Minimizing tool vibrations when turning metals, as a method of energy-efficient cutting

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Abstract. Taking into account the interrelated vibration dynamics of cutting and the temperature in the cutting zone allows you to determine the most successful state or cutting mode in terms of energy costs. Purpose of the work: by forming a consistent model, determine the most convenient mechanism for the mode of operation of the cutting system, in which the further wear of the cutting wedge will be stabilized, the cutting force will also be stabilized, as well as the temperature in the cutting zone and the vibration of the tool. The paper examines: The process of metal processing by cutting on a lathe for the case of longitudinal turning of the product. Research methods: The research consists of a series of field experiments on real equipment using a modern measuring stand STD. 201-1, as well as using an experimental complex developed by us. Results and discussion. The results of processing experimental data, in particular, the results of measuring cutting forces, temperature and tool vibrations, are presented. The mechanism of stabilization of the processing process due to the relationship between temperature and vibrations during cutting and the formation of a quasi-stationary cutting mode is experimentally proved. It is assumed that due to the practical application of the results obtained in the work, it will be possible to increase the energy efficiency of metal processing by reducing the energy cost of vibration of the cutting wedge.

1 Introduction

Modern promising areas of quality control of the processing process are rapidly developing vibration monitoring and vibration diagnostics systems [1-5]. Such systems are based on the approach of wide application of vibration accelerometers for measuring the vibration activity of the instrument. However, this approach gives rise to the problem of describing the relationship of vibrations measured by vibration accelerometers on the tool with undetectable, but important, from the point of view of ensuring the quality of cutting, such as the temperature in the contact zone of the tool and the processed product.

To develop such a consistent model, it is necessary to rely on a modern understanding of the vibrations that occur during cutting, which are divided into free vibrations, forced vibrations and self-excited vibrations [6]. Free vibrations are associated with the quality factor of the cutting system, forced vibrations are caused by external influences, such as, for

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example, runouts in the bearings of the spindle assembly, vibrations of the machine body or runouts in the ballscrews. Free and forced vibrations are a well-studied topic, but with self-excited vibrations that can extract energy from the interaction that occurs in the cutting zone, there are no unambiguous and consistent model solutions today. Due to this, the topic of self-excited vibrations during cutting is very popular in publications on modern scientific research [7-11]. However, in these works, self-excited oscillations are understood only as oscillations associated with the so-called regenerative effect. For the first time, the regeneration of vibrations during metal processing on metal-cutting machines was studied by Hahn R. S., Tobias S. A. and Merritt H. E. [12-14]. The works of these authors are the fundamental basis for the analysis of the dynamics of regenerative vibrations of the tool during cutting. The main factor that determines the regeneration of vibrations during cutting is the so-called time delay.

In the domestic scientific journalism devoted to self-excited vibrations of the tool during metal cutting, the issues of assessing the impact of cutting on the" trace " on the dynamics of tool vibrations are considered indirectly, more attention is paid to the construction and analysis of models describing the interrelated dynamics of the processing process [15-17]. For example, in the previously published works [18-20], the analysis of the dynamics of deformation vibrations of the tool is made on the basis of the connection, through a force reaction, of this deformation movement with the cutting elements of the CNC machine system. In the works of leading Russian scientists devoted to the dynamics of the metal cutting process [21-25], it is noted that in the cutting process, in addition to the feedback on the cutting force, which takes into account the regeneration of vibrations when cutting along the "trace", a thermodynamic feedback is formed. However, today this relationship is not well understood, as it seems to us, based on the new element base of modern semiconductor, digital measurement systems, it is possible to form a more correct assessment of such feedback. In our work [26], we gave an example of modeling the influence of temperature in the cutting zone on the cutting force, taking into account the nonlinear influence of temperature on the tensile strength of the metal of the processed part. The aim of this work is an experimental analysis of the relationship between the temperature in the cutting zone and the vibration activity of the tool at different stages of the evolution (wear) of the cutting wedge.

