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ГОЛОГРАФИЧЕСКИЕ ПРИБОРЫ 3-D КОНТРОЛЯ НАД ПОВЕРХНОСТЬЮ СЛОЖНОЙ ФОРМЫ

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HOLOGRAPHIC DEVICES FOR 3-D CONTROL OVER A COMPLEX SURFACE SHAPE

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Аннотация. Дан анализ недостатков приборов неразрушающего контроля над геометрическими характеристиками детали сложной формы. Показано, что конструктивные особенности прибора контроля соответствуют геометрической модели, которая будет применяться для расчета процесса формообразования. Дано описание установки голографического контроля. Установка голографического контроля применяется для определения геометрических характеристик поверхности сложной формы. На основе этих характеристик происходит построение трехмерной геометрической модели поверхности и ее микрорельефа. Трехмерная геометрическая модель поверхности сложной формы содержит информацию о кривизне в локальной области выбранной точки. Трехмерная геометрическая модель поверхности структурируется на основе модульно-геометрического подхода. Дано краткое понятие о модульно-геометрическом подходе, который применяется для описания геометрии поверхности и ее микрорельефа.

Abstract. The analysis of the shortcomings of non-destructive testing devices over the geometric characteristics of a part of a complex shape is given. It is shown that the design features of the control device correspond to the geometric model that will be used to calculate the shaping process. The description of the holographic control installation is given. The installation of holographic control is used to determine the geometric characteristics of a complex surface shape. Based on these characteristics, a three-dimensional geometric model is constructed surface and its micro-relief. A three-dimensional geometric model of a complex surface contains information about the curvature in the local area of the selected point. The three-dimensional geometric model of the surface is structured on the basis of a modular geometric approach. A brief concept of the modular-geometric approach that is used to describe the surface geometry and its micro-relief is given.

Ключевые слова: Установка голографического контроля, микрорельеф, поверхность сложной формы, геометрическая трехмерная модель.

Keywords: Installation of holographic control, micro-relief, surface of complex shape, geometric three-dimensional model.

1.Introduction

Non-destructive testing devices for geometric characteristics of the part surface and its microrelief used in industrial production do not allow determining the numerical values of parameters for constructing the topography of the microrelief. Therefore, among the parts that have the same roughness, the topography of the surface microrelief may be different within a wide range. During operation, this leads to a decrease in service life, rapid wear, changes in functional characteristics, and a decrease in the efficiency of components and assemblies [1] where this part is included as a component element.

The nondestructive testing devices used have a number of significant drawbacks:

- probe probes examine the object-part itself and its surface while interacting with it. This leads to large errors in metrological measurements.

- optical devices that implement methods: interferometry, holographic immersion, etc. provide information on the basis of which you can build a not sufficiently complete three-dimensional geometric model of the part [2]. In particular, this applies to parts that have Aerohydrodynamic surfaces.

- scanning devices allow you to get an idea of the microrelief in the local area without taking into account the curvature of its depressions and peaks.

- devices that control defects in the shape of a part are usually highly specialized. Some of them examine the external geometry, others internal, and others determine internal defects. Also, the devices differ in the ability to control the details of the round handicap, having flat faces, having frame discrete-defined surfaces. There is no universal device that would allow metrological measurements regardless of the size and shape of the part.

The structural defects of devices of nondestructive control is to limit their functionality. As a rule, the design of control devices allows you to measure numerically one-dimensional estimated parameter-the height of the micrometer in the study of surface roughness and fix the surface profile in a flat section.

The consequence of this is that: The calculation of the forming surface of the tool does not calculate the topography of its microrelief. This is due to the lack of sufficient information about the geometric structure of the microrelief as a three-dimensional image, due to the use of a one-dimensional estimation parameter. The use of a one-dimensional estimation parameter-the height of the micro-area-for geometric modeling of the shape of the microrelief gives an idea of the microrelief as a surface with numerical marks. The description of a surface with numeric marks does not define the curvature in the local neighborhood of this point.

Also, the uncertainty of the surface geometry between sections makes it impossible to build a complete geometric image of the surface. Thus, the problem is that no modern nondestructive testing device [3], due to its design features, can make metrological measurements necessary to build a three-dimensional geometric model of the surface of the part, which is a superposition of the geometric image of the surface and the topography of its microrelief.

