American Journal of Mechanical Engineering, 2015, Vol. 3, No. 6, 267-271
Available online at http://pubs.sciepub.com/ajme/3/6/23

DOI:10.12691/ajme-3-6-23

Analysis of Reasons of Steam Turbogenerator Failure

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Abstract Steam turbogenerators are often used for production of electric energy in companies where sources of steam with necessary technical parameters are produced in technological process. Attention is devoted in the paper to state analysis of steam turbine after failure and possible causes of its damage.

Keywords: *turbine failure, damage of rotating wheel, microstructure of material*

Cite This Article: František Trebuňa, František Šimčák, Marián Buršák, and Miroslav Pástor, "XAnalysis of Reasons of Steam Turbogenerator Failure." *American Journal of Mechanical Engineering*, vol. 3, no. 6 (2015): 267-271. doi: 10.12691/ajme-3-6-23.

1. Introduction

Condensation steam turbogenerator (Figure 1) was damaged after approximately one year operation and the failure was accompanied with fire of whole equipment.

Figure 1. Steam turbogenerator

Steam turbogenerator consists of steam turbine, reduction gear box and generator (Figure 2) [1,2,3]. Turbine together with reduction gear is fixed to foundation by common steel frame. The generator is positioned directly in concrete foundation. Turbine rotors (shafts with rotating blades) belong to extremely loaded parts of turbines due to severe mechanical and thermal influences [4,5,6].

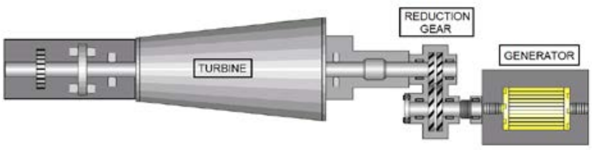

Figure 2. Schema of steam turbogenerator

The paper is devoted to analysis of state of steam turbine after its failure with pointing out to possible causes of such event.

2. State of Steam Turbine Rotor after Failure

After removing of lids of bearing houses as well as lid of steam turbine body was found out that the turbine rotor was damaged in several locations (Figure 3).

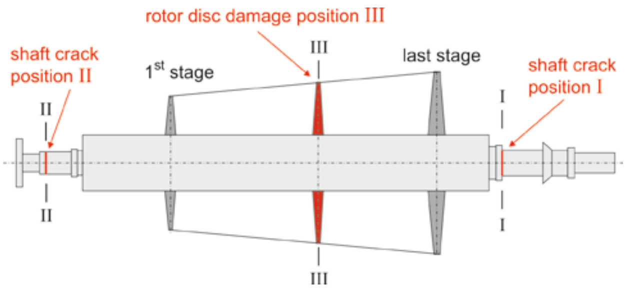

Figure 3. Turbine rotor with locations of failures

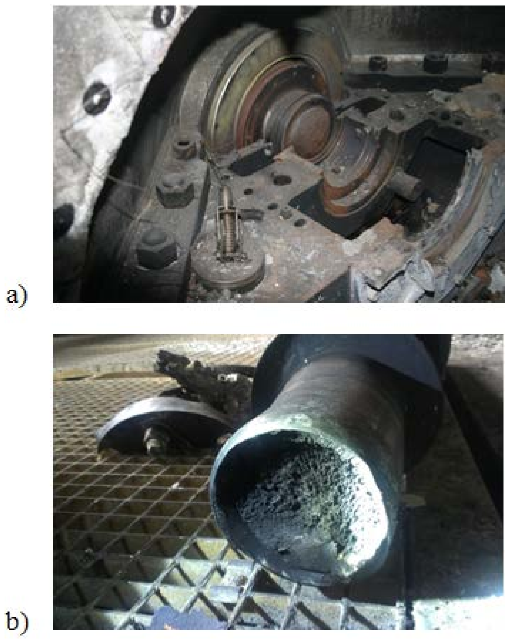

Figure 4. Damage of turbine rotor shaft in cross-section I-I

The shaft of steam turbine was damaged in two cross-sections. In cross-section I-I (Figure 3) the damage of turbine rotor shaft occurred before radial bearing on the side of reduction gear box (Figure 4a) with detail view into fracture surface of broken shaft part in Figure 4b.

