DEVELOPMENT OF BUTTON ELECTRODE WITH IMPROVED TIME RESPONSE

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Abstract

Good time response in a button electrode is essential to realize the bunch-by-bunch feedback / diagnostic systems for future short-bunch spacing accelerators such as an energy recovery linac (ERL) or super B-factory. The impedance matching and the time-domain response of the electrodes especially around the vacuum seal have been studied using 3-D electromagnetic codes (HFSS, MAFIA and GdfidL). Several candidates have been fabricated to examine the tolerances of mechanical pressures and heat stress due to the welding process. The real beam response from a short linac bunch has also been studied using a test beam line at the KEK-PF beam transport section.

INTRODUCTION

The requirements on the bunch-by-bunch beam position diagnostics systems for future short-bunch spacing accelerators, such as energy recovery linac (ERL) or super particle factories such as SuperKEKB, are much harder than those of present accelerators because the systems play a major role in operating the accelerators or to realize the fairly difficult specifications. Since the signal inputs of the system which couples to the beam (head) limit the absolute performance of the system, it is necessary to design good electrodes such as button-type electrodes or stripline electrodes including feedthrough which fulfill the requirements.

The requirements on the front-end parts of bunch-by-bunch diagnostic systems might be summarized as follows:

- Good impulse response without long trailing signals, such as ringing from the bunch signal. It is also necessary to be free from trapped modes which not only make the response worse but easily damage vacuum sealing in high beam current conditions.
- High enough output voltage to keep good signal to noise ratio on succeeding detection circuits.
- Mechanically tough structure with respect to both signal induced heating and possible impacts such as mechanical pressure coming from fastening and unfastening the RF connectors or cable stress. Note it is also necessary to be strong enough in the construction process such as welding them to vacuum chamber.

For the KEKB bunch-by-bunch feedback systems, we designed and fabricated modified-SMA type button electrodes about 10 years ago[1]. We have done 3-D EM simulations such as MAFIA310 or HP-HFSS ver.3 using fairly poor computing power compared those available to now. The installed BPMs have been working excellently under tough conditions, with a maximum beam current of 2A, minimum bunch spacing of around 4ns (about 15nC / bunch), and a bunch length of about 7mm in standard deviation, without any troubles. Good frequency response of the electrodes also helps to investigate beam characteristics such as beam-beam effects or unknown beam instabilities. For an accelerator with a much shorter bunch length, say about 3mm, or with much shorter bunch spacing, however, the electrode might not be suitable.

Since the large permittivity of alumina-ceramics (e_r~9.7) used to seal vacuum makes impedance matching difficult, we have employed a glass of low permittivity (ε_r~4) as vacuum seal of the feedthrough and examined the frequency and time response using current 3D-electromagnetic field simulation codes (GdfidL, HFSS) [2, 3]. Several candidates have been fabricated to examine the frequency response, and tolerance to mechanical and heat pressures. The time response of the electrodes has been studied using the very short linac bunch using the test-beam line at KEK-PF beam transport section. The target specification of the electrodes for SuperKEKB and the ERL test facility proposed in KEK are shown in Table.1.

Specification		unit	
Bunch length	3 <0.9	mm mm	SuperKEKB ERL
Bunch charge	20 7.7	nC pC	SuperKEKB ERL
Time response	<0.5 <0.3	ns ns	SuperKEKB ERL

Table 1 Design target of new button electrodes.

BUTTON ELECTRODE FOR KEKB FEEDBACK SYSTEMS

The structure of the present button electrode used in the KEKB feedback systems is shown in Fig. 1.For support

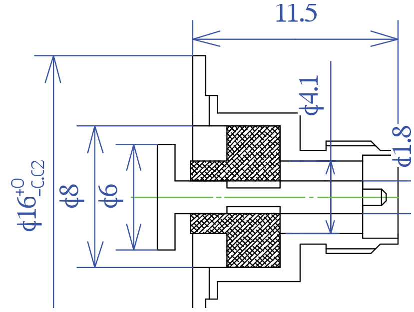

Fig.1 Button electrode for KEKB feedback systems.

