CAST IN PLACE: INTEGRATING NON-CAST COMPONENTS INTO CASTINGS

3-D printing helped a turbine manufacturer improve the dimensional accuracy of a part while adding flexibility to the tooling for streamlined production.

GEOFFREY D. KORFF, QUAKER CITY CASTINGS (SALEM, OHIO); AND
TRAVIS B. STEWART, ELLIOTT GROUP (JEANNETTE, PENNSYLVANIA)

Steam turbines are built using a variety of castings ranging from standard class 25 gray iron to 400 series stainless steels. A typical single-stage turbine can contain up to 21 castings of different variations for the base design, while a typical multi-stage turbine can contain 30 castings or more. This does not include any castings that would be used for add-on equipment, such as trip and throttle valves and aftermarket governors or for other equipment on the equipment train.

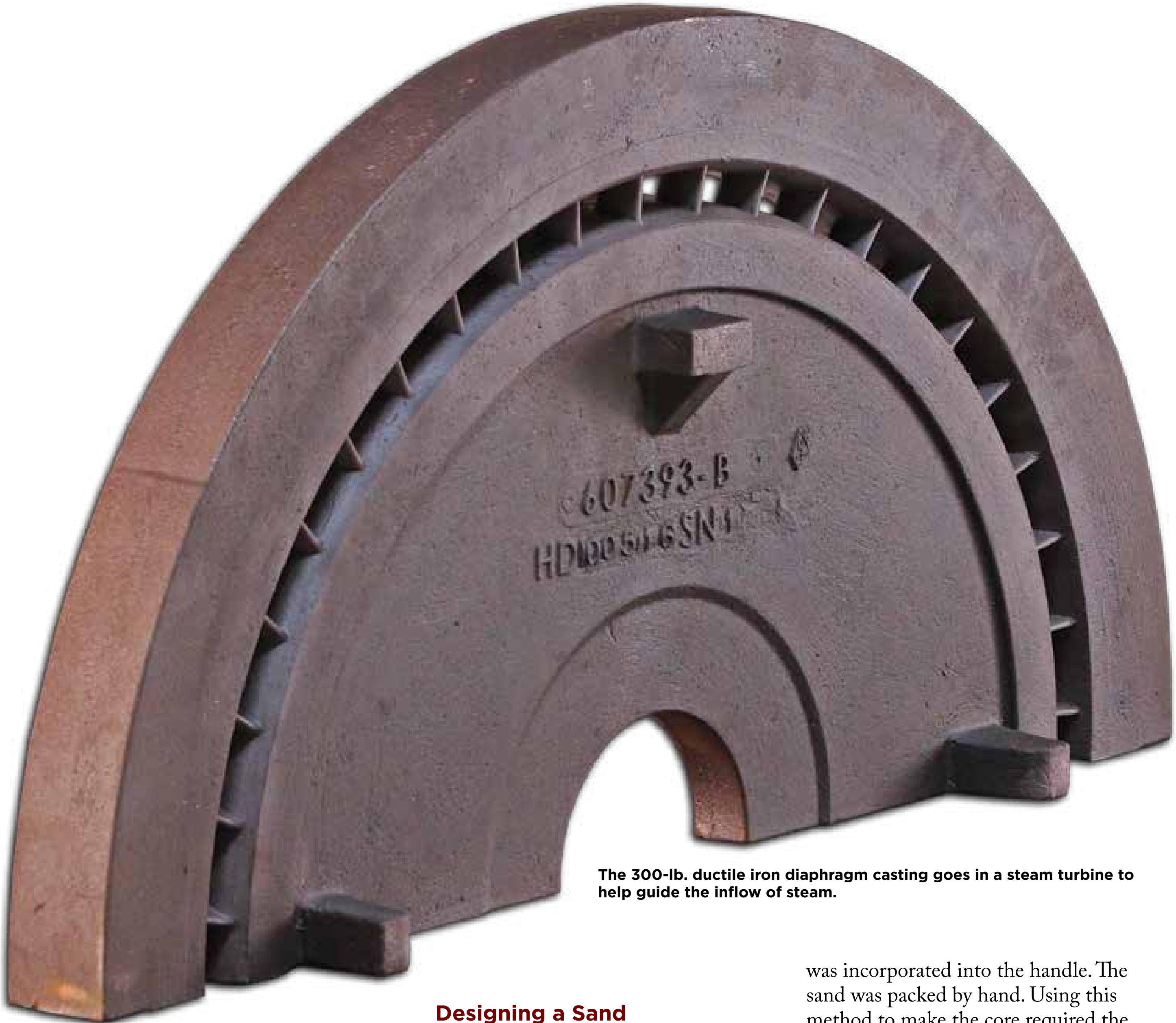
The casting material is determined based on the temperature, pressure, environment, and steam conditions for the turbine application. In many cases, casting materials are interchangeable depending on these factors. For example, iron castings may be used in some applications for their thermal properties and ductility/dampening, while stainless steels may be used in other applications where it is needed for corrosion resistance. Material selection is important not only for the operation of the unit, but also for servicing the unit. Depending on the operating temperatures, there may be requirements for J-Factor calculations to avoid embrittlement in the time vs. temperature designs. Charpy impact testing may be required for low temperature service. For turbines, this is mostly environment-based and not dependent on operating temperatures.

