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Fast-response beam loss monitor

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Abstract

By connecting a polyethylene fiber to a photo-multiplier, a beam loss monitor with a fast response has been fabricated. The beam loss is measured by Cherenkov light generated by a charged particle penetrating a fiber. Although this monitor has the merits that the structure of the monitor is simple and cheap, it has the demerits that the signal has an energy dependence, and deterioration caused by radiation occurs. A plastic scintillating fiber and a quartz fiber have also been tested. The signal of the former fiber is strong and does not depend on the energy of the circulating beam. However, the deterioration is also very severe. On the contrary, the latter fiber has a long lifetime, though its signal is small. Some measurements are discussed here concerning various cases of extraction conditions.

1. Introduction

Five years ago, we intended to make a non-destructive beam-profile monitor in a synchrotron ring. The principal of this monitor is to observe the fluorescence generated by a circulating beam hitting residual gas in the ring. The limited input light by a slit transmits through a photo-fiber (polyethylene fiber) and reaches a photo-multiplier [1]. However, there is much noise due to the circulating beam loss, which produces charged particles that penetrate the photo-fiber, and thus generate Cherenkov light. Since the S/N ratio is very poor, we gave up to make a beam-profile monitor, but changed to make a fast-response beam loss monitor.

2. Structure of monitor

This monitor is very easy to fabricate. The fabrication method is shown in Fig.1.

(Step 1) A photo-fiber is inserted into the hole of an acryl disc, and connected by acryl bonding.

(Step 2) The photo-fiber and the acryl disc is 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. 2. The whole appearance of our loss monitor is shown as Fig.3. When a charged particle generated by beam loss penetrates the photo-fiber, it causes Cherenkov light or scintillation light, depending on the fiber characteristics (i.e., a photo-fiber or scintillating fiber). 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.

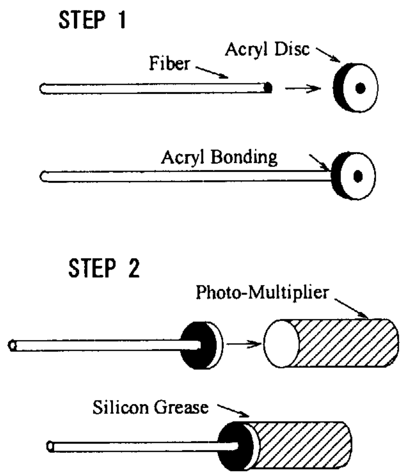


Fig.1 Method used to connect a photo-fiber to a photo-multiplier

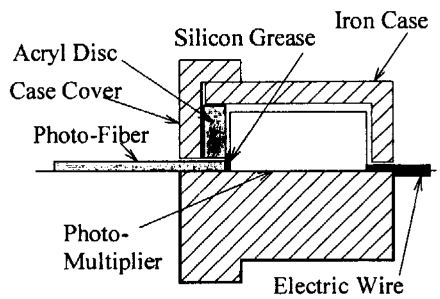


Fig.2 Cross section of the loss monitor composed of a photo-fiber, a photo-multiplier and an iron case

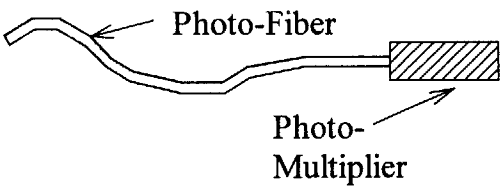


Fig.3 Whole appearance of the loss monitor

3. Setting

Fig.4 shows the plan of the KEK-PS-Booster ring. There are eight main magnets. Since the straight section 1 (between M8 and M1) is the injection area, the injection loss is high near to M1. Also, since the straight section 3 (between M2 and M3) is the extraction

