ВИСОКОЕФЕКТИВНІ ТЕХНОЛОГІЧНІ ПРОЦЕСИ В ПРИЛАДОБУДУВАННІ

UDC 621.7 : 620.178.153.2

MEASUREMENT ERRORS OF THE SHAPE'S PARAMETERS OF DETAIL'S SURFACE BY OPTICAL INSTRUMENTS

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Introduction. *The main problem of all product condition monitoring systems is the untimely determination of the moment of their contact and the determination of measurement errors. Now problems of surface quality control, measurements of current geometric parameters must be solved at the stage of production preparation when choosing the metrological support of the technological process. Therefore, we can identify the main disadvantages that relate to the currently known methods and devices for determining the parameters of forming the detail, in particular in the presence of a complex shape and internal surfaces, such as holes. First, it is clear that a contact measuring tool can degrade of the precision detail's surface. Secondly, studies have shown that all the described methods and devices work only to control and measure the parameters of the outer detail's surfaces.*

Main part. *Therefore, it is an interesting task to control the quality of internal detail's surfaces, for example, holes. In this case, the task becomes more complicated, due to the instrumental features of registration of the current parameters of detail's shaping.*

Therefore, it is necessary to consider a model for determining the error's distribution at process of control details. If we have the presence of waviness, surface roughness, or other deviations of submicrogeometry, this leads to the phenomenon of scattering of incident radiation and ultimately affects the actual reflectivity.

These dependences need to be considered at creation of devices of control and measurements of parameters of forming of a detail's surface. So, for example, thus, it is possible to offer the device of the control of a condition of internal surfaces of a detail which contains the scheme of a fiber-optic three-channel meter.

In addition, if you use radiation sources with different wavelengths, you can get different values of intensities, taking into account the radiation parameters recorded by the photodetector modules, and at the same time get greater accuracy by comparing these values and determining the measurement error.

Conclusions. *Thus, taking into account the proposed method for determining the surface roughness of the part, it is possible to determine the roughness by the intensity of the light flux reflected from the surface. The surface absorption by mass of the technological object is taken into account, then the degree of height of the rough surface introduces a coefficient that determines the roughness parameters. This takes into account the time required for processing, i.e., which takes into account the dynamics of both manufacturing and changes occurring on the surface of a technological object, which is controlled.*

Keywords*: parameters of detail's shaping; internal surfaces; control; measurements.*

Introduction

The actual task of modern production of metal details for precision devices is to ensure the shaping accuracy. Therefore, the problems of surface quality control, measurements of current geometric parameters must be solved at the stage of production preparation when choosing the metrological support of the technological process [1].

The quality of surface layer of the material is due to the properties of material and processing methods. The accuracy and quality of any process of creating an object and, as a consequence, the final product, depends on the deviation of this process from the planned. In order to maintain the proper quality of the technological process, it is necessary to constantly monitor the condition of the manufacturing tools and this particular object. Therefore, the quality of products, especially precision, depends on the parameters of the detail's surface roughness.

At the same time, there are a number of physical reasons for the violation of the accuracy of manufacturing a metal detail.

First of all, the depth of surface distortion has a significant mechanical character, i.e., shells, cracks of different depths and so on. From this series of problems, it is necessary to identify two particularly influential factors that affect the uncertainty of the surface coordinates of the detail, there are geometric deformations and surface roughness, which are mostly predominant in determining the touch of the detail's surface.

When the tool comes into contact with the technological surface, it will touch the tops of the rough surface primarily. In this process, the signal coming from this system will be static or intermittent nature.

The signal will be static in the absence of the cutting tool's rotation, but the probability of hitting the point with the maximum coordinate of tool (in the coordinate system of the tool) in the highest tip on detail's rough surface is too small. In this case, error in determining coordinate for workpiece and for detail will be mostly as a defect of the surface, which does not allow to determine its coordinate more accurately than its roughness.

In order to avoid such a phenomenon, it is necessary to give the tool a rotational motion. The higher the speed of tool's rotation, the better it is possible to determine the coordinate of detail's surface.