In cross-section II-II (Figure 3) the damage of turbine rotor shaft occurred between radial and axial bearing on the side of steam inlet of turbine (Figure 5a). Detail view to fracture surfaces of both parts of shaft after failure is given in Figure 5b.

a)

b)

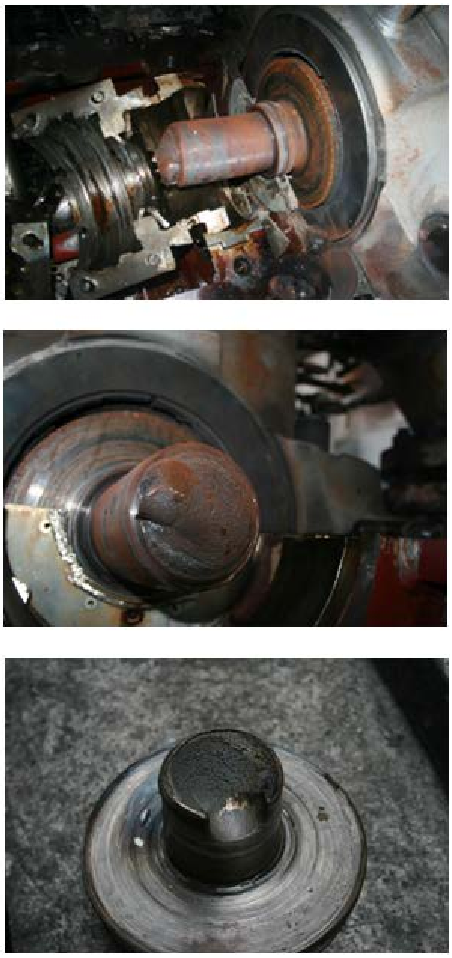

Figure 5. Damage of turbine shaft on the side of axial bearing (cross-section II-II)

After disassembling of turbine covers was found out that the support on the side of axial bearing (Figure 6) is designed such a way that allows thermal dilatation of turbine rotor, but this design does not ensure house shifting to be in the same horizontal plane. This structural part it invokes excessive structural vibrations and consequently increasing of cyclic loading during operation. The deformations are documented in Figure 7.

Figure 6. Support on the side of axial bearing

Figure 7. View to the deformed support on the side of axial bearing

After disassembling of upper turbine body was found out that the fifth stage (section III-III Figure 3) of rotor disc is damaged along whole circumference, see Figure 8. Deformation of disc part in radial direction occurred during disassembling of upper turbine cover.

Figure 8. Damaged rotor disc on the fifth stage

It is apparent from Figure 9 that the part of disc remaining on rotor shows remarkable changes resulting from variable thermal loadings that according to our guess could reach up to 1300°C. This heating could be result of fact that the damaged disc undergoes friction with the holder blades of the sixth stage – see detail in Figure 10.

Figure 9. View to disc part remaining on rotor

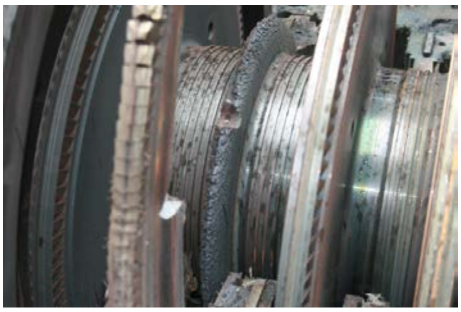

Figure 10. Detail view to damaged rotor disc

After disassembling and releasing of turbine rotor from the bottom part of turbine case is apparent that rotor disc of the fifth stage is damaged along whole circumference. It was connected with change of thickness due to change of mechanical properties of material after heating caused by its friction with the holder of blades.

3. Analysis of Damaged Disc of Fifth Stage of Rotating Wheel

The surface of damaged parts shows by intensive corrugation attributes of thermal overloading and thermal cyclic loading of material. Such process can occur during repeating thermal processing of basic material as well as under change of its specific volume, when it is presupposed that the increasing of surface temperature over prescribed temperature occurred due to intensive friction and to cooling by flowing medium (390°C in input of turbine).

The sample A (Figure 11) was taken from damaged disc (Figure 12) in order to provide analysis of causes of failure of rotation wheel (blade holder of the fifth stage) [7,8].

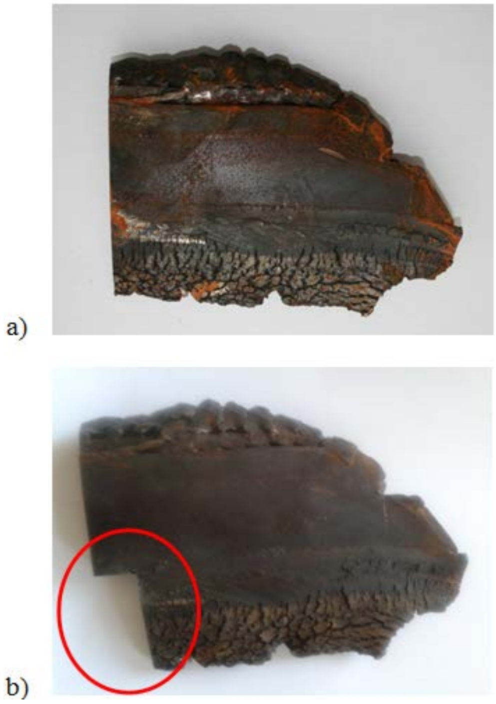

Figure 11. Specimen A from separated part of rotation wheel

The second sampling of material (sample B in Figure 12) was realized in location of rotor (Figure 13).