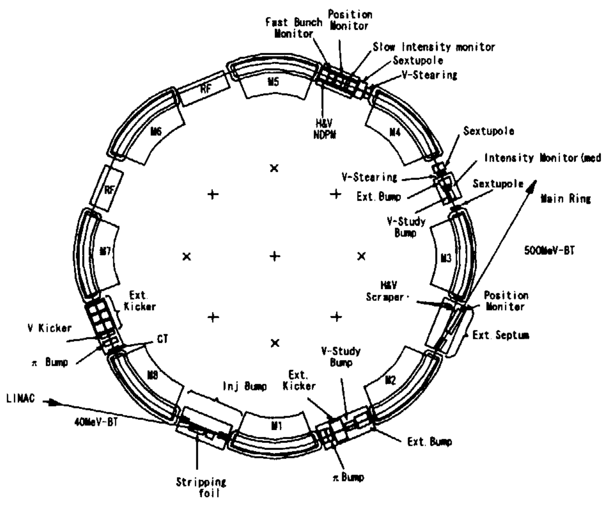


Fig.4 Plan of the KEK-PS-Booster ring

area, the extraction loss is high near to M2. Two loss monitors are set at every main magnet, as shown in Fig.5. Since the photo-fiber is too flexible to stand by itself, it is inserted into an aluminum thin pipe which is held at the same height of the circulating beam orbit, as shown in the Front view of Fig.5. The photo-fiber is led to the floor and connected to a photo-multiplier.

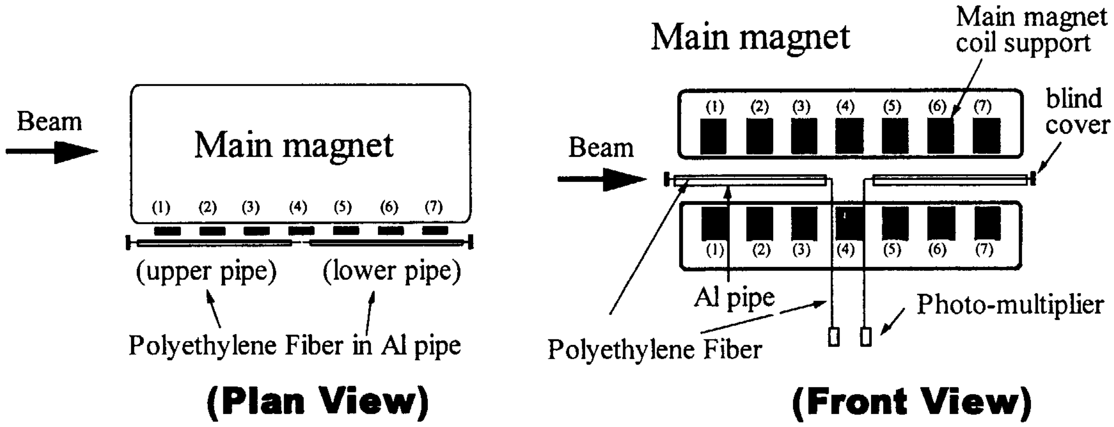


Fig.5 Setting of Al pipes in which polyethylene fiber are inserted

4. Preliminary measurement

1. Signal dependence on the photo-fiber

Before arranging the loss-monitor measuring system, two loss monitors are set as shown in Fig.6 to measure the effect of the photo-fiber. We used a polyethylene fiber composed of 48 fibers with each diameter of 0.265mm. At first, the top of the fibers of the upper loss monitor and lower one were placed at the positions of (7) and (1), respectively. The loss signals at this setting were observed. Those fibers were then gradually cut shorter, and the signals were observed at every position of the fiber top. Fig.7a shows the beam loss at extraction observed by the upper loss monitor, and Fig.7b by the lower loss monitor. In both cases, the bias voltages of the photo-multipliers are the same. We can clearly obtain two results from these pictures:

(1) The signal obtained by the upper loss monitor is much smaller than that by the lower loss monitor. This is the reason that the direction of the Cherenkov light generated by the beam loss is in the same direction as the circulating beam, thus, the photo-multiplier set at the

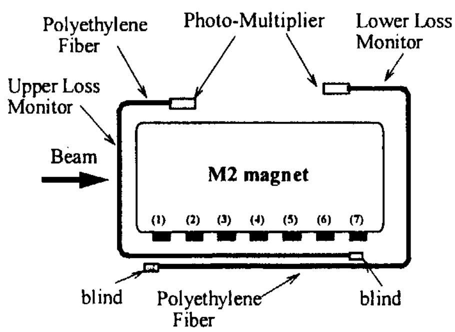
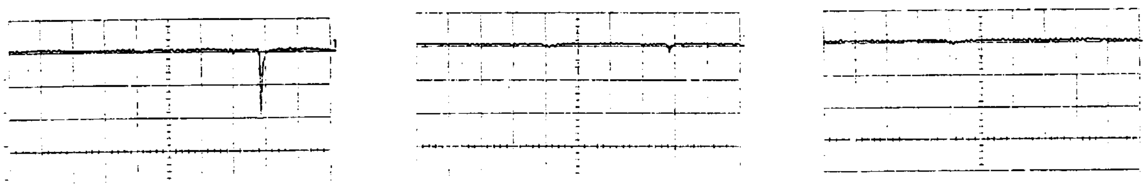


