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INFLUENCE OF CUTTING TIME ON TYPES OF OSCILLATIONS DURING BLADE PROCESSING

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Abstract. Despite many years of research on the impact of vibrations on the quality of manufacturing parts and tool stability during machining, these problems are still relevant. One of the reasons is uncertainty regarding the pattern of occurrence of types of oscillations during mechanical processing and their effect during cutting.

Therefore, the work aimed to determine the patterns of occurrence of types of oscillations during mechanical processing and their effect during cutting.

The research was carried out when turning parts according to various schemes. Turning is a universal operation where it is possible to carry out continuous processing, intermittent turning, and different depths of cutting.

During the experiments, a special device was used, with the help of which it is possible to provide different dynamic characteristics of the cutter. The cutting modes were chosen so that turning occurs with self-oscillations. With the help of eddy current sensors and an electrical contact device, oscillograms of the technological system's oscillations during cutting were recorded, with the cutting time and spindle turn marked on them.

During the continuous turning of a cylindrical part, there are forced oscillations, which are superimposed firstly by the accompanying free oscillations of the technological system, and then by self-oscillations. After the first rotation of the part, the processing is carried out according to the wavy trace of the accompanying free oscillations, which, combined with the phase shift, creates the conditions for self-oscillation occurrence. When turning with a full depth of cut, there are forced oscillations on which self-oscillations are superimposed.

When turning a cylindrical part with a groove, the cutter cuts into it with an impact at each turn. At the same time, there are forced oscillations during cutting, which are superimposed by the technological system's accompanying free oscillations and self-oscillations. Due to the wavy trace on the cutting surface, self-adjustment of the self-oscillations occurs in the transition zone after attenuating the accompanying free oscillations. During idling, free oscillations of the cutter take place.

When turning an eccentrically fixed part, the cutting depth changes continuously. The excitation source of the forced and accompanying free oscillations is the action of the periodic cutting force.

Under such conditions, self-oscillations do not occur.

When turning inserts of a limited length during cutting, forced oscillations are applied, which are superimposed by the accompanying free oscillations of the technological system. Despite a wavy cutting surface, there is not enough time for self-oscillations to occur.

The conducted studies show that during machining, there is a regularity of the action of the types of oscillated oscillations operating throughout the cutting time. At the same time, the accompanying free oscillations of the technological system are superimposed and act on them for a certain time, after which, due to transient processes, self-oscillations occur until the end of the cutting.

Their characteristic features determine the types of oscillations that occur during cutting. When the types of oscillations during cutting are known, measures are prescribed to prevent their impact on the tool's quality of processing and stability.

Keywords: oscillogram, forced oscillations, accompanying free oscillations, self-oscillations, period of oscillations, cutting time

Introduction and Literature Review

With a thrifty attitude to resources, which affects the minimization of the parts' geometric dimensions, the parts' dynamic properties come to the fore when determining cutting modes during their manufacture [1–4]. Knowledge of the vibrations that arise and their impact on the stability of the tool, the accuracy of dimensions, and the roughness of the machined surface allow you to choose appropriate measures that suppress the intensity of these vibrations. At the same time, the question of whether there is a regularity among different types of oscillations during cutting regarding the sequence of their occurrence and action is relevant. This is necessary to determine anti-vibration measures, which depend on the vibrations correctly. It is known from literary sources [5–8 and others] that forced oscillations, self-oscillations, and free oscillations of the tool and parts operate during cutting. Each has personal differences, which is very important for their identification.

Thus, forced non-extinguishing oscillations occur under the action of an external forcing force when the tool cuts into the part. Their frequency depends on the cutting frequency of the tool.

Free oscillations occur after the part or tool is removed from the equilibrium position and the force causing the push-off is removed. The frequency of free oscillations depends on the internal properties of the oscillating system. The amplitude of free oscillations depends on the initial conditions. Under the action of frictional forces, free oscillations die out.

Self-oscillations are non-extinguishing, steady oscillations supported by the energy of a constant non-periodic external influence. The frequency of self-oscillations depends on the internal properties of the oscillating system. The amplitude of self-oscillations does not depend on the initial conditions.

Main Material Presentation

The method of determining the regularity of the occurrence and action of oscillations involves the consideration of several cutting schemes shown in fig. 1. Turning was chosen as the main operation, as it allows to reproduce of the selected patterns, and during cutting sufficient time for the formation of all kinds of oscillations.

Processing according to scheme 1 (Fig. 1) involves the classical turning of a cylindrical part with a diameter of D at a cutting depth of b. According to the second scheme (Fig. 1), a cylindrical workpiece is processed at a cutting depth b, milling a longitudinal groove with a width of c. With this scheme of intermittent cutting, the cutter enters the workpiece with an impact at each turn. According to the third cutting scheme (Fig. 1), the part is fixed in the chuck with an offset relative to the spindle's axis of rotation by the amount of eccentricity e so that there is an idle stroke when the cutter and the workpiece are not in contact. With this cutting scheme, the cutting depth b will change from the smallest value to the largest and vice versa, from the largest to the smallest. The fourth scheme (Fig. 1) differs from the previous one by the presence of a longitudinal groove with a width of c. Cutting with this scheme begins with a cutting depth equal to zero and ends with its largest value when the cutter exits the groove. After idling, the cutter cuts into the workpiece with the greatest cutting depth. Then its value decreases to zero, and the cutter leaves the workpiece. According to the fifth scheme (Fig. 1), turning of inserts of limited length l is provided. Each cutting of the tool into the workpiece occurs with an impact. There is an idle running between the end of the previous cut and the start of the next.