Therefore, there is a problem in estimating the coordinates of surface with high accuracy. Primarily, this problems quality of finish detail's surface and secondly to the relative movement of tool and detail are related. Nevertheless, there is a possibility of significantly reducing the effect of roughness on the accuracy of determining the surface coordinates. On the one hand, this is high speed of touch systems that experience the slightest surface's oscillations and on other hand the depth of chemical impact on detail's surface is reacted [2].

And this provides opportunities to measure the values of the parameters of forming parts and increase the accuracy of manufacturing high-precision parts in the shop directly on automated machines.

Therefore, determining the surface quality parameters of technological objects with high accuracy is a priority of production.

Problem's statement

The main problem of all product condition monitoring systems is the untimely determination of the moment of their contact and the determination of measurement errors. For the most part, the uncertainty of this factor in the production process leads not only to excessive overloading of the objects of the technological process, but also to their destruction. It is simply impossible to obtain a qualitative analysis of this transient process in the absence of accurate information on measurement errors.

A small number of systems have been developed to determine the magnitude of measurement errors and their variance. But a number of design flaws and the complexity of use when installed on equipment prevent their widespread use in production, which leads to a loss of accuracy in the creation of industrial products. This is especially true of tool coordinates, which have a fluid character, which is the main reason for accuracy in the range of 300 - 400 mm, such as modern machine tools.

Achieving high production capacity, sustainable quality of technological process is possible only with development of control and measuring sensors, subsystems and modules of general monitoring and process control, which are characterized by high accuracy and speed in the overall control of metalworking process. The characteristics of such control systems must correspond to modern production conditions.

Therefore, determining the surface quality parameters of objects with high accuracy is a priority.

Theoretical and experimental researches of problems of measuring the characteristics of detail's shaping are known [3 - 11]. Therefore, it is extremely important to determine the errors that determine the accuracy of the measuring system.

So, it is known to exist the correlation between optical methods for characterizing surface roughness [3]: a laboratory scatterometer measuring the bidirectional reflection distribution function (BRDF instrument), a simple commercial scatterometer (rBRDF instrument), a confocal optical profiler. For each instrument, the effective range of spatial surface wavelengths is determined, and the common bandwidth used when comparing the evaluated roughness parameters.

This study shows a correlation of both the Rq and the Rdq roughness values when obtained with the BRDF and the confocal instruments, if the common bandwidth is applied. Furthermore, it is possible to determine the Rq value from the Aq value, by applying a simple transfer function derived from the instrument comparisons. The presented method is validated for surfaces with 1D roughness.

In work [4] the possibilities of retrieving roughness information from measured scattering data for different roughness regimes are discussed. The predicted angles resolved scattering at 325 nm, 532 nm, and 1064 nm irradiation for stochastically rough metal surfaces are offered.

The roughness measuring instrument [5] described is based on light scattering and is suitable in a wide range of applications, especially in micromachining. The most important properties are the sensitivity in the measuring range from below 0.005 i.im up to 2μm (Ra value), the independence of the reflection coefficient due to normalization, and the larger tolerance of measuring distance of ±2 mm.

The scatter models for pits and particles as well as the use of wafer scanners to locate and size isolated surface features are offered [7]. Scatter measurements, now used to determine whether small-surface features are pits or particles and new technology that provides information on particle material, are also discussed.

Geometric analysis allows a visual and subjective evaluation of roughness (a qualitative assessment) [8], whereas computation of the roughness parameters is a quantitative assessment and allows a standardized analysis of detail's surfaces.

Usually measurements with mechanical profilometer equipment (2D) without adequate accuracy and laser profilometer (3D) with no consensus on how to interpret the result quantitatively are performed. The method to evaluate surface roughness, starting from the generation of a visual surface roughness signature, which is calculated through the roughness parameters, computed in hierarchically organized regions are offered.

