UDC 531

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Measurement of linear dimensions of cylindrical parts

The article deals with the process of measuring cylindrical surfaces of large length during machining. It is shown that in the process of measurement it is necessary to monitor each thread pitch with a large sample, both standard and non-standard controls. The characteristic of stationary and non-stationary functions is determined in the production of cylindrical parts.

When solving the problem of straightness and cylindrical measurement, minor deviations from the program and movement of the sensor are provided.

The position of the sensor is characterized by a segment AB. We introduce the notation: *Z* - the instantaneous center of the velocities of the object, *V* - the velocity of point *B*, *L* - the longitudinal segment of the *OB*, $\rho = |BZ|$.We obtain the following equation of motion of a measurable tip.

$$\dot{x} = V\cos\theta\sin\psi,\ \dot{y} = V\sin\theta\sin\psi,\ \dot{z} = V\cos\psi, \tag{1}$$

$$\dot{\theta} = Vc; \quad c = 1/\rho; \ \psi = arctgLc.$$

We believe that $|\theta| < \pi$, $\psi < \pi$. The parameter is taken as the main factor affecting (1), is proportional to this *dc/dt* because the angle ψ is determined by the physical quantity *c*. In this case, the system (1) should be modified:

$$\dot{x} = V\cos\theta\sin\psi,\ \dot{y} = V\sin\theta\sin\psi,\ \dot{z} = V\cos\psi, \tag{2}$$

$$\dot{\theta} = Vc,\ \psi = LVu/\left(1 + (Lc)^2\right).$$

The equation (1), (2) is used in the analysis of the straight-line motion of the measuring tip. In the polar coordinates of equation (1) can be written: $\varepsilon = \pi - \varphi + \theta$;

$$\dot{R} = V\sin\varepsilon;\ \dot{\varphi} = \frac{V}{R}\cos\varepsilon;\ \dot{\varepsilon} = \dot{\varphi} - Vc. \tag{3}$$

System (2) can be written in polar coordinates

$$\dot{R} = V\sin\varepsilon;\ \ \dot{\varphi} = \frac{V}{R}\cos\varepsilon;\ \dot{\varepsilon} = \dot{\varphi} - Vc;\ \ \dot{c} = Vu. \tag{4}$$

In case when $V > 0$, $\dot{\varphi} > 0$. in the equations (1)-(4) can be selected as an independent variable, in accordance *x* or φ, in this way reduce the order of the system. System analogs (1)-(4) will be an equation:

$$\dot{y} = tg\theta; \quad \dot{\theta} = \frac{c}{\cos\theta}; \quad \frac{dc}{dx} = \frac{u}{\cos\theta}. \tag{5}$$

$$\dot{R} = Rtg\varepsilon;\ \dot{\varepsilon} = 1 - \frac{Rc}{\cos\varepsilon};\ \ \frac{dc}{d\varphi} = \frac{u}{\cos\theta}. \tag{6}$$

Move along OX axis corresponds to a zero solution of equations, that is *y*=0, θ=0, *c*=0, *u*=0. Circular motion mode does not correspond to the zero solution of this system and is determined: $R=R_0$, *e*=0, *з =1/*R_0, *u* = 0. Let's introduce the designation: $f=\ln R/R_0$, the value of which is zero on the program mode of motion. Knowing that $\frac{dR}{d\varphi}=R\frac{df}{d\varphi}$ Equation (6) is written as

$$\dot{f}=tg\varepsilon;\ \dot{\varepsilon}=1-\frac{R_0ce^f}{\cos\varepsilon};\ \frac{dc}{d\varphi}=\frac{uR_0e^f}{\cos\varepsilon}. \qquad (7)$$

If the motion of the object is described by the system (5). The challenge is to choose u, as functions so that the zero solution will be asymptotically stable. According to (5) have

$$\dddot{y}=\frac{u\cos^2\theta+3c^2\cos\theta\sin\theta}{\cos^6\theta}. \qquad (8)$$

Managing influence u choose this way, so that equation (8) has a look

$$\dddot{y}=-a\ddot{y}-b\dot{y}-dy, \qquad (9)$$

where a, b, d – const. We have an equation for controlling the influence of the motion of a measuring tip in a straight line

$$u=-\left(ac\cos\theta+\left(b\cos^4\theta+3c^2\right)tg\theta+dy\cos^4\theta\right). \qquad (10)$$

