A Sulzer customer manages a combined heat and power plant that supplies a large city with electricity and district heating. In 2010, the plant operator received an alarming technical information letter from the gas turbine manufacturer. Parts of the installed F-class gas turbine (see infobox) had manufacturing errors that endangered the operation of the engine in the long term. Because there was a risk of equipment and operational damage, the operator had to replace two sets of third-stage blades. The plant operator already had a long-term service agreement with Sulzer and trusted the company as reliable partner. So the customer approached Sulzer and asked for a solution. At that time, these parts were new to Sulzer’s product portfolio, but the service center had a dedicated team of experts reengineering replacement parts. The team immediately reacted to the customer request and began to develop a new design and manufacturing process for these F-class turbine parts.

It is challenging to reengineer F-class parts because they are pushed to the limits of what is physically possible in material and manufacturing technology. Turbine inlet temperatures reach up to 1600°C, which is beyond the melting temperature of conventional metals. This demands advanced materials, cooling, and coating technologies to avoid premature failure of the parts. Figure 1 (page 11) shows how the different technologies (superalloy, cooling, and coating technology) contribute to the ability of E- and F-class turbines to withstand their inlet temperatures.

Sulzer is in a unique position to master the challenges of designing and manufacturing F-class replacement parts. Sulzer’s experience in repairs gives the service teams a good understanding of the life-shortening deficits certain gas turbine components possess. This insight enables Sulzer to create reengineering solutions that give the customers a better return on their investment.

Development program for F-class turbine parts
Reengineering processes at Sulzer are divided into defined tollgates and are well controlled. The process involves multidisciplinary development teams for each part. Each team consists of design and process engineering, quality assurance and control, procurement, and part ownership. The process ensures that the intellectual property rights of the original design and manufacturer are not infringed in any way. So, the first step in deciding whether to develop a new program is the patent review phase. This part of the process
Advances in gas turbines and power plant technology

Gas turbines are widely used for power generation. Burning an air-fuel mixture produces hot gas that spins a turbine, which drives a generator. Gas turbines are grouped into classes according to their air volumetric flow, compressor pressure ratio, and firing temperature:

- E-class gas turbines dominated the market during the 1980s. The firing temperatures are up to 1200°C (2200°F).
- F-class gas turbines became available in the early 1990s and are increasingly used today. The F-class brought a significant improvement on efficiency and power output (see diagrams). Thanks to advanced materials and turbine-cooling techniques, the firing temperatures can reach 1600°C (2900°F).

In gas turbine power plants with a combined cycle configuration, the waste heat is recovered to produce more useful energy. This way, the energy conversion efficiency can reach 60% (instead of 40% for simple cycle gas turbine power plants). The waste heat can be converted to electricity or used directly as thermal energy, e.g., for district heating. Such combined heat and power plants (CHP), also called cogeneration plants, offer a promising approach to reducing carbon emissions in a cost-effective way.
defines and identifies all relevant patented features and designated countries. The review is continuously monitored throughout the program cycle. Furthermore, it is well documented and independently verified and approved.

The development program continues by defining the characteristics of the full engine and its parts. On the part level, advanced data capture techniques are applied:

- 3D blue light and computational tomography scanning
- Metallurgical analyses
- Functional testing as modal analysis and flow testing

The characterization includes the basic aspects of any design (structural, functional, and operational). This is repeated continually depending on the availability of parts. The part characteristics are assessed, and potential modernizations and improvements of performance and lifetime are identified without jeopardizing part interchangeability. The need for modifications may also arise to avoid patent infringement.

