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STUDY OF THE PERFORMANCES OF A 3D PRINTED BPM*

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Abstract

Following previous results which have shown that some components built using additive manufacturing (3D printing) are compatible with ultra high vacuum, we have adapted the design of a stripline BPM to the requirements of additive manufacturing and built it. We report here on the design adaptation and on its mechanical and electrical performances.

INTRODUCTION

The introduction of polymer 3D printers in laboratories is often accompanied by the apparition of new mechanical designs that would have been impracticable with conventional manufacturing techniques. Although metallic additive manufacturing (later referred to as i3D) requires complex and expensive machines, we can expect it to trigger a similar bloom of creativity once its suitability will have been proven. We are studying how i3D can be used in accelerators. Last year we reported preliminary results showing that i3D is compatible with Ultra-High Vacuum [1] this has been confirmed by more recent results to be published soon.

To take our study further we decided to take a standard accelerator component and to study how we could simplify it using i3D. The chosen component is a stripline BPM. We chose that component as several BPMs have recently been manufactured at LAL as part of the ThomX project [2, 3]. This BPM has been manufactured using 316L stainless steel powder.

ADVANTAGES OF A 3D PRINTED BPM

Topological Optimisation

One of the advantages of i3D is that it allows to make complex shapes and thus allows topological optimisations of shapes for a given function (for example sustain the force due to the pressure difference) with minimal material. Such optimisation was done using the software INSPIRE from ALTAIR around the BPM flange to reduce the weight of the BPM as is shown in Figure 1. With these optimisation the resulting part weights only 40% of the original one. A 3D view of the BPM is shown in Figure 2.

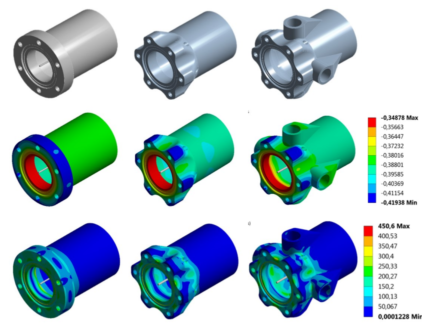

Figure 1: Topological optimisation of the BPM. The left column correspond to the original BPM, the center column to the end of the i3D BPM not on the feedthrough side and the right column the i3D BPM on the feedthrough side. The top line shows a view of the CAD model, the middle line show the stress induced displacement in millimeters when the BPM is bolted and the bottom line the Von Mises strains in MPa.

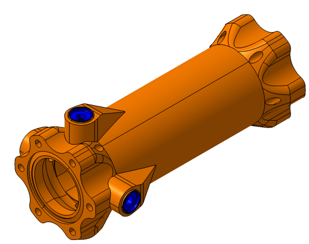

Figure 2: CAD 3D view of the i3D BPM.

Difficult Shapes

One of the difficulties of BPM manufacturing by traditional means was the thin cylindrical striplines: to have the correct relationship between the body diameter and the electrodes diameter, the electrodes had to be less than 2 mm thick but attempts to make this with traditional manufacturing methods using a lathe failed as this was too thin. The same electrodes with a 2 mm thickness were manufactured without any difficulty by i3D.

i3D Optimised Design

To avoid having to use support during the manufacturing the BPM has been manufactured with the beam axis vertical and a taper has been added under the electrical feedthrough. This allows a manufacturing without the addition of any supporting structure. The drawing of the i3D BPM compared to the traditionally manufactured BPM (later referred to as TM-BPM) are shown in Figure 3. The i3D BPM is made of

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a single part (excluding the electrical feedthrough) whereas the TM-BPM is made of 4 parts (excluding the electrical feedthrough) that had to be welded together. This also allows to make the i3D BPM shorter by 20 mm as no space has to be left for the welding of the flanges on the body.

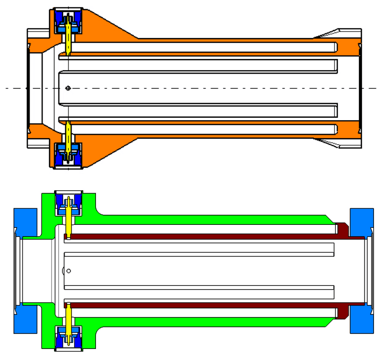

Figure 3: Drawing (side view) of the i3D BPM (top) and the TM-BPM (bottom). Each color corresponds to a different part. The i3D BPM is shorter by 20 mm for the same functionality.

Improved Efficiency

Using i3D has also the advantage of allowing to send directly the CAD model to the printer without having to produce drawings. The i3D BPM after manufacturing can be seen in Figure 4.

