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MECHANICAL DESIGN, FABRICATION AND CHARACTERIZATION OF ELECTRON BEAM POSITION MONITORS FOR SIRIUS

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Abstract

Beam Position Monitors (BPM) were designed and manufactured to meet Sirius operation requirements. Final dimensional accuracy and stability of the BPM were achieved by careful specification of its components' manufacturing tolerances and materials. AISI-305 Stainless Steel was used for the BPM support fabrication due to magnetic and thermal expansion constrains. High purity molybdenum for the electrode pin and Ti6Al4V F136 G23 alloy for housing were used to manufacture the sensor components for their thermal characteristics. The electrical insulator was made of high alumina. The materials were joined by active metal brazing process using 0,01mm accurate fixtures. The brazed sensors were subjected to dimensional, mechanical and metallurgical testing, as well as leak detection and optical microscopy inspection at each stage. The sensors were joined in Ti6Al4V F136 BPM bodies using TIG welding. Dimensional sorting was used to choose groups of sensors-to-body, and body-to-support pairs during final assembly. 160 BPMs are currently in operation on Sirius storage ring. In this contribution, we present the results of BPM manufacturing and testing processes developed for Sirius.

INTRODUCTION

Part of the mechanical design of the BPM pick-ups is consequence of electromagnetic analysis and impedance optimization. Duarte, H.O.C. discussed some proposed geometries, and the bell-shaped button demonstrated to be the best candidate considering electromagnetic, thermal performance and fabrication aspects. Advantages using reverse polarity and the button as a single pin with constant diameter were also discussed, as well as using threaded connection as RF shielding and as improvement of thermal contact [1, 2]. The objective of this work is to present the complete manufacturing workflow developed by LNLS for these components.

MECHANICAL DESIGN

The materials selection for the BPM pick-up components started with our experience with metal-ceramic brazing. Kovar and alumina were successfully used on metal-ceramic brazing for LNLS UVX previous machine, but Kovar's magnetic properties were avoided for Sirius in order to not disturb the magnetic fields.

The materials listed in the Table 1 were used for the BPM feedthrough's manufacturing.

Table 1: BPM Pick-Up Materials Properties

	CTE, linear (µm/m-°C) @20-1000°C	Modulus of Elasticity (GPa)	Tensile Strength, Yield (MPa)	Thermal conductivity (W/m-K)
Ti6Al4V	9,7	114	880	6,7
Molybdenum	6,5	330	324	138
Alumina 99%	8,3	-	-	35

Ti6Al4V alloy demonstrated to be a good replacement for Kovar at these geometries. Several prototypes were brazed and tested, and a reliable vacuum tight joint was achieved. Molybdenum was chosen for the button/pin given its thermal expansion coefficient close to alumina, but also because the higher the button electrical conductivity, the lower the button power dissipation [3, 4].

A cross section of the BPM pick-up showing its materials and joining processes is presented in Fig. 1.

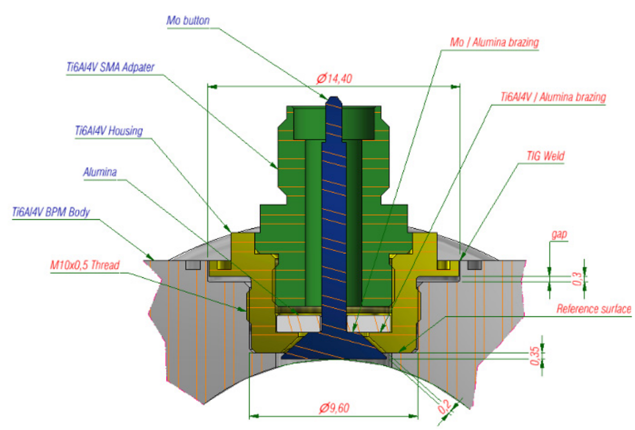

Figure 1: BPM pick-up cross section.

Ti6Al4V as a material for housing also allows for a TIG welding process to be made to the BPM body, as long as the body is also made of Ti6Al4V. The SMA adapter was also fabricated on the same material so it could be TIG welded on BPM housing. Ceramic disks made from alumina 99% (Al_2O_3) and 1mm thickness were used as insulator.

The main premise for the geometry constraints is that there would not be any kind of adjustments in BPMs position. It was designed to be positioned in place, fixed, and its own geometry constrains place the sensors at the correct position. Thus, tight tolerances were necessary on lateral and horizontal contact faces at both support and BPM body. These faces were used as references when positioning the support over the girders, and the support faces used as reference for body positioning as show in Fig. 2.

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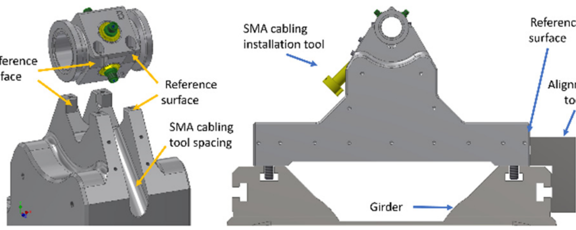

Figure 2: BPM body and support positioning.

