

DAMPED BUTTON ELECTRODE FOR B-FACTORY BPM SYSTEM

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Abstract

A new concept of damping of resonances in a button electrode has been proposed and tested in the BPM system for the B-Factory project at KEK (KEKB). Since a very high current beam has to be stored in the machine, even a small resonance in the ring will result in losing a beam due to multi-bunch instabilities. In a conventional button electrode used in BPMs, a TE₁₁₀ mode resonance can be trapped in the gap between the electrode and the vacuum chamber. In order to damp this mode, the diameter of the electrode has been chosen to be small to increase the resonance frequency and to radiate the power into the beam pipe. In addition, an asymmetric structure is applied to extract the EM energy of the TE₁₁₀ mode into the coaxial cable as the propagating TEM mode which has no cut-off frequency. Results of the computer simulations and tests with cold models are reported. The quality factor of the TE₁₁₀ mode was small enough due to the radiation into the beam pipe even in the conventional electrode and the mode coupling effect due to the asymmetric shape was significant on a cavity-like TE₁₁₁ mode.

I. INTRODUCTION

In the KEKB accelerator, the beam current will be of several amperes. Since the number of BPMs amounts to about 450 per ring, possible resonances in the gap is of serious concern to avoid coupled bunch instabilities. On the other hand, it is not necessary to take care very much of VSWR in a wide frequency range, since only 1 GHz component of the beam is detected for the beam position measurements. The resonances in the BPMs can be classified into two categories; one due to a button electrode and another due to a ceramic part that is used for a vacuum seal. In this paper, we mainly focus on the resonances at the button electrode.

II. BPM STRUCTURE

We adopted the N-type vacuum feedthrough because it has an advantage of high power rating and the enough mechanical strength compared to that of the SMA type. Connectors will be brazed to the block of copper chamber.

The small button size has an advantage that can enhance the damping of the TE₁₁₀ mode due to the radiation into the beam chamber. On the other hand, the minimum size of the button is limited to accomplish the required precision of the position measurements, i.e., better than 80 dB in the signal-to-noise ratio at the beam current of 10 mA. We determined the diameter of the button electrode to be 12 mm. The gap distance was determined to be 1 mm to avoid the multipacting discharge.

The structure of the asymmetric BPM is shown in Fig. II. Three faces of the button are cut out to enhance its asymmetry, and are connected to the center conductor with a taper.

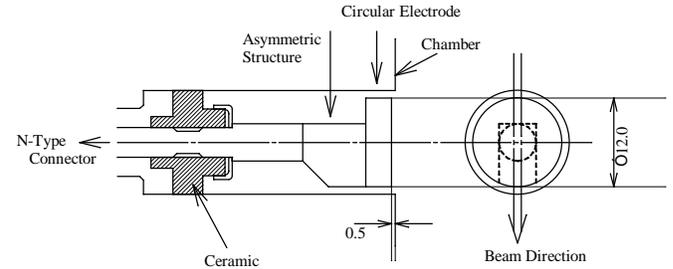


Figure 1. Illustration of the damped BPM. The diameter of the disk is ϕ 12 mm and the gap size is 1 mm. The distance between the electrode surface and the wall is determined to be 0.5 mm to prevent the synchrotron radiation.

III. COMPUTER SIMULATIONS

The damping efficiency of the asymmetric structure has been simulated with the computer code MAFIA. Resonance frequencies and mode patterns (monopole or dipole) are tabulated in Table I.

Table I
Resonance frequency calculated with MAFIA.

| frequency[GHz] | mode pattern | location (label in Fig. 4) |
|----------------|--------------|----------------------------|
| 1.88 | Monopole | |
| 3.96 | Monopole | |
| 5.82 | Dipole | ceramic (C1) |
| 6.21 | Monopole | coaxial (Coax) |
| 7.30 | Dipole | button (B1) |
| 7.89 | Dipole | ceramic (C2) |
| 8.88 | Monopole | |

The field pattern of the TE₁₁₀ mode at 7.3 GHz is shown in Fig. 2.

