HIGH COST-PERFORMANCE FAST-RESPONSE BEAM-LOSS MONITOR USING A PHOTO-MULTIPLIER

Tadamichi KAWAKUBO, Tadaharu ISHIDA and Hiroshi YAMAGUCHI (KEK)

Abstract

There are three types of fast-response beam-loss monitors by using a photo-multiplier. The first type (M1) is one using only a photo-multiplier. The second one (M2) is a combination of a photo-multiplier and a quartz photo-fiber. And the last one (M3) uses a plastic fiber doped by scintillation as the photo-fiber. Although the mechanisms for generating an electro signal due to beam loss are different among these three monitors, their response times are very short (order of 10ns) and the fabrication cost is not expensive. In this paper, the characteristics of these monitors are introduced in detail.

1 FABRICATION

These monitors are very easy to fabricate. The photo-multiplier (HAMAMATSU-R1635) for the three type monitors is surrounded by a black-painted iron case, as shown in Fig.1. The first type of monitor (M1) is only a photo-multiplier, and the second (M2) and third ones (M3) are fabricated in the following ways (see Fig.2):

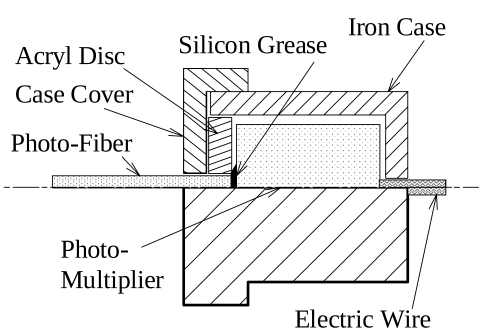

Figure 1: Cross section of a loss monitor composed of a photo-fiber, a photo-multiplier and an iron case

(Step 1) A photo-fiber, which is a quartz-fiber (FUJIKURA SC 600/750) for M2 and a plastic fiber doped by scintillation (KURALAY SCINTILLATING FIBER: SCSF-81M) for M3, is inserted into the hole of an acryl disc, and connected by acryl bonding.

(Step 2) The photo-fiber and the acryl disc are fixed together as a set on the surface of a photo-multiplier by silicon grease, and covered by a black-painted iron case, as shown in Fig. 1. Thus, the whole appearance of our loss monitor is shown as Fig.3.

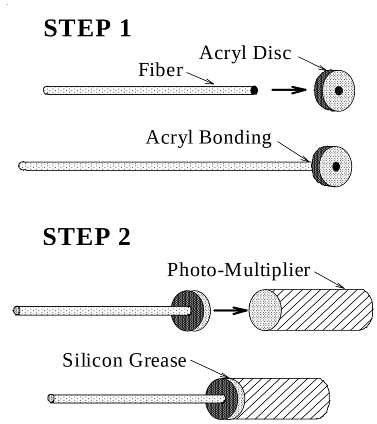

Figure 2: Method used to connect a photo-fiber to a photo-multiplier

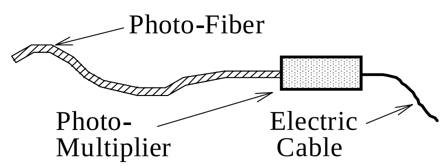

Figure 3: Whole appearance of the loss monitor

2 MECHANISMS FOR GENERATING A BEAM-LOSS SIGNAL

When a charged particle generated by beam loss penetrates the quartz window of the photo-multiplier, Cherenkov light is generated and an electron signal is obtained by M1. In the case of M2 and M3, charged-particle penetration through the photo-fiber generates Cherenkov light or scintillation light, respectively. The light is transmitted through the photo-fiber and reaches the photo-multiplier. Then, an electric analogue signal according to the photo-signal is amplified by a pre-amplifier, transported to a control room and observed by an oscilloscope. The typical signals observed by these loss monitors at extraction from KEK-PS-Booster ring are shown in Fig.4. In order to extract the beam from the Booster ring, a bump orbit is generated just before firing kicker magnets. Therefore, the beam halo is hit by a septum coil and beam loss is generated before the loss due to firing of the kicker magnet. We explain in paragraph 3.2 why the bump loss cannot be observed by M1 and M2 (upper figure), although a clear loss is observed by M3 (lower figure).

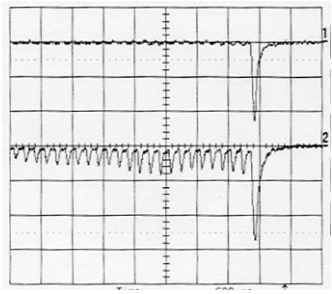

Figure 4: Beam loss at extraction (500MeV)

* Upper figure: by M2 using a quartz-fiber (V_{PM}=800V) (500ns/d, 2V/d)

* Lower figure: by M3 using a scintillation-fiber (V_{PM}=600V) (500ns/d, 2V/d)

3 CHARACTERISTICS OF THESE MONITORS

3.1 Signal Dependence on the Bias Voltage

Fig.5 shows the dependence of the kicker loss signal on the photo-multiplier bias voltage.