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and vacuum sealing, aluminum-ceramic of ε_r=9.7 (Kyocera A473) is used. The outer metal is Kovar (Fe-Co-Ni). The beam response from the KEKB-LER (positron ring) 1st bunch, of bunch charge of about 9 nC, is shown in Fig. 2, with a 43dB attenuator and about 5dB and 15 dB cable loss at 2GHz and 10GHz, respectively. The analogue band-width of the HP54121 oscilloscope was 20 GHz.)

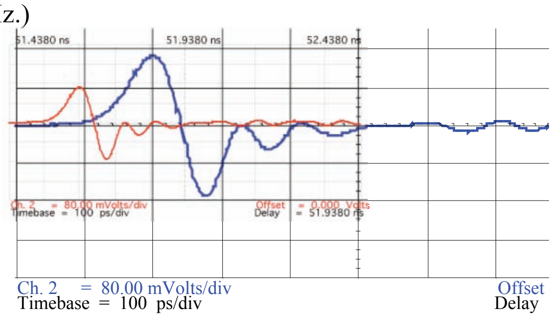

Fig.2 BPM signal from 1st bunch of KEKB-LER at bunch charge of 9nC. The BPM is mounted on a circular vacuum chamber of diameter of 64 mm.

The results of the time domain simulation using GdfidL for a bunch of σ_z=7mm, I_b=1nC are shown in Fig.3 and Fig.4, with time-domain response and the power spectrum, respectively. Taking into account the frequency dependence of the cable loss, the numerical simulation shows good agreement with the real signal.

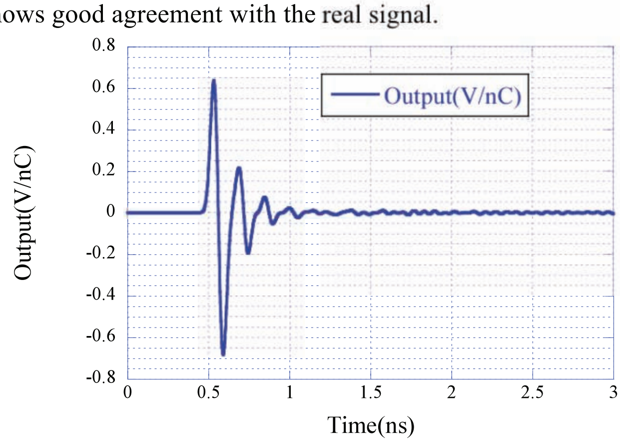

Fig. 3 Simulated time response of KEKB-FB BPM.

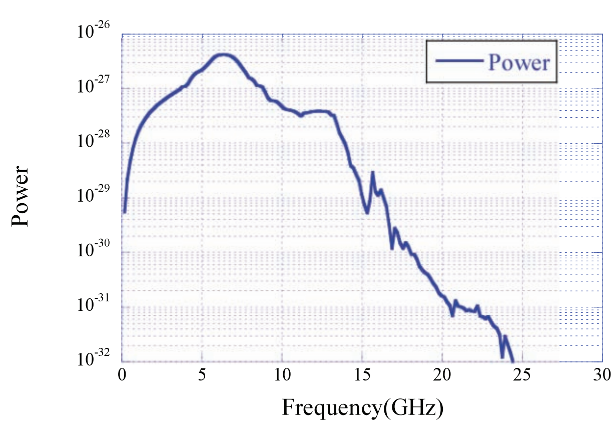

Fig. 4 Power spectrum of KEKB-FB BPM output.

The S-parameter of the electrode is also calculated with Ansoft HFSS (ver.11) under the condition of both button and SMA terminal being completely matched ports as shown in Fig. 5.