The design of turbine castings has changed substantially since the 1970s, when everything was typically made from iron. Those castings were big, bulky, and over-engineered to build-in high safety factors. Contemporary designs are more precisely engineered with tighter specifications and closely calculated safety factors validated by FMEA models. Turbomachinery manufacturer Elliott Group (Jeannette, Pennsylvania) has seen an increase in requirements such as radiography, ultrasonic testing and requirements for 3.2 level certifications. This has caused Elliott to look at new ways to validate the process of producing its castings so they can be ordered without the requirements up front but still meet them on the back side.

One example is a cast diaphragm that is created by casting ductile iron around a series of stainess steel vanes.

The vanes direct and redirect the flow-off steam passing through a multi-stage steam turbine. These diaphragms can be used to generate a large amount of power or to increase efficiency. The current design of the part has been in existence for over 35 years and has undergone only minor changes since its conception date. The chemistry of the iron has been the only adjustment made to the actual part.

The main reason for changing



The 300-lb. ductile iron diaphragm casting goes in a steam turbine to help guide the inflow of steam.

the chemistry was the natural transfers that occur between the iron and stainless steel. These transfers cause a lack of fusion between the dissimilar materials and create large hard spots that hamper machining. Because the pouring temperature plays a large role in the transfer, Elliott Group worked to define a lower pouring temperature and used the vanes as a natural chill. The modified chemistry, along with a controlled pouring temperature, eliminated the lack of fusion and hard spots, giving the casting a uniform surface that is easily machined.

Designing a Sand Core Solution

The process for making the basic shape of the cast diaphragm is relatively simple. Bringing the core to life is a different story.

When the turbine diaphragm design was first conceived and produced, the core was difficult to make, requiring a burdensome manual process. The initial design used a corebox with a spacer that was indexed to create the vane spacing. The spacer was built in to a handle that was mounted in the center of the corebox. As each vane was placed, the handle was moved and secured into a hole with a dowel that was incorporated into the handle. The sand was packed by hand. Using this method to make the core required the foundry to use oil sand due to the long production process.

The biggest downfall to the corebox method was the required total area calculation was inconsistent and virtually impossible to achieve. Hand-packed sand meant there was nothing to maintain the spacing of the vanes after the spacer was indexed. Depending on how hard the core maker packed the sand, the vanes could easily shift both in position and angle. Since the surface area was always well over the defined limits, the vanes had to be bent back into position after the casting layout was completed. This caused more

Each casting is half of a complete rotation. The first vanes on each half must be machined to marry up when assembled, so good dimen-stional stability is needed.

problems than the simple distortion of the vane throat area. Because it takes two diaphragm halves to create a full rotation, the castings have to be laid out to define the split.

The first vanes on each half must be machined to marry up when assembled. With the issue of the vanes moving during coremaking, this was often very difficult to achieve. Surface machining was also often an issue because the surface was defined by the height of the highest vane and vane height tolerance exceptions were common. If the vane was too high, the material around it would peel away, causing the part to be scrapped. Another downfall to the corebox method was the rotation was not interchangeable. The corebox was only good for either clockwise or counter clockwise rotation. As demand increased and new throat sizes were needed, it became apparent Elliott needed new ways to develop the cores in a more efficient and consistent manner.