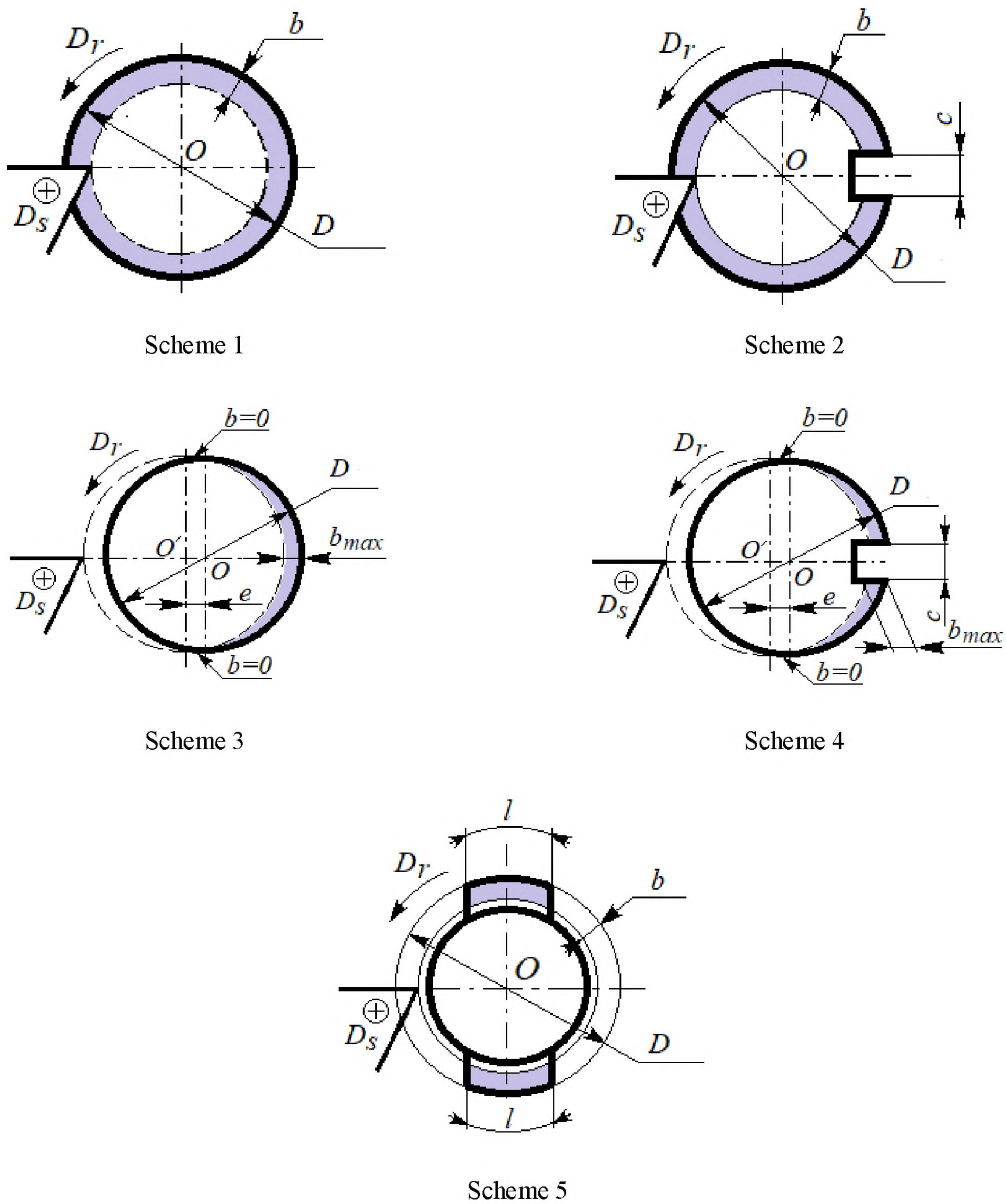

Fig. 1. Schemes of processing parts to determine the regularity of the formation of oscillations during cutting: O – axis of the part O' – axis of rotation with the eccentric installation of the part

The cutting modes were chosen in such a way that unquenchable self-oscillations appeared during turning. This is ensured at a cutting speed of $v = 160$ m/min, a cutting depth of $t = 1$ mm, and a feed of $S = 0.1$

mm/rev. Before conducting the research, the part was turned to remove the radial runout.

The experiments were carried out using a special device for studying oscillations during turning (Fig. 2) [9], which was fixed in the cutter holder of the lathe.

The design of the device allows you to change the frequency of self-oscillations of cutter 2 by using an additional mass 11 and changing the length of its departure from the movable rectangular guides 3. Eddy current sensors 8 and 9, fixed on housing 1 and bracket 10, respectively, are connected to the analog-digital converter and a personal computer and are used to record the movement of cutter 2 in vertical and horizontal directions.

The cutter (Fig. 3) consists of a cutter head, and an elastic element made as a single, non-disassemblable product.

The rectangular cross-section of the cutter's elastic element ensures the cutter's maximum rigidity in the vertical direction and the minimum in the horizontal direction, which is necessary when studying an oscillating system with one degree of freedom.

The research was carried out at a length of 80 mm of the cutter without the use of additional mass. The frequency of free oscillations of the cutter is 463 Hz.

To detect regularities during cutting, each turn of the workpiece on the oscillogram was separated by a signal recorded on insert 2 on the chuck by the eddy current sensor 1, which was fixed in the mandrel on the spindle headstock (Fig. 4). The cutting time from the beginning to the end was fixed through the electro contact network 3.

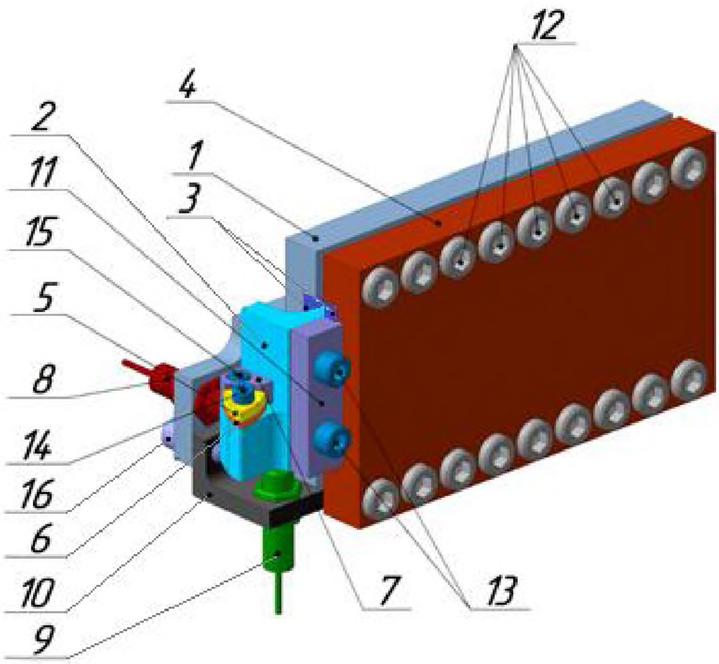

Fig. 2. A device for studying oscillations during turning:

1 – body; 2 – cutter holder; 3 – rectangular guides; 4 – auxiliary cover; 5 – cutting plate; 6 – lining; 7 – base; 8, 9 – eddy current movement sensors; 10 – bracket; 11 – additional mass; 12 – screws for fastening the auxiliary cover; 13 – additional mass fastening screws; 14 – cutting plate fastening screw; 15 – the base fastening screw; 16 – bracket mounting screw

