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SIMULATION OF THE EROSION-CORROSION DESTRUCTION PROCESS OF STEAM TURBINE LOW-PRESSURE CYLINDER BLADES

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This paper is devoted to the important problem of creating a method for predicting the intensity of erosion-corrosion destruction of the working blades material of low-pressure stages of powerful steam turbines, considering the complex physical processes that accompany the emergence, transformation of erosion-hazardous droplets and their interaction with elements of the flow path. The features of the construction of some existing erosion models are considered. The model that is developed at the Institute of Mechanical Engineering Problems of the National Academy of Sciences of Ukraine and based on a deterministic-statistical approach to its creation is analyzed in detail. The calculations performed during the research showed a satisfactory coincidence with the results of experimental tests by various authors, obtained on droplet impact stands, which contributed to the successful use of the model in creating a comprehensive method of predicting the wear of working blades. To do this, it was supplemented by the method of determining the parameters of the erosive environment based on the droplet movement equation, taking into account the size distribution law. Along with that, it is shown that the considered model, although it allows to carry out fairly accurate prediction of the development of erosive wear at the modern level, has difficulties in its construction due to the need to identify it from the data of full-scale experiments, the number of which is limited. It has been established that one of the important reasons for the discrepancies that arise is the failure to include of the electrophysical component of the processes occurring in a two-phase flow. In this regard, the results of comprehensive studies of steam electrization and its influence on the working processes of wet steam turbines are considered. It is shown that the change in the properties of the working medium as a functional erosive medium as a result of electrification causes a significant increase (relative to neutral wet steam) of electrochemical processes. At the same time, the kinetics of the damage accumulation to the metal surface layer changes due to the joint occurrence of several negative processes: droplet impact influence; electrochemical processes caused by mechanical and structural and chemical heterogeneity of the surface; hydrogen absorption; changes in mechanical properties under the electric field influence. It was noted that the contribution of hydrogen absorption to changes in mechanical properties is the greatest. According to a preliminary assessment, the complex negative droplet impact and electrophysical influence on the metal surface reduces the incubation period and intensifies the erosion-corrosion process by approximately 2 times.

Keywords: *steam turbine, wet steam, rotor blades, droplet impact destruction, mathematical modeling, electrophysical effects, electrocorrosive processes.*

Introduction

The presence of a liquid phase in the working medium of steam turbines causes additional energy losses in the stages and the different density of the steam phase and moisture leads to a significant mismatch of their velocities, to a complex picture of the droplets movement with a significant concentration of coarsely dispersed moisture in the upper part of the blades and, as a result, their intense erosional wear.

Scientific interest in the study of working processes in wet steam stages is not weakening, since the developed theory of the emergence, transformation, and interaction of droplet moisture with elements of the flow path does not yet provide a satisfactory explanation for many physical effects associated with the presence of droplet moisture of different dispersion, in particular, electrophysical processes occurring in an electrified two-phase flow. There are still cases of serious damage to the blades of the last stages, due to the occurrence of coarsely dispersed erosion-dangerous moisture in the flow path.

Thus, the theoretical and experimental study of the causes and patterns of the erosion process of the last stages rotor blades remains relevant and is aimed at solving an important problem of stationary energy (this is an increase in the resource of steam turbines for thermal power plants and nuclear power plants).

An important element in solving this problem is the creation of a method for predicting the intensity of erosive wear, which considers the complex physical processes that accompany the emergence, transformation of erosive droplets and their interaction with the surface of the blades, without which it is impossible to develop effective anti-erosion measures.

A detailed analysis of existing erosion models was carried out by the authors in [1]. Models of three generations are considered – from fully empirical first-generation models to third-generation models that consider the contribution to erosive wear of physical phenomena that occur during the formation, transformation, and interaction of liquid droplets with elements of the flow path. Among them are the IPM PAN model [2], the model of the Moscow Aviation Institute developed under the guidance of R. G. Perelman [3], the model of Central Boiler Turbine Institute [4], Skoda model [5], J. Springer model [6], etc.

Among the recent works, the research of the Moscow Power Engineering Institute on the modeling of the processes of formation, transformation, and interaction of erosive moisture with elements of the flow path, should be noted [7].

Note that a common drawback of the above and other existing models is their incomplete physical validity, associated primarily with ignoring the kinetic nature of the destruction of blade materials or with the interpretation of models of blade loading under the action of droplet impacts. An attempt to take these circumstances into account was made in the Anatolii Pidhornyi Institute of Mechanical Engineering Problems of NAS of Ukraine (IPMach of NASU) model developed by the authors [8]. Let's consider its main provisions.

