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Determination of temperature of maximum operability of replaceable cutting hard-alloy inserts based on study of electromagnetic properties change

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ABSTRACT

Introduction. Today, under the conditions of sanctions, the Russian Federation, more than ever before, needs the development of energy-saving technologies in various industries. There is no secret that when assigning cutting modes for new materials, tool companies conduct tests for the destruction of replaceable cutting inserts during cutting, the obtained numerical values are published in catalogs. The greatest impact on the life and operability of hard alloy cutting tools is exerted by the physical and mechanical properties of tool materials. Studies have shown that the physical and mechanical properties of tungsten hard alloys in the process of operation, namely in the process of cutting difficult-to-process materials under the influence of high temperatures, vary symmetrically. During the development of the laboratory plant, a literary review was carried out, which showed that at the moment non-destructive testing methods of technological facilities are widely used. Methods of non-destructive testing of technological objects allow conducting studies of the state of material, defects in the structure, internal changes, without samples destroying; this advantage was decisive during the literary review. **The object** of this study is replaceable cutting hard alloy inserts made of single carbide hard alloy B35 (92 %WC+8 %Co), tetrahedral in the state of supply. **The subject** of the study is the relationship between the changes of the magnetic component of the properties of a single-carbide hard alloy B35 (92 %WC+8 %Co) depending on the effect of high temperatures on it. This study is based on the laws of physics of the division of electrodynamics, as well as well-known non-destructive testing techniques, scientific foundations of material science. All studies are carried out in accredited laboratories of Tyumen Industrial University. The reliability of the obtained data is confirmed by the high correlation of the results of numerical values with the data obtained by the scientific predecessors. **Research methodology.** The paper shows the developed plant for determination of the maximum operability temperature of replaceable cutting hard-alloy inserts on the basis of study of change of electromagnetic properties. The method of research is given. Tests of the specimen are carried out during heating of replaceable cutting inserts made of tungsten hard alloy B35 (92 %WC+8 %Co). The heating temperature interval is selected in accordance with the temperature mode of the cutting process in the blade treatment of hard-to-process materials. Thus, heating is carried out in the range from 0 to 1000 °C. The heating itself is carried out by the flame method manually. **Results and discussions.** Based on the results of experimental studies, tables of the results are compiled, where, with an interval of 10 °C, the corresponding values of the magnetic field of eddy currents induced in replaceable cutting inserts made of tungsten hard alloy B35 (92 %WC+8 %Co) are indicated. The results of the investigation are obtained to determine the maximum operability temperature of replaceable cutting hard alloy inserts based on the study of the change in electromagnetic properties for the hard alloy B35 (92%WC+8%Co) amounted to 460…730 °C, which corresponds to a cutting speed of 18 m/min during the treatment of the alloy EI867-VD (57 %Ni9 %Mo10 %Cr6 %W4.2 %Al4 %Co). On the basis of persistent tests in factory conditions, it is proved that the developed technique allows determining temperature intervals of maximum operability based on the study of changes in electromagnetic properties (magnetic field of eddy currents arising in replaceable cutting inserts) of hard alloys. These intervals make it possible to assign the most appropriate operating conditions for the cutting tool based on a scientifically sound technique that allows using the maximum tool resource.

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Introduction

Today, under the conditions of sanctions, the Russian Federation needs the development of energy-saving technologies in various industries more than ever.

The tasks for designing machine parts, for example in aviation or oil and gas engineering, determine the use of heat-resistant and difficult-to-process materials, including new ones. Metallurgy is constantly developing; there appear new grades of materials with strength, hardness, plasticity, heat resistance properties that are many times superior to their analogs, for example, Russian grades of alloys such as VVP or American alloy martensite. In this regard, in the manufacture of such machine parts, there are many problems with the assignment of technological parameters of the manufacturing process. Primarily, this is due to the implementation of new materials at the start of the product manufacturing or general overhaul and preventive repairs, i.e. custom production of various units and machines.

