EXPANSION OF TECHNOLOGICAL CAPABILITIES OF DIAGNOSTICS OF FINISHING THREAD GRINDING OPERATIONS

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Abstract.

When machining lead screws, the accuracy of thread grinding is influenced by random factors, in particular, axial temperature and residual deformations of the machined parts. Therefore, for high-precision thread processing of premium lead screws, in addition to ensuring the accuracy of thread grinding, it is necessary to use a rational finishing grinding technology.

The existing methods for increasing the accuracy of finishing grinding can be conditionally divided into methods that allow to eliminate the influence of systematic components of the processing error and methods that allow taking into account the influence of a random component.

The paper proposes a method for automated grinding, which makes it possible to take into account the errors of the kinematic chains of the grinding machine. According to this method, a preliminary measurement of machine errors is made, for example, errors of movement of the working bodies of the machine, and then these errors are recorded in the memory of the numerical control system in the form of a spreadsheet, in accordance with the data of which corrective actions are developed, or the error is described functionally, and a mathematical model is fixed in the memory of the system, which reduces the amount of memory occupied. Proactive active control of temperature deformation of precision screws, produced by an automatic system, allows to stabilize temperature deformation at the level of correction setting, and thereby eliminate the random component of the accumulated error of the thread lead.

Keywords: grinding, residual stresses, solid lubricant, system.

1. Introduction.

In addition to ensuring the precision of the grinding machine, it is necessary to use rational finishing grinding technology for high-precision machining of the threads of high-quality lead screws.To increase the stability of the thread grinding technological process, modern machine models are equipped with numerical control systems that allow you to program the thread grinding working cycle. For example, screws 63x10mm with a thread length of 1200 mm after processing had a variation in the accumulated pitch error from 13 to 38 microns, although the technology and processing modes were unchanged [1]. The system of active control of the axial elongation of the screw during grinding, which is equipped with a numerically controlled machine, does not allow time to correct the technology and modes of thread grinding, since the influence of the technological transition on the value of this elongation can be detected only after the end of this technological transition.

2. Research results.

The existing methods for increasing the accuracy of finishing grinding of threads can be conditionally divided into methods that allow to eliminate the influence of systematic components of the processing error and methods that allow taking into account the influence of a random component. The first group includes methods aimed at increasing the kinematic accuracy of the grinding machine. A method is proposed for eliminating errors in the kinematic chains of the machine by using a linear displacement meter of a laser interferometer. An attempt is made to take into account (compensate) the random component of the step error. The essence of the method consists in maintaining the constancy of the ratio of the increment in the angle of rotation of the product $\Delta\varphi$ to the increment in the table displacement ΔS, ($\Delta\varphi / \Delta S = \text{const}$), taking into account the axial deformation of the screw being processed. The control action is the movement of the machine table. With multi-pass machining, it becomes necessary to take into account thermal deformations. A method for compensating the random component of the thread pitch error is proposed, which consists in the fact that before the beginning of each transition, the axial temperature deformation of the workpiece is measured (measured using the displacement sensor of the tailstock quill of the machine) and the axial temperature deformation of the lead screw of the grinding machine. At large values of axial temperature deformations, which in this method of accuracy control change arbitrarily, a decrease in the correlation coefficient between the axial temperature deformation of the part and the accumulated error of the thread pitch is observed. To achieve this goal, it is necessary to control the axial temperature deformations of the machined lead screws that arise in the grinding process. The author [3] proposed a method for controlling axial temperature deformations when grinding threads with multi-thread wheels (rough grinding) by providing the following algorithm:

$$P/V\partial=const \qquad (1)$$

where P is the power of grinding, Vd is the speed of the part. The device consists of such units as the active power sensor of the grinding wheel drive electric motor, an electronic voltage transducer, and units that serve to generate a signal.