Mathematical model of droplet impact erosion by IPMach of NASU

The main elements of the information system structure for wear prediction are, in fact, the model of rotor blades erosion and the model of formation and transformation of moisture in the flow path.

The problem of erosion prediction is posed from the standpoint of the kinetic concept of strength.

Erosion damage at a given point during the exposure time $t_{\exp}$ is determined from the equation

$$\int_0^{\omega}(1-\omega)^k\,d\omega=-\frac{1}{1+k}\int_1^{\Psi}\psi^k\,d\psi=2\cdot\pi\cdot n\cdot t_{\exp}\int_{r_R}^{\infty}r\,dr\int_0^{t_{\text{act}}}C[\sigma(r,t)]^k\,dt,$$

where n is the droplet load (the number of droplets falling per unit time per unit surface area); r is the distance from the center of the contact point; r_R is the inner radius of the load zone; $\psi=1-\omega$ is the continuity parameter; ω is the erosion damage parameter; C, k are the erosion damage constants; σ is the highest tensile stress at the considered point; t_{act} is the time of action of the load from the impact of one droplet.

The time dependence $\sigma(r, t)$ is determined by the conditions in the middle of the interval $0\leq t\leq t_{\text{act}}$, and the spatial dependence is determined by the law of stress decay depending on the distance r. When the exposure time is equal to the time of the incubation period t_{inc}, destruction occurs, i. e. $\omega=1$, $\psi=0$.

In the adopted erosion model, the load in the interaction zone is divided into dynamic, due to the passage of Rayleigh wave, and a longer quasi-static, determined by the process of droplet spreading.

To determine the incubation period, we have the equation

$$t_{\text{inc}}=\left[2\cdot\pi\cdot(k+1)\cdot n\cdot C\left\langle\int_{r_R}^{\infty}r\,dr\int_0^{t_R}[\sigma_R(r,t)]^k\,dt+\int_{r_R}^{r_{\max}}r\,dr\int_0^{t_{\text{st}}}[\sigma_{\text{st}}(r,t)]^k\,dt\right\rangle\right]^{-1},\tag{1}$$

where $t_R=0.25\cdot d_{\text{drop}}\cdot\frac{w'_{\text{norm}}}{C_{\text{sh}}^2}$ is the duration of "loading by Rayleigh wave"; C_{sh} is the shock wave velocity in the liquid of the falling droplet; $t_{\text{st}}=\frac{r^2-r_R^2}{d_{\text{drop}}\cdot w'_{\text{norm}}}-\frac{r-r_R}{C_R}$ is the duration of the quasi-static load; C_R is Rayleigh wave velocity.

As a result of integrating equation (1), after substitutions and simplifications, we obtain

$$t_{\text{inc}}=\frac{1}{2\cdot\pi\cdot(k+1)\cdot C}\cdot\left[\sum_{i=1}^{i_{\max}}n_i\frac{\sigma_{R_i}^k\cdot d_{\text{drop}_i}^3\cdot(w'_{\text{norm}_i})^3}{C_R^4}\left\langle\frac{A_R}{k-1}-\frac{A_{\text{st}_i}\cdot(k+1)}{(k-1)\cdot(k-2)\cdot(2k-3)}\right\rangle\right]^{-1},\tag{2}$$

where $d_{\text{drop}\,i}$ is the i-th droplet diameter; $w'_{\text{norm}\,i}$ is the velocity of normal collision of i-th droplet; $\sigma_{R\,i}=0.75\cdot P'_{\text{mid}\,i}$ is the maximum tensile stress in Rayleigh wave from the action of the i-th group of droplets depending on the average pressure on the contact point; $A_R = 0.18\cdot\frac{C_R^2}{C_{\text{sh}}^2}$ is the dynamic constant arising in the process of time integration of dynamic load; $A_{\text{st}} = 0.0216\cdot\left[\frac{0.463\cdot(1-2\nu)\cdot C_R^2}{C_{\text{sh}}^2\cdot w'_{\text{norm}}}\right]^k$ is the static complex for the i-th group of droplets, which arises in the process of integration over the time of the quasi-static load.

The expression (2) is the main result of the theory because the value of the incubation period t_{ink}, which characterizes the properties of the material under consideration in terms of its ability to resist fracture, can be interpreted as a universal characteristic of wear (Fig. 1). It serves as the basis for solving a more general problem of the fracture front movement deep into the part.

