Success Story

Optimized Design for 3D Printed Valve Block Sheds Weight, Size and Gains Improved Performance

Key Highlights

Industries
Additive Manufacturing, Hydraulic Components, Engineering Services

Challenge
Optimization and design of a valve box with regard to additive manufacturing requirements (SLM method)

Altair Solutions
OptiStruct, OSSmooth, access to 3-matic via Altair Partner Alliance

Benefits
- Overall reduction of the component's size and weight
- Improved fluid flow in internal channels
- Meet stress and strength requirements

New approach realizes full benefits of additive manufacturing

Additive manufacturing, more commonly known as 3D printing, offers many advantages over traditional manufacturing methods. Additive manufacturing can produce very complex component geometries, gives designers and engineers unmatched design freedom, and allows for a much more structurally efficient and lightweight design. Increasingly, companies in a wide variety of industries are looking to reap the rewards of additive manufacturing. They soon realize, however, that they can only gain the full benefits of 3D printing when the components to be produced have been designed to meet the specific needs and constraints of the additive manufacturing process.

In 2015, VTT (Technical Research Centre of Finland Ltd.) conducted a research project to explore the feasibility of additive manufacturing in Finland. The project was funded by several public and private organizations, including Tekes, a government funding body in Finland, VTT, and several smaller Finnish companies.

VTT is the leading research and technology company in the Nordic countries, with a national mandate in Finland. For 73 years, VTT has provided expertise, top-level research, and science-based solutions to domestic and international customers and partners in both the private and public sectors. The researchers at VTT develop new smart technologies, create innovative and profitable solutions, and cooperate closely with their customers to produce technology that benefits both the client companies and society in general.

For the additive manufacturing project, VTT engineers chose the example of a valve block from Nurmi Cylinders, a Finland-based manufacturer of hydraulic cylinder products

Keywords: Additive Manufacturing, OptiStruct, Lightweight Design, Optimization, Altair Partner Alliance, Materialise

VTT Success Story

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Erin Komi,
Research scientist, VTT

for offshore, industrial, marine and mobile hydraulics, and one of the project's funders. Together the companies wanted to showcase what a design specifically targeted for additive manufacturing had to look like in order to fully benefit from the manufacturing method. The goals were to use additive manufacturing to reduce the size and the amount of material needed for the valve block, and to optimize and improve the valve block's internal channels to produce a better component for the customer.

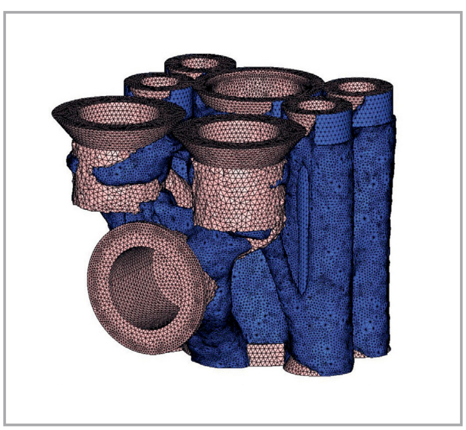
The engineer in charge of the 3D printed valve block project was Erin Komi, research scientist at VTT. Erin works with finite element acoustic simulations, making acoustic models of different products for VTT's customers. More recently, she also started to do design projects for additive manufacturing, where she is applying topology optimization and other design tools.

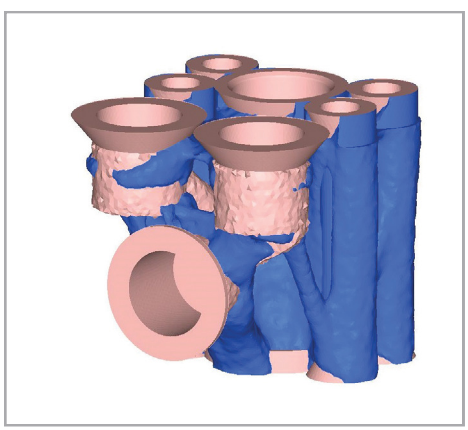
Finding the best printable design

Not every component or product is suitable for 3D printing, depending on its size, form and design as well as the quantity needed. A valve block is very suitable for 3D printing and has a high potential for improvement in weight, performance, and design freedom when additively manufactured.

