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Energy and Power Parameters of Rolling Profiles for Wheel Rims of Reduced Metal Intensity with Toroidal Flanges

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The article contains experimental evaluation of technological possibilities of the wave-shaped profiles and confirmation of classical metal flow on profiles of wheel rims with toroidal flanges. The following parameters are recorded during the experiments: temperature in the finishing gauge, rolling force in the 2^{nd}, 4^{th}, 6^{th} and 7^{th} passes, current, voltages and motor speeds. The analysis of experimental data of rolling profiles 7.0-20-03, 8.5-20-03 and 228G-020-01 shows that technological capabilities of special rolled products for the truck wheel rims with wavy central part are much higher than serial profiles, where the central zone is of rectangular shape. It is possible to reduce the mass of profiles without changing the process parameters, *i.e.*, rolling force and torque. This indicates the influence of additional and kinematic effects on the deformation zone in real production conditions.

Key words: wheel rims, metal intensity, energy and power parameters, rolling, workpiece.

У статті проведено експериментальну оцінку технологічних можливостей профілів хвилеподібної форми та підтвердження класичної течії металу на профілях ободів коліс з тороїдальною посадковою полицею. Під час експериментів реєстрували такі параметри: температуру в чистовому калібрі, зусилля прокатки у 2-му, 4-му, 6-му і 7-му проходах, струм, напругу та число обертів двигуна. Аналіза експериментальних даних прокат-

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ки профілів 7.0-20-03, 8.5-20-03 і 228G-020-01 показує, що технологічні можливості спеціяльного прокату для ободів коліс вантажних автомобілів із хвилеподібною центральною частиною значно вищі за серійні профілі, в яких центральна зона має прямокутню форму. Можливе пониження маси профілів без зміни параметрів процесу, тобто сили та моменту прокатки. Це свідчить про вплив ефектів додаткового та кінематичного впливу на осередок деформації в реальних умовах виробництва.

Ключові слова: обід колеса, металомісткість, енергосилові параметри, прокатка, заготовка.

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1. INTRODUCTION

Currently, many spheres of activity can be considered knowledge-intensive, *i.e.*, areas where the latest achievements and developments in science and technology are used.

There are industries that provide output of products with high consumer properties or are of priority importance for the state due to one or another reason. Significant capital investment is involved in these productions either in order to maximize profits or to obtain acceptable specifications of the manufactured item. This makes it possible to obtain new quality at reduced costs by means of advanced technologies, equipment, materials, and to ensure highly profitable production with priority development and economic growth [1–6]. In our case, it can be argued that such priorities include the automotive and aircraft engine industries.

The automotive industry ranks first in terms of special rolled products used. The profiles used can be divided into groups: wheel, periodic, spring, for door hinges, and other parts [7–9].

Designs of automotive wheel rims for various purposes are distinguished by the number of main structural elements: rim base, lock ring and side ring. All of these elements have different designs depending on their purpose. The rim base, designed with an inclination of 5° to the flange, is necessary to keep the tire on the rim by tensioning it. Recently, a rim design with a 15° flange for truck, bus, and trolleybus wheels has become more prevalent.

In the automotive industry during the production of truck and bus wheels, the direction of improving designs by reducing the rim components is clearly indicated (Fig. 1). This makes it possible to reduce the metal intensity of the rim by reducing the overlap of the rim parts. There is a need to create a single-piece rim. In addition, the profile itself undergoes changes towards a more rational distribution of metal across the cross-section. This ensures a certain degree of its equal strength: more stressed areas are strengthened and less stressed ele-

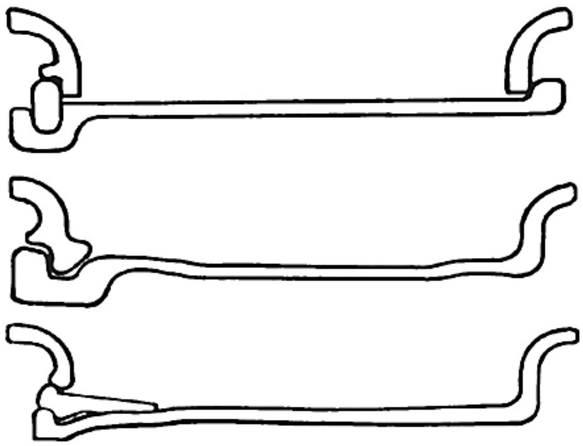

Fig. 1. Hot-rolled profiles of truck wheel rims.

ments are thinned.