This problem is relevant in the manufacture of parts for operational properties, which, in the tribo-conjugations of contacting surfaces, have high requirements. This also applies to blade machines that operate in aggressive gas and liquid environments. It is known that wear resistance, fatigue strength, and other performance properties in tribo-stresses, as well as cavitation wear, are determined by the geometry of the surface and the topography of its microrelief.

The solution is to develop a new generation of non-destructive testing devices.

These devices will make it possible to make metrological measurements necessary for applying the modular-geometric approach in structuring a three-dimensional geometric model of the surface.

2. Modular-geometric approach to modeling a complex surface shape

Extensive theoretical and experimental material accumulated in the field of creating new types of abrasive tools has caused a new wave of development of abrasive processing in production [4]. This allowed us to get broader generalizations.

Shaping is the goal of the abrasive and blade processing process.

The main objectives of the shaping theory are to design the tool and determine the kinematics of the "part-tool" system based on the specified geometry of the surface of the processed part. The inverse problem of the theory is to calculate the forming surface of the part based on the known geometry of the tool and the kinematics of the "part–tool" system.

The success of solving these complex problems and the development of this area of research depend on the applied mathematical methods [5].

Classification of complex-shaped surfaces cannot be constructed. There are no common features in the surface structure. The surface of a complex shape is structured on the basis of the modular principle. The structuring approach is determined by the problems of the theory of shaping. The modular-geometric approach used to solve these problems is to approximate the local area of the surface with a contiguous paraboloid. The Riemann-Christoffel tensor is a geometric characteristic for estimating the curvature of a local section. The analytical definition of a contiguous paraboloid as a second-order geometric image of contact with a given local area of the surface is determined from the Taylor series expansion. The Taylor series defines the geometric images of a higher order of contact: coboloid, quadronoid etc.

In technical applications, you should limit yourself to approximating the local area with a contiguous paraboloid. Since the curvature of the surface at the point of contact is equal to the curvature of the touching paraboloid.

Discretely defined surface of the workpiece, in General, can be approximated by a set of modules that have a smooth "cross-linking". Each module is a contiguous paraboloid of a certain type.

It is established that the modular principle used to describe the geometry of frame discrete-defined surfaces can be taken as the basis for structuring the surface microrelief.

When constructing a model that describes the micro-relief of a surface, the modular principle of structuring a complex-shaped surface is used to solve the problems of smooth "cross-linking" of individual modules. A system of criteria for quantifying the topography of the microrelief is defined: k1, k2 – the main curvature of the surface, Rz-the height of the micro-irregularity. Experimentally confirmed the theoretically justified hypothesis about the information completeness of the system of criteria for topography of the microrelief.

The geometric model of a microrelief is a set of modules that have a smooth "cross-linking" - contiguous paraboloids. Three-dimensional geometric models of the microrelief of surfaces considered in the theory of shaping have been developed: flat, round cylindrical, discrete-defined frame and irregular-shaped bodies.

Developed a simulation model of microrelief flat surface depending on the processing modes [6], for example, flat grinding, which takes into account the changing topography of the surface microrelief of the workpiece depending on the angular speed of rotation of the circle, the speed of part motion, from the time of processing and the depth of grinding.

The proposed geometric model of abrasive processing (the case of flat grinding) takes into account the actual location and geometric shape of the abrasive grains on the surface of the circle, the depth and width of the groove from the grains, the overlap of the grooves during grinding, as well as the real topography of the microrelief of the surface planes of the part.

3. Devices for monitoring the characteristics of the geometry and topography of the surface microrelief

3.1. Probe control devices

In probe control devices (profilographs, profilometers), a needle is used as a probe that is driven in translational motion in the plane selected for determining the microrelief profile. The needle axis is oriented normal to the surface [8]. The mechanical vibrations of the needle are converted into electrical vibrations. The profilogram is displayed as a curve.

Disadvantages of probe control devices:

1. The probe-diamond needle interacts with the studied surface, i.e. it deforms its microrelief. This is usually true for parts made of plastic materials. When the needle interacts with the micro-relief of the surface, the surface of the needle itself changes, which leads to an increase in electronic noise.

2. The needle usually has a radius of 2 microns. The final size of the needle allows you to accurately determine the profile of the microrelief for sufficiently far-spaced micro-surfaces or slightly wavy surfaces.

3. The resolution of the probe devices depends on the radius of the needle rounding and the nature of the surface topography, i.e. on the geometric characteristics of the sensor examining the surface microrelief and the geometric characteristics of the object under study-the microrelief.

