MATEC Web of Conferences **224**, 01135 (2018) https://doi.org/10.1051/matecconf/201822401135
*ICMTMTE 2018*

# Adjustment of specialized technological equipment when machining small diameter internal threads with deforming cutting taps

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**Abstract.** The article provides options for threading process diagnostics. For the previously proposed method of diagnostics, an algorithm for adjusting the machine, equipped with a pneumatic drive and a diagnostic module was developed. The interrelation between the technological system characteristics and the device for diagnostic signal recording was shown. As a result, it is possible to provide maximum productivity of the technological operation without the loss of processing quality.

Adjustment of any equipment, including technological, is associated with significant time costs [1]. Modern machines, in addition to customizing the traditional characteristics of the machining process, require the selection or specification of additional parameters, such as machining strategy, tool adjustment for wear, clamping force, etc. The result of additional settings is an increase in the accuracy and reliability of machining, and in some cases, the only possibility of manufacturing the product within the specified quality and cost requirements.

In order to improve the quality and reliability of the machining, diagnostic modules are installed in metal-cutting machines that monitor and analyze the technological process parameters and give an estimate of its state [2-9].

For the analysis of machining operations, the following methods are widely used:

– acoustic emission [2, 3, 5-7], based on collection, recording and analysis of elastic deformation waves;

– diagnostics based on strength characteristics of the process [3, 4, 9];

– diagnostics based on EMF and cutting temperature for laboratory studies [8].

For cutting small diameter internal threads, machine tool designs with pneumatic drives [10] were developed, and became widespread in machine-building enterprises due to their high reliability and low cost. However, the use of compressed air, as a working fluid, does not allow for precise adjustment of the machine and leads to instability of machining parameters. Thus, for example, when machining a group of similar holes, due to tool wear, the time consumed to form one threaded hole is increased. It can be explained by the absence of a rigid connection between the output characteristics of the machine drive – power and speed.

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This article is devoted to the development of an adjustment algorithm for a machine equipped with a pneumatic drive and a diagnostic module when small diameter internal threads are machined with deforming-cutting taps. The main purpose of the presented development results is to increase the thread cutting process efficiency.

It is possible to increase threading efficiency due to the cutting process diagnostics. The existing diagnostic methods based on acoustic emission and power characteristics are related to hardware implementation difficulties and the way signals are received by control devices.

A diagnostic method was proposed for pneumatic drive machine tools; and as a diagnostic signal this method was based on the thread-cutting time [11].

The basic scheme for implementing this method is shown in Figure 1.

When cutting the thread, spindle 4 from position I moves into position II, which is fixed by sensors 9 and 10, while device 11 (which can be implemented as a data acquisition board) determines the travel time. As the tool wears, the cutting torque increases and the travel time of the spindle increases, which is determined by the use of pneumatic cylinder 1 in the power head design. The proposed method makes it possible, based on the analysis of the intensity of the machining time increase and its approximation to the boundary value, to estimate the moment for changing the blunt instrument, thereby increasing the reliability and quality of the technological operation.

The small diameter threading process is a fast one, thus, it causes some difficulties that arise during machine adjustment.

These difficulties are related to determining the area of the throttle hole 8 and its changes during machining.

The maximum area of the throttling hole, on the one hand, ensures maximum performance, on the other hand, defines a "blind spot" for recording device 11.

A "blind spot" refers to such a combination of signals registered by device 11, when a controlled analog signal, due to various factors, falls into the same digital pulse of the device.

For example, for LA-50USB data collection card, the time of registration, processing, and transfer of the signal to the computer is 50 μs, if the signal difference when machining a certain group of holes is less than 50 μs, the device produces the same value, and the change in the technological process is not observed (see Figure 2).

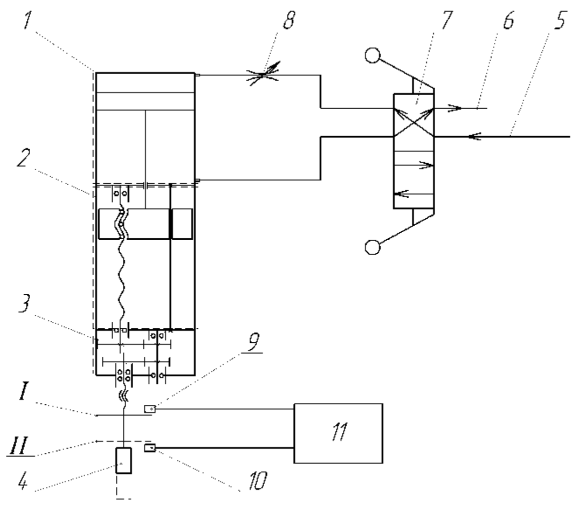


**Fig. 1.** Elementary diagram of equipment: 1 – air cylinder; 2 – motion conversion node; 3 – multiplier; 4 – spindle; 5 – supply line; 6 – exhaust pipe; 7 – air distributor 4/2; 8 – throttle; 9, 10 – sensors; 11 – recording device

