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3D PRINTED BEAM CORRECTORS

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Abstract

Starting in 2018, we designed and created beam correctors using 3D printing technology and two different types of FDM materials, ULTEM and ASA. The design was created based on the ergonomics of the existing machine parts, focusing on avoiding any radial or longitudinal mechanical interference and ensuring the magnetic performances. The resulting windings' size and configuration were considered while choosing the most suitable FDM material for the purpose. Overall, we developed three different prototype models that demonstrated the ability to produce the design performances. These prototypes are currently being used in the SPARC-Lab Experiment [1] in our INFN National Laboratories in Frascati, [2].

INTRODUCTION

Particle beam correctors are important components in accelerators. To ensure optimal performance, the magnetic and mechanical design should be done in advance with other machine parts of the assembly. Sometimes, these elements need to be added to existing locations, requiring consideration of available space and surrounding parts. 3D printing can be used to achieve complex designs that are difficult to manufacture conventionally. Three bi-axial models of correctors have been developed and installed in the SPARC-Lab Project.

First corrector prototype

The first prototype had to be dimensionally designed to be mounted around a BPM (Beam Position Monitor) radially coaxial to a cylindrical magnetic element (coil) belonging to a solenoid for half its inner part length, see Fig 1 below). The magnetic field values to be achieved vertically and horizontally, along with the existing dimensional constraints, guided the definition of a magnetic design, from which the mechanical design was created. We considered various factors before deciding on the most suitable FDM. The corrector is made of two inner and two outer shells. The winding comprises a 3.15mm diameter enameled copper wire laid with the same configuration of turns on three layers for all four supports.

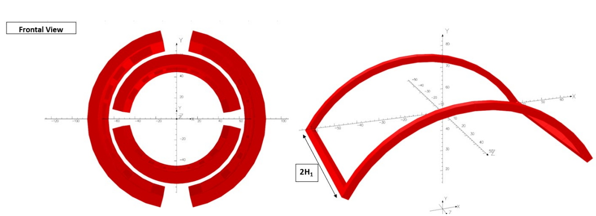

Figure 1: Magnetic project of first corrector prototype.

When designing the conductor winding supports, the mechanics should consider not only the limited space available for the corrector but also the size of the conductor to be used and the required geometry needed to achieve the final architecture of the windings. This is necessary to realize the magnetic fields during the excitation phase.

Figure 2: Corrector winding and support.

The winding support design in Fig 2 considers the installation technique to ensure the desired geometry for the conductor. The four supports, which were 3D printed, are made of a material called ULTEM 9085, [3]. This resin is known for its impressive mechanical and thermal resistance. In addition to the four main supports that house the windings, several other components have been made from the same material to facilitate the winding installation process, as depicted in Fig 3. Some of these components remain a part of the support, while others are solely intended to aid in intermediate winding operations. These components are attached to the main support using brass bolts.

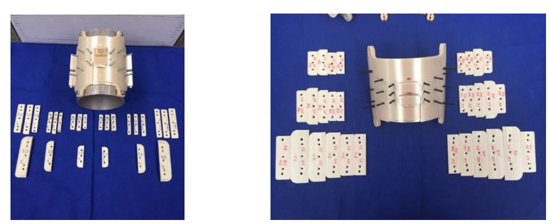

Figure 3: Internal and external supports.

In addition, two mechanical supports have been made on which the two formats of the four shells are attached to a workbench, respectively. Then we proceed as follows:

1. Using a vise the shell to be machine is fastened at its mechanical support on the workbench.
2. Start by laying the cable along the groove provided on the support and securing it with a clamp to the support before forcing it to follow the central body's profile, Fig. 4.
3. You proceed counterclockwise, viewed from above by bolting the stops provided for the various coil positions to the support and the last loop, (bottom part of Fig 4).

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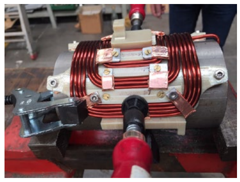

Figure 4: First layer of corrector.

4. Throw now some Araldite 2012 on the winding, avoiding the cleats and screw bars so as not to imprison them. Once secured, the cleats are removed.
5. At this point the cable is moved up a level to create the second layer of windings using the stops provided for each step until the upper winding is completed, proceeding, this time, from the outside to the inside, see Fig 5.

