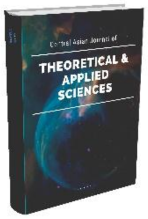


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# Diagnostics Of The Metal Cutting Process Based On Electrical Signals

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***Abstract:*** *The article deals with the use of electrical phenomena occurring in the process of cutting metals as an informative parameter for diagnosing the performance of a cutting tool and controlling cutting conditions.*

***Keywords:*** *detail, production, size, cutting tool, deformation, cutting process, workpiece, electrical phenomena, emission, temperature, contact, informative signal, thermoelectric phenomena, diagnostics, technology.*

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Today, the engineering industry is rapidly developing. New manufacturing enterprises are being created. The volume of production of modern machines is increasing. The need of enterprises for component parts for the production of new machines has grown. The range of manufactured parts is expanding, the requirements for the quality of manufactured products and labor productivity are increasing. The need for accelerated development of new competitive products and reduction of the terms of technological preparation of production has increased. The solution of these problems is impossible without the creation of a modern diagnostic system and new technologies. A database is needed based on the receipt and processing of informative signals from the cutting zone about the quality of the machined surface, the accuracy of the dimensions obtained and the condition of the cutting tool.

The cutting process is a combination of physical and chemical phenomena, which includes the kinematics of the cutting process, plastic deformation and destruction in the chip formation zone, as well as friction, thermal, electrical phenomena occurring on the contact pads of the cutting tool. All of them taken together are closely interconnected and form a single cutting system.

Increasing the efficiency of material processing by cutting is directly related to the creation of new and improvement of existing methods and means of monitoring the performance of the cutting tool. They should be based on a deeper understanding of the physical nature of the cutting process and the study of the relationship of phenomena that occur during processing. The input parameters characterize the technological processing system - a machine tool, a fixture, a tool, a part. Output parameters are defined as the result of the impact of the cutting process on the workpiece and tool, and also characterize the productivity and economy of the cutting process.

Electrical phenomena accompanying the process of cutting metals are increasingly attracting the attention of researchers. Thermo-electromotive force (EMF) is an indicator of the average cutting temperature and characterizes the degree of plastic deformation. This is the most important physical factor characterizing the cutting process. Thermo-EMF and thermal currents can have a direct impact on the cutting process. Generation processes usually occur with the participation of some external source, the energy of which is spent on breaking the electrical bonds that exist between the charges in the substance. When cutting metals, such external energy is the mechanical energy expended on the process of separating the chips from the workpiece.

Thermionic emission is one of the components of the thermoelectric component of the EMF of cutting, which until recently was considered the main reason for the generation of electrical signals during cutting. Studies show that when cutting metals, when the temperature in the zone of contact between the tool and the workpiece does not exceed the melting temperature, the electron energy is determined primarily by the "zero" energy, which depends on the degree of plastic deformation.

Thermoelectric phenomena are associated with the occurrence of electromotive forces in a chain of dissimilar conductors, in which there is a temperature gradient, is the Seebeck effect. Seebeck effect - the phenomenon of the occurrence of EMF at the ends of series-connected dissimilar conductors, the contacts between which are at different temperatures. The term "thermoelectric effect" encompasses three separately identified effects: the Seebeck effect, Peltier effect, and Thomson effect.

The effect of the reverse release or absorption of heat in the junction of two dissimilar metals, when an electric current flows through it, which was discovered by Peltier. The Peltier effect is the reverse phenomenon of the Seebeck effect; the electrical current flowing through the junction connecting two materials will emit or absorb heat per unit time at the junction to balance the difference in the chemical potential of the two materials. The third thermoelectric effect is the Thomson effect, which consists in the reverse release or absorption of heat in a homogeneous conductor through which an electric current flows, while there is a temperature gradient. Undoubtedly, these thermoelectric effects take place when cutting metals and will change the proportion of the thermoelectric component in the integral EMF of cutting.

The electron energy can be changed under the action of plastic deformation. This phenomenon is called low-temperature or exoelectronic emission. Exoelectronic emission arises as a result of the distortion of the electronic energy spectrum of a solid and the subsequent rearrangement of its electronic structure associated with the appearance of defects. It is the plastic deformation that accompanies the process of cutting metals that leads to the appearance and multiplication of defects in the crystal lattice of the metal, which increases the dislocation density by four orders of magnitude. Plastic deformation when stimulated by temperature, oxidation, phase transformations is the main type of energy impact responsible for the emission of so-called "exoelectrons" when cutting metals.

Some studies indicate that when cutting metals in the sliding plane, a stream of defects in the crystal lattice is localized, which excites the electrons of the metal, which is the main reason for the appearance of electrical signals during cutting. The appearance of EMF in solids due to the increase in elementary charge carriers by sound and ultrasonic waves is called the acoustoelectric effect or the emission of stress waves, and is the fourth reason for the generation of electrical signals during cutting.