In Tyumen Oblast, gas turbine engines used for pumping gas undergo capital and emergency repairs. Many difficult-to-process heat-resistant materials are used in their design. Studies have shown that the choice of tool material, as well as the appointment of processing modes (cutting), are the major issues in the processing of steels and alloys that belong to the group of hard-to-process materials [1]. Choosing the rational manufacturing parameters of the cutting process allows building an energy-efficient process for the production and repair of machine parts.

Cutting is a multifactorial process that is very difficult to predict, especially when processing heat-resistant and difficult-to-process materials. However, there is no doubt that under the influence of temperature and cutting forces, there occurs a change in the structure and, accordingly, the properties of the tool and the processed material, with this change affecting the machining process. The study of how the changes in the properties of these materials influence the process of their cutting will allow for a reasonable assignment of rational processing modes.

When assigning cutting modes for new materials, tool companies conduct tests for the destruction of replaceable cutting inserts during cutting, with the obtained numerical values published in catalogs [2]. However, these numerical values do not always correspond to the optimal cutting modes. In practice, the operating conditions for the tool are divided into workability groups [3]. To date, tool companies use seven workability groups in their catalogs. The group may include a large number of processed materials grades, but only a few grades of tool material may be recommended for processing. According to these recommendations, it is not possible to determine which tool material will provide the longest service life when processing the chosen material.

The problem of ensuring the longest service life of the cutting tool was studied from various positions in the works of S. A. Vasin [4], S. N. Grigoriev [5], S. V. Gruby [6], I. Carceanu, G.Cosmeleată [7], C. Ferri [8], J. Kümmel [9], Munish Kumar Gupta [10], K. S. Murthy [11], R. Neugebauer [12], I. Jaafar[13], S. Tangjitsitcharoen [14], A. Patwari [15], W. Tillmann [16], H. Zhang[1 7], and C. L. Zhang [18].

A literary analysis of the works of world-renowned scientists in edge cutting machining has shown that the temperature factor has a resultant effect on the cutting process of hard-to-process materials [4–18].

Tool materials (TM), like other materials, have physical and mechanical properties that can change under the influence of external factors. These properties have a decisive influence on the operability and service life of the tool made of these materials. Studies have shown that the physical and mechanical properties of tungsten hard alloys change symmetrically under the influence of high temperatures during operation, namely during the cutting of hard-to-process materials [19]. The study of the processes occurring inside tool materials, including tungsten hard alloys, will allow for determining and assigning operating modes of this material on a scientifically based methodology taking into account the material's internal changes. It will increase the service life of the cutting tool and provide conditions for the cutting tool to have maximum cutting properties when machining hard-to-process materials [20].

The aim of the work is to determine the cutting speed that ensures the maximum service life of replaceable cutting inserts made of tungsten hard alloy B35 during turning of the chromium-nickel alloy EI867-VD based on the study of changes in the electromagnetic field of eddy currents that occur in replaceable cutting inserts at a temperature change.

To achieve the aim, the following **tasks** were set and solved.

1. To perform a literary review, as well as to analyze existing works devoted to the problems of rational choice of tool material, as well as the appointment of cutting modes.
2. To conduct experimental studies of changes in the electromagnetic field of eddy currents arising in B35 hard alloys under the influence of high temperatures inherent in the cutting process.
3. To research the mechanics of the cutting process during turning of hard-to-process chromium-nickel steel EI867-VD at different speeds with cutters equipped with replaceable cutting hard-alloy inserts made of hard alloy B35.

Research Methodology

The operability of cutting tools is considered to be the conditions under which they can perform cutting in accordance with the established requirements under certain conditions [21].

Solving the second task required conducting laboratory studies of changes in the magnetic field of eddy currents arising in replaceable cutting inserts made of tungsten hard alloy B35. The experiment was carried out in the temperature range from room temperature to the temperature that occurs at the tip of the cutting edge during cutting. It is at such temperatures that the cutting process takes place when machining hard-to-process steels and alloys, such as EI867-VD. An analysis of existing solutions has shown that there are no such devices to meet our requirements. One of the requirements for the device is the possibility of using a replaceable polyhedral hard-alloy insert as a test sample in the as-delivered state for maximum approximation of the results to real conditions. A laboratory plant was built to conduct experimental studies.

