Avoiding Stressed-Out Steam Turbines

Simulation analyzes and optimizes blade designs to minimize peak stresses and improve structural integrity of power-generation stream turbines.

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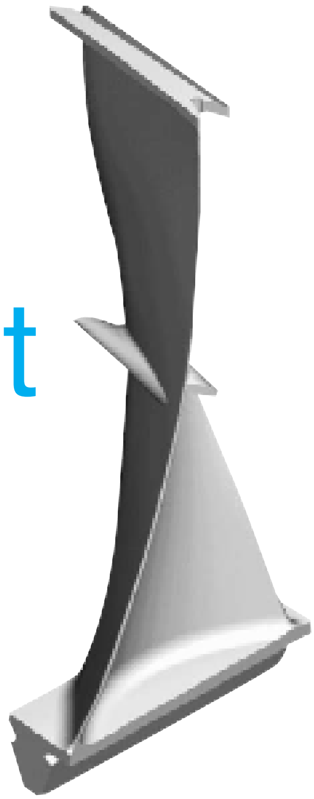


Low-pressure blade types such as this “taper and twist” are some of the most highly stressed parts of power-generation steam turbines

Some of the most highly stressed parts of steam turbines in electrical power generation systems are bladed disks — especially last-stage low-pressure blades that undergo the greatest centrifugal force and bending produced in the entire turbine.

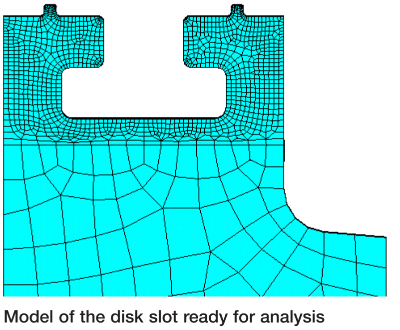
In these assemblies, turbine rotation tightens the blade root into the disk slot. While average stress in the mating surfaces is fully elastic and generally well below yield, peak stress at some contact regions in the slot can reach yield values and extend into the local plastic region of the material. Cracks start at these high-stress locations and propagate, causing fatigue failure and turbine shutdown.

Researchers have proposed several methods to provide reasonable estimates of elasto-plastic behavior and resulting stresses at the blade root and disk slot. Differences among fatigue life predictions by each method can be unacceptably large, however. Moreover, the standard approaches do not account for changes in geometry of the components under large operational displacements, leading to further errors — most importantly in identifying the life expectancy in terms of the number of cycles the blade can safely undergo before cracks are initiated.

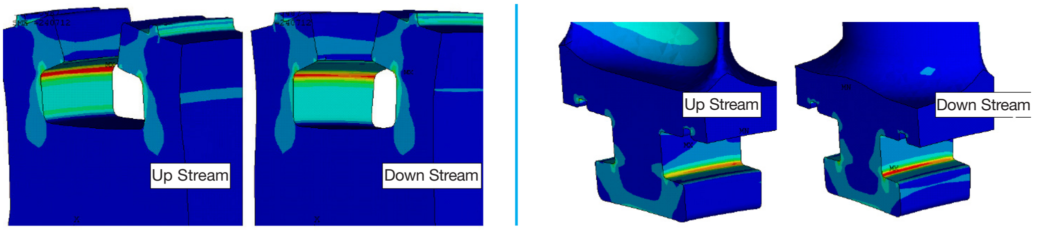
These challenges are being addressed with engineering simulation technology at Triveni Engineering and Industries Ltd., a leading worldwide provider of turbines for power and process plants. In one recent application to study peak stresses in a low-pressure turbine bladed disk assembly, Pro/ENGINEER® CAD geometry was imported into ANSYS Mechanical software and meshed using SOLID185 elements. Frictionless surface-to-surface contact pairs with augmented Lagrangian algorithms were created between mating surfaces.

A matching node pattern was maintained at the root and slot pressure faces, where load transfers take place between the two components. As an in-house design practice, safety factors of 1.5 for the blade and 1.25 for the disk over the minimum yield of the material were the goals at 100 percent (6,000 rpm) and 121 percent (7,200 rpm) of full speed. This safety factor ensured that von Mises stresses in all regions were well within the design stress limit at these critical speeds.

