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MODELING OF A DUPLEX MILLER AND CONDITIONS OF FORMATION OF TREATMENT OF WHEEL PAIRS OF MAIN ELECTRIC CARS, DUAL CARS, ELECTRO SECTIONS

The **subject** matter of the research in the article is the process of restoring the quality and accuracy of the working surface of the wheelsets of the main electric locomotives, electric sections. The **purpose** of the work is to develop a modeling method for a special shaped cutter with increased productivity, designed to process the profile of locomotive railway wheels taking into account the shaping processes, which is based on the theory of modeling the high-speed milling process through the shaping efficiency coefficient. The article solves the following **tasks**: substantiation of the importance of upgrading the most promising designs of "duplex" mills, taking into account the reduction of vibrations due to chip crushing, to increase tool wear resistance, machining accuracy, reduce tool readjustment time and, accordingly, reduce equipment downtime, increase processing productivity, determine the mathematical apparatus for calculating model parameters; development of a method for modeling and optimization of shaping processes in the processing of locomotive wheel sets. Such **methods** were used: fundamentals of system analysis, simulation method. The following **results** were obtained: the design of a "duplex" milling cutter with a predicted increase in resistance and increase in processing productivity due to modeling of forming processes with a decrease in the sliding angle by three to five times, which was not previously taken into account when designating and selecting cutting parameters, is provided. It is concluded that the model design of the cutter, taking into account "duplex" and the tribological process of modeling shaping during processing, can increase the resistance of the cutters and ensure the full operation of all cups of the cutter. The forming component of the cutting conditions was evaluated taking into account the coefficient of efficiency of the process of forming the surface layer of the machined wheel. The conclusion was made about the need to create new processes of shaping the design and modernization of tools. Various ways of modeling tool systems are considered. A method for creating a "duplex" cutter model is defined. A "duplex" mill is considered and design features of the algorithm for creating such tools are given. The functioning of the shaping parameters during the processing of locomotive wheelsets is formalized in the form of separate mathematical models and formulas, on the basis of which a method for modeling the process of increasing productivity and increasing the resistance of mills is described. **Findings**: Thus, a new method was created for modeling the process of shaping when machining wheel sets of locomotives with a "duplex" cutter with minimizing the cost of operating the tool and reducing the sliding angle on the arc of cutting the cutter cup with an increase in the quality and accuracy of processing, which makes it possible to significantly reduce the cost of preparing the production and increase processing efficiency.

Keywords: restoration of quality and accuracy; wheelsets; mainline electric locomotives; modeling; shaping; shaping efficiency coefficient; "duplex" mill; optimization; mill stability; processing efficiency.

Introduction

Restoring the quality and accuracy of the working surface of the wheelsets of the main electric locomotives, electric sections and diesel locomotives is a rather complicated and expensive technological operation.

During operation, wheelsets of rolling stock are subject to significant static and dynamic loads, as well as thermal effects during braking, which lead to thermo mechanical damage to the rim. Damage also causes a change in the structure of the metal, in particular, leads to a sharp increase in the hardness of individual sections of the processing surface. The average mileage of wheelsets with wheels of high hardness is up to 280 thousand km to the first turning, and wheels with standard hardness 110 thousand km.

Analysis of publications and problem statement

The process of restoring locomotive wheelsets consists in machining the flanges of the wheel with the raceway and for more than 60 years has been carried out by the developed design of the cutter with cutting carbide cups mounted in cutters. The consumption of special shaped milling cutters used when turning solid wheels in comparison with the processing of standard wheels increases by 3-5 times, and the productivity of machining decreases by 2-3 times. Processing and restoration of

wheel pairs of rolling stock of cars is carried out by rolling out on special wheel-turning machines of model KZh 1836M by the method of turning simultaneously with two calipers with carbide plates and does not cause such processing difficulties as when restoring wheel pairs of main locomotives of electric locomotives, diesel locomotives, electric sections.

To restore the wheelsets, special two-spindle wheel milling machines of the mod are used. KZh-20, KZh-20TF1 (manufacturer - PrJSC Kramatorsk Heavy Machine Tool Plant) and prefabricated shaped mills equipped with carbide cutting elements - cups $\phi 12$ mm. Milling cutters for wheel milling machines are produced in Belarus (Gomel "Electromechanical Plant"), Russia (St. Petersburg, EFSI). Cutting cups are located on one side of the cutters and completely cover the entire track and wheel flange [1, 2, 3].

