ISBN: 978-3-95450-201-1 doi:10.18429/JACoW-IBIC2018-TUPB04

DEVELOPMENT OF A NEW BUTTON BEAM-POSITION MONITOR FOR BESSY VSR*

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Abstract

An extreme operation mode such as the BESSY-VSR conditions stimulates the development of a high accuracy bunch-by-bunch beam-position monitor (BPM) system which is compatible with the bunch-selective operation for the orbit feedback system. Such a system will also greatly benefit to accelerator R&D such as transverse resonance island buckets (TRIBs). Compensation of the long-range ringing signal produced by the combined effect of impedance mismatching inside the button and trapped TE-modes in the aluminum-oxide insulator (Al_2O_3) material is required essentially to improve the resolution. This is important since the ringing causes a misreading of the beam position and current of following bunches. We show the design study of a new button-type BPM to mitigate the influence of the ringing signal as well as to reduce wake losses by improving the impedance matching in the button and by replacing the insulator material.

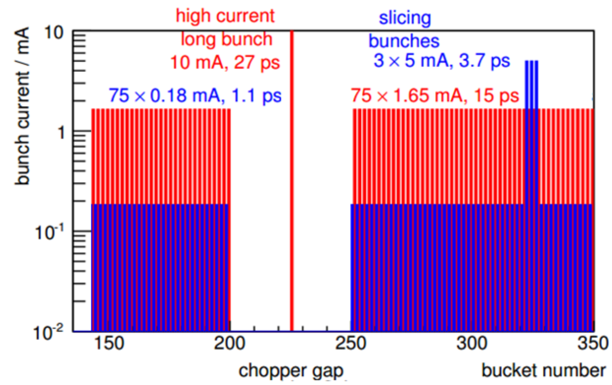

Figure 1: Section of a possible filling pattern with short bunches (blue) and long bunches (red). Trains of short bunches are added to supply THz power as well as high repetition rate short x-ray pulses.

INTRODUCTION

Since 2017, the Helmholtz-Zentrum Berlin launches the BESSY variable-pulse-length storage ring (BESSY VSR) project which is an upgrade project of the existing storage ring of BESSY II to fulfill the future increasing demands to study sub-picosecond, picosecond and longer dynamics in complex systems. This is feasible by installing additional superconducting cavities with harmonic frequencies of 1.5 GHz and 1.75 GHz [1]. The cavities will be installed in a straight section of BESSY II to create long and short photon pulses simultaneously for all beam lines. This also provides a high degree of flexibility in a bunch filling pattern. Potentially, it will lead to more complex filling patterns, such as shown in Fig. 1 [2].

The filling pattern, however, has the disparity in the beam current of long and short bunches since the long bunch buckets have relatively high bunch charge to preserve the present average brilliance of BESSY II. The short bunches are added to relax beam lifetime and to supply THz power as well as high repetition rate short X-ray pulses.

PRESENT BESSY II BUTTON BPM

From the measurement of the present button-type beam position monitor (BPM) signal with 1 mA single bunch with 1.25 MHz revolution frequency in the BESSY storage ring, we observed long-range and strong trapped modes inside the BPM. The trapped modes are also not fully damped within 2 ns, which corresponds to the bunch spacing in the ring, and it causes a signal superposition for neighboring bunches. Especially, the future filling pattern which has a large disparity in the beam charge between the short and long bunches such as BESSY VSR can cause a misreading of the beam position of the short (low-intensity) bunches. The measured BPM signal during single-bunch operation is shown in Fig. 2.

In the spectrum of the measured BPM signal, two strong trapped modes are present at the frequencies of 5.2 GHz and 5.5 GHz. Since the desirable transverse electromagnetic (TEM) mode is allowed to propagate at all frequencies, but at frequencies above the cutoff frequency (f_{cut}), the first higher-order mode (TE_{11}) is also allowed to propagate. The low-frequency cutoff for the undesired TE_{m1}-mode in a coaxial waveguide can be defined as [3]

$$f_{\text{cut}}^{\text{TE}_{m1}} = \frac{1}{\sqrt{\epsilon_r}} \frac{c}{\pi} \frac{m}{r_i + r_o}, \tag{1}$$

where r_i and r_o are the radii of the inner and outer conductors, respectively, $m = 1, 2, 3, \ldots$, which indicates the field variation in azimuthal direction, and ϵ_r is dielectric constant. Since the f_{cut} in a coaxial waveguide is inversely proportional to the square root of a dielectric constant of the insulator, the button has minimum f_{cut} value at the insulator.

