# CONSTRUCTION AND QUALITY CONTROL OF SYNCHROTRON SOLEIL BEAM POSITION MONITORS

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## *Abstract*

SOLEIL is a third generation synchrotron light source built in Saint-Aubin, South of Paris. Due to the high performance required for SOLEIL's diagnostics, a special production procedure was tailored. During the production of 131 Beam Position Monitors (BPM) more than 500 feedthroughs were inspected; all of them passed strict tests at different stages of the production: leak test ($<10^{-10}$ mbar l $s^{-1}$), dimensional controls (tolerance < 0.050 mm), vacuum tests (specific outgassing rate $< 10^{-12}$ mbar l $s^{-1}$ $cm^{-2}$, residual gas analysis) and electrical tests (capacity measurement ~8pF, insulation >50 MΩ, conduction better than 0.1 Ω). All the established procedures and tests have been performed in a tight partnership that was more than a simple contractual framework, and in which an intensive collaboration led to knowledge transfer between SOLEIL and Rial Vacuum. The result has been a high percentage of success (only a few feedthroughs over 500 were replaced) during preliminary tests and a deeper knowledge of "BPM problem solving"; in this article the test procedures to obtain high quality and high performance BPMs are presented.

## INTRODUCTION

The very tight space between the multipole magnets of SOLEIL where the BPMs are installed, prevents the access to their coaxial cable connections. In order to solve the problem, SOLEIL decided to design a new high vacuum SMA feedthrough longer than the ones available on the shelf. Saint-Gobain Solcera designed the feedthrough with SOLEIL providing the electrical engineering expertise. Saint Gobain provided the metal-ceramic and metal-metal brazing expertise for ultra high vacuum in addition to fabricating 550 feedthroughs. SOLEIL ordered separately the BPM fabrication to Rial Vacuum who machined the BPM blocks, assembled them with their bellows, TIG welded the four feedthroughs on each BPM block, performed all the quality checks including baking, vacuum leak tests, and electrical tests. RIAL vacuum and SOLEIL had to address a specific problem with the feedthroughs that arose during the fabrication. Some of them, that were vacuum proof before welding, leaked after various stages of the fabrication and had to be replaced. It is a delicate operation involving more than mechanical expertise. This paper describes the electrical tests that took place during the fabrication process as well as the feedthrough replacement procedure.

## SMA FEEDTHROUGH DESIGN

The feedthrough is shown in figure 1; it is 47 mm long with the SMA connector on one end and the button electrode on the other. The vacuum tightness is assured by an alumina ring brazed in the coaxial structure. An isolator in silica keeps the SMA central pin in position.

The characteristic impedance of the coaxial structure is almost everywhere 50 Ω: in air, alumina and silica. The diameter ratios are computed with the formula:

$$Z_c = \frac{60}{\varepsilon_r} \mathrm{LN}(D/d)$$

with $\varepsilon_r$ the dielectric permittivity (1 for air, 3.8 for silica and 9.5 for alumina); LN the natural logarithm; D the inner diameter of the outer conductor and d the diameter of the inner conductor.

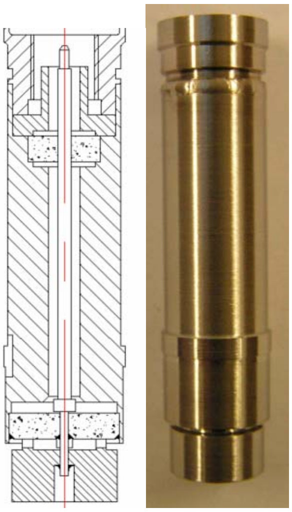

Figure 1: SMA 50 Ω vacuum feedthrough.

The air-to-silica and air-to-alumina transitions have been optimized with the 3D electromagnetic code GdfidL [1]. The results of the time and frequency domain simulations are shown in figure 2a and 2b. The characteristic impedance is nearly 50 Ω all the way from the SMA connector up to the end of the alumina.