A machine vision system is offered, which captures images and extracts surface texture features of machined detail's surface [10]. The texture parameters are extracted, using the gray - level co - occurrence spacial matrix and correlated with different surface roughness parameters recorded by a contact - type profilometer. The image acquisition carried out at different roughness levels in order to extract texture features. The variation between each texture features and surface roughness parameter is investigated. Multiple regression models are developed to predict the subjective estimation of surface roughness parameter (Ra) and qualitative detection of the degree of surface roughness.

Therefore, non-contact methods using laser technology are promising for measuring the geometric dimensions and surface roughness of machined details. The principles of operation of optoelectronic devices for surface quality control of precision details are to use the effect of light scattering by the controlled surface, the angular distribution of which depends on the roughness, for example [9]. Scattered light beams are collected by the optical system and through the light divider enter the matrix of photodetectors. As the roughness increases, the angular divergence of the scattered beams increases.

The proposed method [12, 13] improves the accuracy of measuring the surface roughness of detail by recording and analyzing the characteristics of the electromagnetic field created around the object, as well as determining the dynamic loads. And this provides an opportunity to measure the value of detail's surface roughness and increase the accuracy of their manufacture in industrial conditions.

Therefore, we can identify the main disadvantages that relate to the currently known methods and devices for determining the parameters of forming the detail, in particular in the presence of a complex shape and internal surfaces, such as holes.

First, it is clear that a contact measuring tool can degrade of the precision detail's surface.

Secondly, studies have shown that all the described methods and devices work only to control and measure the parameters of the outer detail's surfaces.

Therefore, it is an interesting task to control the quality of internal detail's surfaces, for example, holes. In this case, the task becomes more complicated, due to the instrumental features of registration of the current parameters of detail's shaping.

Modeling of internal surface of detail's shaping by control and measurement processes

As is known, the light field is a combined intensity of electric and magnetic fields. Experimental studies show that the medium is most affected by electric field, so electric field strength can be determined by light vector. The advantages of optical methods, as mentioned earlier, to determine the quality parameters of object's surface, such as details, are non-contact, as well as the speed of receiving the information signal. Thus, a simple reflexometric method of rapid control of surface roughness is advisable. The surface under study is illuminated by a parallel beam of laser radiation. Part of the light is reflected from the surface in a mirror. The other part is scattered into the surrounding space due to the micro-irregularities of the irradiated surface. By measuring the intensity of scattered radiation at a certain point in space or the diameter of the scattering zone in the focal plane of the special lens, it is possible to obtain information about some averaged surface roughness within the area of the probe beam. Obtaining information about the roughness not in relative units, but in the generally accepted values of R_a, R_z and $R_{\max}$ is possible only by specifying an analytical model of the shape and spatial distribution of inequalities. Currently, this problem is solved only for the Gaussian model of the scattering surface, which is characteristic of many surfaces treated with abrasive powders.

Therefore, it is necessary to consider a model for determining the error's distribution at process of control details.

If we have the presence of waviness, surface roughness, or other deviations of submicrogeometry, this leads to the phenomenon of scattering of incident radiation and ultimately affects the actual reflectivity.

Ellipsometric method and instruments can be used in industry only in the case of laboratory research, because the analytical apparatus and sequential processing of information signals of light field distribution is a complex process that requires some time and appropriate equipment. Therefore, it is proposed to use the analysis of light flux with a normal fall on the detail's surface.

It should also be borne in mind that with the normal incidence of light radiation on the metal surface, there is a partial absorption in the near-surface layer, i.e. by the corresponding coefficients are determined. That is, to describe the losses on absorption, the most descriptive are the absorption coefficients A_S and A_P, and the values are found as $A_S = 1 - R_{S,}\ A_P = 1 - R_P$.

Then finally the value, which depends on the quality of the surface, taking into account the absorption of the surface layer of the detail during finishing or complete cleaning of the surface, can be registered by photodetectors for further processing. Thus,

$$I_P = \rho I_0 \left(A_P + A_S\right)\exp\left[\left(h^2 \cos\varphi\right)t\right],$$

where I_0 is the intensity of the flow incident on the surface, ρ - a factor that takes into account the scattering of the luminous flux of radiation, φ is the angle formed by the reflection of light radiation from the detail's surface, h is a height of surface microroughnesses, t is a time.

