Non-contact Optoelectronic Method for Monitoring the Profile of the Shoulder of the Spring Steam Compressor of the Design Installation

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Abstract. A new method is considered for contactless determination of the profile and curvature of the blades of the desalination plant steam generator at the stage of technological preparation and the general technology of blade manufacture. The geometry of the blades is controlled by processing the probing light flux reflected from the monitored surface, received by the scanning optical nozzle and converted into an electrical information pulse. The time interval between the information and reference pulses corresponds to the angular position of the probe flow, when it has a perpendicular direction to a particular point of the controlled curvilinear surface. The angle found serves as the basis for determining the derivative in the profile function at this monitored point. Thus, to estimate the curvature, the change in the velocity characteristics of the geometric profile function of the blade is used.

1. Introduction
In modern desalination plants, steam compressors are widely used to achieve economical operation modes [1]. The steam compressor is a complex mechanical unit that includes a rotor with a blade unit in the form of an impeller. Ensuring high reliability of the blade unit, increasing its service life, reducing operating costs is largely determined by the reliability of the impeller blades due to the fact that they are statically and dynamically the most loaded nodes.

The considered blades are products with a complex spatial configuration and at the same time are distinguished by high geometric precision of manufacturing.

The need to control the profile of the blades is determined by the fact that its geometry largely determines the operability, consumption characteristics and efficiency indicators of the steam compressor. Measurement and control of geometric parameters is carried out both in the implementation of technological preparation and in the overall technology of blade processing.

2. Problem formulation
At the present time, the geometry of the blade feather is controlled by contact devices of the POMC type and expensive coordinate measuring machines (CMM). The disadvantage of contact profilometers is their low measurement accuracy (of the order of 0.05-0.2 mm). Therefore, there is an urgent need to replace obsolete PKKL contact devices. CMM does not allow 100% control of the blades, because the measurement time of one blade is up to 1 hour. And coordinate measuring machines with laser heads do not allow measuring the curvature of surfaces of high purity without...
using special matting aerosols. These reasons were the prerequisites for the development of an optoelectronic contactless method for controlling the geometry of the profile of the blade of the steam-compressor blades. For example, figure 1 shows a compressor blade of a gas turbine engine, including a complex surface.

![Figure 1. Axonometric view of the blade of the blade from the side of the back with a rotating optical nozzle](image)

3. **Analytical expressions**

As a basis for the development of the method, patents for inventions [2, 3] are taken, the essence of which is that the rotating optical nozzle, moving in the XOY plane, scans the profile of the blade in its specific section (see Figure 1). The location of the controlled sections of the blade is set along the Z axis parallel to the mounting surface of the blade lock. The set of sections along the axis of the blade forms its geometric profile. The precision of blade feathers manufacture is regulated by the industry standard OST 1.02571-86 "Blades of compressors and turbines". Limit deviations of the shape and arrangement of the pen. Changes in the geometry of the surface are expressed in the deviation of the shape of the pen from the theoretical section and the deviation of the angle of installation of the profile.

At each point, when the optical nozzle moves along the OX axis, the light flux reflected from the blade surface hits the receiving end of the optical monocot guide, channeling along which it hits the photodetector, where it is converted into an electrical signal. In this case, the maximum of the electrical signal will be formed when the optical nozzle rotates with respect to the reverse mark by an angle $\alpha$ at which the axis of the radiation pattern of the emitted light flux is perpendicular to the tangent at some point of the blade profile.

Further, in the electronic module from this signal a rectangular pulse is formed, the middle of which corresponds to the maximum of the reflected light flux. Similarly, a rectangular pulse of the reverse mark is formed, in accordance with which the entire device is synchronized. The measured time interval between the middle of the information and the back-square rectangular pulses will be proportional to the angle of rotation of the optical nozzle, which in turn is equal to the angle of inclination of the tangent to the profile at the control point. Having determined the tangent of the angle $\alpha$, one can judge the quantitative value of the derivative of the profile function of the blade, i.e. about the steepness of the surface.

To quantify the light flux that ultimately falls on the photodetector, a mathematical model for the interaction of an optoelectronic converter (OEP) with a controlled blade surface was developed.

Figure 2 shows in formalized form the scheme of interaction of the radiated flow of the OEP with the side surface $P$ (blade back) of the blade, which allows to describe and describe the process of determining the amount of information flow $\Phi_{np}$ entering the photoreceiver after reflection from the monitored surface of the blade, with a linear displacement of the rotating optical nozzle in the plane of a given section The test blade is parallel to the base surface.

Here, in the rectangular coordinate system XYZ, at the distance L from the origin along the OY axis, there is an axis of rotation of the optical nozzle, made in the form of a cylindrical monocenter-stack. A light source and a photodetector are installed from one of the ends of the staff. The opposite
end face of the stack performs the role of an element emitting a light stream in the direction of the monitored surface and receives a stream reflected from it, i.e. F-Optoelectronic transducer. The optical nozzle rotates in the plane YOZ, scanning the formed surface of the blade with a light flux in a certain specific section. When the device is in operation, the axis of the staff forms the current angle with the OY axis γ

![Figure 2. Scheme of interaction of the receiving-transmitting collector OEP with the side surface of the blade of the blade](image)

Notations adopted in the system under consideration:
- \( \Pi \) – controlled surface of the blade in the zone of determining its profile;
- \( \bar{n} \) - normal line to the blade surface at the control point;
- \( S_1 \) - the path length of the ray from the centre of the elementary radiator AUC F to the reflecting point of a specific profile of the side surface P of the blade;
- \( S_2 \) - the length of the path of the beam from the reflecting point of a particular profile of the side surface P of the blade to the centre of the elementary receiving platform FPC F; \( \Delta S_u \), \( \Delta S_{np} \) - elementary radiating and receiving areas;
- \( \Theta_u \), \( \Theta_{np} \) - the angles, respectively, of the radiation and reception of specific rays of the radiation indicatrix \( J(\Theta) \);
- \( R \) - the radius of the PPC of the optical nozzle is the head.

