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Application of Direct Laser Sintering for Manufacture of Synchrotron Components

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Abstract **–** Rapid prototyping of parts in plastic is becoming a familiar step in the development of new products. The process is now starting to migrate to rapid manufacture where extremely complex shapes can be manufactured in low numbers in a short period of time with no tooling costs.

In a similar manner metal parts can now be manufactured with a process called Direct Laser Metal Sintering which has the generic name of Additive Manufacture. This process uses a laser to selectively melt metal powders allowing very complex parts to be manufactured with small feature sizes. The potential advantages are that single components can replace ~~a~~ small bolted assemblies, welding can be eliminated, the stiffness of parts can be increased, weight decreased and parts can be manufactured that could not be manufactured from traditional manufacturing methods.

However, the design of parts may need to be substantially changed to suit the process as large residual stresses can be generated within the part as it is built up and support structures may also need to be included.

Diamond Light source are starting to use components manufactured using this method and this paper will examine the application of this technique to the manufacture of synchrotron components.

Keywords**:** Additive manufacture, direct metal laser sintering.

1 Introduction

Rapid prototyping of parts in plastic is becoming a familiar step in the development of new products. The process is now starting to migrate to rapid manufacture where extremely complex shapes can be manufactured in low numbers in a short period of time with no tooling costs.

In a similar manner metal parts can now be manufactured under the generic name of Additive Manufacture. There are a number of techniques one of which is called Direct Metal Laser Sintering. This paper will examine the application of this method to the manufacture of components for synchrotrons.

2 Additive Manufacture Processes

There are three main additive manufacture processes for metals and these are Electron Beam Melting, Wire Feed Deposition and Direct Metal Laser Sintering.

In the Electron Beam Melting process the fine metal powder is preheated in a vacuum chamber and one or more electron beams are used to melt the powder in the required shape. Machines are available from companies such as ARCAM. They claim no residual stresses are generated and are suitable for reactive metals such as many grades of Titanium Alloys.

The wire feed process uses a laser or electron beam or other heating device to melt wire which is applied using a robotic arm or XYZ gantry system to form a 3D structure. Very large structures can be made and the metal deposition rate can be very high.

Direct Metal Laser Sintering uses one or more lasers to selectively melt a bed of powdered metal layer by layer to produce a solid structure. This process allows highly complex parts to be made and is the process that is discussed in this paper.

3 Direct Metal Laser Sintering

The first stage is to construct a 3D model of the part to be manufactured. This is then modified by adding any required supports and conversion in to a format for the machine. The parts are constructed on a steel platen which currently is of the order of 350mm x 350mm. Many small parts can be manufactured on the one platen. The platen is placed in the machine and a thin layer of powder is applied to the platen. A high power laser then selectively scans the surface of the powder and the powder melts under the laser beam. A further layer of powder is added and the process is repeated until the part is complete. The platen is then removed and the parts cut away from the platen by wire erosion. Support structures are then removed and the part is cleaned of loose powder. Stress relieving is then carried out if required and then final machining of critical surfaces.

