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Optimization of the high-speed profile plunge grinding process

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1. Introduction

An expert evaluation conducted at the first stage provided an opportunity to take into consideration and to compare at the second stage only those methods, which had the highest aggregate indicators and were of practical interest.

A cutting mode for cylindrical plunge grinding shall be determined by:

- rotation speed of the grinding wheel (v_w), m/s;
- rotation speed of the work piece (v_p), m/min;
- radial feed (S), mm/min;
- length of the wheel surface in contact with the workpiece, mm.

Based on the experimentally derived relations between the above mentioned parameters and on the published data [1], a mathematical model of the grinding process was developed to help select the optimal mode for the high-speed profile plunge grinding (hereinafter referred to as high speed profile plunge (HSPP) grinding), to establish a methodological basis for selecting the optimal grinding mode, and to obtain approximate data regarding the grinding mode parameters to be used in further calculations.

2. The solution of optimization of the grinding process

The solution is made by compiling a system (model) and determining quantitative values of the following two elements related to the grinding mode - rotation speed of the workpiece and radial feed. The wheel rotation speed is assumed to be constant and equal to 80 m/s. The length of the wheel surface in contact with the workpiece also assumed to be constant.

$$N \le N_{all} \tag{1}$$

where N_{all} is an allowable capacity of the motor which produces the primary motion. Based on the experimental results

$$N = e^{0.93} v_w{}^{0.18} v_p{}^{0.32} S^{0.56} \tag{2}$$

After substituting (1) into (2) and moving the unknown variables $v_p(n_p)$ and S to the left side of the inequality, we obtain

$$e^{0.83} v_w{}^{0.18} v_p{}^{0.32} S^{0.56} \le N_{all}$$

$$n_p{}^{0.32} S^{0.56} \le \frac{N_{all}}{e^{0.83} v_w} \tag{3}$$

In order for the wheel treads after the profile restoration to have roughness required by the drawings, the following inequality must be satisfied

$$R_z \le R_{zall} \tag{4}$$

where R_{zall} is the height of the profile irregularities at ten points, specified in the drawings (we assume that $R_{zall} = 40$ μm).

Based on the experimental results [2]

$$R_z = e^{2.63} v_w{}^{0.85} v_p{}^{0.15} S^{0.31} \tag{5}$$

After substituting (4) into (5) and carrying out appropriate transformations, we obtain

$$n_p{}^{0.15} s^{0.31} \le \frac{R_{z\,all} 1000^{0.15}}{e^{2.63} v_w{}^{-0.05} (\pi D)^{0.15}} \tag{6}$$

In order for the metal in the wheel rims to sustain the same structure, the following inequality must hold

$$Q_s \le Q_{s\,all} \tag{7}$$

where $Q_s \le Q_{sall}$ is the temperature of the metal on the rim surface layers, at which no changes that might affect the rim functionality will occur. The following temperature ranges shall be considered as allowable

$$Q_{sall} = 350^{\circ}\,\mathrm{C}$$

Based on the experimental results, the interface temperature is

$$Q_i = e^{2.37} v_w{}^{0.21} v_p{}^{0.09} S^{0.17} \tag{8}$$

Temperature of the metal on the rim surface layers $Q_s = 0.7 Q_i$. After substituting into (7) and carrying out appropriate transformations, we obtain

$$0.7 Q_i \le Q_{s\,all} \tag{9}$$

In order to compensate for random errors caused by elastic displacements the treating system, we separate some part of the tolerance range on the surface being treated (a). The remaining part of the tolerance range will be used to compensate for systematic errors

$$u \le aT_p \tag{10}$$

u is an elastic displacement; T_p is tolerance; a is the coefficient, which takes into account the part of the tolerance range used for random error compensation.

Now we transform the expression (10)

$$P_u / j \le aT_p$$

$$P_u \le aT_p j \tag{11}$$

where j is stiffness of the system; P_u is the force.

