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MODEL OF SURFACE ROUGHNESS IN TURNING OF SHAFTS OF TRACTION MOTORS OF ELECTRIC CARS

Purpose. Research on surface roughness in turning of traction motor shaft of electric vehicles, depending on the measure of the main cutting edge angle and rounded-off radius of the cutter. Analysis of the impact of vitrified aluminum oxide disk characteristics on the surface profile after wheel dressing.

Methodology. The research was based on existing empirical dependencies that describe the profile of the workpiece surface being machined during turning and grinding. In this case, probability-theoretical methods and methods of straight-line strip chart recording before and after grinding were used.

Findings. The irregularity of the surface roughness that occurs after turning of the traction motor shaft of electric vehicles has a significant impact on the choice of geometric parameters of the cutting tool. Most often, roughness is considered as a deterministic set of irregularities of the same size and shape. There are dependencies built from the analysis of the kinematics of the treatment process and the shape of the tool cutting part. It is advisable to consider the profile of the roughness of treated surface of the part as the sum of all random deviations superimposed on an ideal geometrically calculated profile. In this case, the roughness profile will have a probabilistic character, which was formed as a result of complex stochastic processes that occur during machining. Depending on the physical phenomena that accompany the treatment process of the material, the levels of the random component should be adjusted depending on the cutting speed.

Originality. For the first time, a composite model of surface roughness is considered taking into account the influence of a random component on the geometric parameters of the cutting tool. Impact analysis of the vitrified aluminum oxide disk's characteristics parameters on the surface profile after dressing the cutting wheel face was conducted.

Practical value. The assignments of cutting conditions, taking into account the rational parameters of the main cutting edge angle and apex spherical radius of a cutter will ensure the necessary surface quality after machining motor shaft of electric vehicles and their collector-and-brush assembly units, which will significantly affect the overall efficiency of the electro-mechanical system of the vehicle. Regularities of forming and describing the relief of a cutting wheel face will make it possible to clarify the number of active gains in the wheel-workpiece contact, the thickness of the cut by individual grains and the components of the cutting force during grinding, which will lead to an increase in the quality of processing the traction motor shaft of an electric vehicle.

Keywords: turning process, surface roughness, surface condition, cutting edge angle, rounded-off radius of the cutter

Introduction. The surface roughness in turning of traction motor shaft of electric vehicles is influenced by such factors as cutting depth and speed, feed, the main and end cutting edge angles, the main back and front clearance angles, tool deterioration and its on-stream time, apex spherical radius of a cutter, properties of the processed and tool material, and others. The main factor is the geometry of the cutting tool. The main geometric parameters of the cutting tool, affecting the surface roughness, are the main and end cutting edge angles and apex spherical radius of a cutter [1, 2]. It is especially important to ensure the necessary surface quality after machining the motor shaft of electric vehicles and their collector-and-brush assembly units, where this significantly affects the overall efficiency of the electro-mechanical system of the vehicle [3, 4] with an electric drive [5, 6]. There are certain peculiarities when processing parts from different materials [7]. The term “surface

quality” is a complex of the following characteristics: roughness (microgeometry); waviness; structural condition (tear, microcracks, structure refinement); hardening (peening) of mat surface (depth and degree of cold work); residual stresses (depth, magnitude and sign). Therefore, by roughness is understood the set of irregularities located within the base length. Deviations within a size larger than the standard portion refer to shape deviations and are not considered in this work.

In addition, the quality of the part, which determines its operational criteria, is mainly formed at the final operation. Such an operation, in most cases, is grinding, as one of the methods of oversize mechanical removal providing a high level of accuracy and quality of the processed surface. The degree of realization of the potential capabilities of this method depends on how well the characteristics of the grinding tool are combined with the processing conditions. After mechanical processing of the shaft with cutters, it is necessary to include the grinding operation in the technological process to obtain

the specified dimensions with high accuracy and achieve a minimum surface roughness. Use of appropriate abrasives is of decisive importance in this operation.

Analytical research survey. An important factor that interferes with the mathematical description of roughness is its irregularity, which occurs due to the physical features of surface formation methods. Therefore, for mathematical modeling of surface roughness it is necessary to use probability-theoretical methods. Most often, roughness is considered as a deterministic set of non-uniformities similar in size and shape. There are dependencies based on the analysis of the kinematics of the machining process and the geometric shape of the cutting part of the tool [2, 8]. In this view, the influence of all random components of the process is not taken into account and does not correspond to reality.