In the BESSY II, the present button BPM has a diameter of 10.8 mm and gap of 0.3 mm. The thickness of button electrode is 2.6 mm and an aluminium oxide (Al_2O_3) insulator with the diameter of 11.4 mm and thickness of 3 mm was used for a vacuum seal. Therefore, the cutoff frequency at the insulator is 5 GHz. The source of the trapped mode is

* Work supported by German Bundesministerium für Bildung und Forschung, Land Berlin, and grants of Helmholtz Association.
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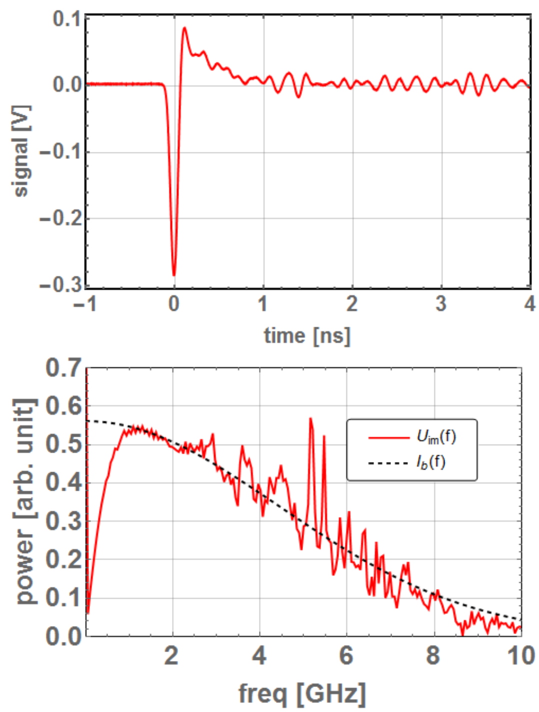

Figure 2: Measured single-bunch signal with the beam current of 1 mA (top) and the frequency spectrum of the signal (bottom) from the BESSY II button BPM. The curve named U_{im} is the Fourier transform of the measured signal and I_b is the spectrum of a Gaussian beam.

confirmed by a numerical simulation using CST-MWS [4]. The electric field distribution of the trapped mode is shown in Fig. 3.

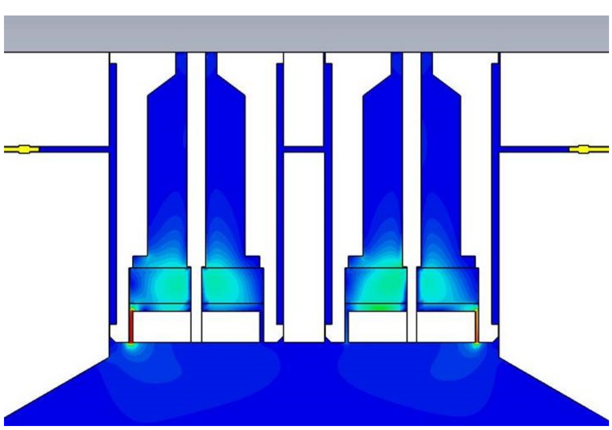

Figure 3: Computed electric field distributions of the trapped mode in aluminum oxide insulator of original button BPM at BESSY II.

NEW BUTTON BPM DESIGN

The vacuum chamber of one straight section including fourteen button BPMs will be completely refurbished for the installation of a cryomodule for BESSY VSR. Main considerations for a new button BPM design are the smaller vacuum chamber dimensions and the mitigation of the trapped mode. The dimension of the vacuum chamber is reduced to 24 mm × 55 mm to improve a vacuum condition and to secure the free space of 10 mm between the vacuum chamber and the magnet bore for heating jackets. The clearance gap between the button housing and vacuum chamber is also minimized to avoid the generation of high order modes. The new BPM buttons are planned to be directly welded on the vacuum chamber without flanges. In order to mitigate the coupling between the ports, the diameter of the button is reduced to 8.4 mm. The thickness of button is also reduced to 2 mm to enhance the signal intensity by reducing the capacitance of the button. The BPM chamber has an asymmetric shape to avoid the power deposited by synchrotron radiation. The cross-section diagram of the new button BPM is shown in Fig. 4.