The upper profile of the rim has an equal-thickness cross-section, although the load is different across the widths. The lower profile is designed so that the section has different thicknesses across the width and a 5° flange on which the tire bead sits with interference. In this case, the side ring in the first design is made for this structure in one piece with the centre part.

There is no need to make a holding ledge that significantly reduces the metal intensity of the profile. The third profile from the top has a thinning in the central part; it is minimally stressed during operation. The wavy lower surface of the centre part of the next profile allows for additional lightness and, at the same time, ensures a minimum temperature drop during rolling in the last finishing pass, which improves its technological capabilities.

This trend in the development of truck wheel rims, taking into account operational and technological features, means that the improvement of designs is associated with a reduction in the weight of the wheel, its individual parts, including special rolled products. Reducing the mass of the unsprang part of the vehicle results in reduced fuel consumption, tire and road wear, and increased life of the wheel-mounting hub.

Rolling of non-standard profiles in metallurgical production allows saving metal at the consumer, where it is used as a workpiece for the manufacture of products of the machine-building complex. This case considers the ‘junction’ of metallurgical and machine-building production where many technological and technical issues can be solved. For example, the creation and development of profiles of special rolled products with reduced metal intensity involves solving a number of issues in different areas of production: in mechanical engineering—issues related to the strength of the product, operational capabilities; in metallurgy—technological issues that determine the possibility of its production and economic feasibility. Comprehensive consideration of peculiarities allows for a new approach to solving emerging problems. In this case, a new task definition and new approaches to its solution appear. Rolling profile, the shape of which is determined by the parameters of loading during operation, can take into account the technological features of production, in particular, plastic deformation. The new statement concerns the technological design of special rolled products, for which it is necessary to know the peculiarities of the technological process, the regularities of plastic flow of metal, stressed and strained conditions [10–14].

Consideration of plastic deformation effect on the shape of rolled products allows not only to predict the result, but also to control the process of deformable medium shape change on the basis of physical and mathematical models. The tool for such control can be the strain non-uniformity in both width and length of the deformation zone.

The theoretical and experimental research results presented in this paper show that there are effects that stabilize the process and high-quality product under conditions of non-uniform plastic deformation of thin-walled profiles.

2. EXPERIMENTAL

Experimental evaluation of technological possibilities of wave-shaped profiles and confirmation of classical metal flow was also carried out on profiles of wheel rims with toroidal flange. The following parameters were recorded during the experiments: temperature in the finishing gauge, rolling force in the 2nd, 4th, 6th and 7th passes, current, voltages and motor speeds.

To measure the rolling force, membrane-type load cells made of 40KhN steel were designed and manufactured. They worked in conjunction with a strain gauge amplifier and a magnetoelectric oscillograph.

A device consisting of a photoelectric pyrometer, isolation transformer, voltage stabilizer, and oscillograph was used to measure the temperature. The loading of the motor of the finishing stand was investigated using an oscilloscope.

3. RESULTS AND DISCUSSION

Generalized values of process parameters for profiles 228G-020 and 228G-020-01 with the groove depth of 1.0 mm are presented in Table 1.

TABLE 1. Results of experimental data during rolling of serial and lightweight profiles 228G-020 and 228G-020-01 (groove depth of 1.0 mm).

