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# THE DEVELOPMENT OF THE SYSTEM STABILIZING THE TEMPERATURE OF THE STEAM TURBINE'S BLADES DURING THE SPRAYING PROCESS OF DIOXIDE ZIRCONIUM

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## ABSTRACT

*Working blades are the most crucial parts, the breakdown of which will inevitably lead to a serious accident. In order to eliminate possible damages and breakages, it is possible to use in repairing a coating of zirconia. Such coatings with increasing thickness have a tendency to increase thermal resistance. Broad application of dioxide zirconium is caused by its low thermal conductivity, high coefficient of thermal expansion and, most importantly the ability to provide high mechanical characteristics of coatings. The main task in receiving the necessary result is maintenance of the set conditions at drawing of a sprayed covering that will increase durability of restored details. There is considered the creation of system for stabilizing the temperature of the blades of steam turbines during the covering of dioxide zirconia in this work. Correctly selected and maintained substrate temperature during spraying will provide a coating with the desired parameters and reduce the probability of damage to the blades because of low-quality covered material. By results of research it is revealed that the developed system could provide stabilization of temperature during the covering.*

**Keywords**: laser spraying, ceramic powders, temperature stabilization, turbine blades, computer simulation of the system

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# 1. INTRODUCTION

The park resource of steam turbines is established based on the resource of high-temperature units of the high and medium pressure part. Information about the resource of the remaining parts of turbines is not specified in normative documentation and or any other documents, as a result of which there may be an erroneous opinion that this resource is unlimited.

In fact, the point is that the resource of the details of steam turbines, in particular working blades and disks, cannot be determined unambiguously, since there are many factors, including accidental ones that affect it, depending on the operation and repair of specific turbo-units. Therefore, manufacturing plants, industry research institutes, specialized repair organizations are constantly working on the introduction of complex measures ensuring reliable operation of the turbine during the whole assigned period. Often during the exploitation, the staff does not pay attention to a number of factors that reduce the life of blades and discs, despite the fact that almost all of them are taken into account in the existing normative documentation regulating the requirements for operation, repair and control. So, it is necessary to consider in more detail the causes of their occurrence and their effect on resource and reliability of blades and disks of steam turbines [1].

To the most frequent damage of the blades can be attributed erosion and corrosion. Erosion of the blades is the mechanical wear of the front edges of the blades under the influence of water droplets, formed in the steam due to its partial condensation and attracted by the steam flow. Such a breakdown is explained by the lower velocity of the water droplets contained in the steam compared to the steam velocity, and therefore, by their other relative direction than the direction of the steam jet [2].

Corrosion damage of the blades is caused by chemical corrosion of their surfaces under the influence of oxygen (rust), alkali, scale, etc. Corrosion mostly affects the bandages, outlet edges and sides of the blades, covering with tuberous growths. Under these growth often revealed the ulcers, which reaching up to 2 -3 mm along the section of the metal of the blades, and at the edges - ulcers passing through and forming patterned, easily breaking edges [3].

Also, the main causes of damage include a high level of temperature, vibration, isothermal and non-isothermal, dynamic and long-term static loads.

The surfaces of dioxide zirconia are less susceptible to this kind of influence, so it allows more durability of individual blades in particular and the facility generally. The recovery of the steam turbine blade according to the proposed method allows reducing the tensile residual stresses, increasing the crack resistance, the endurance limit, and the corrosion and erosion resistance of the recovered blade, improving processability and reducing the cost of the recovery process [3]. Coatings obtained by this method have a high thermal fatigue. This quality is very necessary, because of the operation of the turbine blades takes place under very difficult conditions (high and variable temperature, different effects of the steam jet and centrifugal force, etc.); therefore, it makes high demands on the design of the blades, the material, the manufacturing process and the facility [1].

# 2. FORMULATION OF THE PROBLEM

The blades of the turbine, working under conditions of complex combined effect of static, thermocyclic and dynamic loads, influenced by non-isothermal pressure when reaching extreme temperatures in the cycle of operation. This contributes to the appearance in the material of extensive areas covered by cyclic plastic deformations in which the initial contracting and strength properties of the material undergo significant changes. This in many ways explains the damage that goes into the cracks and the destruction of the wheels and blades of the turbine. However, a complete replacement of the turbine is quite a costly exercise. Therefore, it is necessary to create appropriate conditions for the restoration work of turbine blades, such as the spraying of ceramic compounds on the surface of the blades. This process must take place with certain parameters of the environment and the surface to be sprayed. The sublayer temperature must correspond to the value specified in the technical specifications for the material. Thus, it is necessary to develop a system that will monitor temperature changes on the blade surface and adjust it depending on the set value [4].