4. Low accuracy of measurements along the micro furrows of the surface layer of the part.

5. A large time interval to remove the maps necessary for structuring the topography of the microrelief in the framework of a modular geometric approach.

3.2. Optical control devices

In interferometers (Twyman-green, Fizo, Nomarsky, etc.), the quality of surface treatment is analyzed on the basis of the obtained interference pattern [9].

Disadvantages of optical control devices:

1. The multibeam interferometer of bands of equal chromatic order gives a relief picture averaged over sites with a linear size of about 2 microns.

2. The optical heterodyne Profiler has an insufficient horizontal resolution of about 2 microns.

3. A two-beam polarizing interferometer that implements the differential interference contrast method does not allow quantitative measurements without digital signal processing.

4. The geometric characteristics of the surface recorded by the interferometer depend significantly on the optical properties of the object: its absorption coefficient, reflection, etc.

5. None of the currently used interferometers provides complete information on the geometric characteristics of the surface, which is necessary for structuring the topography of its microrelief.

3.3. Electronic and probing microscopes

The principle of operation of a transmission or raster electron microscope is similar to that of an optical microscope. The difference is that instead of a stream of electromagnetic waves in the visible frequency range falling on the object under study, an electron microscope uses a stream of electrons [10]. The design of an electron microscope for controlling the electron beam includes magnetic lenses, and for receiving the electron beam - a cathode-a tungsten filament or a pointed crystal of lanthanum hexaboride.

Disadvantages of the electron microscope:

1. An electronic microscope is a device for monitoring the micro-relief of local areas. Despite the high resolution, the electron microscope is not suitable for evaluating the microrelief of a complex shape surface in the range of 1 – 0.001 microns for the entire internal and external geometry of the part.

2. The maximum frame size does not exceed 100x100mkm, which is not enough to make a part.

3. The electron microscope does not provide information on the geometric characteristics of the surface necessary for structuring the topography of its microrelief.

In scanning probe microscopes, the micro-relief of the surface and its local properties are studied using special probes. The working part of such probes is about 10 nm in size. The distance between the probe and the sample surface in order of magnitude is 0.1-10 nm. Probe microscopes are based on various types of interaction between the probe and the surface. Thus, the operation of a tunnel microscope is based on the phenomenon of a tunnel current flowing between a metal needle and a conductive sample. Various types of force interaction are the basis for the operation of atomic force, magnetic force, and electro-force microscopes.

The disadvantages of scanning probe microscopes are the same as those of an electron microscope. To this list, it should be added that the recorded characteristics depend on the electromagnetic properties of the test sample [11].

3.4. Installation of 3D holographic control

Installation of 3D holographic size control of complex mechanical engineering parts (hereinafter referred to as UGC) provides:

- state-of-the-art control of dimensions of machine-building parts of complex shapes and profiles;

- displaying the actual configuration of the part (visualization); - preparing data for archiving measurement results;

- possibility of layer-by-layer "penetration" into the material of the part (Assembly) with control of the size of hidden elements, cavities (subdetals and subassemblies). UGC solves the following tasks for enterprises:

- creating a methodological, scientific, technical and technological base for high-precision automated size control of complex machine parts;

- creation tool for high-precision automated control of the dimensions of geometrically

- complex parts of mechanical engineering.

- providing conditions for mass production of high-precision mechanical engineering products with import substitution of components;

- ensuring technological and technical priority;

- development of innovative industrial technologies for creating promising types of weapons, military and special equipment;

- creating a pilot prototype, ready to scale in the enterprises of mechanical engineering.

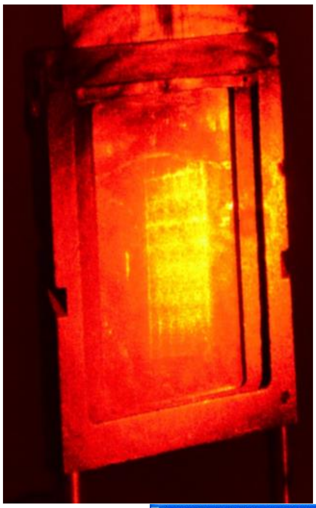
UGC is a complex of systems that include laser, optical, Electromechanical and microprocessor subsystems. The operation of these systems under the control of the controller allows for high-precision holographic 3D control of complex profile parts up to 2000 mm×500 mm×1000 mm with an error of no more than 800 nanometers when working in the visible range (Fig.1) and an error of no more than 50 nanometers when working in the x-ray range.

