ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPL079

BUTTON TYPE BEAM POSITION MONITOR DESIGN FOR THE ELETTRA 2.0 STORAGE RING

S. Cleva*, S. Bassanese, G. Brajnik, I. Cudin, R. De Monte, G. Loda, G. Pangon
Elettra Sincrotrone Trieste, Basovizza, Italy
M. Comisso, Dipartimento di Ingegneria e Architettura, Università di Trieste, Trieste, Italy
A. Passarelli, INFN - Sezione di Napoli, Napoli, Italy
C. Maletta, F. Niccoli, Dept. Mechanical, Energy and Management Engineering,
University of Calabria, Rende, Italy

Abstract

In order to fulfill the target performance of Elettra 2.0 light source, a brand new button type beam position monitor detector has been developed. From a theoretical point of view, the transfer function which relates beam position information to electromagnetic signal intensity induced on pick-up electrodes is well known. In practice, due to a number of constraints, a real device implementing this transfer function is difficult to manufacture. In this paper, a series of practical design considerations involving electromagnetic, mechanical, vacuum, maintenance, and cost issues are reported to illustrate the advantages and disadvantages of the conceived constructive solutions.

INTRODUCTION

The existing third-generation Italian synchrotron radiation facility Elettra [1], is going to be replaced by Elettra 2.0 [2, 3], an ultra-low emittance light source able to provide ultra-high brilliant and coherent photon beams. The quality of the photon beams relies both on the careful design of the machine optic and on the ability to maintain the optic set point stable in practical working conditions. A number of diagnostics and feed-back systems, each to the extent of its competence, will be in charge of ensuring the proper level of operating stability by promptly detecting and fixing any drift from the Elettra 2.0 target working point. In particular, the beam orbit diagnostic system [4, 5] will acquire the signals generated by about 168 beam position monitor electromagnetic sensors (BPMs), distributed all over the ring. This paper describes the preliminary study of two different button type (capacitive or electrostatic) BPMs to be used in the Elettra 2.0 storage ring.

BPM AS ELECTROMAGNETIC FIELD SENSOR

BPM's ability to effectively extract and propagate the beam position signals, maintaining any parasitic effect as low as possible at the same time, relies on a careful electromagnetic (EM) characterization and optimization of the geometry and of material choice. The EM interaction between the charged particle beam and both the sensing and non-sensing components of the BPM device is complex and

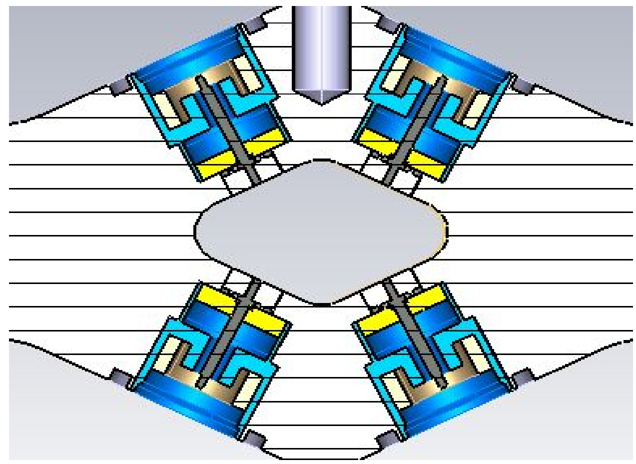


Figure 1: BPM with cylindrical pick up buttons.

dependent on the particular operating conditions of the accelerator. In high-energy electron synchrotrons, where the beam is relativistic ($\beta \approx 1$), the nearly pure transverse electromagnetic (TEM) propagation mode of the beam EM fields allows the derivation of simplified BPM analytical models for simple circular geometries [6, 7].