Therefore, there were developed formulas for calculating roughness obtained empirically. Such models have disadvantages inherent in empirical dependencies and, in addition, they completely neutralize the influence of technological factors on the roughness structure formation, since information about such a structure is lost [9, 10].

Purpose. The objective of this work consists in the study of the roughness of traction motor shaft during turning, depending on the magnitude of the main cutting edge angle, the feed and the rounded-off radius of the cutter. At the second stage, we are to justify the choice of an abrasive tool with desired cutting properties.

Methods. Formation of the machined surface roughness of the traction motor shaft of electric vehicle can be represented by a simplified model as an expansion of the real profile on the deterministic and random components. In mechanical engineering, measurements of deviations of profile irregularities are produced on the parts' surface in a plane section, normal to the base surface within a length l , which represents a straight line in the measurement plane. To evaluate and standardize the roughness quality according to the ISO 4287 and DIN 4768 standards, the following parameters were set: Ra , Rz , $Rmax$ – high-altitude; Smi , Si – stepwise; tp – parameter of profile bearing length ratio.

The parameters Ra and Rz are statistical, and represent the average height of the profile irregularity of the random process $x(t)$, provided that it is centered relative to the baseline m . The value of Ra is most often used in the study of the work of mating parts in the running-in process. The parameter Rz is used in the design documentation for assigning clearance allowance and characterizes technological errors. The influence of factors Smi , Si , tp on the roughness of the machined surface is not considered in this paper.

The value of Rz is influenced by the quantities which are determined by the kinematics of movement and tool geometry, oscillatory motion of the tool, inelastic deformation in the cutting zone. When turning the traction motor shaft of electric vehicles, the deviation of the real profile from the calculated one occurs as a result of inelastic deformation arising in the cutting zone. These deformations are the cause of the microprofile violation on the treated surface. At low feeds, the change in microprofile is significant. It causes an increase in microroughness height of the machined surface of the shaft and increases the role of random component [10, 11].

The separation of the variance causes into two groups leads to a composite roughness model (deterministic periodic basis and the random component that is superimposed on it). In addition, it can be assumed that since the random component is a consequence of numerous factors that randomly and approximately equally affect the process of roughness formation, the ordinate distribution of this component obeys the normal law [12].

The greatest influence on the roughness of the shaft surface is exerted by the feed rate. With an increase in S feed, the roughness also increases. In this case, when moving the cutter along the surface of the shaft during processing with $S_2 > S_1$ microrelief parameter h increases – $h_2 > h_1$ (Fig. 1). That is, variances and depressions form on the shaft surface.

The scheme of influence of the magnitude of the main cutting edge angle φ and end cutting edge angle φ_1 of the cutter on the microrelief of the treated surface is shown in Fig. 2. With the same feed S_2 and angles $\varphi < \varphi'$, $\varphi_1 < \varphi'_1$ the microrelief parameter h increases – $h_2 > h_1$.

The apex spherical radius of a cutter R also affects the microrelief of the shaft surface during processing. With the same feed rate S_2 , identical values of the main φ and end φ_1 cutting edge angles spherical radius $R_1 < R_2$ the value of h will increase – $h_1 > h_2$ (Fig. 3).

Considering the influence of these factors, experimental studies were carried out when turning the traction motor shaft with a diameter D of 70 mm, a feed S , equal to 0.2 mm/rev, a cutting depth t of 1.5 mm, end cutting edge angle φ_1 at a level of 45° , the main cutting edge angle φ , in the range from 30 to 60° , apex spherical radius of a cutter R , equal to $0-0.2$ mm. An analysis of the results showed that for $R < 0.1$ mm, an increase in the value of the main cutting edge angle φ in the range from 40 to 60° leads to an increase in the roughness of the shaft surface. In this case, the apex spherical radius of a cutter and its side edges will be the deterministic component of the parameter Rz . On the other hand, this component will be formed only by the spherical radius $R > 0.1$ mm without the participation of the main cutting edge angle (Fig. 4).

Thus, in order to obtain the required value of surface roughness during machining of the traction motor shaft, it is necessary to assign rational parameters of the cutting conditions. In our case the cutting tool should be selected with apex spherical radius $R < 0.1$ mm and the main cutting edge angle φ from 30 to 50° .

