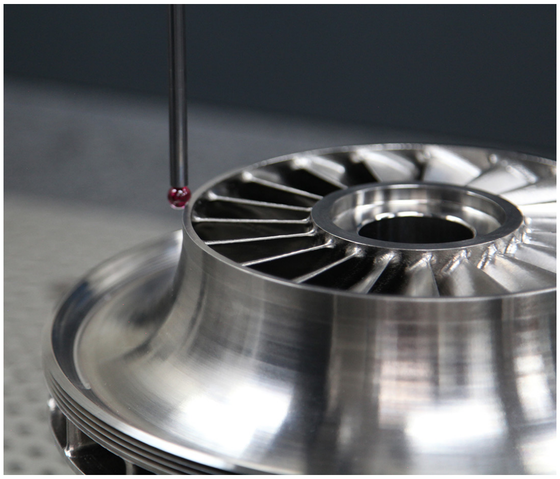
3D Printing Turbomachinery for Super Critical CO2 Systems

Hanwha Power Systems achieves 80% faster build time and 90% less material with VELO3D's Sapphire



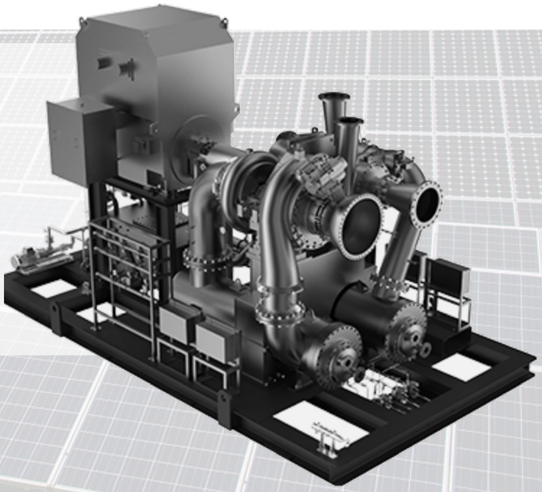
Stratasys Direct ensured accurate dimensional measuring of the shrouded impeller with a Coordinate Measuring Machine (CMM)

While it may take hundreds of parts to construct power generation equipment, there are mission critical ones that can determine the performance of the entire system. Many of these highly optimized parts can be tricky to manufacture and present some of the greatest engineering challenges that high-tech companies face. Tradeoffs often must be made between performance, availability, volume, quality and cost.

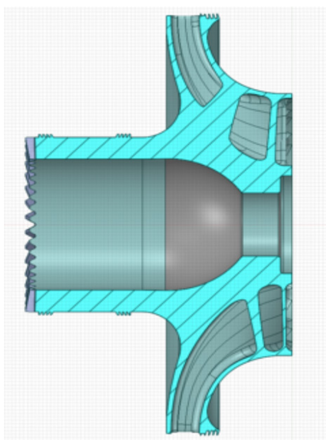
Chad Robertson, senior engineer at Hanwha Power Systems, and his team are developing turbomachinery for a high-efficiency power-generation system utilizing Supercritical CO2 (s-CO2) as the working fluid in a recompression Brayton cycle (RCBC). Heat input to the cycle will be delivered from a concentrated solar-power array. The solar power project, which is in-part supported by the Department of Energy's office of Energy Efficiency and Renewable Energy, has an end-goal of using this equipment for a concentrating-solar-power plant.