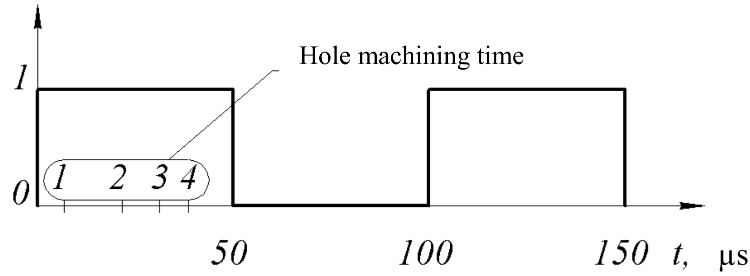


**Fig. 2.** "Blind spot" effect

For effective diagnostics and reliability of threading operations, it is necessary to avoid the above-mentioned "blind spot" effect, which is possible by changing the area of throttle opening 8.

The solution to the task is accomplished by implementing the following algorithm:

1. The limiting value of the maximum torque of cutting forces $M_{\max}^{гр}$ [4] is determined; and the excess of this value indicates errors in the technological process of machining;

2. The limiting value of the minimum torque of cutting forces $M_{\min}^{гр}$ is determined. In this case, it will be equal to the cutting forces torque $M_{кр}$ during the operation of deforming-cutting taps [12, 13]:

$$M_{кр} = \sum_{i=1}^{z} 6{,}632\tau_{сдв} \cdot a^2 \cdot (2i-1) R_i \cdot \left(1 - tg\gamma \cdot \frac{1+\xi^2}{2}\right) \cdot \left(1 - \frac{11250 \cdot tg\gamma \cdot (\xi+1)}{(90-\gamma)^{2,46}} K_L^{0{,}0015(90-\gamma)^{1,27}}\right) +$$

$$+ \sum_{j=1}^{m} 4{,}901 \cdot k \cdot \sigma_\tau \cdot \mu_1 \cdot a^2 (2j-1) \cdot R_j \cdot \left(\frac{1}{\sin\alpha_1} + \frac{1}{\sin\alpha_2}\right) \sqrt{\frac{k\sigma_\tau f}{E} \frac{(D+2\rho_j)}{D} \cos\psi},$$

where $R_i$, $R_j$ are the average radii of the relative position of the tap's cutting and deforming teeth $R_i = \left(\frac{d_{вн}}{2} + 0{,}3725 \frac{P \cdot i}{Z} \cdot tg\varphi\right)$,

$$R_j = \left(\frac{d_{вн}}{2} + 0{,}3725 \frac{P \cdot j}{Z} \cdot tg\varphi\right).$$

3. The resulting range $M_{\min}^{гр} — M_{\max}^{гр}$ is divided into a finite number of equal parts with a necesary sampling value between the intervals $\Delta M$ (see Figure 3).

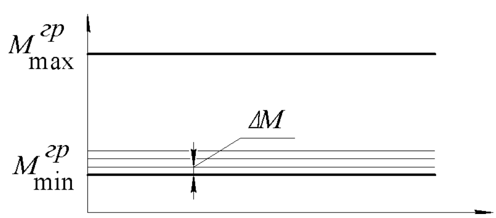


**Fig. 3.** Splitting a range of boundary values.

4. For cutting torque $M_{\min}^{гр}$ and $M_{\min}^{гр}+\Delta M$ vector of values $\vec{t}$ is determined – response time, depending on the vector of the area values of throttling hole $\vec{f_1}$, all other things being equal. This is done by solving a mathematical model that characterizes the work of a pneumatic drive machine:

$$\begin{cases} m\dfrac{d^2x}{dt^2} = p_1S_1 - p_2S_2 - N_{тр} + G - F_4; \\ \dfrac{dp_1}{dt} = \dfrac{kf_1Kp_м\sqrt{RT}}{S_1(x_{01}+x)}\varphi(\sigma) - \dfrac{kp_1}{(x_{01}+x)}\cdot\dfrac{dx}{dt}; \\ \dfrac{dp_2}{dt} = -\dfrac{kf_2Kp_2^{\frac{3k-1}{2k}}\sqrt{RT}}{S_2(s+x_{02}-x)p_2^{\frac{k-1}{2k}}}\varphi(\sigma) + \dfrac{kp_2}{(s+x_{02}-x)}\cdot\dfrac{dx}{dt}; \\ \varphi(\sigma) = \begin{cases} 0{,}2588, & при \quad \sigma \le 0{,}528 \\ \sqrt{\sigma^{\frac{2}{k}} - \sigma^{\frac{k+1}{k}}}, & при \quad 0{,}528 < \sigma < 1. \end{cases} \\ F_4 = \dfrac{P_5}{D_{ср}^2}\left(\dfrac{z_5}{z_6}\cdot\left(\dfrac{z_7}{z_8}\cdot\dfrac{z_9}{z_{10}}M_{рез} - J_{пр7}\dfrac{d^2\psi_7}{dt^2} - c_{упр10-7}\psi_7\right) - J_{пр5}\dfrac{d^2\psi_5}{dt^2} - c_{упр6-5}\psi_5\right) \end{cases}$$