2 Research methodology

In order to determine the relationship between wear, the measured temperature field in the processing zone, the force reaction and vibrations of the tool during metal turning, we conducted a series of field experiments on a 1K625 lathe (see Fig. 1 (a)), with a stand installed on it for studying cutting modes during turning STD. 201-1 (see Fig. 1, b).

a)   b)

Fig. 1. Experimental equipment, a) machine 1k625, b) measuring stand STD. 201-1

Note that the machine shown in Figure 1 was previously upgraded, the motor control, which provides operating modes on the machine, was switched to frequency control, the frequency controller is shown in the upper right corner of Figure 1 (a). Thanks to this, it became possible to smoothly adjust the cutting speed within the selected operating mode of the machine, the elements of this mode in the experiment were as follows: cutting speed V=124 m / min, feed S=0.11 mm / rev, cutting depth tp=1 mm for the entire period of the experiment, the cutting elements remained unchanged. The tool holder MR TNR 2020 K11 was used as a tool and a five-sided plate 10113-110408 T15K6 was used as a cutter on it, the shaft made of steel grade 45 was subjected to processing. The experiment itself and its results are described in more detail in our earlier works [27].

Tool wear in the experiment was estimated by the back face, for this, after each processing step, a photo of the cutting wedge was taken, examples of such photos are shown in Figure 2.
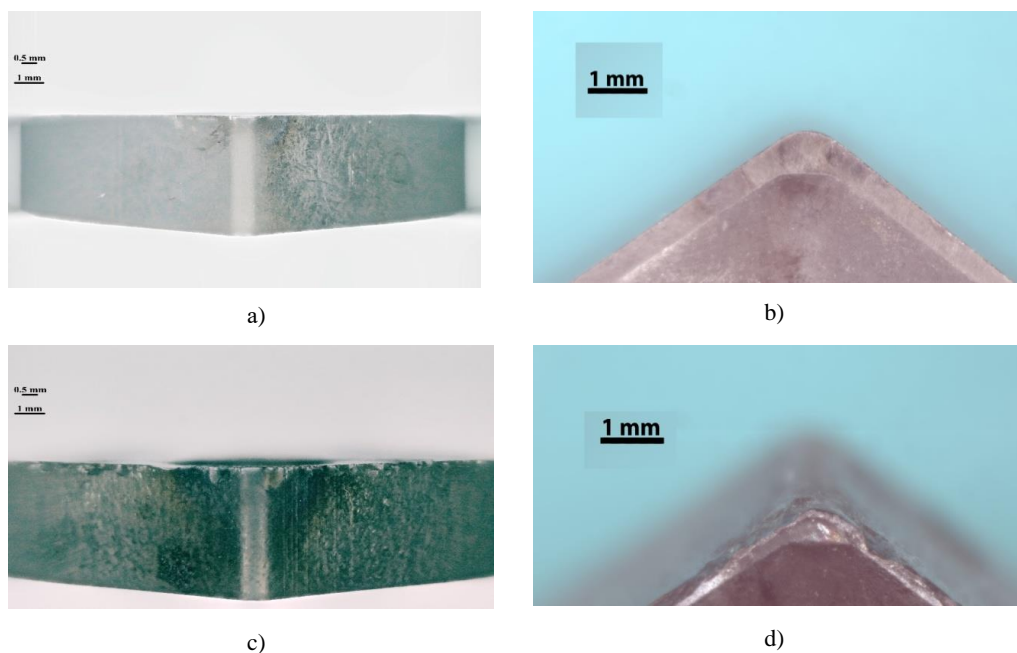

a)

b)

c)

d)

Fig. 2. Photos of the cutting plate 10113-110408 T15K6

In Figures 2 a), c) enlarged photos of the cutting plate that has been pre-worked, while in Figure 2 a) the emphasis in the photo is on the back face of the plate, and in Figure 2 b) the emphasis is on the front face (cutting edge). As can be seen from these photos, the tool wear on the back face is only forming, but there is both a thermal burn and some burn-in of the contacting surface, as for the cutting wedge, there are no changes at all, that is, the cutting conditions do not change. Figures 2 (c), (d) show the back surface of a critically worn plate and the condition of the cutting wedge. In these photos, you can see that the wear on the back face has changed significantly compared to the previous case, here it is about 0.45 mm, and you can also see that the cutting wedge has changed significantly, part of which is literally cut out, which allows us to talk about new cutting conditions.