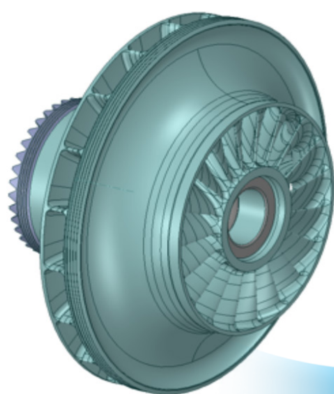
Hanwha Power Systems

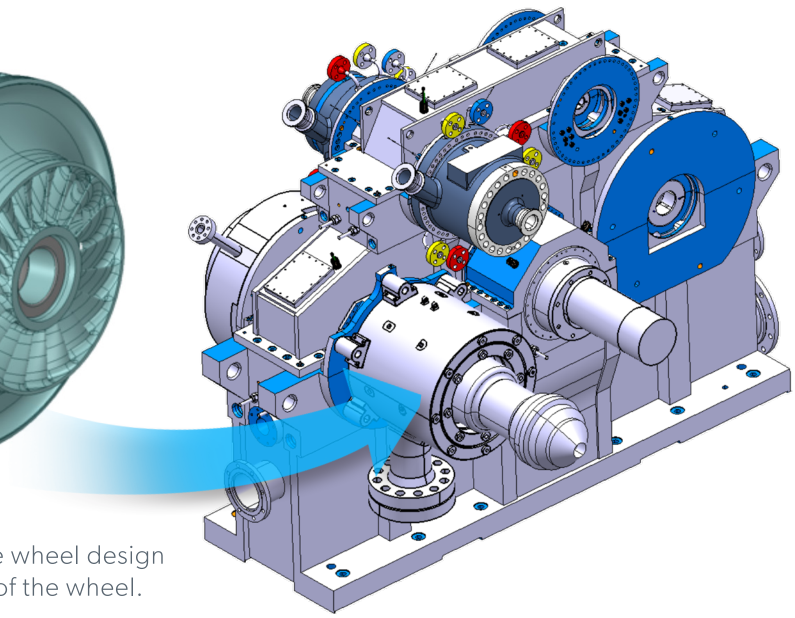
Hanwha Power Systems is part of Hanwha Group, a FORTUNE Global 500 company that is South Korea's seventh largest. There are some 6,000 units of Hanwha-designed and manufactured integrally geared compressors and expanders in operation worldwide.



The S-CO2 being used for the solar-power project is a fluid state of carbon dioxide in which it is held above its critical pressure and temperature. At these conditions the fluid is very dense, resulting in compact machinery and optimal thermodynamic cycle conditions allowing for increased thermal-to-electric energy conversion efficiency when compared to steam Rankine cycles. The overall system works by transferring heat from a large solar array into a working fluid (CO2) that is channeled through a series of radial expanders to extract power. The final expander is connected to a gearbox that drives a generator and various additional compressors needed for completing the power cycle to deliver electricity to the grid.







(Left) Cross section of the Hanwha shrouded turbine wheel design and (right) a CAD image of the exterior structure of the wheel.

“The temperatures and pressures in such a system need to be very high,” says Robertson. “Our goal of optimum efficiency drove us to design a shrouded turbine wheel, or impeller, where the flow path of the working fluid is covered on both top and bottom. This eliminates any gap between the impeller and the housing that would reduce wheel efficiency.”

The Hanwha team evaluated several different potential manufacturing techniques for making the new component.

“These shrouded impellers are a significant manufacturing challenge, even conventionally,” says Robertson. “The geometry is quite complex, as the enclosed, sweeping blades are a three-dimensional shape that is not easy to define, and the high-temperature nickel alloy that we use is difficult to machine.”

With these constraints in mind, the team reviewed and rejected using conventional techniques such as five-axis milling or precision investment casting, identifying roadblocks in cost and accuracy. For example, with traditional manufacturing, the shrouded wheel would have taken multiple steps to manufacture; an open impeller and a shroud would have had to be produced separately and then brazed, with the bonding of the two having the potential for weakness or distortion in the finished piece.

A Shift from Traditional to Additive Manufacturing

Hanwha decided to explore additive manufacturing (AM, aka 3D printing) as a more direct route to dramatic simplification of the entire process. This technology offered an opportunity to iterate more quickly, refine the design, increase performance and optimize function.

Hanwha had previously worked with Stratasys Direct Manufacturing, an additive manufacturing service bureau/contract manufacturer, on prototype test builds for shrouded impellers. "We were looking for an additive vendor that could provide us with a turnkey part," says Robertson. "We wanted to supply design specification, materials requirement—and then get back a finished part we could basically put right on our machine."

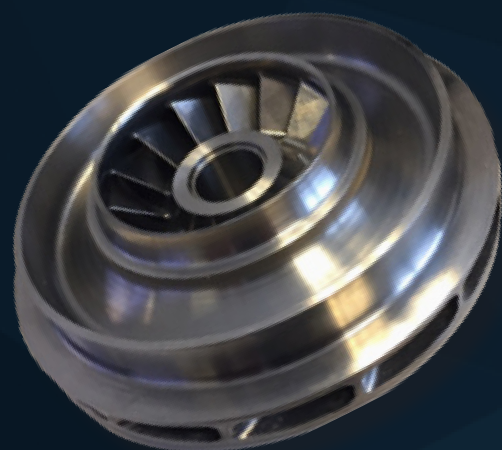
Why Stratasys Direct is a Qualified Contract Manufacturer

stratasys
DIRECT MANUFACTURING

Stratasys Direct has over 30 years of 3D printing, design and engineering experience to ensure customers' project success in each stage of product development.

As true pioneers in advanced manufacturing, they have achieved the following:

- 20,000,000 parts produced
- 1,700,000 hours of engineering time
- 300,000 projects to date
- 150+ materials from 9 processes



To learn more about Stratasys Direct please visit www.stratasysdirect.com

Stratasys Direct was up to the challenge. "What enabled us to take on this shrouded turbine wheel project was what we're calling a next-generation additive manufacturing system," says Andrew Carter, senior process and manufacturing engineer for Stratasys Direct.

