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The Environment Influence on Low Pressure Steam Turbine Blade During Operating Regime

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Abstract: The paper deals with a problem of stress crack initialization during operational regime. A prototype of the moving blade of the low pressure stages of steam turbine with the increased corrosion resistance should be an output. The other goals should lead to a concept of assessment methodology of resistance of moving blades against corrosion and technology increasing fatigue strength of blade steels using surface strengthening. The mention stress analysis together with described environment indicate next procedure of experimental works.

Keywords: Steam Turbine Blade; Water/Steam Chemistry; Pitting; Stress Corrosion Cracking.

1 Introduction

Demands on modernization, which mean especially increase of power and decrease specific heat consumption of turbo aggregate, lead to lower lifetime. That's the reason why it's necessary to deal with this issue. Operational experiences show that the environment which induces cracking of moving blades working in low pressure parts of steam turbines is created in steam condensation area (Wilson line). The temperature of saturation which leads to condensation is different from turbine to turbine and depends on construction and operational conditions of appropriate machine. The results of thermodynamical calculations predict that the concentration of nonvolatile substances (such as chlorides, sulfates, carbonates) in a liquid phase might be up to 100 times higher than in steam. Much higher concentration might be present in deposited sediments where surface draining and moisturizing is repeated. On the other hand, concentration of volatile substances in water phase (of oxygen, carbon dioxide) is lower than ppb under stable operational conditions. However, the concentration of O_2 and CO_2 in condensate might be up to a several ppm in transitional operational state during putting block in and out of operation, condenser leakage, etc. Pitting easier appears in aerated condensate than in case of low oxygen concentration. Oxygen has influence on initiation of corrosive cracks. Its role seems to be lower for macro crack growth. There is a lack of data describing influence of common impact of chlorides and oxygen, determination of critical concentrations which means impact on corrosion-fatigue growth rate. It seems that CO_2 has influence on crack initialization and slower crack growth rate for long cracks, similar to oxygen.

In the past, this problem was solved by an effort to increase steam cleanness as well as choice of different material. In spite of the fact that certain improvements were reached, the problem hasn't been successfully solved in case of turbines of higher powers. The problem becomes more important now because standard turbines are forced to be operated based on renewable resources. This leads to more often peak regimes with frequent power loading changes. These changes have negative influence on steam parameters. The article reacts to permanently rising requirements for component quality of present and newly developed and built classical and nuclear energetic blocks. The increase of fatigue strength of low pressure moving blades in corrosion environment is a key factor for life prolongation of these components. It means longer lifetime of whole steam turbine. The problem-free operation of steam turbine without unexpected shutdowns will lead to cost reduction for electric power production in nuclear and fossil power plants.

2 State of the Art

The materials for manufacturing of moving blades have been developed for a long time. The most applied materials are 12 % of chromium modified martensitic steels, then 12-15 % of chromium precipitation hardened steels and, in sporadic cases, titanium alloys. The fatigue strength in corrosion environment might be increased through suitable surface treatment. Introduced compressive stress in the surface is one of the ways which leads to this goal. Several new progressive methods for surface hardening (such as low plasticity burnishing, laser shock peening and ultrasonic peening) have been discovered recently. These methods offer high innovative potential. Originally, these technologies were designed for extremely loaded components in airplane industry. Their possibilities for application in power generation area have not been tried sufficiently yet. Relatively high price might be a risk of their utilization.

Out of look of static loading the blade is exposed centrifugal force as well as pressure force of medium. The effects of flow medium which flows around blade bars belong to sources of dynamic excitation. Unequal pressure field and rotor shaking should be put into excitation too. This field is caused by wakes behind stationary blades. The transition of particular profile sections and torque moment occur due to centrifugal force and the fact that middles of torsion and the center of gravity of particular profiles are not identical. The effect of this moment is twisted blade around imaginary connecting line of centers of particular profiles. The angle of untwist on the peak of blade is usually in case of blade long about 1000 mm without coupling elements up to 6 ° [1]. During increasing turbine revolutions on nominal values the contact areas of coupling elements begin to get closer and to delimit of clearance. With beforehand define revolutions the contact of coupling elements will occur (locking) and this creates continual bound around circumference. The effect is the increase of bladed disk stiffness and that leads to system retuning to area of high frequencies. This positive effect is used for blade conception because less natural frequencies can be found in a dangerous low-frequency area. The stiffness of blade attachment is to a certain extent non-linear because it is contact stiffness. Bending stiffness of long terminal blades is at least influenced by blade attachment stiffness [1]. These blades have their natural frequencies which are very low and there is a need to tune against some initial harmonical frequencies during conception. For determination of the modal properties of a bladed disk is used rotationally periodic symmetry during a conception of terminal low pressure steam turbine blades. Longer blades generally have lower natural frequencies which are in the area of twice the mains frequency. The failures can occur during generator operating. These occurrences can have harmonious or recurring character with a period of once and twice the mains frequency. These failures may also be the source of terminal blades excitation and excite a so called umbrella waveform of a bladed disk. The natural frequencies for terminal low pressure blades can be determined relatively precisely, but it is very difficult to predict the excitation source. Recently, the so called Tip-timing method is used for operational monitoring of long blades of low pressure degrees. This method allows monitoring of all the blades of the disk. In practice, dimensioning for infinite lifetime based on Haigh diagram is still applied approach and factors of safety including most of indefinitenesses are used.