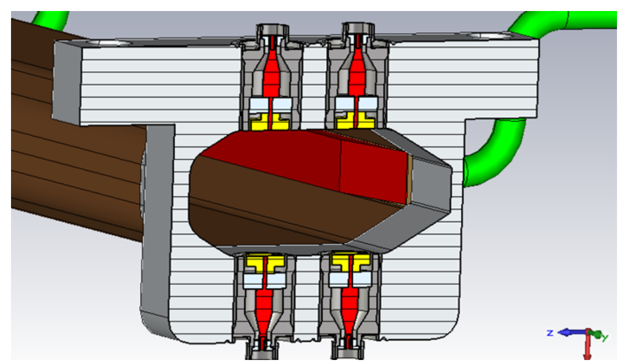

Figure 4: Cross-sectional diagram of new button BPM with diameter of 8.4 mm, thickness of 2 mm, and gap of 0.3 mm.

The insulator materials are evaluated carefully to satisfy a fabrication process and to push the cutoff frequency of the trapped mode higher such that it is damped fully within 0.5 ns. A fused silica (SiO_2), which has the dielectric constant of 3.74, is preferred. The internal button structure is also optimized to match with the impedance of 50 Ω for reducing TEM-modes reflected back to the chamber. The optimization of the relative edge position between the inner and outer conductor is performed because the direction of TEM wave at the edge is varied at the taper. The comparison plots of calculated impedance and signal behavior between old and new buttons is shown in Figs. 5 and 6.

Since the trapped resonance modes excited in the insulator and the gap between the electrode and button housing lead to heating and beam coupling instability [5], the longitudinal beam impedance as a function of the frequency is computed. Calculations have been performed for several combinations of gap, button size, and insulator material because the amplitude of the trapped resonance modes is relevant to the geometric dimension and the material of button, housing, and insulator. This is shown in Fig. 7.

The narrow gap can reduce the stored energy, thus, it requires tighter machining tolerance to avoid electric short between the button and the housing hole. The gap of 0.3 mm and the insulator material of SiO_2 are selected because it

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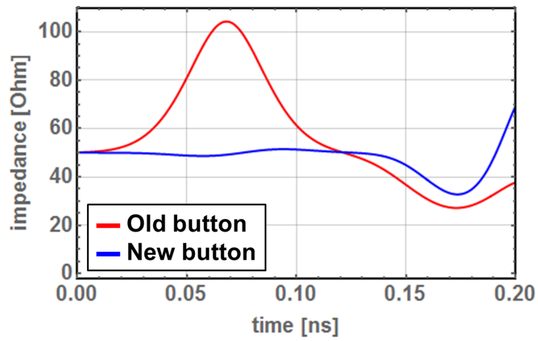

Figure 5: Comparison of calculated characteristic impedance between old and new buttons. The characteristic impedance of new button is almost constant at 50 Ω up to the end of button.

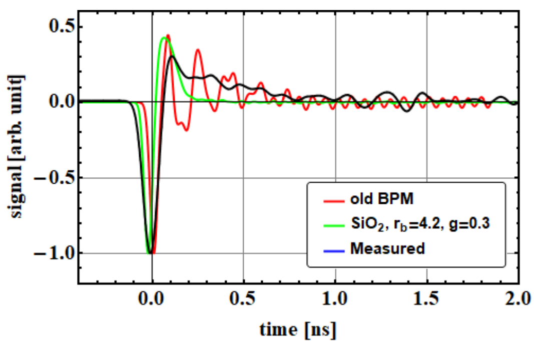

Figure 6: Comparison of signal behavior of old BPM (from CST), new BPM (SiO_2, r_b=4.2, g=0.3 / from CST) and measured signal from present BESSY II BPM.

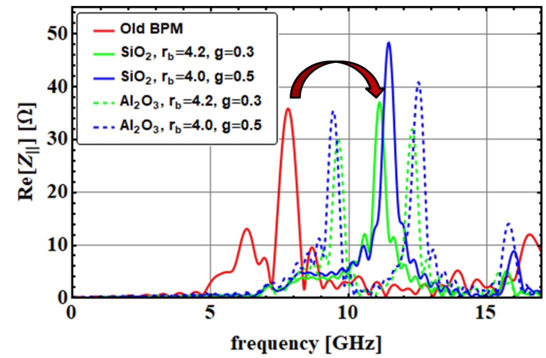

Figure 7: Longitudinal impedance as function of frequency for BPM buttons with various dimensions of button size and gap, and insulator materials.

