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BUTTON-TYPE BEAM POSITION MONITORS FOR ELETTRA 2.0: FROM DESIGN TO REAL MEASUREMENTS

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Abstract

This paper describes the main stages of the journey from preliminary ideas on button shapes to actual measurements on prototypes of Beam Position Monitor (BPM) devices for Elettra 2.0. In the first stage, the electromagnetic phenomena involved in BPM sensors were studied taking into account different pick-up geometries, dielectric and conductive materials, and bunch lengths. Critical aspects such as beam coupling impedance, transfer impedance, impedance matching, trapped/propagating mode effects and heating were evaluated through numerical simulations. In the second stage, three families of vacuum-tight pick-up samples were fabricated in-house, and their actual performance was evaluated both on a microwave test bench and in real operating conditions on the Elettra storage ring. To carry out future measurements on alternative BPM designs, the third family was specifically conceived and built to allow quick and easy pick-up replacement using ultra-high vacuum (UHV) shape memory alloy sealing technology. The third stage focused on comparing the signals produced by the Elettra BPMs with those foreseen for Elettra 2.0, and also allowed validation of the in-house developed BPM electronics.

INTRODUCTION

The Elettra synchrotron light source is currently undergoing a major upgrade toward a new ultra-low-emittance storage ring, known as Elettra 2.0. The redesigned lattice will reduce the horizontal emittance by more than an order of magnitude, enabling the delivery of brighter, more coherent photon beams. Such performance improvements, however, impose stringent requirements on beam diagnostics and orbit control systems. In particular, the reduced beam size and tighter dynamic aperture demand beam position monitors with significantly enhanced sensitivity, linearity, and thermal stability compared to the present generation.

GENERAL CONSIDERATIONS ABOUT BPM DESIGN

A detailed description about the electromagnetic design criteria involved in pickups (PUs) is reported in [1]. Mechanical tolerances and vacuum constraints add complexity to the electromagnetic design. The main goals the BPMs have to get are:

- low beam coupling impedance, ideally as close as possible to resistive wall behavior. Impedance peaks, if any, should be located away from revolution harmonics and at the highest possible frequency;
- high transfer impedance at the detection frequencies (500 MHz and 1.5 GHz for Elettra 2.0);
- long time reliability;
- bake out compatibility;
- simple manufacturing to get device as close as possible each other, both mechanically and electromagnetically;

According to the reduction of the effect of the first trapped mode in cylindrical pick-ups, the conical shape has been adopted for Elettra 2.0 [2]. Both ceramic and glass have been evaluated by numerical simulations as insulating materials, but not yet tested. The delivery time of the prototypes represents a strong constraint in case redesign is required.

REAL DEVICES

In order to reduce the delivery time from theoretical design and real testing, three types of home made pickups, in the following indicated as generations, have been in house machined following an incremental manufacturing complexity approach. Once a generation has been proven reliable in real applications, the next generation has been designed and manufactured to overcome the limitations of its predecessor [3].

First Generation

A PU sample of the first generation is shown in Fig. 1. The PU body, made of stainless steel, is split in two parts screwed together. The central pin is made of copper, the insulator is made of steatite. The UHV proof capability is assured by a thin layer of UHV compatible glue deposited on the top of the steatite ring. The glue is also used for sealing and mechanically connect the PUs to the BPM body. This kind of PU is big enough to be easily assembled and glued by hand, without any extra tool. The signal induced by the beam is extracted through a commercial Sub-Miniature version A connector mounted of the top of the PU assembly. The main goal of the first generation PUs and the corresponding BPM device has been the validation of the UHV sealing capability of glued components in real working conditions.

Second Generation

The second generation PU is shown in Fig. 2. The PU body is made of stainless steel, the central pin of aluminum.

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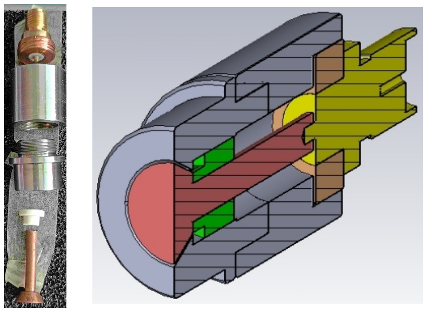

Figure 1: First generation home made pick-ups.