## 3. THEORY

Control theory is the science of the principles and methods of controlling various systems, processes and objects. It bases on the cybernetics and information theory. Essence of the control theory: a mathematical model of the control object, based on system analysis, is compiled, after which the control algorithm is synthesized to obtain the desired characteristics of the process or control purposes.

Stabilization systems are designed to maintain the regulated value in constant condition, in this case the temperature - t. Monitoring of these parameters is carried out through the negative feedback. Initially, the desired temperature value is set, according to the normative documentation for this process [5]. The method of gas-thermal spraying of a ceramic coating includes spraying of metal sub-layer and then a ceramic layer of powders based on partially stabilized zirconia at a substrate temperature of 150-200 °C and the surface temperature of the emerging coating heated to 1300 °C. A monolayer of ceramic particles is initially deposited on the sublayer at the temperature about 20-80 °C [6].

Reading of the temperature value from the control object (turbine blades) is makes by pyrometer. The sensor of this kind allows to measure temperature without direct contact with the detail surface that facilitates work of system and its autonomy [7]. The principle of its operation is based on the fact that all the bodies, when heated, emit waves in the IR and light range, the intensity of this radiation and registers the device in relation to the temperature for which this radiation is characteristic. Further, the system checks the setpoint with the current value and, depending on the result obtained, gives a signal to the relay. Then the current flows to the solenoid valve, which serves to supply gas to the heating torch. Its main purpose is to burn fuel in the atmosphere to ensure the required level of heat transfer. As a liquid fuel, mainly use gasoline, kerosene and ethyl alcohol. Natural gas and liquefied hydrocarbon gases are widely used as a gaseous fuel for heating burners. The flame from the burner is directed to the control object (blade), thereby generating the heating of the blade. At the same time, the temperature is sensed by the sensor. When the corresponding value is reached, the relay and the valve will be disconnected, and as a result, the heating will stop [8].

The temperature stabilization system is part of the blade repair system. Next, the structural diagram of the entire system will be considered.

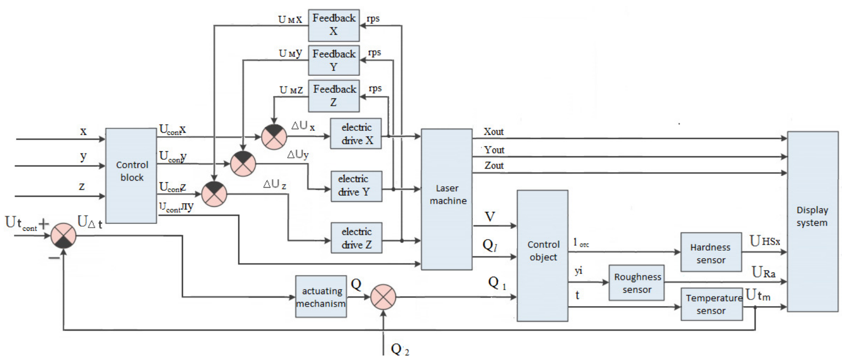


**Figure 1.** Structural diagram of the control system of the process of dioxide zirconium spraying and reflowing it with a laser beam onto the steam turbine blades.

At development of the system of recovery process, it was necessary to take into account the fact that the spraying process must take place under certain conditions. Consequently, the control of these parameters must be controlled throughout the whole process.

The structural scheme can be divided into four parts. The first of them moves the laser unit. The second controls the spraying process, the power of fusing the powder on the blade surface. The third part controls the values of the sensors and displays them on the display. In the fourth, the temperature stabilizes and the blades are preheated before spraying.

The facility, corresponding to this scheme, allows to carry out the restoration work, spraying of dioxide zirconium to the surface of the blades without their dismantling from the rotor of the steam turbine.

Before starting the work, the operator brings the unit to the rotor and in manual mode runs the unit over the blade. Then he fixes it to start work. To process the remaining blades, only the rotation of the rotor installed on the axis is required, at a certain angle. The temperature sensor monitors the substrate condition before applying the powder and, if necessary, opens the flaps of the heating torch to maintain the set temperature. After the spraying process, the operator checks the treated surface with the help of roughness and hardness sensors and, if necessary, changes the parameters for the process. Further in the figure 2 it is possible to see how the turbine looks after spraying of dioxide zirconium.

