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THE RESTORATION OF PHYSICAL AND MECHANICAL PROPERTIES OF WHEEL RIM METAL

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Abstract. Despite reduced resistance to wheel rim wear, after every grinding, only geometrical parameters of wheels are restored at maintenance depots. A tendency towards a decrease in the exploitation of wheel rim working edge induces the acquisition of new wheels, is related to a considerable increase in axle load and train speed as well as linked to the ineffective methods of repairing wheel rim working edge. A solution to the problem of restoring the surface of wheelset rolling, as a wider problem of rolling stock durability, is determined by the fact that the breakdown of the rolling wheelset and the loss of its efficiency shortens the service time of the wheelset. The cost of pointless and inefficient renovations of geometrical wheelset parameters increases and is of a very high rate. The problem of efficient renovations to rims and steel used for wheels within the maintenance of wheelsets becomes a burning issue today.

Keywords: wheelset rim, wheelset rim metal, thermal processing of wheelsets, restoration.

1. Introduction

In order to find ways of prolonging wheel working time and improving the reliability of their exploitation, it is necessary to know the general picture of operating conditions for rolling stock, the circumstances of damage while changing their dynamics, wear resistance, work refusal and work continuance. Any of damages to the surface of wheel roll has a negative influence on cutting conditions while restoring its profile. When determining cutting conditions, it is necessary to pay attention to the character of damages and their influence on the repair process (Лысюк 1997).

An exception to the exploitation of rolling stock is repair, both planned and unplanned, usually done by identifying 4 groups of causes: roll surface wear, defects to the roll surface, rim, wheel flange and tread, defects to pulley, the central part of the wheels, worn tread in the central part of the wheel flange and axle half shafts (Mikaliūnas 2000; Mikaliūnas *et al.* 2002, 2004; Lingaitis *et al.* 2004).

Roll surface wear occurs due to related force effect and squash with ordinary force. The equal wear distribution pump should be observed. The wear of the profile is not evenly distributed and depends on the priority of wheel abutment and rail contact condition to run round which seems to be a helpful tool for avoiding the wear of the flange. Under such conditions, the wheel passes to compact contact with the rail and flange wear sharply slows down and takes place when both flange and the profile of the roll surface wear at the same time; mostly it gets to condemn the thickness of a wheel pair of flange ‘B’. In the vertical flange section, flange wear prevents from roll surface wear.

Defects to the roll surface may be twofold – caused by wear and those of thermodynamic origin. All these defects are caused by the whole complex of reasons, including technological (low steel quality, breach of processing routine), and are able to make use of 9 wrong types regulating the gathering momentum of the wheel pair, a wagon position, its plan and profile etc. (Somov, Bazaras 2007).

The upper metal layer of the roll surface of the axle half shaft gets into grinding and the whole picture essentially differs from that of the new wheel. It can be explained by the ‘burn’ zone that reveals the presence of both sections – a ‘white layer’ having the hardness of 7.0÷10.0 GPa and an extremely granulated grain structure on its surface. Grain size is from 2 to 3 mcm. According to microscopic electron analysis, microstructure consists of martensite and carbides. The size of carbide pieces is in the range of 1.0÷1.5 mcm.

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2. A Technical Review of the Main Reasons for Wheelset Withdrawal and Analysis of the Dynamics of Wheel Breakage

In a modern wagon park, continuous rolling wheels of freight wagons are taken out of operation first of all not because of wear but on account of damage to the wheel roll surface due to local displacements at wheel-and-rail contact places. The presence of the above-mentioned defects is the main reason why wheelsets get repaired at traction and rolling stock maintenance depots (see Table 1).

Table 1. The main reasons for wheelset withdrawal at maintenance depots

Defects to the roll surface	Slips of hard layer breaks	Split-offs of the exterior rim side	Fatigue deformation	Local metal displacements	Overall
%	6.63	1.22	1.22	90.93	100.00

When wagons are in the planned repair, quite a different picture of the wheels to be repaired can be observed.

The largest amount of wheels (49.9%) is brought to the depot because of differences in the diameter of the wheels in a wheelset; 25% of wheels are processed by limited rolling; 10% of wheels are processed because of local displacements and 4% – due to slipping caused by fatigue deformation; the breaks of the hard layer and the fragments of the exterior side of the rim make up 5.66, 0.03 and 5.8% respectively (Силин 1984).

The wheels of the northern-direction train exhibit a higher wear rate due to the use of brake blocks. The highest percentage of wear caused defects can be noticed in trains travelling in Trans-Siberian direction (90.4%) the wheel pairs of which with hard surfacing, slips and kinks are rarely found.

