3D PRINTING FOR HYDRAULIC COMPONENTS

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In times of ever-changing requirements and customer demands, engineers are faced with interesting challenge of developing new, sustainable and, above all, flexible production methods when designing and manufacturing products in the modern era. 3D printing is certainly one of the methods that allows designers to incorporate new and innovative solutions into the final designs. While these solutions can be effectively implemented from an energy consumption point of view, they are still hindered by the cost and time factor. Hydraulics is just one of the many areas where 3D printing is demonstrating its full potential and ability to create complex structures and labyrinth-like internal structures. Optimizing parts has never been easier, and this new generation of parts has never been easier to manufacture than with the 3D printer. Using only the material that is absolutely necessary for the strength (existence) of the part offers a great opportunity for material savings.

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additive manufacturing,
hydraulic components,
new technologies

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1 Intruduction

Additive manufacturing (AM) differs from subtractive manufacturing in the very idea of removing material from the initial geometry. Instead of subtracting, as the name suggests, this technique adds material where it is needed. It allows the user to add material only where it is needed from a structural standpoint.3D printing uses a variety of materials such as photo-resistant resins, filaments or powders to create a specific shape of the final part. 3D printing offers the designer almost complete freedom to create new parts. This allows new approaches to create a new generation of products that can offer geometries never before possible with improved properties and performance.

Different types of 3D printing based on manufacturing techniques of material used:

- By manufacturing (fusion, sintering)
- By material (polymers, metals, biomaterials, other…)
- By geometry of base material (powder, particles, pellets, resin, rod, sheet, wire…)

Development is mainly focused on lightweight construction (optimisation), which is needed in all major engineering disciplines:

- Aerospace,
- Robotics,
- Medicine,
- Automotive,
- Agricultural, and more.

2 Various tools and principles for AM-oriented design:

- **Parametrical:** Firstly, designers can create virtual models for 3D printing using CAD software and define all the features of the geometry parametrically. This process is well known, but with additive manufacturing, designers can create completely new features that were previously very difficult or impossible to realise. This is especially true for complex internal structures.

- **Topology optimization and generative design:** Because additive manufacturing is not constrained by the limitations of conventional manufacturing, designers can use modern approaches to design new parts. This could be achieved through topology optimisation, where the computer itself, with sufficient input from the designer, determines the amount and position of material needed. Based on FEA or CFD, designers familiar with both methods should be able to create new parts using these tools. Generative design is a slightly more complicated process that uses artificial intelligence to try to create geometry that meets the requirements specified by the designer.
- 3D scanning: Printing the structure that was 3D scanned is a great tool to copy existing parts and duplicate them, possibly at different scales. 3D scanning of statues and reliefs, for example, is already used in archaeology and restoration. With the knowledge of 3D modelling, there is also the possibility of repairing scanned models (broken pieces, cracks, missing parts…) and printing improved or restored versions of statues, buildings or anything else.
- **Lattice:** The design of parts that contain segments with an intentionally weakened structure in order to minimise the mass of the parts is called lattice design. This type of geometry optimisation, previously almost impossible in traditional manufacturing, allows the designer to reduce the mass of the final product by reducing the amount of material used by creating a specially patterned lightweight structure.

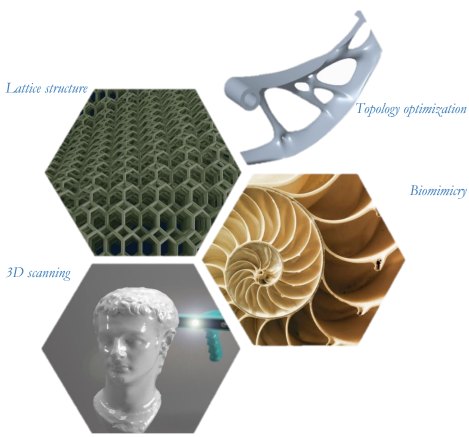

Figure 1: Tools and principles for 3D printing orientated design.
Source: own.

3 Disadvantages of additive manufacturing

As with any manufacturing process, there are some features of AM that can have a negative impact on the parts produced if they are not taken into account. Some of these are listed below:

- Postprocessing

The surface finish obtained directly in AM processes is relatively poor compared to some other manufacturing processes. Usually, the surfaces that come into contact with other parts during operation need to be postprocessed with a milling or grinding machine to meet the required specifications. Chemical treatment is also an option, but it does not usually achieve as smooth finish as fine grinding.

