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New Technologies of Surface Treatment of Complex Shape and Control over its Geometry and Topography of the Microrelief

Evgeny Alexandrovich Belkin*, Vyacheslav Nikolaevich Poyarkov, Oleg Ivanovich Markov

Department of experimental and theoretical physics, faculty of physics and mathematics, Orel state University. I. S. Turgenev, Orel, Russia.

Corresponding author:* ***Evgeny Alexandrovich Belkin*

Abstract: *The need to take into account the three-dimensional characteristics of the surface layer microrelief is particularly relevant in the manufacture of parts with specified performance properties. It is known, for example, that wear resistance, fatigue strength, etc.performance properties are largely determined by the shape of the surface microrelief. The part processing process is a single closed structure. One of the results of this process is the formed topography of the microrelief of the surface layer of the functional surface of the part. At the moment, the topography of the microrelief of the part is evaluated, as a rule, after its processing, and not in the process of formation of the microrelief. Methods of engineering geometry, allowing to link the curvature of the surface with its surface of contact, developed (modular geometric approach in the simulation of Aerohydrodynamic surfaces), but are not used in the absence of the instrument base. Therefore, with the geometric representation of the surface layer microrelief it is not possible to restore its structure with a sufficient degree of accuracy necessary to predict its topography and to control its geometric parameters during the part processing. Thus, the development of technology and devices for non-destructive 3D-control over the formation of the surface layer, the structure and geometry of parts, as well as to assess the topography of the surface layer microrelief, is relevant, which ultimately will not only assess the quality and control, but also to obtain parts with predetermined properties and type of structure. The given topography of the microrelief can be obtained by an abrasive tool with the given geometric characteristics of the microrelief of the forming surface and the dynamic characteristics of the bundle. A method that allows a high degree of accuracy to reproduce the geometry of the surface of the part and its microrelief for a given geometric characteristics is grinding tool on a flexible bond in a magnetic field. A prototype of the installation of holographic control over the geometry and topography of the microrelief and the internal structure of the Aerohydrodynamic a surface of parts made of hard-to-process materials was created. The holographic control unit includes an optical profilograph for passive control, operating in the visible range of electromagnetic waves (red light) and an x-ray profilograph for active control over the formation of external geometry, the internal structure of the Aerohydrodynamic surface and the topography of its microrelief.*

Keywords: *optical profilograph, an x-ray profilograph, microrelief, topography.*

1. INTRODUCTION

In modern geometric models of the blade of a gas turbine aircraft engine of a military aircraft, there is no information about the change in its curvature and the topography of its microrelief. In the working drawing, the blade is presented in the form of oriented sections. Between cross sections, the geometry is not defined. Therefore, the control devices for the formation of the external geometry of the blade and its microrelief are designed in accordance with these models, so that they can only carry out passive control in the selected plane. The microrelief is estimated by the height of the microrelief. There is no topography of the microrelief in the working drawing. The production of blades does not take into account the compliance of the microrelief of the surface with the type of its wear and the correspondence of the curvature of the working part of the blade to the flow regimes of its gas medium having a high temperature and high pressure [1]. Gas turbine blades in the conditions of modern production can be made with an accuracy of 0.1 - 0.01 microns.

The modular-geometric approach allows us to obtain a superposition of the external geometry of the blade and its topography of the microrelief [2] with an analytical description and preservation of the natural curvature of the surface, i.e. to obtain its sufficiently complete 3-D model. The external geometry of the blade is represented as a smooth "cross-linking" the slant helices with a certain angle of twist. The topography of the microrelief is represented as a smooth "cross-linking" of contiguous paraboloids. In a 3-D model of the blades on a cross-link oblique helices located "crosslinking" osculating paraboloid.

The installation of holographic 3-D control, which allows building a 3-D model of the gas turbine blade on the basis of a modular geometric approach. Installation of holographic 3-D control is a complex of systems including laser, optical, Electromechanical and microprocessor subsystems. The combined operation of these systems under the control of the controller allows for high-precision passive (before and after processing) and active (during processing at various stages) 3D holographic control of complex parts up to 2000 mm×500 mm×1000 mm. With an error of not more than 245 nm (blue-green light) when operating in the visible range (holographic profilograph). And an error of not more than 0.5 nm when operating in the x-ray range for ~ (soft x-ray) [3] and an error of not more than 0.0005 nm for ~0.001 nm (x-ray).