One of these new methods incorporated an aluminum corebox with loose pieces to accommodate several different vane lengths. The handle for indexing the spacer was replaced by a series of 48 loose pieces to set the spacing and angle. Each of the loose pieces was numbered so they could be placed in defined positions to allow for the 180-degree bend in the core. This method represented an improvement but still had several flaws. The possibility that the loose pieces could shift slightly remained, which would cause the spacing and angle to be off. The loose pieces were dropped in from the top of the core and could not be locked in place. This was still largely a manual process that required the core maker to be precise. If he packed the sand too tightly, the vanes and loose pieces would shift. Since this method was more accurate and much simpler, the cores could now be made from air set sand with a minor binder adjustment to lengthen the working time.

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In this method, the loose pieces were still able to move, and operator errors still introduced variability into the process. Elliott saw an improvement to the surface area calculation, but it was still out of tolerance and the vanes had to be bent into place. The same downfall applied to this aluminum corebox design as the previous, in that it could only accommodate one rotation. If the other rotation was needed, a second corebox was needed. At the time, the cost of the corebox was in excess of $90,000 and couldn't accommodate all of the variation that was to come. Elliott recognized this method was untenable for production purposes.

With all of the advances in additive

manufacturing, Elliott Group began exploring new ways to make the cores using 3-D printing. Eventually, and in collaboration with Quaker City Castings (QCC) (Salem, Ohio), the company arrived at a solution.

3-D Printed Sand Cores

In 2014, Elliott approached QCC to discuss a solution to the issues with casting the cores and vanes of turbine diaphragms. QCC had experience using additive manufacturing or 3-D printing to combine complex core assemblies into a single core. After several discussions between engineering staff at Elliott and QCC, both companies agreed QCC would develop a process to manufacture 3-D printed sand cores in tandem with a method to ensure the vanes would be correctly spaced and dimensionally accurate.

The first step in the process was to identify a source to print the cores. QCC does not own a 3-D sand printer and instead has relied on a small group of vendors to produce sand cores and sand molds. The engineering teams agreed on a core design which would allow the core package to be printed as a single unit. This would create uniformity in the spacing and angle of the vanes. The vanes would be inserted directly into the core at the foundry, after which the entire core package could be placed in the drag with the vanes in them. Once the design was set, QCC placed the order for the core with a vendor who could print the cores.

In addition to 3-D printing the cores, QCC also developed a series of fixtures to ensure the vanes could be inserted into the core at the appropriate depth prior to being inserted into the sand mold.

The steel vanes are set at the appropriate positions and glued into place using a hot glue gun through slots incorporated into the top of the core. This ensures the vanes do not move while the core is transferred to the mold. The molders must also take great care to avoid any unnecessary friction between the vanes and the core so the vanes are inserted snug to the core without rubbing loose any significant amount of core sand. A loose-fitting vane in the core introduces a level of variation in the process that both QCC and Elliott strove to avoid.

When the glue is dry, the core is transferred to the mold to be closed and poured. Metal is then poured around the vanes, locking them into place and producing the diaphragm.

Due to the different materials and section thicknesses present in the finished part, the blasting and cleaning processes had to be specially tailored to remove the core sand while protecting the structural integrity of the part. During the first several months of production, the scrap rate from post-casting processing was higher than either QCC or Elliott was willing to accept, but new processes and close process controls brought the scrap rate down to an acceptable range. QCC was able to produce a finished part through additive manufacturing with the highest consistent dimensional accuracy of any process that Elliott has attempted.

The method of 3-D printing sand cores for the vanes in the diaphragm casting has proven to be efficient, cost effective and repeatable. It has allowed the total area variation to be held within +/- 0.5% over the entire 23 blade section. The former processes had a total area variation of approximately 10%, and Elliott had to manually bend the vanes to get the area back into the acceptable range.

Unlike the prior two processes, the 3-D printed cores also enable the tooling to be used for both rotations. This has saved a significant amount in tooling costs and ensured repeatability in the process. Only minor adjustments (change core prints) are required for the tooling to be used for either rotation.

Despite the initial cost increase associated with 3-D printing, the total cost of these parts has been reduced and the part consistency has been significantly improved, thus demonstrating one of the unique ways 3-D printing can be used in the foundry to improve quality, reduce lead times, and ultimately, save money. ■

Steel vanes are inserted directly into the 3-D printed core and then the whole core package is placed in the drag part of the mold for pouring.