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PROSPECTS OF ADDITIVE MANUFACTURING FOR ACCELERATORS*

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Abstract

Additive manufacturing allows the production of mechanical components often much faster than traditional manufacturing. Several accelerators components built using additive manufacturing have already been qualified for use in accelerator. A workshop was held in Orsay in December 2018 to discuss the prospects of using additive manufacturing for particle accelerators and particle detectors. We report here on the prospects as far as accelerators are concerned.

INTRODUCTION

Metal additive manufacturing (i3D) is a fast growing field where mechanical parts are built by adding layers one by one (by opposition to conventional manufacturing where usually a block of materiel is machined to remove matter). To see how this new technique will impact the field of accelerators and particle detectors a workshop was organised on the topic in Orsay in December 2018. The programme of the workshop and the presentations given at that occasion are available at `http://programme.i3d-metal.fr/` and at `https://indico.lal.in2p3.fr/event/4990/timetable/` and we give here some results that came out of this workshop.

ADVANTAGES AND CHALLENGES OF METAL ADDITIVE MANUFACTURING APPLIED TO ACCELERATORS

During the workshop we discussed the advantages and the challenges of additive manufacturing applied to particle accelerators.

The following **advantages** were noted:

- **New shapes:** Additive manufacturing allows to produce shapes that would not be possible with conventionnal means. Among them we note:
  - *Embedded cavities:* Such cavity can be produced in additive manufacturing. During the manufacturing process the cavity will be filled with powder so there must a hole in the cavity for emptying it.
  - *Cooling channels:* Similarly to cavities, winding cooling channels close from the area to be cooled can be designed. However here also the design must permit an easy removal of the powder.
  - *Mesh structures:* Two-dimensional and three-dimensional mesh structures can be produced. Care must be taken with the machine settings to ensure that the mesh will not collapse during manufacturing.
- **Topological optimisation:** Because of its versatility additive manufacturing allows to produce shapes that have being designed using topological optimisation.
- **More economical on complex parts:** In additive manufacturing the cost is proportional to the volume, not to the complexity of the part, so complex parts (that is parts that would require several different manufacturing operation with conventional techniques) are often more economic using additive manufacturing.
- **Faster:** For the same reason than above, additive manufacturing parts are often faster to produce.
- **Repair old or broken parts:** Additive manufacturing can replicate any shape. This includes old parts that are no longer produced by the manufacturer. It can also be used to rebuild a damaged surface to repair a broken part.

However this technology is not yet fully mature and still faces some **challenges** (some of which are been addressed):

- **UHV compatilibility:** To be usable in an accelerator its UHV compatibility must be demonstated.
- **Electrical conductivity:** Many accelerator components have to conduct electricity. At the moment there is limited data available on the behavior of i3D accelerator components when a beam passes nearby.
- **RF:** Many complicated parts in accelerators involve RF. How do i3D structures behave when conducting RF?
- **New materials and new alloys:** Additive manufacturing allows the production of new materials and new alloys. How will these behave in an accelerator?

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- **Multi-materials:** Can parts involving several materials (for example a metal and an insulator) be manufactured additively?
- **Mechanical strength:** The tensile strength of a metal depends on how it is melted and cast into solid form. It is known that the cristalline structure of additively manufactured metals is different. How does that affect their tensile strength?

There are also some **issues** that need to be addressed before this technology can be widely used:

- **Postprocessing:** In most cases the parts produced have to undergo some sort of post-processing (for example to improve knife-edges in the case of UHV parts). It is important to find how to keep this to a minimum.
- **Surface quality:** Because of the way they are built i3D parts have a very rough surface. It is important to understand if this is an issue, for example for vacuum or for electrical impedance.
- **Machine to machine reproductibility:** Additive manufacturing machines have a lot settings that can be adjusted. For a given specification it is important to understand which parameters are important. Powder quality can also affect the final result.

ADDRESSING THE CHALLENGES

During the workshop several presentations dicussed how work is being done to address the above mentioned challenges and we present here some of the results that were shown.

Tensile Strength

To better understand the tensile strength the French project '3D metal' has initiated a comparative study of additively manufactured specimen produced on different machines with different technologies and different parameters to better understand what affects the tensile strength of parts produced using additive manufacturing. Examples of these specimen are shown in Fig. 1.

Figure 1: The specimen produced by the '3D Metal' project to measure the tensile strenght of additively manufactured parts produced on different machines with different technologies and different parameters.

As part of this work, some specimen have been studied using a scanning electron microscope to analyse the crystaline structure of the specimen. An example of images taken during this study is shown in Fig. 2 and more information can be found in [1].