A higher wear rate of wheel flanges is usually observed in wagons following the routes full of small radius curves. On these routes, in case there is an unplanned turning of wheel pairs, flange cutting is the main factor.

A higher rate of defects to the wheel roll surface is also evidenced by other sources. The analysis of the dynamics of wheel breakage over the period of 30-years of exploitation has shown that the character of occurring failures has essentially changed to the side of remarkably lower failures due to wear and contact fatigue. At the same time, the amount of defects that have appeared due to braking has increased for all types of wagons.

Brake defects make up to 75÷90% in uncoupled repair nowadays. Wear defects make up to 58% and brake defects – 15.8% in planned repairs. Cutting flanges is steadily growing.

In the last ten years, the breakage of exploited wheels has displayed the following tendencies: the amount of damaged wheelsets with slips and hard surfacing has remained at the same level; the number of repairs due to the wear of flanges and sharp run-in has significantly increased. The growth of wheel fracturing and rim splitting has been also observed.

As noted above, the proportion of damages to the roll surface of the wheelset strongly depends on physical and mechanical properties of steel used for wheels and exploitation conditions for rolling stock. An increase in wheel quality determines changes in the percentage of defects, which prevents from wheelset exploitation. An increase in the strength properties of steel used for wheels has nearly allowed avoiding defects such as slipping caused by fatigue deformation and those of thermo mechanical origin.

T. B. Larrin, B. A.Kislik, M. M. Mashneva, I. G. Uzlova etc. have conducted ever increasing research on physical and mechanical properties of wheel steels (Лысюк 1997).

The Ministry of Transport and Communications of the Republic of Lithuania in collaboration with institutes and manufacturing industry carries out complex research on manufacturing wheels that would better meet the requirements for the prolonged exploitation of wheels.

To increase the contact strength of the wheel roll surface, the following ways can be recommended: first, an increase in the area of contact between wheel and rail; second, the use of sturdy elements in a wheel pair and railroad structures; third, the use of new materials that would allow high thermal and contact pressure; fourth, improvement to thermal processing during steel production and restoring the structure of wheelset steel with the aim at forming rational physical and mechanical properties in the upper layers of the wheel roll surface.

3. Theoretic and Experimental Research on the Process of High-Speed Profile Grinding (HSPG)

Today, a grinding process for repairing the profile of the wheel roll surface is not as widespread as turning or cutting. In the machines used for grinding the profile of the roll surface, a low cutting level taking much time is applied. This is the reason why the majority of machine constructions are created for processing wheelsets with no wheeling them from under the rail carriage or truck. The low efficiency of a grinding machine is compensated by the elimination of lifting, dismantling and assembling, which justifies the above discussed situation. In addition, there is a possibility of processing a wheel pair produced by using a mechanical process and possessing a hardened surface without removing an efficacious metal layer of the rim.

Presently, wheelset grinding is used in the countries that operate high speed railway lines which means the application of higher requirements for the precision and quality of processing wheel pairs.

In Osaka, Japan, a grinding machine for the profile of the wheelset roll surface serves the entire high-speed railway line in New Tokaido. Wheelset rotation of grinding is made using a 22 kW motor and the rollers resting on the wheel flange. A peripheral (linear) speed of wheel rotation is 1000 mm/min and the speed of the feed – 0.015÷0.15 mm/min.

Grinding the profile of the roll surface is performed on a special facility that allows processing 4 wheels for one carriage at once leaving the wheelset under the wagon. It takes 40 minutes to process the wheels of one carriage.

According to the data source from Japan, since 1965, a machine for tire grinding has been used on the same railway line in Tokaido. A rotational speed of leading rolls rotating a wheel pair is 5÷15 RPM. A rotational speed of the grinding circle is 300 RPM with the diameter and thickness of 845 mm and 96 mm respectively in the beginning. Notwithstanding higher standards maintained in the manufacture of wheelsets used in the above mentioned railway line, irregular granularity due to braking still occurs and usual tiring methods are not used because of a harder metal used for producing wheels. The capacity of the facility is 40 wheel pairs (10 wagons) per day.

In the USA, two companies started manufacturing grinding machines for restoring the profile of the wheel roll surface. The grinding machine made by the *Belt Railway Co* guarantees a rotational speed of a wheel pair reaching 4÷5 RPM. A grinding circle of 365 mm in diameter rotates at about 65 m/s. When the circle wears off, rotational speed increases and cutting speed is kept unchanging.