In this model, the BPM is not placed at the chamber wall but at the cylinder that has a magnetic-short boundary at the end.

Among these modes, EM energy of the monopole modes are extracted to the outside of the BPM and have negligible effects on the beam instabilities. The dipole modes under cutoff frequency of the coaxial lines, however, are trapped inside the BPM. The electric field of the dipole mode at 5.8 GHz is localized at the ceramic, so that the coupling between this mode and the beam is small. As shown in Fig. 2, the TE₁₁₀ mode at 7.3 GHz is not effectively converted to TEM modes. The coupling between the two modes can be enhanced by increasing the length of the asymmetric structure. However, this method has a

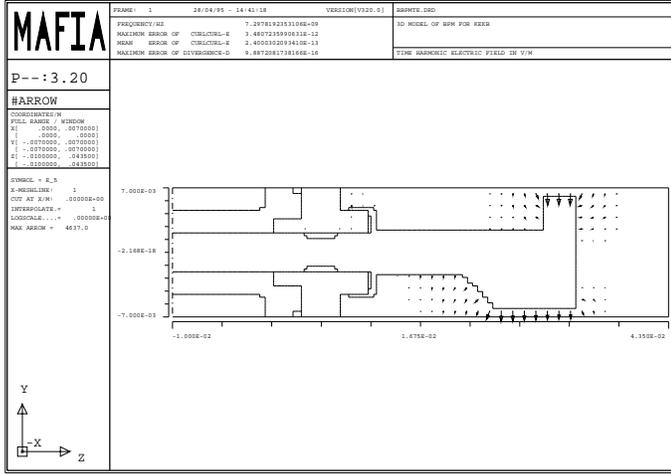


Figure 2. Electric field pattern of the TE₁₁₀ mode. EM energy is concentrated at the button electrode.

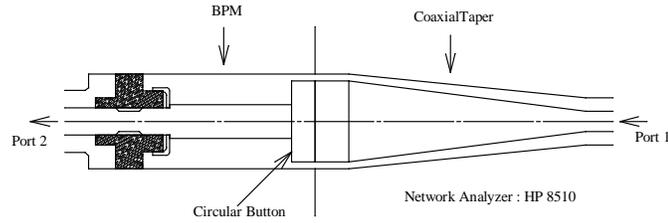


Figure 3. The setup to measure the transmission characteristics of BPM.

disadvantage of the dipole mode at the ceramic penetrating into the beam chamber.

It is difficult to estimate quality factors of the resonance modes from this calculation because this model does not include the radiation into the beam chamber. We calculated the wakefields using the T3 code of MAFIA, and estimated the loss parameters k of the TE₁₁₀ mode to be 0.4 mV/pC.

IV. EXPERIMENTS AND RESULTS

We measured at first the transmission characteristics (S_{21}) of the electrode with a setup shown in Fig. 3.

The TEM-mode signals are fed to the electrode through a taper. Figure 4 shows the S_{21} response of a conventional circular electrode.

There are two sharp peaks at 6.2 GHz and 8.8 GHz, which are labeled as C1 and C2 in the figure. We measured the S_{21} response without ceramic and found that these peaks are resonances in the ceramic. The difference between the calculation with MAFIA and the measurement is explained by two reasons: one is that the resonance frequency listed in the Table I is the calculation for the damped BPM, and the other is that the measured BPM is not brazed. The peak around 8 GHz, labeled as B1, appears when the button electrode is placed at the off-center position. The broad peak labeled as Coax denotes the resonance of the whole coaxial structure. In this setup, it is difficult to measure