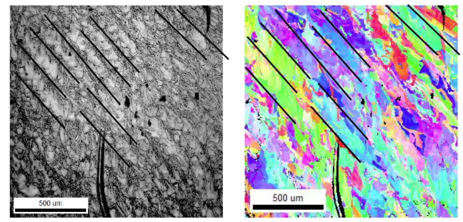

Figure 2: Images of the microstructure of additively manufactured specimens. The growth direction and different layers can clearly be seen.

Ultra High Vacuum

Before building complex parts for accelerators one needs to demonstrate that additively manufactured components are comptabilble with the ultra-high vacuum (UHV) requirements typical of particle accelerators.

To demonstrate this, UHV beam pipes have been produced and UHV tested. The raw beam pipes right after manufacturing can be seen in Fig. 3 and their behaviour under static vacuum is shown in Fig. 4. The detailed work is described in [2].

Figure 3: Beam pipes on their manufacturing support, right after they were printed using selective laser melting (SLM). Before being used the pipes had to be sawed off their support (the saw can be seen on the top right corner of the image) and the knife-edge improved with a lathe. Image taken from [2].

Electrical Conductivity

Another important feature of several accelerator components is their electrical conductivity. Work has been ongoing in several institutes to produce by additive manufacturing some components whose electrical properties were important. For example there have been several reports about a Beam Position Monitor that has been produced by additive manufacturing and then successfully tested [3,4] (see Fig. 5). At CERN waveguides have been additively manufactured and their electrical response has been measured (see Fig. 6).

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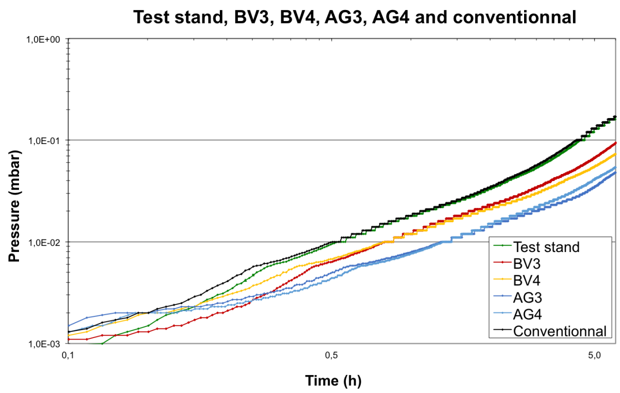

Figure 4: Behavior of a several bean pipes under static vacuum. The beam pipes AG3, AG4, BV3 and BV4 have been additively manufactured whereas a witness one called "conventional" was purchased from a UHV manufacturer. More details can be found in [2].

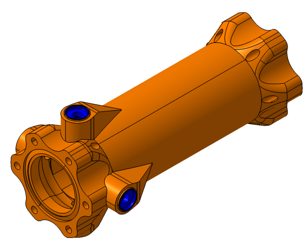

Figure 5: A Beam Position Monitor whose shape has been optimised using topological optimisation and built using additive manufacturing (more details can be found at [3,4]).

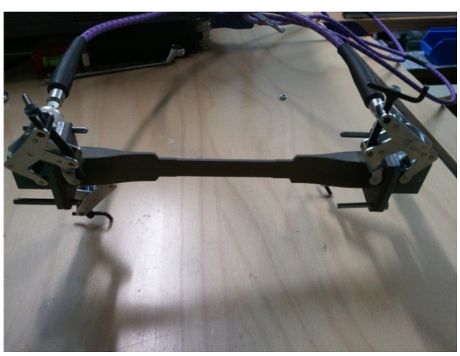

Figure 6: Measurement of the RF parameters of a waveguide buyilt using additive manufacturing (Source: Alexej Grudiev, CERN, `https://indico.cern.ch/event/275412/`).

During the workshop we also heard about RF antenna for space applications that have been produced using additive manufacturing.

Pushing the tests one step further the additive manufacturing group at CERN has manufactured a 6 GHz niobium cavity using additive manufacturing (see Fig. 7).

Figure 7: A 6 GHz Niobium cavity built in two manufactured at CERN using additive manufacturing (Source: Romain Gérard, CERN).

CONCLUSION

There is significant work ongoing to qualify additive manufacturing for particle accelerators. Addditive manufacturing allows to build parts with optimized shapes and complex features. Some impressive results have been produced in the past years but some challenges still need to be addressed to use the full potential of additive manufacturing in accelerators.

ACKNOWLEDGEMENTS

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