The results of processing data on the force reaction and temperature in the contact zone of the tool and the processed part for the entire time of the experiment, as well as the development of wear of the cutting wedge, are shown in Figure 3.
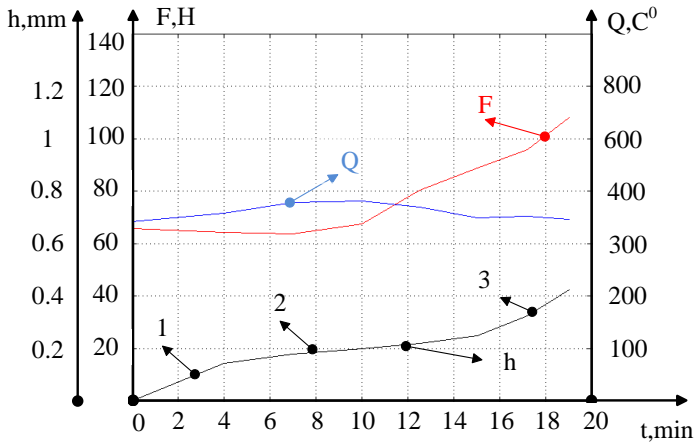
Fig. 3. Results of data processing for the entire time of the experiment

Figure 3 shows three graphs, a tool wear graph, a graph of the change in the average temperature value, and a graph of the change in the average value of the total cutting force. As can be seen from this figure, at the tool burn-in stage, characterized by a stabilization of the wear rate (section 2 of the h curve), there is an increase in temperature in the contact zone of the tool and the workpiece, as well as some stabilization and even a slight drop in the cutting force. In this regard, the following observation is true: the formation of the primary contact area of the back face of the tool and the processed part during the burn-in process leads to an increase in temperature both in the zone of this contact and in the zone of primary plastic deformation, as a result of which there is a stabilization of the cutting force. The transition of the cutting force to an increase, after reaching the value of the cutting wedge wear value of more than 0.25 mm, is associated with a change in the cutting conditions. That is, here, when the back face is worn above a certain value, which is designated as critical, a sharp increase in the force reaction begins. This is due to the fact that at this amount of wear, the front cutting edge of the tool begins to cut off (see Figure 2 (d)), which significantly affects the conditions for forming the force reaction from the processing process to the shaping movements of the tool.

The above analysis does not answer the important question, due to which, at the stage of tool burn-in, section two of the wear curve in Figure 4, there is an increase in temperature in the contact zone of the tool and the workpiece, because the cutting forces do not increase, and the processing speed does not increase, that is, there is no increase in the power allocated here. The obvious answer to this question is precisely the contact area formed as a result of running the tool on the back face. The explanation of the phenomenon of temperature increase in the area of stabilization of the wear curve is explained by a decrease in tool vibrations in the same area. To numerically estimate the energy of the vibration signal of tool vibrations, we introduce the following integral indicator:

$$VA = \sqrt{\frac{1}{T_v}(\int\limits_{0}^{T_v} \frac{dy}{dt}^2 \, dt)} \, , \qquad (1)$$

where *VA* - can be interpreted as the background noise of the signal, or the energy of the vibration signal during the observation period (experiment) -T_v, while for the case in the first section of the wear characteristic *VA*=30.29 m/s, for the case in the second section *VA*=21 m/s, and for the case of critical wear *VA*=107 m/s. As can be seen from the

calculated values of the energy of the vibration signal, the energy of the vibration signal decreases almost one and a half times during the run-in, and when the tool is worn out above the critical value, the energy of the vibration signal increases almost five times, relative to the run-in value.