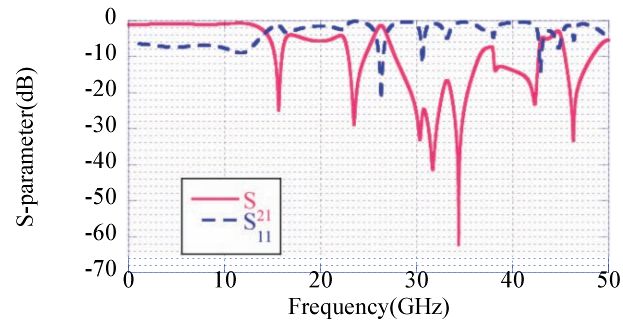

Fig. 5 Simulated S-parameter of KEKB-FB button electrode.

As is clearly shown, the lowest trapped mode of the electrode sits as around 16GHz. At KEKB, this resonance can be ignored because of the longer bunch length. However in future accelerator with much shorter bunch lengths, this characteristic makes the situation fairly difficult. Figure 6 and 7 show the simulated response in the case of σ_z=3mm.

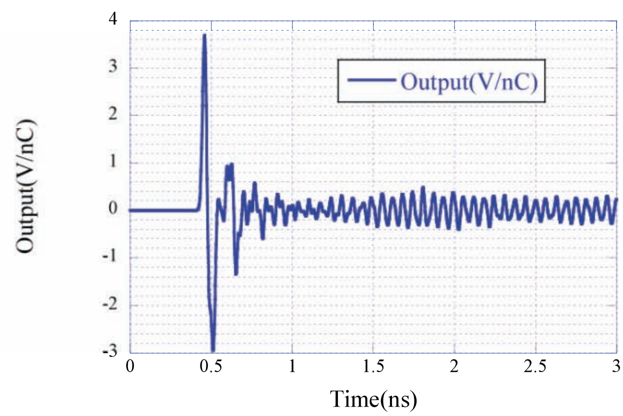

Fig. 6 Simulated time response of KEKB-FB BPM with bunch length of 3 mm. Note that we have used the narrower pipe (24 mm in diameter) for the simulation.

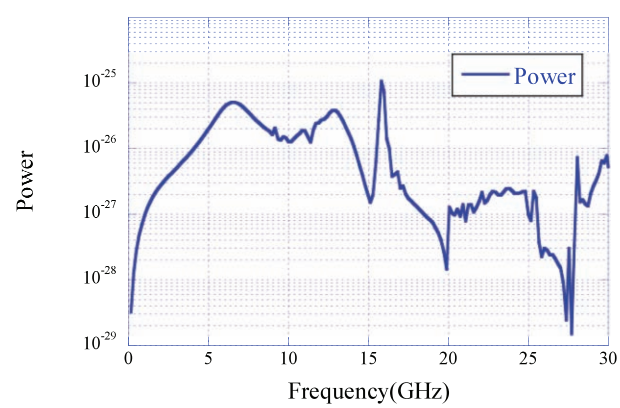

Fig. 7 Power spectrum in the case of bunch length of 3 mm.

The high-Q resonance around 16 GHz which is estimated to be coming from the ceramic part makes a long ringing tail. For a high beam current machine, this may heat up the ceramic which will cause fatal breaking of the vacuum seal.

BUTTON ELECTRODE WITH GLASS SEALING

To make impedance matching easier and to shift the possible trapped modes to higher frequencies, employing a low permittivity material as vacuum seal is always promising. We have designed the electrode using glass-type sealing with ε_r~4 (Kyocera KC-1), as shown in Fig. 8 (D01-type). The simulated S-parameter is shown in Fig. 9. Clearly it shows no suspicious structure up to 50 GHz. MAFIA 2D (e420) calculations also showed no trapped modes inside the glass seal under 50 GHz.

