STACK UP THE LAYERS

Gautam Chhibber, Steffen Jahrmarcht, and Scott Tackett, Siemens, USA, explore how additive manufacturing technology can optimise the production of centrifugal compressors.

Radial impellers play an integral role in the performance and reliability of turbocompressors. The stresses placed on the impellers during operation are typically higher than those placed on any other component of the rotating assembly. As a result, even the smallest manufacturing defects can lead to (at best) inefficient operation and (at worst) total compressor failure. Both have significant cost implications for users, particularly pipeline operators, who require compressor stations to operate efficiently 24/7/365.

Unlike many other spare parts, impellers must be precisely manufactured to meet the specific aerodynamic, thermal, and mechanical requirements of the compression application. They cannot be mass produced using traditional milling processes, which means high costs and long lead times for end-users when replacements are needed.

In 2016, Siemens set out to solve this problem using additive manufacturing (AM) to commercially produce turbocompressor impellers. In October 2019, extensive quality and stress testing were completed. The first AM units are now ready for distribution to the market. They are designed to improve rotor dynamics, reduce weight and product waste, and shorten lead times from months to weeks.

Impeller manufacturing challenges

Manufacturing compressor impellers is a complex task that often requires original equipment manufacturers (OEM) to satisfy a multitude of competing design requirements.

First and foremost, the impeller must be able to deliver acceptable distributions of relative velocity on the blades' driving and trailing surfaces to prevent flow separation, which can negatively impact performance. Secondly, after aerodynamic characteristics have been specified, the impeller must be evaluated to ensure that it can safely withstand the mechanical and thermal stresses it will be subjected to throughout its useful life. Finally, the impeller must be designed in such a way that it can be reproduced accurately using an automated manufacturing process.

Many large impellers today are fabricated via milling; however, for smaller impeller wheels, conventional milling techniques often impart too much impact on the material, increasing the likelihood of creating structural weaknesses. Additionally, for many high-performance and mission-critical applications where extreme manufacturing precision is required, the use of milling processes can result in minuscule defects on blade surfaces, leading to separation of flow and higher losses.

A popular alternative to milling smaller impeller wheels has been an electrical discharge machining (EDM) process known as erosion. Erosion is a non-contacting method that enables machinists to achieve extremely close tolerances and intricate contours that would otherwise not be possible with conventional cutting processes. The primary disadvantage of EDM, however, is that it is highly cost prohibitive. Like milling, EDM also results in long lead times – typically to the tune of months.

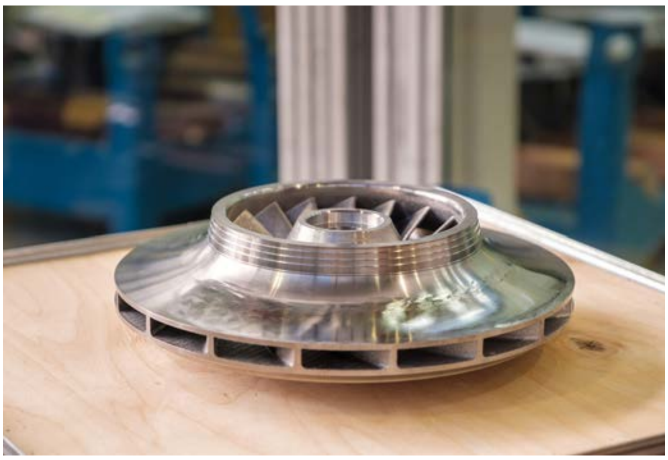

Figure 1. **Additively manufactured radial impeller after overspeed test.**

Overcoming conventional techniques

In recent years, an increasing number of companies have begun leveraging AM processes to overcome the challenges of conventional manufacturing techniques.

Siemens started investing in AM in 2009 to produce critical components for gas turbines. In 2013, the company installed the first 3D-printed burner tips and burner swirls in gas turbines. Then in 2017, the first hot gas path blades were successfully printed and tested. Around the same time, 3D-printed burner heads were also installed for commercial operation. Another development came in 2018 when an additively manufactured sealing ring was installed on a steam turbine in commercial operation.