Fig.6 Arrangement of two polyethylene fibers to measure the position effect of the fiber top

lower stream can receive light directly, although one set at the upper stream receives only reflected light (see [note]).

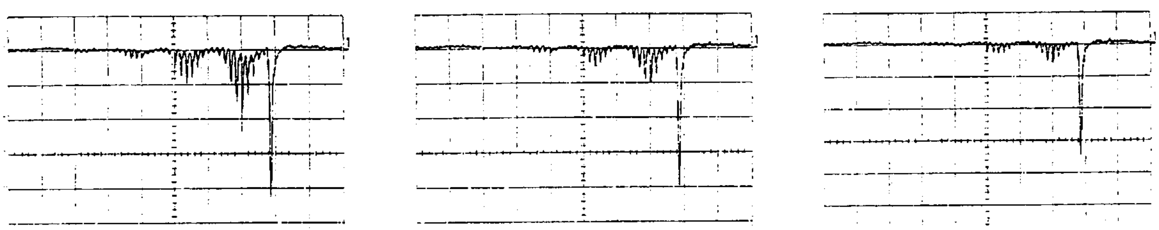
(2) The beam-loss signal by the upper loss monitor cannot be observed from where the top of the fiber is set at position (5), and the loss signal by the lower loss monitor, from position (7). This means that the beam loss arises near to position (6).

[Note] In order to remove the signal dependence on the position of the photo-multiplier, the fiber is folded double, as shown in Fig.8. Supposing that a beam comes from left to right, the Cherenkov light reaches the photo-multiplier directly, as shown by the full line arrow. On the contrary, in the case of a beam coming from right to left, the Cherenkov light transmits through the fiber from right to left first, but makes a U-turn along the fiber, and at last reaches the photo-multiplier directly.

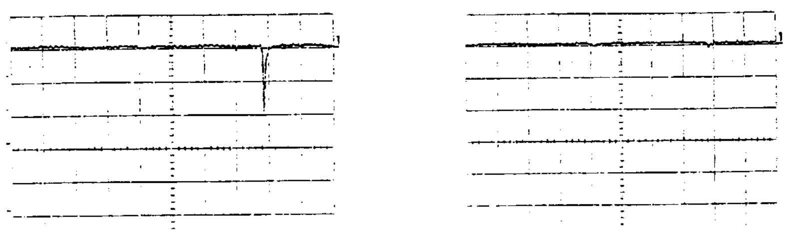


at position of "6" at position of "5" at position of "3.5"

. Fig.7a Beam loss at extraction observed by upper loss monitor (x:1μs/d)



at position of "1" at position of "2" at position of "5.5"



at position of "6.8" at position of "7.5"

Fig.7b Beam loss at extraction observed by lower loss monitor (x:1μs/d)

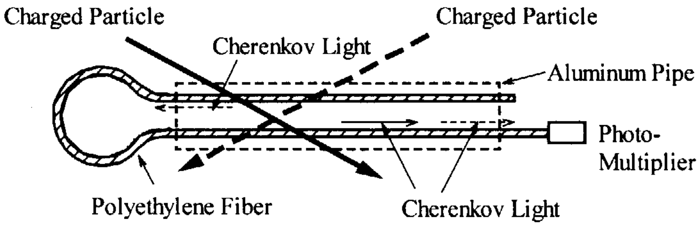


Fig.8 How to set the photo-fiber for removing the position effect of the photo-multiplier

2. Loss signal dependence on the circulating beam energy

A vertical bump orbit can be made at straight section 3 by two vertical bump magnets (set at S2 and S4). By exciting these magnets and hitting the circulating beam on the vertical scraper set at S3, any degree of beam loss can be generated at any timing. Fig.9 shows that the loss signal dependence at the polyethylene photo-fiber on the circulating beam energy during KEK-PS-Booster injection and the extraction energy (40-500MeV). Although we have not explained the measurement result quantitatively, the loss signal increases with a log-scale according to the circulating beam energy. Therefore, the loss monitor using polyethylene photo-fiber can observe the beam loss at the Booster extraction (500MeV), but hardly at injection (40MeV).

