NEWLY DEVELOPED 6mm BUTTONS FOR THE BPMS IN THE ESRF LOW-EMITTANCE-RING

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Abstract

For the small beam pipe of the BPMs in the LE-ring a development of 6mm button-UHV-feedthroughs was launched and has resulted in the delivery of a total of 27 prototypes from both the Kyocera and the PMB-ALCEN companies. These buttons are flat, without skirt, with a central pin of Molybdenum ending in a male SMA connector. Among these prototype units are versions with Copper, Steel and Molybdenum material for the button itself, with the aim of assessing possible different heat-load issues. All design considerations, that are compatible with a further button reduction to 4mm, will be presented next to issues of costs, mechanical tolerances and feasibility.

DESIGN ASPECTS OF THE SMALL BPM BUTTONS-FEEDTHROUGHS

The European Synchrotron Radiation Facility has decided to replace its existing double-bend-achromat lattice for 7-bend-achromat lattice that aims to reduce the horizontal emittance from 4 to below 0.15nm·rad. [1]

In this new Ring a total of 288 BPM stations (9 in each of the 32 cells) are foreseen with beam-pipe diameters much reduced with respect to the dimensions in the present Ring. The Fig.1 shows the cross-section of two examples of the preliminary design.

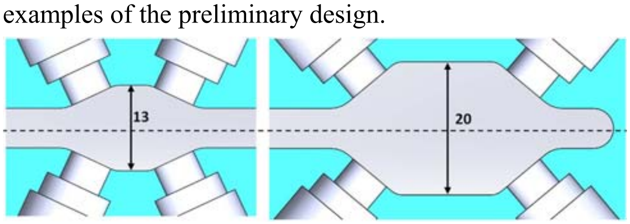

Figure 1: Cross sections of two different future BPMs.

In the existing Ring at total of nearly a thousand of buttons of 10mm diameter (but in BPM cross-sections of 70x34mm) have been successfully used for over 22 years for BPM purposes in a reliable way, i.e. without failures on the UHV aspects, or on the RF-signal pick-up aspects. This reliability issue was important to inspire the design of the new buttons.

For the new BPMs a diameter of 6mm for the button was decided and the study and the realisation of such button were pursued with two independent companies : Kyocera (Japan) and PMB-ALCEN (France). [2, 3]

The pictures in Figs.2 and 3 show the design of the entire button and feedthrough. The main characteristics can be resumed as follows :

- The button, the UHV feedthrough and the (male) SMA connector are all self-contained in one housing that can be (circularly) welded to its lodging hole of the BPM block. This design has successfully served the ESRF for its present ring and also avoids fully the use of vacuum flanges.
- The button (6mm diameter, 4mm height) is without skirt. It is brazed to the central pin and has a support ring (3mm) to the ceramic (but not brazed).
- The central conductor is of Molybdenum and forms the central pin of a standard SMA connector.
- The ceramic disk is of Alumina (Al_2O_3) and of 9mm diameter and 2.5mm height.
- The housing (13mm outer diameter) is of Stainless Steel.
- The concentricity specifications are at 50um between the button and the outside of the housing.

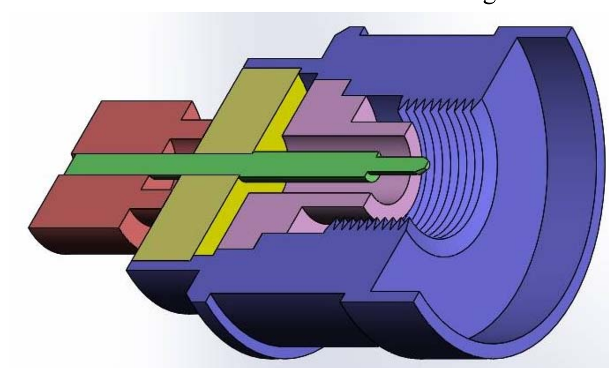

Figure 2: illustration of the button, central-pin-conductor, ceramic isolation, (male) SMA connector and housing.