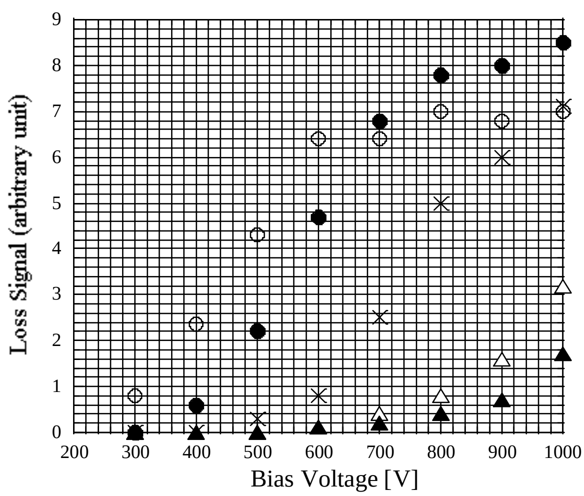

Figure 5: Dependence of the kicker loss signal on the bias voltage of the photo-multiplier

*White circle: by M3 (using a new scintillation-fiber)

*Black circle: by M3 (using a five months used scintillation-fiber)

*Cross: by M1 (using a five months used photo-multiplier)

*White triangle: by M2 (using a new quartz-fiber)

*Black triangle: by M2 (using a five months used quartz-fiber)

The signal by M3 (using a new scintillation-fiber) can observe the loss signal from a bias voltage of 300V, and begins saturation from 600V. There is some deterioration in another M3 (using a five months used scintillation-fiber). Other monitors (M1 and M2) need higher bias voltages to measure the beam loss.

3.2 Signal Dependence on the Beam Loss

Fig.6 shows the dependence of the kicker loss signal on the quantity of proton beam loss.

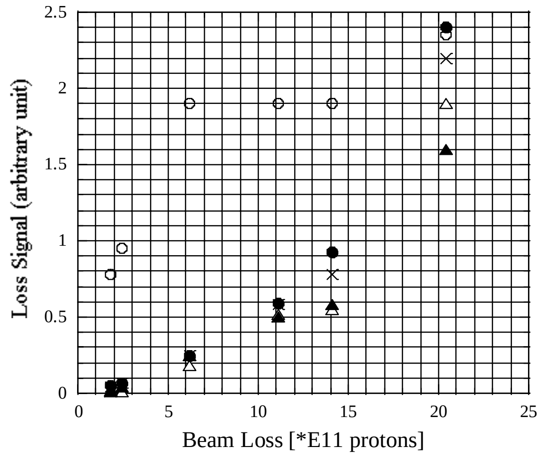

Figure 6: Dependence of the kicker loss signal on the beam loss

*White circle: by M3 (using a new scintillation-fiber)

*Black circle: by M3 (using a five months used scintillation-fiber)

*Cross: by M1 (using a five months used photo-multiplier)

*White triangle: by M2 (using a new quartz-fiber)

*Black triangle: by M2 (using a five months used quartz-fiber)

The signal by M3 (using a new scintillation-fiber) can observe the loss signal from the small beam loss (less than 2E11 [protons]) and reaches a plateau signal height from the beam loss of 6E11 [protons], which is not due to the saturation of a photo-multiplier. On the other hand, the signals of the other monitors are very small at low beam loss, and increase lineally. Therefore, this is the explanation for Fig.4, that the beam halo can be observed by M3 using a new scintillation-fiber, although other monitors cannot.

3.3 Signal Dependence on the Beam Energy

Fig.7 shows the dependence of the kicker loss signal on the circulating beam energy. The loss monitors were set just at a lower stream of the septum magnet, and all of the circulating beam in the PS-booster ring was collided with the septum magnet by exciting the kicker and bump magnets at any accelerating timing. Therefore, we can measure the signal dependence of these loss monitors based on the beam energy from booster injection (40MeV) to extraction (500MeV).

