System for blade’s output edge measuring in low pressure cylinder of closed turbine

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Abstract
System that will allow visual and measuring inspection of blades is proposed. Geometrical characteristics of the system are given. Theoretical error of system measurement is calculated. The physical model of inspection method is developed. The results of experiments with metal object are presented.

Keywords: Blades measurement, scanning system, 3D measuring, triangulation

1. Introduction
Nowadays the electrical energy is one of the most important energy sources. There are some categories of plants generating electricity: hydroelectric power plant (HPP), thermal power plant (TPP), wind power plant (WPP), geothermal power plant, solar power plant (SES) and nuclear power plant (NPPs).

The most effective is a nuclear power plant, but it requires the safety in operation. Electrical energy of this plant is generating by wheeling a big turbine connected with electro generator. This movement is provided by high-pressure steam that comes from water cisterns. These cisterns are heated by nuclear reaction energy. Steam is cooled in its way through turbine and water drops appear. They damage blades because of huge kinetic energy they have. Critically damaged blades may be dangerous having this wheeling speed. To admonish such accidents plant workers make scheduled inspection and service of turbines [1].

There are two kinds of scheduled inspection: on open turbines and closed turbines [2, 3, 4]. Methods of inspection belonging to the first group require breakdown of the turbine body. Unbuttoning is held once a few years because this process takes a lot of time. This fact is the reason for developing methods for inspection of the second group. Some systems used on closed turbines make photo registration or produce alert signals but they don’t measure blades defects [5]. Other systems measure blades defects but they can’t present visual information.

The objective of this work is development of system for blade’s output edge measuring in low pressure cylinder of closed turbine which will allow visual and measuring inspection of blades to have more information about them and reduce risk of accidents.

2. Subscribing of proposed system and geometrical calculation
The proposed system is based on triangulation method of measurement. This method implies using of elements described below:
1. A receiving unit which comprises of:
   a. Optical system (OS 1)
   b. Image analyzer (IA)
2. Source of structured light
   a. The radiation source
   b. Optical system (OS 2)
   c. Two gratings
3. The processing and control unit (PCU)
4. The monitor (UWC)
5. Power supply unit (PSU)

Under the geometrical calculation some development conditions were taken from the technical task for the system [6]. These values designate length of blade \((L = 500 \text{ mm})\), measuring step \((d = 1 \text{ mm})\), distance to the object \((D = 100 \text{ mm})\). Chosen method of obtaining spatial coordinates provides information about part of the object that observed in field of the camera view. It has been decided to use several receiving units and sources of structure light to monitor blade along its entire length. To ensure effective work of the system arrangement of all elements needs a calculation.

Camera EVS VEC–545–USB \((2562 \times 1922 \text{ px, } f' = 6 \text{ mm})\) as a receiving unit and laser source \((545 \text{ nm, } 3 \text{ mW})\) as a radiation source were chosen. First we need to measure length of object \((a')\) that will be captured by one receiving unit at distance of 100 mm. This value is calculated by focal length of lens \((f')\), size of image analyzer \((a)\) and distance to it \((D)\) in this expression

\[
a' = \frac{a \cdot D}{f'} = \frac{7.2 \cdot 100}{6} = 120 \text{ mm}
\]

Following this value number of receiving units will be

\[
n = \frac{L}{a'} = \frac{500}{120} = 4.2 \approx 5
\]

Number obtained before must be round to larger integer because system should monitoring blades for the entire of its length. Number of structured light sources must be at one greater than receivers units and equal to 6. They are located midway between receivers. Scheme of elements location to each other is presented in Fig. 1.

![Fig. 1. Scheme of system elements.](image)

The error of object’s shape measurement can be described by theoretical consideration of spatial coordinate calculation. It depends on distance to the object \((D = 100 \text{ mm})\), the base between receivers unit and sources of structured light \((50 \text{ mm})\), resolution \((2562 \times 1922)\) and physical size \((7.2 \times 5.3 \text{ mm})\) of image receiver. Surface of blade is not flat this fact entails changing distance from object to receiver unit. So the error of measurement will be different. The interval for researching was chosen from 90 to 130 mm. The dependence of measurement error from distance is shown in Fig. 2.
3. Experimental investigations

The physical model of triangulation method was realized to verify measurement of developing system. It consists of receiver 1 and the frame with source of radiation and two gratings 2. Physical model is presented in Fig. 3.

Using it we have registered the illuminated metal object. This object has shape like real blades used in power stations turbines. The program written in Matlab processes experimental picture, find lines of structure light and calculate dislocations of it. This information is used for calculation a three-dimensional model of object. Captured picture and calculated model are presented in Fig. 4.
4. Analysis of experimental data

To verify the data obtained on physical model of system we used the laser tracker for shape measurement of experimental object. The values of both measurements have been compared. The average deviations in three dimensions are presented in Table 1.

Table 1. Comparing of measurements.

<table>
<thead>
<tr>
<th>specimen No.1</th>
<th>$\sigma_x, \mu m$</th>
<th>$\sigma_y, \mu m$</th>
<th>$\sigma_z, \mu m$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>35</td>
<td>32</td>
<td>76</td>
</tr>
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These values mean that the chosen method may be used to measure blades defects with accuracy specified in technical consideration. Also experiments showed that system could cope with such interference like glare by modernization of software.

5. Conclusion

As a result, the physical model of the chosen method was developed. The software allows obtaining a spatial model of metal surfaces of objects with an accuracy of 50 $\mu m$. In the future we plan to conduct energy calculation of system and develop the experimental model for blade’s output edge measuring in low pressure cylinder of closed turbine.

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