For precision production of gas turbine blades on its 3-D model, structured, based on the modular geometric approach developed machine-cyclotron. The machine is a resonant accelerator-cyclotron. In it, the charged abrasive particles are dispersed in an electric field, then falling into the magnetic field that controls them, moving along trajectories corresponding to the 3-D model of the blade. Precision machining of the pen blade 0, 001мкм. 3-D production of gas turbine blades on the cyclotron machine sharply reduces cavitation wear of their working part, as the principle of compliance with the topography of the microrelief with the type of wear is realized. Also significantly increases the life of the blade units of the engine and increases its efficiency, power and thrust. Accordingly, the speed of a military aircraft is increased several times.

2. OPTICAL PROFILER

2.1. Analysis of control devices

Modern control devices are designed in such a way that the recording devices record the values of the parameters from the contour maps of the object. Contour maps are determined or with large errors, or for a sufficiently large period of time. It is not possible to control a hard – to-reach object-abrasive grain moving in the material [4]. There is one way to expand the capabilities of control devices and use the information obtained with their help, to build three-dimensional models, the use of devices exploring the holographic image of the object.

The principle of control of the devices under consideration is based on the latest studies of the processes of obtaining a holographic image of the object in the optical and x-ray ranges. Devices of this series allow studying the processing processes not in the projection [5] on the plane, and in space.

Known profiling. Based on contact measurement of the parameters of the surface microrelief. The sensing element of these devices is a mechanical probe (diamond needle), sliding on the surface, which through a lever mechanism transmits information about the microrelief to the converting element [6] (inductive, piezoelectric, electrodynamic), where electrical signals are generated, corresponding to the vertical movements of the probe [7].

The disadvantages of such profilographs are the limited ability to register information in the form of a profilogram, removed only perpendicular to the grooves of the surface treatment of the part, increased design [8] and technological requirements for the diamond needle and lever mechanism (strength, alignment of the interfaces of parts), which increases the cost of production of such devices. In addition, at the stages of transmission of information from the sensitive through the converting element in the measuring circuit there are various kinds of distortion.

The proposed device (optical profilograph) is designed to solve a specific control and measurement problem, which is to ensure the increase, accuracy and measurement capabilities of the restored holographic image of the microrelief of the controlled object.