Figure 5: Second layer of corrector.

6. Proceed for the last layer by fitting the stops when provided leaving them in place as for the first layer proceed from the inside out.
7. Disassemble the retention studs.
8. When all four shells are ready, corrector may be assembled.

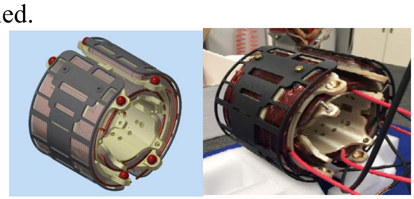

Figure 6: 3D CAD vs Real.

9. Assemble the shells to make magnetic measurements, (Fig. 6).

For the alignment with the coordinatometer we use 8 brass slots provided for positioning of the 1/2-inch CCR (Corner Cube Reflector) needed to keep the reference positions with the Laser Tracker, Fig. 7

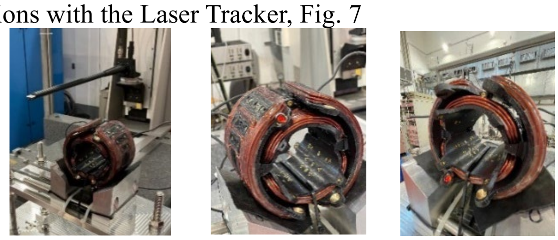

Figure 7: Magnetic measurements.

Second corrector prototype

The magnetic design of the second corrector is shown in Fig 8.

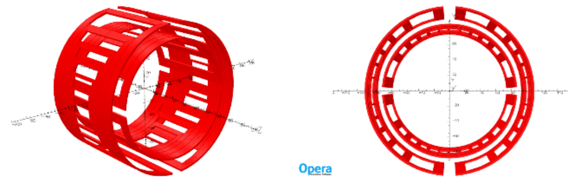

Figure 8: Magnetic project of second corrector prototype.

A new technique has been developed to re-tension windings on a substrate, using a copper conductor with a diameter of 2 mm and only one layer. This technique adopts a specific winding architecture and several turns to avoid using Araldite. The winding supports are made of a FDM product called ASA filament, (Acrylonitrile Styrene Acrylate) [4] [5]. It is a versatile thermoplastic, that is ideal for 3D printing and can be used for various applications. It has three improvements more common ABS plastic: optimized mechanical properties, superior aesthetics, and UV resistance.

First, windings were designed consistent with the magnetic design, (Fig. 9).

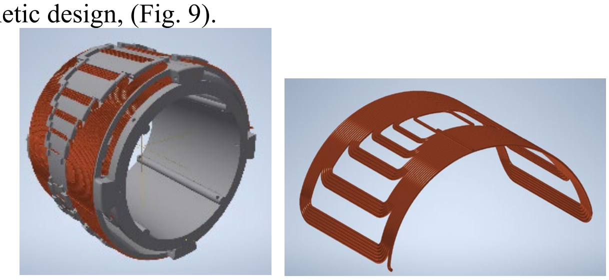

Figure 9: Corrector winding.

Then, the shells to hold winding were designed to provide a telescopic system of dowels useful for progressively retaining the winding during assembly. Fig. 10, show the final result of one of the two inner shells with the winding installed, from virtual to real.

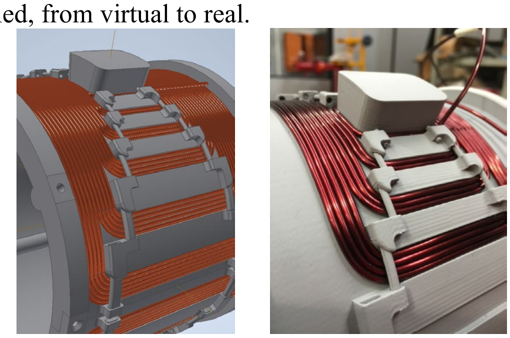

Figure 10: From virtual to real

To simplify the installation of copper conductors on the shells, a mechanical stand was created. The stand can be mounted on a workbench table with identical external dimensions to the accelerating section where it will be placed. The stand is also hollow from the inside, which allows scanning with the hall probe during magnetic measurements, (Fig. 11).