Grinding both the wheel roll surface and rim is carried out by performing circle cuttings. In the grinding machines produced by the above mentioned company, grinding the wheelsets of diesel locomotives is performed following the process they are wheeled out. The procedure takes about 4 hours to process a double axle trolley depending on the condition of bandages.

The grinding machine manufactured by *Withing Corporation* is designed for processing wheelsets with and without wheeling them out of a locomotive. The profile of the grinding wheel is corrected after processing every two wheelsets. Therefore, a special correcting facility is established on the supports. Correction takes 20 minutes. Despite frequent corrections, it is possible to grind out 200 wheels with one grinding circle.

The grinding circle of 914 mm in diameter has a fully negative profile of the bandage. The 40 HP DC motor rotates the wheel at a speed of about 33 m/s. Processing modes are shown in Table 2.

It is known that grinding is used for repairing wheel bandages of a tram wagon.

Heavy machinery manufacturer *Kramatorian* designed a modernized machine with 4 supporting wheel holders by replacing roughing supports with grinding stocks. Slants with the gradients of 1:20 and 1:7 are to be grinded. The speed of the grinding circle was suggested to be kept constant at V_i = 50 m/s; grinding with emulsion was done. The power of the motor is 46.65 kW. A rotational speed of the circle is 950÷1900 rpm and the feed reaches 0.15 rpm (Bhateja 1979).

Table 2. The modes of grinding the wheelset roll surface

Cutting mode characteristics	Rough processing	Clean processing
Cutting speed V_i, m/s	30÷65	30÷65
Wheel rotation speed V_g, mm/s	200÷300	100÷170
Circle giving s, wheel, mm/turn	0.02÷0.06	0.005÷0.01

The company *Sculfort Systemes Sonim* presented the results of research on the comparison of the following three methods for secondary grinding of a wheelset: grinding, milling and turning. This enabled French National Railway Corporation SNCF (*Société Nationale des Chemins de Fer Français*) to decide on choosing processing by turning on a digitally controlled machine with a wear-resistant tool made from the titan-carbide layer. According to SNCF, the secondary shaping of the wheel using a cutting tool under equal conditions is 4 times less expensive than shaping using a grinding circle. Thus, they rejected processing by milling at the first stage of research. The company did not research the process of high-speed grinding because they considered the possibility of using the above-mentioned methods for repairing high-speed equipment when the quantity of metal removed from the wheel rim was not large.

The above-mentioned cases show that the level of cutting modes used for the existing technology for grinding the wheelset roll surface is not high. Presently, a qualitatively different grinding method for steel forge roughing is used both in our country and abroad. This technique, initially named as a power and high-speed method in Russia, as a high-efficiency method in the USA and as an integral method in Germany, ensures the best effectiveness and manufacturing output when a large amount of metal is removed. The method replaces turning, milling and shaving with the removal of a large amount of chips. At present, in foreign countries, machines for round grinding of up to 2000 mm^3/mm capacity are operated.

In other countries, this process found its place in metal factories and is used for roughing rolled stock, which also guarantees the removal of metal up to 12.7 mm in one pass with no loss of precision. It should be mentioned that the above introduced method of high-speed grinding became widely used in the field of shaping surfaces.

In grinding shaped surfaces applying the cutting method, certain machines cut as deep as 50 mm and the grinded outline is 300 mm wide. The power consumed during this process is 110 kW. High-speed grinding, as a new technology, became realizable with the invention of new high-speed abrasive circles, rigid and vibration-resistant grinding machines and by using more reliable safeguards for grinding circles.

The analysis of methods used for mechanical processing of the wheelset showed that the high-speed profile grinding (HSPG) process method was the most preferable one in the restoration of the roll profile of the repaired wheelset. The analysis of cost effectiveness has also indicated that the best way for restoring the wheelset roll surface is using a specialized high-efficiency grinding machine. The available results led to making a proposal on designing an experimental grinding machine for re-establishing the wheelset roll surface using the HSPG method.

HSPG is characterized by a high cutting mode level and the maximum summed length of all cutting blades working simultaneously. A high level of the cutting mode is achieved using a high speed of cutting (80 m/s and above) and cutting feed (10 mm/min and above). The maximum summed length of all cutting blades working simultaneously was received using a shaped profile and the most abrasive circle known today.

As far as the kinematical scheme is concerned, HSPG does not differ from an ordinary cutting-based grinding process; however, the progress of its physical and mechanical processes distinguishes itself by many important peculiarities. Research on these processes was not sufficiently reviewed. Instead, experimental and theoretical research on the HSPG process of producing wheel steel was done.