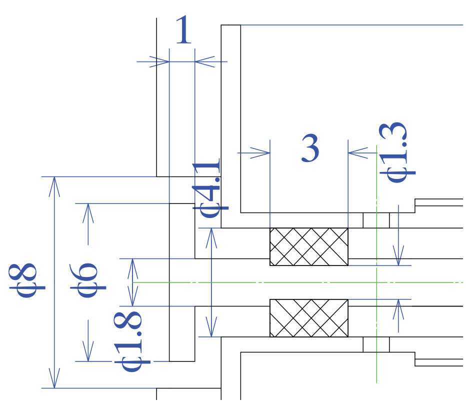

Fig. 8 Button electrode with glass sealing (D01-type).

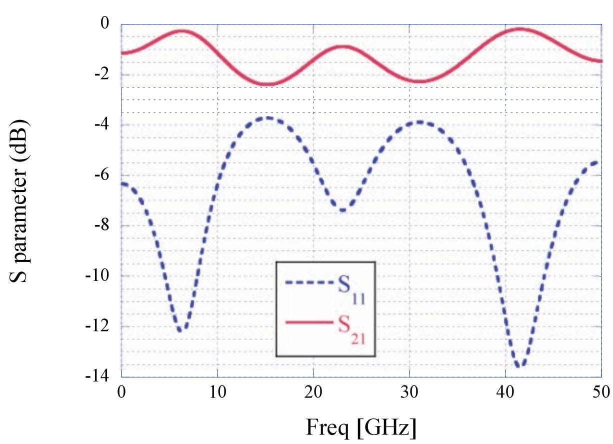

Fig.9 Simulated S-parameter of the D01-type BPM.

The feedthroughs must sustain various mechanical impacts such as fixing and releasing of the RF connectors. We have fabricated several test pieces that fit a pulling test machine with the same vacuum sealing structure, and have measured the breaking points. Figure 10 shows the results of D01-type feedthroughs and other simple feedthroughs with various diameters of inner conductors using KC-1 glass. Also the results of the KEKB-FB type feedthrough are plotted. In general, the mechanical strength of the feedthrough will be proportional to the area of bonding if the materials on both sides of the bonds

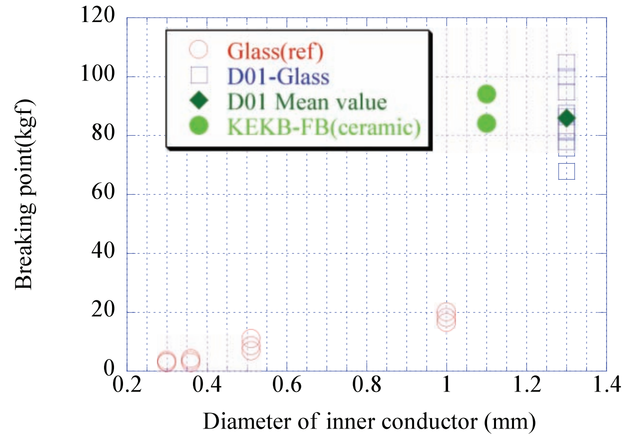

Fig. 10. Breaking points versus diameter of inner conductor.

are the same, as shown by the reference glass seal data. The D01-type feedthroughs show much higher tolerances. Note all the breaking of D01-type occurred in the inner conductors, not in the glass seal. The mean value of about 80 kgf is comparable to that of the KEKB-FB type.