In order to increase the efficiency of the wheelset recovery process, it is necessary to solve the following problems: justification of the importance of upgrading the most promising designs of "duplex" mills, taking into account vibration reduction due to chip crushing, to increase tool wear resistance, machining accuracy, reduce tool readjustment time and, accordingly, reduce equipment downtime, improve processing performance, the definition of the mathematical apparatus for calculating model parameters; development of a modeling method and optimization of shaping processes in the

processing of locomotive wheel sets using system analysis methods and simulation methods.

Justification of the importance of increasing the efficiency of shaping wheelsets

The wheels are machined on the machine (fig. 1) without rolling out at the same time by two mills - left and right (fig. 2), which differs from each other by the location

of the shaped profiles of the cutters and the direction of the bevels at their ends.

The known design of a special shaped cutter (fig. 3), designed for processing the profile of railway wheels of locomotives, contains a housing in the longitudinal inclined grooves of which flat cutters are placed at an angle $\tau = 15^\circ$ (fig. 4) with a shaped profile along which cylindrical nests are installed; and cutting elements in the form of carbide cups $\varnothing 12\text{mm}$ are fixed with screws (fig. 5). Cutters in the cutter body are fixed with end caps using wedges and screws [2, 3, 4, 5].



Fig. 1. Processing wheels without rolling out on a machine model KZh-20TF1

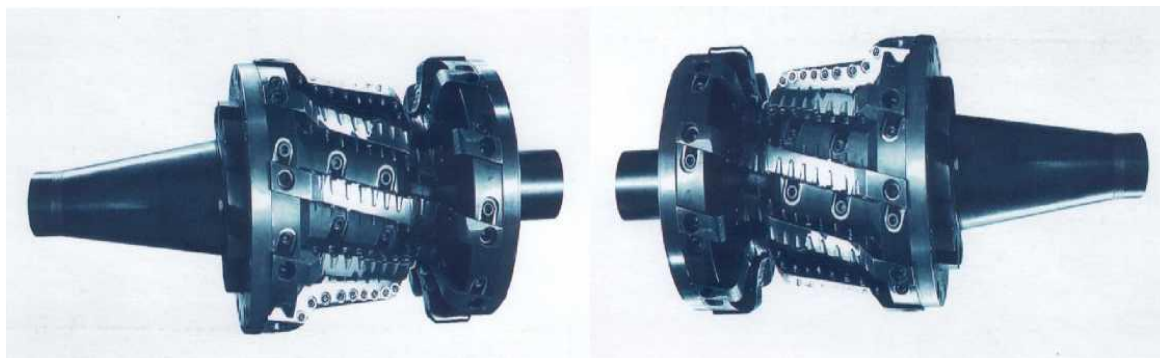


Fig. 2. Set of mills for installation on the machine mod. KZh-20TF1

At the ends of the cutters, one bevel is made at an angle to the front plane equal to the angle of inclination of the cutter in the case ($\tau=15^\circ$).

