Concepts NREC
The Experts in Turbomachinery

Case Study

Engineering and Manufacturing a Unique Compressor Design

TK Engineering (Cincinnati) sought a turbomachinery manufacturing company in 2004 to design and produce a fixed stator case as part of the United States Air Force (USAF) Small Business Independent Research (SBIR) support of the Unmanned Aerial Vehicle Propulsion improvement program. Selected was Concepts NREC for its ability to meet the required quality and cost specifications.

"We had other companies' estimates for doing this project," says Bob Turnbull, Chairman of TK Engineering. "Concepts NREC was the most capable company, and it came in with the best price, so we wanted them to work with us. The fact that they did it less expensively was important. We already had the contract. It was a question of using the money we had most effectively, and we feel we did so," Turnbull asserts.

Following five years of development, completed parts were delivered as scheduled. The extended timeframe reflects the design's evolution from an aero design to a mechanical concept design, and then to a manufacturing concept requiring new technology.

"This was a very advanced compressor from the aero standpoint, primarily because of the pressure ratio and high objective efficiency on the axial compressor," says Turnbull. "The pressure ratio had to be 13:1, making it a high-risk design that, in the end, required an advancement in engineering technology."

Blading for the axial and centrifugal compressor was based on TK's aero design requirements. The parameters required an overall pressure ratio of 13 in two stages: an axial pressure ratio of 2.5 and a centrifugal pressure ratio of approximately 5.2.

Turnbull says that achieving the centrifugal pressure ratio is not difficult. "Enough wheel speed will get you that. The real challenge was the axial ratio of 2.5 in a single stage."

Concepts NREC had to change the inside configuration of the axial rotor to reduce stresses on the part. Jeff Pfeiffer, Concepts NREC Director of Business Development, explains: "It was a very unique configuration because of its internal shape. We worked with a subcontractor to perform the difficult internal machining work, and assisted them by making some design modifications to make sure the area was accessible."

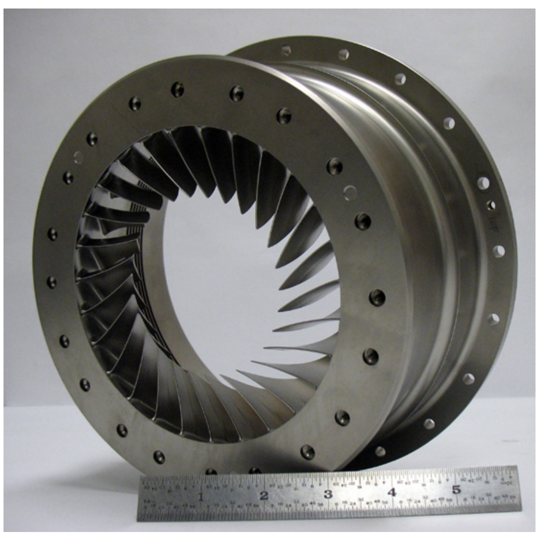
Manufacturing the axial rotor initially appeared to be achievable only by casting, but material strength requirements didn't allow it to be cast. It had to have forgiving properties. Ultimately, the axial rotor part of the project became an intricate tooling assignment requiring machining inside the bore to form the semi-ball-shaped design to reduce stresses.

The fixed stator part of the project originally didn't appear to be as challenging, because it was considered to be a multiple-piece design that could be welded together. It ended up having to be redesigned as a single or integral piece, and posed a similar machining challenge to the axial rotor, because the original one-piece design couldn't be machined due to limited access to the vane-ring area.

"We developed new tools and methods to manufacture this product," says Bill Pope, Concepts NREC Director of Operations.

After design analysis on the parts, Concepts NREC determined that the casing could be done as two separate axial parts initially so that the stator vanes could be accessed for machining. Circumferential Electron Beam (EB) welding of the casing was done immediately ahead of the stator vanes to gain access for machining. Then, the two parts were EB welded together and a final machining process performed to final specifications.

To handle sand ingestion, a US Army requirement, Inconel 718, a super-alloy, was chosen. Using Inconel 718, which requires a heavy chip load when machining, made the manufacturing process more challenging, as production required boring on a lathe and new design considerations. Custom tooling was developed and tested to withstand the cutting force and achieve the required dimensions and surface finish.



The casing could be done as two separate axial parts initially so that the stator vanes could be accessed for machining, then EB-welded together and machined to final spcifications

The center of the vaned ring was removed with a P01404 drill and SMO08436 blade insert from YG-1 Tool Co. (Vernon Hills, IL). Roughing was done with Concepts NRECMG 642-KC5510 and CPMT 3252-KC5510 inserts from Kennametal Inc. (Latrobe, PA).

The vane ring was semifinished using roughing mills. This part required two operations and was oriented on two 0.125" (3.2-mm) diam fixture holes drilled at two locations with rough mill blades on the flange side. A C40 U five-axis machining center from Hermle Machine Co. (Franklin, WI) was used and equipped with an end mill (RA216.23-1250BAK09P) from Sandvik Coromant Co. (Fair Lawn, NJ) and standard length collet holder.

Concepts NREC workshop with Hermle C40 U five-axis machining center used for rough and finish-machining vane rings for the aero fixed stator case.

To prevent distortion of the airfoils, Concepts NREC applied heat treatment for age-hardening once rough machining was complete. The parts were heated to 1350°F (720—720°C) for 8 hr then furnace cooled to 1150° F (620° C) for 8 hr using BodyCote thermal processing.

The vane rings were finish-machined on the Hermle C40 U machine with a Sandvik Coromant RA216.44-1230 AK06N ball mill with standard holder HSK63A and a 3" (76-mm) end-mill extension.

Inconel 718 was also used for the fixed stator case, which was developed as a design using individual vanes intended to be brazed to the outer case. In typical aero designs, the fixed stator case and related parts are machined as separate pieces and the blades are usually brazed together in a slide-in ring assembly. TK Engineering preferred making all

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the parts integral with the outer case.

The blades were positioned radially inward, which presented a new challenge to Concepts NREC engineers who didn't want the blades to relax or spring after they were machined, affecting the performance of the machine.

"The blades of the impeller look like potato chips with a ring around them," Pope says. "Our CAM department developed new capabilities by intermingling toolpaths created with both our *MAX-SI*™ and *MAX-AB*™ CAM software modules. Doing this, along with choosing the proper cutting tools and toolholders allowed us to completely access the area and accurately machine the vanes. The methods we developed on the fixed stator can now be applied to future projects."

Concepts NREC's engineering group used its *Agile Engineering Design System*® software to engineer the fixed stator case product and its *MAX-PAC*™ software module for machining. The project from receipt of contract to manufacture of the product took five years. It took three weeks to work out the machining process once the engineering was complete, and Concepts NREC engineers verified that the design was sound through analysis and testing. From beginning to end, it took three to four months for manufacturing, including test cutting and final production.

Through its experience with the TK Engineering project, Concepts NREC developed advanced technology to produce three parts: an axial rotor, an integral fixed stator case and a special diffuser for which Concepts NREC designed the centrifugal compressor. The new concept in design and manufacture of the fixed stator case has potential for commercial and military small engines.

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