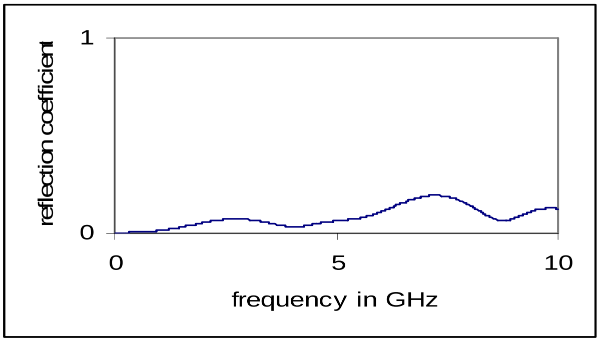

Figure 2a: Frequency domain reflection (GdfidL simulation)

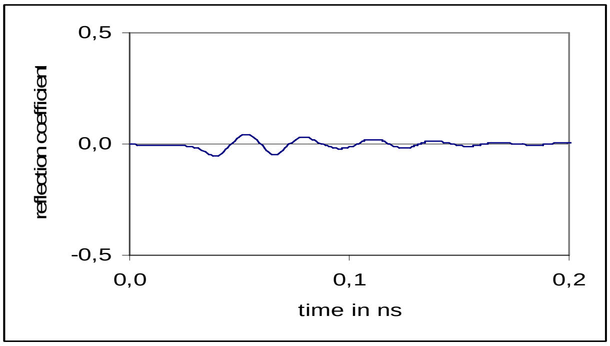

Figure 2b: Time domain reflection (GdfidL simulation).

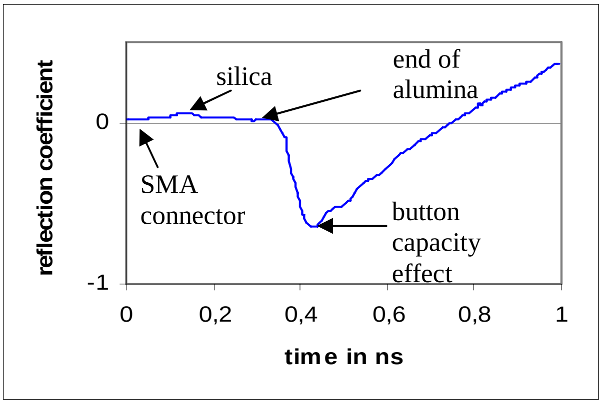

Figure 2c: Time Domain Reflectometer measurement (Agilent model 54754A). The 0-to-0.34 ns part of the graph represents the coaxial structure of the feedthrough, but the timescale has to be divided by 2 for an actual comparison with graph 2b. The signal after 0.34 ns corresponds to the button capacity.

The graph of figure 2c is taken on a feedthrough mounted in its BPM block so that the button capacity can be known by measuring the slope of the curve. The button sensitivity depends on its capacity. Different button capacities on a BPM create crosstalks between horizontal and vertical plane measurements. In addition to the dimensional controls and leak tests, all button capacities have been measured at Saint-Gobain on a reference bore before being sent to RIAL vacuum. They were placed in a box by order of increasing capacity.

## TEST AND PROCEDURES

During the Beam Position Monitor (BPM) production at Rial Vacuum different manufacturing processes were involved: turning, milling, wire cutting and TIG welding; among them the most demanding process was the feedthrough hole milling. In order to have the electrical center very close to the geometry center, the four buttons must have the same capacitance within 7%. For achieving it, the four holes must be very precisely dimensioned and located, within a few hundredth of millimeter.

Milling: After the milling process the feedthroughs were inserted into the holes for a first capacitance measurement. This is to make sure that the four feedthroughs once inserted in their actual hole were still matched. In order to check that the measured capacities will be stable after welding, the feedthrough was slowly rotated in its bore while monitoring its capacity. The tolerance was set to 3%. At the same time the four buttons of a BPM must have the same capacity within 5%.