In this kind of PU the ceramic ring is not required because the UHV glue acts both as electric insulator and vacuum proof barrier. The nominal thickness of the glue is 1 mm. Due to the small size of such kind of PU, a dedicated assembly tool has been realized. Its goals are both to assure the right radial and axial mechanical alignment between the central pin and the PU housing, and to fix the insulator thickness, limiting the penetration of the glue up to a limiting surface. The glue is also used for sealing and mechanically connect the PUs to the BPM body. The signal induced by the beam is extracted through a 2.92 like connector. The main goal of the second generation PUs and the corresponding BPM device has been the validation of the quality of the signals induced by the beam in real working conditions.

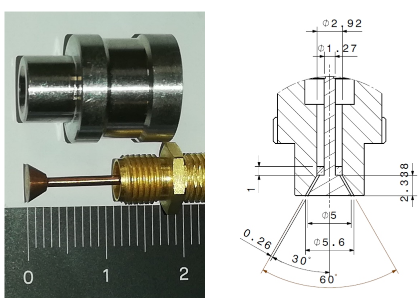

Figure 2: Second generation home made pick-ups.

Third Generation

The third generation PU is shown in Fig. 3. The materials, the sealing technology and the general design are almost the same already used in the second generation. The signal induced by the beam is extracted through a 2.92 connector. The sealing mechanism between the PU body and the BPM body is now based on shape-memory alloy (SMA) technology [4]. Compared to the traditional welding, the great advantage of SMA technology is the negligible thermal stress induced on the parts to connect each other [5]. To assure an effective vacuum tightness, the thermal cycle required for the SMA approach is of the same order of bake-out cycles, that means a maximum temperature of about 250 °C. A secondary advantage of SMA is the ability to open the joint between BPM body and each PU just by cooling the sealing collar with liquid nitrogen. This feature is very useful in case of diagnostics equipment validation, in particular button type PUs, that can simply be replaced by newer ones by just a thermal cycle and a gasket replacement. The full assembly of the third generation BPM body is shown in Fig. 4. A 40 cm long low gap vacuum pipe, from now named as combined BPM (CBPM), has been modified in order to host three groups of four PUs. Two groups have been assembled using eight third generation PU, while for third group a set of four commercial PUs based on ceramic insulation has been adopted. The close distance between the three groups, 10 cm, has been chosen to assure that the detected signals were as close as possible between corresponding PUs. The main goals of third generation PUs and corresponding BPM devices have been on one side the comparison of the beam induced signals and the corresponding calculated beam positions between different families of commercial PUs, on the other side the validation of vacuum sealing through the SMA technology.

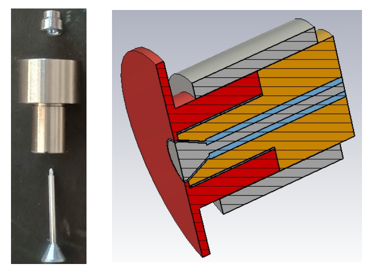

Figure 3: Third generation home made pick-ups.

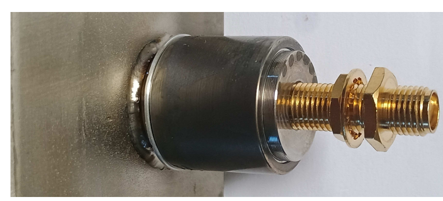

Figure 4: BPM body with shape-memory alloy.

TEST-BENCH VALIDATION

For each PU generation a number of samples has been manufactured and tested for both UHV and electromagnetic compliance to be used in a real particle accelerator.

UHV Testing

Once glued, each PU hermeticity has been evaluated measuring its helium leak rate, whose nominal value is less than 1×10^{-10} mbar L s^{-1}. Only the first generation PU samples required extra glue to fix the out of range helium leak rate. The first and second generation PU samples have been then glued on the corresponding BPM body, and the whole assembly, BPM body plus four PUs, has been tested to comply the target leak rate and operating pressure. Due to the different sealing technology, a heating cycle has been performed on a batch of eight third generation PUs assembled on the corresponding BPM body through SMA collars. Even in this case the UHV hermeticity has been tested and validated.