The device works as follows. In the process of processing, the active power signal is amplified and enters the electronic converter device, where the part speed signal is simultaneously received. At the output of the device, a P/Vd signal is generated, which is compared with the value set in the reference block. If they differ, the speed of the part is automatically corrected by increasing or decreasing the latter until the condition is met: $P/Vd = P/Vd$. This method made it possible to significantly increase the processing accuracy during the multi-thread grinding operation, but it is unacceptable for the finishing multi-pass grinding operation. The P/Vd criterion is an energy criterion and determines the work spent on grinding a unit of length of the workpiece processed surface, i.e. actually characterizes the amount of heat introduced into the workpiece during multi-thread grinding. In this work, it was indicated that as the cooling intensity increases, the Biot criterion, the length of the cooling zone increases), the uniqueness of the dependence of the axial temperature deformation and the specified criterion ($\Delta L = f\,(P / Vd)$) is violated. This dependence takes place for conditions of low-intensity heat transfer, which is quite acceptable for a multi-strand grinding scheme, since the error is formed on the width of the grinding wheel, the effect of cooling can be neglected. The article proposes a method for increasing the grinding of threads based on the diagnostics of the technological operation. The mathematical model characterizing the technical state of the technological system of multi-pass single-thread grinding of threads [1] has the following form:

$$l_{ij} = \sum_{n=1}^{\infty} \frac{4\exp(-\mu_n^2 F_{02}) B_i^2}{\mu_n^2(\mu_n^2 + B_i^2)} \left\{ \frac{qLRL_p\gamma}{s\lambda} \left(2F_{01} + \frac{1}{4} - \frac{2}{\mu_n^2} + \frac{1}{B_i} - \sum_{n=1}^{\infty} \frac{2\exp(-\beta_n^2 F_{01})\mu_n^2}{\beta_n^2(\mu_n^2 - \beta_n^2)}\right) + l_{0ij} + (T_{\text{в}} - T_c) L_p \gamma \right\} - \gamma L_p (T_{\text{в}} - T_c) \tag{2}$$

where l_{ij}, 10_{ij} – current and initial temperature elongation of the i-ro screw blank at the j-th technological transition; *Lp, R* – length of the threaded part and radius I of the workpiece; $Foi = a_{\tau i} / R^2$ $(i = 1,2)$ – generalized Fourier variables characterizing the heating time $\tau 1 = Lp\ a / \upsilon_\partial R^2$ and cooling $\tau_2 = lcool / \upsilon_o$, *Lp*, *L* are the length and width of the contact of a real heat source; $\upsilon_{\text{д}}$, $\upsilon_0 = \upsilon_{\text{д}}$ sinφ – circumferential and axial speeds of the workpiece; $\varphi = arctan\ (s / 2\pi R)$ – thread rise angle; *S* – thread pitch; $Bi = \alpha / \lambda$ R – BIO criterion; α, γ, λ, α – coefficients of heat transfer, linear expansion, thermal and thermal diffusivity;

μn, βn are the roots of the characteristic equations I_0 (μ_n) Bi-I_1 (μ_n) $\mu_n = 0$ and I1 (βn) = 0; I0, I1 – Bessel functions of the first kind of zero and first order; *Tv, Tc* – air temperature.

Equation (1) describes the mechanism of formation of the lij value during finishing grinding. However, due to the complexity of this equation, it cannot be directly used for the mathematical support of the control computer. In a limited range of variation of the variables F_{01}, F_{02} and Bi, the function lij (F_{01}, F_{02}, Bi) can be represented by a linear relationship. For example, with 9.75 • 10-5 ≤ F01 ≤ 58.5 • 10-5; 0.0679≤F02≤0.2037 and 0.1≤Bi≤1.5 equation (1) will have the form:

$$l_{ij} = a_1 \frac{P_{ij}}{n_{ij}} - a_2 \frac{P_{ij}}{n_{ij}^2} + a_3 l_{0ij} - a_4 \frac{1}{n_{ij}} \tag{3}$$

where Pij, nij - grinding power (W) and part speed (rpm) at the j-th technological transition of the i-th machined screw; as (s = 1, 2, 3,4) - coefficients determined by the following formulas:

$$a_1 = 1{,}276 L_p; a_2 = 5{,}815 L_p; a_3 = 1 - 9{,}702/n_{ij} a_4 = 116{,}33 L_p (T_{\text{в}} - \text{T}_c) \tag{4}$$

To ensure the adequacy of equation (2) to the real process, an automatic correction of this equation during the operation of the technological system is proposed. The essence of this principle consists in automatic correction of the coefficients as in equation (2) based on a comparison of the measured and calculated values of lij. For this, a sensor for the axial elongation of the screw is used, and the algorithm for correcting the mathematical model [2] is based on minimizing the difference between the actually measured (Lfij) and calculated (Lpij) values of axial temperature deformation.

