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Elastic-Plastic Deformation of Steam Turbine Low Pressure Part

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Abstract: Steam turbines are complex rotating machines working at high pressure and high temperature levels. Their low-pressure parts are loaded by lowest steam parameters and it could seem that they are avoiding permanent deformation. This consideration is not right. The driving mechanism of the plastic deformation of the low-pressure casings is mainly the non-uniform temperature field. Permanent changes in geometry become visible in low-pressure turbine casings when they are disassembled after the first time in operation.

Keywords: Plastic; Deformation; Elastic-Plastic; Pressure; Temperature.

1 Introduction

The FEM analysis was done to gain knowledge on possible geometry changes that may appear in low-pressure casings during their operation time. Numerical simulations were performed in the ANSYS 15.0 software for two different operating states. The results were compared to actual displacements measured on a disassembled casing.

2 Analysis Setup

The 3D model was simplified for the purpose of the numerical simulation. Two vertical planes of symmetry were used. It means the quarter of the model was applied in the analysis. One part of the assembly – an arm was not considered. The mesh consisted of 740,000 tetrahedral elements. A frictional contact was set in the splitting plane of the casing where the geometry changes are observed on real casing. Another contact was set between lower casing and the console. The contact was considered as bonded, which is sufficient for the analysis. The bolts connecting the upper and lower half of the casing are simulated as an external force. This bolts connection ensures tightness of the structure.

2.1 Temperature Field

The temperature analysis was done as the first step of the calculation. Two temperature fields were created and used separately as the imported loads into the static structural analysis.

2.1.1 Nominal Load

The nominal load operation is base mode of the turbine. Convection boundary conditions were applied with steam temperature and heat transfer coefficients set according to the operating mode of the turbine. The highest temperature of 315 °C was in the inlet part, while the lowest temperature of 35 °C was in the outlet part. The temperature field is represented in Fig. 1.

2.1.2 Low Load

The low load occurred in the turbine only for certain time of the operation and it is not allowed operation state of the low pressure turbine part. The highest temperature of 334 °C was in the inlet part, while the lowest temperature of 45 °C was in the outlet part. The temperature field is represented in Fig. 2.

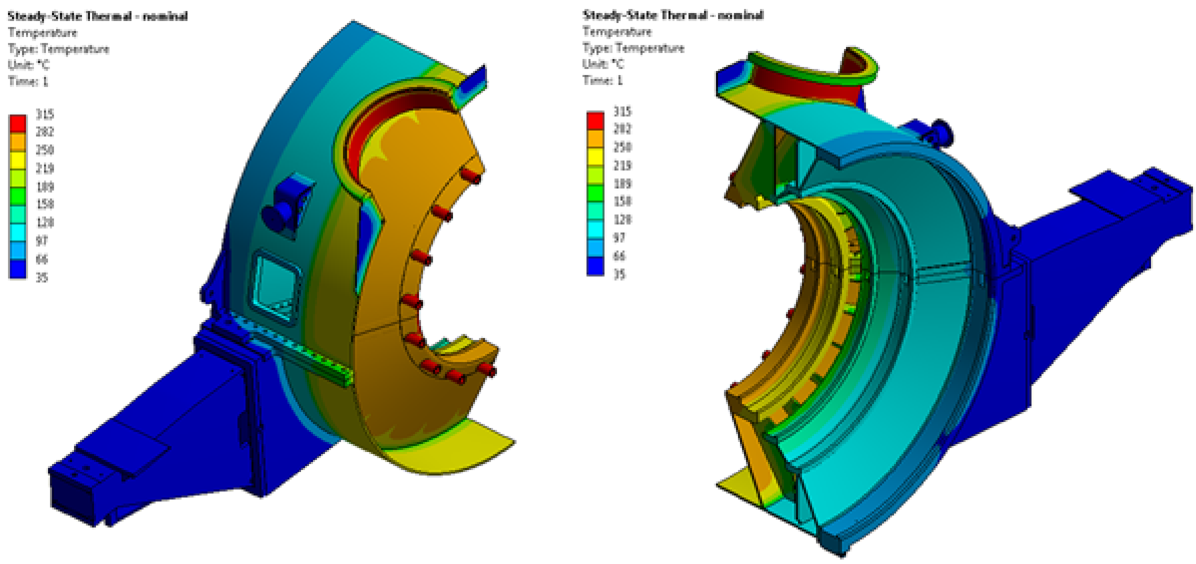


Fig. 1: Temperature field of nominal load.

