Improving the accuracy and quality of machining by controlling the cutting process

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Abstract. The development relates to machine tool construction, in particular, to the technological processes of chip removal with automatic control of technical process parameters. The installation allows you to automatically manage the process of turning. New in the process of turning is that the position of the cutter in the ZOY plane is changed directly in the cutting process, which reduces cutting forces. Registration of which is carried out by an indirect method based on the analysis of vibroacoustic emission, and is corrected by information about the torque on the main drive of the machine. The installation is a tool rotation mechanism, in which the worm-worm sector, is equipped with a controlled drive and a feedback control circuit on the position of the worm.

1. Introduction

Considered to improve the accuracy and quality by reducing the depth of the deformed layer and residual stresses during turning. The development allows you to automatically manage the process of turning. New in the process of turning is that the position of the cutter in the ZOY plane is changed directly during the cutting process, which reduces cutting forces, the latter are recorded indirectly by analyzing vibroacoustic emission, and are corrected by information about torque on the main drive of the machine. The installation is a tool rotation mechanism, a worm-worm sector, equipped with a controlled drive and a control loop with feedback to the position of the worm.

2. Cutting control scheme

A new technological method consists in changing the position of the cutter in the ZOY plane directly during the cutting process, which allows a reduction in cutting forces on a narrow range of variation of the front cutting angle $\gamma$. Registration of which is carried out by an indirect method based on the analysis of vibroacoustic emission and is corrected by additional information about the torque on the main drive of the machine. The main diagnostic feature of the method is the functional connection of the main drive torque of the movement of workpiece and the output signal from the vibroacoustic emission converter installed in the direction of the component of the cutting force $P_y$ or $P_x$. The minimum torque causes the maximum vibroacoustic emission signal. The proposed development is based on the study of the dynamics of the cutting process, based on the analysis of the spectrum of forces and movements in a
wide frequency range. The features of the dynamic phenomena occurring in the chip-formation zone are taken into account, taking into account the changing physicomехanical characteristics of the materials of the tool-blank contacting pair [1-15].

The automatic control system for optimizing the cutting process includes registering changes in the cutting force, in particular, recording the selection of the active component of the main drive power, functionally related to the power load of the cutting wedge [6-9], is performed from the electrical part of the main motion drive. Next, carry out the registration of additional physical parameters that carry information about the conditions of destruction of the material, in terms of the plane of the "cleavage" of the chip zone. As the conditional physical parameter, the most informative frequency component of the spectrum of the lamellization process in the chip control zone is selected. At the same time, the vibroacoustic emission spectrum of the emitted chip formation zone is recorded from the back side of the cutting tool 1, in the direction of the pressing force component P_y using the vibroacoustic emission converter 2 (Figure 1 and Figure 2).

![Figure 1. Installation Management Functional Diagram](image1)

![Figure 2. General view of the drive turning the cutter and its cut](image2)

The selection of the most informative frequency component of vibroacoustic emission is carried out using the selective diagnostic channel [10-11]. It consists of a series-connected preamplifier 3, a selective amplifier (narrowband filter) 4, an amplitude detector 5. And also - block 10, averaging (low pass filter) 6, the first comparison circuit 7, connected to the second input of the setter 8. Additionally - the permissible value of the parameter being monitored, the automatic tuning block 9, the tuning of the selective amplifier 4. By the maximum output signal at the output of the averaging block 6, as well as the automatic adjustment of the controller of the permissible counter value parameter 8, which stores the maximum amplitude value of the level of the most informative lamellization frequency of the chip-forming process, performs diagnostics of a multi-pass recorder 10, including a two-input coincidence circuit, a switch of the type of changes and a relay-regulator. In addition, the selective channel additionally performs automatic tuning tunable selective amplifier 4 using the automatic tuning system. In the process of control processing at constant, optimal from the point of view of obtaining maximum performance and a given quality of forming the surface, parameters of cutting speed, longitudinal feed,
depth of cut - V, S, t [2-5]. In this case, in the initial state, the value of the front angle \( \gamma \) is chosen with the maximum possible positive value, limiting it to the value of the back angle \( \alpha \) [3]. The variation of the value of the front angle \( \gamma \) is carried out with the help of a specially created controlled turning mechanism, equipped with an adjustable electric drive, including blocks 11 - 16. The design features of the turning mechanism, including the worm pair 14 - 15, are dictated by the need for a smooth change the value of the rake angle directly during processing, keeping the position of the tip of the tool unchanged. In the case of the worm wheel 15, the fingers are rigidly fixed (maximum three) 17 along the radius with the center of rotation passing through the tip of the tool, equidistant to the pitch diameter of the worm wheel. The fingers 17 perform the functions of the bearings together with the segment guide grooves, the latter are also made equidistantly dividing the diameter of the worm wheel in the housing of the rotation mechanism 18. The length of the groove (guides for the fingers 17) is equal to the limiting angle of rotation of the cutter relative to the axis OX in the plane ZOY. The installation radii of the fingers 17 and the guide grooves made in the housing 18 of the turning mechanism are equal to each other. The initial value of the position of the forward angle \( \gamma \) is set by a controlled setting device 11, in the form of an analog voltage supplied to the input of the second comparison circuit 12, an adjustable electric drive 13. The latter, as the forward angle \( \gamma \) increases from positive to negative values, changes the value of the reference voltage at the second input of the second circuit comparison 12 by applying an analog voltage from the feedback sensor 16, registering the true value of the angle of rotation of the worm 14. Automatic reduction of the front angle \( \gamma \) from positive value to the negative value has a significant effect on the temperature and speed factors in the chip-formation zone by increasing the chip shrinkage coefficient \( k \), and reducing its speed, based on the condition:

