

Numeric Simulation Improves Operational Reliability

WOLFRAM LIENAU
PAUL MEUTER
SULZER PUMPS

For economic reasons, modern coal-fired power stations are designed for sliding pressure operation. Here, the pressure in the feed water storage tank varies corresponding to the load state of the power station unit. Using an elaborate finite element (FE) calculation, Sulzer Pumps simulated the thermo-mechanical loads occurring in the pumps during operational transients. Already in the design phase, FE calculations deliver information on the behavior of such heavy-duty pumps which previously could only be obtained by experimentation.

▶ Boiler feed pumps are of paramount importance when implementing modern operating concepts for large thermal power stations (Fig. 1). According to the type of drive, a distinction is made between turbine-driven – using the power station steam – and electrically operated boiler feed pumps (ESP), whereby the ESP assume an operational reliability role in the case of failure of the turbine-driven boiler feed pumps and in start-up mode. ESP used as standby pumps perform quick-start and load transfer functions in all operational states. During operational transients or faults, turbine-driven boiler feed pumps must be either preheated (warm-up mode) or cooled (cool-down mode) to prevent damage through thermal stresses or water hammer in the pipe system.

Modern Power Station Concept

With an installed power of $2 \times 933 \text{ MW}_{el}$, the Lippendorf brown-coal power station near Leipzig (DE) has the most advanced large-scale firing equip-

ment in Germany's eastern federal states. The power station produces mainly electricity, but it is also used for district heating (310 MW_{th}). Owners are Vattenfall Europe AG, E.ON Kraftwerke GmbH, and Energie Baden-Württemberg AG (EnBW). Sulzer Pumps supplied the boiler feed pumps for this and for other newly built power stations of the same operator.

Sliding pressure operation permits regulation of the steam turbines dependent on network load, hence contributing to the economical and environment-friendly operation of a power station. But this operational mode also imposes very high demands on the boiler feed pumps (Fig. 2), which are subject to high thermal and mechanical loads. Realized for the first time in these power stations is a combined warm-up and cool-down system for the boiler feed pumps, which reduces the loads for the pumps. In warm-up mode, the pumps are preheated during the start-up phase or held at temperature during brief standby periods. This

avoids excessively high stresses and unacceptably large deformations in the pump casing.

Should the boiler feed water pressure fall, the cool-down mode lowers the water temperature so quickly that boiling point is never reached, preventing thermally induced pressure fluctuations in the pump and the pipe system.

Highly Loaded Pumps

On commissioning the Lippendorf power station in December 1999, damage occurred to the wear rings of the impellers of the turbine-driven feed pump. Recordings of the torque by the operational monitoring (Fig. 3) indicated that initial rubbing had occurred in a cool-down phase during rotor turning gear operation. (In the cool-down phase, the rotor turning gear allows the steam turbine and the pumps to continue running at low speed to avoid deformations of the turbine rotor.) The processes during this operating mode are extremely complex, as the temperature and the flow states in the pump change over time. Through

1 Boiler feed pumps in modern power stations are subject to high stresses. This is the brown-coal power station at Lippendorf (Germany), for which these pumps were supplied by Sulzer Pumps.





2 Boiler feed pumps in the brown-coal power station at Lippendorf.

the cooler water injected in the cool-down mode, the pump and in particular its barrel casing deform relative to the rotor in such a way as to permit bridging of the clearances at the underside. The precise temperature-time characteristics and the thermal expansions could be determined on a well-equipped test rig, though the operational monitoring of a power station does not supply all the data required to analyze the course of events.

3 Recordings of the damage case in the cool-down phase: At 20.10 hours, the rotor turning gear engaged (yellow curve = torque). The boiler feed water temperature (green) displayed large fluctuations due to the inadequate cooling-down. The subsequent synchronous fluctuations in the torque characteristic are evidence that the rotor is rubbing against the casing. Red is the casing temperature.

Elaborate FE Simulation

In order to analyze the sequence of events, Sulzer Pumps decided on an FE simulation of the entire pump including the stationary components and the rotor (Fig. 4). From around 100,000 tetrahedron elements, a three-dimensional model was constructed for the pump casing whose individual parts were coupled by constraints. For the same calculation grid, a thermal model was created with nodal temperature as the degree of freedom and a mechanical model with the three spatial directions as degrees of freedom. Thermal couplings together with thermal boundary conditions permit the simulation of the thermal flux, whilst the mechanical model calculates the displacements resulting from thermal expansion.

The rotor was simulated as a 2D beam model. The impellers are zero-mass beam elements which model their thermal expansion, whilst the shaft elements take into account mass influence as well as thermal expansion. The rotor model is fixed in bearings at two points. The position of these bearing points is determined through the thermal displacement of the bearing shells in the casing model and also by the bearing setting. In

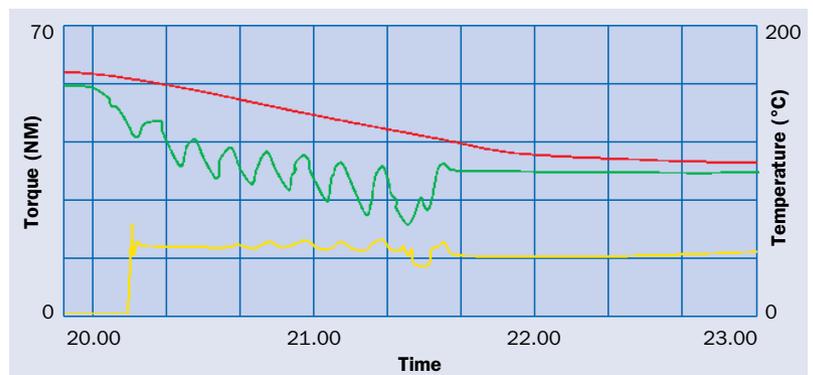
this way, a coupling is defined between the casing and rotor. The beam elements can be loaded with different boundary conditions for the temperature.