The performed computational studies showed a satisfactory agreement with the test results (Fig. 2) obtained on droplet impact stands, which contributed to the successful use of the developed model in creating an integrated method for the rotor blades wear prediction [8].

To do this, it must be supplemented by a method for determining the parameters of the erosive medium, that is, the kinematic characteristics of the droplets.

This is done based on the equation of motion of a droplet (3), considering the law of distribution of droplets by size in the edge wake and determining the mass of the largest droplet by the critical value of the Weber crushing criterion

$$\frac{d\vec{C}'}{dt} = 0.75\cdot C_{\text{res}}\cdot d_{\text{drop}}^{-1}\cdot\rho''\cdot\left(\rho'\right)^{-1}\cdot C_{\text{rel}}\cdot\left(\vec{C}''-\vec{C}'\right), \qquad (3)$$

where $C_{\text{rel}} = \left|\vec{C}''-\vec{C}'\right|$ is the main flow velocity relative to the droplet; C_{res} is the resistance coefficient of a droplet moving in the flow; ρ'', ρ' are the densities of steam and liquid, respectively.

Finally, for the final closure of the proposed method for the rotor blades wear prediction under turbine operating conditions, the problem of identifying an erosion model based on the data of a full-scale experiment is considered. For its implementation, the apparatus of linear regression analysis was used. The results of identification in relation to the leading edges of the rotor blades of the last stage of 200 MW turbine according to field observations of the development of the wear zone width [9] are shown in Fig. 3.

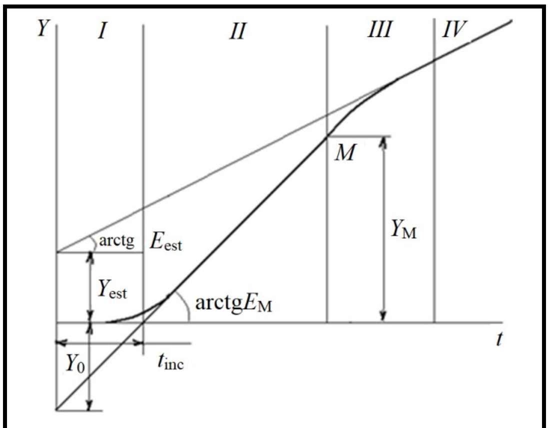


Fig. 1. The erosion kinetic curve

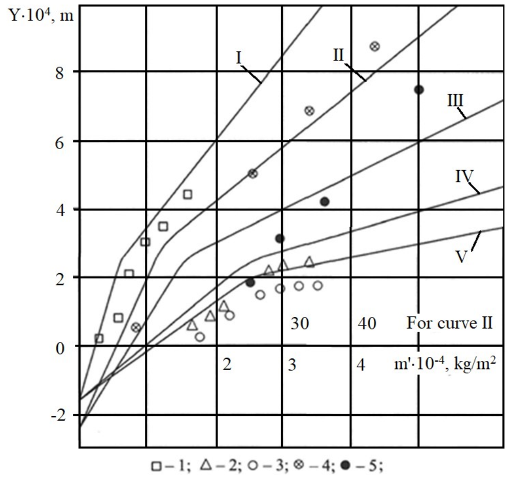
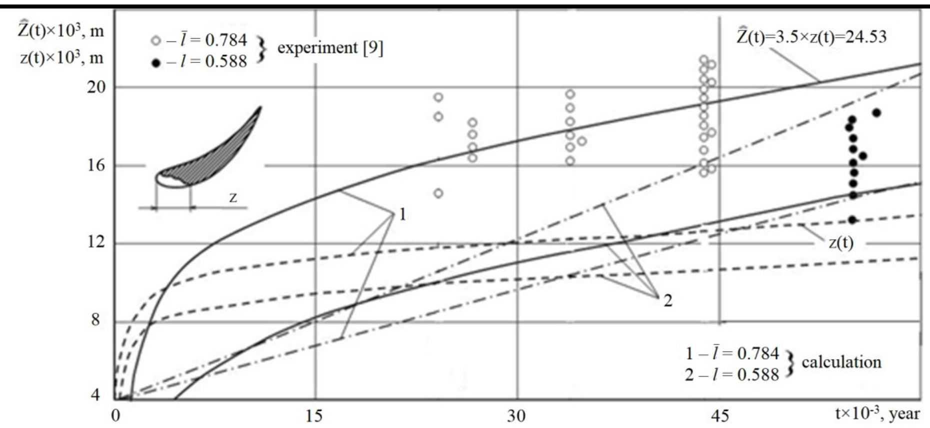