**Material selection, redesign, and qualification**

In F-class turbine parts, the superalloy plays the biggest part in helping the turbine to withstand the harsh environment. These alloys exhibit outstanding mechanical properties at elevated temperatures. By altering the casting process, one can change grain structure and orientation to increase strength and manufacturing complexity:

- Equiaxed (EQ), i.e., randomly oriented grains
- Directionally solidified (DS), i.e., grains parallel to the major stress axes
- Single crystal (SX), i.e., no grain boundaries in the material

Typically, the first stage needs to be made of single-crystal or directionally solidified material. In downstream stages where the gas temperature decreases, equiaxed material is sufficient. Throughout the years, various alloys have been developed to increase the high-temperature resistance of gas turbines. Sulzer manufactures alloys that are similar to commonly used materials, and it can modernize the selected alloy to enhance part life.

Modern numerical techniques such as finite element analysis (FEA) and computational fluid dynamics (CFD) are used to verify and validate the design, see Figure 2. In a delta analysis, the design is compared with predefined design limits and constraints and the base configuration. It requires knowledge of the operating conditions of the gas turbine. Acceptance criteria are established based on the validation and 3D model. Production drawings are approved and released. Quality assurance and control is embedded in the entire redesign, development, and production program to ensure high standards. In the manufacturing phase, all (special) processes such as casting, machining operations, and coating must be qualified and approved according to predefined processes and part and supplier requirement specifications. The production thereafter is based on a proven and frozen process.

**Production process and delivery**

The hot gas path parts are made primarily by investment casting, which is based on the lost wax principle. F-class turbine parts are challenging to manufacture because of the stringent acceptance criteria, complex (internal) geometry, and superalloy grain orientation. Sulzer’s casting process yields high-quality parts that comply with strict quality criteria. To speed up the casting development, concurrent product development between Sulzer and its supplier is key. Besides this, Sulzer uses numerical simulations to predict metal flow and solidification rates and modern 3D printing processes to further shorten lead times.

The castings require machining to achieve the final dimensions and to add additional cooling holes. In F-class parts, there may be upwards of 450 cooling holes per part. Machining processes such as milling and grinding, as well as electrochemical-, electrical-discharge-, and laser beam material removal are used. A protective coating system is applied to increase corrosion and oxidation resistance and reduce heat transfer to the base material. Sulzer can apply high-velocity oxygen fuel (HVOF), low-pressure plasma spray (LPPS), and air plasma spraying (APS) coatings in house.

Sulzer’s development program of replacement parts for F-class turbines was a complete success. The project for the customer mentioned above was completed in a record time of only 14 months, including redesign, development, and manufacturing. The replaced parts are currently in operation with nearly 16 000 cumulative operating hours.

Since this project, Sulzer has supplied F-class parts all over the world. Customers confirm that the new parts achieve the expected performance. Thanks to Sulzer’s innovative reengineering solutions, power plant operators can get the most out of their gas turbines—and the population can count on a reliable supply of energy.

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Reengineering of gas turbines at Sulzer

Sulzer has offered refurbishment of gas turbine parts since the 1970s. It has refurbished millions of gas turbine parts in its workshops—especially at the Venlo Service Center in the Netherlands. In the early days, mostly B- and E-class parts passed through the workshop in Venlo. During the early 2000s, Sulzer succeeded in manufacturing the hot gas path replacement parts for E-class engines (General Electric 9E and Siemens SGT5-2000E/V94.2). As the demand for F-class turbine parts increased, Sulzer launched a development program of replacement parts for F-class engines (Siemens SGT-1000F/V64.3A and General Electric 6FA+e/6FA.03) in 2010. This program focused on the design and manufacturing of the compressor, combustion, and hot gas path sections. Today, Sulzer is an independent service provider for these engines—including replacement parts for the compressor, combustion, and turbine section.

www.sulzer.com/gas-turbine-parts

1 Different technologies (superalloy, cooling, and coating) are applied to E- and F-class first-stage blades to help them withstand turbine inlet conditions. The blue bars show that the superalloy contributes most to temperature resistance, and that in F-class parts, the improvement on cooling technology is significant.

2 Thermal-stress and fluid-dynamic simulations of an F-class first-stage blade.