Theoretical research on the parameters of the HSPG process using the methods proposed by Prof. S. S. Silin (Силин 1984; Силин, Масляков 2003) was carried out.

The balance of mechanical and heat energy is determined by the following basic equation:

$$P_z \cdot U_c = Q_d + Q_c + Q_{ch}, \tag{1}$$

where: U_c – cutting speed (circle rotational speed); Q_d, Q_c, Q_{ch} – heat transferred from the grinding zone to the detail, circle and chip respectively; P_z – cutting power.

The theory of similarity allows using the following dimensionless complexes (criteria of similarity).

$A = \dfrac{P_z \cdot V_c}{S \cdot L \cdot \theta_p}$ – an energy criterion characterizing grinding power and thermal activity of the wheel, where θ_p – slant angle;

$P_e = \dfrac{V_d \cdot t}{a}$; $P_e' = \dfrac{V_c \cdot t}{a}$ – a criterion that expresses the influence of conditions for the cutting mode and thermal properties both of the metal being processed and circle.

$B = \dfrac{t}{S_1}$ – a geometric criterion of the total cross-section, where t – temperature;

$C = \dfrac{t}{D_c}$ – a parametric criterion, where D_c – disc diameter;

$G = \dfrac{z}{t}$ – relative granularity of the processed material, where z – the number of blades;

$D = \dfrac{V_d}{V_c} = \dfrac{P_e}{P_e'}$ – a criterion that characterizes the ratio of the speed of circle (V_c) to the speed of detail (V_d);

$E = \dfrac{\rho_1}{a}$ – a criterion that characterizes the geometry of cutting blades, where a – the thickness of a removable layer, ρ_1 – blade No 1;

$K = \sqrt{\dfrac{(\lambda_{mid})_g}{(\lambda_{mid})_d}}$ – a criterion that reflects the influence of thermal properties on both grain and detail material;

$L = \dfrac{1}{62 - 2 \cdot n}$ – a criterion that characterizes the quantity of grain bulk in the composition of the circle;

$M = tg\varepsilon \cdot \left(0.5 \cdot \pi \cdot \sin\varepsilon + 2 \cdot \dfrac{\Delta}{a_1 \cdot (\cos\varepsilon)}\right)$ – a criterion that characterizes grain geometry.

Geometric parameters of the HSPG grinding zone. The arc length of the contact:

$$l = \left(1 \pm \frac{V_d}{60 \cdot v_{kr}}\right) \cdot \sqrt{\frac{D_{kr} \cdot d \cdot t}{(D_{kr} + d)}}. \tag{2}$$

The average thickness of the layer being removed:

$$a_{mid} = \frac{V_d \cdot t_\varphi}{60 \cdot V_{kr} \pm V_d}. \tag{3}$$

Heat transferred from the grinding zone to the detail, circle and chip:

$$\frac{Q_d}{\lambda \cdot s \cdot \theta_p} = 0.085 \cdot P_e^{0.5} \cdot C^{0.25} \frac{\sqrt{1+K_1}}{\left(1 - \frac{1}{M_1}\right)^{0.25}}. \tag{4}$$

$$\frac{Q_{kr}}{\lambda \cdot s \cdot \theta_p} = 8.75 \cdot \frac{D_{kr}}{S} \cdot K \cdot M \cdot \left(\frac{V_d \cdot D_{kr}}{a}\right)^{0.5} \cdot C^{1.15} \times D^{1.27} \cdot \left(\frac{Z}{D_{kr}}\right)^{1.08} \cdot \left(1 - \frac{D_{kr}}{d}\right)^{0.25}; \tag{5}$$

$$\frac{Q_s}{\lambda \cdot s \cdot \theta_p} = 0.74 \left(\frac{v_d \cdot D_{kr}}{a}\right)^{0.65} \cdot C^{0.89} \cdot D^{0.042} \cdot \left(\frac{\Omega}{t}\right)^{0.05} \times \left(\frac{Z}{D_{kr}}\right)^{-0.43} \cdot (62 - 2 \cdot n)^{0.108}. \tag{6}$$

The influence of the cutting mode on heat quantity transferred from the cutting zone to the detail, circle and chip respectively is shown in Figs 1 and 2. The analysis of formulas (1÷6) and Figs 1 and 2 shows that heat quantity transferred to the detail and circle increases with an increase in detail speed and grinding depth.

