Implementing an internal water-mist spray cooling system

Innovative dual operation

Sulzer Turbo Services successfully implemented a unique retrofit for a steam turbine for operation in a dual mode. As a result, the customer can now generate electricity during the summer and sell steam to a pharmaceutical plant during the winter, which maximizes the profitability of the plant's operation. Sulzer Turbo Services, through its sound engineering, offers tailored solutions to one-off problems that the OEMs would not typically show the flexibility to tackle.

Sulzer Turbo Services was contracted to study the feasibility of implementing and to design a cooling-mist system for a steam turbine operated in a combined heat and power plant. The client's objective was to allow full-steam extraction after the second stage of expansion. The customer determined that it would be more profitable to sell the steam to an adjacent pharmaceutical plant rather than to generate electricity with it during the winter. Hence, the plan was to divert all the steam after the second stage of the turbine—but only during the winter months. During the summer, the pharmaceutical plant did not require the steam, so the turbine would be used at its full capacity to generate electricity.

This dual-operation mode (winter vs. summer) posed a few design challenges.

In thermal power plants, steam can be used for power generation, heating, and chemical processes. Sulzer engineers the ratio according to the needs of the customer.

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In the winter mode, the turbine would certainly overheat without a steady flow of steam through the stages downstream of the second stage. In addition, the retrofit needed to allow for normal operation (i.e., steam flow through every stage) during the summer months.

The solution consisted of an internal water-mist spray cooling system and its associated instrumentation and control system. This unique retrofit was implemented in 2007 and has been operating succesfully ever since.

This large-scale adaptation of turbine mist-curtain technology is a perfect showcase of how Sulzer's application of old-school engineering concepts combined with world-class talent can yield unique and highly effective solutions. In addition, experts were hired to assist with windage friction issues and appropriate remediation of the same.

The solution addressed our client's issues in a revolutionary manner that provided the company with considerable added value and flexibility.

Allowing full-steam extraction

A relatively simple schemes has been developed that allows full-steam extraction while keeping all casing temperatures at safe levels. No additional cooling steam has to be used other than the steam leaking from the labyrinth seal between the second and third stages. Cooling water is introduced at stages 3 and 8 only.

Figure 1 shows a cross section of the turbine; the water injection sites are marked in green. The first location is upstream of the third-stage rotating blades, where the cooling water has the form of water mist in order to lower the steam's temperature to optimal levels for case cooling. The other location is downstream of the eighth-stage blades. There, the cooling-spray system consists of fan-shaped sprays. Located in several locations are thermocouples to monitor case temperature as well as drains to rid the turbine of water condensate. The cooling-water flow required for the third stage is 96 lb/hr (0.19 gpm, 0.7 L/min) to achieve the desired cooling. For the eighth stage, the cooling-water flow requirement is 132 to 169 lb/hr (0.26 to 0.34 gpm, 1 to 1.3 L/min).

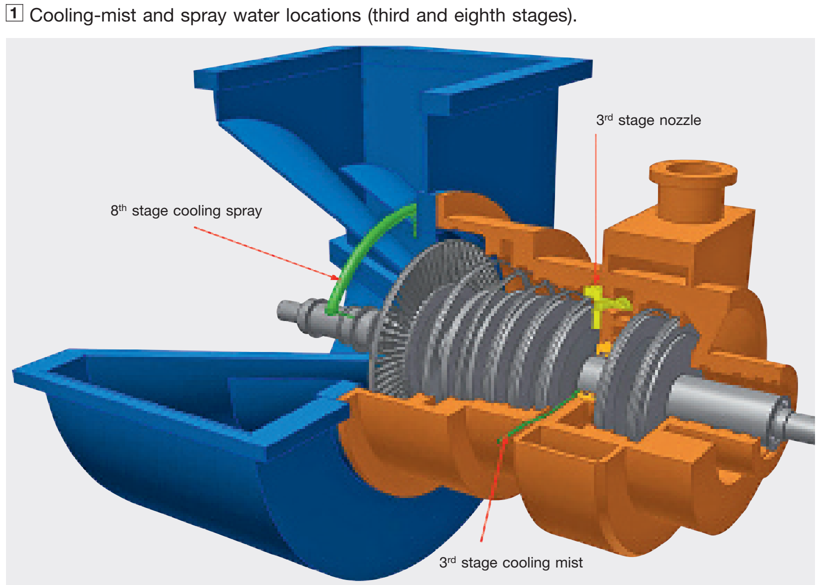
These cooling-water requirements are considered quite low. The water flow designed for this system is 25% to 50% more than the estimated flow, and the water flow is then throttled via a needle valve near the point of injection. For the eighth stage, this is an energetic spray—60 psi (4.13 bar)—to overcome the turbulent flow coming out of the blades. The water temperature ranges between 102 °F and 107 °F (39 °C and 42 °C).