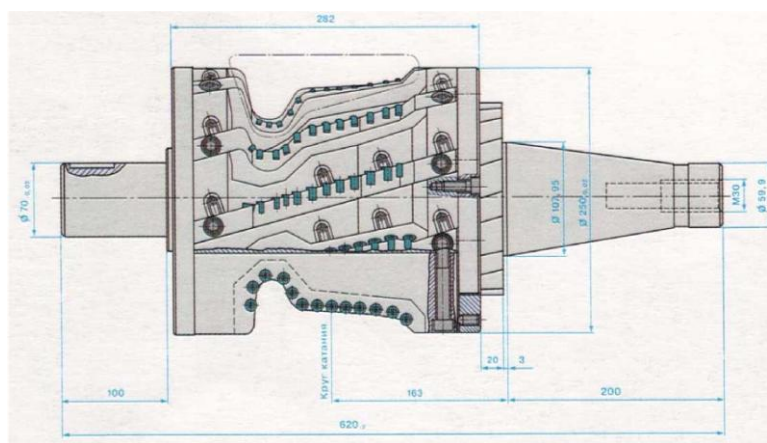


Fig. 3. Known design of a special shaped mill



Fig. 4. Mill cutters with carbide cutting cups-rollers

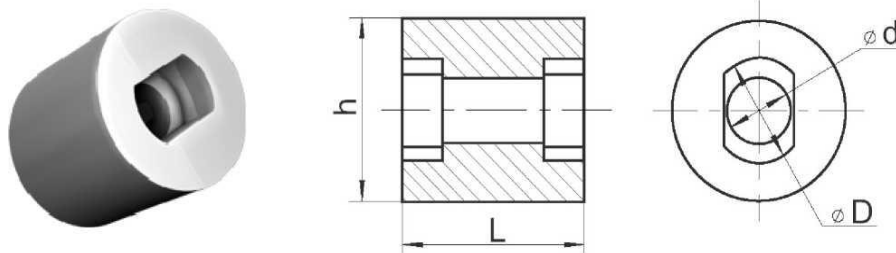


Fig. 5. Carbide cutting roller cups

The dimensions of the cup-rollers are given in table 1.

Table 1. The dimensions of the cup-rollers

Product designation	Dimensions, mm			
	L	D	d	h
RNUX 1212 M0 TN	12	6,5	4,2	12

The design of the mill provides 10 cutters, in each (fig. 4) of which 12–13 cutting cups-rollers are placed. Cups in each of the cutters are shifted in axial and radial directions in order to ensure optimal cutting conditions and obtain the necessary bandage profile. Thus, each of 120–126 cups has an individual, different position from others.

The advantage of the mill is that the long shaped edge is replaced by separate small circular edges-sectors of the cutting elements - cups $\varnothing 12$ mm, installed overlapping from cutter to cutter to ensure smooth bending around the shaped profile of the wheel bandage. This design of the mill provides a vibration-free milling process and provides chip crushing. In addition, turning carbide cutting elements - cups $\varnothing 12$ mm in the middle of their wear around the axis, and also reinstalling them on the reverse end, increases the total tool life by 8-10 times. [1, 5, 6, 7]

The round shape of the cutting edge of a relatively large curvature causes errors in the machined profile in the

range of 0.2–0.5 mm, and the roughness of the machined surface exceeds $Ra = 10 \mu\text{m}$. Radial run out of bandages in a circle reaches 0.3–0.5mm.

Hertel (Germany) proposed similar milling cutters with a diameter of the cutting element - cup $\varnothing 25$ mm. However, a decrease in the curvature of the cutting edge and an increase in its length led, under conditions of thin but wide chips, to the appearance of tool vibrations during the cutting process. In addition, the Hertel mills are cantilevered in the machine, as except for the cone, the second supporting neck. They are not widely used in the CIS countries.

The technology of milling with shaped mills provides for the removal of the entire allowance in one revolution of the wheel. The process of operation of the tool occurs in fairly severe conditions due to unfree cutting and variable hardness of individual sections of the machined surface of the wheel bandages.

The disadvantage of the considered design of the mill is that the blades relatively quickly (after processing an average of 8 pairs of wheels) fail (fig. 6) due to the intensive abrasion of the sections of their outer surface-based rollers located between the cutting elements. Changing the mill requires a significant amount of working time, as the manufacture of new cutters due to their complex design is characterized by a long cycle. This, in turn, leads to equipment standstill and reduced processing performance.

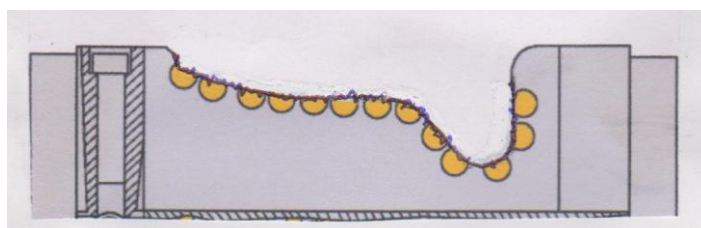


Fig. 6. Typical wear of the rollers and their bearing surfaces in rails

A method for modeling the characteristics of "duplex" milling cutters and the processes of forming wheel sets

In the proposed new design of the mill, called "duplex" [1, 2] on shaped cutters, additional shaped profiles are provided, each of which is made on the opposite side of the corresponding cutter, and the nests for the cutting sections of the additional and main profiles are

located in the same plane so that their axes form an angle in the case. Also, an additional bevel is made at each end of the cutter, the angle of inclination of which to the main bevel is also equal to the double angle of inclination of the cutters in the case. In addition, the largest recess of each additional shaped profile is made in the opposite direction to the main direction and at the opposite end of the cutter [1, 5, 7, 8, 9].