At the same time, for the shaft surfaces on which the bearings will be fixed, the roughness requirements are even stricter. Only chiseling is not enough. Therefore, in the technological process, a grinding operation with the use of abrasive wheels is used [13]. For these operations, the most common is an abrasive tool vitrified with electrocorundum. It is used in the processing of machine parts from various steels and allows obtaining a given surface roughness at minimal cost. The main disadvantage of this tool is a tendency to burns and low performance. In our case, it is recommended to use an abrasive wheel made of electrocorundum grade 24A on a ceramic bond

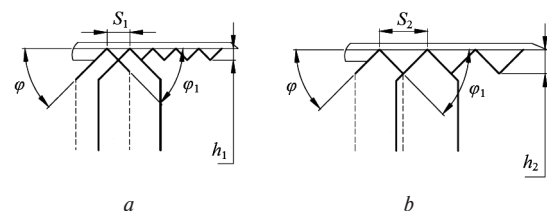


Fig. 1. Microrelief of the shaft surface when feeding $S_2 > S_1$

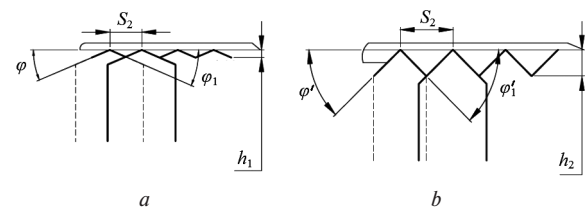


Fig. 2. Microrelief of the shaft surface at $\varphi < \varphi'$, $\varphi_1 < \varphi'_1$

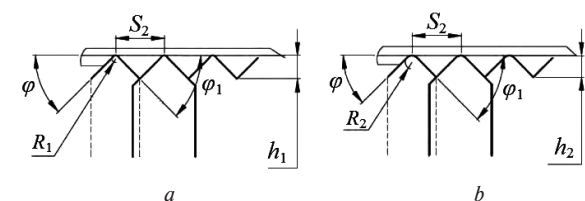


Fig. 3. Microrelief of the shaft surface at $R_1 < R_2$

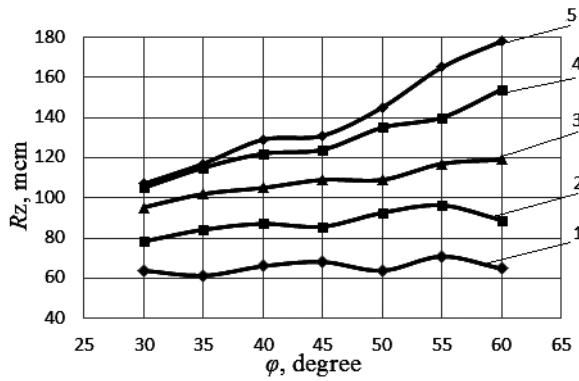


Fig. 4. The dependence of the roughness parameter Rz on the main edge angle φ of the cutter depending on the radius r :
1 – 0.2 mm; 2 – 0.15 mm; 3 – 0.1 mm; 4 – 0.05 mm; 5 – 0 mm

V for processing wear-resistant steel. The optimal parameters of this cutting tool in the appropriate processing conditions include granularity, hardness and structure.

Also, when choosing the wheel grain size it is necessary to take into account the resistance of the circle, the given accuracy and surface roughness, and the properties of the material being processed. The removal of material from the processed shaft is carried out using the cutting surface of the wheel (CSW), the desired relief of which is achieved by grinding in a certain mode. Wheel dressing is carried out on appropriate modes with diamond-coated insert, rollers, and others.

After grinding the CSW characteristics of the abrasive wheel are modified by the geometry parameters of the cutting surface relief [14, 15]. The main ones are the profile bearing length ratio t_p and mean height of profile irregularities in crests l_p . The information about the wheel surface relief after grinding is obtained by a method for probing with diamond stylus. In contrast to standard methods, the method of straight-line profiling along the same path after dressing and grinding was used. This will allow developing and choosing an abrasive wheel with high structure, which will increase the productivity of machining.