Based on the experimental results

$$P_u = e^2 P_{uw}^{-1.17} v_p^{0.63} S^{0.13}$$

Now we transform the expression (11) and move the unknown variables to its left side [2]

$$n_p^{0.63} S^{0.13} \le \frac{aT_p j 1000^{0.63}}{e^{2.81} v_w^{-1.17} (\pi D)^{0.63}} \tag{12}$$

Taking into account the equipment capabilities for allowable feed rates and work piece rotation rates; insufficient balance of a wheel-set ($n_p \le n_{pall}$); and expediency to work beyond the heat-affected zone ($10 \le v_w / v_p \le 20$; $S \le S_{all}$), the following inequalities must be satisfied

$$\left.\begin{array}{l} S_{min} \ge S \ge S_{max} \\ S \le S_{all} \\ n_{pmin} \le n_p \ge n_{pmax} \\ n_p \le n_{all} \end{array}\right\} \tag{13}$$

Let us combine the inequalities (3), (6), (9), (12), and (13) into the system

$$\begin{array}{l} n_p^{0.32} S^{0.56} \le \dfrac{N_{all} 1000^{0.32}}{e^{0.83} v_w^{0.18} (\pi D)^{0.32}} \\ n_p^{0.15} S^{0.31} \le \dfrac{R_{zall} 1000^{0.15}}{e^{2.63} v_w^{-0.05} (\pi D)^{0.15}} \\ n_p^{0.09} S^{0.17} \le \dfrac{Q_{sall} 1000^{0.09}}{0.7 e^{2.37} v_w^{0.21} (\pi D)^{0.09}} \end{array} \tag{14}$$

The relationship that determines primary time for plunge grinding shall be used as an evaluation function

$T_p = \dfrac{h}{n_p S}$, min, in the form of $f = \dfrac{C}{n_p S}$

where h is an allowance for treatment; C is a constant.

In order to reduce the inequalities of the system (14) to linear expressions, we calculate their right sides and introduce the following notations

$$lg n_p = x_1; lg S = x_2; lg f = f_0; lg C = C_0$$

The system in a linear form is

$$\left.\begin{array}{l} 0.32x_1 + 0.56x_2 \le 1.41 \\ 0.15x_1 + 0.31x_2 \le 1.8796 \\ 0.09x_1 + 0.17x_2 \ge 0.309 \\ 0.09x_1 + 0.17x_2 \le 0.408 \\ 0.63x_1 + 0.13x_2 \le 4.3979 \\ 1.0 \le x_2 \le 2.0 \\ 2.7 \le x_1 \le 4 \\ f_0 = C_0 - (x_1 + x_2) \end{array}\right\} \tag{15}$$

Solution of the equations - inequalities system (Fig. 1) provided the following values for the variable elements of grinding modes: $v_p = 220$ m/min, $S = 10.3$ mm/min. For calculation, the cutting speed (v_{wc}) was assumed to be constant: $v_{wc} = 80$ m/s.