All parts are prepared, assembled and then brazed according to the specific methods and technology of each of the two companies. The mechanical tolerances, and notably the concentricity, are accepted by each company as part of the final specifications at delivery.

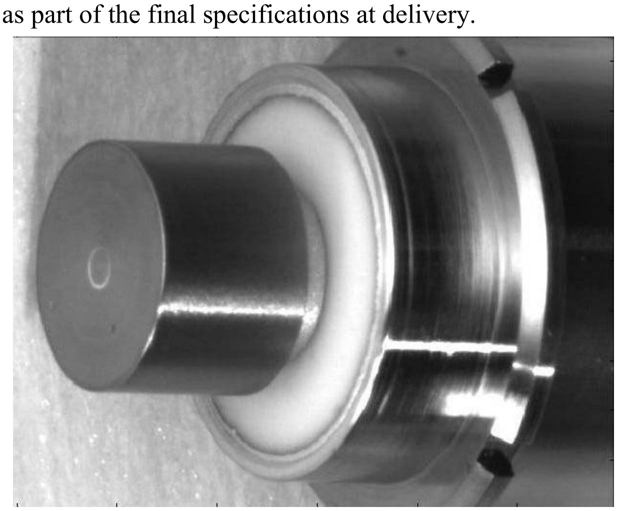

Figure 3: Photograph showing one unit with the 6x4mm button, its central pin welding and its support to the ceramic, and the UHV side of the housing.

The design of the outer body features two cylindrical rings at 9.5mm distance that should facilitate and ease these final delicate operations of correctly inserting it into its lodging hole and then properly welding it. These final operations (done by non-specialists) thereby avoid both the use of special tools or jigs and the risks of mal-positioning by twists or movements at the time of the welding.

The lower ring contains 4 small grooves to facilitate vacuum pumping.

The absence of the skirt (as present with today's buttons at the ESRF) was motivated by the possibility to maintain tight mechanical tolerances on both the buttons' concentricity and that of its lodging hole in the BPM block. The lodging hole, at the section of the button has a diameter of 6.5mm so the nominal gap around the 6mm button is 250um. With the (non-)concentricity specification at 50um we believe that this will not lead to any significant variations of the RF pick-up characteristics, or the heat-load issues.

The absence of the skirt also totally avoids any RF wake-field losses arising from the annular slot around the skirt. [4]

The values of any (non-)concentricity were easily measured, one by one, using a simple optical set-up after inserting the unit under test into a standard reception (or "dummy") hole. Out of a total of 27 delivered units we found the worst case at slightly above 60um, with a resolution/precision of the measurement set-up of about 10um. The Fig.4 shows two examples of images taken of 2 different buttons in that dummy lodging hole.

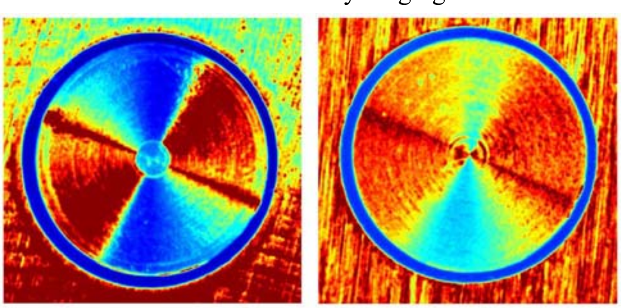

Figure 4: high-contrast images showing the 6mm button and the 250um gap around it, for a non-perfect (left) and close-to-perfect (right) concentricity.

Buttons of Steel, Molybdenum and Copper

The choice of material suitable for the button, but also for the central conductor pin, is mainly influenced by considerations of how much power the button could possibly absorb due to effects of RF fields trapped under different electron beam conditions (i.e. charge and bunch-length), and of the heat conductivity aspects that determine how any button heat-load will evacuate to the outside (i.e. BPM block).

The precise calculation of power absorption due to any RF trapping is far from straight-forward.

However, since the present Ring will still be operating for about 4 more years, and with beam conditions (total current, current per bunch, bunch length) quasi identical to that for the new Ring, we are going to use that opportunity by implementing a Test-BPM-Chamber in one of the straight sections. Not only does this make it possible to assess the button and BPM characteristics with beam now (as reported below) but also to follow-up carefully its behaviour over a time-scale of months and years.