Post-processing includes not only surface treatment, but also the removal of support material and sometimes heat treatment. Since 3D printing in most cases applies heat to the parts, there is a possibility of delayed stress after cooling, which can result in the tensioning of part and its failure. For metals, it is usually necessary to reheat the finished part after printing to avoid cracking.

- Supporting structures

Since the whole idea is to add material where it is needed, this automatically means that the structure cannot be started without support, that being a build plate surface or some other type of disposable structure. In most cases, these structures have to be removed after printing, which drives up the time and cost of post-processing.

- Heat transfer

Most 3D printing processes involve some kind of material heating or warming. This means that the material either melts completely or is partially heated so that it can bond with other layers or the base plate. After the locally heated material has cooled, it usually tends to deform. The deformation or warping of the material is a serious problem that is difficult to solve, either partially or completely. Deformation of the printed parts while printing is still in progress can lead to faulty prints or in some cases seriously damage the machine. In most cases this problem is solved (or attempted to be solved) by conducting heat into the base structure or supports, but this means that the material must be thermally conductive to some degree.

- Anisotropy

As the part is printed in layers, the final product will have some anisotropic properties. If the designer is aware of this, it could be used as an advantage, but it could also lead to catastrophic part failures. Metal 3D prints could be subjected to heat treatment, where the part is heated several times to remove most of the anisotropic features, while plastic parts could be chemically treated.

- Layer adhesion

Another disadvantage of manufacturing parts in layers is insufficient layer adhesion. This refers to the quality of the bond between the layers that are printed on top of each other. Poor layer adhesion can lead to delamination, which is a catastrophic failure of the 3D printed part.

- Price

When deciding between additive and conventional manufacturing, there is always the concern of price. Relatively high machine costs and possible unprofitability for large series of identical parts or non-optimised geometries still slow down the integration of additive manufacturing machines in small and large industries. In contrast, the high added value of the parts could justify the use of 3D printing almost everywhere.

Most commonly when talking about the cost of AM, there are two arguments that were already mentioned to use AM in production. These are low numbered series and high complexity of parts. Combining the two criteria, even bigger series of extremely complex parts are economical to produce using 3D printing. One of the problems of AM process is that it is almost impossible to decrease production time. Usually, doubling the productivity, using multiple lasers or extruders, drives up the cost of initial investment.

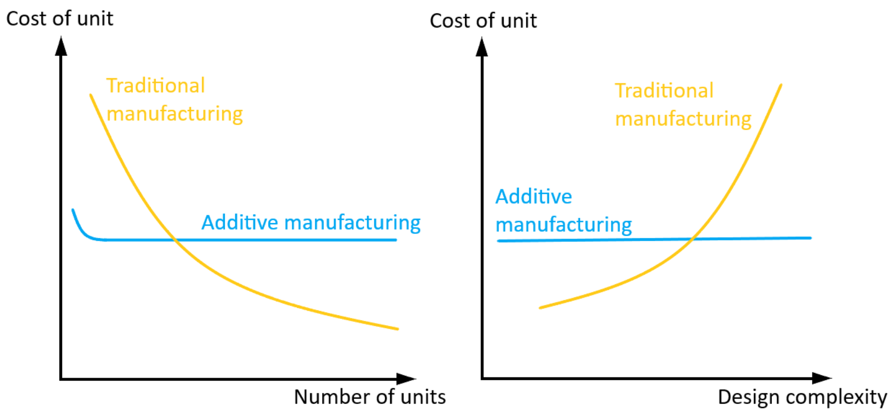

Figure 2: Cost (un)effectiveness of 3D printing based on number of units and complexity of the design.

Source: Busachi et al., 2017: Hopkinson and Dickens, 2003

4 Design rules of additive manufacturing

Design rules of additive manufacturing that designer must follow when constructing parts for AM:

- Overhangs and supports

Overhangs are surfaces that are downward facing, usually at an angle to the vertical line, and in certain circumstances need supports. Most AM techniques allow up to 45 to 50° overhanging angles with 90 being vertical wall and 0 meaning completely horizontal surface.