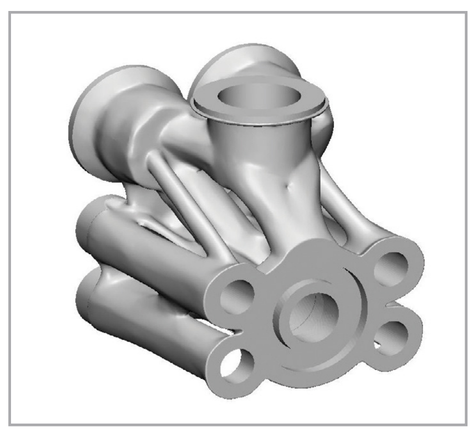
Traditionally, the design of a valve block starts with a block of metal. After being formed by traditional manufacturing methods into the desired shape, internal channels must be drilled to accommodate hydraulic fluid flow. Drilling these channels accurately is difficult – they need to meet cleanly at certain points, but alignment issues are often caused by what is in essence 'blind' drilling. In addition, auxiliary holes are often drilled and then plugged, but this opens the door to potential leakage.

Employing optimization and additive manufacturing, VTT engineers hoped to replace this cumbersome method by

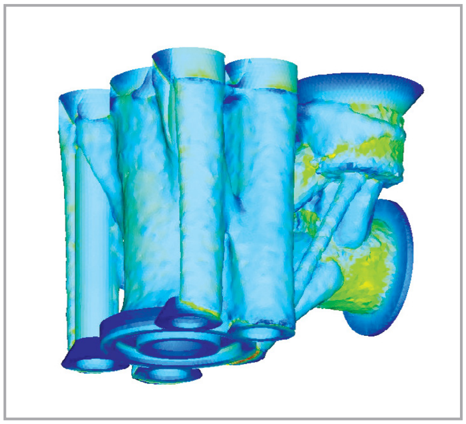


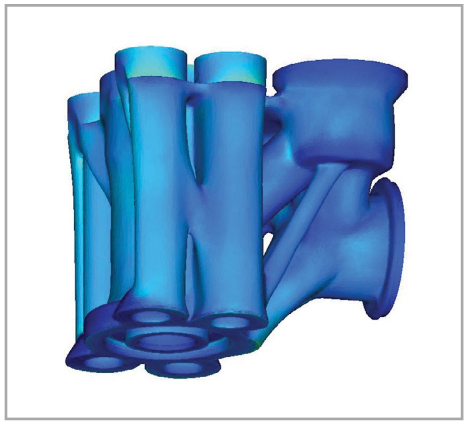


Shape generation with OptiStruct and *OSSmooth*

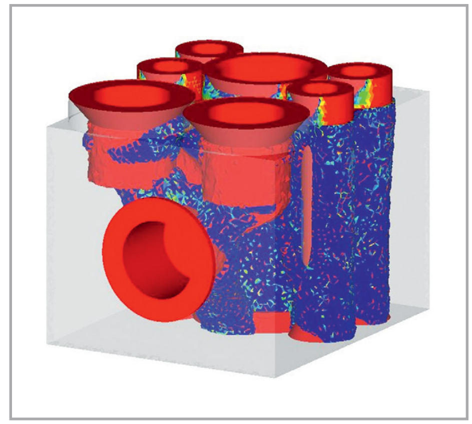


Smoothing of the geometry with 3-matic to prepare modell for 3D printing





Design analysis with OptiStruct



Topology optimization result

improving the design and manufacture of the block's internal channels and ending up with a smaller, lighter, better final product.

To design, optimize, and analyze the valve block, VTT used Altair Engineering's HyperWorks® CAE software suite. OptiStruct®, the optimization tool and finite element solver in the suite, was VTT's first choice. "We went straight for OptiStruct," said Erin Komi. "We've used it in the past, so I understand the workflow, and have been pleased with the results. OptiStruct was the given choice for us."

"There are other products available on the market that allow you to do topology optimization," she continued, "but I think the result interpretation, which is easier with HyperWorks, is also very important. The flexibility of OptiStruct, with many different possibilities to apply loads and to include responses as well as constraints, is very helpful. OptiStruct gives the engineer so much freedom to properly design a model."

Software tools speed design process, tackle challenges

A significant advantage to topology optimization with a tool such as OptiStruct, is that a CAD model isn't really needed to design the component. Once the engineer defines the design space and its limitations, as well as loads and other boundary conditions, the optimization tool proposes an optimal design. In the VTT project, the customer provided the boundary conditions as well as additional internal limitations, such as where the valve actually has to be placed and which machining tolerances had to be considered. The size, position and orientation of the internal channels were also chosen by the customer and part of the non design space. The design space in this case was a block, with some holes where connecting bolts would be placed. An important tool that helped VTT create the optimized design of the valve block was OSSmooth, one of OptiStruct's shape generation tools. With OSSmooth, the engineer can automatically re-mesh the design and run a re-analysis to make sure that all initial design requirements are met and stress limits are not exceeded. At that point the design is only a rough model, and often has stress spikes which make it unsuitable for 3D printing.