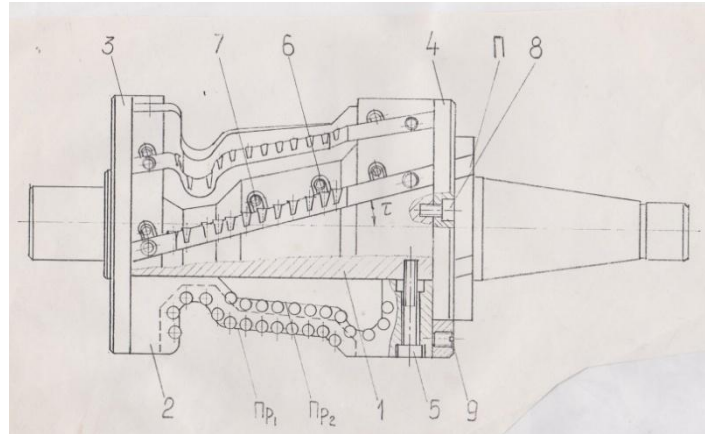


Fig. 7. New duplex design of carbide shaped mill [11]

The essence of the new design of the mill is illustrated by drawings, where fig. 7 shows a general view of the cutter; in fig. 8 – the main view of the cutter with an additional profile, in fig. 9 and fig. 10 – the cross section of the cutters at the axes of the nests and chamfers at the ends of the cutters directed under each other.

The milling cutter (fig. 7) consists of a case 1 with inclined grooves at an angle τ , in which cutters 2 with a

main shaped profile Pr_1 and an additional profile Pr_2 are placed. Cutters 2 are fixed in the case using end caps 3 and 4, transverse screws 5, plate wedges 6 and pressure screws 7.

In the end cover 4, holes are provided for screws 8, fastening it to the mill body 1 and screws 9, pressing cutters 2 to the base ring 3 [1, 3, 10, 11, 12].

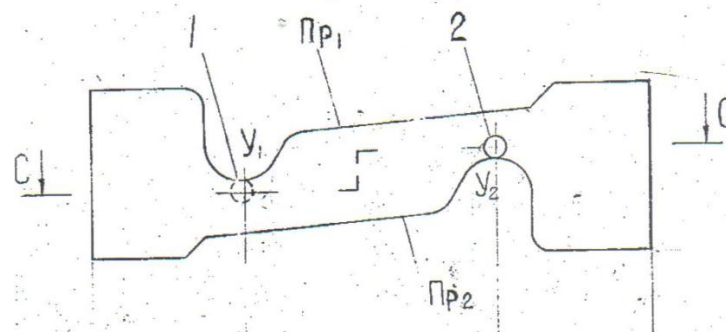


Fig. 8. The main view of the cutter with an additional profile

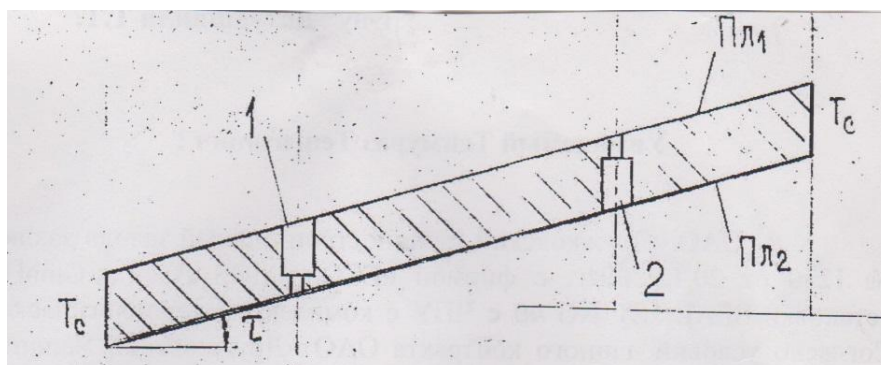


Fig. 9. The cross section of the cutter with the axis of the nests and chamfers at the ends of the cutter

