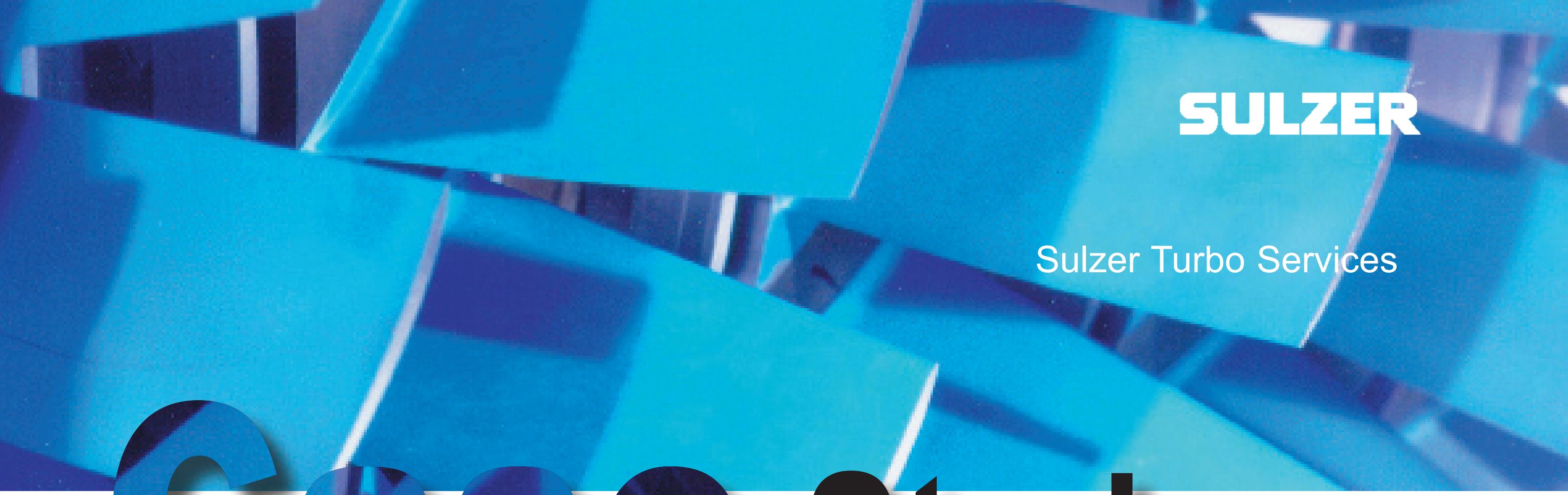


Case Study

Final Stage Blade Modification Extending Life Cycle

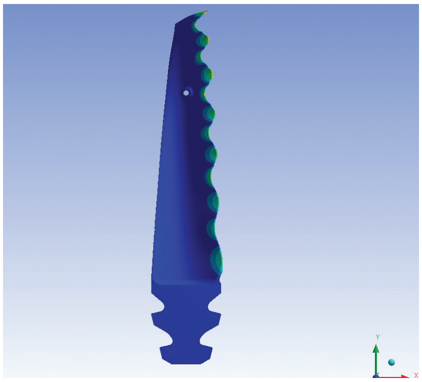
Sulzer Turbo Services Indonesia was contracted by an international nickel production company located in South Sulawesi to perform a complete inspection and repair on their 28 MW steam turbine rotor. The unit was reported as having excessive vibration. Further field inspections found that one of last stage blades and the damping wire were broken. The customer requested Sulzer Turbo Services Indonesia to investigate the root cause of the failure and modify the blade to extend the life cycle.

The last stage blade is a fir-tree free standing blade type with a 4 mm damping wire. The investigation started by collecting the historical information and continued with subsequent analyses:

- Preliminary examination of the failed part
- Metallurgical analysis including chemical analysis, macroscopic and microscopic examination and fractography analysis
- Mechanical stress analysis
- Blade natural frequency testing and analysis

The chemical analysis result indicated that the blade material was X20CrMo13, and the damping wire material was identified as titanium Ti-6Al-4V. Fractography analysis determined two crack initiations located at the blade hole for damping wire and trailing edge.To support the evidences found on metallurgical analysis, stress analysis was then performed. This determined the stress level on the blade and damping wire due to centrifugal force. This analysis was conducted using finite element software. The blade was scanned and measured using portable CMM (Coordinate Measurung Machines) to define the blade profile prior to modeling in finite element program. The result indicated the maximum stress of the airfoil at blade hole was beyond the yield strength of the blade material.

The stress level on the damping wire was analyzed using line elements. A certain section of the wire was modeled and symmetrical constraints were applied to represent the actual condition of the wire. The analysis result showed that the damping wire has a safety factor of 1.25. This safety factor value is marginal and can lead to failure. The damping wire strength may have been reduced by corrosion, galling, and erosion. This would lower the safety factor significantly.