This chamber holds three identical BPMs, adjacent at 60mm longitudinal distance, and each with 4 identical buttons. The only difference between the 3 BPMs is the material of the button. In agreement with the manufacturers we opted for buttons of Stainless Steel, Molybdenum and Copper.

RESULTS OBTAINED WITH 3 ADJACENT TEST BPMS IN TODAYS RING

The ID25 straight section offered sufficient space for the insertion of a Test-BPM-Chamber that itself holds three identical BPMs in the centre and tapered sections on both sides as shown in Fig.5. Not shown are a set of 4 bellows (2 on either side) and a motorized translation table that allows displacing the whole chamber +/-3mm in both planes from its central position.

Note that this translation system is presently not precisely calibrated and was therefore not (yet) used for K-factor and coupling measurements as described further below. However independent and precise position transducers will be installed later and shall then allow such measurements.

The cross-section of that BPM (conceived autumn 2013) is shown in Fig.6 and is different from that of today's foreseen geometries of real future BPM blocks (and shown in Fig.1) simply because of the past year's evolution of the possible vacuum chamber designs. Nevertheless, that Test-BPM cross-section is a good compromise between the two different BPMs, and it will be adequate to fully assess the behaviour and characteristics of these new 6mm buttons.

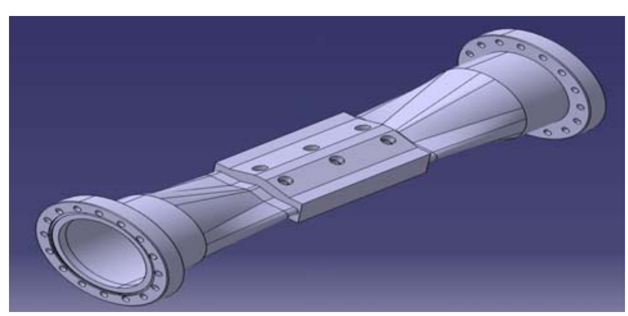

Figure 5: The Test-BPM-Chamber installed in the ID25 straight section of our Ring with 3 adjacent BPMs.

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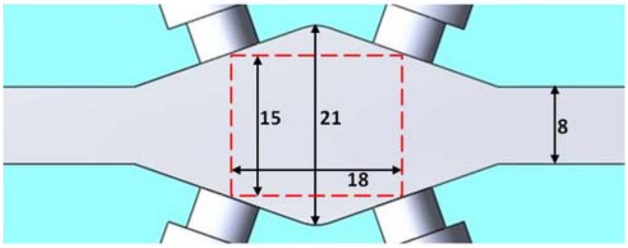

Figure 6: the BPM cross-section in the Test-Chamber.

No Heat-load Issues Measurable on any Button

During 1 week after the installation, all the 12 buttons have been equipped with a small sleeve that slides onto the central male-SMA pin. This sleeve has a small thermocouple integrated and the electric signal from that (via 2 thin wires) is acquired to measure the temperature on this point. This simple temperature measurement system is devised so to keep thermal inertia to a minimum and to obtain a temperature indication of this central pin-conductor with an absolute precision of about 1C and resolution of a fraction of that.

Such similar temperature measurement system had already been installed on the 4 buttons of a different BPM block in our Ring. This former Feedback-BPM block (adjacent to the ID straight section chambers) has a button size of 9.5mm, with a skirt (so also an annular slot around this skirt) and the internal vertical height of the chamber is only 10 mm. Horizontally and longitudinally the 4 buttons are arranged such that the distance between the beam and the centre of the button is only 9.4mm. This geometry is believed to provide rather favourable conditions of heating induced by beam and RF fields. The temperature readings obtained indeed confirm that heating occurs on these buttons since the differential temperature (with respect to the body of the BPM block) of these central conductor pins was evaluated at about 38C for a beam current of 200mA.