The time response of the electrode is also calculated by GdfidL with the condition of 3mm bunch length and 1nC charge. Figures 12 and 13 show the time response and the

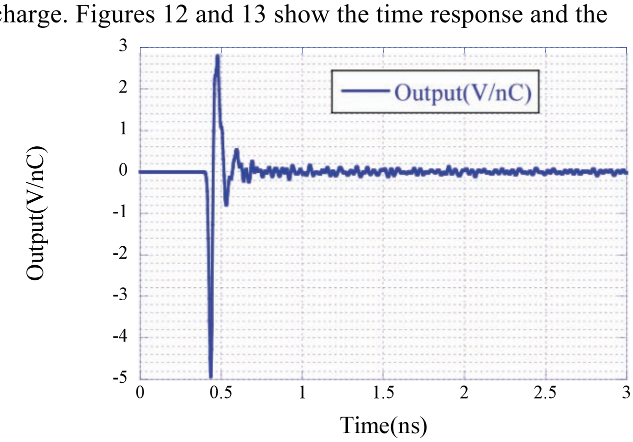

Fig. 12. Time response of D01 type electrode.

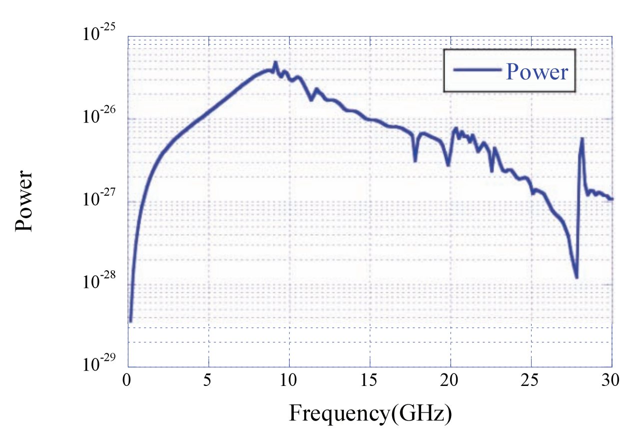

Fig. 13. Power spectrum of D01 type electrode.

power spectrum, respectively.

Next, we started to construct the bunch-by-bunch feedback monitor chamber of inner diameter of 64 mm made of stainless steel (SUS 304) on which we welded 16 D01-type electrodes and 4 KEKB-FB electrodes as reference. Very unexpectedly, during the welding process of the electrodes, we found 4 out of 16 D01-type feedthroughs had become damaged to show slow a vacuum leak, around the order of 1×10^{-10} Pa m^3/s. Though the monitor chamber itself was finally completed without a leak, we were afraid the leak would return again during beam operation. Since manufacture failed to find the cause of the leak, we have tried to examine the welding process by welding the feed-through on simple ICF070 flanges under completely controlled conditions.

The rate of the leaking feedthrough still exceeded 20%. Therefore, we decided to halt the installation of the chamber in the ring and to develop a much stronger feedthrough than the D01-type.

MODIFIED GLASS-SEALING TYPE ELECTRODE

The diameter of the inner conductor at the glass seal of the D01-type feedthrough is reduced from 1.8mm to 1.3mm. Due to this narrow cross section, it is needed to make the glass part in two halves and melt them together in the assembly process. Though this narrow part contributes to good impedance matching, we have decided to omit this part as shown in Fig. 15 (D02 and D03 type). Also we have added a small circular dip near the welding edge and made the thickness around the glass thicker than in the D01-type. For the glass-seal, two different materials have been selected. The first one is the same as the D01-type (ε_r=4, Kyocera KC-1):D02-type, and the other has larger ε_r =5 (Kyocera BH) but has better affinity to Kovar (D03-type). The S_{21} simulated by HFSS is shown in Fig. 16.

Though there still seem no obvious resonance structure up to 50GHz in all cases, both the D02 and D03 types have worse frequency response even with lower frequencies (around 10GHz) showing the impedance matching has been deteriorated by the modification to some degree.

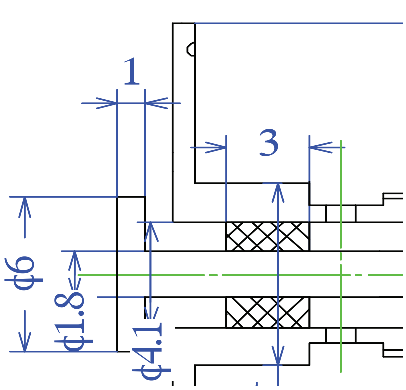

Fig. 15. Modified glass-type sealed electrode (D02 and D03 type).