Figure 12. Specimen B from the part of rotor that remains on the shaft

The test sample was taken also for metallographic investigation. Location of sampling for specimens A are apparent from Figure 11. Metallographic documentation of microstructure of sample A is given in Figure 14 to Figure 16.

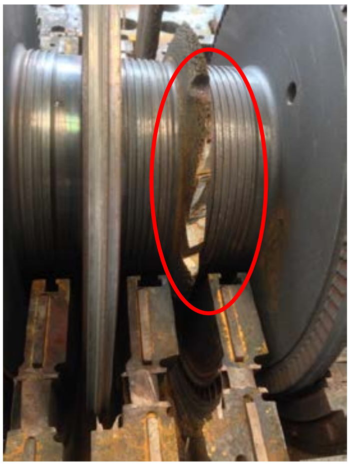

Figure 13. Location for taken specimen given in Figure 12

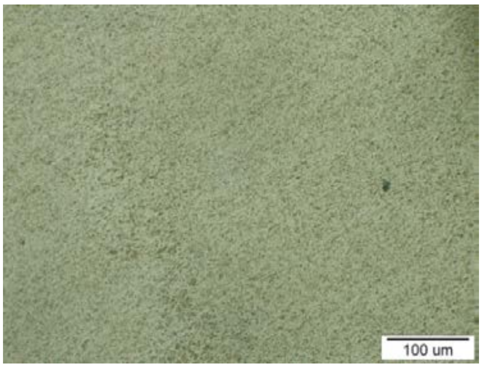

Figure 14. Microstructure of specimen A – tempered martensite - sorbit

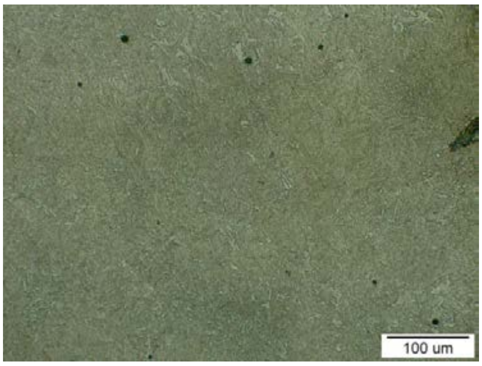

Figure 15. Microstructure of specimen A – coarse carbide parts

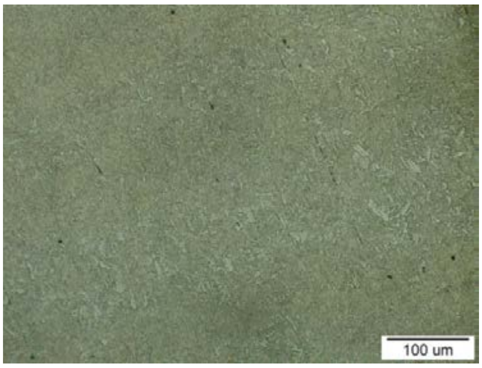

Figure 16. Microstructure of specimen A – coarse carbide parts

Microstructure in Figure 14, Figure 15 and Figure 16 represents tempered martensite - sorbit (Figure 14) and microstructures in Figure 15 and Figure 16 contain carbidic elements. Figure 17 documents a crack initiated from the surface.

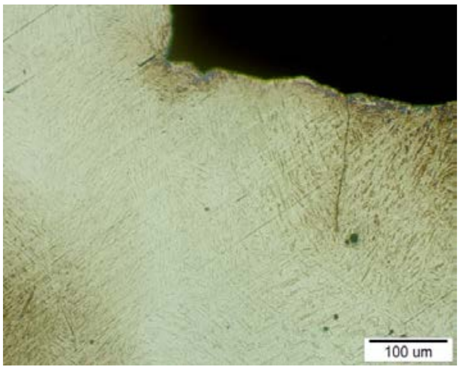

Figure 17. Microstructure of specimen A with a crack initiated on surface

Hardness of basic material with sorbit structure is in range from 340 HV10 to 390 HV10. Microstructure of surface was changed by multiple phase transformations due to thermal influences and their hardness is in range from 430 HV10 to 470 HV10.