Thus, the loss of radiation intensity due to the absorption by the surface layer of the detail's material creates the amount of error that must be taken into account to obtain the value of the parameter of detail's shaping.

The edge of object's surface moving deep into the medium is not stable and not determined in coordinate [13] by the error value **[S]**$_i$.

The refractive index of the medium has a slow variability, which satisfies of $\left[\mathbf{S}\right] > \frac{1}{R}$, where R is the radius of curvature of the trajectory of the rays and, as a consequence, the conditions of geometric optics are applied. A wave generated by a radiation source propagates in the medium

$$E = a\left(r\right)e^{i\left[\omega t - k_0\Phi\left(r\right)\right]},$$

where $a\left(r\right)$ and $\Phi\left(r\right)$ are real coordinate functions, k_0 is a wave number in vacuum.

Therefore, if the eikonal Φ is an unambiguous coordinate function, then the equation

$$\mathrm{grad}\Phi = n\mathbf{S},$$

where $\mathbf{S}$ is the unit vector of the normal to the wave front, it follows that the circulation of the vector $n\mathbf{S}$ in any closed loop is zero, i.e.

$$\oint n\left(\mathbf{S}\cdot dl\right) = 0,$$

where dl is the vector of elementary shift along this contour.

It is possible to measure the square of the modulus of the complex amplitude, but it is impossible to measure the phase and eikonal of the field - they are lost, when the field is registered. To store information about the eikonal, it is required to measure the intensity of the field added from several fields. We take into account that the eikonal is a function that depends on the wave number k_0, i.e. on the radiation's wavelength. Then increase in wavelength leads to an increase of the eikonal Φ magnitude.

These dependences need to be considered at creation of devices of control and measurements of parameters of forming of a detail's surface.

So, for example, thus, it is possible to offer the device of the control of a condition of internal surfaces of a detail which contains the scheme of a fiber-optic three-channel meter.

The circuit contains three pairs from the radiation source and the radiation receiver, which are integrated through the matching optical modules to the fiber-optic modules of transmission and reception of radiation. Thus, the installation size of these fiber modules can be adjusted based on the diameter of the hole of the detail, i.e. to control different dimensions and the flexible instrument it is designed.

Therefore, the flexible fiber optic module is designed to move along the inner surface of the hole of detail to control deviations from the specified diameter size, surface roughness and other parameters of forming the detail.

Undoubtedly, the accuracy of determining the quality of the inner surface of the part depends on the error value **[S]**$_i$. This error occurs due to the difference between real and imaginary trajectories of radiation propagation, ie the phenomenon of technological phantom (TP). Therefore, improving the accuracy of the inner surface depends on this error. Thus, in addition, the value of detail's diameter is known only to the accuracy of $\left[\mathbf{S}\right]$.

Thus, if the refractive index changes in space continuously, the optical length of the beam between any two points is less than the optical length of any other line connecting the same points. But it should be noted that the formulation of the Fermat's principle is that the optical length of the beam is proportional to the time of propagation of light along it. Regarding the Fermat's principle, we have reliable confirmation of the existence of a technological phantom.

Fermat's principle states that the optical length of a real light path or its proportional path is stationary. This means that the difference between the optical lengths of the real and imaginary paths of light is the magnitude of the imaginary higher order of minimization than on both sides the displacement of the imaginary path relative to the real one. So, according to the given example, we have two trajectories of movement: one imaginary, another real.

So, if $ACDEB$ trajectory we are taken as an imaginary trajectory, but $AC'D'E'B$ is real trajectory (Fig. 1).