BPM DESIGN

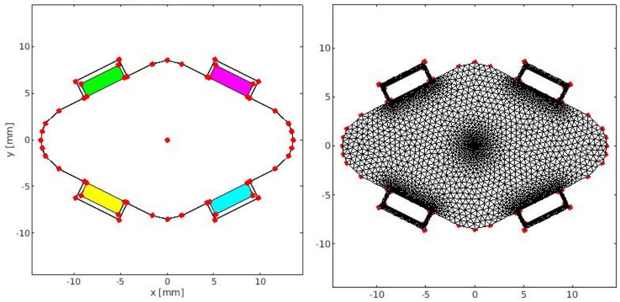
In the case of Elettra 2.0, any analytical approximation results not applicable because of the rhomboidal inner shape of its vacuum pipe (see Fig. 1). Therefore, it is necessary to resort on dedicated EM simulation tools. Among various available tools, both free and commercial, BpmLab [8] and CST Studio Suite [9] have been adopted.

BPM Geometric Distortion Evaluation

BpmLab is a 2D finite element-based software for Matlab. It has been utilized to assess the nonlinear distortion that arises in the calculation of beam position due to the bridge-like arrangement of the pickup electrodes and the off-center position of the beam. Figure 2a shows the locations of the four button type pick ups on the simplified outline of the rhomboidal vacuum pipe, where vertical and horizontal axis are 17 mm and 27 mm in length, respectively. Figure 2b shows the distribution of the mesh density and the areas of mesh refinement, which include the BPM geometric center and the electrodes. Assuming that a difference over

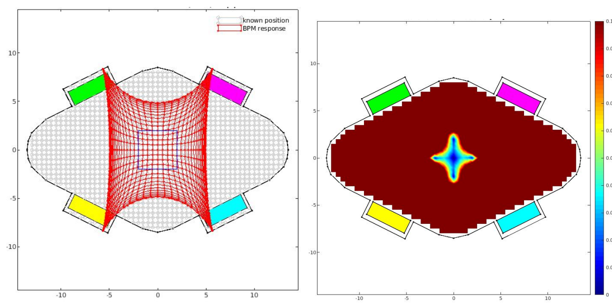
* stefano.cleva@elettra.eu

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPL079



(a) BPM cross section outline. (b) Mesh density.

Figure 2: BpmLab 2D simulations.



(a) DOS response map. (b) DOS error distribution.

Figure 3: BpmLab 2D nonlinear distortion.

sum (DOS) algorithm will be used to process BPM signals, Fig. 3a displays the response map of the simulated BPM, while Fig. 3b shows the corresponding error distribution. The BpmLab code also calculates the scaling factors K_x and K_y, which are calibrated in millimeters.

BPM Full 3D EM Simulation

CST Studio Suite is a 3D software package for EM analysis. It has been chosen to design, analyze and optimize the EM fields and currents inside the BPM to evaluate the mutual interaction between the beam and the device. The beam sensing capability of the BPM has been fully characterized by its beam coupling impedance and loss factor resorting on CST time domain wake field solver. Additionally, the scattering parameters and voltages at the signal ports on the diagnostics acquisition system side have been also assessed. Although CST allows for the evaluation of geometric distortion, the necessary computation time would be too extensive.

Due to the mechanical constraints induced by the small size of the Elettra 2.0 vacuum pipe, the buttons have to be necessarily kept small. As a result, a trade-off must be found between button diameter, position sensitivity, and induced signal level. Additionally, the parasite cavity behind the button must have a low Q factor, and the aperture gap should allow for low coupling with the TEM beam fields to avoid perturbing the beam-induced surface currents and maintain the BPM impedance as low as possible. Based on these considerations and the experience described in previous studies, such as Ref. [10, 11], the initial value for the button diameter is set to 5 mm, the gap width to 0.1 mm, and the button shape is bell like. The BPM model is shown in Fig. 4, where the cyan shape represents the dielectric material used for isolating the button pick up from the vacuum pipe. In order to compare the performance of different types of buttons, including cylindrical pick up buttons shown in Fig. 1, simulations will be conducted once the full characterization of the conical buttons is completed.