Fig-1: *Holographic image of the microrelief.*

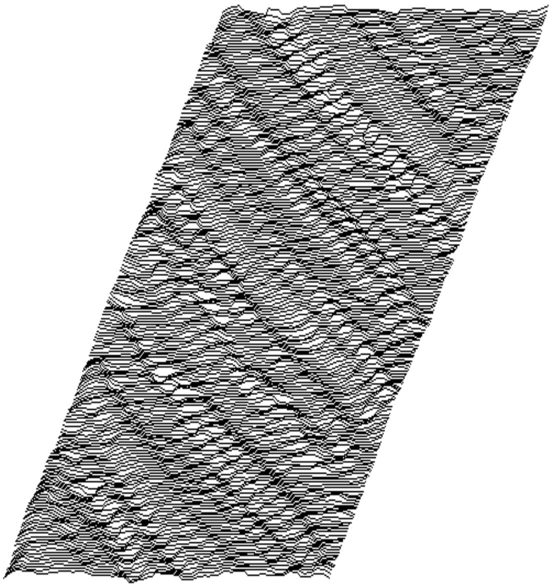

Fig-2: *3D model of the microrelief.*

2.2. The device and principle of operation of optical profilometer

A prototype holographic profilograph for passive control, which operates in the visible range of electromagnetic waves (red light). The prototype includes a table mounted on gas dampers. The table has a system of suppression of mechanical vibrations of low, medium and high frequency. Optical systems for recording and playback of holographic images are installed arbitrarily, i.e. not on a linear guide, as is customary. Mandrels for optical elements: mirrors, micro lenses, dividers of light streams, pin-halls (spatial filters), etc. have magnetic pillows because the surface of the table is made of a material with high ferromagnetic properties. The mandrels for optical elements are mounted on a ball bearing, which allows them to be oriented at a certain angle in an arbitrarily selected plane, i.e. the mandrels have six degrees of freedom [9]. This allows you to quickly and accurately configure the equipment for recording holographic images without a complex expensive electronic control system. Such a number of degrees of freedom is technically difficult to obtain in the manufacture of classical platforms for the positioning of optical elements.

Installation of an optical profilograph, provides for the restoration of the pre-screen image of the object (Fig-1) (the image "hanging in the air"), for the subsequent production of contour maps of the microrelief, the investigated surface.

The subsystem that removes maps from the holographic image of the surface layer is a mechanical arm, the position of which is fixed in space. On the arm is fixed piezo-nano-positioner. The positioner is equipped with a camera-free video camera with an interface.

Maps are transferred to a personal computer for geometric modeling of the surface layer (Fig-2).

3. METHOD OF GRINDING THE GAS TURBINE BLADE TOOL ON A FLEXIBLE BOND IN A MAGNETIC FIELD

3.1. Substantiation of technologies of formation of the microrelief

Three-dimensional geometric models of the microrelief of the forming surface of the tool and the machined surface of the part, developed on the basis of the proposed new criteria for evaluating the geometry of the microrelief, create prerequisites for the principle of compliance of the microrelief of the surface of the part, the type of wear. It follows the formulation of the problem of formation of the microrelief according to the given geometric characteristics [10]. The given topography of the microrelief can be obtained by a cutting tool, comparable in size to the micro cavities and micro vertices. The trajectory of the tool should be strictly defined and controlled during the processing of the surface layer. The tool must have several cutting edges. If this tool is an abrasive tool, it must be made with the specified geometric characteristics of the microrelief of the forming surface and the given dynamic characteristics of the bundle.

Extensive theoretical and experimental material accumulated in the field of creating new types of abrasive and superhard materials, special ligaments, circles with a discontinuous surface, and prefabricated, impregnated, reinforced, circles with predetermined properties.

This circumstance has caused a new wave in the development and use of abrasive processing in production, as well as allowed to obtain broader generalizations.

It follows from this that the more perfect the mathematical model in terms of generalization of the studied processes of forming, the wider the area of analytically complex representable surfaces.

3.2. Methods of forecasting new methods of processing, allowing to form a microrelief on the given geometric characteristics

The method of forecasting new methods of processing is based on the theoretical study of the three-dimensional geometric model of the treated surface and is that on the basis of the classification of the treated surface is established binary correspondence forming surface. According to this correspondence, the prediction of new ways of forming is carried out. The processed surface is represented as a superposition of a three-dimensional geometric model with a smooth "crosslinking"of modules, which gives an idea of the geometry as a whole and a model with a non-smooth "crosslinking" of modules, which contains information about the microrelief of the forming surface.

The types of processing methods are defined. The first type-methods that allow theoretically accurately reproduce the geometry of the processed surface. They are based on the change in the nature of the contact of the tool and the workpiece [11]. The method of grinding the pen blade of a gas turbine is difficult profile tools, refers to the first type. The second type-methods that allow reproducing the microrelief of the treated surface in accordance with the specified geometric characteristics. They are based on a change in the scheme of removal allowance. A method of grinding with CBN tool on the bundle of metal wires relates to the second type. The third type-methods that allow reproducing theoretically accurately the geometry of the treated surface and its microrelief in accordance with the specified geometric characteristics. They are based on the change in the microgeometry of the tool during the processing of the part. The method of grinding the pen blade of a gas turbine on a flexible bundle in a magnetic field belongs to the third type.

