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INFORMATION TECHNOLOGIES OF MEASURING OF GEOMETRICAL SIZES OF AVIATION DETAILS

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The method of the high-fidelity automatic measuring of rotation surfaces on a co-ordinate-measuring machine is developed in this article. The mathematical model of error of measuring of high-precision details is developed and treatment of real interferogram is conducted.

Запропоновано методику високоточного автоматичного вимірювання поверхонь обертання на координатно-вимірювальній машині. Розроблено математичну модель похибки вимірювання прецизійних деталей. Проведено обробку реальних інтерферограм.

Introduction

One of the major tasks of automation of composite spatial surfaces measurings is the creation of the modern control systems by a measuring head, providing automatic implementation of measurings in accordance with the set program, determined with the concrete measuring task [1]. Co-ordinate-measuring machines are widely used for the control of objects with the compound spatial surface the same as surfaces of rotation, which are not analytically described. Exactness of measuring on precision co-ordinate-measuring machines is 0,5 mkm, that dissatisfies with the requirements of details measuring of machine-building and instrument-making industries [1–4]. The digital values of co-ordinates, got by co-ordinate-measuring machines, do not decide the task of control of composite spatial surfaces. It is necessary to compare not only the sets of the points measured and got on a mathematical model, but also the equations of surfaces. The automatic measurings can be executed in the continuous or cyclic mode. The optimization task of the scanning way along the measuring object is the most actual.

The practical value of optimum round of object in a great deal is determined by possibilities which are created by the automatic control systems for the motion of measuring tip. The analysis of existent methods of details automatic control with composite spatial surfaces in the conditions of the flexible production systems showed that a control function acquired a new maintenance and special value.

Target setting

It is necessary to develop the high-fidelity method of composite spatial surface measuring on a precision co-ordinate-measuring machines for the rotation surfaces with the determination of measuring points amount at given probability and define the error of measuring.

Task solution

It the task of algorithm development of is very difficult, because requires to take into account interferences of vibration of mechanical part of co-ordinate-measuring machine and exactness of positioning and round of high-fidelity detail on a spatial trajectory taking into account revolting influences of measuring sensor. Position and form composite profiles and surfaces are set by the set of points co-ordinates values relatively to base surfaces, in the capacity of which the scope surfaces of detail containing the given composite surface or profile are given, as a rule. The directions of perpendicular to every point of nominal position of profile or surface must be known (except for co-ordinates) for estimation of deviations of position or surface form. The polished surface of rotation (relatively to the Z axis) in general case is described by expression

$$Z = \frac{cs^2}{1 + \left[1 - (K+1)c^2 s^2\right]^{1/2}} + A_1 s^4 + A_2 s^6 + A_3 s^8 + A_4 s^{10},$$

where $s^2 = x^2 + y^2$; $c = 1/r$’;

r is radius of curvature;

A_1, A_2, A_3, A_4 are coefficients of spherical deformation;

$K = -e^2$ is function of eccentricity of e conoid or conical permanent.

A surface is one of rotation conoids if all of the $A_i = 0$.

A spherical surface is described by expression:

$$Z = \frac{cs^2}{1 + (1 - c^2 s^2)}.$$

The wave front W determined by the ΔZ deviations from the set surface can be represented as a sedate polynomial:

$$\sum_{n=0}^{k} \sum_{m=0}^{n} B_{nm} x^m y^{n-m}$$

or as a linear combination of the circular polynomials Zernicke:

$$W(\rho,\Theta)=\sum_{n=0}^{k}\sum_{m=0}^{n}C_{nm}R_n^{n-2m}(\rho)\begin{Bmatrix}\sin\\ \cos\end{Bmatrix}(n-2m)\Theta, \qquad (1)$$

where ρ, Θ are polar coordinates;
sin fits the case, when $n-2m>0$;
cos – when $n-2m\le 0$;

$$\rho R_n^{n-2m}=\sum_{s=0}^{m}(-1)^s\frac{(n-s)!}{s!(m-s)!(n=m-s)!}\rho^{n-2s}$$

(for $n-2m>0$).

Application of the Zernicke polynomials is conditioned, in particular, that they describe the classic aberrations used by opticians.

Recently a polynomial of kvazi Zernicke is widely used for description of wave front:

$$W(\rho,\Theta)=R\rho^m\cos(n\Theta+q\Phi), \qquad (2)$$

where ρ is normalize radius of spherical surface (radial co-ordinate);
Θ is azimuthal co-ordinate;
Φ is arbitrary phase change.