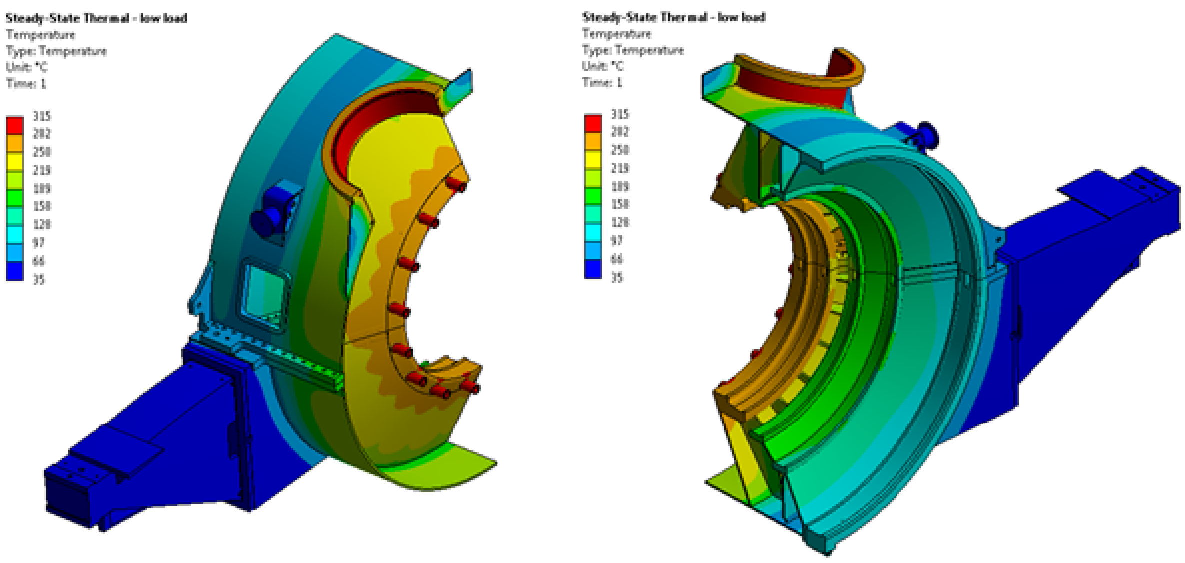


Fig. 2: Temperature field of low load.

2.2 Static Structural Analysis

Static structural analysis was set up from several load steps with different sets of boundary conditions. External boundary conditions were temperature fields. Temperature fields were active separately in two different elastic-plastic analyses. In the exposition load step, these conditions were determined by the supports of the casing, external pressure, weight of the guided wheels and forces imparted by the splitting plane bolts. In the inlet part the highest pressure was 0.531 MPa for the nominal load, for the low load was 0.060 MPa. The lowest pressure of 0.006 MPa was found at the outlet part for the nominal load and for the low load is equal. The pressure at the outlet parts was considered as 0 MPa in both cases. The next load step after the exposition time included gravity load only, splitting plane bolts and all other loads were removed. This load step simulated the actual conditions when the casing deformation was measured. A few additional load steps were included in the analysis, they were useful for gaining insight in the behavior of the casing, e.g. a load step with tightened bolts on the machine after the elastic-plastic deformation, disassembly and reassembly.

Low load static analysis includes the low load thermal field but before these thermal boundary conditions preceded the nominal thermal field. In other words the both fields (nominal and low) are contained in low load static analysis.

Tab. 1: Detected and calculated gaps between upper and bottom part after disassembly.

Measured location No.	1.	2.	3.	4.	5.
Calculated def. [mm]: Nominal load	3.68	3.06	2.55	1.96	0.62
Calculated def. [mm]: Nominal + Low load	5.73	4.77	3.90	3.03	1.01
Detected deformation [mm]:	5.70	4.60	4.15	3.00	0.95
Difference Calculated vs. Detected	+1 %	+4 %	-6 %	+1 %	+6 %
Difference Calculated Nominal vs. Calc. Nom. + Low load	-36 %	-36 %	-35 %	-35 %	-39 %

Measured location No.	6.	7.	8.	9.	10.
Calculated def. [mm]: Nominal load	0.38	3.13	1.69	1.08	0.68
Calculated def. [mm]: Nominal + Low load	0.55	4.86	2.68	1.79	1.25
Detected deformation [mm]:	0.35	5.30	3.00	1.05	1.20
Difference Calculated vs. Detected	+57 %	-8 %	-11 %	+70 %	+4 %
Difference Calculated Nominal vs. Calc. Nom. + Low load	-31 %	-36 %	-37 %	-40 %	-46 %

2.3 Material Properties

The low pressure part consists of two materials with similar strength and thermal properties. The two materials are 1.0553 and 1.0038. The analysis includes only the material 1.0553.