During the development of the laboratory plant, the literature review showed that methods of non-destructive testing of technological objects are widely used at the moment. These methods allow conducting studies of internal changes without destroying samples, which was a decisive advantage in the literary review. There are seven types of non-destructive testing, presented in Fig. 1 [22], each of them has both advantages and disadvantages.

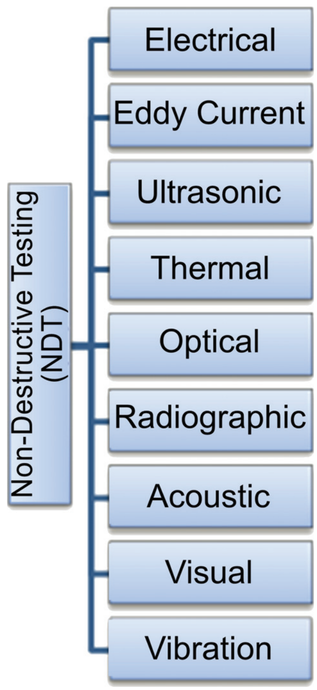

Fig. 1. Types of non-destructive testing (NDT)

The non-destructive eddy current testing method is suitable for studies of internal changes occurring in tool materials [22]. It can also be applied for testing samples of replaceable cutting hard-alloy inserts (RCHAI) in the as-delivered state. This testing method is based on the analysis of the interaction of an external electromagnetic field with the electromagnetic field of eddy currents [23].

This advantage not only meets our requirements but also allows reducing the time for the production of special samples made of tungsten hard alloy B35. In addition, it makes laboratory tests similar to real conditions, which is undoubtedly a significant advantage over other types of non-destructive testing.

Replaceable cutting hard-alloy inserts made of the tool hard alloy B35 in the as-delivered state were selected as the studied samples, Fig. 2.

The characteristics of the selected replaceable cutting inserts are shown in Table 1.

The research was carried out on a special laboratory plant and was based on the eddy current method of non-destructive testing. The scheme of the proposed plant is shown in Fig. 3.

The laboratory plant is a system of devices for measuring changes in the magnetic field of eddy currents arising in ferromagnets. RCHAIs in the as-deliverer state are recommended to use as objects of research since the size of the used coil with a heat-insulating coating is the limiting factor. When changing the coil, studies on samples of other form factors are allowed.

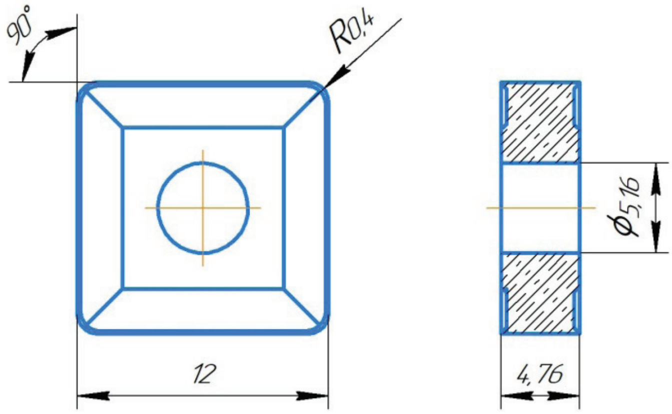

Fig. 2. Replaceable Cutting Hard Alloy Insert

Table 1

Characteristics of selected replaceable cutting inserts

Company	Shape	Dimensions	Material
Kirovgrad Hard Alloys Plant	SNMA	12x12×4.76	B35