After additive manufacturing some minor work had to be done in the workshop: recutting of the flange surface to get a flat surface and sharpening of the vacuum knife (not yet reachable by additive manufacturing). The electrical feedthroughs were purchased separately and welded using traditional techniques.

The BPM has then been tested by the vacuum group. No leaks were found and the outgassing rate was comparable to that of the TM-BPM and compatible with UHV.

For this BPM the manufacturing time was about 36 hours and the total turnaround time from sending the file to the manufacturer to receiving the BPM was less than a week (electrical feedthrough excluded). The additional work (traditional machining) added two extra days plus one day for the welding of the electrical feedthrough. Manufacturing the same BPM with traditional machining would have taken 4 to 6 weeks.

The cost of the i3D BPM (from an external provider) was about 3k€ whereas the price estimate for the traditional BPM was about twice more.

Both the TM-BPM and the i3D one have been checked with a Coordinate Measuring Machine (CMM). The i3D BPM has been found to be within 0.1 mm of the nominal dimensions. For the TM-BPM, the initial tolerances were ±0.02 mm but were relaxed to ±0.2 mm at the request of the mechanical workshop and the BPM was confirmed to be within these relaxed tolerances when checked on the CMM.

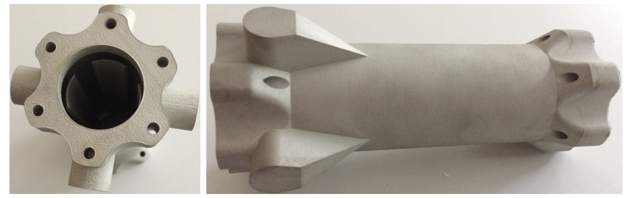

Figure 4: Pictures of the i3D BPM after manufacturing (but before re-machining). On the left the cylindrical electrodes can be seen inside the BPM.

Surface Quality

Whereas a traditionally manufactured part has a very smooth surface, a i3D part has a very rough surface. We have shown previously that this is not an issue for vacuum compatibility [1] but we have not yet checked the impedance of such surface.

TEST RESULTS WITH THE LAMBERTSON METHOD

To test the electrical performances of the BPM we are using the Lambertson method [4, 5]. A vector network analyser (VNA) has been used to measure the signal transmitted between the electrodes. The result of these measurements is shown in Figure 5.

Applying the formula given in [5] we can compute the average electrical offset between the electrodes. The offset as function of frequency is given in Figure 6 and the integrated values for the frequency ranges 20 MHz to 200 MHz and 20 MHz to 400 MHz are given in table 1. As we can see the electrical offset is lower for the i3D BPM than for the TM-BPM. This confirms what has been measured with the CMM machine: accuracy is higher with i3D.

Although these results are very encouraging for a linac BPMs, one should remember that no impedance measurements of this BPM have been done and the lower surface quality may result in a significantly higher impedance, so at the moment we make no claim on the suitability of such a BPM for a ring.

OUTLOOK

The next step will be to perform measurements with a stretched wire. The setup is already in place and the measurements will start in the coming weeks. Once these measurement will have been performed we will test this BPM, together with two TM-BPMs at the PHIL [6] photo injector.