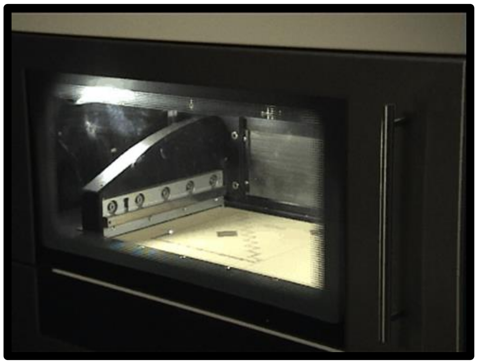


Figure 1- Machine internals

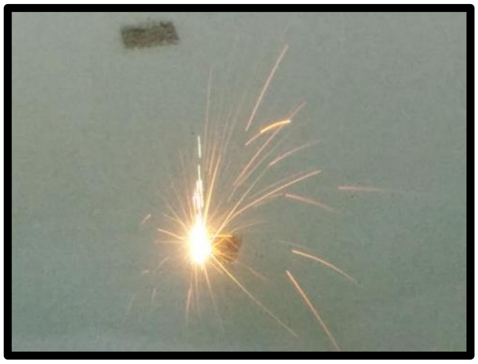


Figure 2- laser spot scanning powder

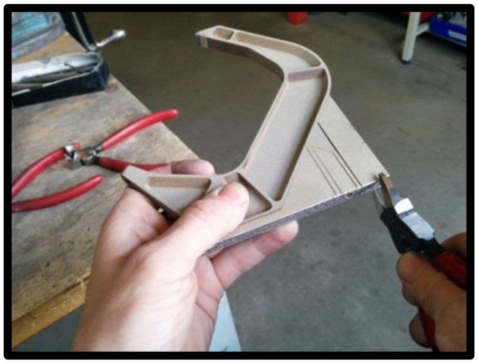


Figure 3- Support removal

Figure 4- Bead blasting

4 Advantages of Direct Metal Laser Sintering

The process uses a small diameter laser beam to melt fine grained powder. The powder can be as fine as 5 microns, the layers can be as thin as 20 microns and walls of 160 microns can be produced. This means that highly complex shapes with small features can be produced. The time taken to produce a part is dependent upon the time taken to melt the powder so a highly complex part with fine features, thin walls and complex curves can be faster and cheaper to manufacture than at simple shape that has a larger mass of material.

This means that shapes can be produced that have lots of ribs, meshes, complex curves, varying wall thickness and internal cavities that could not be produced by traditional milling or wire erosion processes. The advantage is that parts can be stiffer, or have less mass, or two parts can replace one part and so eliminate welding or bolting.

5 Material choices

Materials that can be used include Stainless steel (316L and 15-5PH), Maraging and Cobalt chrome steels, Titanium alloys such as Ti6Al4V, Nickel alloys such as Inconel 718 and Aluminium (AlSi10Mg). Changing a machine from using one powder to another requires extensive cleaning so some sub contract organisations tend to keep each machine on the same powder. Copper and silver are more difficult because of the high thermal conductivity and high reflectivity at the wavelength used by the lasers. There are however some developments using Argentum which is 95.8% Ag with Copper and Germanium.

6 Vacuum suitability

The process is called direct metal laser sintering and sintering suggests a structure that is not fully dense, could be porous and may include blow holes. The truth is however that the material is over 99.9% dense. To test if components are suitable for in vacuum use a test sample was manufactured in 316L. A test chamber was baked to 200°C for 3 days and a base pressure of $2x10^{-9}$mbar was achieved. The vessel was vented to dry Nitrogen and then pumped down. The vessel was vented again and the sample placed inside and the vessel pumped down again. The pressure was recorded every 10 seconds. No pressure instabilities or pressure spikes were recorded and the pump down time for the empty vessel and vessel with sample was very similar.