where $m_{пр3}$ is the total mass of reciprocating moving parts of the thread-cutting head; $x$ – piston travel coordinate; $x_{01}, x_{02}$ – initial and final position of the piston; $p_1$ – cylinder pressure; $p_2$ – cylinder stem pressure; $p_м$ – air pressure in the main pipeline; $S_1$ – piston area in a rodless cavity; $S_2$ – piston area in the rod cavity of the air cylinder; $N_{тр}$ – frictional force in the air cylinder; $G$ – gravity; $R$ – gas constant; $T$ – absolute air temperature; $\mu$ – coefficient of friction; $k$ – adiabatic index: $K$ – coefficient; $f_1$ – effective area of the inlet in the rodless cavity; $f_2$ – effective area of the inlet in the rod cavity; $\sigma$ – dimensionless pressure; $z_{7...10}$ – the number of gear teeth; $\psi_5, \psi_7$ – angle of rotation of gears 5 and 7; $J_{пр5}, J_{пр7}$ – given moment of inertia relative to the rotating elements; $c_{упр6-5}, c_{упр10-7}$ – torsional stiffness of the motion conversion unit and the multiplier; $M_{рез}$ – cutting torque; $D_{ср}$ – average diameter of splined shaft; $P_5$ – step of the shaft splines.

5. The data obtained in stage 4 are approximated by the following formulae:

$$t_1 = A_1e^{-b_1f_1},$$

$$t_2 = A_2e^{-b_2f_1},$$

where $t_1$ — vector of values of the spindle moving time at cutting moment $M_{\min}^{гр}$;

$t_2$ — vector of values of the spindle moving time at cutting moment $M_{\min}^{гр} + \Delta M$ ;

$A_1, A_2, b_1, b_2$ — coefficients corresponding to the load at $M_{\min}^{гр}$ и $M_{\min}^{гр} + \Delta M$ ;

$f_1$ — vector of throttling hole area values.

Approximated data are represented in Figure 4.

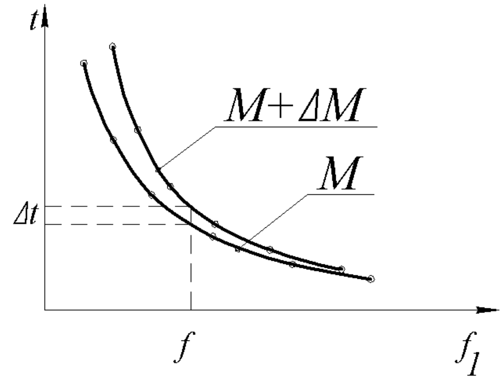


**Fig. 4.** Approximated data based on Point 3.

6. The "blind spot" value is determined by the correlation:

$$\Delta t = t_2 - t_1 = A_2 e^{-b_2 f_1} - A_1 e^{-b_1 f_1} \text{ ,}$$

when $k = \dfrac{A_1}{A_2}$, based on dependence:

$$\Delta t = A_2 e^{-b_2 f_1} (1 - k e^{(b_2 - b_1) f_1})$$

The value of the throttling hole area is found from equation (1). To eliminate the "blind spot" effect and to increase the sensitivity of device 11 to the level at which it reacts to the specified minimum increment of torque $\Delta M$ , it is necessary to increase $\Delta t$ by 3-4 times:

$$\Delta t_{настр} = (3-4) \times A_2 e^{-b_2 f_1} (1 - k e^{(b_2 - b_1) f_1}). \qquad (1)$$

Equation (1) is nonlinear and its solution in relation to $f_1$ is only numerically possible. However, it does not take into account the stochastic factors, which affect the process and can be compensated by an additional coefficient $K_{cm}$, determined, for example, on basis of experimental studies.

Then dependence (1) takes the following form:

$$\Delta t_{настр} = (3-4) \times A_2 e^{-b_2 f_1} (1 - k e^{(b_2 - b_1) f_1}) K_{cm}$$

The developed algorithm for adjusting the machine equipped with a pneumatic drive considering the characteristics of the diagnostic signal recording device provides high efficiency of the threading operation and the required quality.

The proposed methodology can be further adapted to control the process of small diameter internal threading in conditions of flexible automated production in machine systems equipped with pneumatic and hydraulic drives.

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