The emission of stress waves occurs during cutting due to the formation of mechanical stress waves when the points of actual contact of the tool with the workpiece are deformed. It is noted in the studies that if the local pressure on the contact does not exceed the elastic limit of the soft material, then an elastic wave propagates in the material from the deforming contact. When processing metals, oscillations and waves of different frequencies occur, therefore, the EMF from the emission of voltage waves consists of the sum of the EMF corresponding to all components of the frequency spectrum.

This is one of the reasons why there is a variable component in the EMF of cutting in a wide range of the frequency spectrum.

The variable component of the EMF of cutting characterizes the energy fluctuations on the contact surfaces of the cutting tool and the workpiece. The magnitude and nature of the change in the variable component of the EMF of cutting depends on those factors that affect the amount of wear of the cutting tool. These factors include: the physical and mechanical properties of the tool and the part, as well as their heterogeneity, pressure, the actual area of contact, the speed of relative movement, vibration, the state of the contact surfaces, the processes of setting and destruction.

One of the researchers of the variable component of the EMF on the friction of metals indicates that finding the dependences of the change in potentials in the surface layers of pairs that rub against various factors will make it possible to establish the relationship between the change in these potentials and the amount of surface wear. Since the increase in potential characterizes the process of increasing energy in the surface layer of a rubbing pair, and is equivalent to the amount of mass in the surface layer destroyed during friction. Everything that has been said about the friction process can be transferred to the cutting process.

Thus, the EMF of cutting can be represented as the sum of the EMF resulting from: thermoelectric phenomena, including thermionic emission ($E_T$); exoelectronic emission ($E_{EK}$); field emission ($E_{AB}$); stress wave emission ($E_{XH}$) and is expressed as

$$E = E_T + E_{EK} + E_{AB} + E_{XH}, V$$

cutting 20, 50 and 100 m/min, and in the zone of build-up appearance, together with the actual value of EMF - $E_f$ for a given speed, the hypothetical EMF - $E_f$, which corresponds to the absence of build-up, was also taken into account.

According to the relative increase in the EMF of cutting, which was characterized by the ratio of the EMF for two selected cutting speeds of 50 and 100 m/min, the processed materials were located. The greatest increase in EMF corresponds to fine-grained steel, molybdenum, beryllium and nickel. Steels that are similar in chemical composition, primarily in terms of the content of carbon and chromium, are located side by side. Tool steels with high carbon content and high wear resistance are in the first place, while fine-grained and plastic ones close the row. In other words, the same trend is observed as for the tool material of hard alloys. An increase in carbide-forming elements and grains in the material being processed causes an increase in EMF.

The commonality inherent in the mechanism of influence on the EMF of both the processed material and the material of the tool is in good agreement with the proposed EMF generation model, which is fundamentally symmetrical with respect to the contacting surfaces. For this reason, when materials of the same name come into contact in the zone of moderate speeds, the signal has a sign-changing character. The revealed commonality allows us to conclude that the cutting process is symmetrical in terms of generating EMF, which is a specific friction pair. Then the influence of carbide-forming elements is associated with the erasing effect of the processed material.

When comparing the EMF of cutting for parts of one bar of steel 40X, which was subjected to different heat treatment, two trends are observed: an increase in EMF with an increase in the hardness of the material being processed and an increase in EMF with an increase in the pearlite grain size and its transition to a plastic state. It is known that the abrasive ability of 40X steel also increases in parallel. However, the main mechanism of the influence of the hardness of the treated metal on the EMF is the increase in pressure at the interface. Extreme abrasive conditions were created during the processing of fine silicon. In this case, the EMF of cutting reaches hundreds of millivolts, that is, it increases by an order of magnitude. Therefore, a comparison of the traditional characteristics of the machinability of metals with the EMF of cutting allows us to conclude that it reflects a real change in properties during processing, i.e. is an informative signal.

Exoelectronic, autoelectronic and voltage wave emissions affect the "zero" energy of an electron, and thermoelectric phenomena change the share of "thermal" energy in the total energy of an electron. Until recently, thermoelectric phenomena were considered the main reason for the generation of electrical signals during cutting. However, all four components are equal and, moreover, interconnected. The same contact surfaces of the tool with the part can be sources of generation of thermoelectrons, exoelectrons, autoelectrons and electrons of voltage waves.

The presented analysis shows that the electron energy, which determines the electrical phenomena during cutting, depends on the concentration of electrons in the material of the tool and workpiece, temperature, and the degree of plastic deformation. Based on this, electrical signals are a complex parameter that characterizes the process of cutting metals at the microstructural level. In this regard, electrical signals from the cutting zone should carry information about the processes occurring on the contact surfaces of the cutting tool with the workpiece. Therefore, measurements in the process of processing electrical signals from the cutting zone will allow diagnosing the health of the cutting tool, controlling cutting conditions, increasing tool life and creating an information base.

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