Fig. 2. Kinetic curves of erosive wear of samples from material X20Cr13:
I, IV, V – 20H13 (European analogue: X20Cr13), HB=170–181;
II, III – X20Cr13, HB=241–260;
1, 2, 3 – the experiments of the Moscow Power Engineering Institute (X20Cr13, HB=181);
4, 5 – the experiments of Central Boiler Turbine Institute (X20Cr13, HB=241);
I, 1 – $d_{\text{drop}}=1100\times10^{-6}$ m, $w'_{\text{norm}}=300$ m/s;
IV, 2– $d_{\text{drop}}=820\times10^{-6}$ m, $w'_{\text{norm}}=250$ m/s;
V, 3 – $d_{\text{drop}}=690\times10^{-6}$ m, $w'_{\text{norm}}=250$ m/s;
I, 4 – $d_{\text{drop}}=900\times10^{-6}$ m, $w'_{\text{norm}}=240$ m/s;
III, 5 – $d_{\text{drop}}=900\times10^{-6}$ m, $w'_{\text{norm}}=360$ m/s

Some examples of using the proposed model for predicting erosive wear of blades are shown in Fig. 4, 5.

At the same time, the considered model, although it allows to carry out a sufficiently accurate prediction of the development of the erosion process at the modern stage using a combination of a deterministic and statistical approach to its construction, has, like the other mentioned models, one more drawback. It does not directly consider the complex electrophysical phenomena that occur in the flow path of the turbine when moisture droplets appear.



—— – after erosion model identification;
- - - - – before erosion model identification;
—·—· – IMP PAN calculation method
} – IPMach NASU calculation method

Fig. 3. The width of the rotor blade wear zone in sections of the last stage of different heights of 200 MW turbine

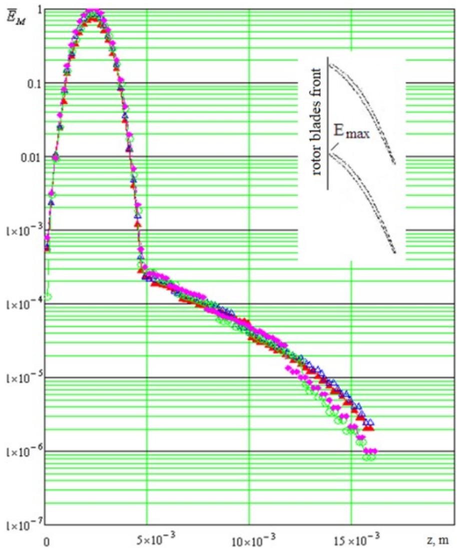


Fig. 4. Change in the relative erosion rate $\overline{E}_M = E_M / E_{M_{\max}}$ *at the leading edge of the low-pressure cylinder of the rotor blade:*

▲ – $\overline{E}_{M_1}$ (C_1=246 m/s, L_z=56 mm);

Δ – $\overline{E}_{M_2}$ (C_1=246 m/s, L_z=49,5 mm);

○ – $\overline{E}_{M_3}$ (C_1=280 m/s, L_z=56 mm);

♦ – $\overline{E}_{M_4}$ (C_1=280 m/s, L_z=49,5 mm)

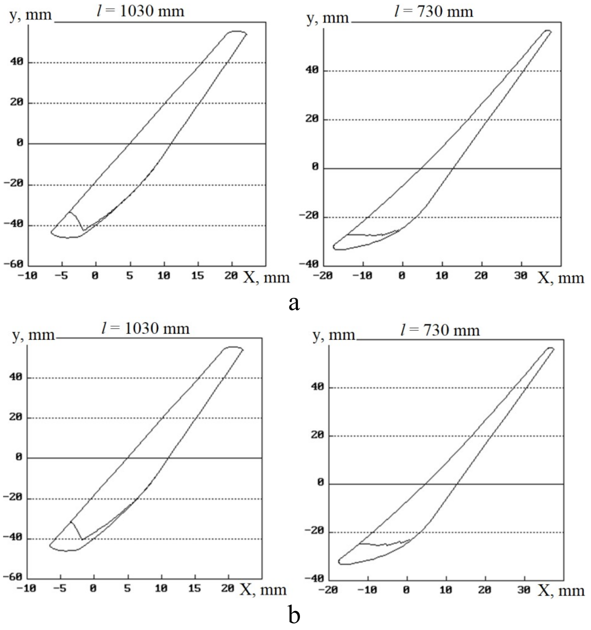


Fig. 5. The calculation of erosion damage to the rotor blade of the last stage of the turbine K-220-44-2M JSC "Ukrainian Energy Machines" in the peripheral zone in the nominal operating mode:

a – 20 thousand hours of operation;
b – 100 thousand hours of operation

As shown in studies carried out under the guidance of Corresponding Member of the National Academy of Sciences of Ukraine A. O. Tarelin [10], the presence of charged droplets in the turbine flow path can lead to a complex of phenomena, resulting in the intensification of erosion-corrosion wear of turbine blades.

Indirect confirmation of this conclusion is the above Fig. 3, which shows a significant discrepancy between the data of field tests and the calculation using a mathematical model, especially in the peripheral area of the blade, which leads to the need to identify the model according to the data of field experiments, the number of which is limited.

It can be assumed that the reason for this is the failure to include the electrophysical component of complex processes occurring in a two-phase flow, especially at the periphery of the blade, where the degree of electrification of the steam flow and, consequently, the electrophysical effect on the blade are maximum.

Thus, in the aspect of building a complex physical model of erosive destruction of steam turbines blades, the issue of studying its electrophysical and electrochemical components becomes very relevant. In addition, this provides additional opportunities for creating special means of anti-erosion protection.

Considering the above, a complex physical model of erosion-corrosion destruction of a blade can be represented as the following components:

– mechanical process – this is the droplet impact destruction due to structural changes in the metal surface;

– electrophysical processes – these are electrocorrosive processes under the influence of charged droplets of the flow.

The first component of the model was discussed above. Let's take a closer look at the second component.

In this regard, it is appropriate to recall the comprehensive studies conducted by the staff of IPMach NASU at various thermal electric stations and combined heat and power plants in Ukraine and the USA, which showed that during the electrization of steam, the charge density in the flow can reach very high values (an order of magnitude higher than in a thundercloud). These phenomena mainly have a negative impact on the operation of wet steam turbines: the electric potential of the rotor increases and the risk of bearing destruction increases; the electrostatic flow generation after the last stage increases the back pressure and dynamic load on the rotor blade, reducing the reliability and efficiency of turbines; the dissociation of water droplets in an electric field and electrolytic dissociation lead to hydrogenation of the flow path structures, etc. In this regard, the first experimentally obtained results on establishing a significant effect of an aggressive electrified steam medium on the rotor blades surface strength are very important in the context of this paper.

In the presence of electrical phenomena on the charged surfaces of the flow path, as well as on the surfaces under the influence of the flow of charged droplets, electrochemical processes similar to cathodic and anodic ones in electrochemical systems can occur, and metal parts can be subjected to negative factors, in particular, cathodic hydrogenation, anodic dissolution, etc.

To carry out the above studies, a wet steam stand was created using artificial steam ionization (Fig. 6), as well as a mechanical-electric stand for the effect of electric fields on metal samples (Fig. 7). The tests were carried out in various thermodynamic and electrical modes. These studies are presented in detail in [10, 11].

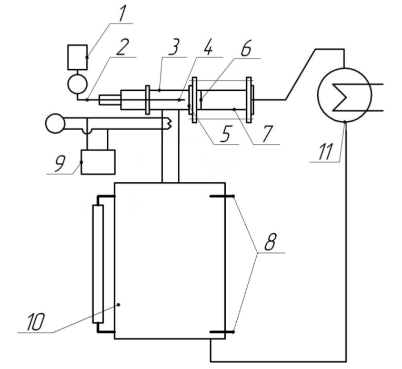


Fig. 6. Conventional diagram of the basic elements of a steam plant with steam ionization by a corona discharge:
1 – high voltage source; 2– high-voltage input; 3 – ionization steam chamber; 4 – corona electrode; 5 – nozzle; 6 – module for fastening a steel sample; 7 – sample processing chamber; 8 – water level sensors; 9 – superheater; 10 – boiler; 11 – condenser

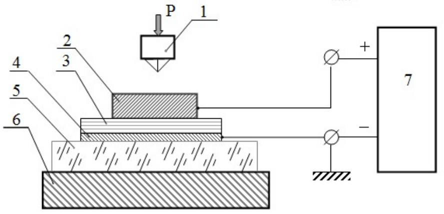


Fig. 7. Scheme for measuring the microhardness of the sample surface in an electric field:
1 – indenter; 2 – sample; 3 – fiberglass; 4 – foil; 5 – insulator; 6 – the subject table of the microhardness tester; 7 – voltage source

Below are the final results of these tests.

