

Steam-powered turbines now generate some 80 percent of the world's electricity and are expected to do so well into the future. But given the changing face of energy markets and economic and environmental pressures for greater efficiency and reduced CO₂ emissions, steam turbine performance is being scrutinized under a design and optimization microscope. For manufacturers and power plant operators alike, the goal is to squeeze maximum wattage out of the available energy source.

Fast-starts help squeeze watts

Alstom Power utilizes Abaqus FEA to improve steam turbine efficiency

WINNING THE WATTAGE RACE

Modern steam turbines are exposed to greater stresses than earlier versions. The faster you can get a turbine up to operating conditions, the more energy you can produce. These rapid start-ups put tremendous thermal stresses on a turbine as the temperature is raised by several hundred degrees in less than an hour. In the past, power providers took their time during start-ups—a typical start-up might have taken over four hours—and as a result, stresses were much lower. Today's power plant operators do not have this luxury, and need to

shave start-up time to maximize energy production and efficiency.

Due to variable operating conditions, transient events have become common. Unscheduled operations such as double-shifts or load following operation are also the norm. "Steam turbines need to be able to start-up rapidly, react to load changes in a quick and predictable way, and tolerate the stresses inherent in these operating conditions," said Andreas Ehram, project manager at Alstom Power in Switzerland. "These are key technological challenges for modern power plants and for our engineering team." In the future, the challenges will only increase. According to Ehram, "The target for hot start-up of next-generation Combined Cycle Power Plants (CCPP) steam turbines is well below 30 minutes." With 100 years of experience designing and building steam turbines, and having supplied major equipment for 25% of the world's existing electric power generation plants, it's easy to see why Alstom >>

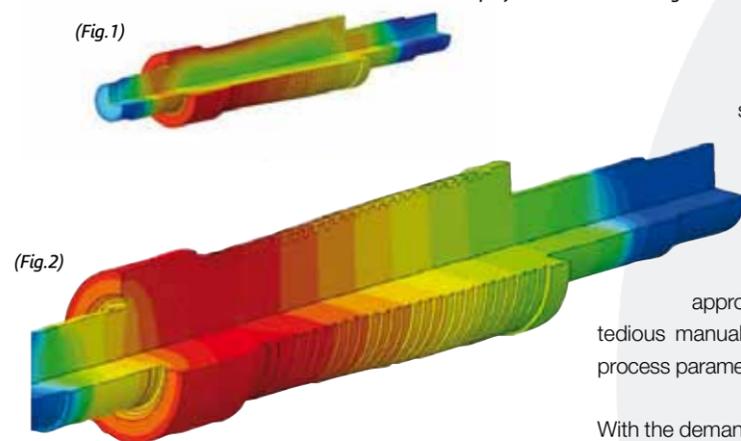
80%

Steam-powered turbines now generate some 80% of the world's electricity and are expected to do so well into the future.

Steam turbine rotor



(Fig.1) Rotor model non-stationary temperature profile at 60 minutes start-up.
(Fig.2) Rotor model with steady-state temperature profile at base load. Images courtesy of Alstom



Power is continuously looking for ways to improve turbine performance and maximize power production.

Alstom Power has been optimizing steam turbine start-up processes for years. They use Abaqus FEA from SIMULIA because of its powerful thermo-mechanical simulation capabilities.

In simplified terms, the rotor in a steam turbine is composed of rows of rotating blades that capture the energy from high-velocity steam jetted from stationary nozzles between the rows. During transient events in the operation of a steam turbine, thermal stresses occur, causing high fatigue loading—and these stresses are especially prevalent in thick-walled components. At the same time, turbines experience gradual creep loading as a result of general operation at high temperatures. Combining creep and fatigue loading over time puts stresses on the turbine, eventually leading to crack initiation and growth that can limit turbine lifespan.

AUTOMATING A START-UP SIMULATION

Alstom Power has been optimizing steam turbine start-up processes for years. They use Abaqus FEA from SIMULIA, the Dassault Systèmes brand for realistic simulation, because of its powerful thermo-mechanical simulation capabilities. Prior to this, early optimization analysis at Alstom Power was based on finite difference codes and simplified component models. Moving to FEA, Alstom engineers would first derive the transient thermal boundary conditions for the whole start-up

simulation, basing it on a set of predefined process parameters. In a second step, they would perform a finite element analysis to verify these thermal boundary conditions. This sequential approach required numerous iterations—a tedious manual process—to arrive at the optimal process parameters.