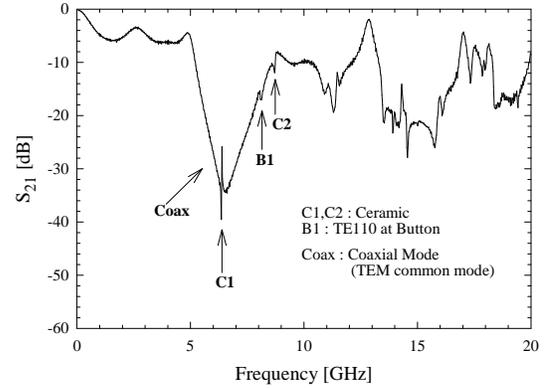


Figure 4. S_{21} measurement of circular BPM.(Network Analyzer HP 8510)

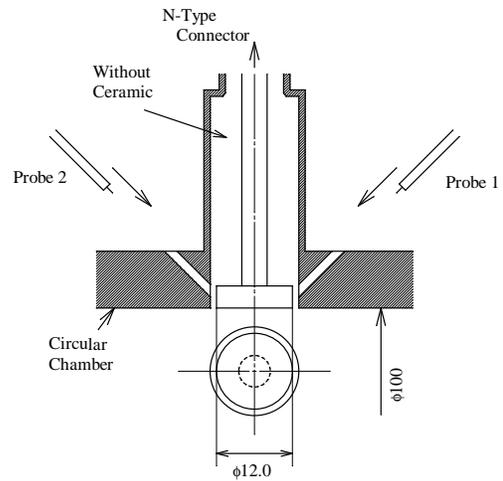


Figure 5. Experimental setup of the TE₁₁₀ measurement. Two semi-rigid cable is used as an antenna to excite the TE₁₁₀ mode at the disk. The BPM was mounted on $\phi 100$ mm circular beampipe, at those ends absorbers were loaded.

the quality factor of the TE₁₁₀ mode resonance because only the coaxial mode can be excited.

Next, we excited the TE₁₁₀ mode directly with the setup shown in Fig. 5.

Two probes inserted through $\phi 2$ mm holes excite the TE₁₁₀ mode at the button electrode, while the N-type connector is connected to the matched load. To avoid ceramic resonances, we did not attach the ceramic part during this measurement.

Figure 6 shows the S_{21} spectrum of the circular electrode, where three large peaks are recognized. The first peak around 7.8 GHz, marked as A, is TE₁₁₀ mode at the electrode. This resonance frequency is consistent with the numerical results of MAFIA. The quality factor of the mode was estimated to be 40. Another measurement with an asymmetric electrode showed a small decrease of the quality factor.

The second peak marked as B in the figure is identified as the TE₁₁₁ cavity mode inside the BPM. This mode is trapped in a coaxial volume behind the button. The resonance frequency of

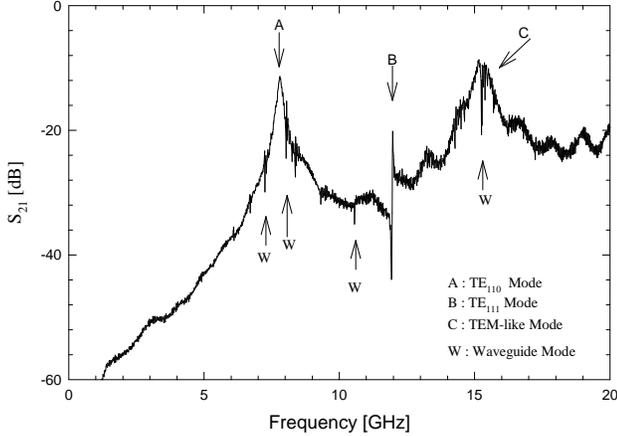


Figure 6. Dipole mode resonance of the circular BPM.

this mode is given by $k = \sqrt{k_z^2 + k_c^2}$, where k is the wave number of the resonance frequency, $\lambda_z (= 2\pi/k_z)$ the wavelength determined by the length of the electrode axis, k_c the cutoff wave number. The quality factor is about 300 with the circular electrode and about 50 with the damped electrode. Since this measurement did not include the ceramic part, the resonance frequency and the quality factor may be different from those of the actual BPM. We will investigate the coupling of this mode to the beam in near future.