The resulting graphs for the change in microhardness after exposure to neutral, positively, and negatively charged steam are shown on Figs. 8 – 10.

Experiments with the effect of a steam flow on the blade steel surface showed that a charged dispersed medium is an additional factor intensifying surface degradation. Experimentally, under conditions close to real-life thermodynamic processes in the turbine flow path, it was recorded that the positively charged flow has the greatest softening (by 40–50 %) effect on the metal surface (Fig. 9). This effect is explained by the specific conditions of cathodic polarization followed by active saturation of the metal with hydrogen protons.

As for the results of exposure to a sample with a neutral and negatively electrified steam flow, it leads to an insignificant change in the metal microhardness. In this case, the destruction occurs mainly mechanically. The insignificant effect of negative charges on corrosion processes is probably due to the presence of two mutually compensating phenomena simultaneously: anode electroetching (destruction) and an increase in surface energy due to a change in electron density (hardening).

The presence of charged droplets in the steam flow is the reason for the appearance of a space charge, which generates an electric field of the flow, thereby exerting an additional effect on the strength properties of the surface layer of the blade material. The latter circumstances are confirmed by the studies presented in [12, 13], in which the effect of electric fields on the microhardness (it can decrease or increase) of the metal is noted. In a real turbine, the rotor blades, when blown by an electrically charged wet steam flow, also accumulate charges that create electric fields [14]. Moreover, these fields can be both pulsed high-voltage and low-voltage alternating and constant, and the value of their potential depends on the internal resistance of the "blade – disk – shaft – grounding brush" circuit and can lie in the range up to 10 V. In this case, an important factor is the polarity the potential of the electric field, on which the nature and degree of change in the surface energy of the metal depend.

Since the tests presented above were carried out without taking into account the influence of electric fields, special studies were carried out in this regard on a mechanical-electric stand.

Below are the results of these studies (Figs. 11–13).

It can be seen from the graphs that the sign of the relative change in the surface microhardness is opposite to the polarity of the stress on the sample. This is explained by the redistribution of the surface electron density, and with it the specific surface energy, which leads to an increase (or decrease) in the microhardness of the sample surface.

It was experimentally established (Fig. 12) that alternating electric fields in the range from 200 to 20 000 Hz have a significant effect on the microhardness of the blade steel surface layer, which manifested itself in a relative decrease in the microhardness HV 0.01 and HV 0.02 by 18–30 % and 15–18 %, respectively.

A constant magnetic field (Fig. 13) reduces the microhardness of the sample surface, depending on the penetration depth of the indenter, by 10–30 %.

Based on the obtained results on the effect of electric fields on the metal microhardness, the following conclusions can be drawn:

– the electric field, both constant and variable, acting on the surface of the blade steel sample changes the microhardness during plastic deformation;

– the maximum decrease in microhardness in a thin surface layer of steel under the influence of electric fields can reach a value of about 30 %.

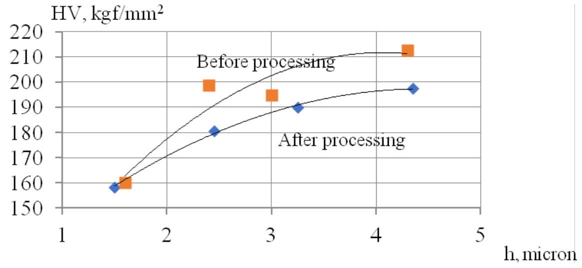


Fig. 8. Change in microhardness (HV) in depth (h) after treatment with neutral steam

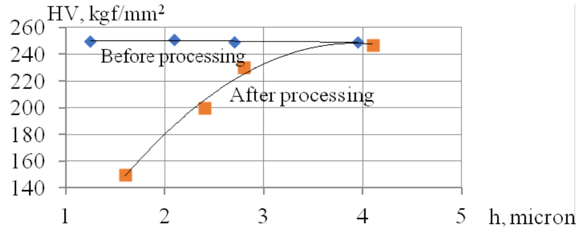


Fig. 9. Change in microhardness (HV) in depth (h) after treatment with positively electrified steam