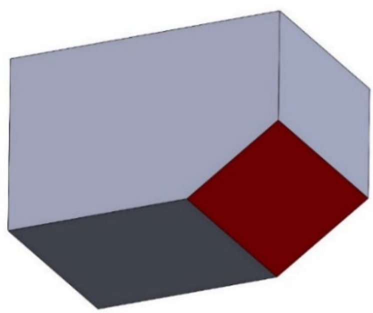

Figure 3: Overhanging surface.

Source: own.

– Wall thickness

Supported and unsupported wall thickness again depends on the particular technique and the machine used. Normally, the lowest achievable wall thickness is 0.2 to 0.3 mm, but is usually in the range of at least 0.8 mm.

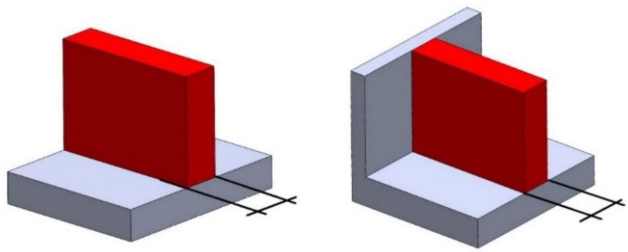

Figure 4: Supported and unsupported wall thickness.
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– Pin diameter

The pin diameter and minimum feature size are similar parameters to the minimum wall thickness. It depends on the machine, but the minimum diameter would be 0.4 mm for high precision machines.

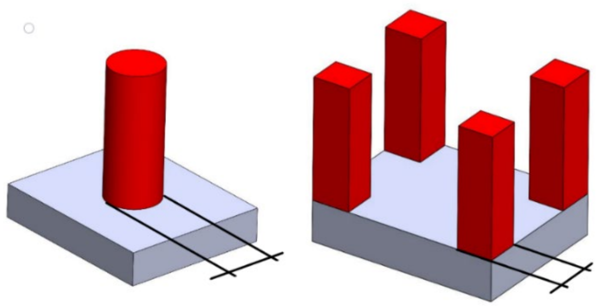

Figure 5: Pin diameter and minimum feature size.
Source: own.

– Bridges

Horizontal bridges or structures connected with an overhang that is not supported should be avoided when designing parts for 3D printing, or redesigned to eliminate any strictly horizontal surfaces to a slope. With FDM machines, the maximum bridge spacing is 20 mm with sufficient cooling, but with other processes it is almost impossible to create bridges without supports.

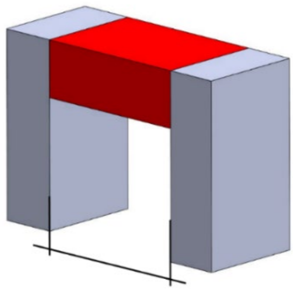

Figure 6: Bridging distance maximum length.
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– Minimum hole diameter

The minimum achievable hole diameter is again related to the characteristics of the machine. Usually it is linked to the nozzle, the diameter of the laser dot, screen resolution or numerically to the computer hardware of the machine and the settings of the slicers.

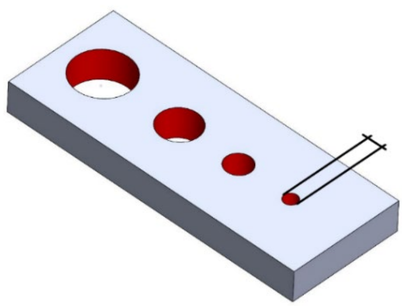

Figure 7: Minimum hole diameter dimension.
Source: own.

– Unsupported horizontal axis holes

Holes with a horizontal axis, unlike bridges, can be made without supports. Up to a certain diameter, the structure is self-supporting, so it does not need supports. The rule of thumb would be a maximum hole diameter of 10 mm.

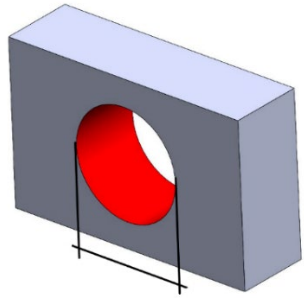

Figure 8: Maximum horizontal axis hole diameter.
Source: own.

– Connecting parts in assembly

Joining parts, either two 3D printed parts or one 3D printed part to others, requires a bit of expertise on specific machine and knowledge of its capabilities. The machine also needs to be calibrated to get the most accurate measurements possible. This is the only way the parts can be joined together, otherwise postprocessing must be performed.