Cylindrical nests 1 and 2 (fig. 8, fig. 9 and fig. 10) for cutting elements – cups f12mm are made along the main shaped profile Pr1 and additional Pr2, and the largest

recess of the additional profile U2 is made in relation to the recess of the main profile in the opposite direction and at the opposite end of the cutter.

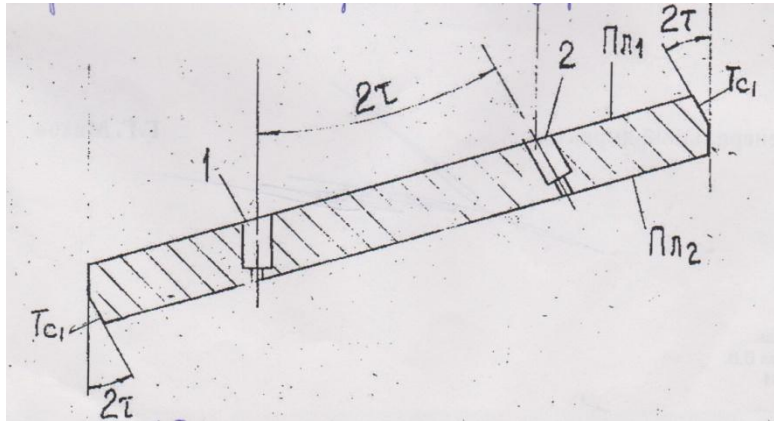


Fig. 10. The cross section of the cutter with the axis of the nests and chamfers at the ends of the cutter, directed at an angle of 2τ to each other

To ensure the use of cutters with an additional profile Pr2 in the case of the same cutter, for example, the maiden or right, the sockets 2 of the additional profile (fig. 9 and fig. 10) are made on the plane П11, i.e. in the same place as the cutters in the case – 2τ . In addition, at each end of the cutter, an additional bevel Tc1 is made, which is also inclined to the nests 1 of the main profile Pr1, but their axes are located at an angle to the axes of the nests 1, equal to the double angle of inclination of the cutters with respect to the main bevel Tc at an angle of 2τ . Thus, after failure of the cutters along the Pr1 profile, they can be reinstalled in the housing of the same cutter to work along the Pr2 profile based on the Tc1 bevels.

The execution of nests for cups f12mm in an additional profile on the same plane with the nests of the main profile, but with an inclination of their axes at an

angle of 2τ , provides after reinstalling the cutters in the housing the location of the front cutting surfaces of the cups f12mm of both profiles.

Performing additional bevels on the ends of the cutters at an angle of 2τ to the main bevels allows, after reinstalling the cutters in the case to work with an additional profile, to ensure the necessary fit of the ends of the cutters to the end caps, namely, along the plane, and not along the sharp edge.

The exclusion from the specified combination of at least one of the listed structural elements will not allow achieving the planned result.

The proposed design of the mill (fig. 11) can significantly reduce the tool changeover time and, accordingly, reduce equipment downtime, increase processing productivity.

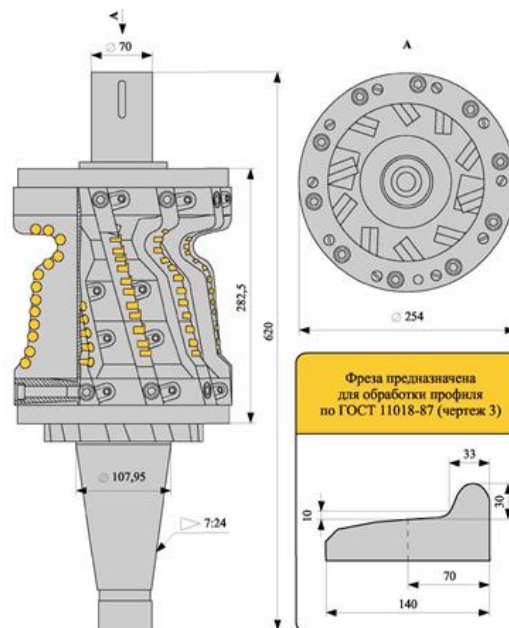


Fig. 11. Duplex design of carbide shaped milling cutter for machining a wheel profile according to GOST 11018-87 (drawing 3)