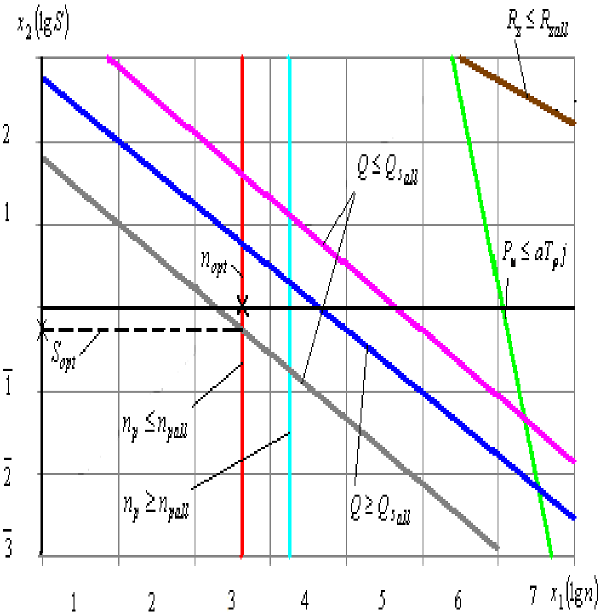


Fig. 1 Solution of the optimization problem

High speed profile plunge grinding can be used to substantially enhance the mechanical treatment process for shaping the wheel rim profiles - during restoration as well as manufacturing of wheels. In addition, the results of experimental research conducted by the personnel of Kramatorsk Heavy Machine-Tool Building Plant were compared to the restoration of wheel tread profiles using a conventional grinding method [3]. This analysis showed that when the wheel-sets were restored by the high speed profile plunge grinding method, the functional metal layer on the rim was used economically, because in this case the presence of the thermo-mechanical deteriorations on the wheel treads did not affect the treatment process, therefore the metal layer of the rim was not unnecessarily cut into metal chips - what typically happened during the turning process which removes the outer crust. According to the Guidelines [4], it is permissible during restoration to treat the wheel-sets with the black marks on the wheel tread; in this case the HSPP grinding method also helps to treat the functional metal layer of the rim more efficiently. Therefore, the HSPP grinding method leads to the increased wheel's service life.

Based on the research of the HSPP grinding process, a method for efficient restoration of wheel-sets and increase of their functionality was developed. This method includes the HSPP grinding process and requirements specification for a HSPP grinding machine tool unit intended for the implementation of this method.

3. The economic estimation of renewing methods

The account value method was used and economic characteristics of the processing method were used as indices on the third analysis stage. This is ascertained counting expenditure of wheel efficiency renewing by using different methods in conditional wheel department working with different programs. And branch economic effect separately from wheel resource increase at renewing not just geometry but physic-mechanical characteristics of the rim metal, economic transport metal expenses, too.

Annual economic effect, connected with work equipment intensification in conditional department level was estimated by calculated expenditure differences.

Economic possibilities of compared variants are shown in the graphic of calculated expenditure dependence on the annual conditional department program (Fig. 2). Expenditures not related to some program limits (capital investment, equipment and industrial area springing, present repair and supply between the repairs) are shown like slating straight parts when drawing graphics.

The ordinate difference in setting annual program describes effectiveness of one method comparing to another. As it is seen in Fig. 2 using whetting with primal and following thermo-processing methods with machines 1836 and 165 and HSPP grinding with following high rate tension is appropriate with programs accordingly to 5 and 13 thousand wheel pairs per year [5]. However, the marginal programs decrease markedly with the inclusion of the wheel work length increase.

According to Russian railways, the whetting with primal inductive heating is already effective with the whet 2.5-3 thousand wheel pair program. The larger program is, the bigger effect is received. The expected branch wheel resource increase economic effect because of using cut-in profile with high speed grinding (CPHSG) and thermal processing with high rate tension (HRT) is calculated with formula

$$E_e = B\left[p\left(\frac{1}{T_1}-\frac{1}{T_2}\right)+\frac{C}{2}\left(T_1+T_2\right)\right] \tag{16}$$

here B is made production annual amount; T_1, T_2 are wheel work length after 1 an d 2 renewing variant; p is wheel pair price; C is repair cost price.

The expected economy sum effect of using HSPP and thermal processing with high rate tension would come to 55 000 Euro for each renewed wheel pair (according to prices of year 2009) [6].

Applying recommendations of perfecting wheel repair technological supply (regimes, equipment and tools), according to Russian railways data, provided for wheel work length increase not less than 20% and gave confirmed economical effect.

