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Original Research Article

# Experimental and analytical research on relationship between tool life and vibration in cutting process

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New identification and evaluation techniques for machining systems lead to an increase in the efficiency of a production system. This paper presents relationship between tool life, design features, fatigue strength and parameters of vibrations. To cope with this objective, vibration influence on tool wear is assessed, which considers the phase shift of vibration in different coordinates and forces on rake and rear faces of the tool. Tool life is predicted based on fatigue strength of tool material and parameters of tool vibrations. Static and dynamic characteristics of cutting tools during different machining conditions are analyzed using different cutting tools. Test results of cutting tools with different clamping types during static, dynamic and cutting processes, together with the simulation results suggest a relationship between the characteristics of the tool, the elastic system vibrations and tool life.



## 1. Introduction

Modern metalworking technology level of cutting process is characterized by extensive use of indexable cutting tools, high-performance tool materials and high speed of movable operating element. Problem of investigating relationship between dynamic phenomena in cutting process and output characteristics of the process, such as performance, tool life, tool strength, precision machining and surface finish is particularly relevant [1]. The importance of this problem is increasing in modern metalworking, characterized by introduction of new tool materials, increased cutting speeds, feed rate and quality requirements.

Metal cutting under any cutting conditions is accompanied by vibrations. Changing machining conditions only can change the character of the vibrational spectrum of the system machine–tool–workpiece and the level of its individual components. Causes of vibrations, the influence of the vibrations parameters on output characteristics of the cutting process are

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devoted by a lot of work [2]. Most authors tend to assume that for tool materials having low cyclic durability, such as cemented carbide, cutting ceramics, superhard materials, there is some vibration amplitude limit, above which tool wear increases sharply [3]. Vibration amplitude limit decreases with increasing the frequency. Tool life depends not only on the ratio of the vibrational motion speed to the cutting speed [4], at the same time it depends on cutting force, friction coefficient and the law changes of these parameters over time [5].

Among the works, in which the question of the influence of vibration on tool life and strength are studied, two directions of research can be singled out. The first direction is associated with the so-called "vibration-assisted cutting". The increase in tool life in the process of vibrational cutting is explained by the fact that the introduction of additional energy into the cutting zone facilitates the process of chip formation, increases the energy of dislocations [6]. It is noted that the method of vibration-assisted cutting is particularly effective in the processing of difficult-to-cut materials [7]. The second direction of research is related to the study of vibrations during cutting process, their influence on tool life and strength, the quality of the machined surface and the accuracy of processing [8]. Two groups of vibrations are usually distinguished: low-frequency, measured in tens and hundreds of hertz, and high-frequency, measured in thousands of hertz. The frequencies of oscillations of the first group are close to the eigenfrequencies of the workpiece and the spindle group, and the second are closed to the eigenfrequencies of the tool.

Some authors proposed predicted models on tool life for optimization of process parameters and analyzing the influence of process parameters on tool wear [9]. There are different opinions on the mechanism of the effect of vibrations on tool life and strength of the tool: some researchers believe the actual cutting speed variation is the main reason for decrease in tool life [10], while the other believes that tool life decreases because of the force variation acting on the cutting edge [11]. When using tools with indexable inserts the vibration of elements of the tool should be studied. The first idea of the nature of the dynamic process in metal cutting, performed by Taylor [12] were associated with forced vibration of closed loop systems under the influence of the periodically changing cutting force. Cutting force was considered as an external force with respect to the elastic system of the machine and its periodicity was associated with the formation of chip components and the build-up of the unstable breakdown.

The cutting tool and workpiece during machining process are subjected to severe thermal and mechanical loads causing vibration and thermal expansion of the workpiece and cutting too [13]. To increase the quality of the machining, the machine tool vibration should be determined [14]. However, there is less information about studying dynamic phenomena in cutting process, application of which would allow to predict the parameters of vibration at frequencies above 10 kHz, which is especially important in analyzing the performance of indexable cutting tools. In this regard, it is a relevant task to create a model that describes the relationship between parameters of vibrations and design features of cutting tools (in particular, lathe tool), properties of the tool material and durability of such tools.

The aim of this paper is to develop a method for calculating durability of indexable lathe tools in terms of their design features, fatigue strength of the tool material and parameters of vibrations during cutting. To achieve this goal a physical model is proposed to assess the effect of vibration on tool wear by taking into account the phase shift of vibration in different coordinates and forces on rake and rear faces of the tool; a mathematical model for predicting durability of the cutting tool based on the fatigue strength of tool material and parameters of tool vibrations during cutting is established and finally static and dynamic characteristics of cutting tools in terms of cutting and friction are studied.

## 2. Development of mathematical modeling

### 2.1. *Mathematical modeling between tool strength and vibration in cutting process*

The closed loop system (machine–device–tool–workpiece) in a machine operation state is a spatial oscillating system with multi degree of freedom in a certain frequency range and in some cases it can be simplified. When modeling a mathematical model of a dynamic system of the tool, an important and controversial role of the force on the surface should be considered.

Let us consider cutting tool in the form of a single-mass system with two degrees of freedom, and the process of free-cutting in one plane. Fig. 1 shows the dynamic model of the tool. Coordinates of Y and Z are taken as the starting coordinates and the coordinates coincide with the lathe. Coordinates $\nu$ and $\eta$ are the main directions for which the tool rigidity is the minimum and maximum, respectively. The angle $\varphi$ between the directions (Y, Z) and ($\nu$, $\eta$) is called angle of orientation, the $c_1$ and $c_2$ – stiffness coefficients, and $h_1$ and $h_2$ – damping in directions $v$; and $n$, $m$ are the masses.

On the rake face of the proposed model (Fig. 1) the main component of cutting force acts [15]:

$$P_z^{rake} = kb(a-y) \quad (1)$$

where $k$ represents the specific cutting force; $b$ is the width of the cutting layer; $a$ is the thickness of the cutting layer and $y$ is the tool displacement from the initial position.

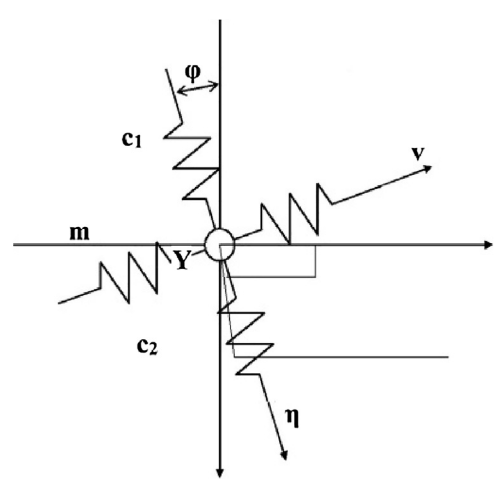


**Fig. 1 – Dynamic model of the tool.**