The disk is not practically involved into the modal characteristics of the blades. This happens if compliance characteristics of disc are negligible compared to the blades, which usually occurs at the end of the low pressure blades. So called nonsymmetrical generator loading is one of the most dangerous effects influencing surfaces and, thus, high cycle fatigue performance of blades. This effect manifests itself as harmonic pulsations of torque moment with frequency which is equal to twice the mains frequency. It can take up to several hours. This time is long enough for potential high cycle failure of blades. The amplitude of excitation moment can reach up to 10 % of nominal torque moment in place of generator winding [1].

Specific dynamic stress amplitudes on surface of blades respond to resonance amplitudes of oscillation. It is up to maximal values in blade root alternatively in tie-boss surroundings. The stress course in neck has a bending character because of almost zero stress in the middle of stem [1]. The static nominal stress in neck of root was determined on base of static analysis of blade which was loaded by centrifugal forces. Moreover, this value is about 7 % higher in the area of blade.

In 2004 the tests of corrosion fatigue were performed on steel Böhler T671 in cooperation with University of Chemistry and Technology Prague when test specimens were immersed in NaCl solution for 24 hours. After this time of exposition, the specimens were removed and dry fatigue tests were performed on a test machine. It is more than obvious that the results obtained by this way cannot be considered as correct because of missing corrosive environment influence during the loading process. It can be assumed that presence of a corrosive environment accelerates the whole damage process.

Tab. 1: Table of chemical composition of the specimens.

Cr	Ni	Cu	Mo	Mn	Nb	Si	C
14.23	6.33	1.29	0.64	0.47	0.41	0.40	0.043

3 Experimental Program

The specimens for the new experimental program were removed from fir tree root of low pressure steam turbine blade. In the Fig. 1 these specimens are marked by yellow color. The roughness of the samples was chosen as 0.8 in accordance with standard ČSN 42 0363 dealing with fine turning. The blade was made as a forging which was subsequently machined on CNC machine. The steel Böhler T671 was used as reference material. The chemical composition of the specimens is mentioned in Tab. 1. It is a high strength martensitic precipitation-hardened steel which exhibits a ferromagnetic behavior. This is a necessary property for generating of an alternating electromagnetic field.

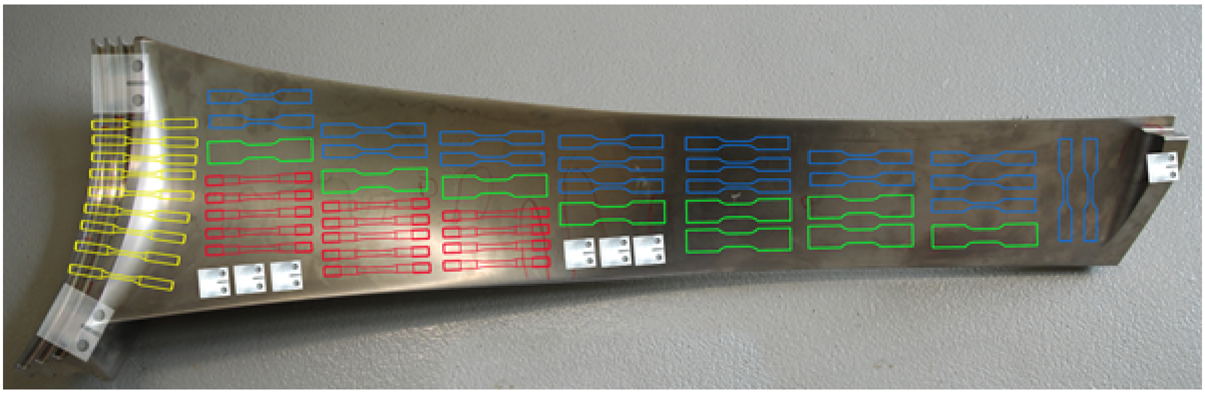


Fig. 1: Cut the blade up to individual specimens.

The specimen dimensions are shown in Fig. 2. The mechanical properties should correspond with the hardness higher than 341 HB, the yield strength higher than 1103 MPa and the ultimate strength higher than 1172 MPa. All these properties were verified on the given material.