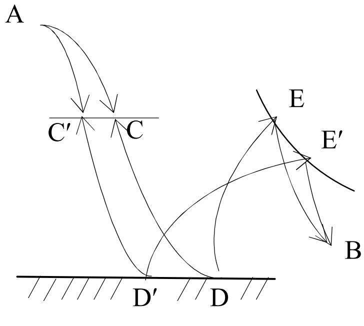

Fig. 1. Model of difference of imaginary and real trajectories of optical beam motion

The model of the difference between imaginary and real trajectories of the optical beam (Fig.1) is applied as a number of examples at control of shape's parameters.

Therefore, if there are distribution surfaces that provide additional distortion of the beam motion, it is necessary to add a number of additions in order to obtain the final result.

If we mark the imaginary trajectory as $U(x,y,z,t)$, then the real will be accordingly is $R(x,y,z,t)$.

From here we get two cases to the Fermat's principle. According to the first, both trajectories must satisfy the condition

$$R(x,y,z,t)-U(x,y,z,t)\le[\mathbf{S}]. \qquad (1)$$

In fact equation (3.170) is an ideal condition that can only be satisfied if

$$\sum_{i=1}^{\infty} n_i = 1. \qquad (2)$$

In addition, the refractive index in equation (2) is a vector quantity, although it is essentially a scalar field of the medium. In the general case, the refractive function depends on the properties of the medium μ, ε.

That is, in the general case it is

$$n=\mu+\varepsilon.$$

The properties of the magnetic field μ and the electric field ε of a certain medium are experimental values, are not stationary and, as a consequence, at each point in the space of the studied medium it will be a different value.

Since the functions of real $R(x,y,z,t)$ and imaginary $U(x,y,z,t)$ motion are holonomic [14], the difference between them can be perceived as an increase of one function relative to another. In this case, we have the opportunity to write

$$df(R,U)=R(x,y,z)-U(x,y,z),$$

where $df(R,U)$ you can imagine as

$$df(R,U)=\frac{\partial f(R,U)}{\partial x}dx+\frac{\partial f(R,U)}{\partial y}dy+ \\ +\frac{\partial f(R,U)}{\partial z}dz. \qquad (3)$$

We have the ability to add a radius vector $\mathbf{r}=\mathbf{i}x+\mathbf{j}y+\mathbf{k}z$ for $U(x,y,z)$ [15] and a radius vector to the scalar field

$$\mathbf{r}=r+dr=\mathbf{i}(x+dx)+\mathbf{j}(y+dy)+\mathbf{k}(r+dr)$$

for $R(x,y,z)$.

As a consequence, expression (3.172) can be represented as

$$df(R,U)=\left(\mathbf{i}\frac{\partial f(R,U)}{\partial x}+\mathbf{j}\frac{\partial f(R,U)}{\partial y}+\right. \\ \left.+\mathbf{k}\frac{\partial f(R,U)}{\partial z}\right)\times(\mathbf{i}dx+\mathbf{j}dy+\mathbf{k}dz), \qquad (4)$$

the second factor of which is define as

$$dr=\mathbf{i}dx+\mathbf{j}dy+\mathbf{k}dz=[\mathbf{S}].$$

On the other hand, there is a connection between an imaginary function, a phantom, and a real object (function) in the form of:

$$R(x,y,z)=\mu(1+\eta)\cdot U(x,y,z).$$

This provides an opportunity to rewrite the first factor (4) in the following form

$$\mathbf{i}\left[\frac{\partial R(x,y,z)}{\partial x}-\frac{\partial U(x,y,z)}{\partial x}\right]+\mathbf{j}\left[\frac{\partial R(x,y,z)}{\partial y}-\frac{\partial U(x,y,z)}{\partial y}\right]+ \\ +\mathbf{k}\left[\frac{\partial R(x,y,z)}{\partial z}-\frac{\partial U(x,y,z)}{\partial z}\right]= \\ =\mathbf{i}\left[\frac{\mu(1+\eta)\cdot\partial U(x,y,z)}{\partial x}-\frac{\partial U(x,y,z)}{\partial x}\right]+ \\ +\mathbf{j}\left[\frac{\mu(1+\eta)\cdot\partial U(x,y,z)}{\partial y}-\frac{\partial U(x,y,z)}{\partial y}\right]+ \\ +\mathbf{k}\left[\frac{\mu(1+\eta)\cdot\partial U(x,y,z)}{\partial z}-\frac{\partial U(x,y,z)}{\partial z}\right]= \\ =\mu(1+\eta)\,\mathrm{grad}U(x,y,z).$$