The selection and designation of the most effective cutting modes is based on the theory of modeling the

process of high-speed milling [8, 12, 13, 14, 15, 16] through the efficiency of shaping K_p . (1)

$$K_{\rho} = \frac{\sin \Psi_{\max} - \sin \Psi_{SK}}{\sin \Psi_{\max}} \cdot 100\%. \quad (1)$$

Substituting the technological processing parameters in (1), we obtain an expression of the coefficient of formation efficiency, convenient for theoretical and experimental studies:

$$K_{\rho} = \left(\frac{\arcsin \left(K_c \cdot \frac{\rho \cdot 10^3 \cdot V \cdot Z}{S_{\min i} \cdot \pi \cdot d_{fr} \cdot \sin \phi} \right)}{\arcsin \frac{2 \cdot \sqrt{t \cdot (d_{fr} - t)}}{d_{fr}}} \right) \cdot 100\%. \quad (2)$$

where $K_c = 0,5$ when machining with carbide cutting cup RNUX 1212 M0 TN without coolant.

During milling, the variable thickness of the cut-off layer a_i is defined as the distance between two consecutive trajectories of the cup point $\phi 12\text{mm}$, measured in the direction of the mill radius and determining the instantaneous position of the contact angle. The thickness of the cut is simplified by the formula (3):

$$a_i = S_{Z\min} \cdot \sin \Psi_{sl} \cdot \sin \phi, \quad (3)$$

where $S_{Z\min}$ – minimum feed to the cutting edge of the cup $\phi 12\text{mm}$ (tooth of a duplex carbide shaped mill) at which the process of milling the wheel, flange begins.

Thus, the start of milling without coolant begins when $a_i > 0,5\rho$. Then, given the value $S_{Z\min}$, the sliding angle is determined Ψ_{sl} .

Sliding occurs at a certain sliding angle Ψ_{sl} until plastic deformations go directly from cutting from micro cutting, i.e. when the thickness of the cut does not reach a certain depth, relative to the introduction of a cup $\phi 12\text{mm}$ having a radius of rounding of the cutting edge ρ .

Thus, improving the quality of the surface layer of locomotive wheelsets, reducing roughness, significantly increasing productivity and regulated durability of a duplex carbide shaped mill is ensured by establishing a fixed feed rate at which the ratio of the initial cut thickness to the rounding radius of the cutting edge of the mill corresponds to the smallest sliding angle.

Sample. When milling wheelsets with a duplex carbide shaped mill with a diameter of $D = 250$ mm, the number of cutters $z = 10$, a cutting speed of 3 m/s, and a minute feed $S_{\min} = 230$ mm/min. feed per tooth, $S_z = 0.1$ mm/tooth, radius of the cutting blade $\rho = 0.25$ mm, angle of inclination of the cutter in the cutter body $\phi = 20^\circ$:

$$\Psi_{sl\min} = \arcsin 0,453216 \approx 27^\circ;$$

$$a = 0,1 \cdot \sin 27^\circ \cdot \sin 20^\circ = 0.016 \text{ mm.}$$

When gear hobbing with different values of ρ , the minimum slip angles are obtained:

$$\rho = 0.25 \text{ mm, } S_{Z\min} = 0,1 \text{ mm/tooth, } \Psi_{sl\min} = 27^\circ;$$

$$\rho = 0.25 \text{ mm, } S_{Z\min} = 0,5 \text{ mm/tooth, } \Psi_{sl\min} = 5^\circ 12';$$

$$\rho = 0.1 \text{ mm, } S_{Z\min} = 0,5 \text{ mm/tooth, } \Psi_{sl\min} = 5^\circ 26'.$$

Thus, an increase in the machining performance of the wheel flanges with the smallest sliding angle is achieved in the above example for $\rho = 0.25$ mm, $S_{Z\min} = 0,5$ mm/tooth, $\Psi_{sl\min} = 5^\circ 12'$.