In [4], an algorithm for correcting the mathematical model is described, which consists in determining the additions Δap to the coefficients as, according to the formula:

$$\Delta a_p = \frac{\Delta y \frac{\partial f}{\partial a_p} \frac{1}{c_p}}{\sum_{s=1}^{k} \left(\frac{\partial f}{\partial a_s}\right)^2 \frac{1}{c_s}} \tag{5}$$

where $\Delta y = (l_{\phi ij} - l_{pij})$ is the difference between the measured and calculated values of the predicted value; f (-) is the equation by which the predicted value is calculated; c_i – weighting factors allowing to adjust the value and ratio of calculated additions Δa_s.

Taking into account formula (3), the algorithm for determining the adjusted values of the coefficients of the mathematical model (2) will have the following form:

$$a'_1 = a_1 + \frac{\Delta y}{A_{c_1}} \frac{P_{i1}}{n_{ij}}; \quad a'_3 = a_3 + \frac{\Delta y}{A_{c_3}} l_{0i1};$$
$$a'_2 = a_2 - \frac{\Delta y}{A_{c_2}} \frac{P_{i1}}{n_{i1}^2}; \; a'_4 = a_4 - \frac{\Delta y}{A_{c_4}} \frac{1}{n_{ij}}; \tag{6}$$

where $\Delta y = (l_{\phi i1} - l_{pi1})$

$$A = \left(\frac{P_{i1}}{n_{i1}}\right)^2 \frac{1}{c_1} + \left(\frac{P_{i1}}{n_{i1}^2}\right)^2 \frac{1}{c_2} + \frac{l_{0i1}^2}{c_3} + \left(\frac{1}{n_{i1}}\right)^2 \frac{1}{c_4} \tag{7}$$

As a result of the analysis of the influence of the weight coefficients ci, (i = 1.4) on the forecasting accuracy lij under the conditions of automatic correction of equation (2) of the mathematical model according to the described algorithm, it has been established that there is an optimal ratio of the coefficients ci at which only one from the weighting factors. For example, with successive correction of equation (2) by coefficients a2 and a4, the correction algorithm has the following form:

$$a'_2 = a_2 - (l_{\phi i1} - l_{pi1}) \frac{n_{i1}^2}{P_{i1}}$$
$$a'_4 = a_4 - (l_{\phi i2} - l_{pi2}) n_{i2} \tag{8}$$

In the described correction method, the identification of the control object, that is, the finishing grinding technological process, is carried out in a minimum time equal to the duration of one or two technological transitions. After determining and indicating Lpij, during the entire time of the technological transition, it is in 60 state of waiting for a signal, the appearance of which means the end of the technological transition. The signal is used to enter the actual deformation value Lpij into the computer. As a result, the values of Lphij (obtained at the beginning of the transition) and (obtained at the end of the transition) are found simultaneously. Moreover, the value Lfij is a preliminary (predicted) estimate of Lfij. With ideal forecasting, these values should be the same, that is, Lpij = Lϕij. However, predicting the Lpij value based on equation (2) gives an error Δy = (l_phi1-l_pi1). To reduce this error, the equation (2) of the mathematical model is corrected. In this case, at the beginning of each technological transition, the calculated value Lpij is displayed on the external indicator, and at the end (when the KV = 1 signal appears), the content of the transition counter increases by 1. The described cycle of operation is carried out until the next signal appears, which means the end of processing of this part. The estimation of the forecasting accuracy Lij during the system operation was carried out experimentally on the "Matrix 5708" grinding machine. The processing was carried out with a single-thread grinding wheel with the characteristic 92A16SM17K5. During the processing, I-20A oil was used. Each method for correcting equation (2), implemented by the corresponding control programs, was investigated when processing a batch of blanks of at least 10 pieces, and the logging of experimental data Loij, Pif, nij, Lpij, Lϕij was performed automatically in the data accumulation and forecasting mode.

