HIGH SPEED BEAM LOSS MONITOR AND ITS DETERIORATION BY RADIATION

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Abstract

High speed beam loss monitor is very useful for tuning and operating the beam in an accelerator, especially in the injection and extraction period. We made a new type beam loss monitor by connecting a fiber to a photo-multiplier (PMT). In the case that the fiber is made of scintillation fiber, the signal comes from the scintillation effect. And in the case of quartz, the source of the signal is Cherenkov effect. The quartz is much stronger than the scintillator to the radiation, but generates light much weaker than that by scintillator, especially in low energy beam. It is very easy to make this monitor and the fabrication cost is cheap. The monitor can observe the bunched beam loss with an order of 10 ns. After long time use under high irradiation, the signal of the monitor using scintillation fiber will decrease. Therefore, we also report the dependence of the signal strength on accumulated radiation.

STRUCTURE OF MONITOR

The schematic cross section of the monitor is shown in Fig. 1. The Photo-Multiplier* (PMT) is covered by an iron case and connected to the end of the photo-fiber. The schematic drawing and the picture of the monitor are shown in Fig. 2 and 3, respectively.

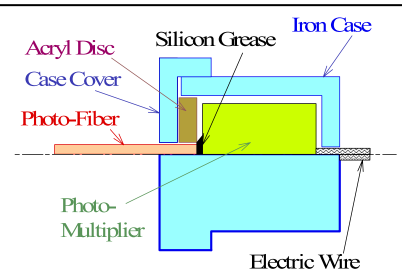

Figure 1: Schematic cross section of the monitor

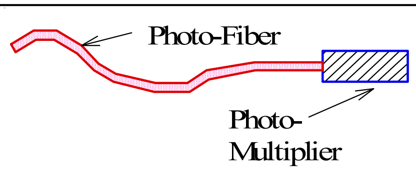

Figure 2: Rough sketch of monitor using a photo-fiber

The materials of photo-fiber (3m length) are scintillation † fiber or quartz ‡ fiber covered by black plastic pipe for shielding light. The signal of the monitor using the former fiber is generated by scintillation effect and the latter by Cherenkov effect caused by penetration of charged particles. These monitors (Type A) have a merit that we can observe the beam loss with the long range area, because the photo-fiber works not only as the material transferring light but also as the material generating light by the beam loss.

The construction connecting a scintillation block to the top of the quartz fiber is also used as a loss monitor (Type B). The merit of this type is to detect the loss point with narrow area, because the scintillation block is small but generates much stronger light than that by quartz fiber. We use a plastic scintillator § or liquid scintillator ** contained in a metal pipe for the scintillator block.

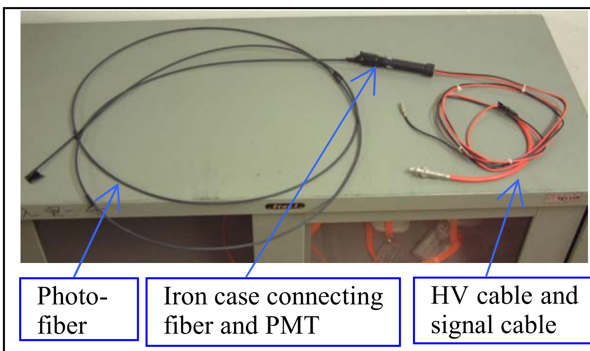

Figure 3: Picture of monitor using photo-fiber

MONITOR SIGNAL

Typical Signal in KEK-PS Booster

- Adjust bump field

In the KEK-PS booster, beam is extracted by using the combination system of bump, kicker and septum magnet (see Fig. 4). At the extraction stage, bump magnets are excited first, and the beam is brought near the septum coil. Then, it is kicked into the gap of a septum magnet by firing a kicker magnet. When the bump field is strong, the

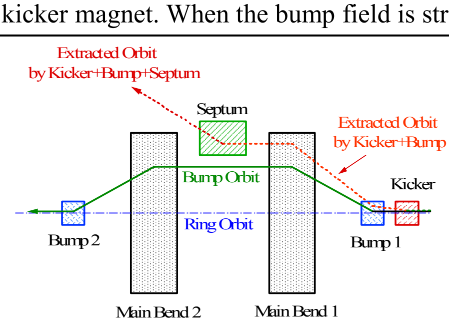

Figure 4: Extraction system using combination of bump, kicker and septum field

* Hamamatsu-Photo, R2496 (10.5mm$^{\phi}$ * 45mm^{L}): light wavelength=160-650nm, Gain=1.1*10^{6}

† KURARE "SCSF-81M", core diameter=2mm, emission colour=blue

‡ FUJIKURA "600/750", core diameter=0.6mm, clad diameter=0.75mm

§ ELJEN Technology "EJ-200"

** ELJEN Technology "EJ-399-04"

halo of the beam circulating along the bump orbit is scraped by the septum coil. This is shown in Fig. 5 as chain of bunched beam loss with the envelope of betatron oscillation. On the contrary, Fig. 6 shows the case of the weak bump field. In this case, the beam loss due to the bump field does not occur, however, the loss due to the kicker field is large, because the total orbit shift by the bump and kicker field is not enough.