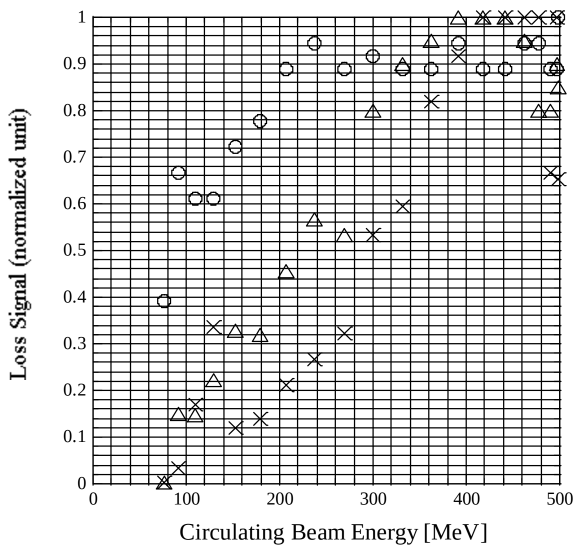

Figure7: Dependence of the loss signal on the circulating beam energy
*White circle: by M3 (using a new scintillation-fiber)
*White triangle: by M2 (using a new quartz-fiber)
*Cross: by M1
(using a five months used photo-multiplier)

A loss monitor M3 using a new scintillation-fiber can observe the loss signal at a circulating beam energy of 70MeV, where other monitors cannot observe. Its signal reaches a plateau at 200MeV, while other monitors at 400MeV. Therefore, although M3 can observe the injection beam loss at the Booster ring, other monitors cannot observe the beam loss, as shown in Fig.8.

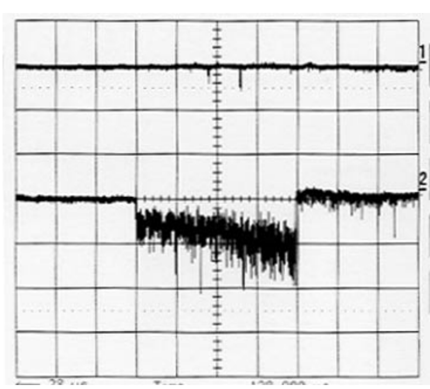

Figure 8: Beam loss during H^- injection (40MeV)
* Upper figure: by M2 using a new quartz-fiber (V_{PM}=1kV) (10µs/d, 50mV/d)
* Lower figure: by M3 using a new scintillation-fiber (V_{PM}=1kV) (10µs/d, 50mV/d)

3.4 Deterioration of a Photo-fiber

Monitors are deteriorated by radiation from the beam loss. It appears that although the deterioration of M1 (photo-multiplier only) and M2 (quartz-fiber) is small, that of M3 (scintillation-fiber) is large. Therefore, we measured the deterioration of M3 by setting it at two different places of the Booster ring (Injection point and upstream of Septum magnet). Upstream of the Septum magnet, we tried to make twice measurements. The results are shown in Fig.9.

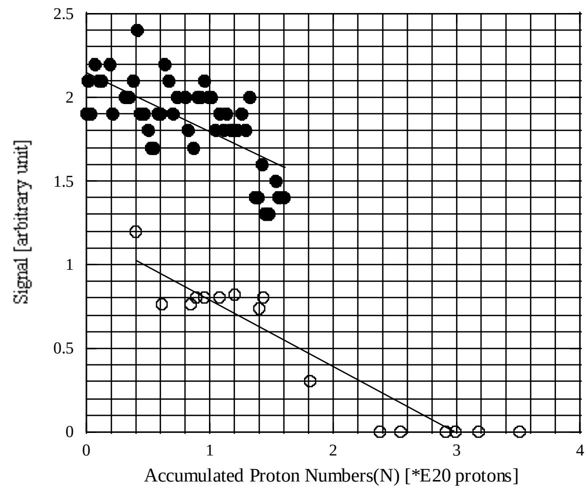

Figure 9: Deterioration of M3 using a scintillation-fiber (Dependence of loss signal due to Bump orbit on accumulated extracted proton numbers)
*White circle: first measurement
*Black circle: second measurement

We do not understand why there is a difference between the first and second measurements. The normalized and averaged deterioration rate is 0.25 [1/(1*E20protons)]. By taking account of the dose rate at this location, the deterioration rate is 6.9E-05 [1/(Gy)]. The rate measured at the injection point is 2.7E-04 [1/(Gy)], which disagrees with the above rate by a factor of 4. However, we can say that the deterioration rate is on the order of 1E-04 [1/(Gy)].

4 SUMMARIES

A photo-multiplier is very useful for measuring beam loss with a time range of order 10ns. If you wish to cover the beam loss with a length of some meters, the combination of a photo-fiber and a photo-multiplier is useful. By taking a quartz-fiber as the photo-fiber, one can use the monitor for a long time, but can use it only in the case that the beam loss is big and the circulating beam energy is larger than 200MeV. On the other hand, by using a scintillation-fiber, one can observe a very faint loss with small circulating beam energy. However, its deterioration rate is on the order of 1E-04 [1/(Gy)], which means that the output signal might be zero after exposure of 1E4 [Gy]. If one wishes to measure the spot beam loss, a photo-multiplier is useful, but its characteristic is the same as in the case of a quartz-fiber.