3.3. Method of grinding the gas turbine blade pen tool on a flexible bond in a magnetic field

A method for grinding the pen of a gas turbine blade with complex profile tools is known. In this method, the tool and the parts report the relative motion of the envelope from the condition of providing a linear contact of the original tool and the machined surface. Before processing, the working part (inlet, outlet edge, back, trough) of the gas turbine blades is described analytically on the basis of a modular geometric approach. The resulting analytical task of the blade pen is used to profile the abrasive tool designed for each module. Each of the abrasive tools working on a method rolling. Processing of the blade with profiled tools for its 3D model is made on a multi-axis CNC machine.

In the process of processing the aerodynamic surfaces of the blade on the multi-axis CNC machining center, in one pass, the formation of the surface module of the blade profile pen, for example, trough, and then another tool is processed back of the blade, etc., which along with a significant increase in productivity and geometric accuracy of processing reduces the complexity of finishing operations.

Reducing the heat stress of the grinding process is achieved by creating a quasi-discontinuity effect, which reduces the possibility of cracks, burns and other thermal processing defects.

However, the use of abrasive treatment with complex tools, due to the chaotically given microgeometry of the abrasive tool does not allow to control the process of formation of physical, mechanical and geometric parameters of the surface layer of the blade pen. This significantly reduces the performance of the part: wear resistance, fatigue strength, etc.

As a prototype, a method of abrasive treatment of the outer surface of a cylindrical part in a magnetic grinding device was chosen. In this method, the workpiece is installed in the space formed by the magnetic poles with the possibility of rotation, and the rotating magnetic field obtained from the installation of a common for the cores and poles of the annular yoke in the gap between the surface of the part and the end surfaces of the poles, holds the magnetic abrasive particles in the gap. At the same time, the windings wound on iron cores are installed symmetrically relative to the center, and the profile of the ends of the magnetic poles protruding to the center is less than the cross-sectional area of the iron core.

The disadvantages of the known method of processing are that in a magnetic grinding device, the magnetic field is a bundle that holds the abrasive particles on a constant shape of the forming surface. This limits the process of forming the geometry of the part, only the details of the cylindrical shape and the fact that due to the random location of the abrasive grains on the forming surface there is an uncontrolled process of forming the surface layer microgeometry.

The tasks for which the invention is directed are to combine into one production cycle in one technological system the main operations of abrasive processing of the pen of the gas turbine blade, starting with a rough operation and ending with a superfinish one. Also in the expansion of the range of types of processed blades, improving the accuracy of the blade pen shaping and controlling this process according to the specified characteristics. Given characteristics: depth of grinding, temperature field, Gaussian curvature of the surface, etc.

The tasks are solved by the proposed method of grinding. In this method, at the resonance accelerator – cyclotron (Fig-3), the charged abrasive particles controlled by a magnetic field, regarding misleading details, the movement on the General gombitova trajectory. This followed the terms of the security camphor changes in the General gomontovo the shaping surface in accordance with the type of the blade, changing the view of the helical path of abrasive particles in accordance with a predetermined shaping surface, and the possibility of replacing a fraction of the abrasive grains.

Thus before processing, the working (input and output edges, the back, the trough) of blades of a gas turbine describe analytically based on a modular geometric model of the surface complex shape, the analytical task of the pen blades, is used to calculate the total gombitova trajectory of the abrasive particles.

The method is as follows. Analytical task of the modular geometric model of the working part of the gas turbine blade is a set of equations of the form:

$$x_i \sin k_i z_i + y_i \cos k_i z_i = (l_i z_i + p_i)(x_i \cos k_i z_i - y_i \sin k_i z_i)^2$$

$$0 \le z_i \le h, k_i = \frac{\alpha_{im}}{h_i}, l_i = \frac{p_{im} - p_i}{h_i}$$

Where $i = \overline{1, n}$ - is the number of the module oblique helicoid, you can easily feather the blades,

α_{im} - the maximum rotation angle of the $x_i y_i$ coordinate system relative to the origin.

p_{im}– the parameter of the parabola $y_{im} = p_{im} + x_{im}^2$,

p_i - the parameter of the parabola $y_i = p_i + x_i^2$,

h_i – the height of the oblique helicoid with the number i.

