MEASURING THE DIMENSIONS OF BODIES OF COMPLEX SHAPE USING AN OPTOACOUSTIC RANGING METHOD

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A description is given of an automatic apparatus for measuring the dimensions of objects of complex geometrical shape using an optoacoustic ranging method. The results are given of measuring the dimensions of a test object, a steam-turbine blade, and a shoemaker’s last. An accuracy of better than ±50 μm was achieved.

Means of measuring the dimensions of bodies of complex geometrical shape are at present being used more and more in various branches of the national economy. The principal branches in which such devices are employed are automobile engineering (bodywork and its components), aircraft engineering (streamlined components, cabin glazing), the shoemaking industry (lasts), orthopedics (prosthetic and orthotic devices), power engineering (turbine blades), tool production (dies), computer production (dies), restoration work (replicas), design.

The authors have developed and manufactured an apparatus designed to measure objects such as steam-turbine blades. The principal requirements imposed on the apparatus during its development were as follows: the measurements must be made automatically and without mechanical contact with the object, maximum overall dimensions of the investigated components of 1000 x 100 x 100 mm, weight below 40 kg, time to measure one component less than 5 min, measurement accuracy better than ±0.1 mm.

In creating such an apparatus the authors had to correctly choose a noncontacting method for measuring the dimensions. Only two methods were considered as having the specified measurement accuracy. These were either to use different versions of the photoelectric method [1] or to use the optoacoustic ranging method [2, 3]. It is well known that the photoelectric methods, based on analyzing light beams scattered by the surface of the object, are characterized by high accuracy (an error of ≤5 μm) with a short time required to obtain the results. However, serious disadvantages include a small working range of measurement (1-10 mm), a complex electronic processing circuit, and also an absence of Russian-made measurement heads operating in accordance with this principle.

The optoacoustic ranging method consists of recording acoustic pulses in air which arise when laser radiation interacts with a surface, and measuring the time intervals required for the sound to propagate from the object to a microphone. This method provides the specified accuracy and has a working distance range of 10-1000 mm. Since the processing electronic circuit is quite simple and the measuring part is capable of being made in practically any laboratory, the authors decided on the optoacoustic ranging method when they were developing the apparatus.

The kinematic scheme of the interchangeable component and measuring part was dictated by the measured object and was conventional (rotation and vertical motion of the object, movement of the measuring part of the apparatus in a horizontal plane). The radiation source generating the acoustic pulses took the form of a laser of 1.06 μm wavelength, pulse duration 10^{-8} sec, and pulse energy 50 mJ.

The acoustic pulses were received by a half-inch microphone (sensitivity 10 mV/Pa). The signal from the microphone was fed to an electronic processing unit which consisted of analog and digital parts (respectively a narrow-band amplifier and a device for measuring time intervals). The information from the electronic unit was fed directly into a personal computer.

The control system consisted of a ROBOX 186 controller, a personal computer, and also slave motors and tachometer-generating device. It made it possible to program the combined motions of the component and the measuring part (depending on the shape of the object) and also to energize the laser at specified moments during the rotation.
It was established during the investigations that the overall error of the control system and the mechanical part of the apparatus was less than $\pm 10 \mu m$. The resolving power of the electronic unit was $15 \mu m$. The main error components were due to both the optoaoustic ranging method and the quality of the preliminary adjustment of the apparatus (determining the base distances along the axes, securing the component, aligning the laser and the microphones).

In the testing stage measurements were made of the dimensions of the following objects: a test object (a 50 mm diameter 500 mm long steel cylinder), a 980 mm long 100 mm chord steam-turbine blade, a 210 mm long wooden shoemaker's last. The test object was secured to the center of the apparatus table, the blade and last in special attachments.

A complete estimate of the measurement error (systematic and random) could be made only in the case of the test object which was manufactured with a high (known) accuracy of $50 \pm 0.005 \text{ mm}$. The manufacturing errors of the last and the blade were unknown. Thus the authors did not have any appropriate instruments for determining the dimensions of the blade. However the blade dimensions were determined with templates in specified cross-sections, but along a limited number of extended sections (not more than six in each cross-section). It was therefore difficult to make a direct comparison between the template data and the measurements using the apparatus. In the case of these two objects it is only possible to speak of the random error component.

The estimate of the test object error was $\pm 50 \mu m$; that of the turbine blade was $\pm 70 \mu m$, and that of the last was $\pm 200 \mu m$.

The large error in measuring the dimensions of the last was above all caused by the algorithm for specifying its motion having been developed for objects such as blades (whose cross-sectional profile is determined by circles of different radii). The drawing of the last was specified differently and when it was moved it was not always found possible to ensure angles of incidence of the laser beam on the surface close to $90^\circ$. The error increased sharply for oblique beam incidence. Figure 1 shows the results of the measurements on the last.

The experimental data accumulated by the authors make it possible to reckon on reducing the error in devices of the kind to 10-20 $\mu m$. Tests are presently concluding of a portable apparatus for measuring the dimensions of large objects, such as hydroturbine blades, for which the optoaoustic ranging method is also applicable.