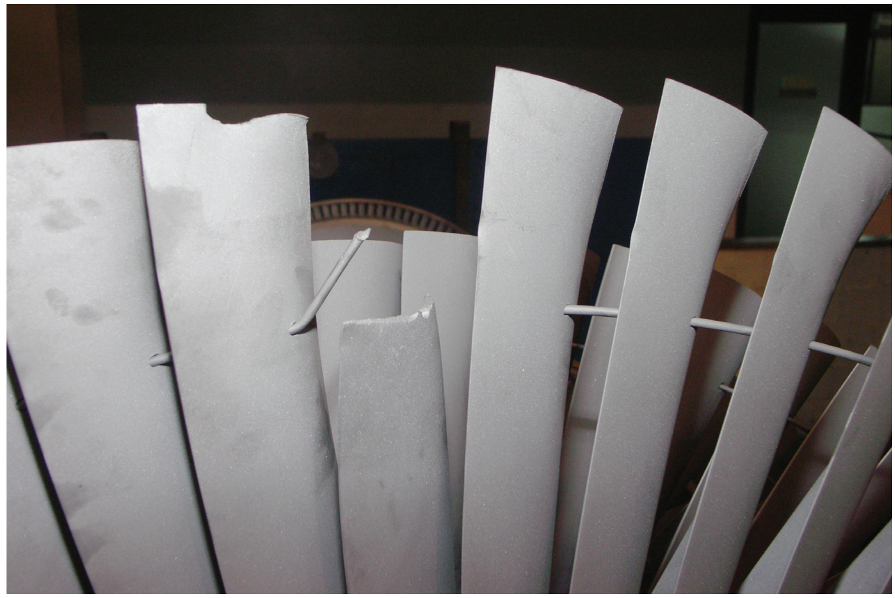


Finite element analysis of the blade.

Modal analysis was also conducted to determine the natural frequencies of the blade. The blades' natural frequencies were analyzed numerically by using finite element method. This model was also used for stress analysis. To verify the model and analysis results, the blade natural frequencies were tested using a frequency analyzer equipment. The blade frequency testing was done by clamping the blade at its root area. First testing was performed by analyzing the natural frequency of the blade only, without damping wire. The effect of the damping wire to the blade was simulated on the second test. The result indicated no significant difference in natural frequencies between the first (without damping wire) and second testing (with damping wire). This proves that damping wires would not alter the natural frequencies.

The result of both tests on the blades showed that there is no significant difference with the numerical analysis result by finite element method. This indicates that the natural frequencies obtained can be used for further analysis.The natural frequencies of the analysis were then plotted on Campbell diagrams to identify significant resonance points. Campbell diagrams depict turbine speed on the horizontal axis and frequency on the vertical axis. The natural frequencies and the frequencies of exciting forces were plotted. The coincidence of natural frequencies with the exciting forces is used as the definition of resonance. The data was next analyzed at blade pass frequency (BPF) and nozzle pass frequency (NPF). Some intersections were noted.

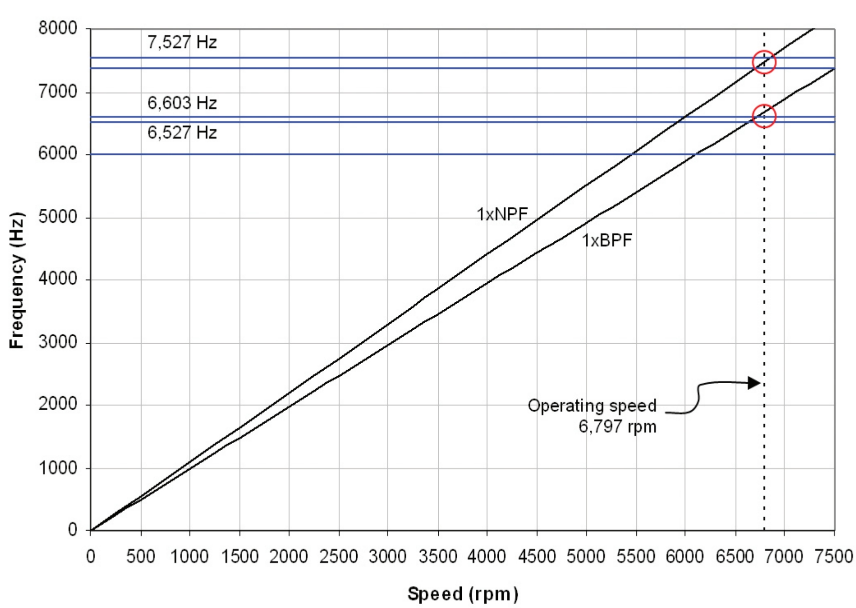
In order to know the mode shape of the blade in the intersection frequencies, the post-processing of the numerical analysis at these frequencies was chosen. Based on the analysis results, it was concluded that the root cause of the failure was the low safety factor of the damping wire. Once the damping wire failed, the blades were no longer damped and the amplitude of resonance became high enough to start initiating the crack at the trailing edge. A proposal was made to enlarge the damping wire size and blade redesign to shift the natural frequencies from resonant as well as increasing the blade safety factor to counter indicated problem and eliminate all risks.



Incoming condition of the last stage blades.

The final redesign came to damping wire size enlargement and adding reinforcement at blade hole. The finite element analysis of the modified blades and new size of damping wire was conducted to see how significant ly the stress level would be reduced. The analysis result indicated the stress level of the airfoil at the blade hole for damping wire decreased by 38% and the new size of the damping wire had 34% of the stress level of the original one. The natural frequency analysis also indicated no significant change in natural frequencies.

The final design of modified blade was then forwarded to the blade manufacturer for blades production. The new blades were then moment weighed and installed in the unit.The unit is now running at full capacity without any problems.



Campbell Diagram.

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