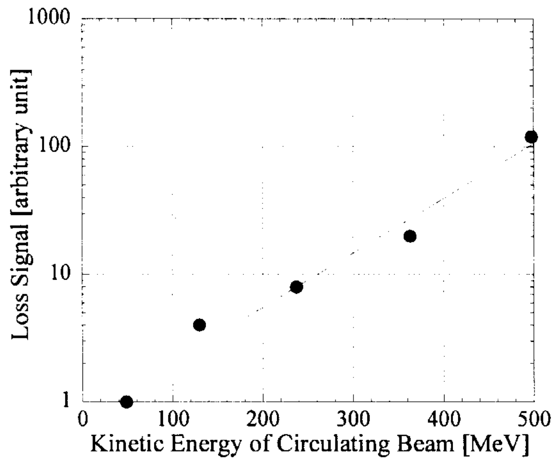


Fig.9 Dependence of loss signal by polyethylene photo-fiber on the circulating beam energy (40MeV-500MeV)

3. Various materials for the photo-fiber

There are three kinds of materials which we have tested for the photo-fiber of the loss monitor. Their merits and demerits are as follows:

(1) Polyethylene fiber

This fiber is composed of 48 fibers (each having a diameter of 0.265mm)

*(Merit) Cost is cheap ($1/m)

*(Demerit) Short life (about 2 months)

Small signal (because the light source is Cherenkov light)

(2) Plastic scintillating Fiber (see Fig.10a and 10b: lower figures)

The diameter is 2.0mm

*(Merit) Large signal (because the light source is scintillating light)

Not expensive ($6/m)

*(Demerit) Short life (about 1 month)

(3) Quartz Fiber (see Fig.10a and 10b: upper figures)
The diameter is 0.9mm
*(Merit) Long life
*(Demerit) Small signal (because the light source is Cherenkov light)
Expensive ($38/m)

(Note) As the Photo-multiplier, we use Hamamatsu-Photo (R2007) (13.5mm^2 * 84mm^L)
(Light wavelength: 185~850nm, Gain:1.0*10^6, Cost: $1.000).

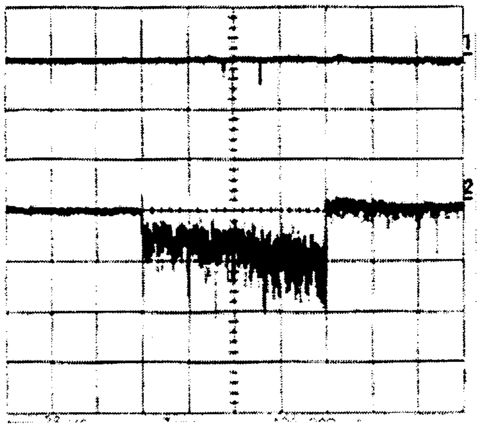


Fig.10a Beam loss during H$^-$ injection (40MeV)
* Upper figure: by quartz fiber (V_{PM}=1kV) (10μs/d, 50mV/d)
* Lower figure: by plastic scintillating fiber (V_{PM}=1kV) (10μs/d, 50mV/d)

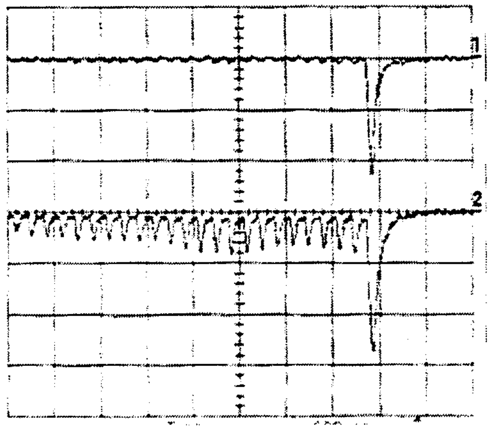


Fig.10b Beam loss at extraction (500MeV)
* Upper figure: by quartz fiber (V_{PM}=800V) (500ns/d, 2V/d)
* Lower figure: by plastic scintillating fiber (V_{PM}=600V) (500ns/d, 2V/d)

(Note 1) "V_{PM}" means the photo-multiplier bias voltage.
(Note 2) The loss monitor using quartz fiber can hardly observe the beam loss at injection; on the contrary, it can observe the beam loss due to the kicker magnet at extraction. We have not understood why the loss signal by the quartz fiber due to the bump orbit is much more faint than that by the plastic scintillating fiber.