Microstructure of sample B is shown in Figure 18 and Figure 19 and it shows that intensive oxidation of surface occurred which resulted to creation of several oxide layers. The thickness of oxidic layer was cca 0.4 mm. The structure in this area is significantlz heterogeneous with presence of many cracks in layer (especially at the bottom part), Figure 19.

Microstructure of sample B is similar to that of sample A. Hardness determined for sample B was cca 280 HV10 for basic material and cca 450 HV10 for surface layer.

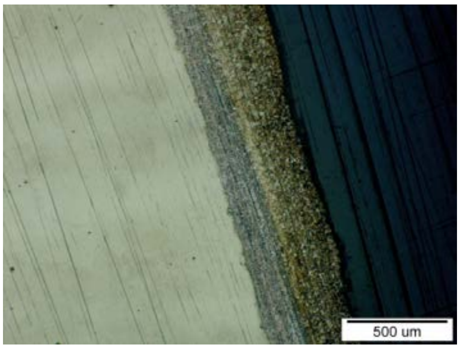

Figure 18. Microstructure of specimen B

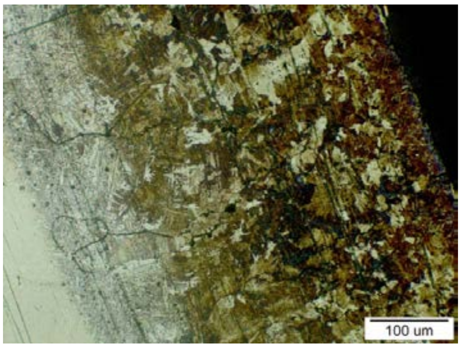

Figure 19. Microstructure of specimen B

Similarly, analysis of chemical composition was accomplished for surface layer of material of disc that remains a part of rotor (in location of sample B). Chemical composition of basic material and surface layer was realized by EDX analysis. Energy spectra for basic material and for surface layer are given in Figure 20 and Figure 21, respectively. The spectra are similar and accordingly similar is a presence of chemical elements.

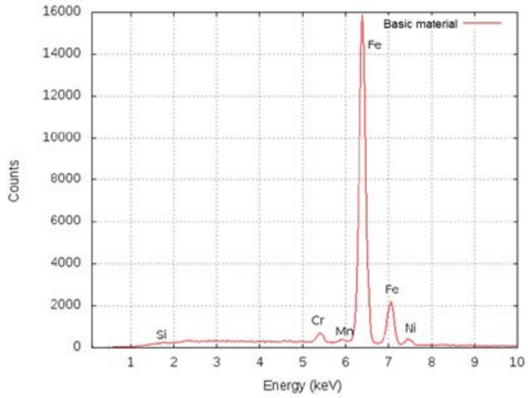

Figure 20. Chemical composition of basic material

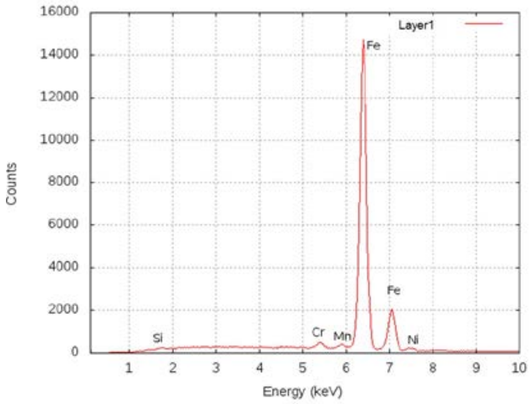

Figure 21. Chemical composition of surface layer

4. Conclusions

On the basis of results gained by analytical and numerical modelling, experimental determination of mechanical properties as well as visual control after damage of turbine and consecutive inspections we have arrived to meaning that primary reason of failure was deterioration and damage of axial bearing of turbine which led to contact of fifth rotating wheel with sixth distribution wheel. The friction had led to repeating increasing of temperatures (at the location of contact the temperature could reach 1300 °C) with consecutive cooling by flowing medium (steam). This process initiate creation of oxidic layers that caused change of structure and material properties of material leading to weakening of fifth stage of rotating wheel in location of increasing temperature. At the time of failure, the fifth stage was damaged in the location of stress concentrator (one of three hole in the disc) and disc locking led to impact with consecutive plastic deformation and damage of journals of turbine rotors in location of radial bearings from internal side. This damage of rotor and high temperature due to friction caused fire because of failure in hydraulic piping.

Acknowledgement

This paper was supported by project VEGA No. 1/0937/12 and by project APVV-0091-11.

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