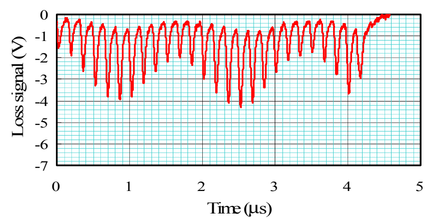

Figure 5: Bunched beam loss due to bump field

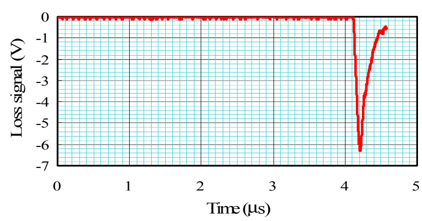

Figure 6: Bunched beam loss due to kicker field

- Adjust trigger timing of the kicker magnet

Fig. 7 shows the faint beam loss in the case that the trigger timing of the kicker magnet is best, however, Fig. 8 shows the large beam loss due to the bad trigger timing of 30ns earlier than the best.

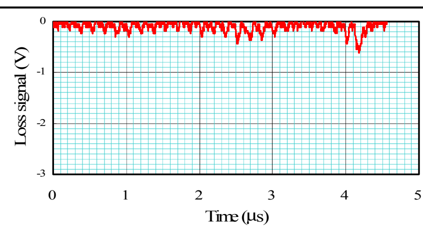

Figure 7: Best trigger timing of kicker magnet

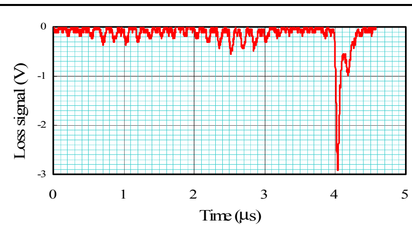

Figure 8: Beam loss due to bad trigger timing of kicker magnet 30ns earlier than the best

Luminescence Generated by Radiation

By setting scintillation fiber (core diameter is 2mm) at KEK-PS 500MeV-BT line, the luminescence generated by the beam going through the beam transport line was observed as Fig. 9. The successive small signal before the big pulse comes from the beam loss at the septum coil placed 6m away from this monitor. The peak signal (1.3V) is generated by the radiation field of 0.12[kGy/s], which was observed by PMT (V_{bias}=350V). On the other hand, the bias voltage of PMT for quartz fiber (core diameter is 0.6mm) is 1000V, which produce the peak signal of 2.5V. Comparing signal strength generated in the both fibers, the luminescence in the scintillation fiber is about $1*10^3$ times larger than that in the quartz fiber.

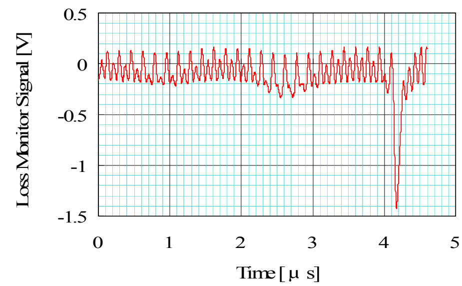

Figure 9: Pulse signal generated in the scintillation fiber caused by the beam going through 500MeV-BT

Characteristics of Scintillation and Quartz Fiber

As explained in the former section, the scintillation fiber can generate much larger luminescence than the quartz fiber at the extraction of booster (500MeV). It can also generate a clear signal by H^- beam loss at the booster injection (40MeV), which cannot be observed by the quartz fiber because the energy is too small for the Cherenkov effect. On the contrary, the scintillation fiber is weak for radiation, but quartz fiber is very strong as shown in the following section.

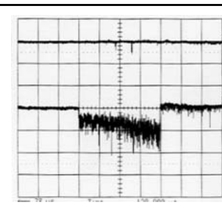

Figure 10: Signal due to H^- beam loss at booster injection (40MeV)

Upper figure: by quartz fiber

Lower figure: by scintillation fiber

DETERIORATON BY RADIATION

Deterioration of Monitor Signal

At the extraction point of KEK-PS booster ring, we set "Type A" monitors using a scintillation fiber and a quartz fiber and "Type B" using the sensor of a scintillation block, liquid scintillation with bubbling and the same material without bubbling. The peaks of loss signal generated by firing bump magnet and kicker magnet (see Fig. 5 & 6) have measured, respectively. Since the beam loss at the booster extraction changes day by day, we adopt the rate of every loss signal divided by the signal by the quartz monitor, because quartz is very hard to radiation as shown in the table of Fig. 12. The clear deterioration of the signal of scintillation fiber by radiation was observed as shown in Fig. 11, but there is no clear deterioration in other monitors. The plot of "by α-source" will be explained in the following term.