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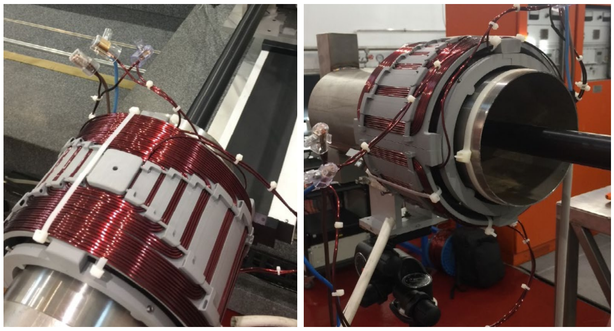

Figure 11: Magnetic measurements.

To connect the four supports and ensure that the corrector is correctly aligned and fixed, holes were drilled into which helicoils were inserted. Threaded holes were not possible due to the ASA material and geometries used. Previous prototype had seats for nuts, which are not present here.

Third corrector prototype

The third corrector, similar to the first one, was fabricated using ULTEM 9085 material. It has been produced for SABINA Project [6] [7]. To satisfy mechanical and magnetic constraints, a copper conductor with a diameter of 1.6 mm was used. Figure 12 shows a plot of magnetic simulation.

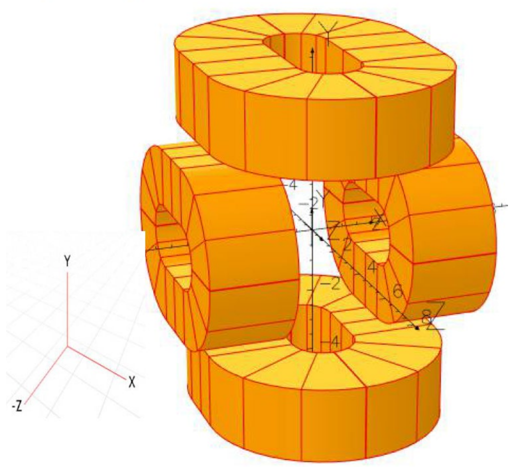

Figure 12: Magnetic plot simulation.

Fig 13 shows the designed supports that best accommodate the windings based on the winding procedure.

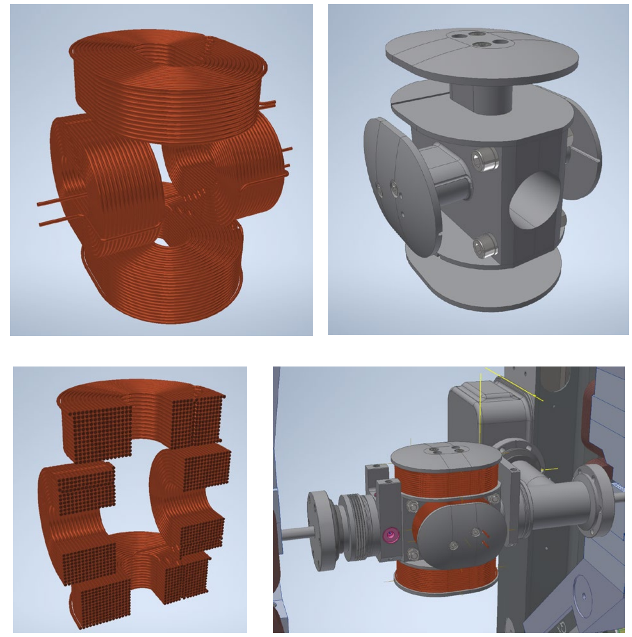

Figure 13: 3D CAD Design

As in the previous two cases, the corrector was measured using a hall probe and a coordinatometer. The conductor temperature was also monitored to ensure that the design performance was accurate. Finally, here is a picture of two examples of the corrector, similar to the first prototype, Fig 14.

Figure 14: 3D CAD vs Real.

CONCLUSION

The work done so far demonstrates the benefits that can be obtained by using new technologies such as 3D printing in terms of complex design, production time, and R&D for existing assemblies where sizing must balance performance, ergonomic construction, and installation. Maintaining constructive discussions with the creators of this technology is crucial for developing new products and materials.

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