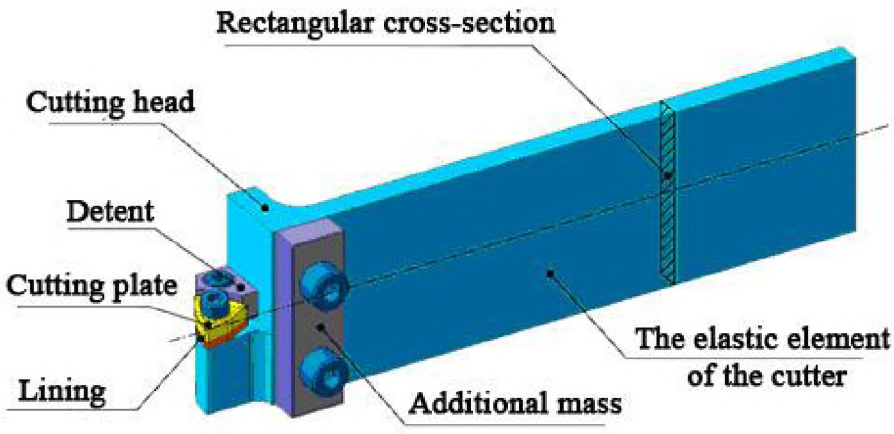

Fig. 3. Cutter design

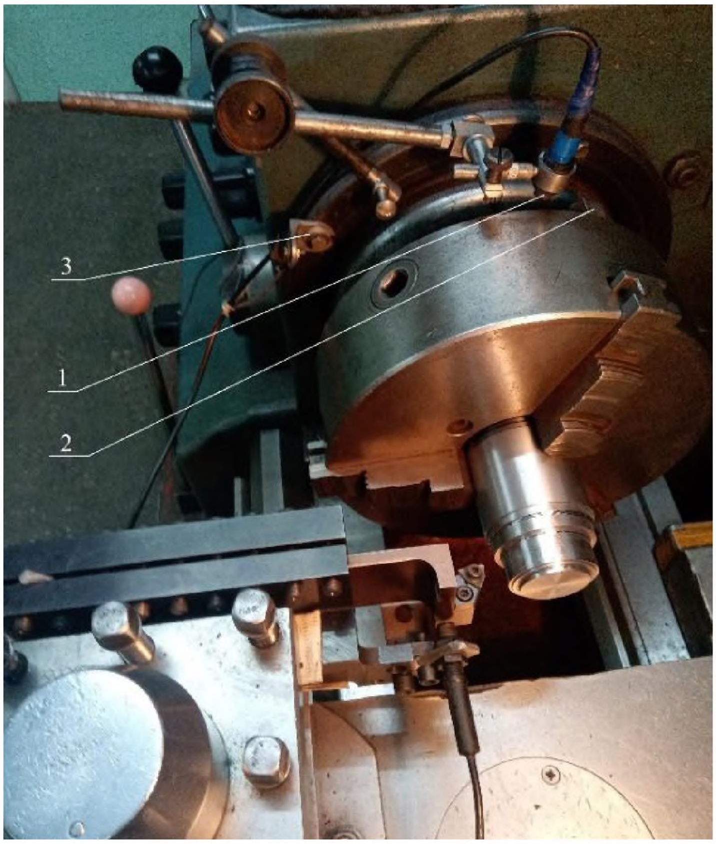

Fig. 4. Elements of the spindle speed and cutting time counter systems:

1 – sensor; 2 – insert; 3 – electro contact network

In Fig. 5 shows an oscillogram of oscillations of the technological system “tool-part” (hereinafter the technological system) in the axial direction during continuous turning according to scheme 1 (Fig. 1). At the same time, under the action of the cutting force, the cutter is pushed away from the position of elastic equilibrium (PEE) by the amount of B_x. After 9 turns of the part, steady, undamped oscillations with a period of $T = 1.86 \cdot 10^{-3}$s ($f = 537$ Hz) appear, a sign of self-oscillations. They work until the end of the cutting. But determining the regularity of the occurrence of oscillations during cutting involves finding out what oscillations there were when cutting the cutter into the part.

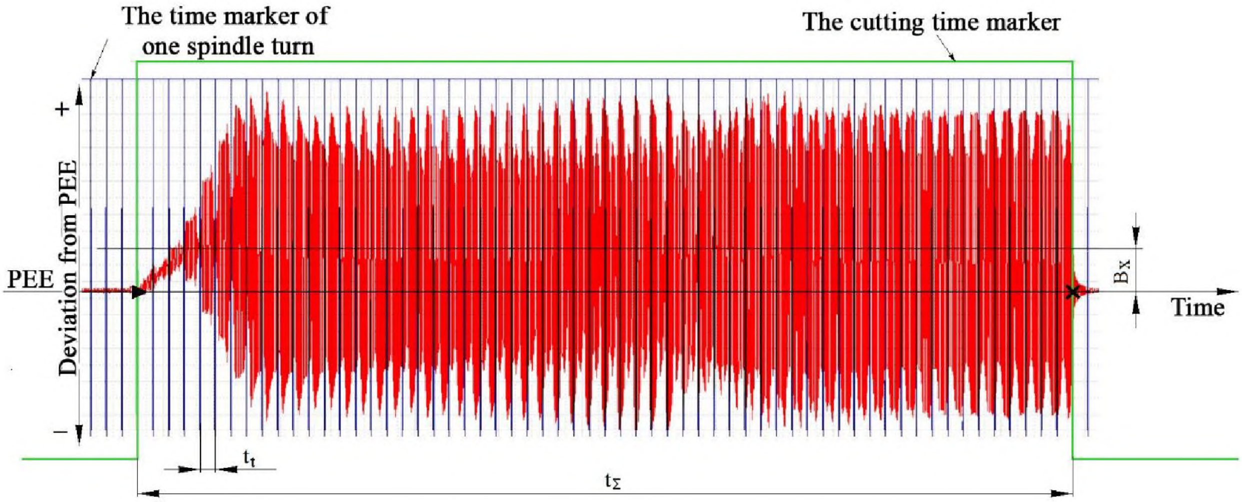

Fig. 5. Oscillogram of fluctuations of the technological system during continuous turning of a cylindrical part:

► – the start of cutting; × – end of cutting; PEE – position of elastic equilibrium;
t_{Σ} – total cutting time; t_t – cutting time for one turn of the part;
B_x – is the static deflection of the cutter under the action of the axial cutting force

Due to the fact that each rotation of the part was recorded on the oscillogram, you can see the beginning of cutting and the oscillations that occur at the same time (Fig. 6).

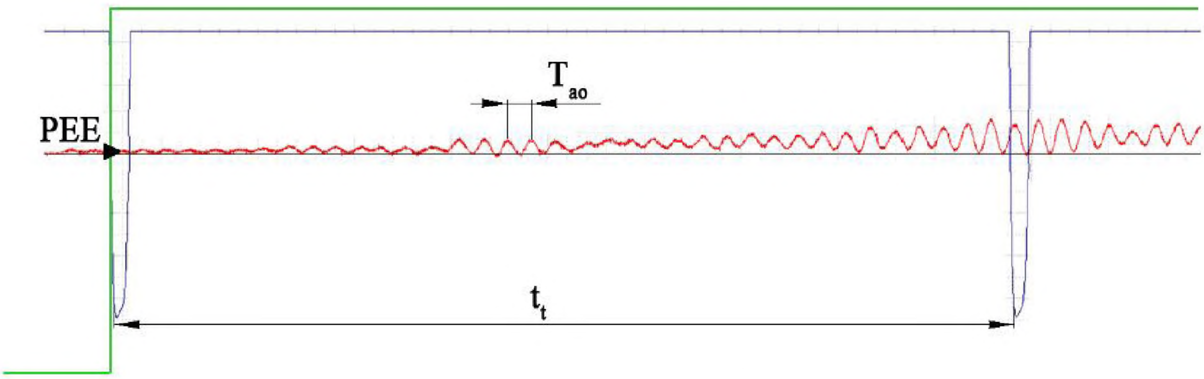

Fig. 6. Fragment of an oscillogram of oscillations of a technological system when cutting into a part during continuous turning of a cylindrical part