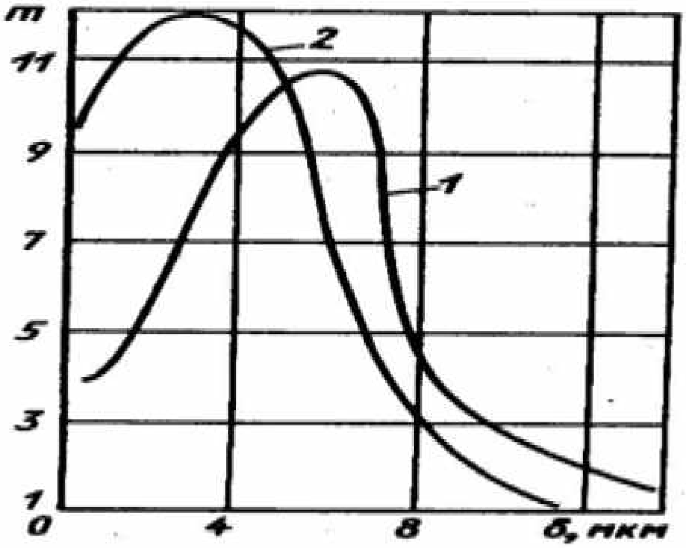

Fig. 1. Distribution of the forecast error with one (curve 1) and two-time (curve 2) correction of the mathematical model; m- frequency.

In fig. 1 shows the distribution curves of the prediction error for the cases of one- and two-time model correction. In the first case (curve 1), the correction of the mathematical model is carried out after the first technological transition once during the processing cycle of the part. In the second case (curve 2), the correction is carried out sequentially after the first and second technological transitions. Analysis of curves 1 and 2 shows that the probability of forecasting Lij with an error of up to 6 μm for one- and two-time correction is 60 and 72%, respectively.

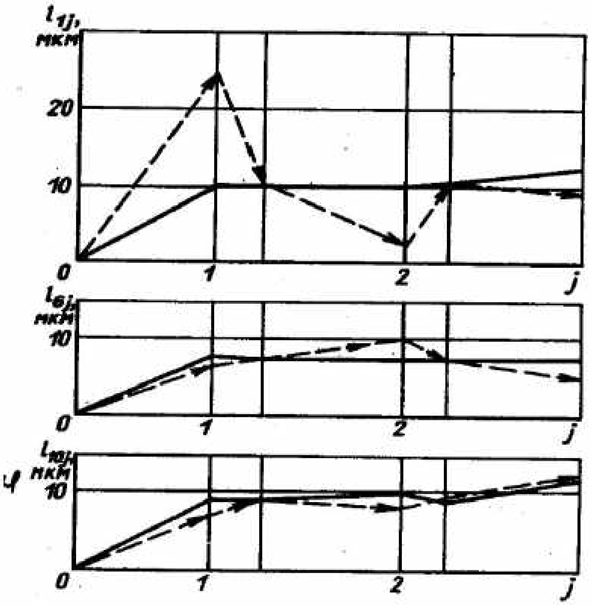

Fig. 2. Timing diagrams of the calculated (dashed line) and actual (solid line) axial deformations of the machined screws 63x10x630 mm (j is the number of the technological transition).

In fig. 2 shows the experimentally obtained time diagrams of axial deformations of the first (L1j), sixth (L6j) and tenth (L10j) machined screws, selectively taken from sequentially machined parts. Left-hand threads are ground in the feed direction from the front center of the machine to the rear, and right-hand threads are vice versa. To compensate for the displacement, it is necessary, continuously, during the transition of thread grinding, to control according to the criterion:

$$\frac{\Delta\varphi}{\Delta l} = const \tag{9}$$

where Δφ is the increment in the angle of rotation of the screw to be ground;

Δl - increment of axial thermal deformation of the ground screw, measured by the axial deformation sensor.