**Figure 2.** Rotor stage after application of zirconia.

There is considered the blade temperature control system in this work. An electromagnetic valve regulating the supplying of gas to the burner will be used as actuating mechanism. Advantages of this valve is a low time delay and tripping, the developed effort on the valve stem, the possibility of frequent switching. The supply voltage of the valve is 24 V, the response time is 0.05 seconds, and the fuel consumption rate is 6 $m^2$/hour. The specific heat of combustion of gas G20 is 34.02 MJ/$m^3$. Those. 1 $m^3$ of G20 during combustion will allocate 34.02 MJ. So, the coefficient of power demand will be 945 J/s. As the efficiency of the gas burner generally does not exceed 40-60%, the energy transfer coefficient will be equal to $k_p = 600$ J/s. The gain is equal to the ratio of the input y value to the output x:

$$k_{AM} = \frac{y}{x} = \frac{V}{k_p} \quad (1)$$

$$k_{AM} = \frac{24}{600} = 0{,}04$$

This valve is inertial link and is described by transfer function of the first order:

The time constant of the valve is 1/3 of the travel time of the regulating organ's valve by of the nominal stroke after a gradual change in its input signal. Actuation time of the valve $T_v$ = 0, 05 s.

$$T_{AM} = \frac{1}{3} \cdot T_V = \frac{1}{3} \cdot 0,05 \approx 0.0167$$

Thus, the transfer function of this link can be written in the form:

$$W_{AM} = \frac{k_{AM}}{T_{AM}\, p + 1} = \frac{0,04}{0,0167\, p + 1} \tag{2}$$

Where P is the Laplace parameter.

The heating torch gives energy in second – $Q_1$. For the same second, the blade gives energy to the surrounding space – $Q_2$. The difference in energy $Q_1$-$Q_2$ ensures the heating of the blade. [9] The equation for the heat balance is:

$$Q_1 - Q_2 = C_B \cdot m \cdot \frac{dt}{d\tau}, \tag{3}$$

Where $C_B$ is the heat capacity of the blade, *m* is the mass of the blade, *t* is the blade temperature, and τ is the time. The cooling capacity depends on the size of the blade and the temperature difference between the blade and the surrounding air. In the first approximation it is:

$$k_2 = \alpha(t - t_1) \cdot S \tag{4}$$

$$Q_1 - \alpha(t - t_1)S = C_B p \cdot m \cdot \frac{dt}{d\tau}$$

The transfer function will look like:

$$W_B(p) = \frac{k_p - k_2}{T_{heat}\, p + 1} \tag{5}$$

The time constant of the heating process will be:

$$T_{heat} = \frac{m \cdot c}{S \cdot \lambda},$$

Where is $\lambda$ the heat transfer coefficient from the surface, *m* is the blade mass (m = 2 kg), *c* is the specific heat (c = 500 J/kgK), *S* the blade area is about (S = 0.08 $m^2$).

$$T_{heat} = \frac{2 \cdot 500}{0,08 \cdot 46} = 273$$

The energy released by the blade surface will vary with the temperature difference. The temperature in the production room is a constant value and will be $t_1$=20°C. The temperature required to produce laser surfacing is t=150°C. [10] Therefore for simplification the average value undertakes:

$$k_2 = 47 \cdot 65 \cdot 0,08 = 122 J / s$$

The transfer function is:

$$W_B(p) = \frac{600 - 244}{273\, p + 1} = \frac{356}{273\, p + 1}$$

As a temperature sensor, the pyrometer MLX90614-BCI with a measurement range from -70 to +382 will be used. The pyrometer's inertia index is 0.33 s. The transmission / gain ratio is equal to = 0.95. Since this element has one time constant, its transfer function will be identical to the transfer function of the inertial link of the first order and will have the form:

$$W_{TS}(P) = \frac{k_{TS}}{T_{TS} \cdot p + 1} \quad (6)$$

After replacing the constants with their numerical values, we get:

$$W_{TS}(P) = \frac{0,95}{0,33 \cdot p + 1}$$

The transfer function of a closed system will be:

$$W_T(P) = \frac{W_{AM}(p) W_B(p) W_{TS}(p)}{1 + W_{AM}(p) W_B(p) W_{TS}(p)} \quad (7)$$

