IOP Conf. Series: Earth and Environmental Science **87** (2017) 082026 doi:10.1088/1755-1315/87/8/082026

Application of Computer Simulation to Identify Erosion Resistance of Materials of Wet-steam Turbine Blades

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Abstract. A problem of identifying the efficiency of using materials, coatings, linings and solderings of wet-steam turbine rotor blades by means of computer simulation is considered. Numerical experiments to define erosion resistance of materials of wet-steam turbine blades are described. Kinetic curves for erosion area and weight of the worn rotor blade material of turbines K-300-240 LMP and atomic icebreaker "Lenin" have been defined. The conclusion about the effectiveness of using different erosion-resistant materials and protection configuration of rotor blades is also made.

1. Introduction

Erosion of rotor blades of power plant wet-steam turbines, drive turbines, and other turbine plants, operating on wet steam, is a significant limiting factor for improving their efficiency and reliability [1-3]. According to operating experience, the most effective method of erosion-preventive protection of wet-steam turbine blades is the use of erosion-resistant materials of rotor blades, erosion-preventive coatings and entrance edge facings [1, 2, 4].

Erosive wear of wet-steam turbine rotor blades is characterized by long duration, complexity and irregularity of the behavior [2]. For technical and economic reasons, full-scale erosion experiments are difficult, therefore, the study of the processes in the turbine plants is often carried out using methods of mathematical and computer modeling. Thus, the development of new, more advanced methods and algorithms for solving problems of mathematical and computer modeling of turbine blade erosion is an important task.

On the basis of LPI-BITE (Leningrad Polytechnic Institute – Bryansk Institute of Transport Engineering) work [5-8], there has been developed a method of distributed simulation of wet-steam turbine rotor blade erosion, which allows one to increase the speed and accuracy of modeling gas-dynamic and erosive processes [9]. This method is implemented in software packages "Miral" [10] and "Erosion" [9, 11]. The adequacy of mathematical models and algorithms of these packages is confirmed by acceptable agreement between the results of computer simulation of erosion and the examination results of real wet-steam turbines [2].

The aim is with the help of computing experiments for different turbine types to determine kinetic curves of erosion of various materials used in the blades, coatings, linings and solderings.

Numerical experiments were carried out for the rotor blades of turbine K-300-240 LMP and turbine-powered icebreaker "Lenin", operating on the modes with the most erosion provoking steam parameters.

2. Results and Discussion

For protection against erosion of marine turbine rotor blades made of steel type 12X13 (Russian grade abbreviation, composition: Fe – 84%, Cr – 12-14%, C – 0.09-0.15%, Si – up to 0.8%, Mn – up to 0.8%, Ni – up to 0.6%, S – up to 0.025% and P – up to 0.03%) erosion-resistant plasma coatings with colmonoy and CBCh (Russian grade abbreviation, composition: Fe – the basis, Cr – 42-52%, C – 4-6%, B – 0.7-0.9%, Si – 0.5-1.4%) alloys; electric spark coating with alloy T15K6 (Russian grade abbreviation, composition: TiC – 15%, WC – 79%, Co – 6%) and electrolytic chrome coating were used [9]. To determine the most resistant of these coatings, numerical experiments for different durations of operating turbine-powered icebreaker "Lenin" from 10 to 100 thousand hours with the pitch of 5 thousand hours were conducted. Coating thickness for all materials was chosen as 0.3 mm. The area of erosion spot does not depend on the coating thickness of the chosen model. Therefore, the kinetic curves in figure 1, plotted on the basis of the results of the calculations, are invariant related to the thickness of the erosion-preventive coating. Figure 1 shows that coatings with CBCh, colmonoy and T15K6 alloys have approximately the same erosion resistance exceeding the resistance of steel 12X13.