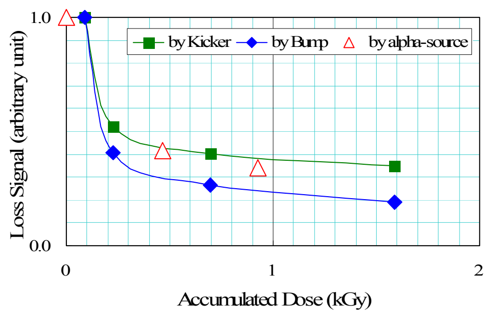

Figure 11: Decrease of signal in scintillation fiber by accumulated Dose (Beam loss is generated by firing kicker and bump magnet, respectively.)

Deterioration of Material

(1) Transparency of block sample [1]

The test samples of 10mm square block were made of plastic scintillator, pylex glass and Quartz. The plastic scintillator was irradiated by γ-ray from ^{60}Co and 500MeV proton beam loss of KEK-PS-booster synchrotron. Pylex glass and quartz were only irradiated by the beam loss. The radiation was measured by Alanin Dose meter. The transparency of the block was measured by the combination system of light source and spectrophotometer (200nm-600nm). The dependence of the transparency of light at 450nm on the accumulated Dose was measured by repeating above procedure. The Dose which makes e^{-1} reduction of the original transparency was shown in Fig.12. Comparing Fig. 11 and 12, the blocks are stronger to the radiation than the scintillation fiber, but, pylex glass is very weak comparing to other blocks.

Sample name	By γ-ray [kGy]	By proton beam loss [kGy]
Plastic Scintillator	1100	230
Pylex glass	-	6
Quartz	-	No deterioration

Figure 12: The radiation Dose which makes e^{-1} reduction of the original transparency

(2) Scintillation fiber

In order to measure the deterioration including the luminescence and the transparency of the scintillation fiber in detail, the test fiber holder was made (see Fig. 13). A scintillation fiber irradiated by some quantity of radiation is set in the center hole of the square rod, and connected to the surface of the PMT as the same technique shown in Fig. 1. Setting an α-source onto a hole of the rod, the spectrum of PMT signal was observed. By integrating the spectrum over the wavelength at every α-source position, the signal dependence on the α-source position is obtained. Fig. 14 shows the normalized case that the signal at (x=1) equals 1 in three case of Dose.

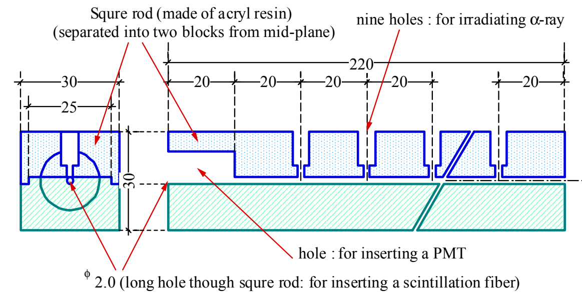

Figure 13: Sample holder to measure the dependence of the signal on the position of α-source

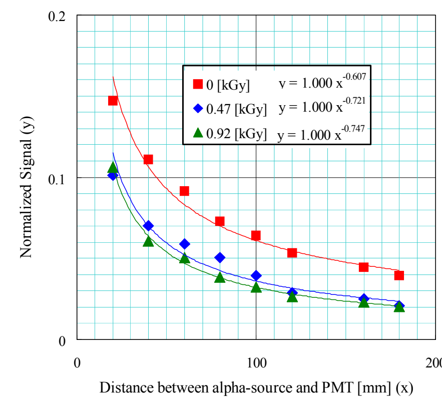

Figure 14: Normalized signal dependence in the scintillation fiber on the position of α-source

By integrating above approximated equations along x from 1500 to 3000 [mm], where the scintillation fiber generates luminescence by the beam loss, the calculated results at three accumulated Dose are plotted in Fig. 11. These values are in good agreement with the deterioration of loss monitor signal using scintillation fiber.

SUMMARY

Scintillation fiber, quartz fiber and scintillation block are good material for the fast beam loss monitor. It is most important to use quartz for the surface of PMT instead of Pylex glass because of the radiation hardness.

Material should be selected according to the place where the monitor is used. In the place of small radiation field, scintillation fiber is very useful. In the strong radiation field which is generated by low energy beam, the scintillation block connecting to a quartz fiber should be used. And for measuring strong beam loss with the wide range caused by high energy beam, quartz fiber is useful.

REFERENCES

[1] T. Kawakubo, T. Sanami and T. Ishida, Proceeding of KEK-RCNP International Mini-Workshop for Scintillating Crystals (Nov.18, 2003) (to be published)