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EXPERIMENTAL STUDY OF THE EFFECTS OF A CONSTANT AND VARIABLE ELECTRIC FIELDS ON THE STRENGTH PROPERTIES OF THE BLADE STEEL SURFACE LAYER

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It is known that in wet steam turbines the wet steam flow is electrified when passing through the turbine flow path. In this, the mutual electrification of the condensed moisture flow and flow path surfaces occurs. Until now, experts in the field of steam turbine operation have been aware of the problem of electrical phenomena in flow paths in terms of electroerosion phenomena associated with the accumulation of electric charges on the rotors. Similar phenomena in the working fluid flow are less known. As a result of the research conducted at IP-Mash NAS of Ukraine, it has been established that the electrification of the wet steam flow leads to the formation of a volume charge in the flow path, which can have a significant value (up to 10^{-3} *C/m*^{3}*) and exert a significant effect on the working processes in the turbine and condenser. The volume charge of the steam flow in the flow path also generates electric fields with constant and variable components. As a result, parts and assemblies of the flow path may be under the action of an electric field. In particular, turbine blades may be in the electric field of the volume charge of the working fluid. As is known, the impact of an electric field can reduce the strength of the metal surface layer. Therefore, an experimental study of the effect of electric fields, similar to those occurring in the turbine flow path, on the strength properties of blade steel is an important task. The article presents the results of the experimental determination of the microhardness of the 15H11MF blade steel surface layer exposed to a constant or variable electric field. It is shown that its effect significantly reduces the microhardness of the blade steel surface layer. Since the strength of the surface layers of the working blades is one of the most important characteristics of their erosion resistance, the effect of the electric field of the steam flow volume charge can be one of the negative factors that reduce the erosion resistance of turbine blade surfaces. Based on the obtained results, it can be concluded that it is necessary to further improve the system for neutralizing the accumulation of electric charges in the flow path, which currently mainly performs the function of turbine rotor grounding.*

Keywords: *microhardness, electric field, blade steel.*

Introduction

The wet steam flow in the flow paths of wet steam turbines is accompanied by the mutual electrification of the condensed moisture flow and flow path surfaces [1–3]. As a result, a volume electric charge of the same sign is formed in the wet steam flow, and a charge of opposite sign accumulates in the flow path material. Accordingly, an electric field appears in the flow path, under whose influence there are parts of the flow path, the surfaces with a high degree of curvature being exposed to it to the greatest extent [4]. The electric field in the flow path can also be variable, which is caused by the accelerated motion of charged particles, changes in the charging time of the steam flow. In addition, the accelerated motion of charged particles and electrical discharges in a charged flow can cause electromagnetic radiation [5, 6]. It is known that the effect of an electric field on a metal surface can change the strength properties of the surface layer [7–11]. The experimental studies carried out on single crystals of zinc, aluminum, zirconium, copper, iron showed that the presence of a small, up to 5 V electrical potential on a sample, can change the surface microhardness by 10% or more. In a wet steam turbine, during the electrification of the steam flow, the parts and components of the flow path may be under the action of electrical potentials of the order of a few volts. In particular, such potentials can be on the surfaces of turbine rotor blades depending on the intensity of the steam flow electrification, quality of the rotor grounding system, and electrical resistance of the "blade surface – ground" circuit. In this connection, the task of experimentally verifying the effect of electric fields, similar to those occurring in the turbine flow path, on the strength properties of blade steel is of current interest.

Problem Formulation

In order to select the magnitude of the field strength on the surface of a blade steel sample, an approximate estimate of the field strength in the low pressure turbine cylinder between the rotor blades and guide vanes was given. As was shown in experimental studies [1], the range of variation of the bulk charge density in the turbine steam flow in a turbine flow path is from ~10^{-10} C/m^3 in the phase transition zone to ~10^{-3} C/m^3 in the turbine exhaust, and the field strength behind the last stage is up to $2{\cdot}10^5$ V/m. For the estimated calculation, a value of ~ 10^{-6} C/m^3 was chosen, which is close to the average value of the volume charge change range. The distribution of the charge density in the flow is mainly associated with the distribution of the coarse moisture in the flow path, which can be illustrated by the volume charge density diagram [4] (Fig. 1).