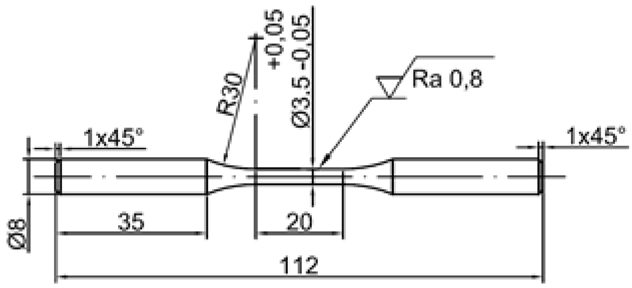
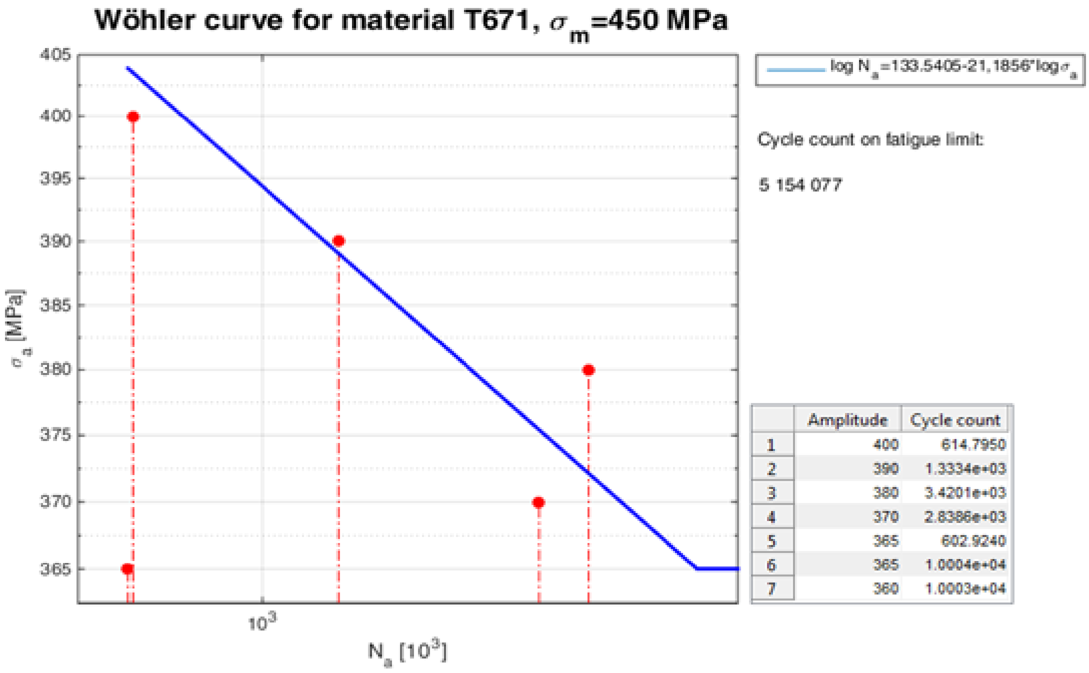


Fig. 2: Specimen dimensions.

The material was quenched at temperature 1040 °C, tempered at temperature 510 °C and then stress relief annealed at temperature 500 °C.

A total amount of 7 specimens was used for the compilation of Wöhler curve. Since this was the first test of a series of planned tests, the specimens were not loaded in a corrosive environment. The value 450 MPa was chosen as a mean stress. The loading frequency of 80 Hz has been selected. The stiffness of the whole system by which all oscillations were adjusted, ranged from 22.6 to 24.5 kN/mm. The stress ratio, i.e. the proportion of the algebraic values of the lower and upper stress waveform ranged from 0.06 to 0.1, namely by asymmetries these were pulsating oscillations in tension. Fatigue limit was determined and confirmed by two specimens for the amplitude of 365 MPa. The results are shown in Fig. 3. The graph shows one value at the level of 365 MPa, which is obviously beyond trend and is probably caused by a manufacturing defect surface. This specimen was not counted in the trend line.



	Amplitude	Cycle count
1	400	614.7950
2	390	1.3334e+03
3	380	3.4201e+03
4	370	2.8386e+03
5	365	602.9240
6	365	1.0004e+04
7	360	1.0003e+04

Fig. 3: Wöhler curve with particular points and equation of slanted branch.

A corrosion cell is prepared for further tests. In this cell there will be the location of the working part of the specimens. The corrosive environment with the temperature of 80 °C will flow across the cell. The concentration of NaCl and the concentration of oxygen content will be controlled.

4 Conclusion

Preliminary tests show that fatigue limit is around 450 ± 365 MPa. From the stress analysis, it is obvious that the values of stress do not reach the measured fatigue limit even in the resonance. Nevertheless, the cracks and damage occur on the blades. The reason is that the fatigue limit on real components must be diminished by the influence of stress concentrators. The aggressive operating environment together with increased temperature has a big influence as well.

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