# Beam-Power Damage of Beam Monitor Components

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## Abstract

Recently, the Accumulation Ring (AR) ran with high beam current of 500 mA for the KEKB. Some troubles in hardware components of a beam monitor system were found. The most serious trouble was that a deflector electrode of a transverse feedback system blocked off a beam after it was heated up and bended. Moreover, a coaxial cable connected to the electrode was shorted. A bench test suggests that these troubles were triggered by rf power from the beam.

## 1 Introduction

The AR was originally constructed as an injector of the TRISTAN main ring and commissioned in 1983. After terminating the TRISTAN in 1995, the AR is operated as an electron storage ring at 6.5 GeV with beam current of 30 mA. Typical operating hours are about 3000 hours/year. Recently, the AR ran with high beam current of 500 mA at 2.5 GeV.[1] A beam monitor senses the beam current using a ferrite core and the beam position using a pick-up electrode. Thus the monitor components suffered from rf power of a beam pulse in addition to radiation dose from the synchrotron radiation. This note describes rf-power damages for components of the position monitor.

The beam position monitor (BPM) uses signals from button electrodes. An resistive type attenuator as shown in Appendix is attached to every button electrode to throw charge on an electrode away and prevent a device from the discharge. A stripline type of the deflector electrode is used for the transverse feedback system.[2] Since the deflector is traveling wave type with the impedance of 50 Ω, no cooling system is required. The deflector electrode is installed in a vacuum chamber and formed by a pipe 20 mm in diameter and its longitudinal length is 1.92 m. Both ends of the electrode are mechanically movable in the longitudinal direction to absorb thermal expansion. A deflection signal and beam power can be monitored through a coaxial cable (8D-BTXE, Hitachi) connected to an end of the deflector.

## 2 Estimation of beam power

Assuming that an electode picks up $N$ bunches stored in a ring, the bunch power induced on an electrode can be estimated by

$$P_{bunch} = \frac{N}{T_0}\int_0^{\tau}\frac{V^2(t)}{Z}dt. \qquad (1)$$

Here $T_0$ is the revolution period, $V(t)$ is voltage of a picked-up pulse, $\tau$ is duration of the pulse and $Z$ is the impedance of measuring system. Assuming that a waveform of the picked-up pulse is approximated by a mono-cycle sine, the picked-up power is given by

$$P_{bunch} = \frac{NV_p^2\tau}{2ZT_0}. \qquad (2)$$

Here, $V_p$ is the amplitude of the mono-cycle wave. The bunch power is proportional to the number of bunches and to square of the amplitude. Since the picked-up wave is a pulse, the bunch power is also defined using the peak power as $P_p = V_p^2/Z$. A simple estimation shows that the peak power at a button electrode reaches 500 W when the bunch current is 40 mA and the bunch length is 2 cm.

On the other hand, a bunch produces the wake fields by an interaction with a chamber wall. The wake fields eventually lead to energy loss determined by the loss parameter. The loss power is given by

$$P_{loss} = \frac{kT_0I_t^2}{N}, \qquad (3)$$

where $It$ is total beam current and $k$ is the loss parameter depending on the bunch length. Since the frequency of the wake fields is usually higher than the cut-off frequency of a vacuum chamber, most parts of the wake fields may propagate inside the wall. However, an electrode acts as an antena and may catch a part of the wake fields. Thus, the beam power is the sum of the bunch power and the loss power. Table 1 shows the expected bunch power picked up by a stripline and by a button for three cases of beam conditions, I, II and III. The power of a stripline is subtracted by the power lost in a cable from picked-up bunch power. The stripline power is still larger than that of a button. The loss power of a stripline deflector is 500 to 600 W at the total beam current of 500 mA with 16 bunches, where the measured loss parameter of $k$=0.04 V/pC[2] was used at the bunch length of 2.4 cm. However, the loss power reduces to 150 W with 100 bunches at the same beam current. It is assumed here that the loss parameter is inversely proportional to the bunch length. Both bunch power and loss power are maximum at the beam condition II of Table 1. Even if 10% of the loss power is picked up by the deflector, the loss power is much larger than the bunch power.