Today, doing exactly the same measurements on the 12 pins of the buttons of our Test-BPM-Chamber, we found no measurable temperature effect. The body of the chamber (measured by independent thermocouples) itself heats up from 23C (no beam) to about 35C (200mA) but the 12 measurements on the button-pins show no differential temperature rises. By consequence no difference between the 3 different button materials is measurable.

This method is not perfect since it measures on the pin and not on the button itself. From the design in Fig.2 it can be easily deduced that a considerable amount of (hypothetical) heat deposited in the button would be evacuated by the ceramic disk and then the housing etc. So any temperature rise on the pin only reveals a fraction of that on the button itself. Nevertheless, temperature rises on the pins of these former F-BPM buttons are clearly measureable while measurements with the same method on the new 6mm buttons show no effect at all. We therefore believe that there is no risk of heating issues with these buttons in our foreseen BPM blocks.

First Results from the RF Signals and the Beam Position Measurements Characteristics

The 12 button signals of these 3 BPMs have been connected to a set of 3 Libera-Brilliance units in an electronic cabinet via RF cables (RG-223) of about 25m length. The RF input of the Liberas is preceded by a 3dB attenuator and a 40MHz bandpass filter as is the case for all the other 224 units of our BPM system for beam position measurement and slow & fast orbit control.

The first measurements with beam allowed us to compare the strength of the RF signal (352.2MHz) generated by the 6mm buttons to that of the standard (10mm) buttons in our BPMs. This RF signal is about a factor 0.7 compared to that of the standard BPMs.

The coherency (also often expressed as the Q value of the BPM) of the 4 signals also looks satisfactory on each of the 3 BPMs.

The conversion of the relative strength of the RF signals measured on each of the 4 buttons into the position of the electron beam is usually done by the simple delta / sum formula. For e.g. the vertical plane this z coordinate equals : Kz $*$ (A+B-C-D) / (A+B+C=D).

At the time of starting the acquiring the RF signals from these Test-BPMs with real beam we had not yet made any calculation or approximation of these Kx and Kz factors. However, it was relatively straight forward to obtain these values by measuring the responses from the 3 test BPMs while making a set of precise beam displacement bumps in that ID25 section.

The ID25 straight section has two standard BPMs on its extreme ends : BPM C24/7 up-stream and BPM C25/1 down-stream. The distance between these 2 standard BPMs is 6015mm and the (1rst or up-stream) BPM in the Test-BPM-Chamber is at 1026mm distance from the C24/7 BPM. There is no magnetic element between these 2 standard BPMs. Moreover their K-factors are precisely known (error <2%) from independent measurements in the past [5].

By applying a pre-qualified local bump, using three adjacent steerers in that region, the beam's transverse displacement AND the beam's angular path can be determined by readings of these C24/7 and C25/1 BPMs. The so caused beam displacement in the 3 Test-BPMs is then simply calculated from the known geometrical distances. In the horizontal plane this was done for 21 different values : from -1mm to +1mm in 0.1mm steps. For the vertical plane we limited this range to 11 steps from -0.5 to +0.5mm.

This real beam displacement is then compared to the value yielded by the Test-BPMs in which a preliminary K-factor had been applied. After this the correct K-factor can be established which turned out to be 6.43mm for Kx and 12.44 for Kz.

These values have later been confirmed (within 1% error margin) by initial theoretical calculations of the electromagnetic field distributions in our BPM design using the CST Studio Suite software. [6]

But the scope and interest of this measurement go beyond finding these K-factors only for the centre of the BPM block : The linearity of these same factors can be assessed precisely when the beam is no longer close to the BPM centre. Having done the horizontal beam displacements over a +/-1mm range from the centre allows to see how the Kx factor varies over this range.

In each of the following figures the results of the 3 BPMs are shown by the 3 different colours (black, blue and red) of the curves.

The results shown in Fig.7 are for a beam displacement around the BPM centre : the Kx value varies only slightly (1.5%) from typically 6.43 to 6.53 for a 1mm displacement from centre.