For the support, LNLS decided to opt for a material with CTE closer to the magnets material's CTE (SiFe). The premise is that if a thermal variation on the ambient occur, both materials should expand or contract at similar levels, reducing the relative movement between them. Given the lower permeability of SS305 and lower price, it was chosen as the material for the BPM support.

BPM MANUFACTURING

BPM Feedthroughs

Pairs of Mo pin and Ti6Al4V were matched based on the actual dimensions after machining and inspection, in order to minimize the offset error of the assembled pair. This way offset tolerance deviations could be minimized.

The BPM feedthroughs were brazed in a high vacuum furnace, using 0,01 mm accurate fixtures. Ticusil (Ag-26.7Cu-4.5Ti wt%) active metal alloy was used as filler metal. Figure 3 shows a simplified schematic of the BPM feedthrough and its components.

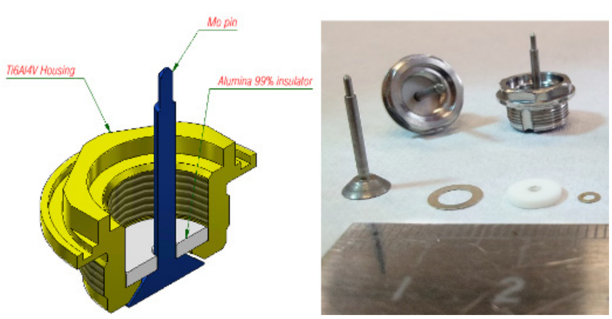

Figure 3: Schematic of feedthrough and its components.

The feedthroughs were subjected to leak test after brazing, dimensional inspection, visual inspection, capacitance testing, short circuit testing and a go / no go mechanical strength testing to check its vacuum tightness reliability, applying a 45N force over the pin while being leak tested.

BPM Body

BPM feedthroughs were classified according its dimensional offset after brazing, and the same classification is made on each of the four BPM feedthrough sit surfaces on each body after the Coordinate Measure Machine inspection.

A dimensional sorting was made to match each feedthrough to each sit surface in order to improve the mechanical symmetry on each BPM body. This procedure was also recommended in order to improve the symmetry of thermal loading conditions and minimizing the deformation asymmetry [2].

TIG welding was executed to join the feedthroughs to the body. The weld of each feedthrough is proceeded by visual inspection in stereoscope and leak detection testing after the welding of each face of the body. After the four feedthroughs are welded and leak tested, another visual inspection using the stereoscope and final leak testing is performed in the body to guarantee the leak tightness of the component. The final welded body is shown in Fig. 4.

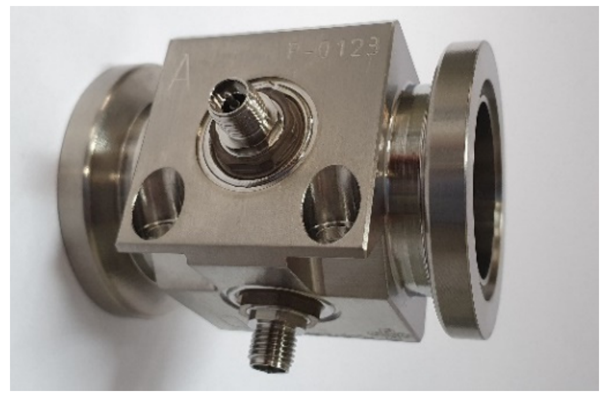

Figure 4: BPM bodies after welding.

BPM Support

The BPM supports were sand-casted in 305 stainless steel and heat treated to improve its non-magnetic characteristics, in a preform shape close to the final dimensions. X-ray analysis was performed in samples to guarantee the supports were free of voids, cracks or inclusions. After casting, the metal was machined to its final dimensions and subjected to CMM dimensional inspection. BPM supports after casting and after machining are shown in Fig. 5.

Figure 5: Casted metal and machined supports.

Sorting was also used to find the best BPM bodies and BPM supports pairs aiming to reduce clearance from machining deviations. Based on the fitting dimensions of each component, it was possible to reduce the overall clearance of the complete BPM array globally.

PICK-UPS MECHANICAL CHARACTERIZATION

Three types of strength setup tests were performed in order to measure the feedthroughs mechanical strength. The first setup was designed to measure the loads that the feedthroughs are subjected when attaching and detaching an SMA cable. A mechanical device was built such as a sole button/pin piece was mounted on top of a load cell, and the SMA adapter (green piece in Fig. 1) fixed in the correct position outside the load cell. A calibrated 0.9 N.m torque wrench tool was used to perform several attaching and detaching procedures of a commercial reverse-polarity SMA connector. Positive forces were recorded as pushing the pin against the load cell and negative forces were recorded as pulling forces from the load cell. A maximum force of 45 N was recorded while most of the forces ranged between +20 N and -10 N. The results and can be found on Fig. 6.