To tackle that challenge, VTT used a software application called 3-matic from Materialise, offered under the Altair Partner Alliance. The Alliance gives HyperWorks customers access to third-party tools under their existing HyperWorks license at no additional cost. The 3-matic software enables design modification, re-meshing and the creation of 3D textures, lightweight models and conformal structures, all on STL (StereoLithography) levels. In this case 3-matic helped turn Komi's optimized mesh into a printable file. "I learned about Materialise through Altair," explained Komi. "At some point in the development process I had tried to prepare a model for printing with HyperMesh, but it was very cumbersome. It was taking me days and the result wasn't all that great. Once I learned about 3-matic and tried it, what used to take days is done in hours and the results are so much better. An additional benefit is that we can access the tool via our HyperWorks licenses, so we don't even have to invest in additional software."

The valve block went through several design iterations. In certain areas, the initial size of the design space provided by the customer was cutting into the result Komi had come up with. As it turned out, the customer had decreased the size of the design space, assuming that with a smaller design space a smaller final design would be the optimization result. This is not necessarily the case. Given the natural flow of the stresses and forces, and by applying full freedom to the design, the engineer usually receives the best optimization result, including the smallest and lightest design, with the highest stiffness.

To further optimize the valve block's performance, Komi changed the route of the internal fluid channels. Initially these channels were curved like an S, with the cross sections

having a circular shape. To actually produce the valve block with additive manufacturing, VTT had to use SLM (selective laser melting) machines. For the SLM method, the recommendation to add supports internally in the channels was close to impossible, since the channels are very small.
The solution VTT came up with, together with the customer, was keeping the same cross sectional area but changing the shape and path of the channels.

One of the major goals of the project was to create 'design rules' for SLM. These include guidelines such as designing an oval or diamond shape channel instead of a circular one, since this design doesn't need support structures and will result in an overall structure that can be better printed with the SLM method. Another result VTT received is that printing structures at a 45 degree angle to the base plate is better than using other angles. Based on these kind of best-practice design rules for the SLM printer, VTT could define a set of 'design rules' which were consequently recommended to the customer.

Optimized design creates smaller, lighter, improved product

The result of this new approach to the valve block design and its production were striking: an overall reduction in the component's size and weight, improved fluid flow in the internal channels, and all stress and strength requirements met. A similar valve block made with traditional drilling techniques is estimated to weigh over two and a half kilos. The new optimized and 3D printed valve block weighs less than 600 grams, a 76 percent weight reduction compared to traditional design and manufacturing methods. The new additive manufacturing process also results in less material waste.
The success of the research project has benefitted not only the customer, Nurmi Cylinders, but VTT as well, Komi said. "Everybody involved in the project is really pleased with the results," Komi noted. "Because it was a public project, we can show and talk about our results and the solution path we took. It was also an interesting project because with the valve block you have a well defined load case, which is important when trying to optimize a structure. The topology optimization resulted in a really interesting looking, complex, organic shape design, which was challenging to print and made planning for the printing process a very good learning experience. In detail we had to consider the print orientation on the platform, eliminate the need for internal supports, minimize the need for external supports, and much more. It has also been a nice learning process for us to handle the 3D printing itself," she continued. "VTT has had an SLM printer for roughly a year, and we were still evolving our design process to learn what a design targeted for 3D printing would look like. Having this focus on actually designing for 3D printing has been a learning experience. We could see the benefits of 3D printing early in the design phase and take that into consideration. This project gave us the opportunity to use it successfully."

Komi believes that, without the application of topology optimization tools, it would have been difficult to reach the same design. The valve block now has a natural organic shape, proposed by optimization with OptiStruct and refined with 3-matic. Simply looking at the initial block of material, without the insights provided by the Altair HyperWorks tools, it's doubtful anyone could have created a similar design.

"The Altair tools were crucial to the success of this project," Komi stated. "We need OptiStruct for the topology optimization and to define the optimal placement of material within our design space. We need a tool like OSSmooth to interpret the optimization results and produce a feasible solution. In addition a tool such as 3-matic is needed to smooth the resulting mesh and turn it into a shape you can and want to print. In the end you need OptiStruct again, to re-analyze the final smoothed design. With this process, you obtain a reliable design ready to be printed."

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