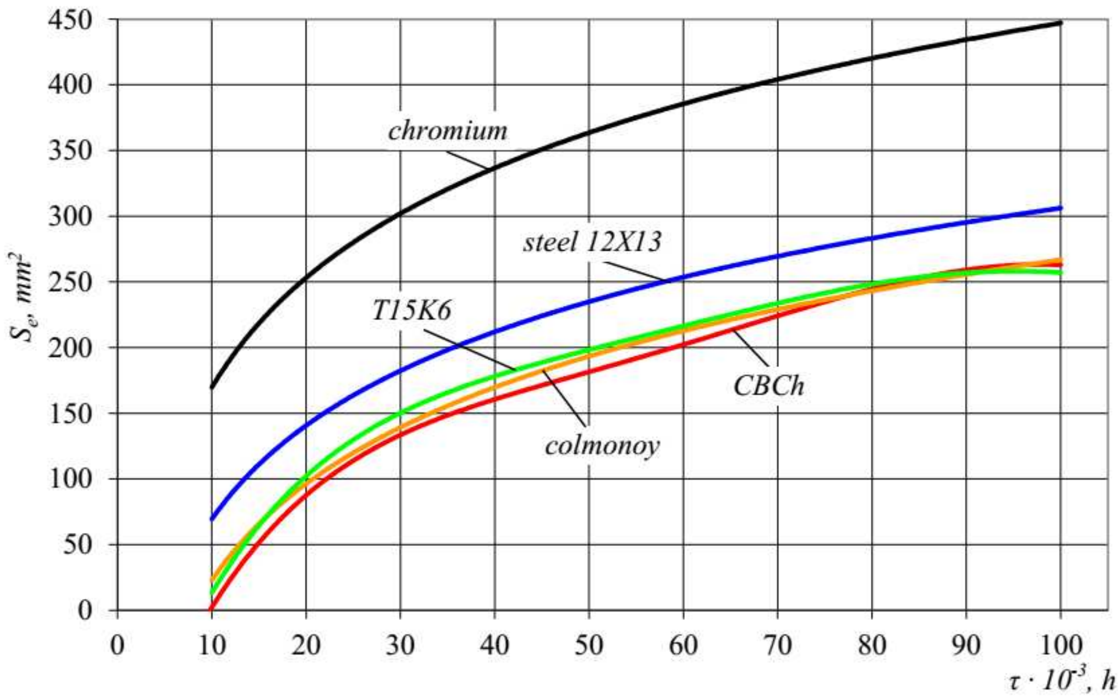

Figure 1. Kinetic curves of area of erosion spot of last stage blade of icebreaker "Lenin", protected by various coatings.

In addition to selecting the coating material, an important task of erosion-preventive protection is to choose its optimal thickness. The coating should have a thickness at which full protection of the basic blade material is guaranteed during the design life of the blade. For blades of steam turbines design life is operating time during 100 thousand hours.

According to these assumptions, there were carried out numerical experiments, which allowed to build kinetic curves of erosion of coatings with different thickness (figure 2).

Kinetic curves of the weight of eroded blade material allow to determine the point of destruction of the protective coating according to changing erosion rate. Erosion rate after its destruction increases due to the relatively rapid wear of the basic blade material.

As a result of numerical experiment, it is determined that a protective layer of electrolytic chrome with a thickness of 0.3 mm is destructed after 40 thousand hours. This time is determined by the overlaps of the kinetic curve graphs of chromium coatings with a thickness of 0.45 mm and 0.3 mm (figure 2). With the further increase of the thickness of the protective coating with the pitch of 0.05

mm, the kinetic curve of erosion remained unchanged. Thus, for electrolytic chromium coating, the thickness of 0.45 mm is optimal.

A similar pattern was observed for coating with CBCh alloy. Originally assumed thickness of the coating (0.3 mm) did not provide full protection of the basic blade material during the design life. Approximately after 45 thousand hours of turbine operation the protective layer of the last stage blades was worn, after which the erosion rate grew (figure 2). The increase of the protective layer thickness to 0.35 mm showed no change in erosion kinetics during 100 thousand hours. Therefore, the coating thickness with CBCh alloy of 0.35 mm can be considered optimal.