Thus, to difference between imaginary and real trajectory we obtain in the form

$$df(R,U)=\mu(1+\eta)\,gradU(x,y,z)\cdot[\mathbf{S}]. \qquad (5)$$

From equation (5) we conclude that the realization of an imaginary trajectory into a real one can be the case, when $df(R,U)\le[\mathbf{S}]$, but for this it is necessary that μ and η, as properties of the medium, are equal to one and zero, respectively, which is possible only theoretically. Such properties must have an absolute vacuum, which is left by any physical reaction.

As a result, we get the coordinate of surface $R_0+R_{\max}+[\mathbf{S}]$, radius is formed

$$\lim(R_{\max}-R_{\min})>[\mathbf{S}],$$

that is the definition of the radius is not better than $[\mathbf{S}]$ for example [2].

Thus, the possibility of deviation from the internal size is taken into account.

In addition, if you use radiation sources with different wavelengths, you can get different values of intensities, taking into account the radiation parameters recorded by the photodetector modules, and at the same time get greater accuracy by comparing these values and determining the measurement error.

Conclusions

Thus, taking into account the proposed method for determining the surface roughness of the part, it is possible to determine the roughness by the intensity of the light flux reflected from the surface. The surface absorption by mass of the technological object is taken into account, then the degree of height of the rough surface introduces a coefficient that determines the roughness parameters. This takes into account the time required for processing, ie, which takes into account the dynamics of both manufacturing and changes occurring on the surface of a technological object, which is controlled.

As a result of the study, it can be concluded that taking into account the gradient of the distribution of the error, which characterizes the quantitative parameters of the technological phantom, increases the accuracy of measuring deviations of the detail's surface shaping.

Therefore, further research will develop in the direction of determining the magnitude of the measurement error depending on the hardware used. It is necessary to investigate the specific values of the parameters of the internal surfaces under the condition of changing the material of a detail. This is especially true of the instability of surface treatment modes.

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УДК 621.7 : 620.178.153.2

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ПОХИБКИ ВИМІРЮВАННЯ ПАРАМЕТРІВ ФОРМИ ДЕТАЛІ ОПТИЧНИМИ ПРИЛАДАМИ

Вступ. Основною проблемою всіх систем контролю стану будь-якого продукту обробки матеріалу є несвоєчасне визначення моменту їх контакту та визначення похибок вимірювань. Проблеми контролю якості поверхні, вимірювань поточних геометричних параметрів повинні вирішуватися на етапі підготовки виробництва при виборі метрологічного забезпечення технологічного процесу. Тому ми можемо виділити основні недоліки, які стосуються відомих сучасних методів та пристроїв для визначення параметрів формування деталі, зокрема за наявності складної форми та внутрішніх поверхонь, таких як отвори. По-перше, зрозуміло, що контактний вимірювальний інструмент може погіршити поверхню деталей точності. По-друге, дослідження показали, що всі описані методи та пристрої працюють лише для контролю та вимірювання параметрів поверхонь зовнішньої деталі.

Основна частина. Тому цікавим завданням є контроль якості внутрішніх поверхонь деталей, наприклад, отворів. У цьому випадку завдання ускладнюється через інструментальні особливості реєстрації поточних параметрів формування деталей.

Отже, необхідно розглянути модель для визначення розподілу помилок у процесі контрольних вимірів. Якщо ми маємо наявність хвилястості, шорсткості поверхні або інших відхилень субмікрогеометрії, це призводить до явища розсіювання падаючого випромінювання і врешті впливає на фактичну здатність відбиття.

Ці залежності потрібно враховувати при створенні пристроїв контролю та вимірювання параметрів формування поверхні деталі. Таким чином, наприклад, можна запропонувати пристрій контролю стану внутрішніх поверхонь деталі, що містить схему волоконно-оптичного триканального вимірювача.