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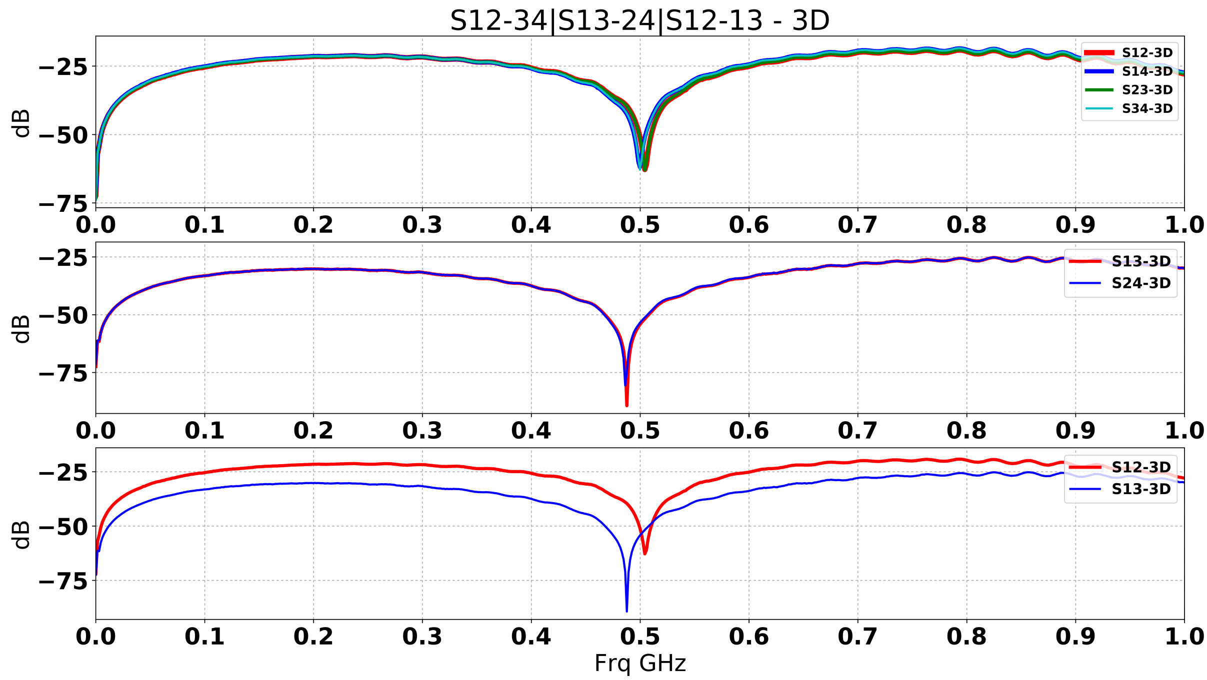

Figure 5: VNA measurements of the transmission between the electrodes of the i3D BPM. The electrodes have been numbered clockwise with an arbitrary start.

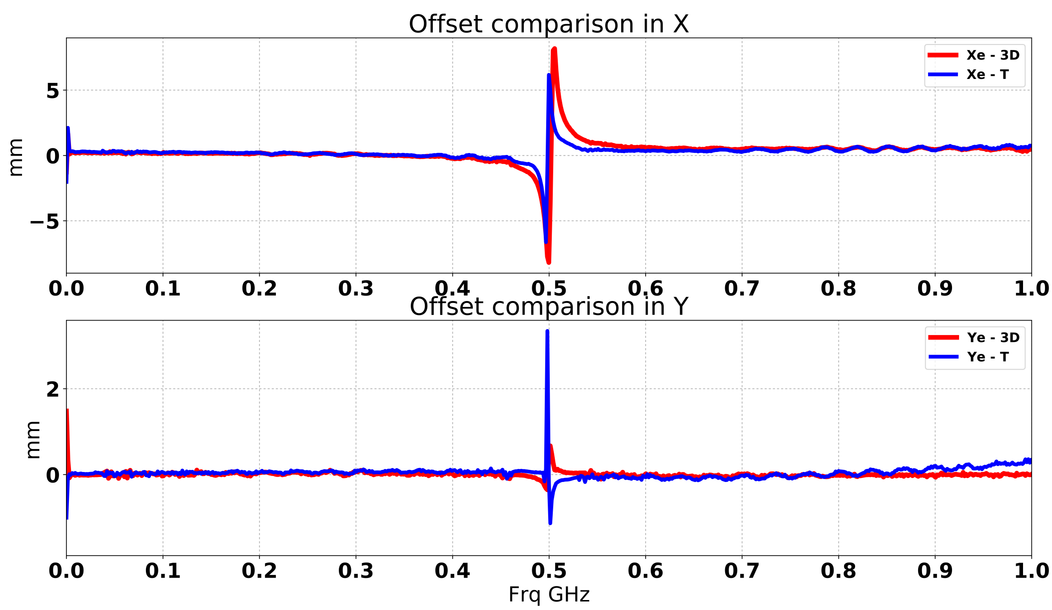

Figure 6: Calculated electrical offset versus frequency (using the formula given in [5]) for the i3D BPM (in red) and the TM-BPM (in blue).

Table 1: Measured average electrical offset between the electrodes. The top two lines of values are raw value and the bottom two lines assume a linear calibration coefficient k=14 mm as defined in [5].

	X		Y	
	20 MHz to 200 MHz	20 MHz to 400 MHz	20 MHz to 200 MHz	20 MHz to 400 MHz
Trad. manuf. (raw value)	17 ± 3	11 ± 3	3 ± 2	4 ± 2
i3D (raw value)	13 ± 2	8 ± 3	1 ± 2	1 ± 2
Trad. manuf. (k=14 mm)	238(36) µm	154(44) µm	36(26) µm	51(24) µm
i3D (k=14 mm)	178(30) µm	107(48) µm	36(26) µm	20(31) µm

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