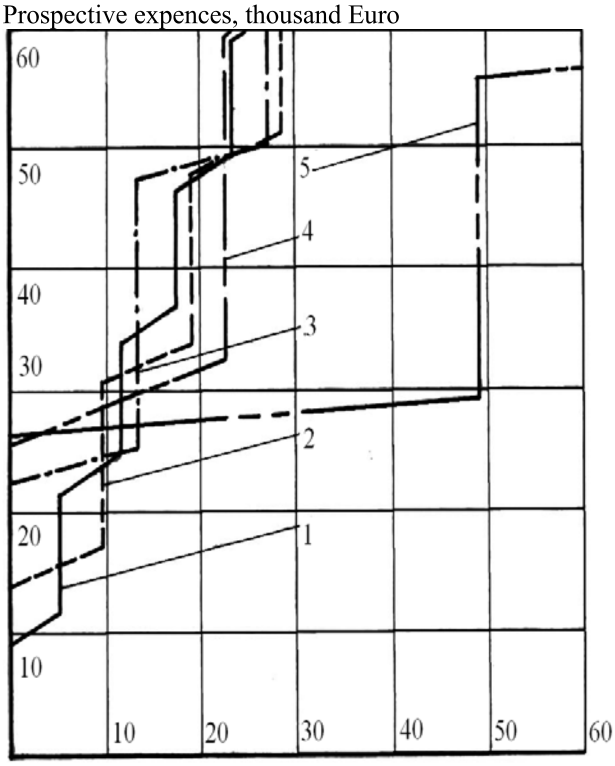


Fig. 2 Realized consumption dependence on annual programs processing wheel profiles. Here: *1* - profile processing using 1836 machine method; *2* - profile processing using early inductive heating; *3* - profile processing using 165 machine method; *4* - profile processing using early inductive heating; *5* - profile processing using Russian railways method

Systematization and analysis wheel producing and renewing methods revealed wheel cut-in profile high speed grinding with following physic-mechanical wheel rim feature renewing.

4. The wheel work length increase estimation

Hatched parts are OHBC (Fig. 3) areas, which show technical wheel resources, marked as areas 2, 4, 6, 8 are not used because of not economic run profile geometry renewing technology. Because of defects on the run surface (carriers, burns, etc.) and possible tool break the profile processing is made "under crust", which means that shavings are made of cut rim metal layer. The wheel resource decreases in 35-40 % and sometimes even to 60%. The used resource makes about 60 % of the intended resource.

The wheel resource scheme which gives a possibility to value wheel resource increase using compared renewing methods: method 1 - turning with one or several tools which are put coherently wheel set using early thermal processing with inductive heating which improves processing (high rate tension + whetting) and method 2 - high speed cutting profile outside grinding using thermal processing after it, which restore physic-mechanical roll profile features (HSPP grinding + high rate tension) [7].

The wheel resource scheme which gives a possibility to value wheel resource increase using compared renewing methods: method 1 - turning with one or several tools which are put coherently wheel set using early thermal processing with inductive heating which improves processing (high rate tension + whetting) and method 2 - high speed cutting profile outside grinding using thermal processing after it, which restore physical – mechanical roll profile features (HSPP grinding + high rate tension).

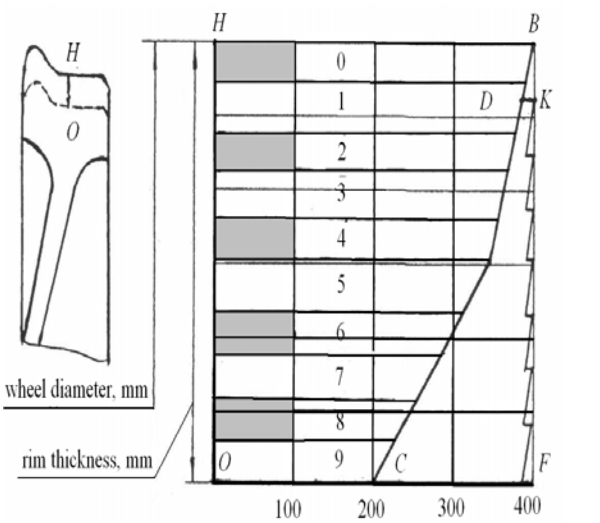
Using primal thermo-processing high rate tension to renew wheel run profile by whetting practically does not influence the wheel resource technical changes, because all the "under crust" defects are distinctive to this method [8]. After every whetting (Fig. 3) function wear off resistance BC) wheel strength characteristics decline. The main high rate tension destination increased wheel run surface processing with Lithuanian railways that is why the amount of not used wheel resource T_{unused} (Fig. 3 BFC area) does not change. The HSPP grinding method with following high rate tension allows rim metal layer work economy and physic-mechanical property repair. Minimizing amount of not used T_{unused} resource on economic renewing account, the amount of not used T_{used} resource will get close to fixed T (resource)