Cutting on each turn of the part takes place in time t_t. which is equal to t_t = 0.074 s. The forced oscillations occur when the cutter increases until the full cutting depth are reached. At the same time, from the impact of the cutter on the part, forced oscillations are superimposed, according to the definition of Ya. H. Panovko [10], accompanying free oscillations of the technological system "tool-part" with the period $T_{ao} = 2.05 \cdot 10^{-3}$s ($f_{ao}$ = 488 Hz). Their amplitude increases with the cutting depth (chip width). A waviness is formed on the cutting surface. On the next turn of the part, the processing is already behind the trace. Because the frequency of the accompanying free oscillations (f_{ao} = 488 Hz) is not a multiple of the spindle rotation frequency (n = 800 rpm, f = 13.33 Hz), a phase shift between the Δφ waves occurs on subsequent turns of the part. This is visible when superimposing fragments of the oscillogram of oscillations of the technological system during cutting on the previous and next turns of the part (Fig. 7).

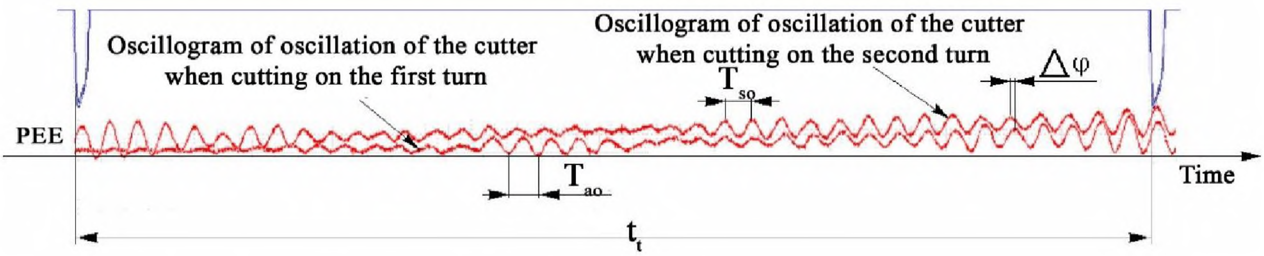

Fig. 7. Phase shift of the oscillation waves on the next cutting surface relative to the previous one

Trail processing and phase shift Δφ contribute to the emergence and maintenance of a certain level of self-oscillations with a period of $T_{so} = 1.86 \cdot 10^{-3}$ s ($f_{so} = 537$ Hz). When turning with the full depth of cut, the processing on the next turn of the part is accompanied by a transient process, which contributes to the maintenance of self-oscillations due to the adjustment of the phase shift Δφ to (π/2). This can be seen when overlaying fragments of the oscillogram of oscillations of the technological system during cutting on the previous and next turns of the part (Fig. 8).

Based on the obtained data, with continuous turning, the cutting time is determined from the insertion of the cutter into the part and its exit from it. In the beginning, along with forced oscillations, the technological system has accompanying free oscillations, which leave a wavy mark on the cutting surface. From the second rotation of the part, turning takes place behind the track, which, together with the phase shift, induces the occurrence of self-oscillations. When turning with a full depth of cut, at each turn of the part, there are forced oscillations and self-oscillations superimposed on them.

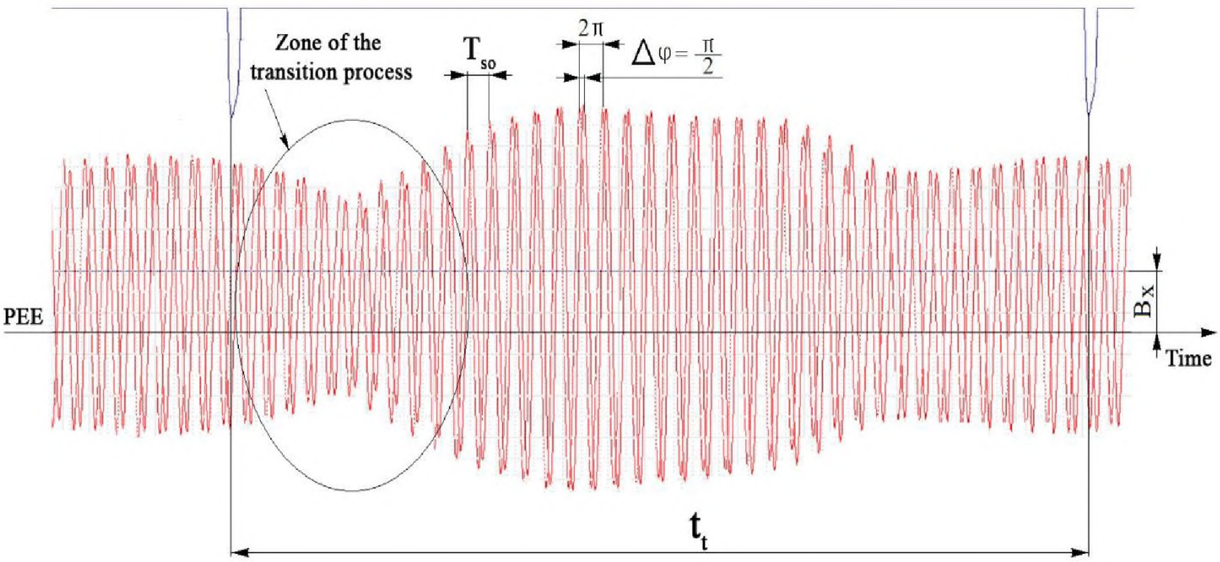

Fig. 8. Transitional process during sub-adjustment of self-oscillations on the next turn of the part

In Fig. 9 shows an oscillogram of oscillations of the technological system in the axial direction during the turning of a cylindrical part with a longitudinal groove according to scheme 2 (Fig. 1).

Similarly, as with continuous turning, forced oscillations with accompanying free oscillations of the technological system superimposed on them with the period $T_{ao} = 2.05 \cdot 10^{-3}$ s ($f_{ao} = 488$ Hz) act during cutting (Fig. 10). After the end of cutting and entering the groove, free oscillations of the cutter occur with a period of $T_{fo} = 2.16 \cdot 10^{-3}$s ($f_{fo} = 463$ Hz).