$$W_T(P) = \frac{\frac{k_{AM}}{T_{AM}p+1} \cdot \frac{k_1 - k_2}{T_{heat}+1} \cdot \frac{k_{TS}}{T_{TS} \cdot p + 1}}{1 + \frac{k_{AM}}{T_{AM}p+1} \cdot \frac{k_1 - k_2}{T_{heat}+1} \cdot \frac{k_{TS}}{T_{TS} \cdot p + 1}}$$

$$W_T(P) = \frac{\frac{0,04}{0,0167p+1} \cdot \frac{356}{273p+1} \cdot \frac{0,95}{0,33 \cdot p+1}}{1 + \frac{0,04}{0,0167p+1} \cdot \frac{356}{273p+1} \cdot \frac{0,95}{0,33 \cdot p+1}} = \frac{\frac{13,598}{1,07p^3 + 210.83p^2 + 273.4p + 1}}{1 + \frac{13,598}{1,07p^3 + 210.83p^2 + 273.4p + 1}} =$$

$$= \frac{13,598}{1,07p^3 + 210.83p^2 + 273.4p + 19,164}$$

## 4. COMPUTER MODELLING

One of the best ways to test the system parameters is computer simulation. Matlab can help with this. This is a package of applications for solving technical computing problems and the programming language of the same name used in this package. As part of Matlab'a there is a graphical environment for simulation modeling - Simulink. It allows using block diagrams in the form of directed graphs, to build dynamic models, including discrete, continuous and hybrid, nonlinear and discontinuous systems. The interactive environment of Simulink allows to use of ready-made libraries of blocks for simulation of electric, mechanical and hydraulic systems, as well as applying a developed model-oriented approach in the development of control systems, digital communication facilities and real-time devices.

Simulink implemented the principle of visual programming, according to which the entire model is built from standard library blocks and blocks upgraded or developed by the user. Each block realizes its mathematical function. The blocks have inputs and outputs and are connected in the model by communication lines along which the arguments arrive at the input of the functions. In addition to sections with typical blocks, the Simulink library has additional sections with blocks for different applications, for example, for modeling electromechanical devices, data transmission channels, etc. One of these sections is Real-time Windows Target. Blocks from this section allow to connect a wide variety of I / O boards, as well as create a real-time system and manage it for rapid prototyping and hardware-in-the-loop simulation.

Figure 3.1 and 3.2 show the Simulink model of the system and the data from the Scope block.

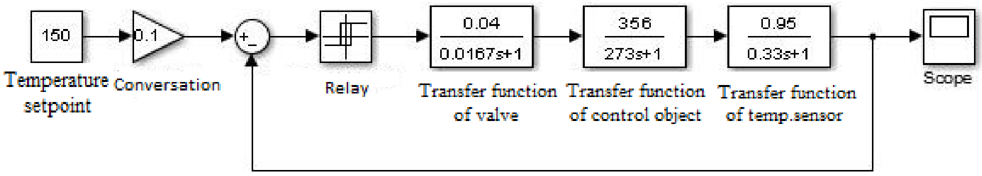


**Figure 3.1.** Simulink-model of the system for stabilizing the temperature during spraying

The model was constructed in the Simulink simulation system. It corresponds to the calculated transmission functions of the stabilization system blocks. In the "Temperature setpoint" block the required temperature of the control object is set. Next is the conversion of the signal to compare it with that obtained from the negative feedback. The relay operates if the value received from the sensor does not reach the set value. Next come blocks with transfer functions of the valve of the heating torch, the control object and the temperature sensor. The obtained temperature value from the sensor is output to the Scope bloc (Figure 3.2).k and returns to subtract from set value