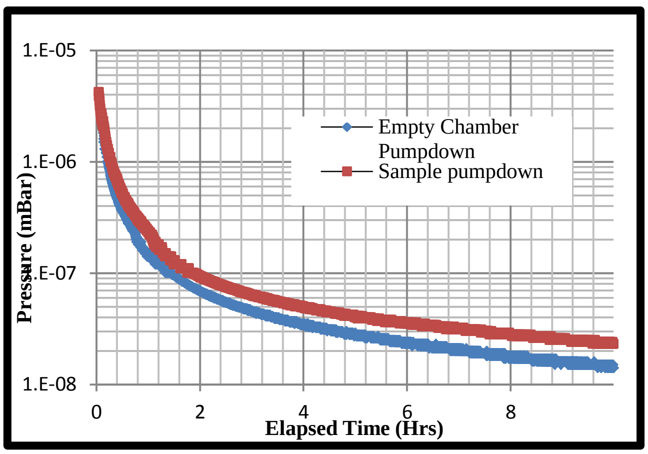
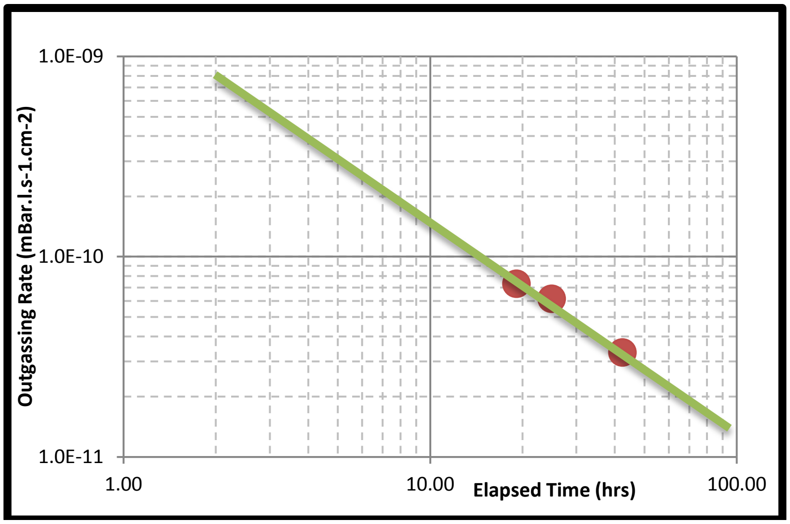


Figure 5- Test sample

Graph 1- Outgassing results

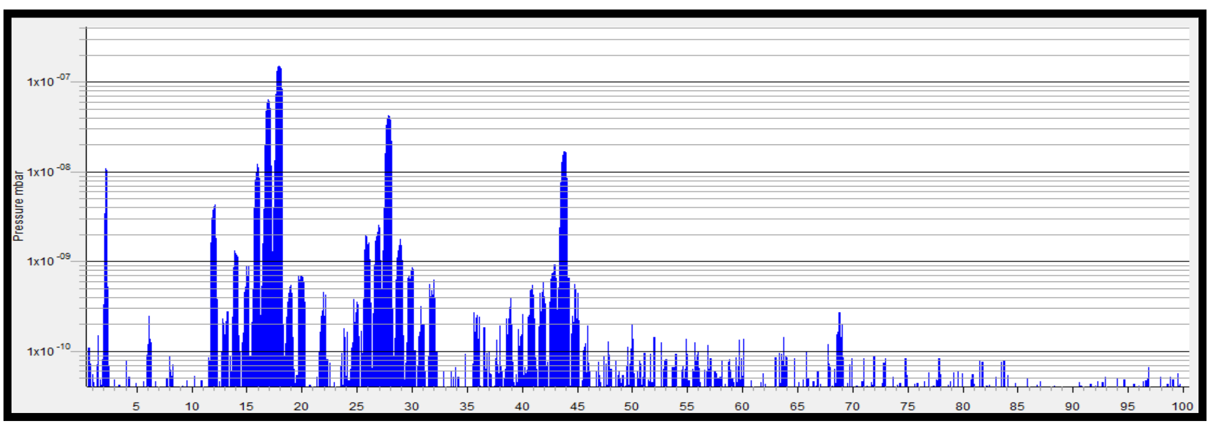
The outgassing rate was measured after 19~~1~~, 25 and 43 hours. When plotted on a log-log scale graph the data points fall on a straight line as expected. After 10 hours the specific outgassing rate is extrapolated to be $1.6x10^{-10}$ mbar.l.s/cm^2. This is typical of unbaked stainless steel.