In order to clarify the previously obtained new ideas about the interrelated dynamics of the metal turning process, we developed a new experimental measuring system, which is presented in the most general form in Figure 4).
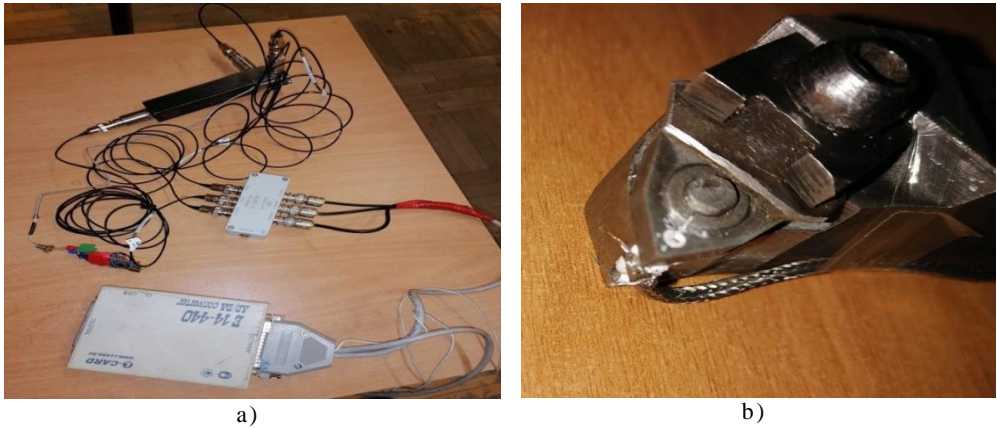

a)   b)

Fig. 4. Measuring complex for the assessment of tool vibrations and temperature in the processing area a) the complex itself, b) the cutting plate with a thermocouple

The measuring complex presented in Figure 4 (a) includes a standard holder 2102-100 with a removable 6-face plate "broken triangle" WNUM 120612 (02114-120612) H30 (T5K10) KZTS fixed on it, which was previously cut by the method of electroerosion treatment, for placing an artificial thermocouple in it (see Figure 4.b)).

In addition to the artificial thermocouple, the experimental complex includes three vibration sensors, which were used as vibration transducers of the company GLOBALTEST AR2081-10 connected to the GLOBALTEST AR13 cable. For the experiment to assess the relationship between temperature and tool vibrations, we used the same 1K625 lathe, which is shown in Figure 5.
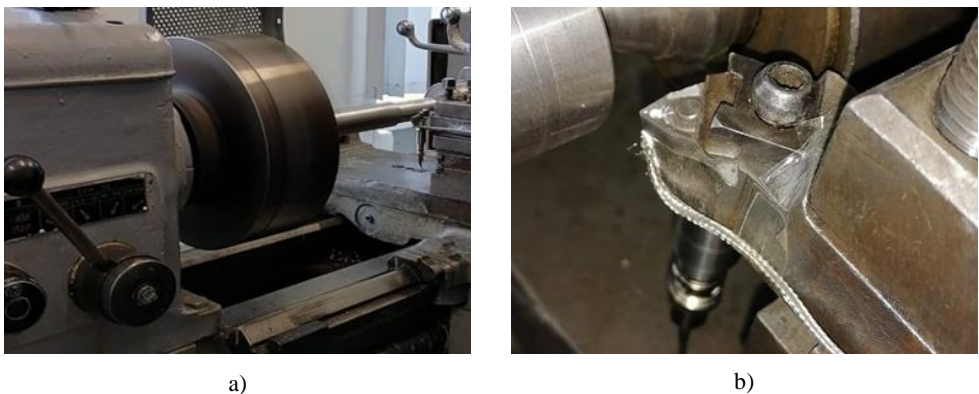

a)   b)

Fig. 5. Machine 1K625 with installed measuring system, a) machine with equipment, b) tool in the caliper