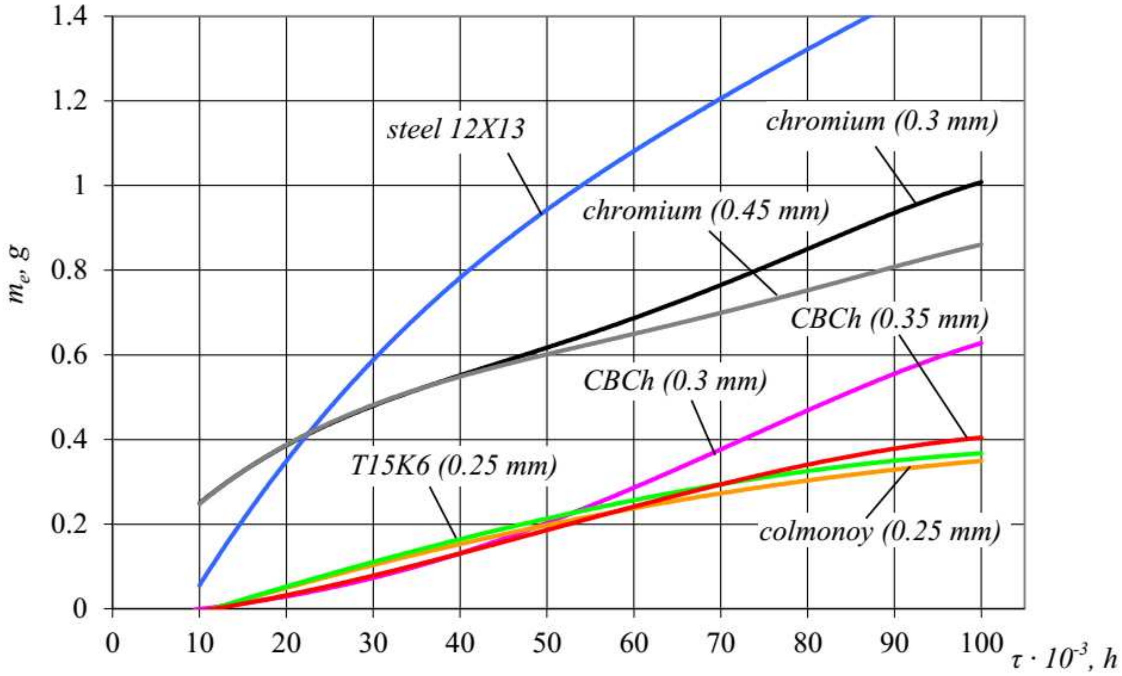

Figure 2. Kinetic curves of the weight of eroded material of last stage blade of icebreaker "Lenin", protected by coatings of different thickness.

According to the series of numerical experiments for coatings with T15K6 and colmonoy alloys, the thickness of 0.25 mm is optimal, with accuracy of 0.05 mm.

The comparison of the erosion kinetic curve of steel 12X13, used for the production of turbine blades of the icebreaker "Lenin", with the kinetic curve of chromium coating shows the advantage of erosion resistance of chromium steel over electrolytic chromium from the start of operation up to 22 thousand hours (figure 2).

For the blades, designed to operate during 100 thousand hours and more, it is preferable to use coatings with colmonoy alloy. It provides the smallest area of erosion spot and the lowest loss of blade weight when operating during their design life. T15K6 and CBCh alloys are inferior to this coating a few percent by the weight of the eroded material. Chromium coating has the worst indicators of erosion resistance among the examined coatings by the area of erosion spot and the weight of the eroded material.

Protection against erosion of last stage blades of powerful steam turbines is implemented by choosing erosion-resistant materials for manufacturing the blades, and also relatively thick (2-3 mm) solderings and linings on their entrance edges. The aim of the study at this stage is to identify the most erosion-resistant materials of powerful wet-steam turbine blades operating at nominal mode as well as optimal dimensions and location of protective elements.

In the first series of numerical experiments there were obtained kinetic curves of blade erosion for the most commonly used blade materials – steel 12X13, titanium TS5 (Russian grade abbreviation, composition: Ti – the basis, Al – 5%, V – 2%, Sn – 3%, Zr – 2%, Si – 0.08%, O – 0.1%, C – 0.05%, H – 0.008%) and blades of steel 12X13 protected with stellite solderings (figure 3).