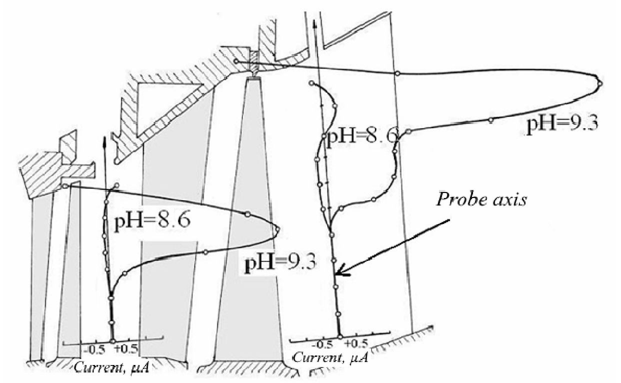

Fig. 1. Dependence of the volume charge density on the position relative to the blade and the feed water pH

The estimated calculation of the volume charge distribution was carried out on the basis of the conditional distribution diagram for the condensed moisture in the inter-bade space of one stage. For the simulation, we used the ELCUT program (free version), which allows simulating physical fields by the finite element method.

The estimated calculation of the field strength was performed for a two-dimensional electric model of the inter-blade space in the wet steam zone, in the form of a charged region bounded by grounded surfaces. The inter-blade space was selected with an average inter-blade distance of 170 mm and a blade height of 960 m (Fig. 2).

As can be seen from the figure, in the model, the maximum field strength on the blade surface is about 7000 V/m.

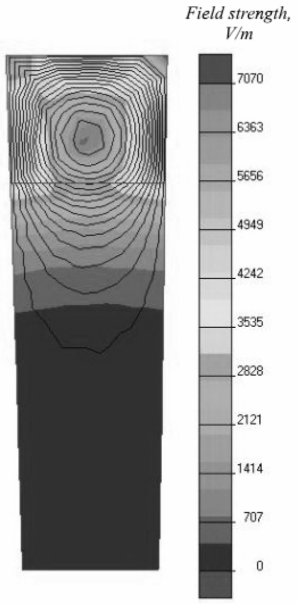

Fig. 2. Field strength distribution between the guide vanes and rotor blades

Test Stand

In order to conduct an experiment to study the electric field effect on the mechanical properties of the blade steel surface, a test installation was assembled based on the PMT-3 device. The scheme of connecting the electric potential to the sample is similar to the schemes given in [9, 10].

Installation design: a foil fiberglass plate was fixed to the dielectric base, foil to the dielectric. The sample to be studied was fixed to the plate top. Conductors for supplying potential difference were soldered to the foil and sample. The source of the potential difference was a stabilized laboratory power source.

Fig. 3 shows the diagram of the indentation system in an electric field with a sample.

In the figure above, pressure P is applied to an indenter 1, which is embedded in a sample surface 2 attached to a dielectric base 3.

At a sample potential of 9 V, the field strength distribution between the sample and negative electrode is shown in Fig. 4.

The numerical value of the field strength on the surface is about 8000 V/m, which is comparable with the above estimate of the field strength in the flow path.

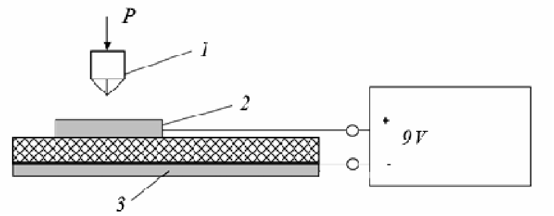

Fig. 3. Indentation system in an electric field

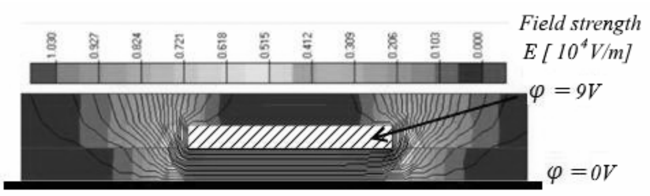

Fig. 4. Field on the blade steel sample surface

Experimental Technique

For the experiment, 10×5×1 mm 15H11MF steel samples were used. The electric field on the sample surface was created with the help of an auxiliary electrode. The electrode was a 85×20 mm plate of 1.5 mm thick one side foiled fiberglass. The sample intended for investigation was attached to the non-foiled surface of the plate using plasticine. A strip of foiled fiberglass was glued to the 110×25×2 mm vinyl plastic plate base, with the foiled side to the base. The prepared system of the auxiliary electrode with a sample was mounted on a PMT-3 device.

When a constant field was applied, a positive potential was given to the sample, and a negative potential was given to the foil, potential difference being 9 V. When a variable field was applied, a potential difference of 6 V was used.

The indentation was carried out under the direct action of an electric field, however, the electric field was applied from the side opposite to the indentation. This variant of potential application differs from that used in [9] and [10], since the sample under study in those experiments was placed on top of one of the electrodes and the electric field was not concentrated between it and the other electrode.

The results of microhardness measurements prior to the exposure to an electric field and in the field are presented in the table below.

When a constant field was applied, the average microhardness values for ten measurements for a load of 10 g were the following: the initial value was 158 kg/mm^2; when the field was applied, the value was 141 kg/mm^2. For a load of 20 g the initial value was 172 kg/mm^2; when the field was applied, the value was 151 kg/mm^2.