5. Measurement Results

In this section, we introduce some typical losses in the Booster ring.

1. Difference between large and small bump orbits

Fig.11 shows the extraction system of the KEK-PS-booster. At beam extraction, there is a space between the circulating beam and the septum coil because of the emittance adiabatic dumping. Since the magnetic field of the kicker magnet is too weak to kick into the gap of the septum magnet, a bump orbit is prepared by exciting two bump magnets (Bump1 and 2) just before firing the kicker magnet. Supposing that the bump field is stronger than the proper field, the circulating beam hits the septum coil according to the betatron oscillation, and the beam loss due to the bump orbit can be observed. On the contrary, when the bump field is smaller, the beam loss due to the bump orbit cannot be observed at all; however, the beam loss due to the kicker magnet is larger than the former because the total magnetic field of the kicker and the bump is too small to kick the beam into the septum magnet.

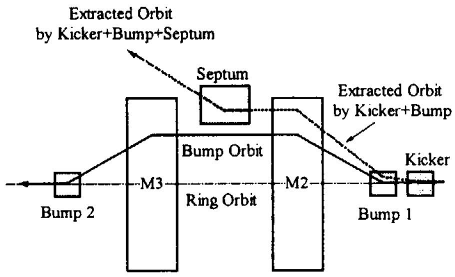


Fig.11 Booster extraction system composed of a Kicker, two Bumps and a Septum magnet

Figs.12a and 12b show evidences concerning above two cases, which were observed by a polyethylene photo-fiber. The top figure is the signal observed by the loss monitor set at M3 (upper stream), and the middle at M3 (lower stream). The bottom figure is the signal by a fast intensity monitor. It can be said that every bunch loss can be observed by this monitor system.

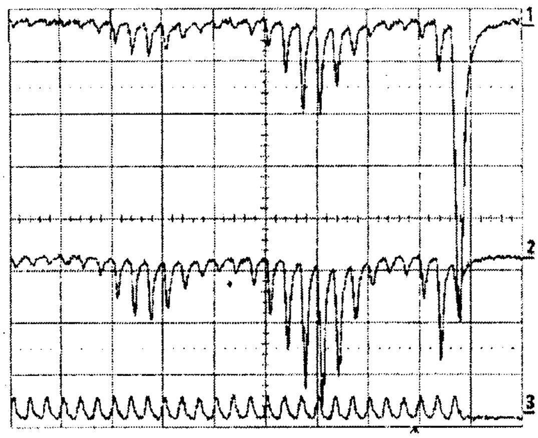


Fig.12a Beam loss in the case of a large bump orbit (500ns/d)
(Top: at M3 upper, Middle: at M3 lower, Bottom: Bunched beam by fast intensity monitor)

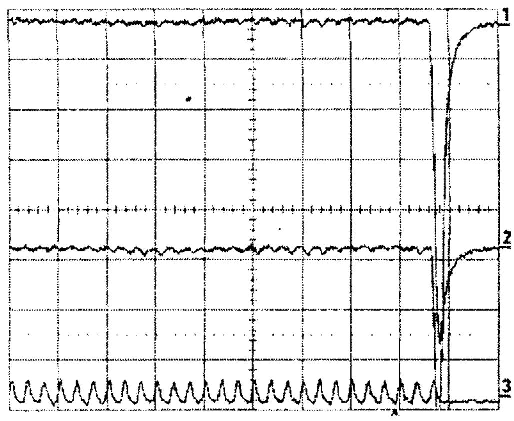


Fig.12b Beam loss in the case of a small bump orbit (500ns/d)
(Top: at M3 upper, Middle: at M3 lower, Bottom: Bunched beam by fast intensity monitor)

2. Difference between a good tune and a bad tune

Sixteen loss monitors are set at the upper and lower stream of every eight main magnets in the Booster ring (see Fig.4). The loss signals obtained by these monitors are gathered by a computer (see Fig.13) and displayed on a screen all at once, as shown in Fig.14. Figs.14a and 14b show the Booster loss using a polyethylene photo-fiber in the case of bad bump tuning and good tuning, respectively.