\[
V_s = \frac{V}{k}
\]

where \( V_s \) - chip flow rate; \( V \) is the cutting speed, and also due to a change in the position of the angle \( \beta \) (\( \beta \) is the angle of inclination of the conventional shear plane), which affects the kinetics of the chip formation process as a whole. Moreover, for the optimum value of the front angle \( \gamma \), a value is chosen such that the energy level of the most informative frequency component of the lamellarization spectrum of the chip forming process increases by 2–3 times. At the same time, the consumption of active cutting power is reduced by the selected optimal values of \( V, S, t \). A decrease in the positive value of the front angle \( \gamma \) to negative values is accompanied by a decrease in the speed of the chip according to formula (1) and, consequently, the frequency of lamellization of the chip formation process decreases. Spectrum modification is monitored automatically using the automatic tuning unit 9 by tuning the narrow band filter 4 to the most informative vibroacoustic emission frequency according to the maximum value of the output signal of averaging unit 6. When the energy level of the most informative frequency component specified by the set (filled) setting unit 8 is exceeded control processing at the output of the comparison circuit 7, a differential analog signal appears. The latter, together with the signal functionally associated with a decrease in the active power output of the main motion drive (consisting of blocks 19-22), is applied through the logic element & (two-input matching circuit) to the relay controller. The output signal of which stops the further increase (change) of the variation of the angle \( \gamma \), acting on the block 11 of the drive automatic rotation of the tool. This reduces the value of the analog voltage at its output to a value equal to the corresponding optimum value of the angle \( \gamma \).

The control signal, functionally associated with the power of destruction of the material (cutting power), form, from the reaction of the electrical part of the drive of the main movement to change the cutting force, by forming the block 25 of the control signal embedded in the electric main movement 19.

Moreover, the signal from the third comparison circuit 20 is fed to the input of the electric drive of the main movement, and to the input of which a torque master 21 and a feedback sensor 22 are connected.
3. The experiment results
The presence of several extreme values of the functional dependence of the cutting force on the active power component of the main drive electric drive and the most informative components of the AEM on the variation of the front angle $\gamma$ at constant values of $V$, $S$, $t$, allows you to choose such optimal values of the angles $\gamma$. This allows you to ensure the specified quality of forming the surface with the maximum performance of the process.

The tests were carried out on a RV106 lathe with a built-in adjustable electric drive of the main movement and equipped with an automatic control system for the angle of rotation of the tool in the ZOY plane while its tip stabilized [11–12]. For this purpose, a rotating mechanism was specially manufactured, the design features of which are shown in Figure 1 and Figure 2, mounted on the support of the machine.

The variation of cutting forces with variation of the rake angle $\gamma$ is shown in Figure 3 and Figure 5 for materials - gray and high-strength cast iron (in comparison with steel C45), and in Figure 4 for alloyed steel (in comparison with high-strength cast iron).