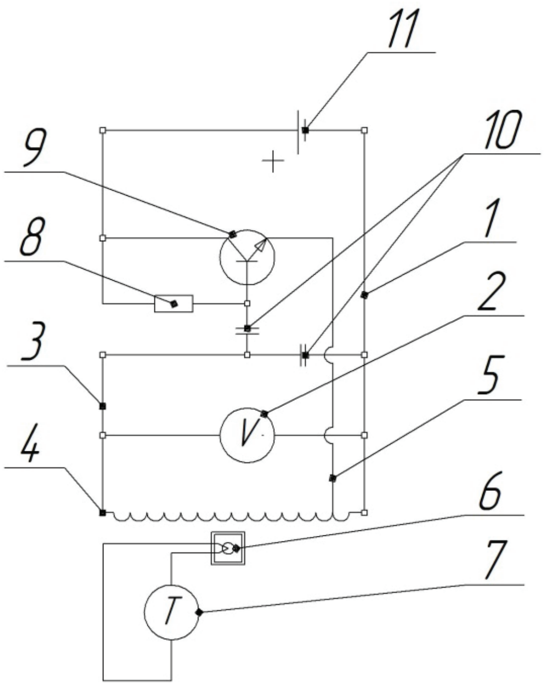

Fig. 3. Diagram of developed plant for determination of maximum operability temperature of replaceable cutting hard-alloy inserts by electromagnetic properties:

1 – self-oscillating circuit; *2* – voltmeter; *3* – coil 1 output; *4* – coil; *5* – coil 2 output; *6* – replaceable cutting insert; *7* – thermometer; *8* – resistance; *9* – transistor; *10* – condenser; *11* – power supply

The plant includes a self-oscillating circuit (SOC) and an instrument panel (a multi-voltmeter is used to measure the quantitative complex characteristics of changes in the EC (eddy currents) magnetic field, and a digital thermometer was used to measure the temperature state during the entire experiment). The electronic part of the device is an electronic circuit consisting of two series-connected condensers, a resistance, a transistor, and a power supply. The SOC is made in the form of a self-transformer, as the excitation winding of an eddy current converter. The winding is coated to prevent the harmful effects of heating and the destruction of the winding itself.

The samples were tested during heating of replaceable cutting inserts made of tungsten hard alloy B35, Fig. 4.

The heating temperature range was chosen in accordance with the temperature regime of the cutting process during blade machining of hard-to-process materials. Thus, the heating was carried out in the range up to 1000 °C. The heating itself was carried out by the gas-flame method manually.

The studies stages were: the sample was heated, in our case, the sample is a replaceable cutting hard-alloy insert in the as-delivered state, then a magnetic field was induced on the sample under study by a non-contact method. Changes in the values indicating internal changes in the hard alloy were recorded on the measuring device (voltmeter) of the developed plant. The results were displayed on the screen of a computer monitor.

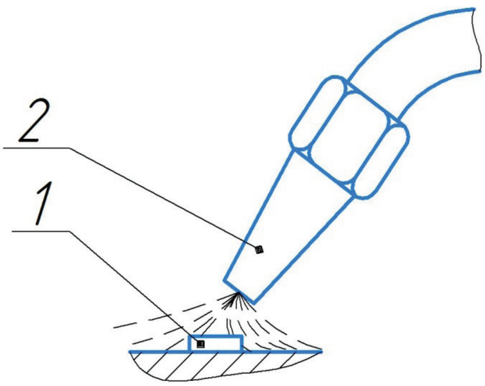

Fig. 4. Heating of replaceable hard alloy cutting insert:

1 – sample, replaceable carbide insert from hard alloy B35 (92 %WC + 8 %Co); *2* – heating device

Results and discussion

The experimental studies results were compiled in the tables where the corresponding values of the eddy currents magnetic field induced in replaceable cutting inserts made of tungsten hard alloy B35 were indicated with an interval of 10 °C.

The polynomial dependences of the obtained data on the heating temperature were constructed using the capabilities of the mathematical apparatus of the MS Excel software, Fig. 5. The temperature range *12* of Fig. 5, in which experimental studies were carried out, corresponds to the temperature range characteristic of the cutting process.