The use of the developed technological regulations for the selection and assignment of processing parameters during high-speed milling, taking into account the required parameters of the surface layer of locomotive wheels, establishes optimal milling conditions under which full participation of all mill teeth is ensured.

Determination of minimum sliding angles when machining wheels by milling, based on the physicochemical processes of friction mechanics, can significantly increase the efficiency of the process of forming wheels and the operational properties of their surfaces.

Theoretical and experimental studies allow us to determine the optimal sliding angles Ψ_{sl} , at which the milling process is stable, the necessary conditions for tool life and the quality of the machined surface with respect to the largest contact angle of the cutter tooth Ψ_{\max} with the machined wheel.

The presence of additional shaped profiles on the mill cutters allows for quick readjustment of the tool without removing it from the machine by reinstalling the cutters in the case to use additional shaped profiles and this significantly reduces equipment downtime and increases processing productivity.

Conclusions

1. The possibility of modeling the design of the mill is shown, which ensures the milling process without vibrations due to chip crushing.

2. By choosing this method of processing with a "duplex" mill, it is possible to significantly increase the tool wear resistance, reduce vibration loads, and improve processing accuracy.

3. The arrangement of insert cutters of the provided additional shaped profiles is shown, each of which is made on the opposite side of the corresponding cutter.

4. The proposed design of the "duplex" mill can significantly reduce the tool changeover time and, accordingly, reduce equipment downtime, increase processing productivity.

5. The selection and designation of the most effective cutting modes is based on the theory of modeling the process of high-speed milling through the coefficient of efficiency of forming K_{ρ} .

6. Determination of minimum sliding angles when machining wheels by milling, based on the physicochemical processes of friction mechanics, can significantly increase the efficiency of the process of forming wheels and the operational properties of their surfaces.

7. The conducted theoretical and experimental studies allow us to regulate the optimal sliding angles Ψ_{sl} , at which the stability of the milling process is ensured.

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МОДЕЛЮВАННЯ ДУПЛЕКСНОЇ ФРЕЗИ І УМОВ ФОРМОУТВОРЕННЯ ОБРОБКИ КОЛІСНИХ ПАР МАГІСТРАЛЬНИХ ЕЛЕКТРОВОЗІВ, ТЕПЛОВОЗІВ, ЕЛЕКТРОСЕКЦІЙ

Предметом дослідження в статті є процес відновлення якості і точності робочої поверхні колісних пар магістральних електровозів, електросекцій. **Мета** роботи – розробка методу моделювання спеціальної фасонної фрези з підвищеною продуктивності, призначеної для обробки профілю залізничних коліс локомотивів з урахуванням процесів формоутворення, яка базується на теорії моделювання процесу швидкісного фрезерування через коефіцієнт ефективності формоутворення. У статті вирішуються наступні **завдання**: обґрунтування важливості модернізації найбільш перспективних конструкцій "дуплексних" фрез з урахуванням зниження вібрацій за рахунок дроблення стружки, підвищити зносостійкість інструменту, точність обробки, знизити час переналадження інструмента і, відповідно, знизилася не простої обладнання, підвищити продуктивність обробки, визначення математичного апарату для обчислення параметрів моделі; розробка методу моделювання та оптимізації процесів формоутворення при обробці колісних пар локомотивів. Використовуються такі **методи**: основи системного аналізу, метод імітаційного моделювання. Отримані наступні **результати**: надано конструкція "дуплексної" фрези про прогнозованим підвищенням стійкості і підвищенням продуктивності обробки за рахунок моделювання процесів формоутворення при зменшенні кута ковзання в три-п'ять разів, що раніше не враховувалася при призначенні і виборі параметрів різання. Зроблено висновок, що моделювання конструкції фрези з урахуванням "дуплексності" і трибологічних процесів моделювання формоутворення при обробці дозволяють підвищити стійкість фрез і забезпечити повну роботу всіх чашок фрези. Була оцінена формотворна складова режимів різання з урахуванням коефіцієнта ефективності процесу формування поверхневого шару оброблюваного колеса. Зроблено висновок про потребу створення нових процесів формоутворення проектування і модернізації інструментів. Розглянуто різні способи моделювання інструментальних систем; визначений спосіб створення моделі "дуплексної" фрези. Розглянуто "дуплексна" фреза і приведені конструктивні особливості алгоритму створення таких інструментів. Функціонування параметрів формоутворення при обробці колісних пар локомотивів формалізовано у вигляді окремих математичних моделей і формул, на основі яких описаний метод моделювання процесу підвищення продуктивності і підвищення стійкості фрез. **Висновки**: таким чином, створений новий метод моделювання процесу формоутворення при обробці колісних пар локомотивів "дуплексної" фрезою з мінімізацією витрат на експлуатацію інструменту і зниження кута ковзання на дузі різання чашки фрези з підвищенням якості і точності обробки, що дає можливість значно знизити витрати на підготовку виробництва і підвищити ефективність обробки.