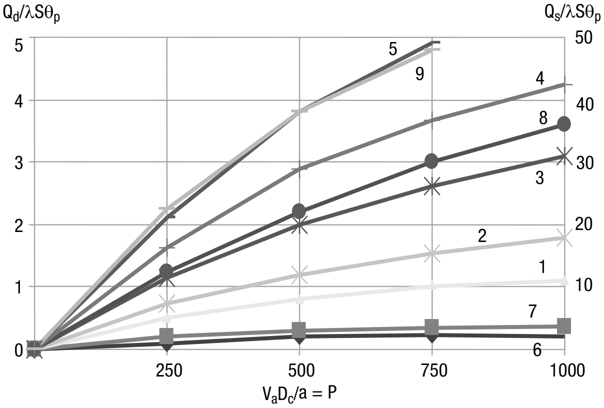

Fig. 1. The dependence of the cutting mode on the quantity of heat transferred to the detail and chip, where 1, 2, 3, …, 9 – experiments performed

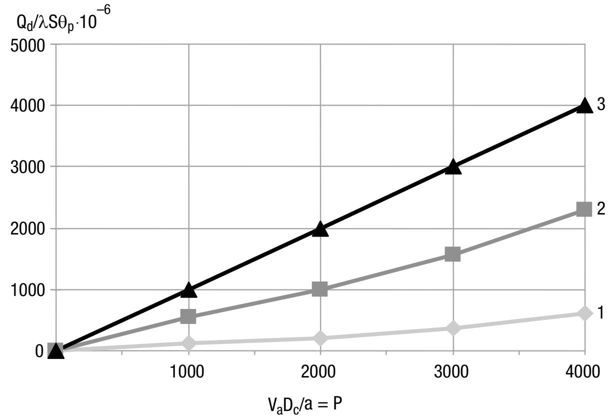

Fig. 2. The dependence of the cutting mode on the quantity of heat transferred to the circle, where 1, 2, 3 – experiments performed

An increase in cutting speed and circle diameter determines a decrease in heat quantity transferred to the circle. The growth in the ratio of cutting depth and wheel diameter results in the rise of heat quantity transferred to the chip ($\frac{t}{D} = 0.2 \cdot 10^{-3} - 6$; $2 \cdot 10^{-3} - 7$; $25 \cdot 10^{-3} - 8$; $50 \cdot 10^{-3} - 9$, see Fig. 1).

The growth of ratio $\frac{t}{D_k}$ increases heat quantity transferred to the detail ($\frac{t}{D} = 0.02 \cdot 10^{-3} - 1$; $0.2 \cdot 10^{-3} - 2$; $2 \cdot 10^{-3} - 3$; $25 \cdot 10^{-3} - 4$; $100 \cdot 10^{-3} - 5$, see Fig. 2).

The growth of ratio $\frac{t}{D_k}$ increases heat quantity transferred to the circle ($\frac{t}{D} = 2 \cdot 10^{-3} - 1$; $25 \cdot 10^{-3} - 2$; $50 \cdot 10^{-3} - 3$, see Fig. 2).

We shall consider the HSPG mode when cutting speed is $V_k = 80$ m/s and relation between the grinding circle and the wheel (detail) is determined by the following expression:

$$\frac{V_c}{V_d} = \frac{5.5 \cdot M^{0.79} \cdot K^{0.79} \cdot C^{0.9} \cdot P_e^{0.4} \cdot \left(1 - \frac{D}{d}\right)^{0.4}}{(62 - 2 \cdot n)^{0.21} \cdot \left(1 + K_1\right)^{0.3} \cdot \left(\frac{S}{D}\right)^{0.79} \cdot F_1^{0.79}},$$

where: dimensionless function F_1 is determined by expression $F_1 = \frac{A}{\sqrt{P_e}}$.

Thermal and mechanical properties of the material machined and that of the tool are as follows:

$a = 9.45 \cdot 10^{-6} m/s$; $\varepsilon = 30$; $\partial = 1.1\,\text{GPa}$; $n = 6$;
$\lambda = 19.6$; $c_p = 1.54 \cdot 10^{-6}$; $Z = 0.4 \cdot 10^{-3}$ m;
$\rho = 0.02 \cdot 10^{-3}$ m.

Dimensionless complexes K, M, $\frac{Z}{D_c}$, L, $\frac{D_c}{d}$ are calculated as outgoing from known information. Considering an allowable wear of a high capacity circle, we determine a rotational speed of the detail (wheelset) to be $v_d = 190$ m/min when cutting feed is 11.8 mm/min.