Initial results from a linear analysis indicated stresses much higher than the 585 Mega Pascal (Mpa) yield strength of the material for both the upstream and downstream portions of the blade root and slot. Clearly, these results called for further study using nonlinear analysis taking into account local material plasticity in determining stress concentrations for various different load levels. Because such exhaustive non-linear analyses are extremely resource intensive, however, the



Model of the disk slot ready for analysis

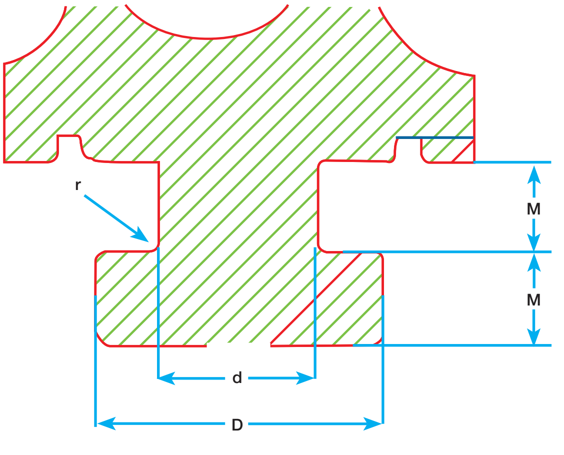


Von Mises stress of unmodified design in elastic domain at 6,000 rpm. Peak stress of 1,904 Mpa is indicated at blade root (left) and 250 Mpa average stress at blade neck (right). Peak stress of 1,660 Mpa is seen at the slot.

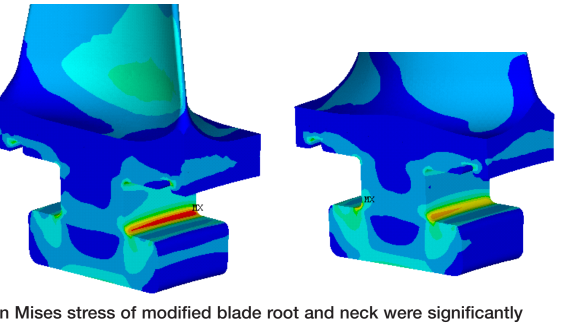
engineering team reduced the scope of the analysis using approximation techniques based on the Neuber formula [1], which estimate the plastic stress–strain state from linear analysis runs.

This analysis indicated even higher peak stresses of 1,904 Mpa in the blade root fillet and a very poor low-cycle fatigue lifecycle. Also, Triveni's in-house design criteria (established based on experience and experimental tests) limits peak stresses to 1,200 Mpa for the component life of 5,000 startup/shutdown cycles. Hence, the geometry of the blade root needed to be optimized to bring down the peak stress to an acceptable level and to ensure satisfactory fatigue life. By studying stress concentration factors at the blade root, much can be learned about how to produce designs that can better withstand repeated loads and how to evaluate the influence of various geometric features.

Key dimensions of the blade root were modified using ANSYS Parametric Design Language (APDL) capabilities, with ANSYS Mechanical software analyzing the various combinations of parameters. In this way, engineers evaluated the sensitivity of the design to the geometric modifications in reducing the stress concentration factor (SCF), with the chart from Peterson's book [2] used as an edge finder [3]. Modifications resulted in peak stress value of 1,153 Mpa from 1,904 Mpa at blade root fillet; in a similar manner the peak stress in disk slot reduced to 1,102 Mpa from 1,660 Mpa. SCF was reduced from 10.4 to 6.



Key blade root dimensions to be modified using ANSYS APDL were root radius r, blade neck d, land height M, and land width D.



Von Mises stress of modified blade root and neck were significantly lower compared to the initial design in the elastic domain.

This project demonstrates the effectiveness of this approach for evaluating the strength of low-pressure steam turbine bladed disk assemblies using ANSYS Mechanical technology. The software offers a comprehensive range of stress analysis and other capabilities in an integrated package for such large-scale, complex problems. An integrated infrastructure, ANSYS Parametric Design Language customization capabilities and non-linear simulation with contact plasticity work together to provide powerful simulation capabilities for this type of application. ■

This article is excerpted from the paper Finite Element Analysis of Low-Pressure Steam Turbine Blade Disk under Centrifugal Loads at Constant RPM *by K. Kumar, Triveni Engineering and Industries Ltd., and Santhosh M. Kumar, ANSYS India, ANSYS India User Conference, November 2008.*

References

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[2] Pilkey, W.D. Peterson's *Stress Concentration Factors*, John Wiley & Sons: 1997.

[3] Kearton, W. J. *Steam Turbine Theory and Practice*, CBS Publishers and Distributors: New Delhi, Seventh Edition, 1988.