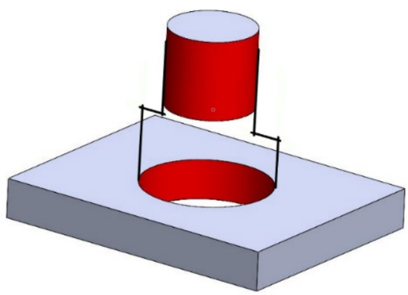

Figure 9: Dimensions for connecting parts.
Source: own.

– Holes for hollow structures

Escape holes are the necessary evil when designing parts for 3D printing with powder or resin. The hole in the structure serves as an extraction port for the material that would otherwise remain trapped inside the hollow structure. It is recommended that the holes are larger than 4 mm in order to remove the resins sufficiently. When designing hollow structures, the designer must also be aware of internal chambers where resin or powder could become trapped.

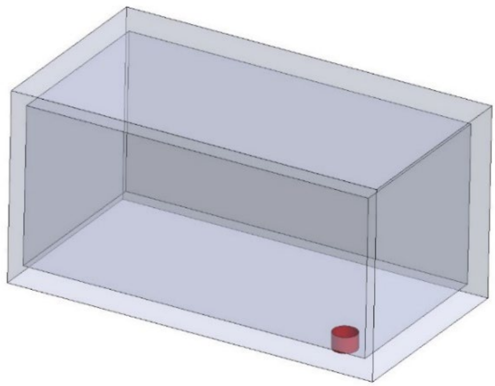

Figure 10: Hole in hollow structure for extracting trapped material.
Source: own.

- Tolerances

Tolerances are part of a similar issue as fitting parts together and are usually dependent on the machine's capabilities and its calibration. 3D printed parts without and kind of postprocessing are known not to be the most accurate for tight measurements. Surface roughness can also have a big impact on measurements and therefore tolerances.

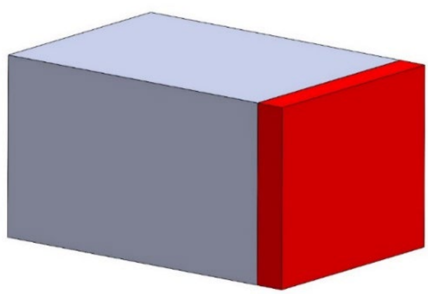

Figure 11: Tolerated dimension with its maximum and minimum possible state.
Source: own.

5 3D print in Hydraulics and pneumatics

It makes sense to 3D print some parts to improve the properties of a particular component and thus of a large system made up of those components working hand in hand with parts made traditionally. It is not about producing the same products as with conventional manufacturing techniques but producing a new generation of parts with the same purpose/functionality but improved performance and properties.

When designing parts for hydraulics and pneumatics, there are certain components where 3D printing makes more sense than others. For example, it would be irrational to 3D print hydraulic hoses for general use. 3D printing lightweight hydraulic valves for aerospace applications or for mobile hydraulic machines, where every gramme counts, makes the whole story of 3D printing much more economical and sensible. So, all in all, it makes sense to improve the properties of parts that are made from a "block" of base material and have a lot of excess volume and mass (or this mass has been removed during the subtraction process in manufacturing) and redesign them to reduce material, production and operating costs to a maximum. This can be achieved by optimising the geometry manually or by using modern software that offers different approaches to solving complex technical requirements for the final part.

Parts that are based on fluid power applications and are worth redesigning for 3D printing are:

- Hydraulic and pneumatic valves
- Hydraulic block
- Collecting manifolds and other types of collectors
- Custom parts for specific use and with special demands for geometry or structure
- Soft structures

Normally, hydraulic valves are casted or manufactured using CNC mills. Casting allows the designer to save some material compared to CNC-milled valves, but even this does not offer as much complexity as 3D printing. AM allows the production of most complex parts and the highest material savings when done correctly, up to 90% in some cases compared to CNC milled valves.

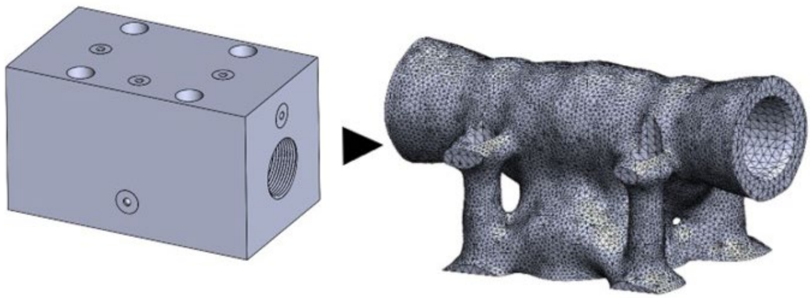

Figure 12: Optimizing geometry of topology optimization.
Source: own.