Siemens is now applying its knowledge of 3D printing to commercially produce closed radial impeller wheels for turbocompressors using an AM process based on powder bed fusion (PBF) – also known as selective laser melting (SLM), direct metal laser sintering, or electron beam melting.

With PBF, a 3D computer-aided design (CAD) file is sliced into 2D elements corresponding to laser scan vector data for each layer. A layer of metal powder with a specified thickness is then applied over the forming platform. The powder is melted selectively by a laser to produce the desired component in layers. Any powder that is not melted by the laser is brushed away from the part and collected for reuse.

In recent months, Siemens has optimised this manufacturing process to improve the physical characteristics of additively manufactured radial impeller wheels, such as the surface quality of the blades. The blade channel of the first AM impeller wheel has a so-called 'stepping effect.' These steps are surface defects that lead to the creation of flow turbulence that can reduce compressor efficiency.

Siemens has qualified a continuous process chain to ensure the fulfillment of all quality requirements, including an extensive non-destructive and destructive test programme to validate the mechanical integrity of radial impeller wheels. Figure 1 shows a 3D-printed impeller after a successful overspeed test without any indication.

The company has also improved the manufacturing process itself by proving that in a single printing run, three separate impeller wheels can be produced by stacking one above the other. This method can increase the efficiency of impeller production because preparations, such as warming up the printer, are undertaken once – instead of three separate times.

In addition to the wheel itself, covers for the impeller mounting screws (i.e. hub caps) can be manufactured using AM. Traditionally, hub caps have been fabricated by turning out cylinders, but the process typically results in as much as 95% of the metal being chipped away and discarded as waste. With AM, the caps can now be produced with virtually zero waste.

A design study showed that another benefit of AM could be a reduction in the overall weight of the impeller by as much as 30%, which contributes to better rotor dynamics of the compressor. It also offers advantages for the AM process itself, as every reduced gram of material that does not have to be melted by the laser saves time and money.

Finally, AM has allowed Siemens to reduce spare part lead times and serve short-term orders more efficiently. In the past, using traditional manufacturing techniques, it was not uncommon for impeller wheels to take up to several months to deliver, particularly during times of high capacity utilisation. While this timeframe is not necessarily a problem if the impeller is changed as part of a scheduled service plan, it is far too long in the case of an unexpected shutdown when the replacement is needed as soon as possible. Siemens' goal is to deliver AM impeller wheels to customers in as little as six weeks, which would be a huge reduction in current lead times.

Accelerating adoption of new technologies

Over the past five years, AM has emerged as a transformational technology for the energy industry – enabling OEMs to create new designs and geometries that have not been possible with conventional manufacturing methods. The production of radial impellers using AM is just one of the many examples of how it is being leveraged to deliver measurable value to equipment end-users – from improved blade surface quality and decreased weight, to reduced waste and significantly shortened lead times.

Overall, AM has enabled Siemens to respond to customer requirements more effectively and expeditiously. It has also increased flexibility in the design process, allowing developers to tweak 3D models digitally to develop prototypes that can be used for testing. Parts can be rapidly printed and checked for certain properties before serial production begins, massively speeding up innovation cycles.

Historically, the oil and gas industry has been conservative when it comes to adopting new technologies, and AM has been no exception. Siemens has illustrated some of the benefits of 3D printing for the manufacturing of gas turbine components, and is now applying this added knowledge to compressors.

Ultimately, as energy providers, including pipeline operators, seek to improve efficiency and increase the availability of their compression assets, the benefits of 3D printing will become harder and harder to ignore. The technology is rapidly maturing, and every year more components are being tested and validated in real-world applications. Siemens has demonstrated this, and will continue to invest in the development of AM products and services that comprehensively address the equipment lifecycle – from design and fabrication to operation.