Крім того, якщо використовувати джерела випромінювання з різною довжиною хвилі, можна отримати різні значення інтенсивності, враховуючи параметри випромінювання, реєстровані модулями фотоприймачів, і в той же час отримати більшу точність, порівнюючи ці значення та визначаючи похибку вимірювання. При цьому цей модуль переміщується вздовж внутрішньої поверхні, що надає можливості уточнення результатів контролю стану виготовленої деталі.

Висновки. Таким чином, беручи до уваги запропонований спосіб визначення параметрів формотворення поверхні деталі, можна визначити величини та характер інтенсивності світлового потоку, відбитого від поверхні. Поглинання поверхні масою технологічного об'єкта враховується, тоді висоту нерівностей профілю поверхні можливо визначати, якщо ввести коефіцієнт, який визначає параметри відхилення форми. При цьому враховується час, необхідний для обробки, тобто, що враховує динаміку як виготовлення, так і змін, що відбуваються на поверхні технологічного об'єкта, який контролюється.

Ключові слова: параметри формування деталей; внутрішні поверхні; контроль; вимірювання.

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ПОГРЕШНОСТЬ ИЗМЕРЕНИЯ ПАРАМЕТРОВ ФОРМЫ ДЕТАЛИ ОПТИЧЕСКИМИ ПРИБОРАМИ

Введение. Основной проблемой всех систем контроля состояния любого продукта обработки материала является несвоевременное определение момента их контакта и определения погрешностей измерений. Проблемы контроля качества поверхности, измерений текущих геометрических параметров должны решаться на этапе подготовки производства при выборе метрологического обеспечения технологического процесса. Поэтому мы можем выделить основные недостатки, касающиеся известных современных методов и устройств для определения параметров формирования детали, в частности при наличии сложной формы и внутренних поверхностей, таких как отверстия. Во-первых, понятно, что контактный измерительный инструмент может ухудшить точность поверхности деталей. Во-вторых, исследования показали, что все описанные методы и устройства работают только для контроля и измерения параметров поверхностей наружной детали.

Основная часть. Поэтому интересной задачей является контроль качества внутренних поверхностей деталей, например, отверстий. В этом случае задача усложняется из-за инструментальных особенностей регистрации текущих параметров формирования деталей.

Следовательно, необходимо рассмотреть модель для определения распределения ошибок в процессе контрольных измерений. Если существует волнистость, шероховатость поверхности или другие отклонения

субмикрогеометрии поверхности детали, это приводит к явлению рассеяния падающего излучения и влияет на фактическую способность отражения.

Эти зависимости нужно учитывать при создании устройств контроля и измерения параметров формирования поверхности детали. Так, например, можно предложить устройство контроля состояния внутренних поверхностей детали, которое содержит схему волоконно-оптического трехканального измерителя.

Кроме того, если использовать источники излучения с различной длиной волны, можно получить различные значения интенсивности. При этом, учитывая параметры излучения, которые регистрируются модулями фотоприемников, можно получить большую точность, сравнивая эти значения и определяя погрешность измерения. При этом измерительный модуль перемещается вдоль внутренней поверхности, что дает возможность уточнения результатов контроля состояния изготовленной детали.

Выводы. Таким образом, принимая во внимание предложенный способ определения параметров формообразования поверхности детали, можно определить, например, изменение величины и характера интенсивности светового потока, отраженного от поверхности. Поглощение поверхности массой технологического объекта учитывается, тогда степень высоты образованной поверхности детали можно вычислять, вводя коэффициент, определяющий параметры нестабильности полученной поверхности. При этом учитывается время, необходимое для обработки, то есть, учитывающее динамику, как изготовления, так и изменений, происходящих на поверхности контролируемого технологического объекта.

Ключевые слова: параметры формирования деталей; внутренние поверхности; контроль; измерения.

Надійшла до редакції
15 травня 2020 року

Рецензовано
23 червня 2020 року