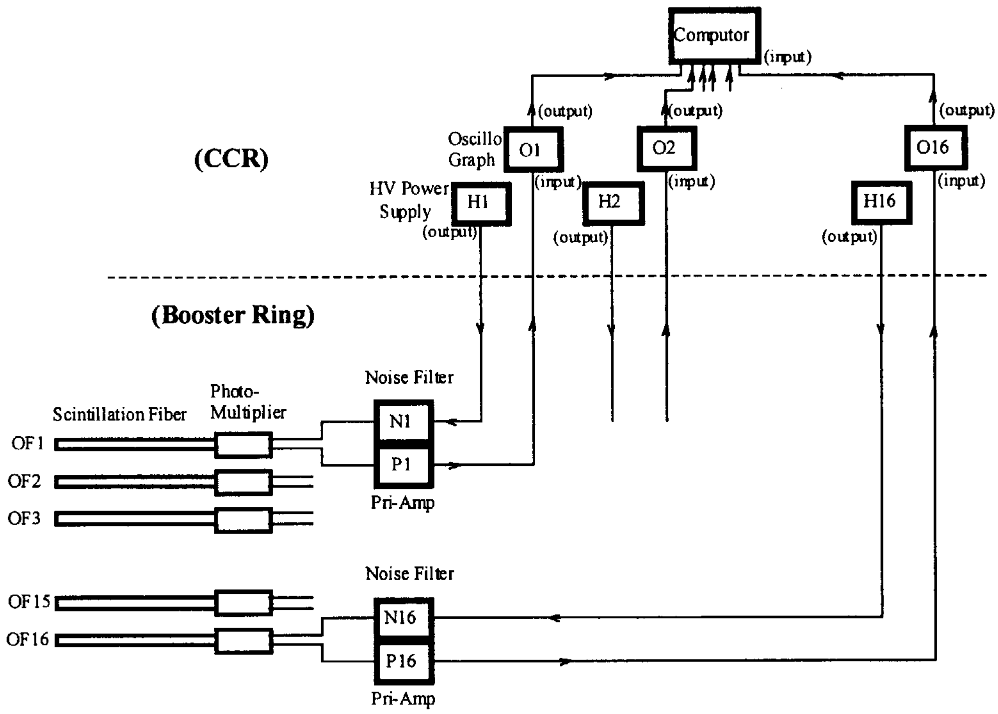


Fig.13 Block diagram to gather signals obtained by 16 loss monitors into a computer