The experimental results show that the blades of chromium steel are exposed to relatively more intensive drop impingement erosion. The erosion resistance of blades made of titanium alloy TS5 is 5-5.5 times higher than that of the blades made of steel 12X13 without additional protection. The blades protected with stellite W3Co (Russian grade abbreviation, composition: Co – the basis, C – 1.0-1.3%, Cr – 28-32%, Si – 2.0-2.7%, Ni – 0.5-2.0%, W – 4-5%, S – up to 0.07%, P – up to 0.03%, Fe – up to 2%) have a greater resistance in comparison with titanium ones only during the first 15 thousand hours of operation. On the time interval from 15 thousand hours and more erosion resistance of titanium blades is higher than resistance of steel blades with stellite solderings (figure 3).

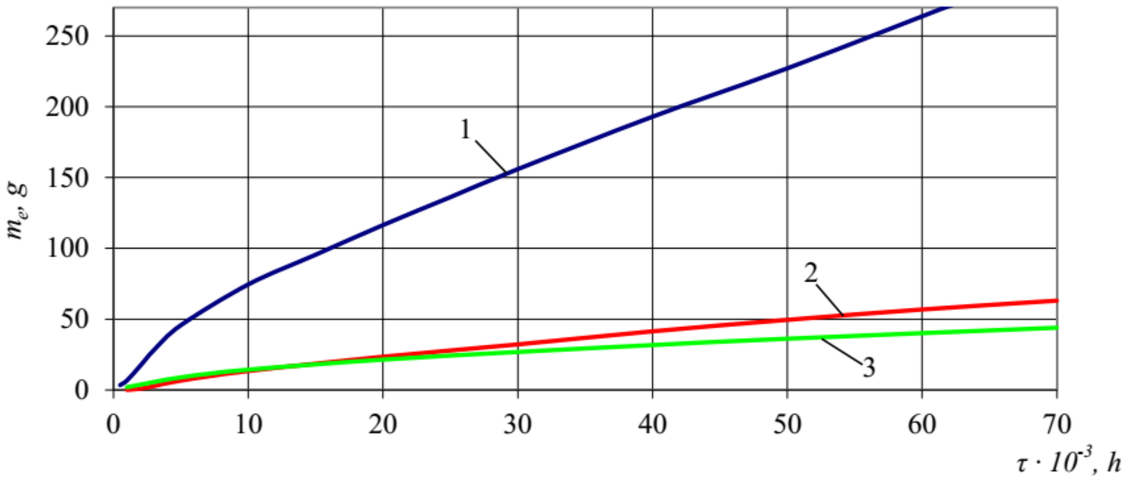

Figure 3. Kinetic curves of erosion of the last stage blade of turbine K-300-240 LMP: 1 – steel 12X13; 2 – steel 12X13 with stellite solderings by alloy W3Co (width – 13 mm, thickness – 2.44 mm and total length – 376 mm); 3 – titanium alloy TS5.

The cause of more rapid erosion wear of steel blades is a small area of a blade entrance edge protected with stellite. After 15 thousand hours of operation the greatest contribution to erosion wear is made by the blade surface areas, which are below stellite protection. The analysis of eroding blade profiles showed that after 100 thousand hours of operation, the intensive erosion area is observed on length of 680 mm. So, it is advisable to expand the length of the protective band from 376 to 680 mm, which, however, requires further analysis of changing the stage vibration characteristics.

During operation for several tens of thousands of hours the area of intensive erosion occurs in the peripheral part of blades directly behind stellite solderings (along the blade width). In this case, it is advisable to increase the width of protective plates. As the analysis of the design profiles of eroding blade shows, it is possible to improve the protection of the entrance edges during 100 thousand hours significantly by changing the plate width from 13 to 15 mm.

The resistance of titanium blades is increased by protecting them with nitinol solderings of different grades. To determine the relative resistance of nitinol and stellite solderings in the next series of numerical experiments, their geometry was equal, and the thickness of the plates was 2.44 mm; the width – 15 mm; the total length of protection – 680 mm. According to the simulation results of blade erosion of turbine K-300-240, protected with solderings and operating for 100 thousands hours, there have been plotted kinetic curves of erosion (figure 4).

New geometry of stellite protection resulted in the 40-time decreasing of the weight of eroded material of steel blades for the time period of 50 thousand hours, and 24 times — for the time period of 70 thousand hours.