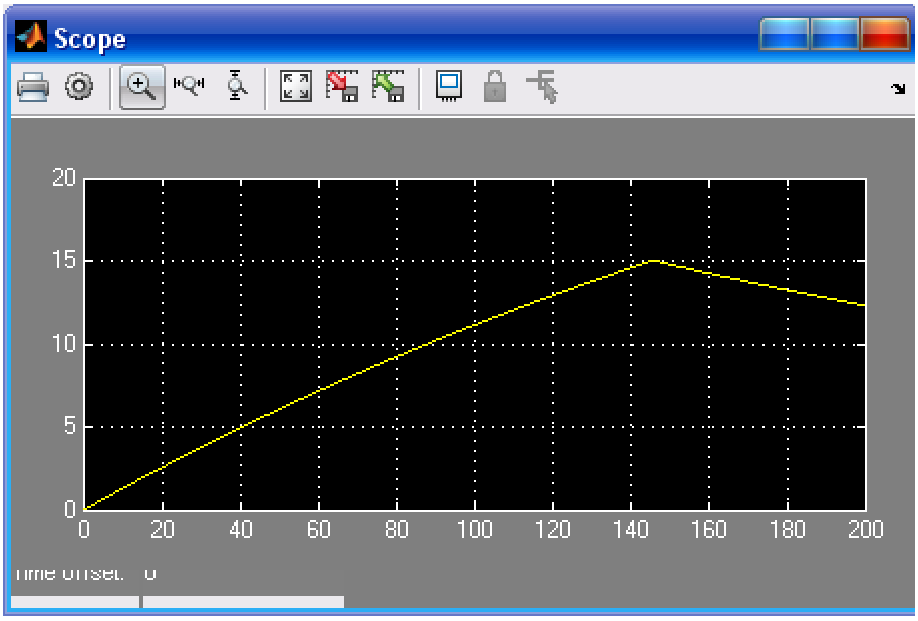


**Figure 3.2.** Scope unit, output from the temperature sensor

## 5. SEMI-DETAILED MODELING

The system was redesigned with blocks from the section Real-time Windows Target to connect the external devices, Figures 4.1 and 4.2 show the experimental model of the system.

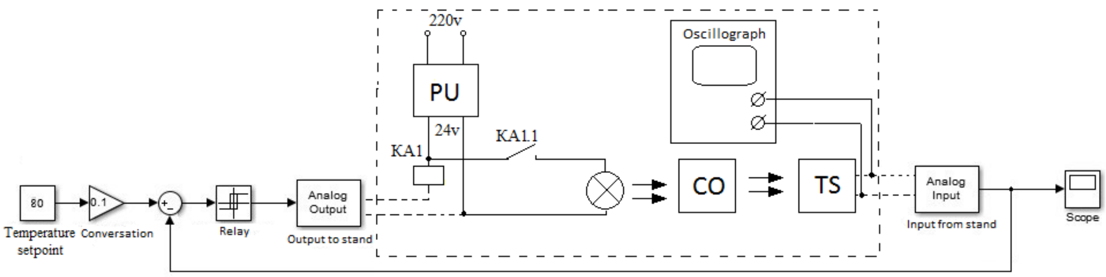


**Figure 4.1.** Simulink model with external devices connection

Where PU - the power unit 220/24, КА1 - the relay, CO – control object (a metal plate), TS - the temperature sensor (pyrometer)