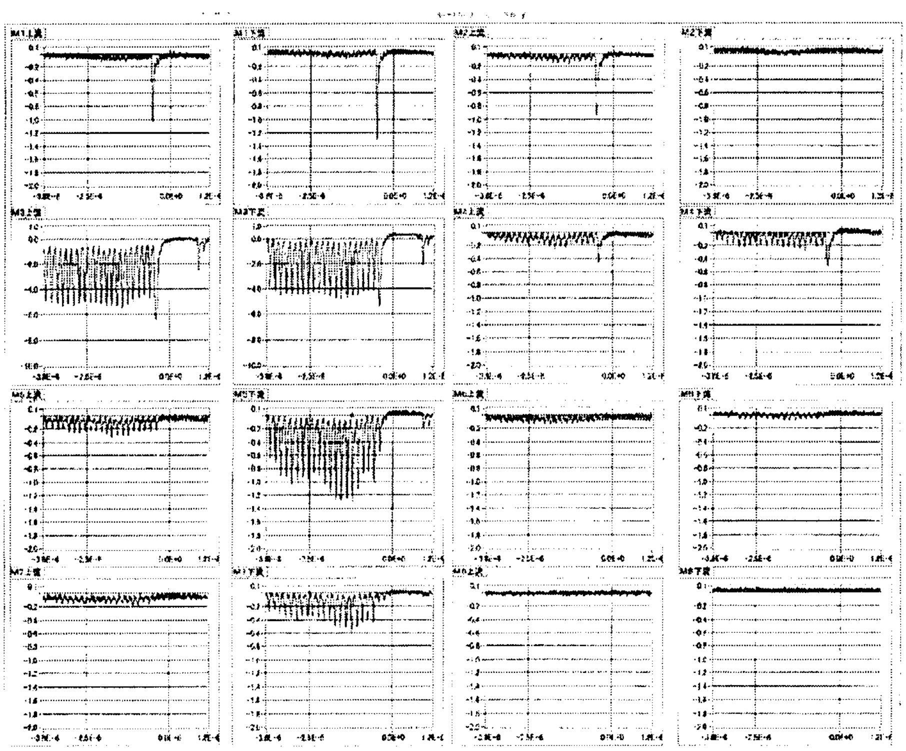


Fig.14a Loss around the Booster ring at extraction
(In the case that two bump magnet currents are poorly tuned)
(Figures from the top left to the bottom right: M1 upper, M1 lower, M2 upper, ...M8 lower)

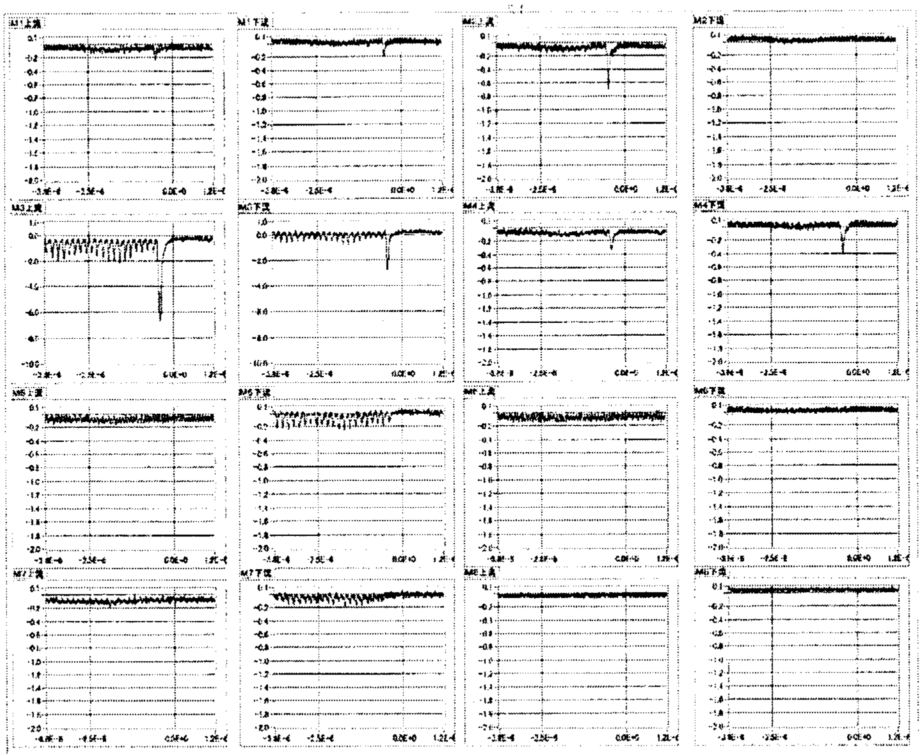


Fig.13b Loss around the Booster ring at extraction
(In the case that two bump magnet currents are well tuned)

6. Summary of this Loss Monitor

The special features of our loss monitor system are itemized as follows:

- Easy fabrication
- Not expensive (about $1,500/one set)
- Fast response (10ns order)
- Large dynamic range (by adjusting the bias voltage of the photo-multiplier)
- Big signal (by using plastic scintillating fiber), but short lifetime
- Long lifetime (by using quartz fiber), but small signal

Therefore, we are looking for a "Quartz fiber doped scintillating material with cheap cost".

7. References

[1] T.Kawakubo, E.Kadokura, T.Kubo, T.Ishida and H.Yamaguchi, "Non-destructive Beam Profile Measuring System Observing Fluorescence Generated by Circulating beam", 1995 Particle Accelerator Conference, Dallas, TX, USA, May 1-5, 1995