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Electromagnetic Testing

Once glued and hermeticity validated, each PU has been electromagnetically characterized through TDR (Time Domain Reflectometer) and VNA (Vector Network Analyzer) techniques measuring:

- its reflection coefficient, just by direct connection to a port of the measuring instrument;
- its reflection and transmission coefficient, as well as its transfer impedance, through a dedicated multi-port coaxial test bench;

To check that the full BPM assembling procedure had not altered the electromagnetic behavior of the PUs, independently of the technology adopted for PU-BPM body sealing, each PU has been tested by TDR once mounted on its own BPM body.

REAL MEASUREMENTS WITH BEAM

Both machine dedicated and parasitic shifts have been carried out to acquire real measurements of the signals captured by the different generations of PUs in different operating conditions and accelerator locations.

First Generation

Due to the uncertainty about the long time reliability of the glue vacuum sealing, the first generation PUs have been put at the end of the booster's pre-injector, in a location that could be immediately isolated by a vacuum valve in case of vacuum failure (Fig. 5). Single bunch and multi bunch injection scheme have been measured through a 6 GHz oscilloscope. Further details about the obtained results are reported in DEELS2025 (Diagnostics Experts of European Lightsources) [6].

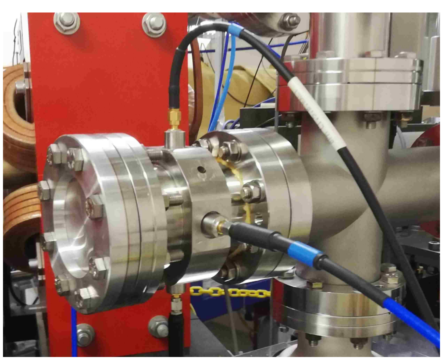

Figure 5: First generations PUs installed in Elettra preinjector.

Second Generation

The good results obtained by the first generation PUs, both in terms of acquired signals quality and vacuum tightness, made acceptable the risk of mounting the second generation BPM device in Elettra storage ring. Single bunch and multi bunch beam induced signals acquisitions have been performed at different stored current.

Third Generation

To further extend the signals comparison capability, the CBPM has been mounted in between two existing Elettra stand alone BPMs (respectively low gap and rhomboidal types). In such a manner a cascade of five groups of PUs very close to each other have been used to compare the signals generated by each group, see Fig. 6. Multi bunch response can be seen in Fig. 7.

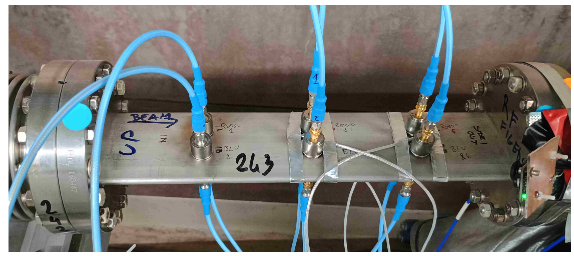

Figure 6: Vacuum pipe with different pickups (CBPM).

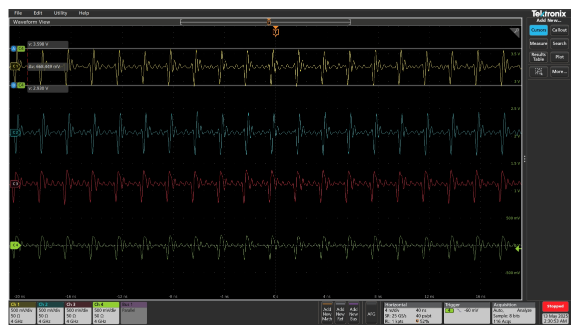

Figure 7: Multi bunch response of third generation PUs.

FULL CHAIN: BPMS AND ELECTRONICS

The new PUs have been connected to new BPM electronics developed together with Instrumentation Technologies, presented in Refs [7, 8], with first tests in Ref. [9]. The full series of 100 electronics have been already produced and shipped to Elettra. The flexibility of the modular design, which has a separate analogue front end, has been proven to be successful even in this case: three stages of amplifiers with fine variable gain can accommodate different response of the various pick-ups.

CONCLUSIONS

The experience gained during the design, test, debug and improve stages followed during the evolution from the first generation to the third one of home made PUs, has permitted to evaluate on time the electromagnetic behavior of the PUs foreseen for Elettra 2.0. The test bench tools have also been validated, making it possible to cut the testing and acceptance times once the definitive Elettra 2.0 PUs will be delivered. As a side effect, even the SMA technology has been validated as a reliable sealing mechanism that could represent an excellent alternative to the traditional welding.

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