> "We've found that the new VELO3D Sapphire system dramatically improves the process and really stands alone in this next-gen category."

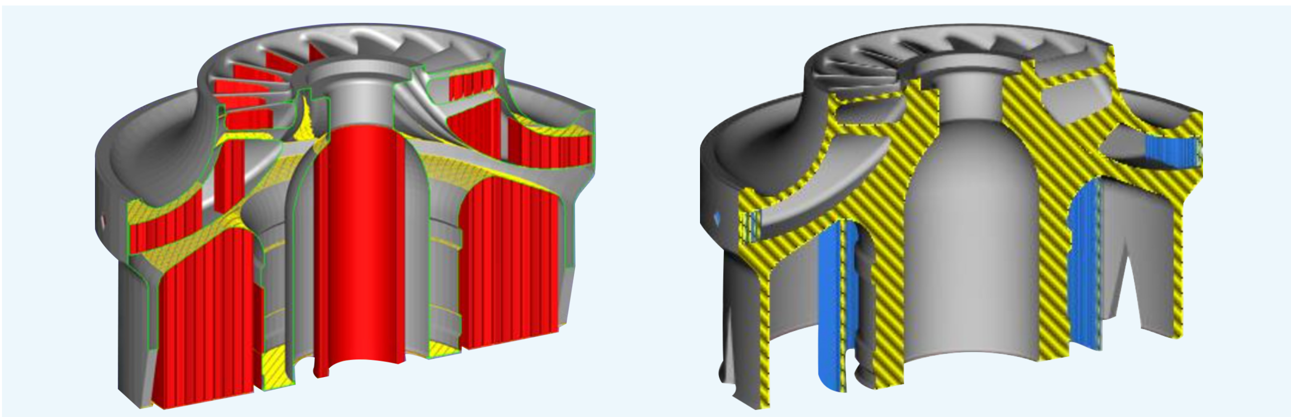
A Sapphire AM machine onsite at Stratasys Direct Manufacturing

SupportFree Metal AM Accelerates Product Development

Prior to owning the VELO3D Sapphire, Stratasys Direct wouldn't have bid on the Hanwha part, Carter says. "Previous projects with other AM-equipment vendors had shown us that the removal and clean-up of all the necessary support structures required for successful prints on their machines was labor-intensive, costly and, in some sections, basically impossible," he says.

With the Sapphire metal AM system, however, the need for supports is greatly reduced—if not entirely eliminated—due to the printer's ability to overcome the "45-degree rule," which dictates that angles lower than that require additional vertical supports to hold up portions of a part during printing.

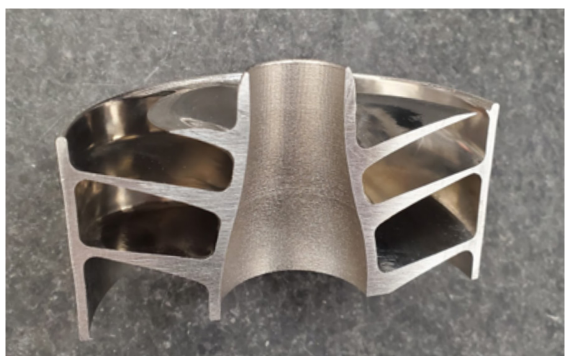
The turbine wheel still attached to the build plate as it came out of the Sapphire metal AM printer.



(Left) Most current 3D printers would need a large amount of support structures (in red) to produce the Hanwha impeller design while (right), the VELO3D Sapphire printer can manufacture the same design with minimal supports (in blue).

By using the VELO3D system to additively manufacture the Hanwha shrouded impeller, Stratasys Direct was able to greatly reduce both the total volume of material used and the surface area for which the system needed to print supports.

The engineers compared a Hanwha component design created with conventional AM support requirements against what would be required by the Sapphire. For the conventional AM printer, they modeled supports for all surfaces less than 45 degrees from horizontal. On the VELO3D printer, they only needed to add supports on surfaces at less than 10 degrees from horizontal. (Stratasys Direct has since then continued improving their process with the Sapphire and can now print all the way down to zero degrees in certain applications without supports.) The difference in the design for Hanwha was drastic—a 90% reduction in support material.