4. Thermal Processing of the Wheel Profile

During the process of manufacturing a primary wheel and bandage, the upper layer hardness of 260÷310 HB is reached in a pulsating hardening way after preheating in the furnace. In the depth of 30 mm, metal hardness usually does not exceed 265 HB because of low heat penetration into metal and bandage. That is why the entire hardened metal layer gets fully removed already within the first two subsequent repairs. During all remaining time, the wheel and bandage are exploited almost without the hardened metal layer; thus, they wear off sooner and defects to contact fatigue appear. Wheels are repaired more frequently, and therefore a useful wheel metal layer is taken off as a chip in the grinding process. When using modern wheels and bandages, a requirement that the metal layer of the run must be of 290÷300 HB hardness should be satisfied. The same hardness must be kept through all depth necessary to be present through the whole exploitation of the wheel. While restoring a wheelset and shaping the wheel roll surface, in order to efficiently use metal, it is not purposeful to grind a part of the metal layer turning it into shaving. There are known wheel regenerating methods when the upper metal layer is repeatedly annealed to the hardened pearlite with its subsequent grinding.

However, these methods do not ensure physical and mechanical properties of metal used for the wheel roll surface important for improving wheel durability. The main purpose of these methods is to increase the productivity of the grinding process and to decrease the use of the hardened layer (Somov, Bazaras 2006; Bazaras, Somov 2009).

The wheel restoration method, by which the wheel roll surface is first processed employing polishing and grinding in order to restore physical and mechanical properties of rim metal, is the void of similar defects. The estimation of the quality of all wheel restoration methods revealed that this method among other assessed methods, according to the classification scheme established by the experts, had the best special quality indices accounting for: its usage in other application fields (P1), the thermal processing of the wheel up to 600 HB (P2) and that of up to 320 HB (P3), the efficient processing of wheels with defects to run surface (P4), physical and mechanical properties of rim metal regeneration (P5), the structural simplicity of a cutting tool (P6), the tool fixing and regulating complexity (P7), the formation of comfortable and easy-to-remove shaving (P8) and the necessity of subsequent shaving processing (P9). As a result, this method possesses the highest value of the general quality index (Q). According to the results of the analysis regarding the effectiveness of restoration methods (Bazaras, Somov 2009), this method seems to be the most acceptable one.

The method that is the most similar to the one discussed above in terms of technical essence and achievable results, is the restoration of the wheel roll surface of railway rolling stock.

The essence of this method is that annealing and sudden cooling of the upper metal layer is done before mechanical processing. Consequently, the metal surface becomes sorbitic pearlite or sorbite of 290÷320 HB hardness in the depth of 8 mm from the roll surface. After thermal processing, processing the mechanical surface using grinding is done, during which a metal layer of 3÷4 mm with damages or defects is taken off.

However, this method does not ensure the thermally processed metal layer to be equal to the whole depth of the wheel roll surface profile. This happens because of a complicated way of making the gap between the inductor and the worn wheel roll surface being equal. The gap can vary in the range of $e = 3 \div 15\,\mathrm{mm}$, depending on the characteristics and diameter of the wheel (Fig. 3). Variations in the gap value result in variations in the inductivity of the system 'transformer–inductor–wheel', and hence, in the resonant frequency of the contour, which results in changes in $\cos\varphi$ and power used by the generator. An increment in the gap decreases power, which means it is not fully used. In addition, the depth of annealing decreases and the system does not work properly. To improve the stability of the system, a separate generator should be connected to every inductor (heating head). Even if the rolled layer of the wheel roll surface is less than 3 mm at some spots of the profile, metal may not attain necessary strength or thermal processing may not occur at the necessary depth of 8 mm. Moreover, thermal processing reaches its maximum depth not on the wheel roll surface having the hardest wear but on the bevel side of the surface.

The prolongation of rolling and rim wear reduces the effectiveness of this method; also, it reduces the depth of the thermally processed layer at some places all along the profile. Some areas with no thermally processed metal layer on the wheel roll surface can appear after grinding (see Fig. 3a).

There are no possibilities of increasing the thermally processed metal layer of the wheel roll surface using this well-known method because it is not allowable to reduce the gap between the inductor and the roll surface by less than 3 mm. It is not possible to heat metal at a temperature lower than 140 ^{0}C because requirements for the isothermal annealing-process mode, on which this method is based on, would be violated.