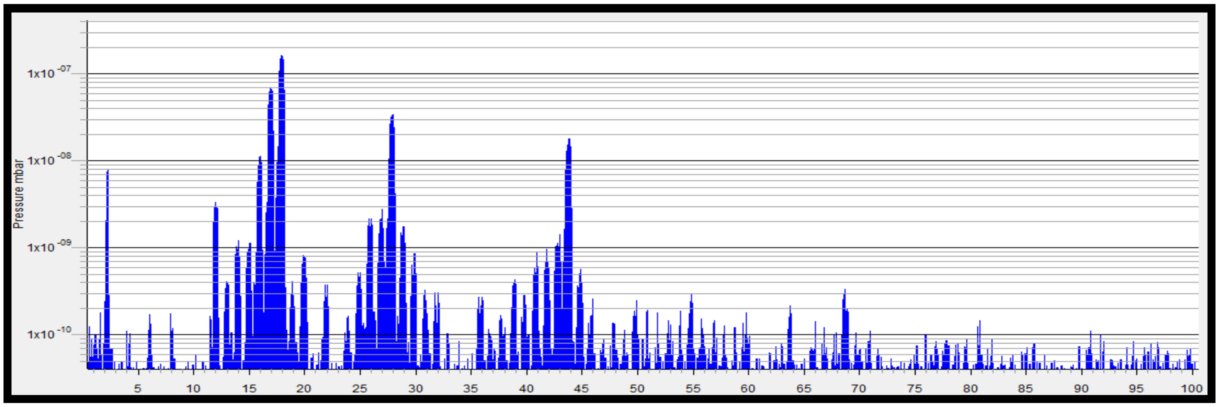
Graph 2 – Outgassing rate

The outgassing rate of the test assembly was also measured by venting the empty test chamber to dry Nitrogen, removing the top flange for a few seconds and pumping back down again. After 24hrs, the outgassing rate measured was 1.9×10^{-8}mbar.l./s. With the sample in the test chamber, the outgassing rate after 24hrs is 2.0×10^{-8} mbar.l./s. This shows that outgassing rate of the test chamber is only marginally better than that of the test sample.

RGA scan of the test chamber was also taken with and without the sample after pumping overnight as shown in Graph 3 & 4. The scans are typical of an unbaked SS chamber. There is no qualitative difference between the scans.



Graph 3 – RGA scan of Empty Chamber



Graph 4 – RGA of chamber and sample

7 Example 1

A part was required for a set of high speed slits. The part was outside the vacuum vessel but there was limited space. A part was designed in Aluminium, but could only be manufactured in two separate pieces and then bolted together. This part was manufactured by Direct Metal laser sintering in Maraging steel. The advantages were as follows:

a) The part was of a denser material and increased the ratio of high speed moving mass to low speed moving mass.
b) The part was manufactured in one part rather than two ~~as~~ so stiffness was increased.
c) The part was cheaper than traditional machining
d) The part was manufactured over a weekend.

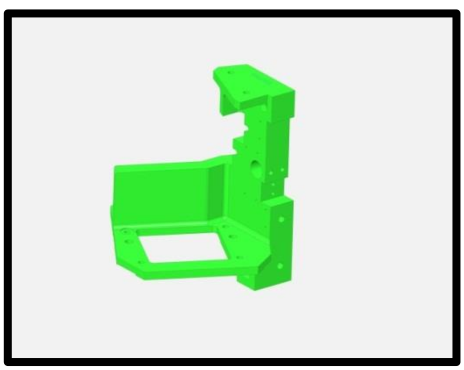


Figure 6- 3D model of support


Figure 7- High speed slits

8 Example 2

A non-standard bifurcated conflat flange adaptor was required with angled faces. The bifurcated tube was made in 316L and the conflat flanges were welded counter boring the ends. This has been leak tested using a Helium leak tester and is currently in use at a vacuum of 10^{-7}mbar. Tests are now being conducted in its long term suitability for use down to 10^{-10}mbar.

Figure 8- Bifurcated C~~c~~onflat ~~e~~ adaptor

Figure 9- Bifurcated adaptor fitted to end station

9 Example 3

A Clamp was required for a pair of 1400mm long water cooled silicon mirrors for Beamline B07. To produce an even clamping force 34 clamps were required. These were designed to be low weight and have a centre of gravity in line with the centre of gravity of the bare mirror substrate. Traditional machining and casting were considered but Direct Metal Laser Sintering was chosen as thinner walls could be achieved, the cost was lower and the manufacturing time was shorter.