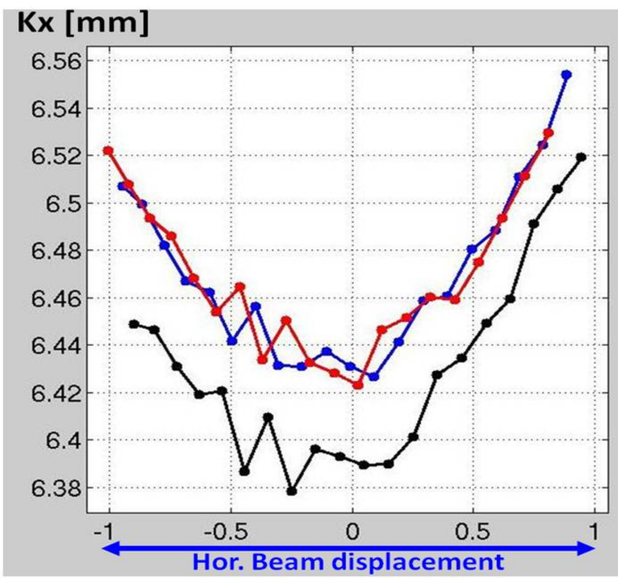

Figure 7: the variation of the Kx factors as function of the horizontal offset between the beam and the BPM centre.

The Fig.8 now shows the resulting value of Kx when the beam is about 2mm (both horizontally and vertically) away from the BPM centre. The K-factor now varies by about 18% (from 6.4 to 7.5).

In other words, the simple delta / sum formula is no longer adequate to convert the 4 button signals into beam position coordinates of reasonably good precision.

The 2nd effect of the too simplistic formula for the geometry of the BPM and its buttons is that it produces coupling between the 2 orthogonal planes. For instance the coupling from a (pure) horizontal beam displacement to a (fake) vertical beam motion is shown in Fig.9.

The green curve shows the vertical tilt of the beam displacement itself, i.e. a horizontal beam bump also produces some vertical bump but it can be measured independently by these 2 standard BPMs of C24/7 and C25/1. Please note that the 3 curves of BPM coupling have not been corrected for this.

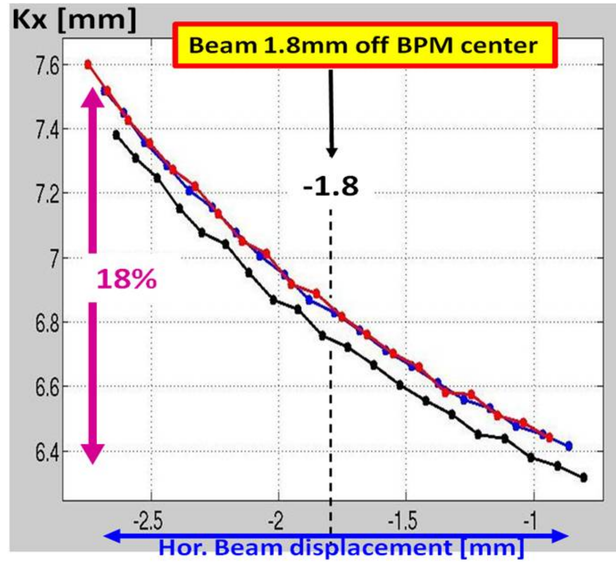

Figure 8: the Kx factor variation as in Fig.7 but now for a 2mm (both planes) offset between beam and BPM centre.