TIG Welding: Once the feedthroughs in place they were TIG welded. The stress due to the welding heat induces mechanical deformations. In order to avoid any displacements, the feedthroughs were tack welded on four points; then during the remaining welding process a strong pressure was applied for maintaining the button distance to the BPM center.

Leak tests and dimensional controls were then performed at this point: the button position with respect to the BPM geometric center had to be identical within a few hundredths of millimeter.

Vacuum treatments and tests: During this phase the BPMs were inserted into a vacuum furnace. A customized baking program was performed, taking into account stress formations due to the different items (bellow, BPM block, flanges). The proper baking schedule required the BPM and the tooling to be baked up to 250°C and kept at this temperature for 24 hours.

The analysis system connected to the BPMs is equipped with an Inverted Magnetron gauge (IMG) and a Spectrometer with Quadrupole Mass filter (QMS); this equipment allows to perform Residual Gas Analysis (RGA), Helium leak test, Outgassing measurements and Thermal Desorption Spectroscopy (TDS).

Results: The vacuum treatments allowed the BPMs to fulfill the following requirements:

- Base pressure lower than 2x10$^{-9}$ mbar
- Residual gas analysis free from fluorine and chlorine contaminants or organic compounds
- Helium leak lower than 1x10$^{-10}$ mbar l s$^{-1}$
- Specific outgassing lower than 1x10$^{-12}$ mbar l s$^{-1}$cm$^{-2}$

Final electrical test: The feedthroughs were connected to an electronic tester in order to check that their electrical insulation with the block was greater than 50 MΩ and that the contact resistance to the Molybdenum pin was less than 0.1 Ω. Once all the feedthroughs fulfilled the above requirements, their response to an electric impulse was checked with a Time Domain Reflectometer (TDR). The button capacity deduced from the TDR response is about 8 pF as expected, and the dispersion between buttons of a same BPM within the 7% required.

## PROBLEM SOLVING

During various phases of the manufacturing and testing process, some of the electrical and vacuum tests failed. The main problem at that point was to restore the feedthrough functionality by repairing or removing it, without loosing the whole BPM.

Vacuum insulation: Over the entire production of 500 feedthroughs only few units (~5) were found to be leaking. The problem always arose after vacuum bake out and happened at the brazing between the central pin and the alumina. In such cases the faulty feedthrough had to be remove. A special procedure has been implemented for removing the welding and adjusting the welding lip of the new feedthrough whose capacity matched the 3 others.

Electrical features: The two main issues were capacity and electrical insulation. The two were often linked, so solving one problem often solved both. The following is a list describing a "modus operandi" that allowed to fix most of the feedthroughs without removing them.

Case #1 (R>50MΩ): Just for completeness a normal feedthrough time domain response is shown below (fig. 3).

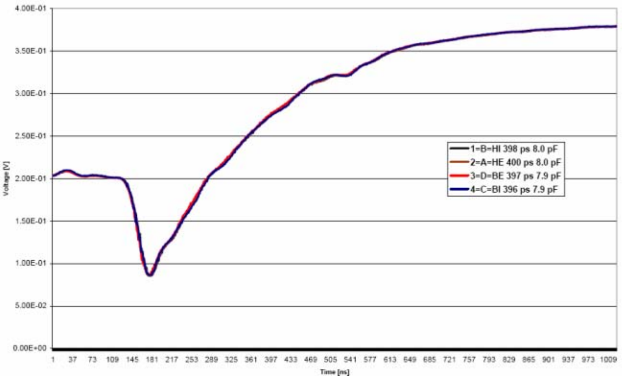

Figure 3 Time domain reflectometer measurement. The responses almost overlap with capacitances in the 7.9-to-8.0 pF range (0.3% dispersion).