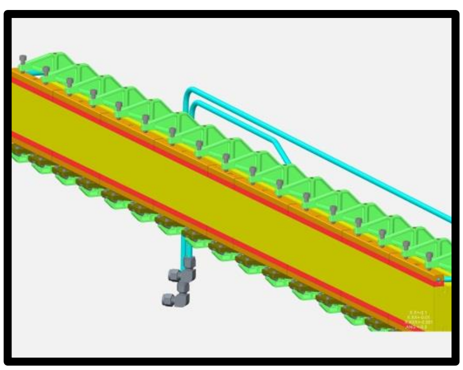


Figure 8~~10~~- B07 Mirror cooling

Figure 11- Mirror Clamp

Horizontal surfaces that faced down were changed to a chamfer. The weight of each item is 190g with a central web thickness of 1mm.Twenty were produced in one setting.

10 Costs

Costs of synchrotron systems can often be dominated by the cost of design and special components such as mirrors, vacuum equipment, actuators and controllers. The cost of manufacture of a machined part increases linearly with complexity but perversely the cost of an additive manufacture component can reduce as the complexity increases. This is because simple shapes with large masses require lots of expensive powder and take a long time for the laser to melt, but more complex shapes may have much thinner structures and so use less powder and are quicker to melt. There is therefore a point where additive manufacture becomes cheaper than machining. This however misses the point that additive manufacture opens up opportunities for improved performance and so a cost increase of some parts may not be significant.

11 Design techniques

The examples given look like they could be produced by traditional machining techniques. The design process was of designing a component in a traditional method. But this is not using additive manufacture to its full potential. To maximise the potential for higher stiffness or weight saving the design process needs to be changed. Firstly we must assume that it is being made by additive manufacture and we can ignore all our experience of machining parts from a solid lump of bar, plate or tube. Secondly we must think about what its function is. If it is to hold one part in relation to another we need only think of the fixation points and the connections can grow much like a spider would build a web. The part can have many thin connections rather than simple solid blocks. An example of this change is from the aircraft industry where weight is critical. In Figure 12 and 13 some brackets have been re-designed to be made by additive manufacture.

Figure 912

Figure 13

This approach raises a number of issues;

a) Commitment at the start of the design stage to make the component by additive manufacture
b) Design staff with little experience of traditional manufacturing techniques may be better at the organic type of design.
c) Common 3D modelling uses simple extrusion and revolve type of design approach. The more organic forms of design are more difficult to implement in these common modelling tools.

In the synchrotron engineering field, weight is not so critical. Free form organic structures with complex webbing may therefore not be so important, but the ability to produce complex cooling channels, thin walls, stiff structures, UHV suitable and with good thermal performance makes additive manufacture using Direct Metal Laser sintering a promising technology.

12 Future developments

There is a desire to produce larger components by Direct Metal Laser Sintering. There is a European commission project called AMAZE with the aim of producing large defect free components up to 2m in size. So we can expect machines with larger working volumes to become available.

As well as single materials there are also developments in mixed materials such as Metal Matrix Composites.

High conductivity copper and silver are currently problematic but some universities are developing methods and mixtures and so parts that are solid copper or part stainless steel with copper conductive parts or surfaces may become available.

Prediction of internal stresses is an issue particularly on large structures and research in this area will enable more components to be built first time with no problems.

The Aeronautics, space and automotive industries are investing heavily in additive manufacture of metals and so developments are expected to happen quickly with more and more contract services becoming available.

13 Summary

Additive manufacture of metals and in particular Direct Metal Laser Sintering, can be applicable to the manufacture of synchrotron components out of vacuum, within a UHV environment and as a UHV boundary component.