Figure 6 shows a graph of the temperature measured after the tool is run-in, that is, after the tool contact area has formed along the back face.
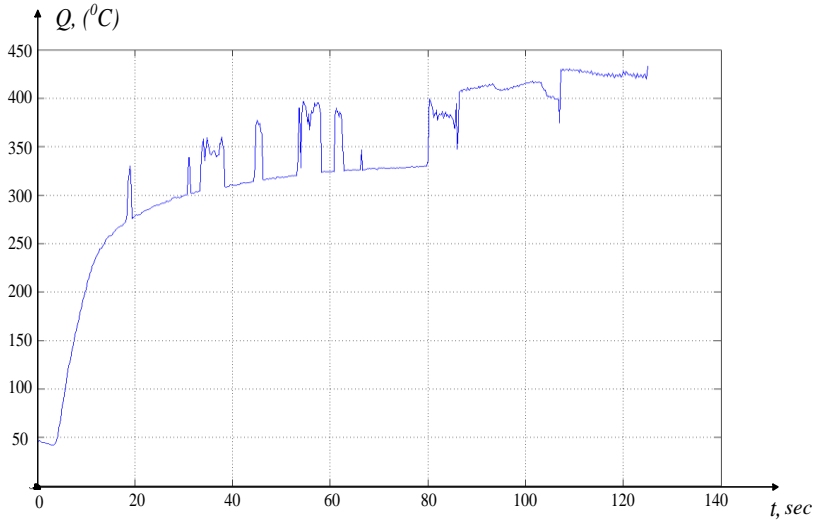

Fig. 6. Graph of the temperature taken from the artificial thermocouple

As can be seen in Figure 6, the temperature increases from values of about 50 0C, the instrument was already warmed up in previous experiments, to a value greater than 400 0C. The results of measuring vibration signals are shown in Figure 7.
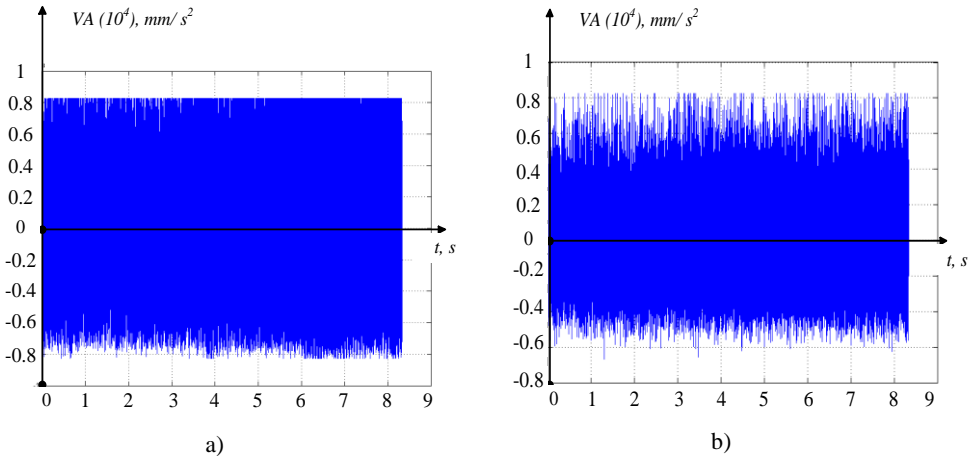

Fig. 7. Graphs of signals taken from the vibration transducer installed in the direction of metal cutting, a) vibrations before tool burn-in, b) vibrations after tool burn-in.

The root-mean-square value of the signal taken from the vibration transducer before the tool was run-in was 309.2 mm / sec2 (see Figure 7 (a)), and after the run-in was 179.75 mm / sec2 (see Figure 7 (b)), which confirms the earlier conclusions and indirectly indicates the adequacy of the measurements made.

3 Conclusion

In the present paper, the experimental justification of the mechanism of stabilization of the processing process revealed in earlier works by reducing tool vibrations and increasing the temperature in the cutting zone is considered. As a result, a new mode of operation of the cutting system is formed, which we have defined as quasi-stationary, and this mode of cutting stabilizes both the further wear of the cutting wedge, and the cutting force, temperature in the cutting zone and tool vibration. In support of the correctness of the position put forward by us are the results of our experiments. From the point of view of practical application of the mechanism of self-organization of the cutting process considered in the work in the process of tool evolution and the position based on it, it is possible to predict the residual durability of the tool from the set of observed data on the cutting force, temperature in the contact zone and the speed of vibration movements of the tool. It is assumed that due to the practical application of the results obtained in the work, it will be possible to increase the energy efficiency of metal processing by reducing the energy cost of vibration of the cutting wedge. As can be seen from the work, the selection of an energy-efficient processing mode will reduce tool vibrations and losses on them up to 60% of the usual cutting mode.

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