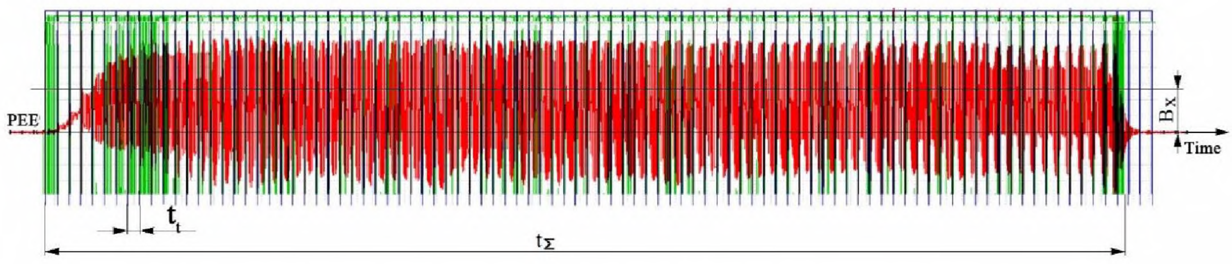

Fig. 9. Oscillogram of oscillations of the technological system during intermittent turning of a part with a groove

The accompanying free oscillations of the cutter leave a wavy mark on the cutting surface, along which turning takes place in subsequent turns of the part. In contrast to continuous turning, when cutting apart with a groove, there will always be accompanying free oscillations of the technological system at each turn of the part at the beginning of cutting (Fig. 10).

When turning with the full depth of cut, the accompanying free oscillations of the technological system with the period $T_{ao} = 2.05 \cdot 10^{-3}$ s (f_{ao} = 488 Hz) are superimposed on the forced oscillations, which act during the time t_{ao} = 0.011 s and decay (Fig. 11). After that, during the time t_{so} = 0.039 s due to the wavy trace on the cutting surface, a transition zone is created, in which the phase shift Δφ is adjusted to (π/2) (Fig. 12) and the further effect of permanent self-oscillations of the technological system with the period of $T_{so} = 1.86 \cdot 10^{-3}$ s (f_{so} = 537 Hz). During the idling of the parts, free oscillations of the cutter with a period $T_{fo} = 2.15 \cdot 10^{-3}$ s operate.

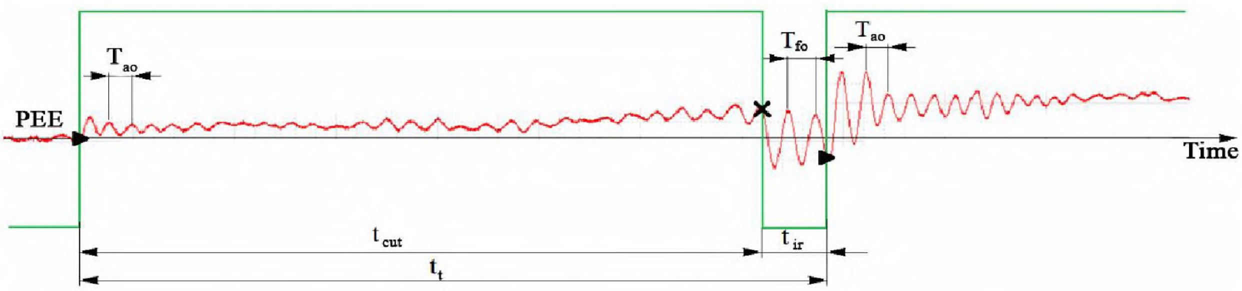

Fig. 10. A fragment of the oscillogram of the technological system oscillations when cutting into a part with a longitudinal groove:

t_{cut} – cutting time; t_{ir} – motion during idle running

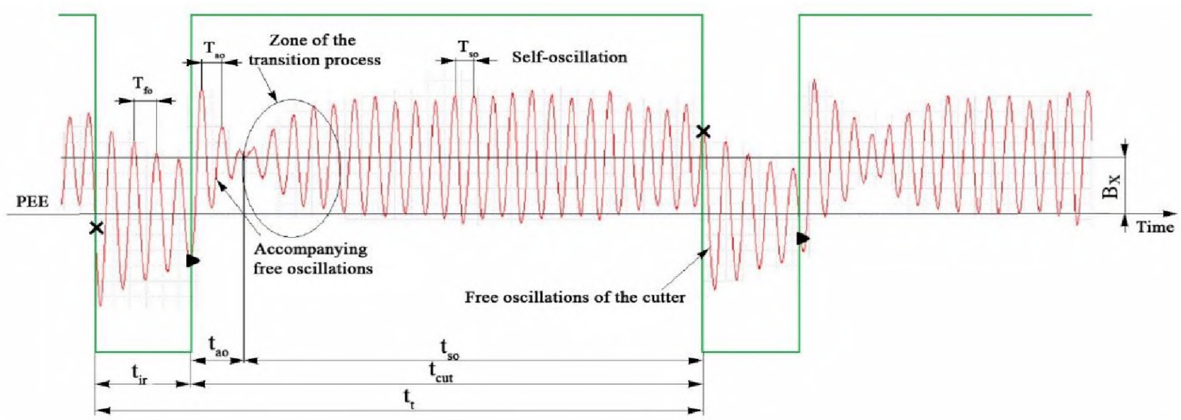

Fig. 11. Fragment of an oscillogram of oscillations of the technological system during turning with an impact at the full depth of cutting

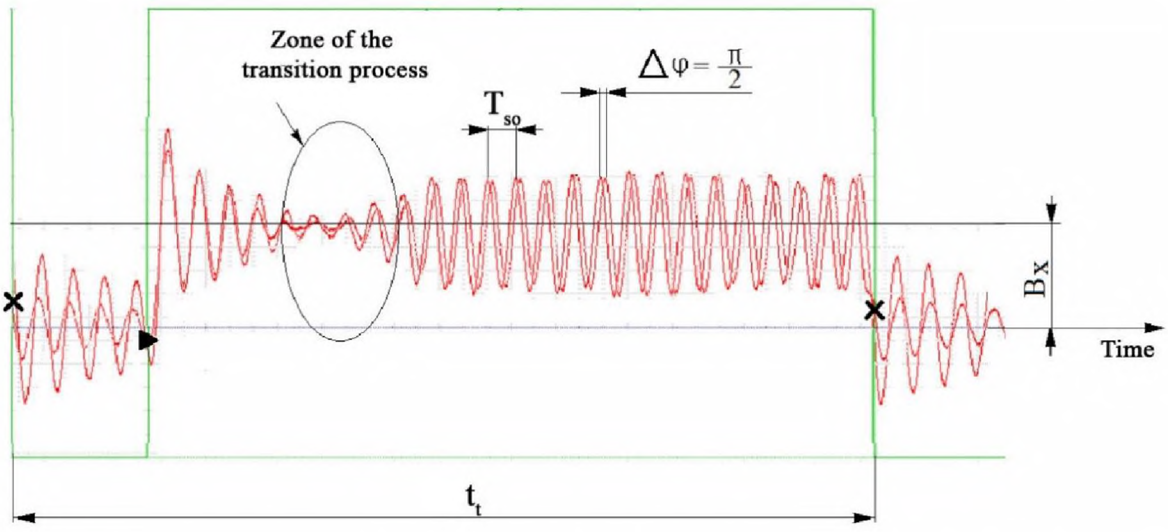

Fig. 12. Superimposition of adjacent fragments of oscillation oscillograms of the technological system

Based on the results obtained during the analysis of the turning of the part with a groove, it can be said that during intermittent cutting, there are forced oscillations, on which the accompanying free oscillations are first superimposed, and then the self-oscillations of the technological system. At the same time, the cutting time consists of the time of action of accompanying free oscillations and the time of action of self-oscillations of the technological system.