Moreover, the number of analytical equations is equal to the number of oblique helicoids that make up this model. The modular geometric model of the working part of the gas turbine blade is a smooth "cross-linking" of oblique helicoids ().

The charge q of the abrasive particle must be such that the Lorentz force acting on it from the magnetic field at this point is significantly greater than the Coulomb interaction force with closely spaced charged abrasive particles, i.e. the condition must be fulfilled:

$$F_K << F_\wedge,$$

$$F_K = \frac{1}{4\pi\varepsilon_0}\left(\frac{q}{r}\right)^2$$

Where is the power of the pendant,

ε_0 - Electrical constant, r - distance between abrasive particles

$F_\wedge = qB_{ik}v_\perp$ - Lorentz's power, that is.

I. e. . $\frac{q}{r} << 2v_\perp\sqrt{\frac{\pi\varepsilon_0 m}{\rho_{ik}}}$

In order to avoid the loss of charge by the abrasive particle in the process of processing the metal surface of the blade pen, the pen surface is reported to charge q_0 the same sign with the charge of the particle, and the value is equal to:

$$q_0 = \frac{S}{\overline{S}_ч},$$

Where S is the surface area of the blade pen, $\overline{S}_ч$ - the average value of the square.

An example of the implementation of the method is the abrasive treatment of the pen of the blade of a gas turbine on a resonant cyclotron.

Blank 1 (Fig..) set in the space between the duants 2 so that the axis of symmetry of the workpiece 1 is at an angle β to the vector of the initial velocity of the charged abrasive particle. An alternating accelerating electric field is created in the space between the duants 2 in the AM section. The abrasive particle is accelerated each time it, having described under the action of a magnetic field a semicircle in the duant, enters the space on the site of AM. After the" scratching " of the blade pen, the speed of the abrasive particle decreases, and it begins to move in the duant 2 on the semicircle of a small radius, accelerating at the site of AM and moving to the semicircle of a larger radius, at the end of the acceleration process again falling on the calculated homovint trajectory lying on the surface of the blade pen. For continuous particle acceleration it is necessary to fulfill the condition of synchronism:

$$T_0=T,$$

Where T_0 –the period of oscillation of the electric field, T - the period of circulation of the particle. Charged abrasive particles from device 3, in which they are informed of the statistical charge, are released in order to reduce the resistance force in the process of micro chip control on the trajectory having a shift along the symmetry axis of the pen blades, through a period of time

Δt.

The device 3 is located in the field of action of an alternating accelerating electric field. Removal of the micro-chip is carried out by an air flow blowing the workpiece 1 from the device 4. Management is charged with abrasive particles in the process of macro and micro formation of the pen blades is carried out using the block 5, give the points gombitova trajectory calculated value of magnetic induction of B_{ik} (Fig.3.7, 3.8). Block 5 consists of micro solenoids, each of which creates a magnetic field at the points of its axis sufficiently remote from the ends of the solenoid:

$$B_{ik} = \mu_0 n I_{ik},$$

Where I_{ik} – where is the current in the solenoid screws,

n – the number of turns per unit length of the solenoid,

μ_0 - magnetic constant,

provided $L >> R$,

where L – the length of the solenoid,

R – the radius of turns of the solenoid.

Changing the amount of current in each solenoid and angle β in accordance with a predetermined program, by the block 6 can be implemented, abrasives type "flexible bundle", allowing to comfortably change gamewindow forming the surface, type gomontovo the trajectory of the abrasive particles along a predetermined gombitova surface, shape gombitova shaping surface, i.e., to make removal of the stock layer by layer to form the macro and micro geometry of the pen blades with high precision, greatly reducing the heat release rate of the forming process, processing blades of various types from a given range. The catcher of 7 abrasive grains allows replacing their fraction, thereby to provide all cycle of forming operations, from rough to superfinish.