Based on the laws of photometry and geometric optics [4], the elementary flow \( \Delta \Phi_{\text{np}} \) illuminating \( E_i(\Theta) \) an elementary site \( \Delta S_{np} \) is defined by the expression:

\[
\Delta \Phi_{\text{np}} = E_i(\Theta) \Delta S_{np}.
\] (1)
Illumination $E_i(\Theta)$ an area inclined at an angle $\Theta_{np}$ from a single beam of intensity $J_i(\Theta)$ radiation indicatrix $J(\Theta)$:

$$E_i(\Theta) = \frac{J_i(\Theta)}{S^2} \cos \Theta_{np},$$

(2)

Where $S = S_1 + S_2$.

To determine the light flux that occurs after reflection on the transceiver, you can use the model shown in Figure 3.

![Figure 3. Model of information light flux formation](image)

The following notations are used here:
- $A$ is the center of the elementary radiating site;
- $C$ - the center of the elementary receiving area;
- $B$ is the reflection point of the radiated beam, belonging to the surface of the profile П;
- $K$ is the trace of the tangent plane to the side surface of the blade at point $B$;
- $L$ is the distance from the receiving-transmitting collector to the reflection point $B$;
- $l_1$ and $l_2$ - the projections of the rays and on the end of the PPC;
- $\beta$ - angle of incidence and reflection of rays $S_1$ and $S_2$;
- $\alpha$ and $r$ - the polar coordinates of the radiation point $A$;
- $\phi$ and $l$ - the polar coordinates of the receiving point $C$.

In accordance with Figure 3, the following expressions can be written:

$$S_1 = \frac{L}{\cos \Theta_u}; \quad \Theta_{np} = 2\beta - \Theta_u; \quad S_2 = \frac{L}{\cos \Theta_{np}} = \frac{L}{\cos (2\beta - \Theta_u)},$$

then

$$S_1 + S_2 = L \left[ \frac{1}{\cos \Theta_u} + \frac{1}{\cos (2\beta - \Theta_u)} \right].$$

(3)

When receiving a beam reflected at point $B$ $J(\Theta_u)$ to the point $C$ with allowance for the scattering indicatrix $T(\Theta_{np})$ an elementary light flux will be recorded:

$$\Delta \Phi_{np} = \Delta S_{np} T(\Theta_{np}) J(\Theta_u) S^2 \cos \Theta_{np}.$$

(4)
Taking into account that $\Delta S_{np} \approx dS_{np} = l \, dl \, d\phi$, the luminous flux received by all elementary reception areas can be written:

$$\Delta \Phi_{np} = \int_{\phi_1}^{\phi_2} d\phi \int_{l_1(\phi)}^{l_2(\phi)} T(\Theta_{np}) \frac{J(\Theta_u)}{S^2} \cos \Theta_{np} \, l \, dl .$$

Further, expressing $l \, dl$ through trigonometric functions, taking into account the notation shown in Figure 3, we can write:

$$l \, dl = L \left[ \tan \Theta_u + \tan \Theta_{np} \right] \times \left\{ \frac{dL}{d\Theta_u} \left[ \tan \Theta_u + \tan \left( 2\beta - \Theta_u \right) \right] + \frac{2}{L} \frac{d\beta}{d\Theta_u} - 1 \right\} \, d\Theta_u = \eta(\Theta_u, L) \, d\Theta_u .$$

4. Results and discussions

As a result, the total flux received by the receiver-transmitting collector of the optical nozzle taking into account all rays of the radiation indicatrix $J(\Theta)$, given in Figure 2, is determined by the expression:

$$\Delta \Phi_{np} = \int_{\phi_1}^{\phi_2} d\phi \int_{l_1(\phi)}^{l_2(\phi)} T(\Theta_{np}) \frac{J(\Theta_u)}{S^2} \cos \Theta_{np} \times \eta(\Theta_u, L) \, d\Theta_u .$$

Further summation over all elementary radiating areas of the receiving-transmitting collector will give the sought-for luminous flux, which eventually falls on the photodetector:

$$\Phi_{np} = \int_{a_1}^{a_2} da \int_{r_1(a)}^{r_2(a)} \Delta \Phi_{np} \, r \, dr .$$

If a semiconductor structure with an internal photoelectric effect is used as a photoreceiver, then according to [5], the generated photocurrent is directly proportional to the intensity of illumination. In particular, for modern photodiode structures [6]:

$$I_{\Phi} \approx 10^6 \frac{\Phi_{np}}{\pi \, r^2} .$$

The simulation allows obtaining both the shape of the electric signal of the photodetector and its quantitative characteristics, to estimate the accuracy of representation of geometric parameters of the blade surface and their reliability.

5. Conclusions

Realizing the proposed method, it is possible to obtain experimentally the values of the derivative of the profile curve of the blade with any step, after which to evaluate the difference between the "experimental" derivatives and obtained analytically or obtained from the reference surface.

The accuracy of the measurement with the proposed method will be much higher than with traditional approaches, because to estimate the curvature, the change in the velocity characteristics of the profile function of the blade of the blade is used.
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