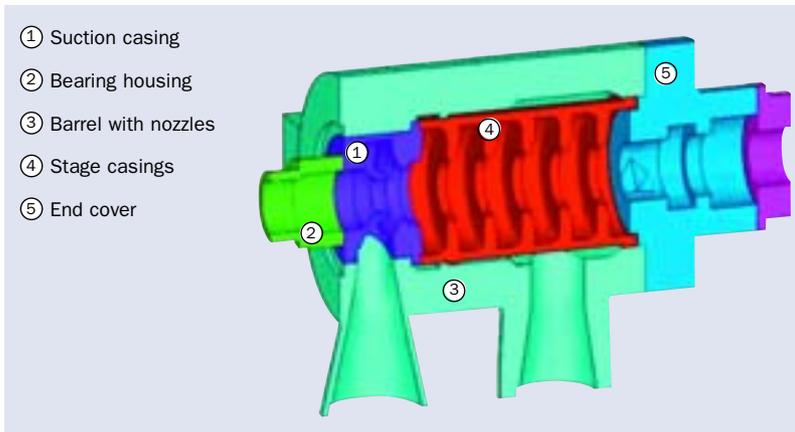
The actual damage case during the cool-down phase of the pump was simulated with this model. The time-dependent boundary conditions were predetermined with rotor speed, fluid temperature, and flow. Then the time characteristics of all relevant variables could be calculated with the model. Of paramount interest were the heat-induced displacements of the casing in the seal gaps (Fig. 5). The simulation clearly showed that the rotor and casing had rubbed during the relevant cool-down phase.

More Reliable Operation

But the analysis also opened up possibilities for fault-free pump operation. With greater clearance for the wear rings and a more accurate process for aligning the rotor, it was possible to find two measures to prevent a reoccurrence of the investigated fault.

The cooling rate at which the transitions from normal to cooling-down mode take place has an influence on the deformation behavior of the pump. Faster temperature changes result in higher gra-





4 All important parts of the pump casing were simulated in an FE model. The size of the calculation grid was reduced by utilizing the symmetry.

dients and greater deformations. The results of the FE analysis also served to define operating rules for the cool-down and warm-up phase, which reliably avoid rubbing of the rotor and simultaneously enable the clearance at the wear rings to be kept as small as possible. Temperature measurements in the pump casing, with which the calculated deformation values were checked, provided an additional safeguard for the calculations. Since the implementation

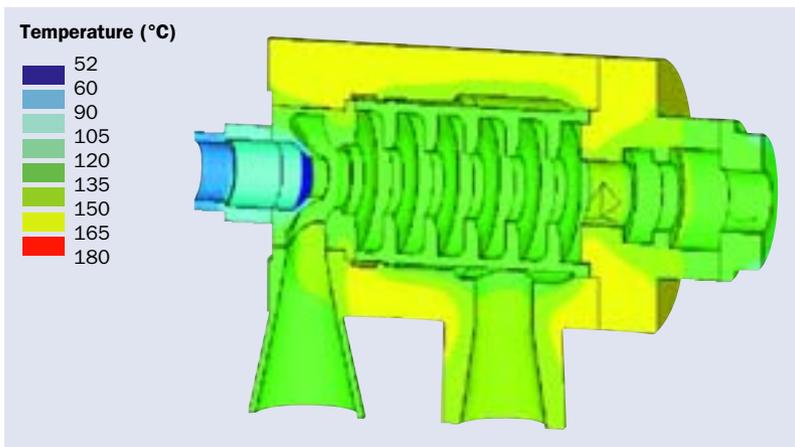
of all the measures, the pump has been recommissioned and has run fault-free since mid-2000.

Tool with a Future

Sulzer Pumps proved that finite element analysis is a suitable tool for forecasting thermo-mechanical deformations at complex components. Providing measured time-characteristics are available for individual variables, the model can be calibrated by adapting the thermal boundary conditions to

permit its use for calculating other load cases. In this way, FE simulations can yield statements on the operational limits of a pump. As the geometric data of the pump – like the ratio of casing length to thickness – influence the thermal characteristics of the machine and these cannot be determined with simple analytical methods, FE analysis will in future play a more important role right at the design phase. With an FE model, it is possible to investigate thermal expansions at critical points and predetermine the effectiveness of design features – such as the arrangement of suction and pressure nozzles. FE analysis is therefore a tool which will allow reliable pumps to be constructed faster and with reduced expenditure on trials in the future. ◀

5 The large temperature differences in the casing – here the state after a simulated time of 102 minutes – result in distortion due to heat, thereby reducing the impeller clearances.



CONTACT
 Sulzer Pumpen AG
 Wolfram Lienau
 Postfach 414
 8401 Winterthur
 Switzerland
 Phone +41 (0)52-262 39 88
 Fax +41 (0)52-262 01 80
 wolfram.lienau@sulzer.com