Low Pressure Steam Turbine - Last Stage Blade Erosion Scarring, Notch Removal and Refurbishments

Parsons 2019 – 10th International Charles Parsons Turbine Conference
16-18th September 2019, Cranfield University, UK

Mehran Zanjani, Ben Morrell and Dave Carr
Uniper Technologies Limited
We are Uniper

Our operations:

- Power Generation
- Commodity Trading
- Energy Storage
- Energy Sales
- Energy Services

Where we operate:

40+ countries around the world
4th largest generator in Europe

Employees: 12,000

- Power generation, Storage, Services - Europe
- Power generation - International
- Commodity Trading, Energy Sales

Main activities:

- Gas fired plants 19.2 GW
- Coal fired plants 10.5 GW
- Energy storage Gas: 8.2 bn m³
- Gas pipelines and infrastructure
- Regasification
- Nuclear plants 1.9 GW
- Hydroelectric plants 3.6 GW
- Trading
- Energy sales (small to large clients, electricity and gas)
- Services

€ 1.7 bn EBITDA
100 years Experience
37 GW Total generation

Data: Uniper Annual report 2018
Presentation Outline

- Erosion scarring and notch formation on last stage blade low pressure steam turbine
- Consequences and impact of scarring and notch formation if left unattended
- Last stage blade design and operation
- Reasons for the formation of erosion damage
- Mitigations, scarring and notch removal
- Benefits gained from notch removal and blade dressing
Last Stage Blade Steam Turbine
Last Stage Blade Steam Turbine Cracking

A number of last stage blades have suffered cracking in aerofoil trailing edge above root platform.
Crack Initiated from Erosion Notch

Causes of crack initiation and propagation are the stress concentrations associated with erosion scarring and notches and occasional ‘worm-holes’.
Ultimate Failure, Aerofoil Liberation

When left unattended, these cracks may result in ultimate failure and aerofoil liberation, damaging other blades, casing, condenser as well as risk of damage to entire rotor train.
Erosion Damage

Erosion damage is caused by water droplets at high speed swirling from tip to the base of the aerofoil scarring the trailing edge and forming macroscopic notches and ‘worm holes’ at the base of these scars.

These notches act as stress concentrators, and in a high stress region become detrimental to integrity of blade.
Last Stage Blade, Erosion Damage Causes

If unattended, the notches act as crack initiators developing into propagating cracks.

In areas of high mean stress (e.g. aerofoil trailing edge immediately above the platform) local stresses have been calculated to increase by a factor of 2.5 resulting in crack initiation.

In combination with dynamic stresses this could quickly develop to a blade failure.
Longer Blade / Greater Efficiency
Design Utopia – Achilles Heel

Drive for greater efficiency has led to longer length last stage blades.

The increased blade size has led to higher rotational stress

By pushing the boundaries of last stage blade design, it has become necessary for utilities and operators to focus on system operation to minimise damaging factors (e.g. no / low load operation, and spray water admission and control).

High stress above the platform on the thin trailing edge
Higher Stresses

In some blades, the increased blade length has resulted in higher mean stresses, particularly above the root platform, close to the yield strength / ultimate tensile strength (UTS) of the material.

Presence a notch acts as a stress concentrator, which has been calculated to increase stresses by about 2.5 times, increasing stresses above the yield / UTS.
Blade Stiffness and Vibration

Increased blade sizes also leads to reduced stiffness, increasing the possibility of blade natural frequencies moving closer to operating engine orders, and increasing the dynamic stresses around at or the positions high mean stresses.

Stiffening of the blades would require additional aerofoil thickness however this would increase loadings in the rotor attachment which is another potential area of weakness.
Main Cause of Erosion Notch Formation.
Operation at Full Speed No Load (FSNL) and Cooling Water Spray

Steam Turbine Start Up:

- Run-ups should be designed so that there is sufficient steam available to synchronise when the turbine reaches full speed (UK / Europe – 3,000rpm) and load up soon after.

- Many steam turbines start from rest and can reach 3,000rpm using only one turbine, typically the high pressure turbine on UK coal units, and intermediate pressure on CCGT units. This results in a small amount of steam running through the other turbines, including the low pressure turbine(s).

- Once at full speed, this is referred to as FSNL and during this period, the blades are rotating in a low vacuum condition.

- High blade velocities can generate elevated temperatures due to windage even under low pressure. Water spray systems are needed to control LP exhaust temperatures to avoid exceeding 200°C.
Mitigation

Once significant cavities and notches have formed, UTG’s preferred method of avoiding crack formation is to remove the erosion notches by dressing and polishing affected areas of the aerofoil.

Re-designed water spray systems may help reduce the amount of ‘free’ water and droplet sizes and reduce erosion notch formation.
Erosion Notch Dressing

Dressing affected areas of the aerofoil and removing the erosion notches would avoid stress concentrations and maintain stress levels (both mean and dynamic) close to original design.

Removal of material around the trailing edges (i.e. the thinnest part of the aerofoil) could result in changes in the stress level in the modified area as well as affecting the natural frequencies and vibration.