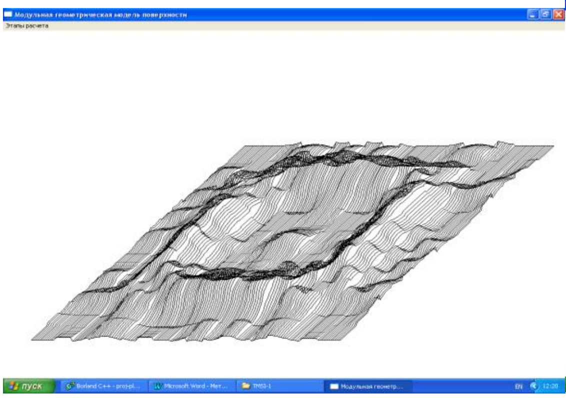
UGC implements technological processes that have a scientific and technological novelty, allowing to find a market application and ensure the creation or manufacture of products with a new quality and a high level of efficiency.

The development of the UGC is based on theoretical and experimentally based methods of modular-geometric modeling of the formation of the surface microrelief [12], allowing them to develop and manufacture devices for non-destructive testing of the surface microrelief of parts with errors specified in the nano-range. Such devices are an optical Profiler for passive control and an x-ray Profiler for active control.

The first device allows you to create maps with a holographic image of an object in the optical frequency range of electromagnetic waves for structuring a modular geometric model (MGM) of an object [13], such as the pen of a gas turbine blade and the topography of its microrelief, before and after processing. The three-dimensional model of the blade pen is a smooth cross-linking of contiguous paraboloids of various types. A model of the topography of the blade's microrelief (Fig.2) is also constructed based on the modular-geometric approach. The blade pen model and the topography model of its microrelief represent a superposition: a microrelief model is located on the top of the pen.

The second device-allows you to control the characteristics, for example, the geometry of the blade pen and the topography of its microrelief during processing [14]. This device can be included in a feedback control system that allows you to change the parameters of the tool installation to obtain the desired characteristics.





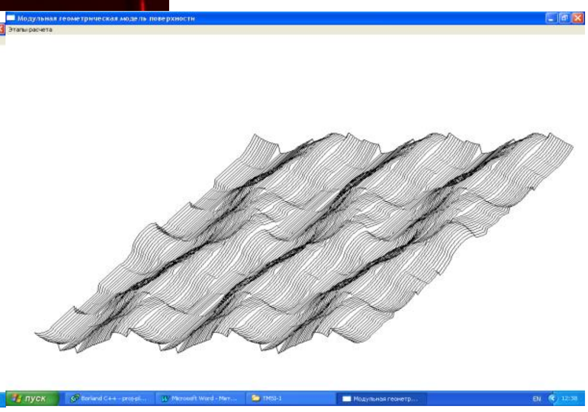


Fig.1- Holographic image micro-relief's. Fig.2- 3D model of the micro-relief.

4. Conclusion

Devices of the developed series belong to the devices of the new generation. Their device implements one of the ways to expand the functionality of monitoring devices and use the information obtained with their help to build three-dimensional models-the study of a holographic image, rather than the physical object itself. Develop non-destructive testing devices have the best performance compared to the prototypes. They allow us to evaluate the geometry and micro-relief of the surface on the basis of three-dimensional geometric models with errors specified in the specified nanointervals.

The passive control Profiler in the optical frequency range of electromagnetic waves allows you to take maps from a holographic image of an object to structure the modular geometric model of the blade pen and the topography of its microrelief, before and after processing. The three-dimensional model of the blade pen is a smooth cross-linking of contiguous paraboloids of various types. The topography model of the blade's microrelief is also based on a modular geometric approach. The blade pen model and the topography model of its microrelief represent a superposition: a microrelief model is located on the surface of the pen.

X-ray active control allows you to control the characteristics of the blade pen geometry and topography of the microrelief during processing. This device can be included in a feedback control system that allows you to change the parameters of the tool installation to obtain the desired characteristics.

High-precision control of complex profile parts is required in the implementation of industrial production of modern mechanical engineering products: precision mechanics, dies, spindles, ballscrews, lunettes, carbide tools in machine tools; animating parts, cumulative craters of warheads, gyroscopes, rudders, etc. in the production of projectiles and missiles; turbine blades in pumps, turbopump units, and other similar elements.

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