Ключові слова: відновлення якості і точності; колісні пари; магістральні електровози; моделювання; формоутворення; коефіцієнт ефективності формоутворення; "дуплексна" фреза; оптимізація; стійкість фрези; ефективність обробки.

МОДЕЛИРОВАНИЕ ДУПЛЕКСНОЙ ФРЕЗЫ И УСЛОВИЙ ФОРМООБРАЗОВАНИЯ ОБРАБОТКИ КОЛЕСНЫХ ПАР МАГИСТРАЛЬНЫХ ЭЛЕКТРОВОЗОВ, ТЕПЛОВОЗОВ И ЭЛЕКТРОСЕКЦИЙ

Предметом исследования в статье является процесс восстановления качества и точности рабочей поверхности колесных пар магистральных электровозов, электросекций. **Цель** работы – разработка метода моделирования специальной фасонной фрезы с повышенной производительности, предназначенной для обработки профиля железнодорожных колес локомотивов с учетом процессов формообразования, которая базируется на теории моделирования процесса скоростного фрезерования через коэффициент эффективности формообразования. В статье решаются следующие **задачи**: обоснование важности модернизации наиболее перспективных конструкций "дуплексных" фрез с учетом снижения вибраций за счет дробления стружки, повысить износостойкость инструмента, точность обработки, снизить время переналадки инструмента и, соответственно, снизить простои оборудования, повысить производительность обработки, определение математического аппарата для вычисления параметров модели; разработка метода моделирования и оптимизации процессов формообразования при обработке колесных пар локомотивов. Используются такие **методы**: основы системного анализа, метод имитационного моделирования. Получены следующие **результаты**: Предоставлена конструкция "дуплексной" фрезы о прогнозируемом повышением стойкости и повышением производительности обработки за счет моделирования процессов формообразования при уменьшении угла скольжения в три-пять раз, что ранее не учитывалось при назначении и выборе параметров резания. Сделан вывод, что моделирование конструкции фрезы с учетом "дуплексности" и трибологического процесса моделирования формообразования при обработке позволяют повысить стойкость фрез и обеспечить полную работу всех чашек фрезы. Была оценена формообразующая составляющая режимов резания с учетом коэффициента эффективности процесса формирования поверхностного слоя обрабатываемого колеса. Сделан вывод о потребности создания новых процессов формообразования проектирования и модернизации инструментов. Рассмотрены различные способы моделирования инструментальных систем; определен способ создания модели "дуплексной" фрезы. Рассмотрена "дуплексная" фреза и приведены конструктивные особенности алгоритма создания таких инструментов. Функционирование параметров формообразования при обработке колесных пар локомотивов формализовано в виде отдельных математических моделей и формул, на основе которых описан метод моделирования процесса повышения производительности и повышения стойкости фрез. **Выводы**: Таким образом, создан новый метод моделирования процесса формообразования при обработке колесных пар локомотивов "дуплексной" фрезой с минимизацией затрат на эксплуатацию

инструмента и снижения угла скольжения на дуге резания чашки фрезы с повышением качества и точности обработки, что дает возможность значительно снизить затраты на подготовку производства и повысить эффективность обработки.

Ключевые слова: восстановления качества и точности; колесные пары; магистральные электровозы; моделирование; формообразование; коэффициент эффективности формообразования; "дуплексная" фреза; оптимизация; стойкость фрезы; эффективность обработки.

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