Understanding the effects of the modification is important to ensure long term integrity of these critical rotating elements.

Finite Element (FE) modelling / analyses can be used to simulate original and modified blade behavior and provide a good prediction of the remaining operating life of the blade.
Blade Modelling and Assessment

Changes in blade vibration and stresses can be determined using finite element model for original and modified aerofoils.

Blade geometry is easily obtained by white / blue light scanning and converting it directly to a CAD and finite element model for analyses.
Finite Element Modelling and Analyses

Example of a finite element model used to determine natural frequency, deformation as well as blade stresses.
Simulation of Aerofoil Metal Removal

Trailing edge (TE) thickness reductions can be carried out in stages, initially allowing a number of iteration in stages:

1. Trailing edge thickness thinning

2. Chordwise dressing to restore trailing edge thickness

3. Further thinning of trailing edge thickness

Maximum levels of trailing edge thickness thinning and chordal cut back can be optimised by using finite element analyses.
CAD/FE Simulation of Modifications

CAD modelling of actual dressing of the trailing edge (thinning).
Stage 1 - Original Trailing Edge Thickness Cut Back

Stage 1 - Modification with trailing edge thickness reduction. Minimal chordal cut back purely to smooth trailing edge during final polishing.
Stage 2 - Chordwise Cutback

Stage 2 – Chordwise dressing used to restore thickness.

Blue - Original Geometry

Brown - Modified Chordwise Cut Back Geometry

Original Blade Profile

Stage 2, new profile is based on the original TE thickness

Stage1, Reduced Profile
Stage 3- Chordwise Cutback and Further Thinned

Stage 3 - The chordwise cutback profile is further dressed (thinned) to remove the newly formed erosion notches.
Stress Distribution for Stage 1 Modifications

Stage 1 modification, small changes in the stress distribution around the dressed area

Original Unchanged Profile Trailing Edge
Original Thickness

Trailing Edge Thickness Reduction 1

Trailing Edge Thickness Reduction 2

Through-wall stress distributions
Stress Distribution for Changes in Stages 2 & 3

Stage 2 - Chordwise Cutback to Restore the Original Thickness
Stage 3 - Chordwise Cutback and Further Thinning

Original Geometry stress distribution

Cutback Chordwise in Direction to Restore TE thickness after Stage 1 Thinning

Stage 3 - Further TE thickness reduction to remove erosion following Stage 2 dressing

Some increase of stress around the chordal cutback areas of TE

Further increase of stress around the chordal cutback and thinned areas of TE
Comparison of Stresses between Original and Dressed Geometries
Operating Mean and Allowable Alternating Stresses for Polished, Good Finished and Scarred and Notched Surface

<table>
<thead>
<tr>
<th></th>
<th>Normalised, Applied Centrifugal Stress (from FEA)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Original</td>
<td>Stage 1</td>
<td>Stage 2</td>
</tr>
<tr>
<td>Good Finish</td>
<td></td>
<td>1.000</td>
<td>1.029</td>
<td>1.027</td>
</tr>
<tr>
<td>Erosion Notches</td>
<td></td>
<td>1.111</td>
<td>1.114</td>
<td>1.114</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Normalised, Allowable Alternating Stress</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Original</td>
<td>Stage 1</td>
<td>Stage 2</td>
</tr>
<tr>
<td>Good Finish, Polished Surface</td>
<td></td>
<td>1.000</td>
<td>0.886</td>
<td>0.894</td>
</tr>
<tr>
<td>Erosion Notches</td>
<td></td>
<td>0.310</td>
<td>0.302</td>
<td>0.302</td>
</tr>
</tbody>
</table>
Conclusions

Erosion notches due to water droplet erosion is detrimental on highly stressed low pressure turbine blades.

Alternating dynamic stresses as well the elastic mean stresses at the base of the notches have been calculated to increase by 2.5 times.

Dressing of the training edge will remove the stress raisers in already near yield strength area, increasing the remaining life of the blade.

Dressing the blades on the suction surface needs to be undertaken in a controlled manner and, ideally, to be supported and verified by analysis.

Analysis is an efficient way of determining the acceptable limits of thickness and chord reduction.
Thank you!

If you need any further information, please contact:

Mehran Zanjani  
Structural & Flow Analysis  
T: +44 (0)7972-217713  
E: mehran.zanjani@uniper.energy

Ben Morrell  
Steam Turbines and Auxiliaries  
T: +44 (0)7976-466454  
E: ben.morrell@uniper.energy

Uniper Technologies Ltd  
Technology Centre  
Ratcliffe-on-Soar  
Nottingham NG11 0EE  
UK

www.uniper.energy

Uniper disclaimer:
This presentation may contain forward-looking statements based on current assumptions and forecasts made by Uniper SE management and other information currently available to Uniper. Various known and unknown risks, uncertainties and other factors could lead to material differences between the actual future results, financial situation, development or performance of the company and the estimates given here. Uniper SE does not intend, and does not assume any liability whatsoever, to update these forward-looking statements or to conform them to future events or developments.