Fig. 13 shows an oscillogram of oscillations of the technological system in the axial direction during the turning of a cylindrical part installed eccentrically concerning the axis of rotation, according to scheme 3 (Fig. 1).

Due to the eccentric installation of the part, each turn includes the cutting time and the idle running time. On the first turn, when turning an eccentrically installed part, forced and accompanying free oscillations of the technological system with a period $T_{ao} = 2.05 \cdot 10^{-3}$ s ($f_{ao} = 488$ Hz) arise from cutting (Fig. 14).

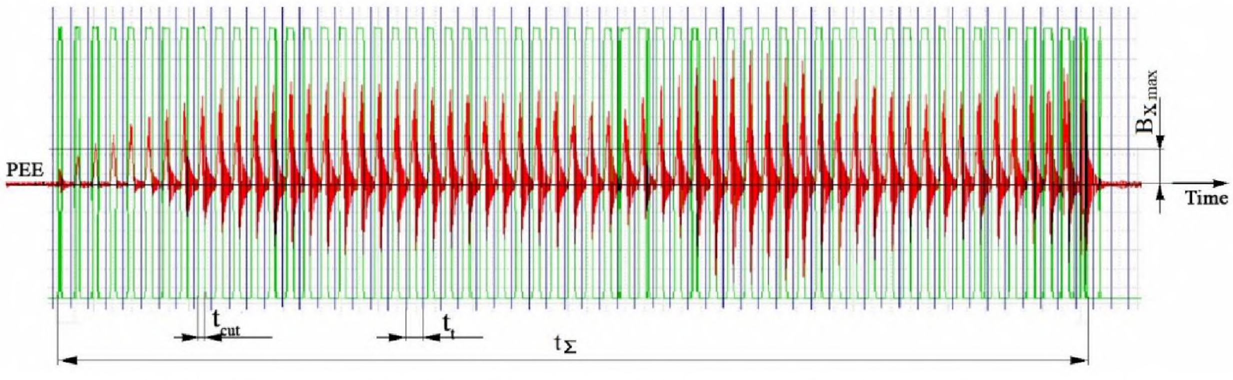

Fig. 13. Oscillogram of oscillations of the technological system during turning of an eccentrically installed cylindrical part

When cutting an eccentrically fixed part, the depth varies from zero to maximum and from maximum to zero. At the same time, the cutting force first gradually increases and then gradually decreases, which leads to a periodic change in the amplitude of the accompanying free oscillations. The section from the smallest cutting depth to the largest amplitude of the accompanying free oscillations of the technological system gradually increases. The section from the largest cutting depth to the smallest amplitude of the accompanying free oscillations of the technological system gradually decreases (Fig. 15).

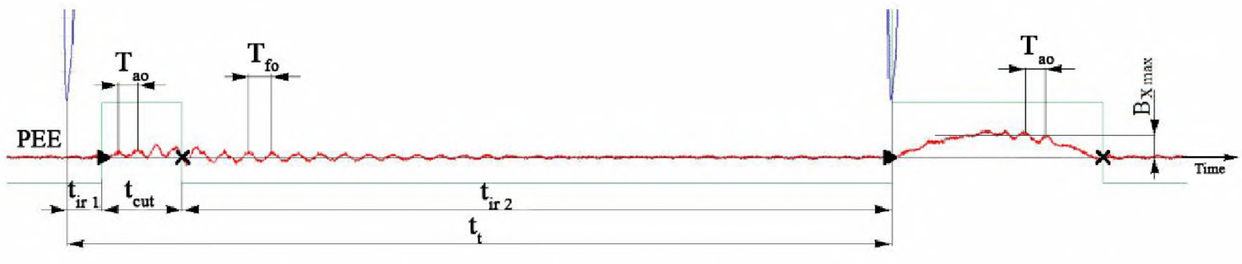

Fig. 14. Fragment of an oscillogram of oscillations of the technological system during cutting on the first turn of the part

Changing the cut depth affects the technological system's properties, which determine the period of the accompanying free oscillations. Therefore, when cutting in these conditions, the oscillogram can be divided into three areas with different periods of oscillation. The values are shown in Table 1.

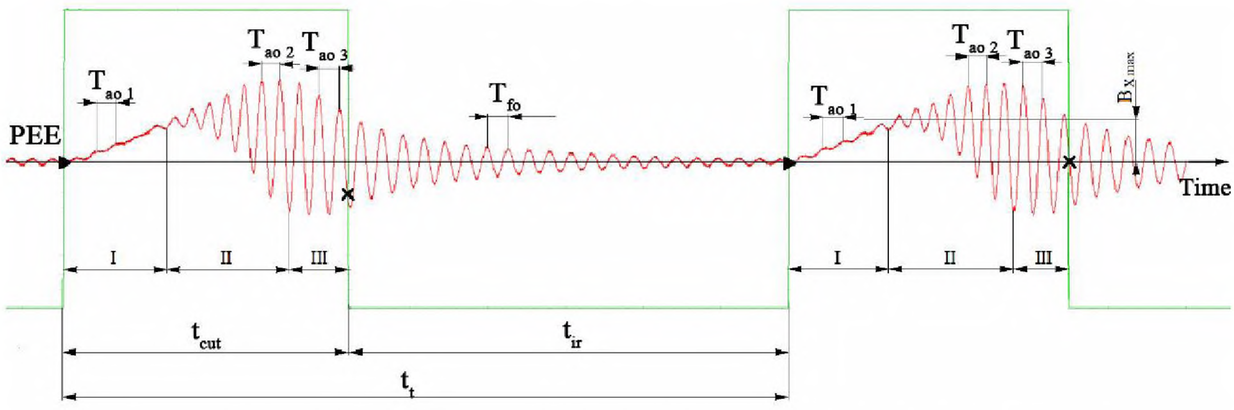

Fig. 15. A fragment of the oscillogram of the technological system oscillations during turning of an eccentrically fixed part at the full cutting depth

Table 1

Periods of accompanying free oscillations of the technological system during turning with a change in the cutting depth of an eccentrically fixed part

Area number	I	II	III
Period of oscillations, T_{ao}, $\times 10^{-3}$ s	2.15	1.84	2.15
Oscillation frequency, f_{ao}, Hz	463	543	463

At the beginning of cutting in section I and at the end of cutting in section III, the period of accompanying free oscillations of the technological system is equal to the period of free oscillations of the cutter.

The analysis of the results of turning an eccentrically fixed cylindrical part shows that during cutting there are forced oscillations and accompanying free oscillations of the technological system, which are excited by the variable cutting force during processing. Based on this, there are no conditions for self-adjustment of self-oscillations.

Fig. 16 shows an oscillogram of oscillations of the technological system in the axial direction during the turning of a cylindrical part with a groove, installed eccentrically to the axis of rotation, according to scheme 4 (Fig. 1).