Thus, it is necessary to establish rational geometric parameters of the cutting surface of the wheel to predict the cutting properties and a reasonable choice of its characteristics. The solution to this problem was based on profiling of the cutting surface of vitrified bonded aluminum oxide wheel. The study was conducted on a specialized research facility, created on the basis of surface grinding machine. The characteristics of grinding wheels varied as follows: grain size – 80, 60, 46; hardness – H, J, L ; structure numbers – 5, 8, 11. To achieve this goal, three series of one-factor studies of the relief of the wheel cutting surface were carried out. The approximation of the experimental dependences is applied by the methods for determining the exponent for the argument and the selection of the correction coefficient for hardness.

It was found that as the graininess increases, a substantial decrease in the bearing length and an increase in the distance between the profile peaks occur. Grinding wheels with greater hardness have a greater value of the bearing length and a smaller distance between the profile peaks. An increase in the number of the wheel structure leads to a slight decrease in the bearing length and an increase in the distance between the peaks. Grinding wear-resistant steels features a certain increase in the profile bearing length, and the average distance between the profile peaks remains almost unchanged. The main reason for limiting the redress life of aluminum oxide wheel is the formation of worn place of grains (for wheels with grain size number 60 the profile width of worn place reaches from 0.03 to 0.05 mm, and the total number of dull grain is about 30 %). When processing experimental studies, the following parameters were determined:

- profile bearing length on the level p

$$t_p = \frac{\sum_{i=1}^n b_{pi}}{L};$$

- mean height of profile irregularities in crests

$$l_p = \frac{L}{z_p},$$

where $\sum_{i=1}^n b_{pi}$ is the total length of peak section; z_p is the number of grain peaks.

The analysis of the influence of the parameters of the characteristics of vitrified bonded aluminum oxide disk (grain size, hardness, structure) on the profile bearing length ratio t_p and average distance between grains l_p along the relief depth p after dressing CSW was made. Based on the obtained experimental data and their approximation, dependencies are defined and shown in Figs. 5–8.

It was established (Figs. 5, 6) that the grain size of the abrasive wheel has a significant effect on the bearing length t_p of the cutting surface relief and on the average distance between grains l_p . For example, with a grain size of 46 (nominal abrasive grain size $d = 0.4$ mm), the parameter t_p is two times less than that with a grain size of 80 (nominal abrasive grain size $d = 0.16$ mm). And the parameter l_p , on the contrary, is 3.5 times greater for a grain size of 46 compared to a grain size

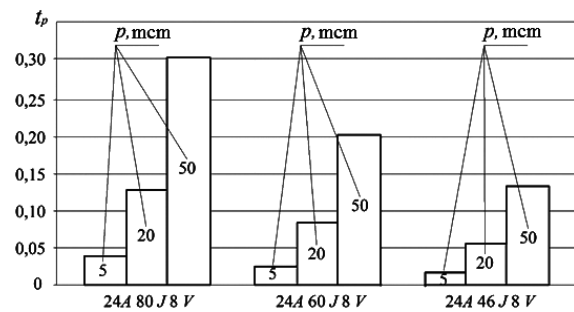


Fig. 5. The effect of grain size (80, 60, 46) and the depth p of the cutting surface relief of the grinding wheel on the bearing length t_p

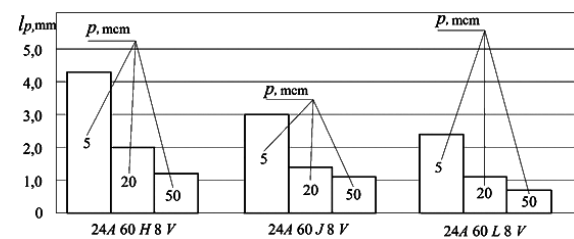


Fig. 6. The effect of hardness (H, J, L) and the depth p of the cutting surface relief of the grinding wheel on the average distance between grains l_p of its relief

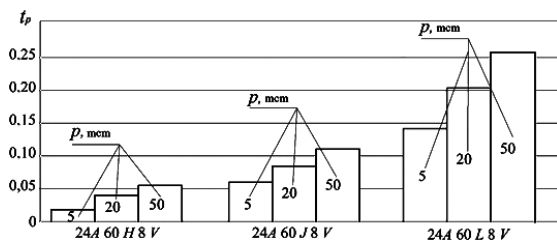


Fig. 7. The effect of hardness (H, J, L) and the depth p of the cutting surface relief of the grinding wheel on the bearing length t_p of its relief