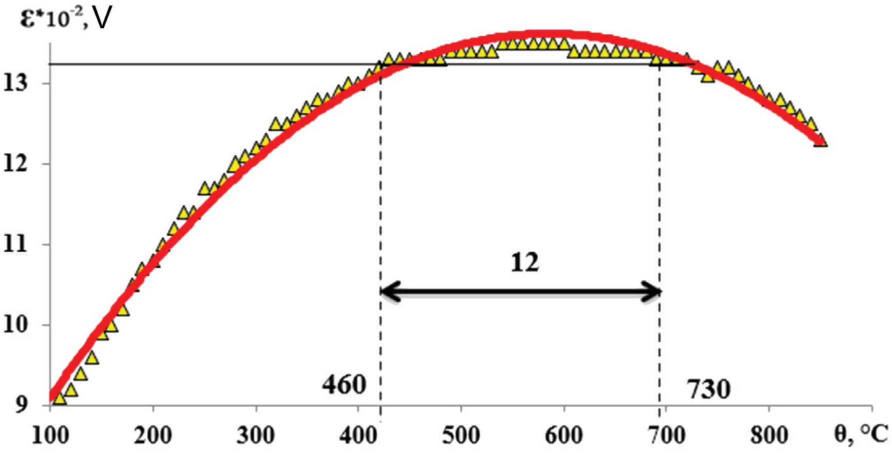

Fig. 5. The obtained one-parameter dependence of change of EMF values under the influence of temperatures during the experiment on replaceable alloy cutting insert B35 (92 %WC + 8 %Co)

The resulting graphical dependence, where a polynomial is chosen as the approximating curve, is processed according to the rules of engineering research in accordance with the 5 % error allowed for such calculations.

A special technique is used to determine the boundary of the temperature range. The 5 percent interval is laid off from the value of the maximum magnetic field. A line parallel to the temperature axis is drawn through this point, through the entire field of the graph. The points where the line intersects with the graph line are taken as the boundaries of the desired interval. From the obtained points, we draw projection lines on the temperature axis. The resulting temperature range is taken as the interval of the maximum service life of replaceable cutting inserts made of hard alloy B35. The tool can be used in the entire temperature range. However, from a technological point of view, it is preferable to adhere to the maximum temperature since it provides the maximum permissible cutting speed.

Figure 6 shows the dependencies of the cutting temperature, the cutting path, and the relative surface wear of the tool. By the nature of these dependencies, we can say that in a certain temperature range there is a minimum of relative surface wear and a maximum of the cutting path, which proves the adequacy of the developed technique. Each point on the graphs represents the arithmetic mean of the obtained values, as a result, at least 3 measurements are carried out.

Based on the obtained dependences (Fig. 6), the change in the EMF values direction corresponds to the structural changes of the first phase transition of cobalt under laboratory conditions. Up to these values, there is an increase in the strength values of the hard alloy, which provides conditions for maximum tool