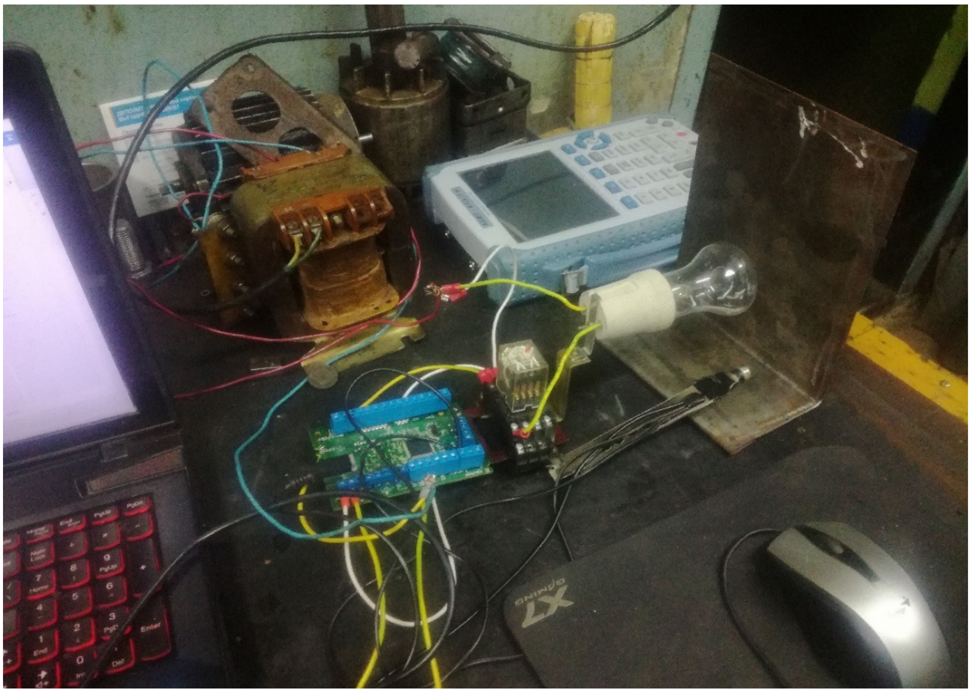

**Figure 4.2.** The stand of the temperature stabilization system

In this model, instead of a heating torch (actuator) an incandescent lamp was used. The system, having received a temperature sensor signal, comparing it with the set one, gives a signal to switch on the relay, which supplies the lamp spiral. It starts to heat the steel plate. The dynamics changes in the voltage at the output of the pyrometer in Fig. 4.3.

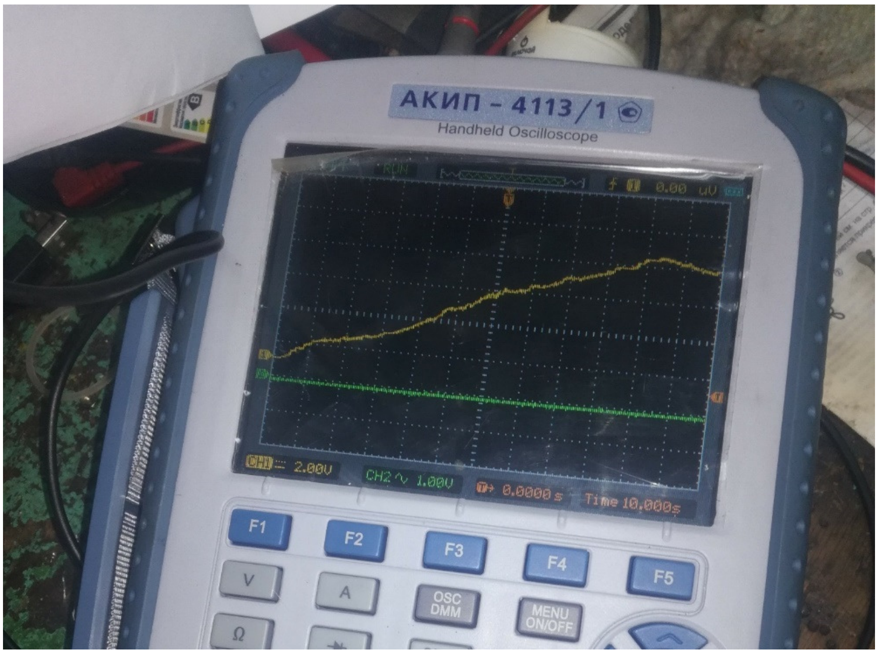


**Figure 4.3.** Changing the voltage at the output of the temperature sensor during the heating process

## 5. THE DISCUSSION OF THE RESULTS

Comparing calculated and actual results it is possible to tell that the system works according to the set requirements. After achievement of the established temperature there is shutdown of power unit and also as in computer model there is its gradual decrease. Naturally, when heated with an incandescent lamp, it is impossible to heat the surface to a temperature of 150 °C, so in the experiment was used the operating threshold of 80 °C. According to the received data it can be determined that the system monitors temperature changes on the heated surface and reacts to them. After switching off the actuator, the temperature rises for a while. This is due to the fact that the heating is not quite uniform, that is, the energy is distributed from the center to the edges gradually. But due to the fact that the documents with technical conditions contain a sufficiently large range of temperatures at which it is possible to produce spraying, then such inertia of the system is entirely permissible.

## 6. SUMMARY AND CONCLUSIONS

1. The developed system allows the operator to perform spraying operations and control the required temperature on the blades by the technical process documentation without the need to use additional devices. That is, without direct manual heating with a heating torch. Such a system reduces the time for restoration work, and also allows you to concentrate directly on the spraying process
2. The system is capable of monitoring the set parameter during operation and signaling if the temperature is out of the permissible limits. This makes it possible to minimize the probability of obtaining a poor-quality coating.
3. There is some inertness of the system, due to uneven heating. But this factor is not significant because of the rather wide range of permissible temperatures during spraying.
4. The development was approved the repair and reconstruction enterprise LLP Remplaza and will be applied to improve the quality of restoration works to repair of steam turbine parts

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