![Figure 3](image1.png)

**Figure 3.** Graph of the results of the study of the dependence of the total cutting force $P_{\Sigma}$ on the rake angle $\gamma^\circ$ (1-2 - high strength cast iron 2; 1-3 - gray cast iron; 1-1 - high strength cast iron 1; 2-1 - Steel C45)

![Figure 4](image2.png)

**Figure 4.** Graph of the results of the study of the dependence of the current value of thermo electromotive force $J_T$ from the front angle $\gamma^\circ$ (1-2 - high strength cast iron 2; 1-1 - high strength cast iron 1; 1-3 - gray cast iron; 2-1 - Steel C45)
Figure 5. Graph of the results of the study of the dependence of the total cutting force $P_\Sigma$ on the depth of cut $t$ (1-2 - high strength cast iron 2; 2-1 - Steel C45; 2-2 – 30HGSA; 2-3 - Steel 65G).

Processing was carried out on steel C45 and cast iron (gray cast iron, high strength cast iron 1, high strength cast iron 2) on the workpiece $D = 90$ mm (cutting plate $(2.5 \times 0.6)$ (mm x mm)) with cutting speed $V_\rho = 2.2$ m/s; $t = 0.5$ min; $S = 0.2$ mm/rpm; $\gamma = \pm 15^\circ$; $\phi = 75^\circ$; $\phi_1 = 15^\circ$; $\alpha = 10^\circ$. Steel C45 was taken as the standard (base), other materials were compared with it — gray cast iron — a sample of gray iron, two samples of high-strength cast iron — high strength cast iron 1 and high strength cast iron 2, respectively. The dependence of the magnitude of the current $I$ (electromotive force) (mA), the thermal electromotive force from the rake angle $\gamma = \pm 15^\circ$ is shown in Figure 4. From the presented figures it can be seen that, at both positive and negative values of the angle $\gamma$, the cutting forces, more often, increase, compared to its zero value. But with positive values of the angle $\gamma$, this growth is most pronounced [11, 13-15]. To improve the performance of the presented design of the incisors can be implemented by installing the support plates of the cutting element with the specified properties. What is achieved by changing their parameters of the surface layer. For this purpose, durability complexes ($D$, $C_3$) and saturation of a contact compound ($H$, $K_x$ - where the material of a more ductile material is embedded in the hollows of less ductile irregularities) are used. Their values are given in [17]. When using them, it is necessary that these parameters are minimally changed during operation and stabilized.

It was found that only some profile parameters will dramatically change their values during operation (for steel St3S - $S_m$, $R_p$, etc.), but almost all surface complexes have more dramatic changes than the profile ones, but still stabilize and accept optimal values after loading (burn-in), see Figure 6 and Figure 7.

Figure 6. Modification of the surface parameters of parts of multi-element cutters for the conditions of contact connection saturation and cyclic loading (Steel St3S) with the application of loads in $P = \{0; 250; 450; 725; 750\}$ kgf.

An experimental test on the use of complexes was carried out on a special installation when the contact is absolutely smooth and rough surface [17]. Profilograms were taken using a profilograph-profilometer mod. 201 (samples obtained finishing processing on the machine 395M), analog-to-digital converter, computing complex and specialized software. It is proved that the parameters of the profile
of the longitudinal section, both height and step, sometimes had large values after loading, at the same time, all the surface complexes under consideration always had smaller values

Figure 7. Modification of the surface layer complexes of samples of multi-element incisors working under conditions of contact connection saturation and cyclic loading (Steel St3S) under the application of loads in \( P = \{0; 250; 450; 725; 750\} \text{ kgf} \)

And this, when using the above-mentioned complexes and more stringent requirements for the surface roughness of parts of block cutters, made it possible to increase the destructive flow by 60%, vibration resistance (reduce the average amplitude of vibrations and increase their frequency) by 20%, reduce the tip offset of the cutter edge by (40 ÷ 80)% [18] (Figure 8). In Figure 8 data for cutter 1.1 and 2.1 after tightening the requirements for the surface roughness of its parts (lower values of the arithmetic mean deviation of the longitudinal section Ra) and cutter 1.2 and 2.2 to tightening the requirements for the roughness of the surface of its parts (higher values of the mean arithmetic of the longitudinal sectioning Ra). The parameter Ra is regulated, since it is he who has the dominant influence on the achievement of the properties of the contact joints of parts of multi-element incisors.

Figure 8. The results of the test tools for wear (on the back surface (h)), mm
4. Conclusions
The introduction of the proposed installation for processing parts of the "shaft" allows increase the utilization rate of the stationary equipment, productivity, accuracy and reliability of the finished products by improving the strength surface characteristics of the parts.

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