Case #2 (500 Ω < R < 50 MΩ): Most problems were in this case (~20 units); many of them were solved without removing any feedthroughs, following a simple and effective procedure. The problem was caused by humidity or dust trapped between the button and the BPM body.

A visual inspection first established whether the button was in the right position (tilt and center). Then the trapped humidity was removed with a heat gun blowing 100°C air on the button. After having cooled down, the BPM was immersed in an ultrasonic bath of high purity ethyl alcohol for 30 minutes. Ultrasounds removed dust and trapped impurities.

Figure 4 shows the cleaning effect on a feedthrough that initially failed the test (~216Ω).

Case #3 (R<500 Ω): This is a delicate case (~6 units), the feedthrough is almost in short circuit. First of all a visual inspection is carried out in order to check that the button is not in contact with the BPM body. If the button is well centered the problem is usually a small metal chip that short circuits it to the BPM body. For removing it a current limited discharge is applied between the feedthrough central pin and the BPM body (the current is limited to 10A under 12 Volt). Figure 5 shows the effect of the treatment to a short-circuited button.

The fabrication has been checked at SOLEIL upon delivery. No leak occurred. The electrical offsets of all 131 BPMs are 152 µm RMS in horizontal and 168 µm in vertical. Excepted for a few BPMs built before the tight fabrication procedure was in place, the H-to-V coupling stayed within 1%.

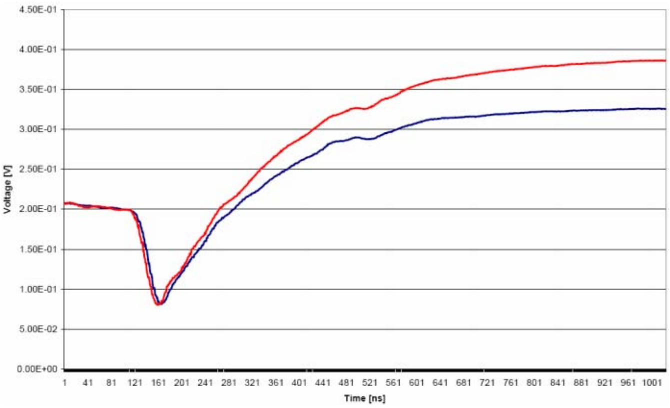

Figure 4 TDR measurement of a poorly insulated feedthrough before cleaning procedure (blue line) and after (red line).

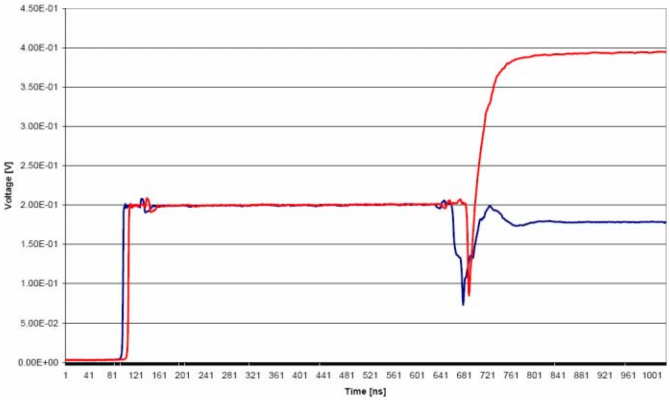

Figure 5 TDR response of a short-circuited feedthrough before electric discharge (blue line) and after (red line)

## CONCLUSION

In this paper we described the troubleshooting procedure put in place during the fabrication. The procedure allowed using all feedthroughs despite their relatively large capacity dispersion. The problems encountered with feedthrough isolation and button capacity matching during the fabrication did not result in any loss of BPM blocks. The electric center offset statistics over 131 units are of about 150 µm RMS, and the crosstalk between horizontal and vertical measurements less than 1%.

## REFERENCES

[1] W. Bruns, "The GdfidL Electromagnetic Field Simulator", http://www.gdfidl.de.