Rolling parameters	Profile type	Pass Nos.						
		1	2	3	4	5	6	7
Reduction, mm	Lightweight	30.9	27.9	15.1	10.8	4.3	2.7	1.0
	Serial	30.9	27.9	15.1	10.8	3.8	2.6	1.2
Temperature, °C	Lightweight	–	–	–	–	–	–	860–980
	Serial	–	–	–	–	–	–	895–982
Rolling force, MN	Lightweight	–	2.9–3.7	–	3.2–4.2	–	1.9–2.5	2.2–3.1
	Serial	–	2.6–3.8	–	2.8–3.5	–	2.1–2.6	2.2–3.1
Motor capacity, kW	Lightweight	–	–	–	–	–	–	517–802
	Serial	–	–	–	–	–	–	525–781
Rolling torque, MNm	Lightweight	–	–	–	–	–	–	0.03–0.05
	Serial	–	–	–	–	–	–	0.03–0.04
Torque arm ratio	Lightweight	–	–	–	–	–	–	0.33–0.45
	Serial	–	–	–	–	–	–	0.34–0.43

The research results for serial and lightweight profiles were compared for the following parameters: absolute reductions, rolling temperature in the finishing pass, rolling force, motor capacity, rolling torque, torque arm ratio. The obtained data of lightweight and serial profiles did not have significant differences. At actually, the same strain mode of rolling the temperature changed insignificantly: on the lightened profile it slightly decreased from 895–982°C to 860–982°C. Higher temperature of the end of rolling, compared to profiles 7.0-20-03 and 8.5-20-03, is explained by higher weight of profiles and simplified configuration of the profile (similar to strip rolled product). The rolling force for the experimental and serial rim is in the same range of 2.2–3.1 mN, although a more detailed analysis shows that there is a bias in the number of measurements towards a lower force magnitude, when rolling a lightweight rim. Other process indicators are also within approximately the same limits: capacity is 517–802 kW and 525–781 kW; torque is 0.03–0.05 MNm and 0.03–0.04 MNm; torque arm ratio is 0.33–0.45 and 0.34–0.43. The workpiece used in rolling for the studied profiles was of the same thickness and equal to 100 mm, which did not introduce additional difficulties in analysing the result. When the rolling end temperature is lowered, the forces are virtually the same. Stability of indicators for lightweight and serial profiles proves the effectiveness of kinematic influence on the rolling process. On these profiles, this conclusion is stronger, since the experimental data were obtained, as can be seen from Table 1, at comparable strain regimes. In addition, the process of obtaining the required profile thickness did not cause any major problems, rolling was stable and without delays.

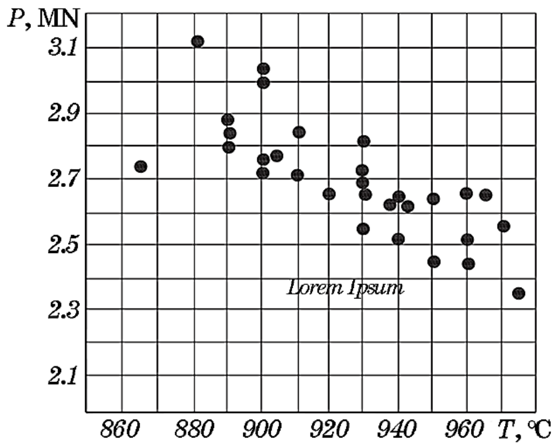

Fig. 2. Dependence of rolling force on temperature in finishing pass of profile 228G-020.

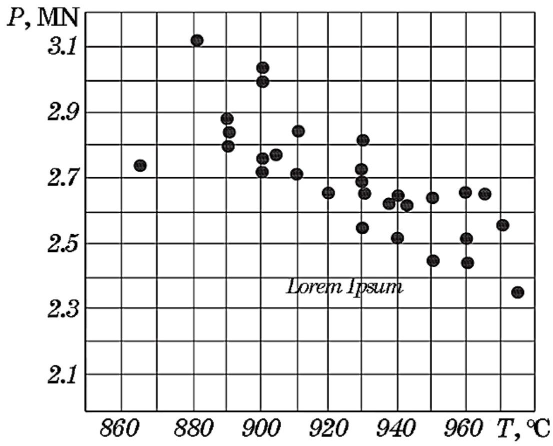

Fig. 3. Dependence of rolling force on temperature in finishing pass of profile 228G-020-01.