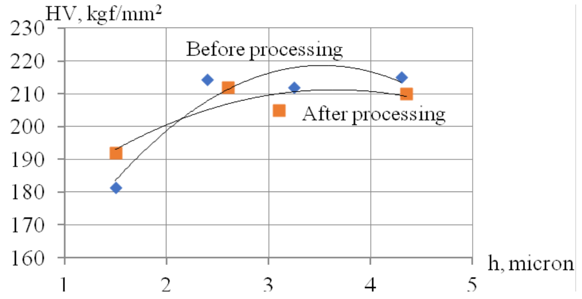


Fig. 10. Change in microhardness (HV) in depth (h) after treatment with negatively electrified steam

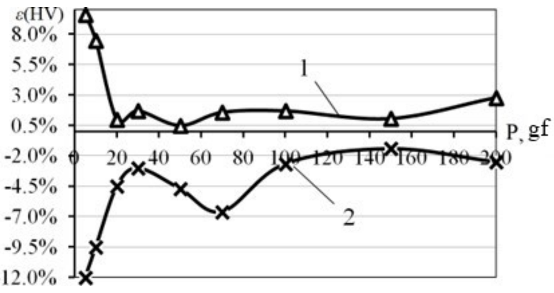


Fig. 11. Relative change in surface microhardness with negative and positive polarization of a sample from steel X20Cr13, measured at indenter loads of 10, 20, 30, 50, 70, 100, 150 and 200 gf:
1 – voltage *U*=–10.0 V; 2 – voltage *U*=+10.0 V

Due to the above results of the study, it can be stated that the combined effect of charged droplets and electric fields on the surface of metals can have a more significant destructive effect (by 60–70 %) than in the case of neutral droplets.

On the surface of the rotor blades, under the action of a supersonic flow of wet steam, electrochemical processes similar to electroetching can also occur. Under the influence of a supersonic wet steam flow on the metal, mechanical destruction of the passivating chromium oxide film occurs on its surface. In this case, the metal surface is activated and interacts with water. Droplets charged negatively can not only have a destructive chemical effect on the oxide film, but also cause anodic corrosion of the blade surface metal, as well as mechanical removal of corrosion products. The process of surface damage is like electrical etching, while the destruction of the metal occurs, but not intense, much less than the effect of positively charged droplets [15].

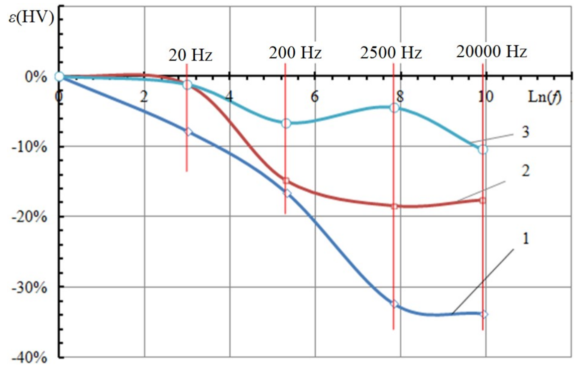


Fig. 12. Relative change in the microhardness of the surface of a sample made of blade steel depending on the frequency of an alternating electric field with a voltage of 10 V:

1 – with a load on the indenter of 10 g ε (HV 0.01);
2 – with a load on the indenter of 20 g ε (HV 0.02);
3 – with a load on the indenter of 100 g ε (HV 0.1)

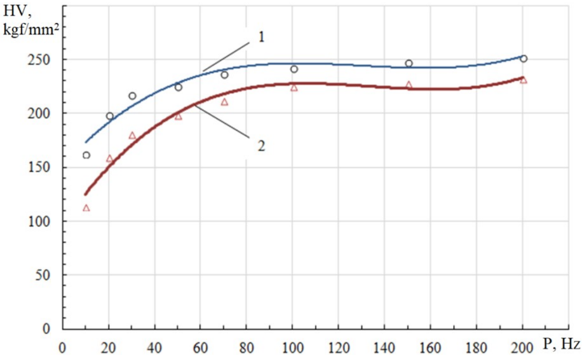


Fig. 13. Influence of a constant magnetic field on the change in the microhardness of the surface of a sample made of steel X20Cr13, measured at various loads on the indenter:

1 – without magnetic field; 2 – in a magnetic field

Conclusions

1. An important and urgent problem of creating a method for predicting the intensity of erosion-corrosion wear of the rotor blades material of the low-pressure cylinders stages of powerful steam turbines is presented. The features of the construction of some existing erosion models are considered. The model developed at the Institute of Mechanical Engineering Problems of the National Academy of Sciences of Ukraine and based on a deterministic-statistical approach to its construction is analyzed in detail.