The use of the last row is conditioned by elements which describe the orthogonal mechanical mode of spherical surface curve in relation to parameters *n* and *m,* related to the generalized aberrations:
$b\rho\cos(\Phi+\Theta_0)$ is tilt;
$c\rho^2$ is longitudinal displacement of focus;
$d\rho^3\cos(\Phi+\Theta_1)$ is decentering coma of the third order;
astigmatism of the third order (a saddle) (a three-cornered coma, a spherical aberration of the third order, a square astigmatism, an astigmatism of the fifth order, a spherical aberration of the fifth order, a coma of the fifth order).

Complete or partial removal of one or a few modes (from the real surface or from its description) does not affect to the sizes of other modes – errors. Residual error, remaining after the deduction of the referred above modes, carries, as a rule, high-frequency, and in considerable, casual character. It is related to influencing of environment (fluctuations of atmosphere, temperatures, gravitations), and also with the errors of measuring.

A stand for the control of turbine shoulder-blades includes an unloading knot, compensating gravity of in 54 supporting points located on three supporting circumferences.

The choice of location of supporting points is produced from the condition of minimization of bendings of spherical surface between supporting points.

For description of errors of spherical surface bending under the influence of gravity, component the most part of high-frequency residual error Δ it is comfortably to decompose this error in the Fure row in axial and radial directions because of periodic character of these deformations:

$$\frac{1}{I}\sum_{j=1}^{I}\sum_{m=1}^{r}\left[a_m(\rho_j)\sin mn_1Q_j+b_m(\rho_j)\cos mn_1Q_j\right]=\Delta w(Q_j), \qquad (3)$$

$$\frac{1}{I}\sum_{j=1}^{1}\sum_{m=1}^{r}\left[\alpha_m(Q_j)\sin mn_2 2\pi\rho_j+\beta_m(Q_j)\cos mn_2 2\pi\rho_j\right]=$$
$$=\Delta w(\rho_j),$$

where n_1 is number of supporting stripe. s on one circumference (frequency of bendings in azimuthal direction);
n_2 is number of zones between supporting circumferences (frequency of bendings in radial direction);
Q, ρ are current values of arctic co-ordinates;
ρ_j, Q_j are fixed values of arctic co-ordinates;
$\rho_{max}=1$;
Δw_i is values of permanent phase change of wave front (rejections of surface).

With respect to the errors related to fluctuation of atmosphere (and temperature), it is assumed to remove it by the apartment of unloading stand in a vacuum pipe, and support an ambient temperature in a narrow range (2–3ºC). As the described rejections sizes of spherical surface are comparable with length of light wave (≈ 0,5 μ·*m*), for their measuring it is necessary to adopt the proper methods and devices. To the most exact methods of measuring, taking into account wave effects, wave nature of light, belong interferometrical and holographic, measuring the phase of wave front with errors, determined stakes of wave-length of.

The Tvayman-Grin interferometer, realizing the differential chart of measuring – measuring of rejection of the controlled surface from standard one, belongs to most exact from them, if is present possibility of the exact tuning. Intensity of luminance on interferogram is described by expression:

$$I(x,y,l)=\left|w_l+w_t\right|^2=\left|ae^{2ikl}+be^{2ikw(x,y)}\right|^2=$$
$$=1+\gamma\cos 2k\left[w(x,y)-l\right], \qquad (4)$$

where $k=2\pi/\lambda$;
l is effective length of way of standard front;
a, *b* are amplitudes of wave fronts;
$\gamma=2ab/(a^2+b^2)$ is contrasting (the depth of interfronts modulation), achieving a maximum ($a>1$, $b>1$) at $a=b$.

As intensity of light harmonically depends on *l*, at the change of *l* with the permanent speed, a useful interference signal can be selected from strongly noise (noise of $n(t)$) signal $I_0=I(t)+n(t)$ (after the light signal shaping in electric one) by a synchronous detector (SD). In-phase component of the output signal SD is:

$$I_1\lim_{T\to\infty}\int_0^T\left\{I\left[\rho,Q,l(t)\right]+n(t)\right\}\sin 2kl(t)dt=\gamma\sin 2kw(\rho,Q),$$

the quadrature is:

$$I_2 \lim_{T\to\infty}\int_0^T \{I[\rho,Q,l(t)]+n(t)\}\cos 2kl(t)dt =$$

$$=\gamma\cos n2kw(\rho,Q),$$

from which

$$w(\rho,Q)=\frac{1}{2k}\operatorname{arctg}\frac{I_1}{I_2}\operatorname{mod}\pi .$$