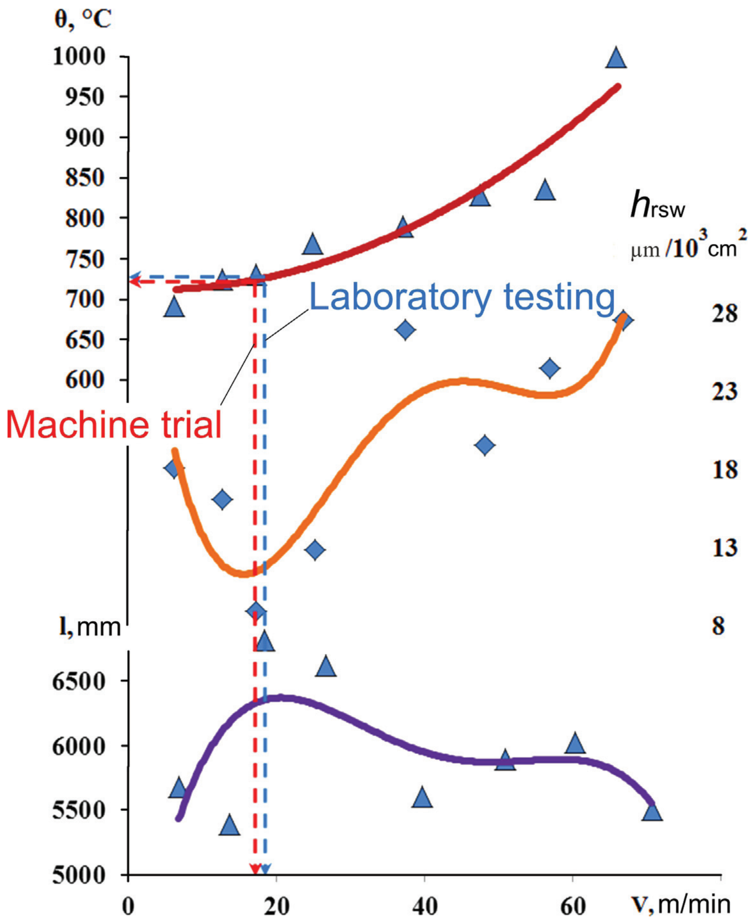

Fig. 6. Dependencies of cutting temperature (θ), cutting path to failure (L), relative surface wear (h_{tw}), cutting speed (V), (material to be treated EI867-VD (57 %Ni9 %Mo10 %Cr6 %W4,2 %Al4 %Co), tool material B35 (92 %WC+8 %Co), Feed (S) = 0,39 mm/n, Time (t) = 1 mm)

operability. This is confirmed by the study of the mechanics of the cutting process during the turning of the chromium-nickel alloy EI867-VD.

The results obtained correlate with the results of research on increasing the service life of cutting tools, Table 2.

Table 2

Comparative analysis of the results with the results obtained by the method based on toughness (KCV)

Material	The method of determining the maximum operability temperature based on impact toughness (KCV) (research by V. M. Kostiv D. S. Vasilega [1])	Authors ‘ methodology to determine the maximum operability temperature by changing the magnetic field of eddy currents (research by the authors)
B35 (92 %WC+8 %Co)	520…730°C	460…730°C

The comparative analysis proves the possibility of using this technique to determine the maximum operability temperature of replaceable hard-alloy cutting inserts based on the study of changes in electromagnetic properties. The maximum allowable temperature of the interval is proposed as the resulting temperature since it provides the maximum service life of the tool and eliminates the possibility of its premature failure.

Thus, changes in the electromagnetic properties of hard alloys for tools react to changes in the state of the material and can be used to determine the maximum operability temperature of replaceable cutting hard-alloy inserts. In production conditions, the cutting speed is easily determined according to this temperature range; the chosen speed provides the longest service life of replaceable cutting inserts using the method of a natural thermocouple or a thermal imager.

Conclusion

The research included experimental studies on changing the electromagnetic field of eddy currents arising in hard alloys of the B35 grade under the influence of high temperatures typical of the cutting process. The experimental studies allowed obtaining a temperature range of 460...730 °C characterized by changes in electromagnetic properties. Studies also comprised testing the mechanics of the cutting during turning of hard-to-process chromium-nickel steel EI867-VD at different cutting modes (speeds) by cutters equipped with replaceable cutting B35 hard-alloy inserts. These studies allowed finding the cutting speed that ensures the maximum service life of the cutting tool.

The study showed that for turning the chromium-nickel alloy EI867-VD, the cutting speed of 18 m/min provides the maximum service life of the tungsten hard alloy B35. This is confirmed by the minimum value (0.225 mm) of the wear chamfer on the flank surface of replaceable cutting plates, and the minimum value of the relative surface wear on the flank surface h_{rsw} 211.97 µm/10^3cm, obtained at a cutting temperature of 730°C. This temperature is included in the temperature range obtained in the laboratory when studying changes in the electromagnetic field of eddy currents occurring in hard alloys of the B35 brand.

Thus, these studies on measuring the structural changes of hard alloys enable identifying cutting speeds that ensure each hard alloy’s maximum service life or maximum operability based on a scientific methodology.

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Conflicts of Interest

The authors declare no conflict of interest.