Protection of titanium blades with nitinol solderings also increased their resistance 19 and 17 times for the time period of 50 and 70 thousand hours, respectively. Relative erosion resistance of steel and titanium blades improved compared to their unprotected versions 1 and 3 in figure 3.

Blades with stellite protection are least eroded during first 67 thousand hours of operation, and after 67 thousand hours blades with nitinol solderings have the best erosion resistance (figure 4). This kind of dependencies is explained by the fact that at the first stage the protected part of the entrance edge is worn most of all and the resistance of stellite is higher than nitinol resistance. During the second phase, soldering wear exceeds the thickness of protective plates and erosion spreads on the areas beyond the protective plates, so erosion rate is determined by the resistance of the basic blade material. The resistance of titanium is higher than that of steel 12X13, that is why steel blades with stellite solderings after 67 thousand of operating hours are worse in erosion resistance than titanium blades protected with nitinol.

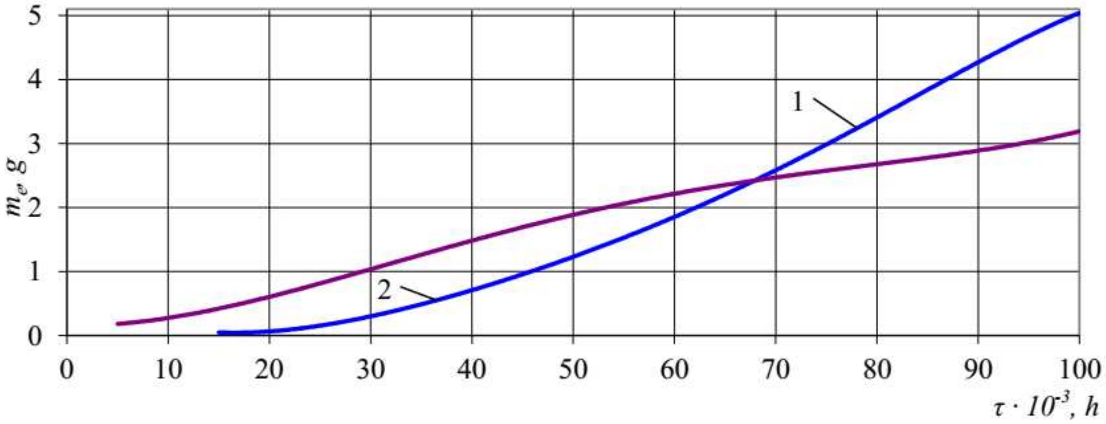

Figure 4. Kinetic curves of last stage blade erosion of turbine K-300-240 LMP with different protection: 1 – 12X13 with stellite solderings by alloy W3Co; 2 –TS5 with nitinol solderings.

During operation for 100 thousand hours it is typical to conduct routine inspection and repair of the turbine for several times. After approximately 50 thousand hours of operation during the repair stellite plates with strong erosion can be replaced with new ones. This will ensure the least loss of material as a result of erosion, than a similar replacement of nitinol plates or the use of blades with one set of protective plates during the design life of blades.

3. Conclusion

According to the results of numerical experiments, one can draw the following conclusion. Protective coating of marine turbine blades with CBCh, colmonoy and T15K6 alloys have approximately the same erosion resistance. Chrome coating has the worst indicators of erosion resistance among the examined coatings. The optimum coating thickness for electrolytic chromium plating is 0.45 mm, for coating with CBCh alloy – 0.35 mm, for coatings with T15K6 alloys and colmonoy – 0.25 mm.

Erosion resistance of rotor blades of turbine K-300-240 LMP made of titanium alloy TS5 is 5 times higher than that of the blades made of steel 12X13. Steel 12X13 blades with the currently used protection made of stellite W3Co have a better erosion resistance than the blades of titanium alloy TS5, only during the first 15 thousand hours of operation. The reason for this irregularity is the small area of blade entrance edges protected with stellite. The increase of protective element dimensions endwise from 376 to 680 mm and edgewise from 13 to 15 mm allows reducing the intensity of steel blade erosion 40 times. Setting nitinol protective plates of the same geometry on titanium blade reduces their erosion 18 times. Last stage blades of steam turbine K-300-240 with stellite plates of a new geometry have a better erosion resistance than titanium blades with protection.

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