If it is present the device allowing discretely scan l hrough the small values Δl (for example Δl = 0,012), it is possible to select the equivalent value of wave front w_i to this point from an enough strongly spatial noise signal, removing an interference stripe. Through projected on the interferogram point of spherical surface with the exactly known co-ordinates ρ_i, Q_i

$$w(\rho_j,Q_j)=\frac{1}{2k}\operatorname{arctg}\frac{\frac{2}{N}\sum_{j=1}^{N} I_j\sin 2kl_j}{\frac{2}{N}\sum_{j=1}^{N} I_j\cos 2kl_j},$$

where N is number of counting out on a period;
I_j is values of light intensity (luminance) for the proper values of l_j.
Defining w for a plenty of points of $w(\rho_j, Q_j)$, the description of the rejection of the polished surface from the surface or wave front of w it is possible to get as one of polynomials (1), (2), defining their coefficients C with the method of least squares.
A vector of coefficients of C we will find from expression:

$$\boldsymbol{C} = (\boldsymbol{H}^T\boldsymbol{H})^{-1}\boldsymbol{H}^T\boldsymbol{W}, \tag{5}$$

representing the system of equations

$$\sum_{m=1}^{1} C_m\varphi_m(\rho_1 Q_1)=w_1(\rho_1 Q_1);$$

$$\sum_{m=1}^{2} C_m\varphi_m(\rho_2 Q_2)=w_2(\rho_2 Q_2);$$

....

$$\sum_{m=1}^{k} C_m\varphi_m(\rho_j Q_j)=w_k(\rho_j Q_j),\quad j=\overline{1...r}$$

in a vector-matrix kind

$$\boldsymbol{HC} = \boldsymbol{W}.$$

The process of measuring of w_i can be strongly simplified or rather substituted for process of finding co-ordinates of ρ_i, Q_i, points of equal intensity and consequently and phase of w at the moderate values of noise, allowing to get enough a clear interferogram.
Indeed, it follows from expression (4), that the minimum value of luminance takes place at

$$w(\rho,Q)-l=\lambda/4(2n-1) \tag{6}$$

and maximum value of luminance takes place at

$$w(\rho,Q)-l=\lambda/4\cdot 2n, \tag{7}$$

where n is number of dark stripe.

At the same time, the points of interferogram are the projections of points of spherical surface in the appropriate scale
$M = D/d$,
where D is external diameter of spherical surface;
d is interferograms.
Although the black stripes of minimum luminance are looked much more legibly, than the lines of maximum luminance on the wide white field in the photo of interferogram, the images read with SD are equivalent to the lines of extreme luminance. The program allowing to fill the goal of points in the lines of minimum intensity (black lines) of processed interferogram and automatically determining its co-ordinates taking into account a scale is developed. The value of subvector elements of w for every line remains constant
$w = \lambda / 4(2n - 1)$
it changes only with the change of line number of n.
The calculation of the coefficients C_m is realized accordingly to expression (5). The possibility of interferogram forming with goal coefficients of aberration C_m in advance on the basis of expression (3), describing intensity of light, is foreseen also for the control of the program work. It is possible to estimate enough high-quality the processing of the real interferogram executable by the program, processing such testing interferogram with the goal coefficients of aberration in advance or other rejections. Additionally to equalization (6) it is possible to use equalizations of lines of maximum luminance (7), it gives more complete description of the polished surface, especially of it's local rejections, because averaging is calculated only according to those points of interstripes, which belongs to the investigated domain.

Conclusions

It is shown, that the points of interferogram are the projections of the points of spherical surface in the article. The method of the high-fidelity automatic measuring of rotation surfaces on a co-ordinate-measuring machine is developed in this article. The mathematical model of error of measuring of high-precision details is developed and treatment of real interferogram is conducted.

References

1. *Фокс А., Пратт М.* Вычислительная геометрия. - М.: Мир, 1982. - 304 с.
2. *Юнусов Ф.С.* Формообразование сложнопрофильных поверхностей шлифованием. - М.: Машиностроение, 1987. - 248 с.
3. *Перепилица Б.А.* Отображение аффинного производства в теории формообразования поверхностей резанием. – Х.: Высш. шк., 1981. - 152 с.
4. *Дружинский И.А.* Сложные поверхности. Математическое описание и технологическое обеспечение. - Л.: Машиностроение, 1985. - 263 с.

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