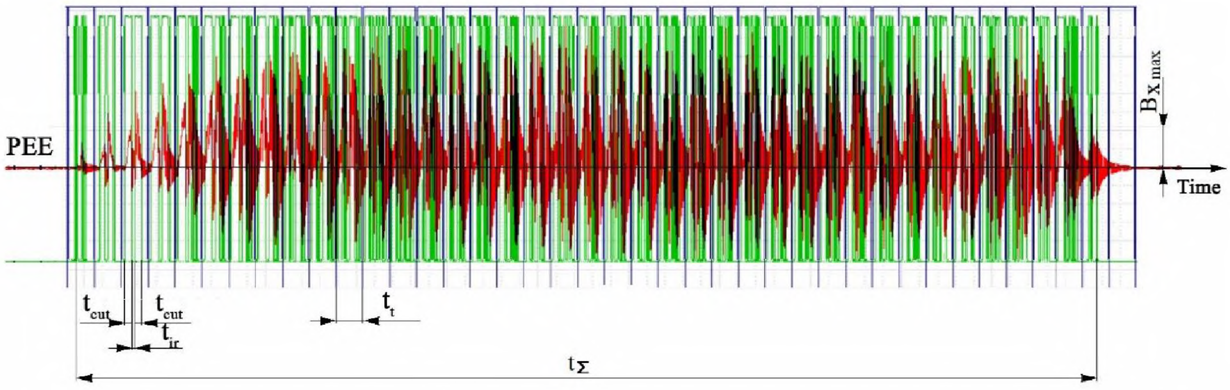

Fig. 16. Oscillogram of oscillations of the technological system during the turning of a cylindrical part with a groove installed eccentrically for the axis of rotation

When turning an eccentrically fixed cylindrical part with a groove, the depth of cutting changes from zero to the maximum, and the cutter goes into the groove. Then it changes after idling from maximum to zero when cutting into the part and leaving it. At the same time, variable forced oscillations appear on the first rotation during turning, which are superimposed on the accompanying free oscillations of the technological system (Fig. 17).

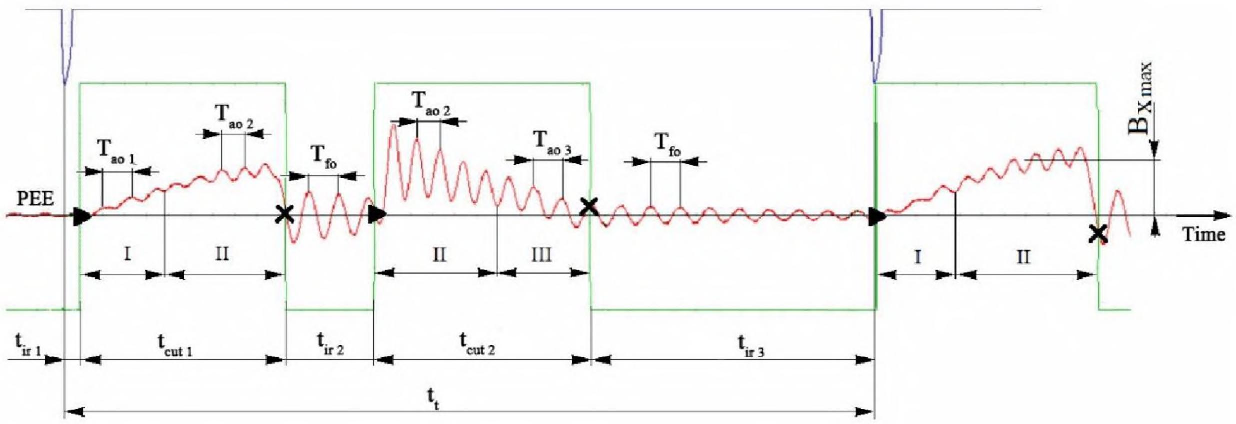

Fig. 17. Fragment of the oscillogram of the oscillations of the technological system on the first turn when turning an eccentrically fixed cylindrical part with a groove

Changing the cutting depth affects the properties of the technological system. Therefore, as in the case of turning an eccentrically fixed cylindrical part without a groove, the period of the accompanying free oscillations of the technological system changes with a change in the cutting depth (Fig. 18).

When turning with the full depth of cut, the amplitude of the accompanying free oscillations increases, but the areas with different oscillation periods do not change.

The values of the periods of accompanying free oscillations of the technological system when turning an eccentrically fixed cylindrical part with a groove are given in Table 2.

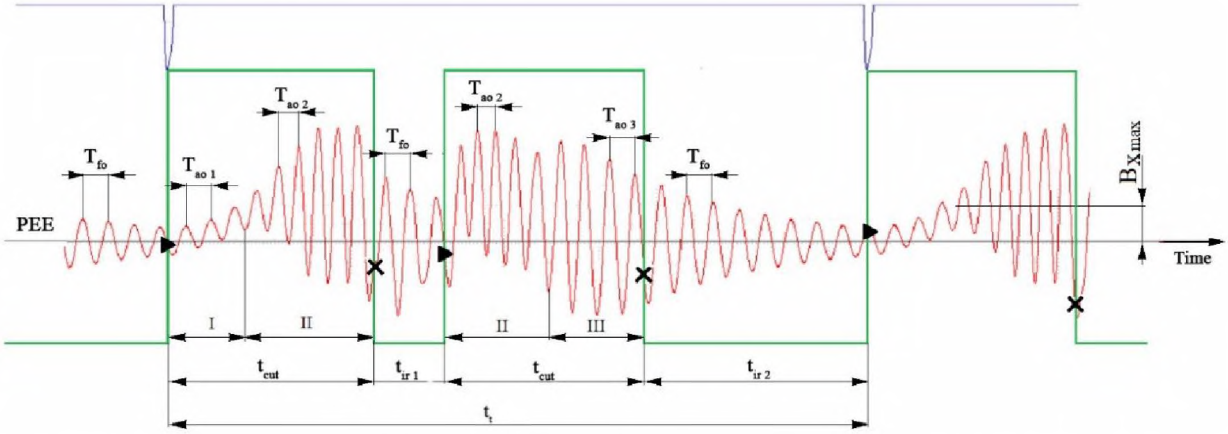

Fig. 18. Fragment of an oscillogram of oscillations of the technological system during the turning of an eccentrically fixed cylindrical part with a groove at the full cutting depth

Table 2

Periods of accompanying free oscillations of the technological system during the turning of an eccentrically fixed cylindrical part with a groove

Area number	I	II	III
Period of oscillations, T_{ao}, $\times 10^{-3}$ s	2.15	1.6	2.15
Oscillation frequency, f_{ao}, Hz	463	625	463

When turning an eccentrically fixed cylindrical part with a groove, an additional source of oscillations, in addition to the variable depth of cut, is the impact of the cutter when cutting into the part with the maximum depth of cut. The presence of constant periodic sources of excitation during the turning of an eccentrically fixed cylindrical part with a groove causes the effect of forced oscillations and accompanying free oscillations of the technological system. Self-oscillations do not occur.