BPM Pick-up Button and Feedthrough Simulation

As soon as the beam induces charge on the pick up button surface, the corresponding current flowing inside the radio frequency (RF) feedthrough has to be driven up to the connector used for external cabling, that is along the coaxial structure shown in Fig. 5. Ideally, if the TEM propagation mode for the **E** and **H** fields associated with this current could be established and maintained throughout the signal propagation path, designing the RF feedthrough and pick up button assembly would be straightforward. This could be achieved by adjusting the ratio of the radii of the inner and outer conductors as a function of the square root of the dielectric permeability [12] (assuming the magnetic permeability of materials identical to that of the vacuum). This approach, however, would require a huge gap between the inner and outer conductors of the coaxial structure, which would compromise any effort to minimize the wake field effects. To find the best trade off between small gap and 50 Ω impedance matching, the frequency domain solver of CST Studio Suite must be employed to simulate the conical transition between the coaxial feedthrough and the pick up button (Fig. 5).

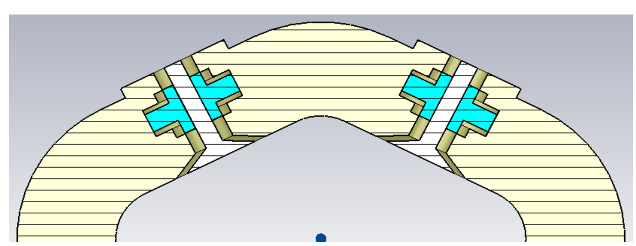


Figure 4: BPM with conical pick up buttons - half view.

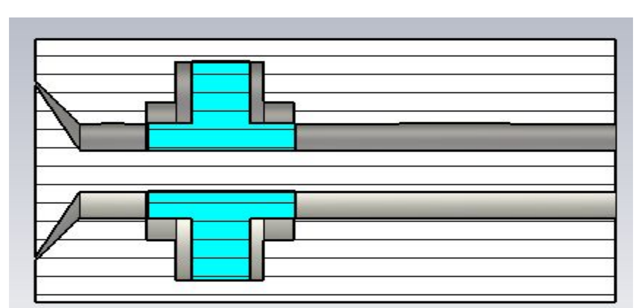


Figure 5: BPM feedthrough plus conical button.

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPL079

TYPE A AND TYPE B BPM

The BPM shown in Figs. 1 and 4, referred to as 'type A' from now on, uses welding to ensure vacuum sealing between the pick up button assemblies and the BPM body. Although this approach is widespread, it requires caution during the welding procedure to maintain the desired alignment of the pick-up electrodes. Furthermore, if high temperature sensitive dielectric is used, its location should be far enough away from the welding area. In case of failure, whether electrical or sealing, the whole BPM assembly has to be replaced.

If a sealing technology based on shape memory alloys (SMA) couplers [13] is used, the welding procedure can be avoided, but at the cost of a more complex mechanical and RF structure. Compared to the type A BPM, the type B one, shown in Fig. 6, needs to be extended radially along the RF feedthroughs (indicated in red) to leave room for hosting the SMA collars (indicated in black) and must be thick enough to withstand the compression force needed for vacuum sealing with minimal mechanical deformation. The RF feedthrough diameter is slightly smaller than the diameter of the corresponding hosting hole on the BPM body, so there is no mechanical interference that could damage the dielectric insulator due to compression. To reduce the effect on the coupled beam impedance of this parasitic cavity, an annular RF spring (indicated in green) can be inserted close to the pick-up electrode. Due to the diameter of the hole that hosts the RF feedthrough, less than 10 mm, low dielectric permittivity insulators are required to ensure the right ratio between the inner and outer diameters of the RF feedthrough conductors for 50 Ω impedance matching. Thanks to the temperature dependent mechanical characteristics of SMA materials, the sealing collar can be slackened and then tightened again for a number of times. This feature makes it possible to extract, replace and reseal the RF feedthrough assembly in case of BPM pick-up upgrade.

Both type A and type B BPMs have the same RF design of the pick-up buttons and RF feedthroughs, despite the differences in their sealing technology and related mechanical construction details. The type B BPM, however, due to its higher complexity compared to the type A solution, is expected to have a higher manufacturing cost. However, the flexibility introduced by the SMA coupler technology could make this additional cost acceptable.