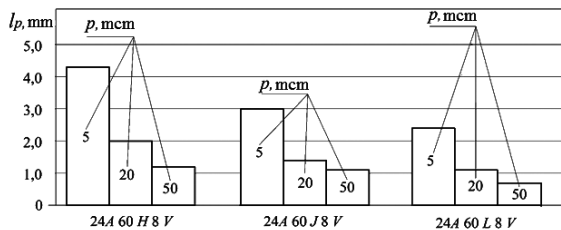


Fig. 8. The effect of hardness (H, J, L) and the depth p of the cutting surface relief of the grinding wheel on the average distance between grains l_p

of 80. This effect of graininess is explained by the limitations that are imposed by the composition of the molding compound in the manufacture of abrasive wheels.

Grinding wheels with a hardness H are characterized by a lower value of the parameter l_p in comparison with abrasive wheels with hardness L . When comparing the parameter l_p its greater value for grinding wheels with hardness of H and its smaller value for L is noted (Figs. 7, 8).

It has been established that the main factor limiting the period of resistance (time to use) of electrocorundum abrasive wheels during dry grinding of hardened high-speed steels according to the criterion “burn” of a grinding surface is the grain-tip blunting at the zero level of the relief with the formation for grain size from 80 to 46 (ISO 8486) the relief worn place from 0.03 to 0.05 mm, depending on the grinding conditions.

Compared with the relief parameters of the wheel cutting surface, defined by the probabilistic-analytical method, the process of diamond truing in the frame creates a less developed discrete relief with less sharpening of the corrected grain profile and a large number of grain tops per unit area, which helps to stabilize the cutting ability of abrasive wheels.

The detected pattern formation and description of the CSW relief allow further move to specified calculations of the number of active grains in the wheel-workpiece contact, the thickness of the cut by individual grain and the components of the cutting force during grinding, which, ultimately, will lead to an increase in the quality of processing the traction motor shaft.

Research is also relevant for shafts of vehicles with hydro-mechanical gears [16, 17]. In terms of the vehicle flow distribution the optimal machine parts’ life-time can be calculated. As a result, the use of the lubricants might be substantiated with the mathematical description of the influence on mechanical parts reliability [18].

Conclusions.

1. The influence of the random component on the roughness of the machined surface was revealed for different feed rates and cutting tool geometries when machining the traction motor shaft of electric vehicles.

2. To obtain the required surface roughness during machining of the traction motor shaft of electric vehicle, rational parameters of the cutting tool are established. Apex spherical radius of a cutter $R < 0.1$ mm and the main cutting edge angle φ from 30 to 50°.

3. It was experimentally established that with an increase in the wheel grain, a substantial decrease in the bearing length and an increase in the distance between the profile peaks occur.

4. The main factor limiting the period of resistance (time to use) of electrocorundum abrasive wheels during dry grinding of hardened high-speed steels according to the criterion “burn” of a grinding surface is the grain-tip blunting at the zero level of the relief with the formation of the relief worn place from 0.03 to 0.05 mm for the grain size from 80 to 46 (ISO 8486), depending on the grinding conditions.

5. Patterns of formation and description of the cutting wheel face’s relief allow further moving to specified calculations of the number of active grains in the wheel-workpiece contact, the thickness of the cut by individual grain and the components of

the cutting force during grinding, which, ultimately, will lead to an increase in the quality of processing the traction motor shaft.

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Модель шорсткості поверхні за токарної обробки валів тягових двигунів електромобілів

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Мета. Дослідження шорсткості поверхні при токарній обробці валів тягових двигунів електромобілів у залежності від величини головного кута у плані та радіуса заокруглення різця. Аналіз впливу параметрів характеристики електрокорундових абразивних кругів на керамічний зв'язці на профіль рельєфу поверхні після правки шліфувального круга.

Методика. Базувалася на існуючих емпіричних залежностях, що описують профіль оброблюваної поверхні деталі при токарній і шліфувальній обробці. При цьому використовувалися теоретико-ймовірнісні методи та методи прямолинійного профілографування до й після шліфування.