In Fig. 19 shows an oscillogram of oscillations of the technological system when turning inserts with a limited cutting length according to scheme 5 (Fig. 1).

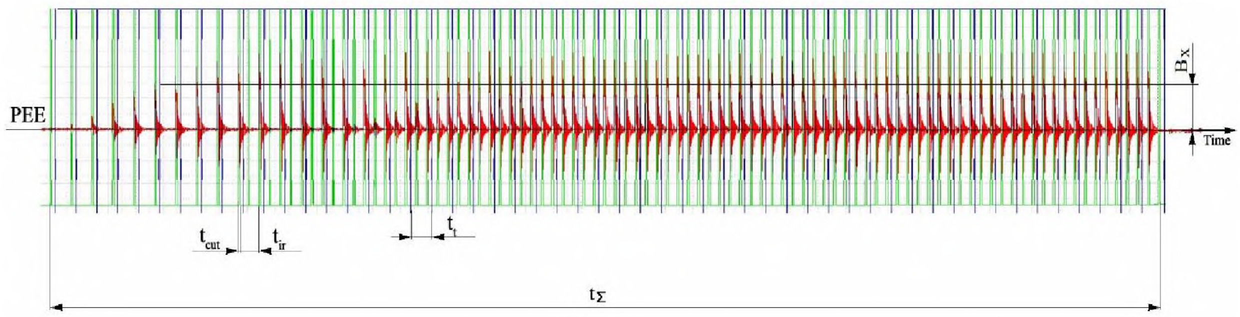

Fig. 19. Oscillogram of fluctuations of the technological system during turning of inserts

A fragment of the oscillogram of the oscillations of the technological system on the first turn of the part shows that cutting the cutter into the insert during the cutting time $t_{cut} = 0.008$ s causes forced oscillations and the accompanying free oscillations of the technological system with the period $T_{ao} = 2.15 \cdot 10^{-3}$ s (Fig. 20). Free oscillations of the cutter with a period $T_{fo} = 2.15 \cdot 10^{-3}$ s occur during idle running. The periods of accompanying free oscillations of the technological system and free oscillations of the cutter are the same.

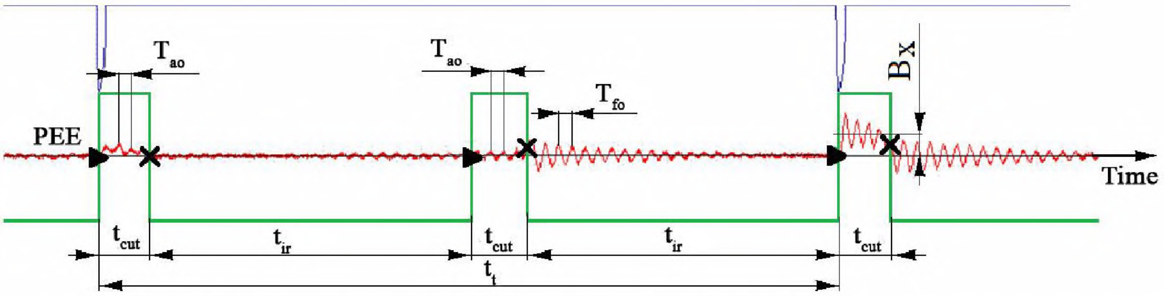

Fig. 20. Fragment of an oscillogram of oscillations of the technological system on the first turn of the part during the turning of inserts

When the full cutting depth is reached, the nature of the fluctuations of the technological system does not change (Fig. 21). Damping accompanying free oscillations of the technological system with the T_{ao} period are superimposed on the forced oscillations during cutting. During idling, the cutter has damping-free oscillations with a T_{fo} period.

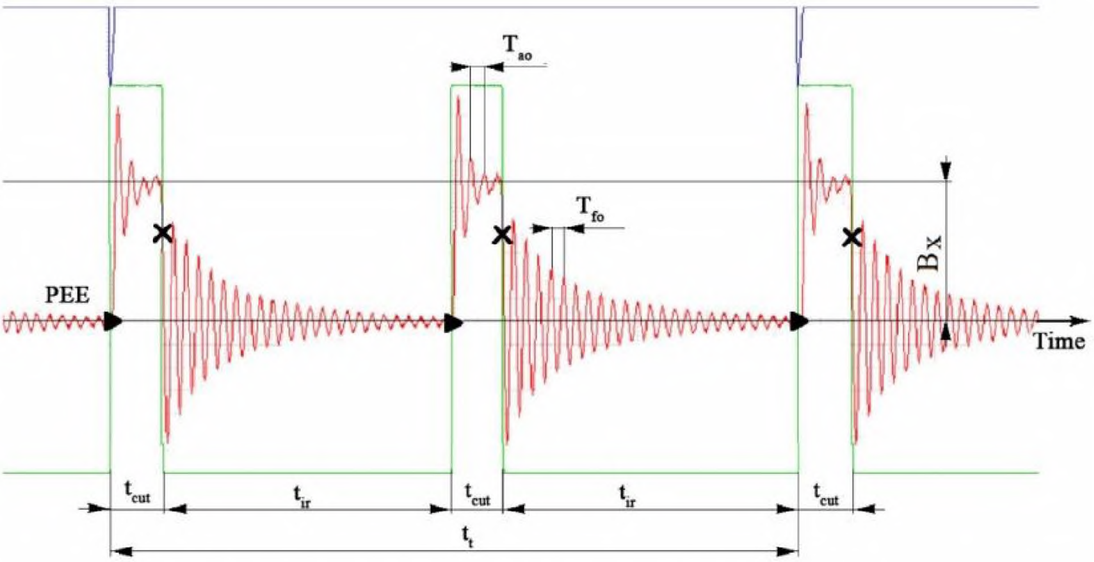

Fig. 21. A fragment of the oscillogram of the oscillations of the technological system during the turning of inserts at the full cutting depth

The wavy cutting surface, which remains from the previous pass, does not affect the damping character of the accompanying free oscillations, but self-oscillations due to the end of cutting do not occur either.

The results obtained when turning inserts of limited length show the oscillations that will operate depending on the cutting time. And if the forced and accompanying free oscillations of the technological system will always be during cutting, then the appearance of self-oscillations depends on the cutting time, that is, on the length of the cutting surface.

Conclusions

The conducted studies show that when cutting metals, there is a regularity in the sequence of occurrence of oscillations, regardless of whether continuous or interrupted turning, forced oscillations to occur when the cutter is inserted. They are first superimposed by accompanying free oscillations and then by self-oscillations of the technological system. But with intermittent cutting, self-oscillation appearance depends on the cutting time. If it is shorter than the time of action of the accompanying free oscillations of the technological system, then self-oscillations do not occur.

When processing eccentrically fixed parts, the cutting force changes gradually and is a source of the technological system's forced oscillations and accompanying free oscillations. At the same time, self-oscillations do not occur because there is a constant source of excitation.

When the types of oscillations that occur during cutting are known, measures are prescribed to prevent their impact on the quality of processing and the stability of the tool.

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