Table 1 Bunch power and loss power.

| Beam Condition | I | II | III |
|---|---|---|---|
| Measured Bunch Power at Stripline through Cable (W) | 3.8 | 5.5 | 1.0 |
| Estimated Bunch Power at Button electrode (W) | 0.9 | 1.3 | 0.2 |
| Estimated Loss Power by Deflector electrode (W) | 200. - 240. | 468. - 624. | 150. |
| Measured Bunch Length (cm) | 5 - 6 | 3 - 4 | 2. |

I: It=100 mA, N=1 II: It=500 mA, N=16
III: It=500 mA, N=100

## 3 Damage of monitor components

The maximum allowable cw power of the attenuator used for the BPM is 2 W and the peak power is 500 W according to a catalog.[3] Table 1 indicates that the cw power is less than the alowable power for a button electrode, but it cannot be allowed for a stripline. One may estimate the peak power in the beam condition I is far beyond the allowable power of 500 W.

The shunt resistance of the attenuator including a coaxial switch can be monitored by suppling DC current. The measurement was carried out during a shut down period of the AR, approximately two times a year. The measurement indicated that several attenuators had an abnormal increase of the resistance during several months operation. The abnormal attenuator always concentrated in specified places, such as at an injection point and near an undulator magnet. Therefore, the abnormal attenuators are estimated to be caused by radiation damage not by overloaded peak power. Exposured radiation sensitive color sheets ("Radcolor") indicated the the radiation dose of more than $10^5$ Gy.

During the beam condition II, a trouble of the deflector electrode was noticed from a time-domain reflectrometer (TDR) measurement. The TDR suggested that an end of the electrode is shorted and the other end may be irregularly bended. By opening the chamber, it was found that the electrode was actually bended inside the wall, blocking off the beam. The surface of the electrode was melted by heat. The TDR also indicated other shorted points in coaxial cables. The shorted cable corresponded to the abnormal deflector. The outer cover and the polyethylene insulator of the cable melted near the shorted point.

## 4 Investigation for components

### *4.1 Power test for attenuator*

First, an rf cw power at 500 MHz is supplied to the attenuator to test rf-power resistance with monitoring the resistance. When an input power reached 2 W, surface temperature of the attenuator increased to 50 $^0$C, nevertheless the resistance did not change. When the input power exceeded 2 W, the resistance began to decrease as estimated from the catalog.

Next, a pulse was supplied to an attenuator to test the peak power. Two kinds of the pulse width were tested; one width is 60 ns and the other 5 μs with the same period of 2.5 ms. An actual beam pulse width is much shorter than the test pulses and is about 160 ps with 1.25 μs period. The duty factors of thses pulses are the order of $10^{-3}$ to $10^{-5}$. The resistance of an attenuator was measured as a function of the amplitude of the pulse. A typical result among four samples is shown in Fig. 1. The resistance of all attenuators did not almost change up to 600V for the pulse width of 60 ns, which corresponded to the peak power of 7.2 kW. However, the resistance abruptly changed to infinity over 250 V for 5 μs pulse width. This voltage is 1.6 times of the nominal value. The other attenuators indicated similar results. Therefore, the allowable peak power of the attenuator depends on the pulse width and should be higher than the nominal peak power of 500 W for a short pulse as an electron bunch.

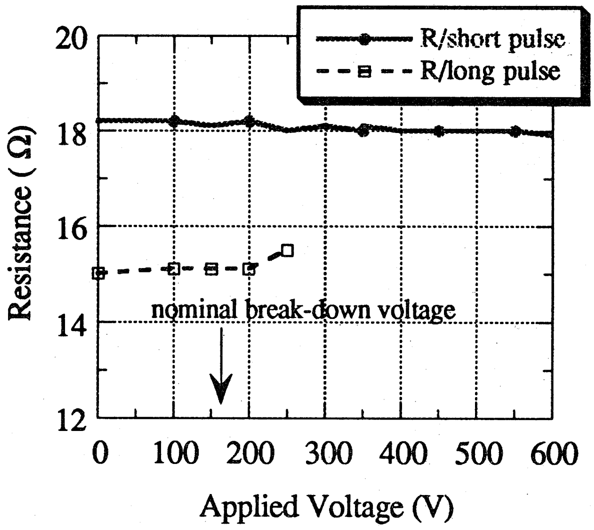


Fig. 1 Serial resistance of an attenuator as a function of applied voltage with the pulse width of 5 μs (white) and of 60 ns (black).

### *4.2 Power test for cable*

Power resistance of a coaxial cable was investigated under the set-up as shown in Fig. 2. The surface temperature of a cable was monitored using a thermo-coupler at three points (A,B and C) as illustrated in Fig.2. Point A and C are marked on a straight cable and C is marked on a curved one. The rf power is generated by a klystron, where the maximum power is 1 kW at the frequency of 1.3 GHz. According to a cable handbook[4], the allowable power of the cable used for the deflector is 400 W at 1GHz. Since rf loss in a cable increases with frequency, the allowable power decreases with frequency.