The stability of the Δφ to Δl ratio can be achieved by turning the machine spindle, or by additional movement of the grinding wheel relative to the profile of the thread to be ground. The signal was blocked if the condition of formula (7) was not met, while, as the screw cooled, the axial temperature deformation was monitored. The value of the reverse stroke speed was set in such a way as to ensure the removal of the required amount of heat from the workpiece during the return stroke, by the method of local irrigation over the entire surface of the part, in order to fulfill the condition of formula (8).

$$\Delta L_{\text{оф}ij} = K_{xb} \tag{10}$$

where L_{ofij} is the actual axial temperature deformation of the i-th screw being ground before the beginning of the last j-th transition,

K_{xb} is the correction made to the machine lead screw.

This method of stabilizing axial temperature deformations during multi-pass grinding was proposed in work / 9 /. If, upon completion of the penultimate transition of grinding, the value of the axial temperature deformation of the screw to be ground is *-Δl (j-1),* and *Δl (j-1)> Kхв,* then to compensate for the excess heat content of the workpiece, on the return travel of the machine table, it is necessary to set the speed determined from the following equations:

$$\Delta l = \frac{2\alpha l_0 \left\{ L_p \gamma \Delta T_M + \dfrac{U_{oj}\Delta l_{j-1} \exp\left(-\dfrac{K}{V_{j-1}}\right)}{V_{j-1}\Big(1 - \exp \Big(-\dfrac{K}{V_{j-1}}} \Big(1 - \exp \Big(-\dfrac{K}{U_{oj}} \right\}}{c\gamma_c R V_{j-1} - \alpha_1 (L_p - l_o)} + \frac{2\alpha_1 \text{К}_{\text{хв}} (L_p - l_0)}{c\gamma_c R V_{j-1} - \alpha_1 (L_p - l_0)}$$

Where $\Delta l = \Delta l_{j-1} - \text{К}_{\text{хв}}$

$$\text{К} = \frac{2\alpha_1 L_p}{c\gamma_c R}$$

$$\Delta T_M = \text{Т}_\text{В} - \text{Т}_\text{М} \tag{11}$$

In the formulas (8) - (11)

U_{oj} is the required reverse speed before the beginning of the last J -th transition, which allows compensating the value of Δl, m / s;

Vj-1 - speed of the part at the penultimate transition, m / s; 176

TV, TM, - air and lubricant temperatures, respectively.

So when processing right-hand threads, control is carried out in two stages, at the penultimate transition and on the reverse, before the start of the last transition:

1. At the penultimate transition, control is carried out in accordance with the criterion *Δl(j-1) ≥Kхв*, while the control parameter is the speed of the part nj-1.

2. On the return stroke, the cooling compensates for the excessive elongation of the screw to be ground, i.e. control is carried out in accordance with the criterion $\Delta l_{0j} = K_{хв}$ and, the control parameter is the cooling time of the part, or the return speed of the machine table - Uoj, calculated by the formula (8) (in this case, the return speed also determines the cooling time of the part).

When grinding left-handed threads, an additional third stage of control appears to compensate for the value of Δl *(lz)*. For this, at each transition, including the last one - j, it is necessary to carry out control in accordance with the criterion $\Delta\varphi / \Delta l = const$.

Conclusions.

1. Axial thermal deformation of the machined lead screws can be used as a parameter characterizing the state of the technological system of final thread grinding, since this parameter predetermines the accumulated error of the thread pitch and characterizes the processing performance.
2. Proactive active control of temperature deformation of precision screws, carried out using an automatic system, allows you to stabilize the temperature deformation at the level of adjustment of the correction ruler, and thereby eliminate the random component of the accumulated error of the thread pitch
3. The accumulation of technological data on a computer and their subsequent processing allow an objective assessment of the quality of the technological operation of the final grinding of threads.

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