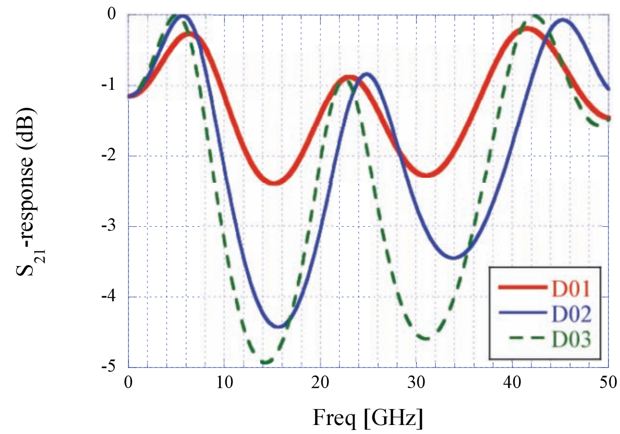

Fig. 16. Simulated S_{21} for three types of the electrodes.

Comparison of the results of time-domain simulation and power spectra by GdfidL for the three types are shown in Fig. 17 and 18, respectively

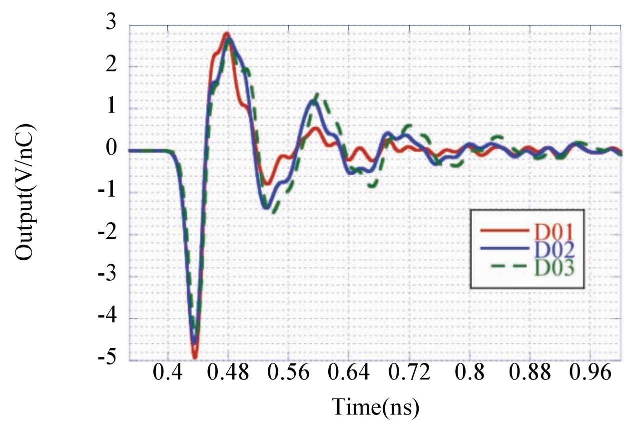

Fig. 17. Comparison of the time-domain simulation for three types of feedthrough.

The differences among the three cases are not so large, though the D01 type still shows the smallest ringing response among the three.

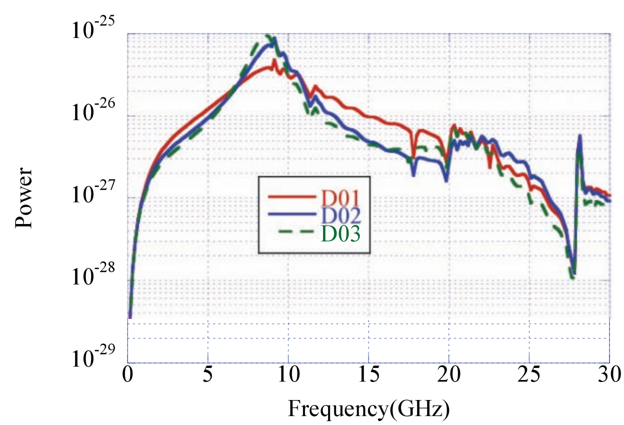

Fig. 18. Comparison of power spectra of three types of electrodes.

To obtain the real beam response of those electrodes, we made a test monitor chamber with KEKB-FB, D01, D02 and D03 type electrodes mounted and installed in the beam test line recently constructed near KEK-PF beam transport line from the 2.5GeV linac [4]. The bunch length is about 8 ps in FWHM. Note by tuning the R56 and T566 parameters, we can compress the bunch length down to 0.5 ps. Since we do not have a good timing line between the linac gun and the test line, we have used an ultra-wideband real time oscilloscope, the Tektronix DPO71604 (BW=16GHz, 50GSPS). Figure 19 shows the measured beam response for (A: KEKB-FB, B: D01, C: D02, D: D03).