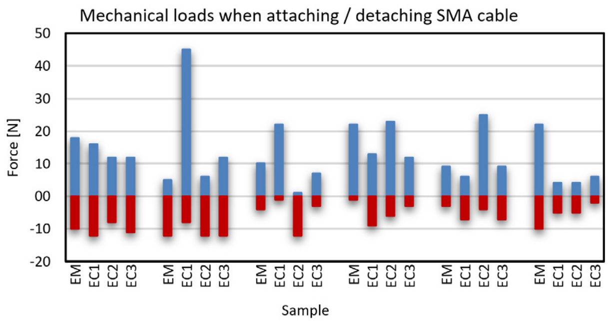

Figure 6: SMA cable mounting loads.

The second test was designed to measure the maximum strength a pick-up button would withstand before collapsing or starts leaking. It was applied a force parallel and against the pin button, at the same time that a leak testing was being performed on the feedthrough. When any of the conditions above were met, the test was stopped and the maximum force was recorded.

While one sample resisted 201 N, most ranged between 400 N and 900 N of maximum force before collapsing. These samples presented no leaking before collapsing, the only leak detected after catastrophic failure. The results can be found in Fig. 7.

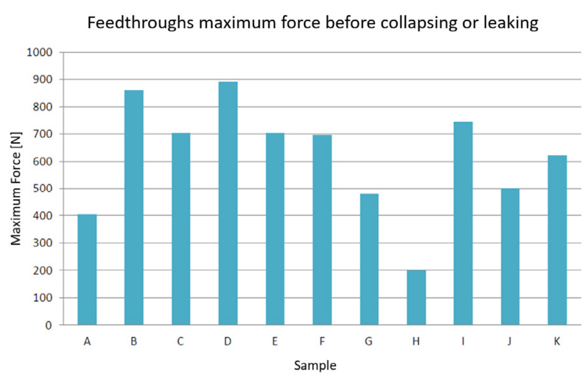

Figure 7: Maximum feedthrough strength results.

All the projected force loaded the brazed joint between the ceramic disk and the Mo button. The failure occurred in the ceramic, indicating that the brazing has a higher mechanical strength than the ceramic material itself at these conditions.

The last test was designed to apply a perpendicular force against the button pin while performing the leak testing. That force would either bend, break the pin or shear stress the brazed joint until failure or leaking while being flexed. The recorded forces can be seen in Fig. 8. While one pin leaked with 19 N, most forces required to bend the pin ranged between 28 N and 32 N, and no leaking occurred. The test was stopped when the actuator reached the limit of the course. Figure 9 shows the bended pins after the testing still leak tight. This indicates a high ductility of the pin and high mechanical strength of the brazing.

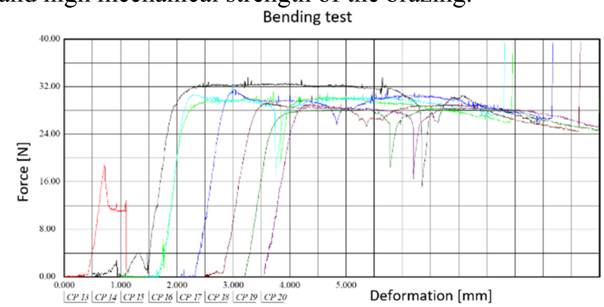

Figure 8: Applied force while bending the pins results.

Figure 9: Pick-up buttons after bending test.

After installation and Sirius commissioning, Beam Based Alignment demonstrated that more than 90% of BPMs had electrical error under 250 µm, as seen in Fig. 10, which is half of the nominal tolerance for Sirius: 500 µm.

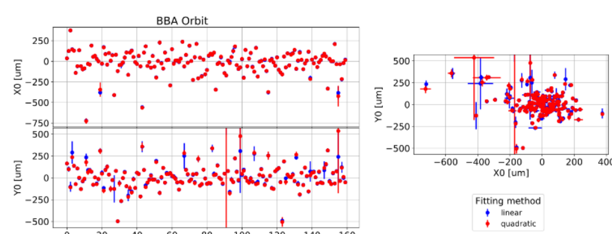

Figure 10: BBA results.

CONCLUSION

160 BPMs were manufactured and installed by LNLS in Sirius storage ring. They are currently in operation and BBA indicated good preliminary results. More than 2000 feedthroughs were brazed between development and final production. It was possible to estimate mechanical forces that a pick-up is normally loaded and test the strength limits of the developed brazed part. Results demonstrated safe operation, good reliability and vacuum tight capable manufacturing processes developed by LNLS.

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