This well-known method enables getting the above-mentioned results only when processing wheels where the layer of the roll surface does not exceed 3 mm, whereas the established limiting value of the rolled layer of the roll surface is 7 mm and that of the freight wagon – 9 mm. Taking into consideration that the thermally-processed metal layer of 3÷4 mm is removed when repairing wheels with the help of the grinding method, it is clear that an uneven thermally-processed metal layer of less than 5 mm remains or, in some places, is absent altogether. Even when the depth of the thermally-processed metal layer is achieved using this method processing the layer of the rolled metal and remains at its maximum, it is, however, less than the required limit value, which means that the thermally-processed layer will serve for the first stage of exploitation only. The above-mentioned drawback is a typical one for the restoration of the wheel profile using grinding, especially in the case of using it while the working metal layer is shaved off. In addition, an increase in hardness up to 320 HB before grinding reduces processing productivity and the efficiency of the cutting mode as well as increases the consumption of hard alloy, as compared with other above-mentioned methods.

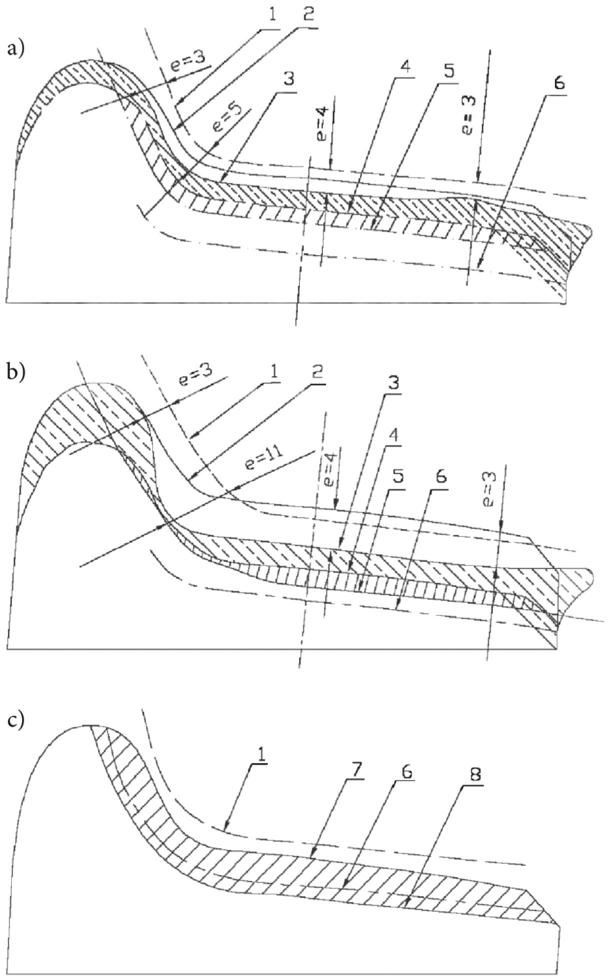

Fig. 3. Thermal processing schemes for the wheel profile: a – nonprime grinding; b – restoration using HSPG and turning methods; c – restoration using the HSPG method, where *e* – gap can; profiles: 1 – theoretical; 2 – practical; 3 – with deterioration; 4 – optimally restored; 5 – after first turning; 6 – after second turning; 7 and 8 – using the HSPG method

The aim of using this method is to improve the durability of the wheel by preserving the rolling metal layer of the rim and by keeping the depth of the thermally processed layer even when the hardness of 290÷320 HB along the whole wheel roll surface is obtained.

This goal can be achieved by means of the above-mentioned method for restoring the profile of the wheel roll surface, according to which the profile of the roll surface is restored employing the method of high-speed profile grinding, which is the most efficient way of preserving the rolling metal layer of the rim. Consequently, the wheel roll surface is restored using thermal processing and ensuring an even gap between the inductor and profile of the worn wheel roll surface. This enables restoring physical and mechanical properties of the rim.

The use of the grinding method ensures an optimal gap between the inductor and wheel roll surface along the length of the profile with the rolling metal layer not being removed. An equal wheel size is guaranteed before and after repair. The resistance of the metal layer of the wheel roll surface to contact wear increases (see Fig. 3c) when the above described processing method is applied. Wheel durability, in case of a thicker layer, increases within exploitation.

5. Restoration and Experimentation on Exploitation

Restoration consists of the following stages: first, the wheel is grinded to restore its worn and defective profile in accordance with the given geometrical parameters; second, to ensure both even and maximum hardness of the thermally-processed layer of 290÷320 HB, an optimal 3 mm gap between the inductor and wheel roll surface is set (see Fig. 3b).