Результати. Нерегулярність шорсткості поверхні, що виникає після токарного оброблення валів тягових двигунів електромобілів, суттєво впливає на вибір геометричних параметрів різального інструменту. Найбільш часто шорсткість розглядається як детермінована сукупність однакових за розмірами та формою нерівностей. Існують залежності, побудовані з аналізу кінематики процесу обробки та форми ріжучої частини інструменту. Доцільно розглядати профіль шорсткості обробленої поверхні деталі як суму всіх випадкових відхилень, накладену на ідеальний, геометрично розрахований профіль. При цьому профіль шорсткості матиме ймовірнісний характер, що був сформований у результаті складних стохастичних процесів, які відбуваються під час механічної обробки. Залежно від фізичних явищ, що супроводжують процес обробки матеріалу, рівні випадкової складової повинні коректуватися залежно від швидкості різання.

Наукова новизна. Уперше розроблена композиційна модель шорсткості поверхні з урахуванням впливу випадкової складової на геометричні параметри різального інструменту. Проведено аналіз впливу параметрів характеристики електрокорундових абразивних кругів на керамічний зв'язці на профіль рельєфу після правки ріжучої поверхні круга.

Практична значимість. Призначення режимів різання з урахуванням раціональних параметрів головного кута у плані й радіуса заокруглення при вершині різця дозволить забезпечити необхідну якість поверхні після механічної обробки валів тягових двигунів електромобілів і їх щітково-колекторних вузлів, що істотно вплине на загальний коефіцієнт корисної дії електромеханічної системи транспортного засобу. Закономірності формування та опис рельєфу ріжучої поверхні круга дозволять уточнити число активних зерен «у контакті коло — заготовка», товщину зрізу окремим зерном і складові сили різання при шліфуванні, що призведе до підвищення якості обробки вала тягового двигуна електромобіля.

Ключові слова: токарна обробка, шорсткість поверхні, якість поверхні, план різця, радіус заокруглення різця

Модель шероховатости поверхности при токарной обработке валов тяговых двигателей электромобилей

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Цель. Исследование шероховатости поверхности при токарной обработке валов тяговых двигателей электромобилей в зависимости от величины главного угла в плане и радиуса скругления резца. Анализ влияния характеристик электрокорундовых абразивных кругов на керамической связке на профиль рельефа поверхности после правки шлифовального круга.

Методика. Базировалась на существующих эмпирических зависимостях, которые описывают профиль обрабатываемой поверхности детали при токарной и шлифовальной обработке. При этом использовались теоретико-вероятностные методы и методы прямолинейного профилографирования до и после шлифования.

Результаты. Нерегулярность шероховатости поверхности, которая возникает после токарной обработки валов тяговых двигателей электромобилей, оказывает существенное влияние на выбор геометрических параметров режущего инструмента. Наиболее часто шероховатость рассматривается как детерминированная совокупность одинаковых по размерам и форме неровностей. Существуют зависимости, построенные из анализа кинематики процесса обработки и формы режущей части инструмента. Целесообразно рассматривать профиль шероховатости обработанной поверхности детали как сумму всех случайных отклонений, наложенную на идеальный геометрически рассчитанный профиль. При этом профиль шероховатости будет иметь вероятностный характер, который был сформирован в результате сложных стохастических процессов, которые происходят во время механической обработки. В зависимости от физических явлений, которые сопровождают процесс обработки материала, уровни случайной составляющей должны корректироваться в зависимости от скорости резания.

Научная новизна. Впервые разработана композиционная модель шероховатости поверхности с учетом влияния случайной составляющей на геометрические параметры режущего инструмента. Проведен анализ влияния параметров характеристики электрокорундовых абразивных кругов на керамической связке на профиль рельефа после правки режущей поверхности круга.

Практическая значимость. Назначение режимов резания с учетом рациональных параметров главного угла в плане и радиуса скругления при вершине резца позволит обеспечить необходимое качество поверхности после механической обработки валов тяговых двигателей электромобилей и их щеточно-коллекторных узлов, что существенно повлияет на общий коэффициент полезного действия электромеханической системы транспортного средства. Закономерности формирования и описание рельефа режущей поверхности круга позволят уточнить число активных зерен «в контакте круг — заготовка», толщину среза отдельным зерном и составляющие силы резания при шлифовании, что приведет к повышению качества обработки вала тягового двигателя электромобіля.

Ключевые слова: токарная обработка, шероховатость поверхности, качество поверхности, план резца, радиус скругления резца

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