2. The good capabilities of the model of IPMach NAS of Ukraine for predicting the development of the erosion process are shown. At the same time, it is noted that the considered model, like other similar models, has difficulties in constructing, associated with the need to identify it according to field test data, the number of which is limited.

3. It has been established that one of the possible reasons for the discrepancies that arise is that the existing models do not consider the effect on wear of the electrophysical processes that occur in the flow path of a wet steam turbine during the electrization of wet steam. It is shown that the nature and degree of change in the microhardness of the rotor blades surface of the wet steam turbines depends not only on fatigue phenomena caused by vibrations of the metal surface during the impact of large droplets, but also on various electro-physical-chemical processes that occur during the electrization of the wet steam flow:

– the cathodic polarization with saturation of the metal with hydrogen ions (hydrogen saturation) with subsequent embrittlement;

– the change in the energy state of the metal surface and microhardness under the influence of electric fields, due to a change in the electron density;

– the anodic metal corrosion (processes similar to electroetching).

4. It has been established that factors such as the presence of a positively charged steam flow, constant and variable electric fields, which were most often recorded during experimental studies on operating turbines of thermal power plants, significantly (by 1.5 or more times) intensify erosion-corrosion processes on the metal surfaces of the blades, thus reducing their working resource.

5. Qualitative and quantitative results of research on steam electrification processes depending on the flow parameters, water-chemical mode, blade material, etc. can be the basis for formalizing the electrocorrosion processes occurring in low-pressure steam turbines, assessing their share of influence in the overall erosion-corrosion process and correction of the corresponding mathematical models.

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Моделювання процесу ерозійно-корозійного руйнування лопаток циліндрів низького тиску парових турбін

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Роботу присвячено вирішенню важливої проблеми, а саме розробці методу прогнозування інтенсивності ерозійно-корозійного руйнування матеріалу робочих лопаток ступенів низького тиску потужних парових турбін, що враховує комплекс складних фізичних процесів, які супроводжують виникнення, трансформацію ерозійно-небезпечних крапель та їх взаємодію з елементами проточної частини. Розглянуто особливості побудови деяких існуючих моделей ерозії. Докладно проаналізовано розроблену в Інституті проблем машинобудування НАН України модель, засновану на детерміновано-статистичному підході. Виконані під час дослідження розрахунки показали задовільний збіг із результатами експериментальних випробувань різних авторів, одержаними на краплеударних стендах, що сприяло успішному використанню моделі при створенні комплексного методу прогнозування зношування робочих лопаток. Для цього вона доповнюється методом визначення параметрів ерозійного середовища на базі рівняння руху крапель з урахуванням закону розподілу за розміром. Разом с тим показано, що розглянута модель, хоч і дозволяє на сучасному рівні здійснювати досить точне прогнозування розвитку ерозійного зносу, але має складнощі в побудові, пов'язані з необхідністю її ідентифікації за даними натурних експериментів, кількість яких обмежена. Встановлено, що однією з важливих причин розбіжностей є неврахування електрофізичної складової процесів, що відбуваються у двофазному потоці. У зв'язку з цим розглянуто результати комплексних досліджень електризації пари та її впливу на робочі процеси волого-парових турбін. Показано, що зміна властивостей робочого тіла як функціонального ерозійного середовища в результаті електризації викликає суттєве посилення (стосовно нейтральної вологої пари) електрохімічних процесів. При цьому змінюється кінетика накопичення пошкодженості поверхневого шару металу за рахунок спільного протікання кількох негативних процесів: крапельно-ударного впливу; електрохімічних процесів, зумовлених механічною і структурно-хімічною неоднорідністю поверхні; абсорбції водню; зміни механічних властивостей під впливом електричного поля. Зауважено, що внесок абсорбції водню у зміни механічних властивостей найбільший. За попередньою оцінкою комплексний негативний крапельно-ударний та електрофізичний вплив на поверхню металу зменшує інкубаційний період та інтенсифікує ерозійно-корозійний процес приблизно в 2 рази.

***Ключові слова**: парова турбіна, волога пара, робочі лопатки, краплеударне руйнування, математичне моделювання, електрофізичні ефекти, електрокорозійні процеси.*

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