3.4. Method of calculation total gombitova path of abrasive particles

Specify the z-axis step Δz, the XYZ coordinate system associated with an oblique helix approximating the input edge of the blade pen. Determine through this step the parametric setting of the curve of the pen profile in each of the sections of the pen parallel planes. The sections are oriented to the z axis at an angle φ, where the angle φ - is the angle between the z axis and the normal KN to the first of the parallel planes: $x_i = x_i \cdot (\eta)$, $y_i = y_i(\eta)$, where, $\forall \eta \in [a,b]$. $a,b \in R$, R - the field of real numbers, $i = \overline{1,n}$, i-the number of the plane, η – the curve parameter of the blade profile in the plane section, $x_i y_i$ – the coordinate system in the plane with the number i.

In each section, through a step Δs_i along the length s of the profile curve, the radius of

Curvature ρ_{ik}, is calculated, where k - is the number of the segment in the plane i, at the midpoint of the segment Δs_i, and the step Δs_i is chosen so that the arc of the segment does not change the curvature sign.

According to the known component of the speed $v_\perp$ -abrasive particles determine the magnitude of the magnetic induction B_{ik} (Fig-4) at the point at which the radius of curvature is equal to the computational value ρ_{ik}:

$$B_{ik} = \frac{mv_\perp}{\rho_{ik} q},$$

Where m- is the mass of the abrasive particle, q-is the charge of the abrasive particle,

$$v_\perp = v \sin\alpha,$$

α - угол между векторами $\vec{v}$ и $\vec{B}_{ik}$, v - скорость абразивной частицы в данной точке.

Step gomontovo the trajectory of the abrasive particles:

$$h = v_{\parallel} t - \frac{\bar{a} t^2}{2},$$

Where $v_{\parallel} = v\cos\alpha$, t – the movement of the particles, $\bar{a}$ - the average acceleration of the abrasive particle, which is determined by the formula:

$$\bar{a} = \frac{v_0 - v_t}{t},$$

v_0, v_t - respectively the initial and final velocity of the particle gombitova trajectory (Fig-5).

The tasks that are thus solved by the proposed method consist in combining in one production cycle the main operations of abrasive processing of the pen of the gas turbine blade, from rough to superfinish in one technological system, expanding the range of types of processed blades, increasing the accuracy of shaping.