Hydraulic blocks are in some ways similar to valves on a larger scale. Because 3D printing allows for extremely complex geometries and also only needs to add material where necessary, a 3D printed hydraulic block looks like a bunch of pipes supporting the structures around them. The next step would be to combine valves and hydraulic blocks by integrating valves into the block geometry. This could further reduce the mass of the overall assembled structures.

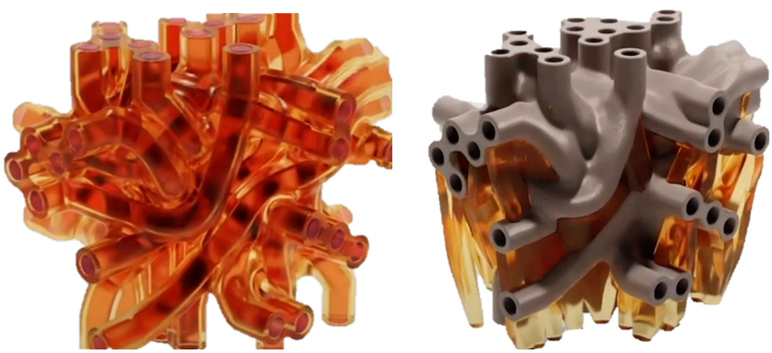

Figure 13: Hydraulic block optimized to achieve minimum mass requirement.
Source: own.

Printing manifolds of almost any type could also be economical as they add complexity such as hydraulic blocks. In some cases, 3D printing of manifolds and the initial design of manifolds for 3D printing allows designers to use some new features, such as unusual shapes, for the part. Features (bends, shapes, sizes…) that were previously limited by manufacturing technology can now be made with AM.

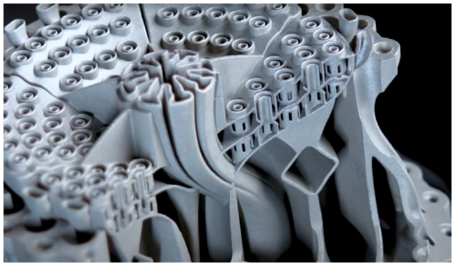

Figure 14: Hydraulic manifold optimized for efficient flow conditions.
Source: own.

Customised, non-series parts and products in small batches, made for specific purposes and with minor adjustments between parts, could still be the most important factor for the use of AM in almost all industries. In this category we find all kinds of parts that cannot be pressure moulded since big and expensive tools are needed that are rigid and do not offer much flexibility. 3D printing offers exactly that. By making minor corrections to the designs, each part can be unique, while the option to make copies of the same design is still available.

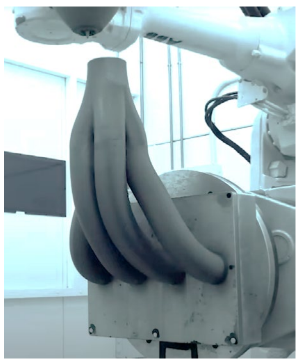

Figure 15: Custom 3D printed manifold.
Source: own.

Soft structures that are designed to deform under pressure to perform specific movements are another example of a field where 3D printing has great potential. The use of soft materials such as TPU or other rubbery polymers is important because pneumatic grippers have complex internal and sometimes external structures that are difficult to achieve with other manufacturing methods. There are always debates about the impermeability of 3D-printed parts, but the same concerns could also apply to silicone or rubber.

Figure 16: Pneumatic soft robotic gripper.
Source: own.

6 Conclusion

All in all AM is a tool that offers great potential to any industry. It is flexible and allows designers to achieve completely new level of complexity of their parts. This parts have very high enhanced value and can easily deliver huge performance increases to the users.

In this article there were only briefly presented some challenges that designers using this technology must know about. Specific values are usually based on machines, software an the experience of each individual user. Presented were also different approaches and disciplines in hydraulics, where 3D printed parts just make sense. Additive manufacturing is and will continue to develop in the future so that it could rival conventional techniques in as many industries as possible.

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