CONCLUSION

The design of a brand new button type BPM is a complex task, which requires a careful evaluation of the whole set of interdisciplinary aspects involved in this kind of activity. Preliminary analysis has been conducted on the beam sensing features of the future BPMs, including geometric distortions, beam coupled impedance, and RF signal extraction, taking into account the limitations imposed by the small size rhomboidal vacuum pipe of Elettra 2.0. Two possible sealing technologies, traditional welding and SMA coupling, have been considered, and an accurate comparison between them is still in progress. At this initial phase, the effects of beam-induced heating and propagation of high-order modes within the RF feedthrough have not been taken into account.

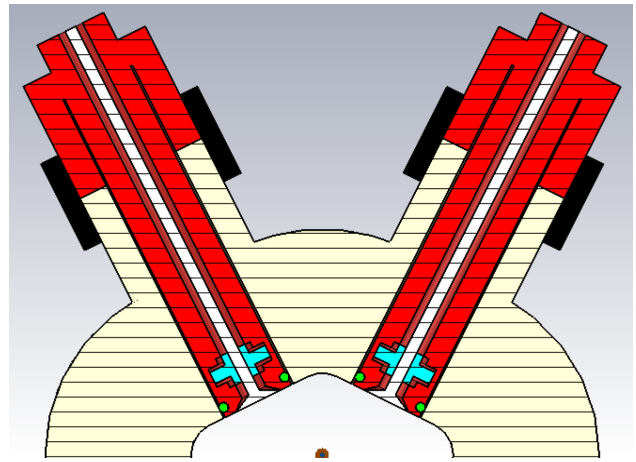


Figure 6: Type B BPM - half view.

REFERENCES

[1] E. Karantzoulis, A. Carniel, and S. Krecic, "Elettra, Present and Future," in *Proc. IPAC'19*, Melbourne, Australia, May 2019, pp. 1468–1470. doi:10.18429/JACoW-IPAC2019-TUPGW031

[2] E. Karantzoulis, "Elettra 2.0 — the diffraction limited successor of elettra," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 880, pp. 158–165, 2018. doi:10.1016/j.nima.2017.09.057

[3] E. Karantzoulis, "Elettra2.0 – Italy's lightsource for science and outreach," presented at IPAC'23, Venice, Italy, May 2023, paper MOXD2, this conference.

[4] S. Bassanese *et al.*, "Towards Elettra 2.0: Beam Diagnostics Overview," presented at IPAC'23, Venice, Italy, May 2023, paper THPL078, this conference.

[5] G. Brajnik, G. Gaio, R. D. Monte, S. Bassanese, and S. Cleva, "Elettra 2.0 eBPM: Complete System Overview," presented at IPAC'23, Venice, Italy, May 2023, paper THPL077, this conference.

[6] P. Lorrain and D. R. Corson, *Electromagnetic fields and waves :* 2nd ed. Freeman, 1970.

[7] A. W. Chao, *Physics of collective beam instabilities in high-energy accelerators*. 1993.

[8] A. A. Nosych, U. Iriso, and J. Olle, "Electrostatic Finite-element Code to Study Geometrical Nonlinear Effects of BPMs in 2D," in *Proc. IBIC'15*, Melbourne, Australia, Sep. 2015, pp. 418–422. doi:10.18429/JACoW-IBIC2015-TUPB047

[9] "CST studio suite getting started." https://www.3ds.com/

[10] H. O. C. Duarte, S. R. Marques, and L. Sanfelici, "Design and Impedance Optimization of the SIRIUS BPM Button," in *Proc. IBIC'13*, Oxford, UK, Sep. 2013, pp. 365–368. https://jacow.org/IBIC2013/papers/TUPC07.pdf

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPL079

[11] A. F. D. Morgan, "Technological Review of Beam Position Button Design and Manufacture," in *Proc. IBIC'19*, Malmö, Sweden, Sep. 2019, pp. 448–452. doi:10.18429/JACoW-IBIC2019-WEAO01

[12] T. Moreno, *Microwave transmission design data*. Dover Publications, 1948, vol. 459.

[13] F. Niccoli, V. Giovinco, C. Garion, C. Maletta, and P. Chiggiato, "Niti shape memory alloy pipe couplers for ultra-high vacuum systems: Development and implementation," *Smart Materials and Structures*, vol. 31, no. 6, p. 065 014, 2022. doi:10.1088/1361-665X/ac6999