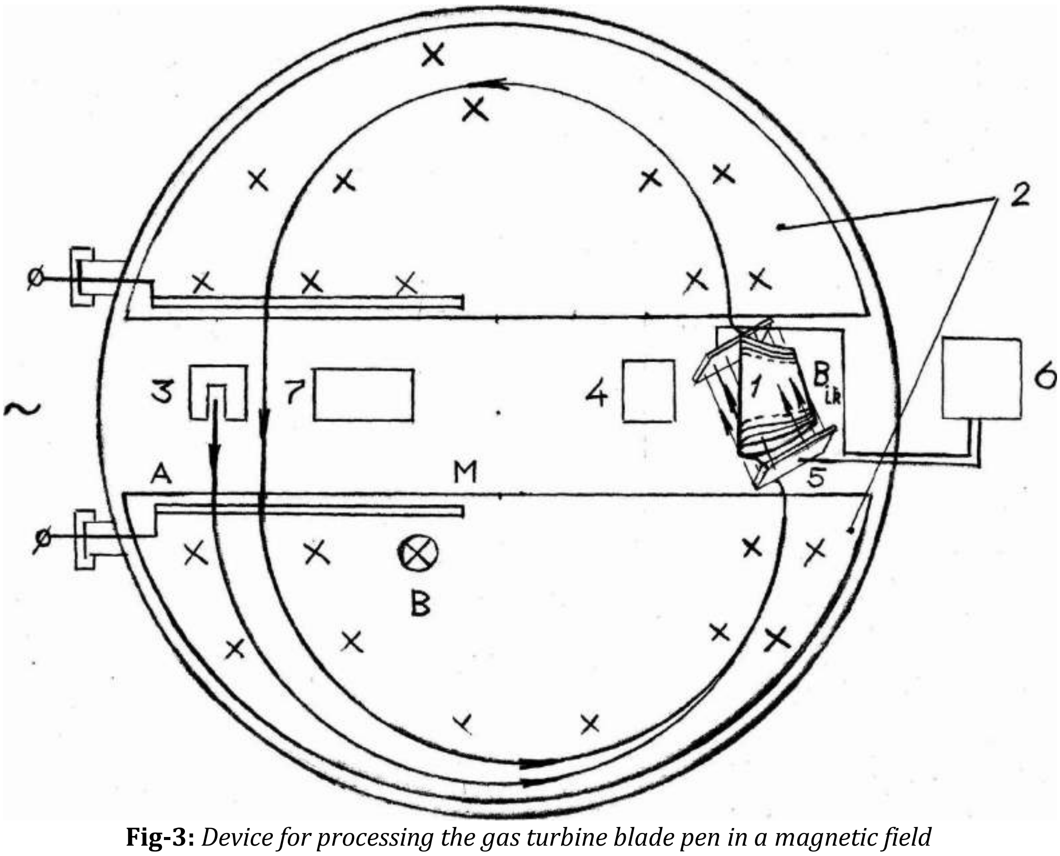

Fig-3: *Device for processing the gas turbine blade pen in a magnetic field*

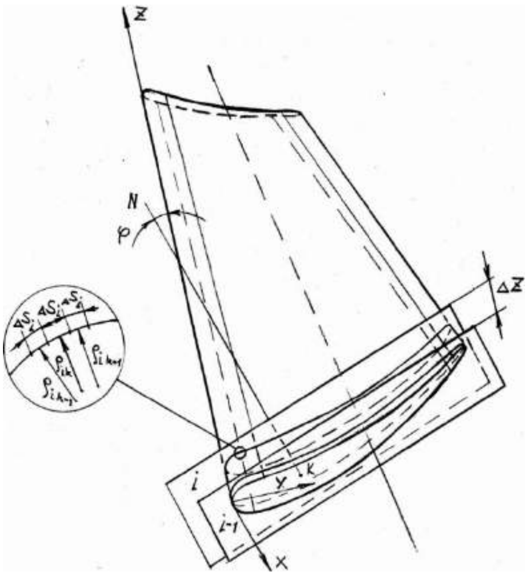

Fig-4: The breaking of the pen turbine parallel planes

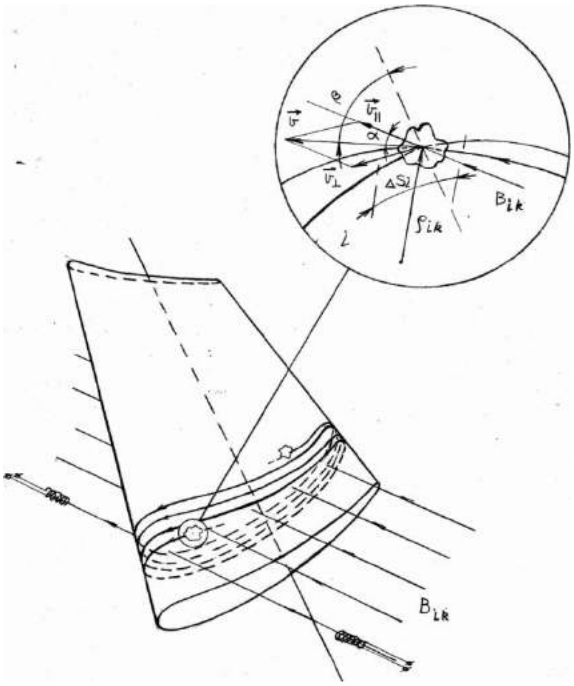

Fig-5: To the calculation of the trajectory of the blades of gas abrasive particle on the feather blades of the gas turbine

4. CONCLUSIONS

High-precision control [12] of complex-profile parts is required in the implementation of industrial production of modern engineering products: precision mechanics, dies, spindles, lunettes, carbide tools in the machine tool industry; animated parts, cumulative funnels of the warhead, gyroscopes, and rudders. As well as in the production of shells and missiles; turbine blades and compressors in gas turbine aircraft engines, turbo-pump units and other similar elements.

On the basis of the x-ray profilograph, a 3-D sensor for monitoring the wear of the working part of the gas turbine blade during its operation in the aircraft engine of a military aircraft is developed.

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