Twice differentiating the first equation of the system (7), we have

$$\dddot{f}\cos^3\varepsilon=3\ddot{f}\dot{\varepsilon}\cos^2\varepsilon\sin\varepsilon-\dot{\varepsilon}\sin\varepsilon-R_0\frac{ac}{d\varphi}\dot{e}-\dot{f}\dot{e}R_0c.$$

Managing influence u choose this way, so that the transients in the system are described by a differential equation, similar (9)

$$\dddot{f}+a\ddot{f}+b\dot{f}+df=0 \qquad (11)$$

find the equation for the managing influence u:

$$u=\frac{\cos\varepsilon}{R^2}\Big[3(\dot{\varepsilon})^2\sin\varepsilon+(a\cos\varepsilon-\sin\varepsilon)\dot{\varepsilon}+$$
$$+(b\cos\varepsilon-Rc)tg\varepsilon+df(\cos\varepsilon)^3, \qquad (12)$$

where $\dot{\varepsilon}=\frac{d\varepsilon}{d\varphi}=1-\frac{Rc}{\cos\varepsilon}$, physical quantities R, f, e are expressed through Cartesian coordinates $x\ y\ z$; point B and the angle θ according to the ratio:

$$R=\sqrt{x^2+y^2+z^2};\ f=\ln\frac{R}{R_0};\ \varepsilon=\pi+arctg\frac{y}{x}-\theta.$$

According to (8) in the linear approximation equation looks like facility man-agement

$$\dddot{Y}=u \qquad (13)$$

Introduce phase vector $\nu=[y\dot{y}\ddot{y}]'$ (stroke means transposition), then the equation (13) can be written as follows:

$$\frac{d\nu}{dx}=A\nu+Bu, \qquad (14)$$

where $A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \end{bmatrix}$ – matrix system, $B = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$ – matrix input, ν – state vector, u – vector entrance.

According to (9), (13) the constants *a, b, d* determined by the law of the feedback loop

$$u = k\ \nu\ , \tag{15}$$

where k – matrix of gain coefficients.

The law of feedback (15) can be found by solving the linear quadratic problems [3, 4]. The system (14) optimized for quadratic quality criterion

$$I = \int_0^{\infty} \left(\dot{\nu} Z \nu + r u^2 \right) dx \tag{16}$$

In the linear approximation $\dot{y} = \theta,\quad \ddot{y} = c,$ possible to choose the following matrix structure Z, and it represented in (16):

$$Z = diag\{0,\ 0, 1\} = PP',\quad P = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix}.$$

To solve tasks – finding the matrix k it is necessary to use the procedure of the space state method [7]. Taking into account the form of the matrix Z In this task, we use the frequency method [3, 4], connected with the factorization of the characteristic determinant ($\lambda(s)$) Hamiltonian matrix of the variational task, conditioned by the ratio (14), (16). It is known that the roots of this polynomial lying in the left half-plane coincide with the roots of the characteristic polynomial of the optimum closed system "object+ regulator". In the accepted notation is a polynomial $\lambda(s)$ looks like [3, 4]:

$$\lambda(s) = -\gamma(s)\gamma(-s)\left(1 + \frac{1}{r} H(-s) H(s)\right);$$

$$(\gamma(s)) = \det(Es - A),\quad H(s) = P(Es - A)^{-1} B.$$

if

$$\gamma(s) = s^3,\quad H(s) = \frac{1}{s^3},$$

so

$$\lambda(s) = s^6 - \frac{1}{r}.$$

The constants *a, b, d* can be determined through parameter *r*.

Conclusion. The algorithm for stabilizing the movement of the measuring tip of three coordinate IBC for measuring complex spatial surfaces during the scanning of the object of measurement, in a straight line and in a circle has been developed. An equation for control effects on the measuring head is obtained. Similarly, it is possible to construct an algorithm for stabilizing the motion of a measuring head on a curve for software platforms with numerical control in determining objects based on implicit equations of classical surfaces (plane, cylinder, sphere).

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