$$T_{used} - T\ ,\ T_{unused} \geq \min$$

$$T_{used} = 0+1+2+3...+8+9$$

New used resource T_{used} meaning makes about

$$T_{used1} = 0.95T$$



Rim metal wear off resistance, thousands km/mm

Fig. 3 Wheel resource description scheme

Like it was mentioned earlier, primal thermo - processing high rate tension 2 method after renewing wheel rim profile geometry parameters allows to renew physical-mechanical rim metal surface layer properties [9-12].

Then new wear off resistance function (Fig. 3) will be reflected on BDFK line. Technical wheel resource will increase to area CDKF and will make about 20% of OHBC area. The new possible to use wheel resource T_{used2}

$$T_{used2} = T_{used1} + 0.2T = 1.15T$$

$$T_{used2} / T_{used} = 1.15T / 0.6T = 1.9$$

Comparing to existing used resource T_{used}, it increased 1,9 times. The same size decrease of the need of Lithuanian railways in wheels processing using the given technology is possible.

5. Conclusions

1. The processed wheel pair renewing method realization on the wheel rim geometry parameter economical renovation using HSPP grinding method and physic-mechanical property of its' metal account, allows an increase of technical wheel pair resource comparing to already used existing resource in 1.9 times. It is possible to decrease the need of Lithuanian railways in wheels, processed with this technology, the same size.
2. Analyzed axles run surface technical renewing process HSPP grinding capabilities showed that axles renewing development has prospects.
3. The latter was approved by the Ministry of Means of Communication of the Russian Federation and endorsed by the Ministry of Machine and Tool Building Industry (Minstankoprom).

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GREITOJO PROFILINIO ŠLIFAVIMO PROCESO OPTIMIZAVIMAS

R e z i u m ė

Straipsnyje pateiktas greitojo profilinio šlifavimo optimalių parametrų parinkimo, metodinių pagrindų kūrimo, šlifavimo parametrų nustatymo užduoties sprendimas. Naudojantis literatūros šaltinių ir bandymų duomenimis sudarytas šlifavimo proceso matematinis modelis.

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OPTIMIZATION OF THE HIGH-SPEED PROFILE PLUNGE GRINDING PROCESS

S u m m a r y

This paper presents the based on the experimentally selection relations between the above mentioned parameters and on the published data, a mathematical model of the grinding process developed to help select the optimal mode for the high-speed profile plunge grinding (hereinafter referred to as HSPP grinding), to establish a methodological basis for selecting the optimal grinding mode, and to obtain approximate data regarding the grinding mode parameters to be used in further calculations.

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ОПТИМИЗАЦИЯ ПРОЦЕССА ВЫСОКОСКОРОСТНОГО ПРОФИЛЬНОГО ВРЕЗНОГО ШЛИФОВАНИЯ

Р е з ю м е

В настоящей работе приведено решение задачи по выбору оптимального режима высокоскоростного профильного врезного шлифования, установления методических основ выбора оптимального режима шлифования, получения ориентировочных данных по параметрам режима шлифования для включения в дальнейшие расчеты. Составлена математическая модель процесса шлифования на основе зависимостей, полученных экспериментально и используя литературные данные.

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