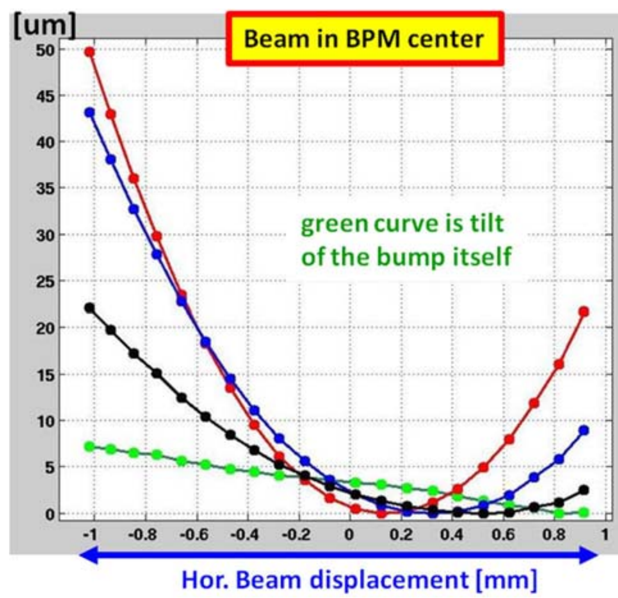

Figure 9: the coupling of the hor. beam displacement into (fake) vertical motion, for a centred beam.

The same coupling (hor. to vert.) was also measured with an offset (roughly 1.8mm for both planes) between the beam and the BPM centre. The results of that are shown in Fig.10 : The coupling now reaches strong values up to 300um but quite different for the three BPMs. This can be (partly) explained by the fact that the vertical offset of the three BPMs was quite different : i.e. +0.4, 0 and -0.6mm for respectively the up-stream, middle and down-stream BPMs. This could be explained by a vertical tilt of the BPM-Test-Chamber but this is not yet verified.

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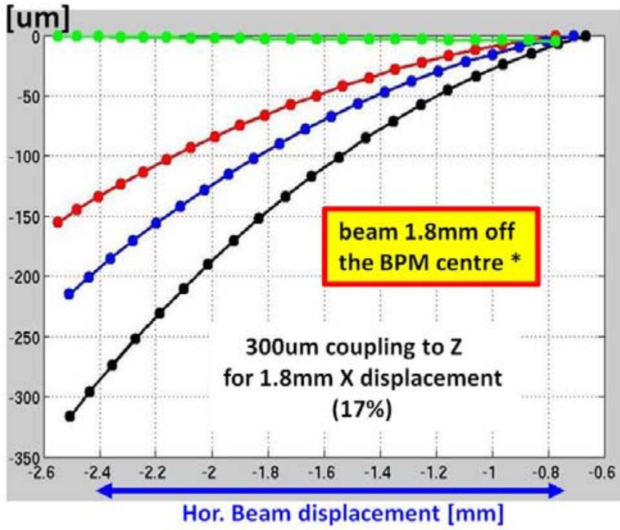

Figure 10: the coupling of the hor. beam displacement into (fake) vertical motion, for an 1.8mm off-centred beam.

Measurements of the (dis-)linearity of the Kz factor and of the coupling from vertical-to-horizontal plane have also been performed, as a function of offset between the beam and the BPM-centre. These are not reported here but lead essentially to the same observation of the restrictions of that simple delta / sum formula for beam coordinate calculation from the 4 buttons signals.

PRELIMINARY CONCLUSIONS AND FUTURE DEVELOPMENTS

The prototypes of new 6mm BPM buttons have been realised by two independent companies and have meet their specifications.

Subsequently integrated into a BPM chamber they have shown satisfactory characteristics and behaviour in tests of (only) 2 weeks since the installation in the Ring in August 2014. Both their RF characteristics for the use as a BPM system, and their apparent immunity to significant heat-load problems have been assessed.

Further measurements on the beam to characterise the BPM geometry will soon be possible in a straight forward manner and compatible with normal conditions under User operation. This is needed to obtain a precise "mapping" of that BPM geometry and for which a precisely calibrated motorized translation system will be used instead of the above beam bump methods.

In parallel, the simulations and calculations with the CST tools will be pursued for also different beam offsets from the BPM centre. This will be used to compare and validate a simulation model and then to apply it also the BPM geometries of the two real BPMs.

The simplistic delta / sum formula shows significant limitations and restrictions in terms of linearity and coupling, even for moderate offsets between the beam and the BPM centre.

The 6mm diameter button seems a good compromise so far but if simulations would show that a smaller diameter (down to 5 or even 4mm) would yield a more acceptable dislinearity & coupling when using simple delta / sum formulas (which have their own advantages) then technically both companies have confirmed that they can reduce the button diameter without any major change to the rest of the feedthrough itself.

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