

REDESIGN OF A STEAM TURBINE WITH UNKNOWN BOUNDARY CONDITIONS

MACHINE REPAIR SHOULD ADD POWER AND EFFICIENCY

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Several levels of overhaul are possible depending on time and money. When both are at a minimum, the redesign of aging turbomachinery stages can be an option while maintaining existing dimensions for the rotor and casing.

However, when parts of the machine are no longer functional, the boundary conditions of these elements are unknown. This can make the redesign process complicated and time-consuming although it is still possible to restore the geometry and increase performance.

The main steps of this process are:

- Extracting geometrical parameters from 3D models of existing and functioning parts
- Estimating the boundary conditions for the missing part (stage or group of stages)
- Designing the missing part
- Calculating the whole performance of the turbine with the newly designed part

These steps were applied to a scenario of a six-stage LP 30MW steam turbine with a damaged last-stage bucket caused by mechanical failure or erosion. For this turbine example, only select parameters were known: inlet total pressure, 218 kPa; inlet total enthalpy, 2,787.4 kJ/kg; outlet static pressure, 14.46 kPa; rotational speed, 3,600 rpm; mass flow rate, 35.812 kg/s; and approximate power, 11.46 MW.

Obtaining geometry

To determine the conditions for which to design the piece being replaced, it was first necessary to create a model of the functioning part by importing the main geometrical parameters of the existing parts. Among them are blade heights, throats, metal angles, leading and trailing edge radii.

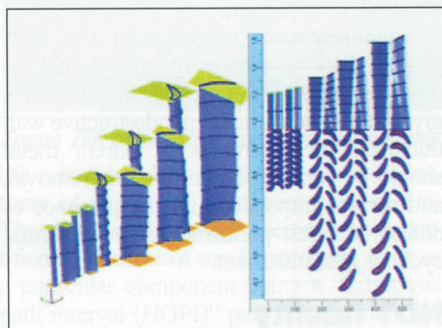
This step can be performed three different ways: through manual measurements directly on the blades and nozzles, from CAD models or from 3D laser scanning, all of which have their advantages and disadvantages. The first method is not the most accurate or time efficient but it does not require any specific equipment.

The second step calls for computer-designed element files while the last approach necessitates expensive tools. Either way, the more stages involved, the longer it takes to obtain the geometry, which is why

an efficient system is recommended. This makes seamless data extraction possible for a performance analysis, which allows analysis of both CAD models and 3D laser scans (cloud of points).

When the 3D airfoils were imported, they were sliced by a specified number of sections and the profile parameters required for the calculation were extracted automatically.

For some parts of the original airfoils, the CAD model's automatic recognition did not provide accurate results due to the bad quality of the models. For those sections, recognition in manual mode using a specially developed tool for profile recognition obtained the necessary data within hours.



3D CAD model data extraction using SoftInWay Ax-Stream software

When usable geometry is acquired, it must be uploaded into the design software to define the boundary conditions for the last stage. With accurate information (geometry and known inlet boundary conditions), the missing boundary conditions can be found (total pressure, total enthalpy and flow angle at the partial turbine outlet).

In the case of this steam turbine, the first five stages were imported to a design tool along with the pressure, temperature at the inlet, shaft rotational speed and clearances, to determine the pressure and temperature before the missing stage.

In order to do so, an analysis of the partial machine performance for different outlet total pressures was performed to find the one that provided a mass flow rate similar to the original turbine. The outlet flow angle was used for the design of the last stage to ensure a smooth transition.

Once the stage inlet boundary conditions were known, the missing row geometry could be designed from scratch while taking into account rotor and casing dimensions, as

well as axial and radial clearances.

An inverse task solver allowed the rapid generation of thousands of possible designs to compare them against design and off-design conditions, filter out unwanted solutions and study the influence of parameters on machine performance to find their optimum value.

Axial turbine preliminary design involved the use of an inverse 1D problem for the stage heat calculation. This included flow path generation, automated design, calculation, and an optimization algorithm using a quasi-random search.

Next, meridian dimensions and cascade angles could be determined based on the fulfillment of some conditions on the stage uniformity (congruence). Geometric parameters like chords, gaps, and others were assigned according to the set of rules for making an object in computer-aided design.

Flow path synthesis was completed using an inverse stage-by-stage aerodynamic calculation. The clearances and number of blades and nozzles had to be adjusted to fit the requirements given by the rotor and casing.

When the newly designed stage was adjusted to the requirements of the old flow path, it could be combined with the five original stages to estimate overall performance. A calculation had to be performed to consider the influence of blades twist. Compared to the original design, power increased by 0.46 MW. The off-design performance for the whole scope of operating modes improved.

The application of the geometry restoration process enabled the recovery of the geometry, as well as a performance improvement. The presented approach provided the opportunity for rapid geometry restoration which is impossible to recover by means of laser scanning. Due to the short period required for the redesign process it can even be applied during a turbine overhaul. ■

Author

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