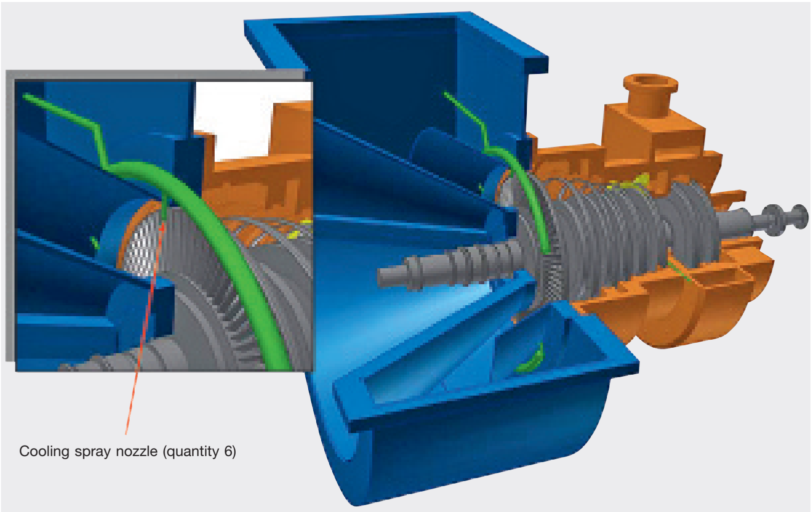
Engineering analysis

The engineering analysis calculated the windage loss via empirical formulas. Steam conditions (pressure and temperature) at each stage of the turbine were approximated based on experience with this type of design. The cooling-water flow was calculated based on a maximum allowable casing temperature of 575 °F (300 °C) for stages 3 through 6, 370 °F (188 °C) for stage 7, and 185 °F (85 °C) for stage 8.

The third-stage shaft seal leakage was calculated to be between 600 and 1600 lb/hr (6.3 L/min and 16.8 L/min), for the nominal clearance and for twice the nominal clearance, respectively. A situation involving twice the clearance was considered as a worst-case scenario corresponding to excessive wear or a rub condition. According to calculations, the cooling-water flow to the third stage could be fixed at a single value for the entire range of seal leakage values under

1 Cooling-mist and spray water locations (third and eighth stages).





2 Manifold for the water spray nozzles downstream of eighth-stage blades.

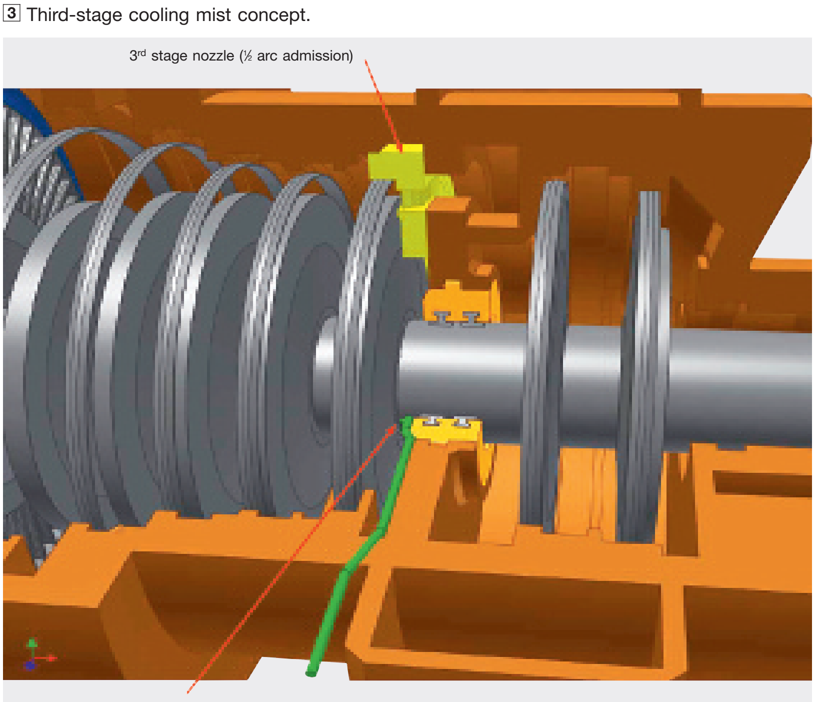
consideration without exceeding stage temperature limits.

A solution minimizing the impact

Figure 2 shows a different angle of the turbine section in which the manifold that houses the spray nozzles can be seen in more detail. Six fan-shaped spray nozzles spread out evenly around the circumference of the manifold. The nozzles are about one-half to three-quarters of the blade height downstream of the blades' trailing edge, and they are aimed close to the blades' platforms. A pipe to carry the water to the manifold was welded to one side of the fabricated exhaust case.

Figure 3 shows schematically how the water is introduced in the third stage. A stinger pipe brings the water to a hole near the diaphragm wall. This solution minimized the amount of case machining required. It effectively brings the water to the mist heads in the small space, addressing the constraints of the upper half-casing.

3 Third-stage cooling mist concept.



Useful control strategy

Separate control system logic for stage 3 and stage 8 was installed. The fact that the cooling-water flow could remain constant for stage 3 simplified the control scheme. Only the eighth-stage cooling water had to be modulated and with little flow variation.

An on/off thermostat with a fairly wide dead band provided a successful approach—ca. 185 °F (85 °C) on, 150 °F (65 °C) off. A control strategy that has proven useful is to turn this fixed cooling-water flow on when the third-stage readmission valves are moved close to the fully closed position. The precise ramp rate and turn-on point were determined during some simple commissioning tests.

Cutting-edge engineering

Because of the cooling requirement at the third stage, the potential for erosion damage of subsequent stages existed. The rate of erosion was not predictable; however, the faces of the disks and blades were coated against erosion. In addition, it was recommended that the customer perform periodic inspection of the disks and blades to check for erosion.

Cutting-edge engineering from Sulzer Turbo Services has provided the client the capability to run its turbine in a dual mode. The solution implemented gave the client considerable added value and flexibility. The turbine is now used to produce vapor, which is sold in the winter, and to produce electricity during the summer.

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