The bilinear isotropic hardening model of plasticity was used. The total strain ε_t consists of elastic ε_{el} and plastic strain ε_{pl}.

The input data for ANSYS isotropic hardening is yield strength σ [MPa], elastic modulus E and tangent modulus E_T. Input material data for hardening was added for six different temperatures: 20 °C, 100 °C, 200 °C, 250 °C, 300 °C, 350 °C.

3 Results

Gaps in the casing split after disassembly were taken as results. Gap means the width of the vertical opening between upper and bottom part of the casing. Disassembly state includes gravity load only, while all other loads (splitting plane bolts etc.) were removed in the analysis. Fig. 3a represents the detected gaps on the real casing, Fig. 3b represents the calculated gaps of low load static analysis, which combines two temperature fields (nominal load and low load).

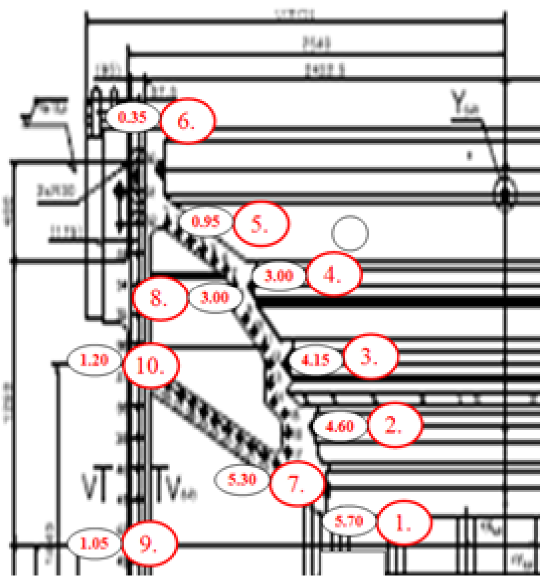
The opening in specified positions is recorded in Tab. 1. The table also contains difference between detected gaps and gaps obtained from the analysis. The average difference between calculated gap with two temperature fields (nominal load and low load) and measured gap is 17 %.

The resulted gap for the analysis with nominal temperature field only is also included in Tab. 1. The gap is approximately up to 37 % lower than for the combination of two temperature field.

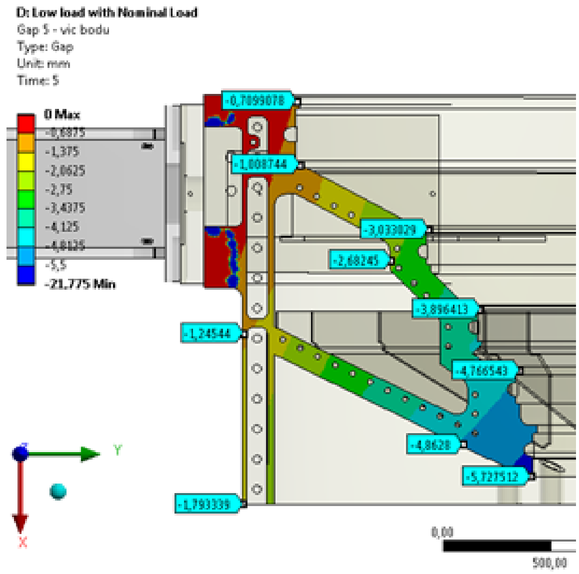
4 Conclusion

The results from the numerical simulation were compared with the measured opening on the casing. The results from low load static analysis, which combines nominal and low load temperature fields, have approximately 17 % higher values than measured opening on real casing. If we consider nominal temperature load only, the results are circa 37 % lower than with the combination of nominal and low load. The conclusion is that the temperature field significantly influences the residual plastic deformation of the low pressure casing.

The total deformation of the low pressure casing would be significantly lower if the casing would not be affected by the operation state with low load temperature field.



(a) detected gap on the real casing



(b) calculated gap which includes two temperature fields (nominal load and low load)

Fig. 3: Detected and calculated gaps on the casing.

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