With the demand for increased operational flexibility and more accurate modeling, Ehram's engineering team looked to the automation capabilities in Abaqus to bypass the time-consuming iterative simulation process. To automate the optimization, the group developed a design tool that interlinked Abaqus with Alstom's in-house thermodynamic code using Python, the programming language of the Abaqus kernel scripting interface. This solution, according to Ehram, "allowed direct and easy communication between our proprietary code and Abaqus/CAE." The result was a tool that determined optimal transient thermal boundary conditions based on real-time thermal stresses and automated the search for optimal process parameters through the use of a feedback control algorithm. "Use of this tool eliminated the need for the high number of manual iterations that were previously required," added Ehram. "As a result, the process became much more efficient."

The automated simulation happens in the following way: Abaqus calls a subroutine to apply the thermal boundary condition to the model of the turbine

The use of this design tool eliminated the need for the high number of manual iterations that were previously required. As a result, the process became much more efficient.

**Andreas Ehram, project manager
Alstom Power Switzerland**

rotor. Then it queries the Alstom thermodynamic program for the thermal boundary condition for the first time-step. With this input, Abaqus completes

the thermo-mechanical analysis. To calculate the thermal boundary condition for the next time-step, Abaqus extracts the actual stresses at critical locations from its output database, calls the control algorithm to determine the optimal mass flow, queries the Alstom code for the thermal boundary conditions based on this information, and finally performs the thermo-mechanical analysis. This computational loop is repeated for each time-step—from 10 to 60 seconds depending on the application—comparing the computed stresses at critical locations with the material stress limits, while making sure that the mass flow approaches, but does not exceed, the stress limits.

A typical time for a start-up optimization using the previous manual method was about 10 man-days. With the new tool, this was reduced 50%, to only five.

AUTOMATION TRUMPS ITERATION

To put the tool to work, Alstom Power chose to simulate a steam turbine rotor during a typical 60 minute start-up. They used Abaqus for a number of steps: for preprocessing; for the creation and meshing of 2D models of simple parts such as axisymmetric rotor models; and for optimization automation using Python scripts. More complex 3D models were created in CATIA V5 and, depending on the application, imported into Abaqus using the CATIA V5 Associative Interface for Abaqus or the CATIA V5 Import feature. The team then used Abaqus to mesh the model and perform the finite element analysis of the rotor. The time step for mass flow control and automation was set to 60 seconds.

To start the simulation, Ehram's group modeled the initial temperature profile of the component before start-up. First, the turbine was accelerated to nominal speed for grid synchronization. Then, throughout the 60 minute start-up, the team optimized the loading gradient so the maximum stress in the hottest section of the rotor was kept just below the material stress limit of the rotor materials (see Figure 1 page 10), until steady-state temperature profile at base load was reached (see Figure 2 page 10). Running on a standard

engineering PC, this automated optimization took approximately 16 minutes. Although the earlier manual calculations each took only about a third of this run time, they consumed significantly more set-up time because they were based on estimates that had to be changed manually from run to run.

"As a result of the automated process, we were able to determine the fastest start-up parameters and process without exceeding stress limits," said Ehram. This led to a change in the design of the rotor grooves based on global deformation and heat flows. "Comparing the sequential versus automated method," Ehram said, "we demonstrated time-savings and improvements in accuracy using the automated tool." A typical time for a start-up optimization using the previous manual method was about 10 man-days. With the new tool, this was reduced 50%, to only five. The Alstom Power team validated the automated analysis against the previous process and found good agreement between results data.

"In the world of power generation, small changes in efficiency can save millions of dollars a year in fuel cost," said Ehram. With savings on this scale, using simulation and optimization together to squeeze maximum wattage out of turbines will become increasingly important to power producers in the future. 🔄



Detail of a low-pressure steam turbine rotor

For more information:
www.alstom.com
www.simulia.com