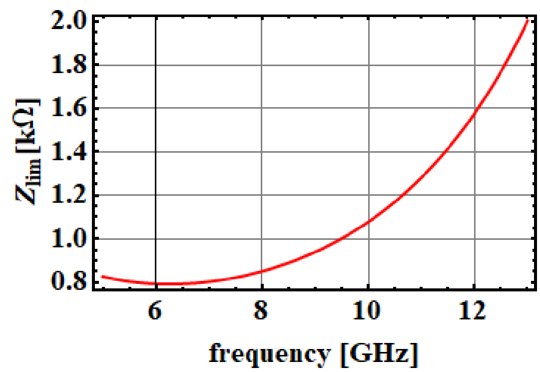

Figure 8: Acceptable limit of narrow-band impedance as function of frequency with bunch length of 18 ps.

has almost the same amplitude but has at a higher frequency. The gap of 0.3 mm is equivalent to the present BESSY II BPM button since we have experienced no troubles with the BPM. The material of the button is determined to be molybdenum, which has an electrical conductivity σ_{MO} =17 $\times 10^6$ S/m, because the power of the trapped more will be predominantly dissipated in the BPM chamber rather than in well-conducted button [6].

The acceptable limit of the narrow-band impedance for avoiding coupled-bunch instabilities is a function of the frequency of the resonant mode and is given by [7]

$$Z_{lim}[\text{k}\Omega] = \frac{3 \times 10^9}{f} e^{(2\pi f \sigma_z / c)^2}, \quad (2)$$

where f is the resonant frequency, σ_z is the bunch length, and c is the speed of light. In order to evaluate the effect of the longitudinal impedance, the acceptable limit of the narrow-band impedance as a function of the frequency is calculated with the bunch length of σ_z = 18 ps which corresponds to the nominal bunch length of BESSY II and long bunches of BESSY VSR. This is shown in Fig. 8.

The acceptable limit of the narrow-band impedance is relaxed when the resonance frequency of the trapped mode is increased. Since the new button has relatively high resonance frequency, the effect of the narrow-band coupled-bunch instabilities are not foreseen.

SUMMARY

We investigated the trapped mode in the present button BPM of the BESSY II storage ring which can cause a misreading of the beam position of neighboring bunches on extreme operation modes such as BESSY VSR [8] and transverse resonance island buckets (TRIBs) [9]. The trapped mode is produced by the aluminium oxide insulator in the button and the mode has a long decay time and the resonance frequency of 5.2–5.5 GHz. In addition to the investigation, the design study of a new button-type BPM is performed to mitigate the influence of the ringing signal as well as to reduce wake losses by improving the impedance matching in the button and by replacing the insulator material. The calculation result of the new button BPM shows great promise. It could be integrated with a recently improved treatment of RF-signals for bunch resolved position determinations at a few µm uncertainties [10].

REFERENCES

[1] A. Jankowiak *et al.*, "The BESSY VSR Project for Short X-ray Pulse Production", in *Proc. IPAC'16*, Bu-

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san, Korea, May 2016, pp. 2833–2836. doi:10.18429/JACoW-IPAC2016-WEPOW009

[2] A. Jankowiak, J. Knobloch, *et al.*, "Technical Design Study BESSY VSR", Helmholtz-Zentrum Berlin, 2015, doi:10.5442/R0001.

[3] A. Blednykh *et al.*, "NSLS-II storage ring BPM button development", in *Proc. IPAC'15*, Richmond, USA, 2015, pp. 748–750. doi:10.18429/JACoW-IPAC2015-MOPMN021

[4] CST-MWS, https://www.cst.com/.

[5] M. Masaki *et al.*, "Design optimization of button-type BPM electrode for the SPring-8 upgrade", in *Proc. IBIC'16*, Barcelona, Spain, 2016, pp. 361–364. doi:10.18429/JACoW-IBIC2016-TUPG18

[6] I. Pinayev and A. Blednykh, "Evaluation of heat dissipation in the BPM buttons", in *Proc. PAC'09*, Vancouver, Canada, 2009, paper TH5RFP014, pp. 3471–3472.

[7] C.-K. Ng *et al.*, "Simulation of PEP-II Beam Position Monitors", SLAC, CA, USA, Rep. SLAC-PUB-95-6899, May 1995.

[8] P. Schnizer *et al.*, "Status of the BESSY VSR project", in *Proc. IPAC'18*, Vancouver, Canada, 2018, pp. 4138–4141. doi:10.18429/JACoW-IPAC2018-THPMF038

[9] P. Goslawski *et al.*, "Transverse resonance island buckets as bunch separation scheme", in *Proc. IPAC'17*, Copenhagen, Denmark, 2017, pp. 3059–3062. doi:10.18429/JACoW-IPAC2017-WEPIK057

[10] F. Falkenstern *et al.*, "Accurate bunch resolved BPM system", in *Proc. IBIC'16*, Barcelona, Spain, 2016, pp. 312–315. doi:10.18429/JACoW-IBIC2016-TUPG03