The relative change in the microhardness was determined for the mean values by the formula $\delta = \dfrac{H_\mu^F - H_\mu}{H_\mu} \cdot 100\%$, where H_μ^F is the value of the microhardness in the field, H_μ is the microhardness prior to exposure.

When a constant field was applied, at a load of 10 g, δ was -11%; at a load of 20 g, δ was -12%.

When a variable field was applied, the average microhardness values of ten measurements for a load of 10 g were the following: the initial value was 144 kg/mm^2; when the field was applied, the value was 112 kg/mm^2. Accordingly, the relative change in microhardness δ was -22%.

Table. Results of the steel layer surface microindentation when the surface is exposed to a constant or variable electric field

Constant field, 9 V				Variable field, 6 V, 1000 Hz	
Prior to exposure		In the field		Prior to exposure	In the field
Indentation load, g					
10 g	20 g	10 g	20 g	10 g	10 g
Microhardness H_μ, kg/mm^2					
163	181	163	148	153	122
144	156	139	159	142	105
153	156	147	144	131	95
153	176	170	150	134	108
142	181	144	146	142	97
198	173	131	163	139	112
150	159	124	166	156	134
163	184	129	131	134	124
153	176	118	147	156	110
160	179	139	153	150	110

The observed microhardness changes are significantly greater than the measurement error of a microhardness meter (5% according to the instrument passport).

Conclusions

A constant or variable field significantly affects the microhardness of the surface layer of the blade steel. Indentation can be considered as one of the types of mechanical tests. This is due to the fact that with increasing load on the indenter material, as with any other type of mechanical testing, it consistently undergoes 3 stages: elastic, elastic-plastic and fracture. As a consequence, the value of microhardness can be considered as an integral characteristic of the strength of the local element of the material surface layer. Thus, when an electric field is applied to the sample surface, the reduction in microhardness means the deterioration of the strength properties of the steel surface layer.

Based on the data obtained, it can be concluded that the occurrence of an electric field in the turbine flow path during the electrification of the working fluid can adversely affect the surface strength of turbine blades. In this case, the erosion resistance of blade surfaces may decrease. Since the electric field of the volume charge is associated with the electrification of condensed moisture, perspective methods of erosion protection should be aimed not only at reducing the amount of erosion-hazardous condensed moisture, but also at reducing the degree of electrification in a turbine.

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Експериментальне дослідження впливу постійного й змінного електричного поля на міцнісні властивості поверхневого шару лопаткової сталі

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Відомо, що у вологопарових турбінах потік вологої пари електризується, проходячи через проточну частину турбіни. Водночас відбувається взаємна електризація потоку крапельної вологи та поверхонь проточної частини. До цього часу фахівцям в галузі експлуатації парових турбін проблема електричних явищ в проточній частині була більшою мірою відома в аспекті електроерозійних явищ, пов'язаних з накопиченням електричного заряду на роторі. Явища, пов'язані з накопиченням електричного заряду в потоці робочого тіла, були менш відомі. Однак, як було показано в дослідженнях ІПМаш НАН України, електризація потоку вологої пари приводить до утворення об'ємного заряду в проточній частині, який може мати значну величину (до 10^{-3} *Кл/м*^{3}*) та чинити істотний вплив на робочі процеси в турбіні і конденсаторі. Також об'ємний заряд в потоці пари в проточній частині породжує електричні поля, що мають постійну і змінну складові. Через це деталі і вузли проточної частини можуть знаходитися під дією електричного поля. Зокрема, в електричному полі об'ємного заряду робочого тіла можуть бути робочі лопатки турбіни. Як відомо, вплив електричного поля може знижувати міцність поверхневого шару металу. Тому експериментальне дослідження впливу електричних полів, які є подібними до тих, що виникають в проточній частині турбіни, на властивості міцності поверхневого шару робочих лопаток є актуальною задачею. У статті наведені результати експериментального визначення мікротвердості поверхневого шару лопаткової сталі 15Х11МФ під впливом постійного і змінного електричного поля. Показано, що вплив постійного і змінного електричного поля суттєво зменшує мікротвердість поверхневого шару лопаткової сталі. Оскільки міцність поверхневого шару робочих лопаток є однією з найважливіших характеристик їхньої ерозійної стійкості, вплив електричного поля об'ємного заряду парового потоку може бути одним з негативних чинників, що знижують ерозійну стійкість поверхні лопаток турбіни. На підставі отриманих результатів можна зробити висновок про необхідність подальшого вдосконалення системи нейтралізації накопичення електричних зарядів в проточній частині, яка на цей час в основному виконує функцію заземлення ротора турбіни.*

Ключові слова: *мікротвердість, електричне поле, лопаткова сталь.*

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