First, a new cable was tested. When the power is increased up to 500 W, the surface temperature reached 50 $^0$C at the three points. A change for the monitored power was not noticed. Next, a used cable which is exposed by the radiation environment of the AR more than 10 years was tested. Before the rf power is supplied to the cable, the TDR measurement did not indicate any reflection for the used cable. However, some cracks were noticed on the surface of the cable. Moreover, a network analyzer indicated large rf loss in the cable, which corresponded to the loss of 3D class (outer conductor is 3mm in diameter). When the rf input power was carefully increased and set at 100 W, the monitor power gradually decreased in spite of keeping the input rf level constant. Then the surface temperature increased specially at the curved region of point B as shown in Fig.3. After supplying the rf power for one hour, the surface temperature at B reached 90 $^0$C and the cable began to melt there. The monitored power was only 30 W at that time, thart is, 70 W was dissipated in the cable.

The used cable melted only for the input power of 100 W at 1.3 GHz. The power is about 1/5 of the loss power at the beam condition II When the cable is shorted, the beam power is reflected and return to the electrode. Moreover, if an end of the electrode is shorted by accidental thermal expansion, the electrode acts as a cavity. Thus, the power is stored in the electrode and it heats up the electrode. The temperature of the bended electrode is expected to reach the melting temperature in vacuum.

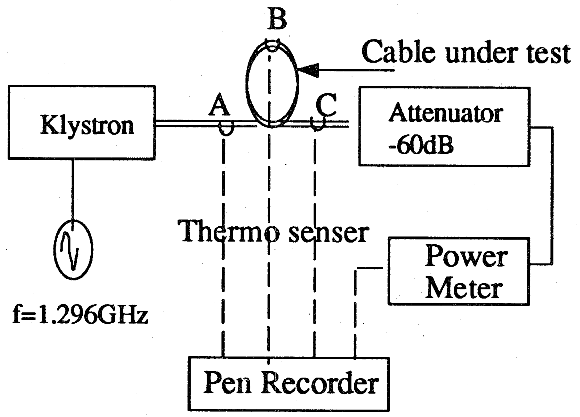


Fig. 2 Set-up for measuring power resistance of a coaxial cable.

## 5 Summary

The allowable peak power depends on the pulse width. The beam power picked up by an electrode includes the loss power in addition to the bunch power. It is important to monitor high frequency characteristics of devices exposured in radiation environment. A new delfector electrode instead of the broken one is now constructing with a mechanical support to prevent a short circuit.

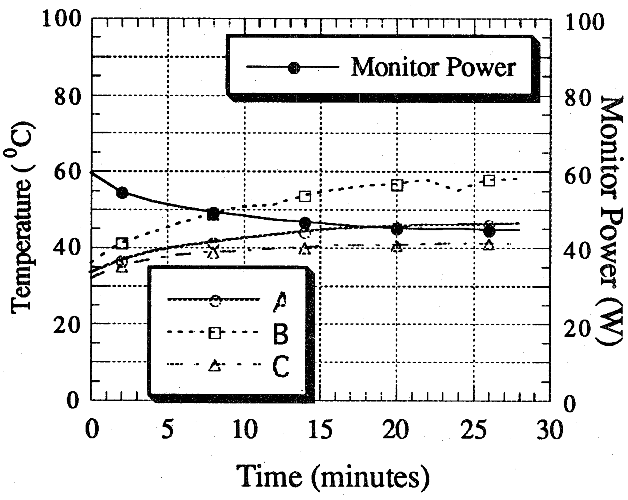


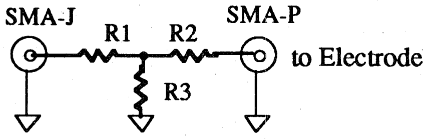
Fig. 3 Surface temperature at point A, B and C of a used cable and the monitor power as a function of time. The output power of the klystron is 100 W.

## References

[1] Y. Funakoshi and K.Akai, "*High Beam Current Experiments for the KEKB Conducted at the TRISTAN Accmulation Ring*" KEK Preprint 97-62, submitted to 1997 PAC, Vancouver, BC, Canada (1997).
[2] T. Ieiri et.al., "*The Transverse Feedback System for the TRISTAN AR*", Proc. of 5th Symp. on Accelerator Science and Technology, Tsukuba, Japan (1984)114.
[3] Lucas Weinschel, model 3T.
[4] Showa Cable Ltd. (in Japanese).

## Appendix

T type of an attenuator is used as shown below. Typical value of the resistances are R1=R2=8.2 Ω and R3=150 Ω for 3 dB attenuation.



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