The third peak marked as C is the TEM common-mode resonance. This mode is harmless because of its low quality factor and high coupling to the external circuit. There are several sharp peaks marked as W. These frequencies are identified as cutoff frequencies of TM_{nm} modes in a $\phi 100$ mm circular chamber.

V. DISCUSSION

The beam current spectrum and the power spectrum of the KEKB are shown in Fig. 7, for a natural bunch length σ_z of 4 mm. This figure shows that we should avoid resonances in the frequency range below about 15 GHz.

We estimate the growth time of the instability due to the TE110 mode. The R/Q is calculated from the loss factor k calculated with MAFIA and from the relationship [1]

$$k = \frac{\omega_r}{2} \left(\frac{R}{Q} \right) e^{-\omega_r^2 \sigma_t^2}, \quad (1)$$

where ω_r is the resonance frequency and σ_t is the bunch length in units of time. The experimental results show the Q value of the TE110 mode is about 40, leading the peak impedance $R = 1.0 \Omega$ per one BPM (4 buttons). The growth rate of longitudinal coupled bunch instability is given by [2]

$$\tau^{-1} = \frac{\alpha N e^2}{2ET_0^2 \omega_s} \sum_{p=-\infty}^{\infty} (p\omega_0 + \omega_s) \text{Re} [Z(p\omega_0 + \omega_s)] e^{-\omega_r^2 \sigma_t^2}, \quad (2)$$

where N is the number of electrons (positrons) in the ring and E is the beam energy. The calculated growth time of the instability is 120 ms in the LER and 520 ms in the HER, which are

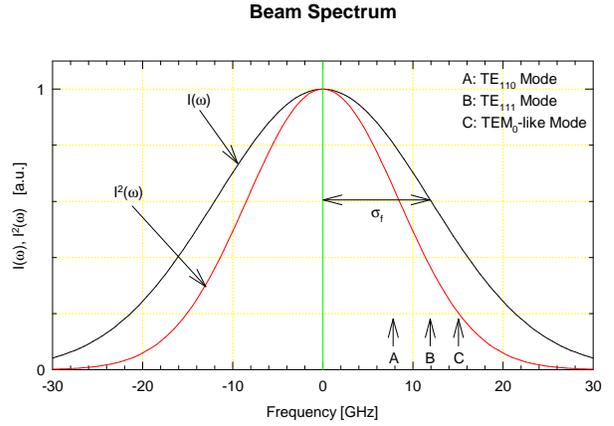


Figure 7. The beam spectrum of KEKB for the natural bunch length $\sigma_z = 4$ mm. The solid line shows the beam current spectrum $I(\omega)$ and the dotted line shows the power spectrum $P(\omega) \propto I^2(\omega)$.

sufficiently larger than the radiation damping time of 43 ms in the LER and 23 ms in the HER.

Though it is possible to enhance the mode mixing between the TE110 mode and the TEM mode by increasing the length of the asymmetric structure, the quality factor was already small enough to prevent the instabilities. Therefore, if we only think of the TE110 mode, we may adopt the circular button in the final design of the KEKB position monitors.

The TE111 mode exists only inside the BPM and it may affect little on the beam impedance, however, the coupling has not been estimated yet. Since the asymmetric structure have good damping effect on the mode, there is still some possibility of using the structure.

At last, we mention about the resonance in the ceramic briefly. Since it is difficult to damp these modes, we will optimize the thickness of the ceramic to detune the resonance from the RF harmonics.

Fabrication tests on brazing the electrode to the copper chamber is in progress. There still remain technical problems in the ceramic feedthrough, i.e., some of the feedthrough had vacuum leakage troubles after the brazing process. We are trying to optimize the detailed structure of ceramic part and sealing metal parts to meet both requirement of the brazing process and the RF impedance issues.

ACKNOWLEDGMENT

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References

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