Obviously the response of the D01 type electrode is the best of the four. Also, the KEKB-FB type electrode shows a long ringing tail similar to the simulation (the frequency of larger than 10 GHz) and it seems it is radiating the ringing components into the vacuum chamber and is detected with the other electrodes afterwards. The difference between D02 and D03 is not so clear.

DISCUSSION

We have fitted the first part of the response (starting near the falling edge to about 250 ps) by the derivative of a gaussian distribution. Since the sampling frequency was 50 GHz, it has about 14 points for the fit. Though all the fitted widths are within fitting error, the χ^2 parameter showed the relation, D01 << D02 < D03 ~ KEKB-FB. The deviation comes not only in the tail part but also near the falling edge, especially in the D02 and D03 types.

The differences between the D01, D02 and D03 types are not large, and all of them might be acceptable for bunch-by-bunch diagnostic systems in storage rings, such as SuperKEKB. For applications at much shorter bunch lengths, the response of the D01-type will not be sufficient. Since the mechanical tolerance around the inner conductor might be regarded as large enough, we can try to reduce the diameter for better impedance matching. To improve the heat tolerance in the welding process, further study and investigation will be needed.

SUMMARY

We have designed and tested button-type electrodes with improved time response. The mechanical tolerance of the feedthroughs including the shocks due to construction of the monitor such as the welding process have also been examined. The real beam response of the electrodes has been tested using a test beam line with very short bunches from a linac. Further development for better time response with enough strong mechanical structure is underway.

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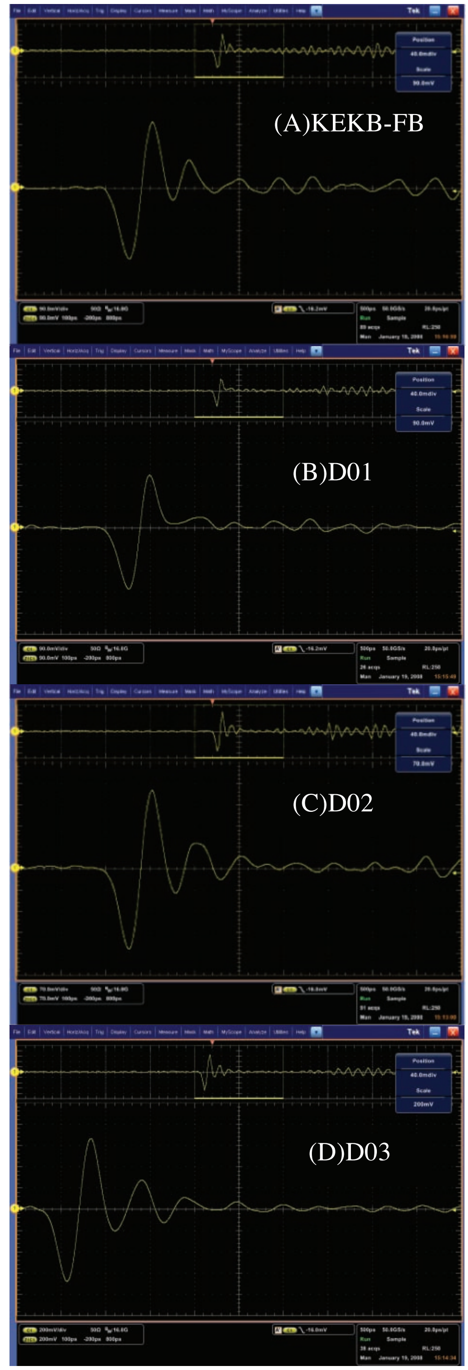

Fig. 19. Beam response of BPMs from linac beam.

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