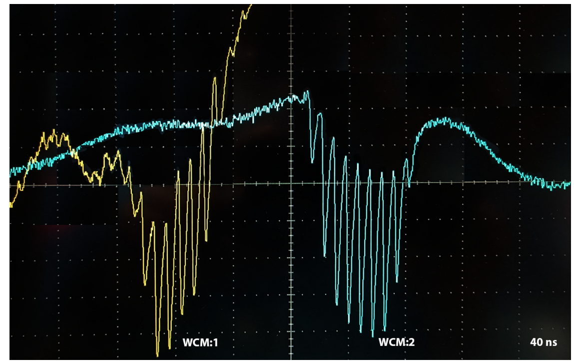

Figure 6: Wall current monitor signal at the HBT upstream (yellow) and downstream (green).

CONCLUSION

The optical fiber based beam loss monitor has been proved to be very useful and informative. Larger fiber core is more sensitive than smaller core. However, sensitivity and total cost have to be compromised. At SPS, beam loss scenarios during injection were characterized. This leads to better understanding of the machine operation and a guideline for machine improvement.

Optical fiber based BLM is a cost effective method for BLM system because it can cover a large area with a few PMTs. Details of both position and quantity of the losses can be interpreted. However, it is known that optical fiber exposed to radiation can be deteriorated over time. Anyway it is still radiation harder than scintillating fiber. For SPS-II, the low emittance machine, optical fiber based beam loss monitor will be an important asset for machine commissioning and operation.

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