A supercritical CO_2 pump inducer designed by Barber-Nichols. Turbomachinery is an excellent candidate for VELO3D's support-less process. This is one of the most challenging parts to machine, and the ability to 3D print these without support structures makes them a viable and profitable part for AM. Source: Barber-Nichols

VELO3D Metal AM Solutions Comparison Chart

	Existing Metal AM Solutions	VELO3D Metal AM
Build Time		80% faster
Post-Processing		90% less support structures
Cost Savings		Less material waste and reduced labor expenses
Assured Quality		Material properties validated by CMM, FPI, and CT-scan

Using less material provides significant savings in a number of ways, notes Carter. “In addition to lower material costs to our customers overall, requiring far fewer supports has eliminated a lot of post-processing work,” he says. “This, in the long run, will contribute to reduced labor time and expense on the shop floor.”

Fine-Tuning the AM Build

The Sapphire also enabled Stratasys Direct to print a high-temperature nickel alloy (718) for this impeller with extreme accuracy.

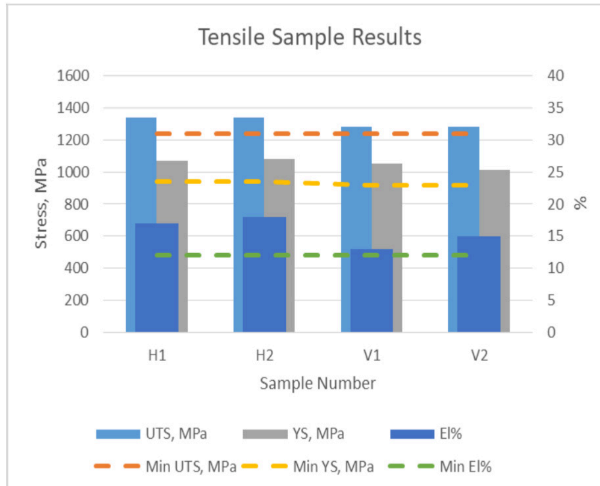
The Hanwha shrouded impeller assembled on a rotor shaft

> “Due to the consistency we get from the VELO3D system, we ended up with a near-net shape part on the build plate that required correspondingly less in the way of post-processing,” says Carter.

Build-time reduction was another benefit of using the next-gen AM system. The printer features two 1kW lasers with full build-plate coverage aligned to less than a 50μm overlay tolerance. This means that each laser has the capability to reach anywhere on the build plate and deliver a full kilowatt of power (for bulk-metal processing). Combined with the time savings from having much less support material to produce, the dual, the high-power lasers enable an 80% reduction in overall print time.

Validation of Part Quality

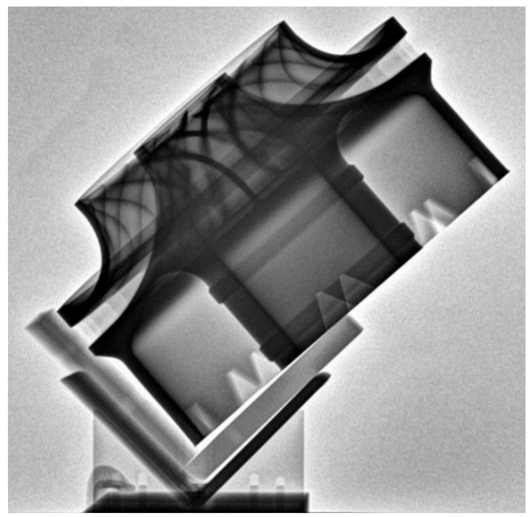
Ensuring sound mechanical properties of the Hanwha turbine wheel is extremely important for the test program as it moves forward. The wheel will be rotating at greater than 14,000 RPM during testing and will be in a high temperature environment—so it is critical that the material properties of the turbine are well understood. As part of the project, Stratasys Direct printed test samples and heat-treated them alongside the turbine to measure tensile and stress rupture properties.



Samples H1 & H2 Oriented Horizontally, V1 & V2 Oriented Vertically During Build
Minimum Requirements per ASTM 3005-14 Class D

ASTM F3055-14 provided a general specification for the additive manufacturing of nickel alloy 718. The measured tensile results all exceeded the ASTM F3055 minimum requirements. The chemical composition of the test samples was also reviewed and met ASTM requirements.

The impeller was also subjected to review using digital X-Ray, CT-Scanning, and FPI. No measurable defects were detected by the scans. The turbine was then balanced and spin-tested at speeds exceeding the design conditions and rechecked for surface cracks using FPI.



CT scan of the Hanwha shrouded impeller

"The success of the centrifugal impeller wheel prototypes Stratasys Direct made for us with the Sapphire machine from VELO3D has definitely increased our interest in additive manufacturing," says Robertson. "It has opened up design freedoms for our team, and sparked a renewed effort to better quantify the material properties and capabilities of additively manufacturing parts. The combination of the state-of-the-art 3D printing and expert project management truly did make the impossible possible."

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