By means of two half-coil inductors powered by one generator for each wheelset, one for each wheel, the wheels are processed by multi-pulse heating, chilling and cooling in the same way as in the well-known method, which enables to get the structure of sorbitic pearlite or sorbite of 290÷320 HB hardness in an agreeable depth from the roll surface evenly distributed along the length of the profile.

After such processing, the wheelset of the size as it was before repair is further exploited and the hardness of its thermally-resistant metal layer is 290÷320 HB in depth which is equal to or even greater than that required along the roll surface.

While trying to increase wheel durability by using this method, differences appear when mechanical processing (grinding and polishing) is made before annealing a multiplex impulse. To evaluate resistance to both wear and other mechanical damages of the wheelset processed in accordance with the suggested technology and to compare it with that of typical wheelsets, experiments in exploitation were performed.

As an object to experimentation, thermally-processed wheels of 960 mm in diameter of RU-1 type were chosen (wagon service of Murmansk station, Oktiabrskaja Railway, Russian Railways). The number of both types of wheelsets was 8, and each wheelset was processed using different methods. Those wheelsets were wheeled under the wagons of model 10–4022.

Wagons having differently processed wheelsets were directed to the circular route. The section (Apatites – Murmansk, Russia) is 185 km in length and has 160 curves of 350÷500 m radius. An average speed in this section is 70 km/h and the general weight of the train is 8000 tons.

Difficult exploitation conditions in this section increase the wear of wheelsets. The main reason for wheel rejection is the wear of the wheel edge. Experimentation took place from April to May 2008. Estimation criteria for the average run of the tested wagon making up to 400 km within 24 hours were chosen to be the degree of rim wear and the wear of the wheelset roll surface, both depending on the mileage of the wagon. The criteria were set by considering the prevailing samples and other mechanical damages. The average wear of the wheelset at the end of the experiment consisted of:

- the rim: typical wheel – 4.6 mm, experimental – 2.6 mm.
- the roll surface: typical wheel – 3.9 mm, experimental – 2.4 mm (see Figs 4 and 5).

Based on the results of the conducted experiments, a *Temporary Technological Instruction* on annealing the roll surface of wagon wheelset together with *Induction Heating and Thermo Cycling* (Технологическая инструкция по… 2008) was drawn up.

6. Conclusions

1. The analysis of the obtained results has revealed that experimental thermally processed wheelsets are more resistant to abrasion than the typical ones. Experimental rims of the wheelset exposed the strongest resistance to wear. No defects in those wheelsets were found within the whole time of exploitation.
2. The presented method for restoring the profile of the wheelset rim is based on high-speed profile grinding and aimed at obtaining, after mechanical processing is performed**,** necessary physical and mechanical properties of metal used for the wheelset rim considering layer depth that exceeds the limit values of measured deteriorations.
3. The introduced method for restoring the profile of the wheelset rim, by means of which the geometrical

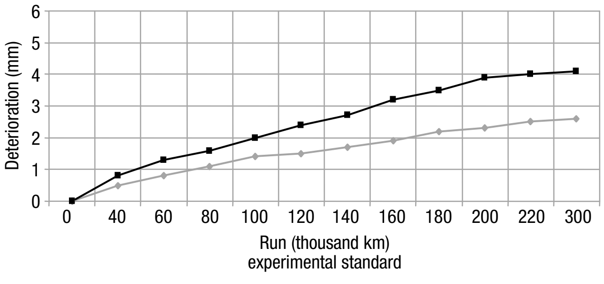

Fig. 4. The dependence of the wear of the wheelset roll surface on the rim

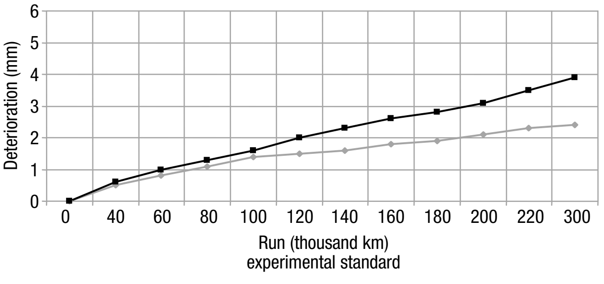

Fig. 5. The dependence of the wear of the wheelset roll surface on the run

parameters of the roll surface of the wheelset rim are regained with the subsequent restoration of physical and mechanical properties of the surface layer of metal used for the wheelset rim, enables strengthening the wheelset rim against deterioration by about 30%.

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