Let us consider the experimental data in more detail to analyse the validity of the obtained result. Figures 2 and 3 show the values of rolling force depending on temperature for serial profile 228G-020 and lightweight 228G-020-01, which support the generally accepted ideas: with increasing temperature the rolling force decreases, and the data scatter is less than for profiles with a tapered flange.

Figures 4 and 5 for profiles 228G-020 and 228G-020-01 show the dependence of rolling torque on temperature. The data demonstrate that no such dependence is observed for profiles with tapered flange. There is no effect of temperature on the rolling torque within the exist-

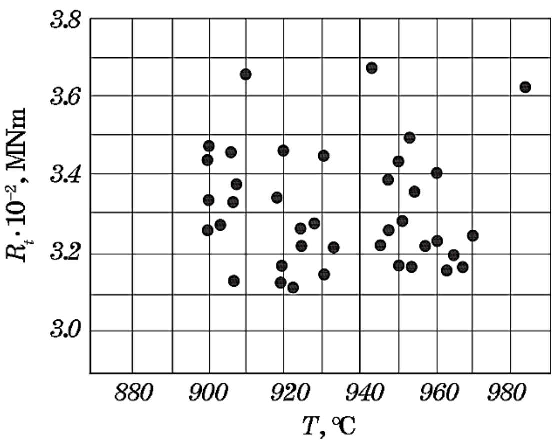

Fig. 4. Dependence of rolling torque on temperature in finishing pass of profile 228G-020.

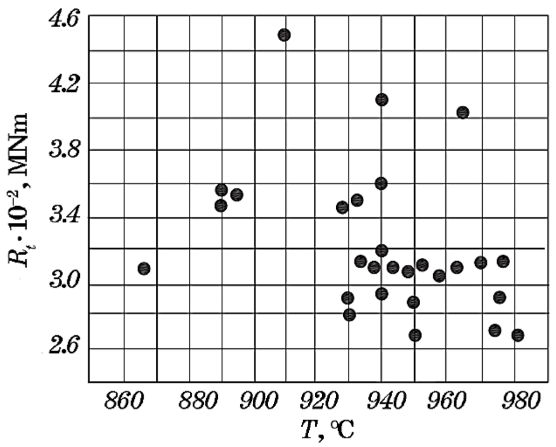

Fig. 5. Dependence of rolling torque on temperature in finishing pass of profile 228G-020-01.

ing process parameters, while reducing the metal intensity.

The dependences of rolling torque on temperature have a correlation factor significantly less than 0.5. If there is no such dependence, then, the arm should increase with the increase of metal rolling temperature. For profiles with a tapered flange, the arm and rolling torque arm ratio also depend linearly on the temperature and increase with its increase.

This is due to redistribution of yield strength along the length of the deformation zone. Processing of experimental data for profiles with toroidal flanges showed a similar qualitative dependence.

Figures 6 and 7 show the data of torque arm ratio ψ from temperature T at rolling in the last finishing pass. The relationship between the above factors can be seen for serial and lightweight profiles. This is an important conclusion, as it suggests that rolling of lightweight profiles will not be accompanied by deterioration of the above parameters.

In addition to additional and kinematic effects on the deformation zone, there is a peculiarity of energy character when the proposed strain changes in the plastic flow do not lead to additional energy inputs.

This allows, for example, when cooling the rolled product to obtain

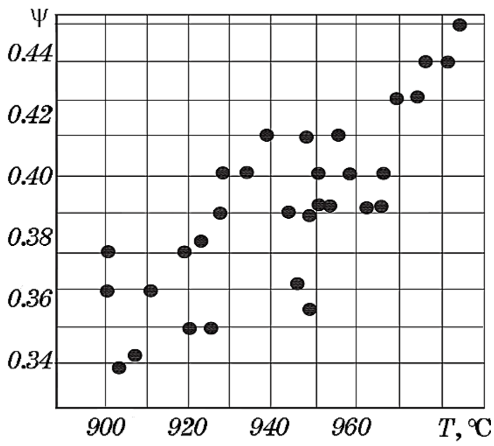

Fig. 6. Dependence of rolling torque arm ratio on temperature in the finishing pass of profile 228G-020.

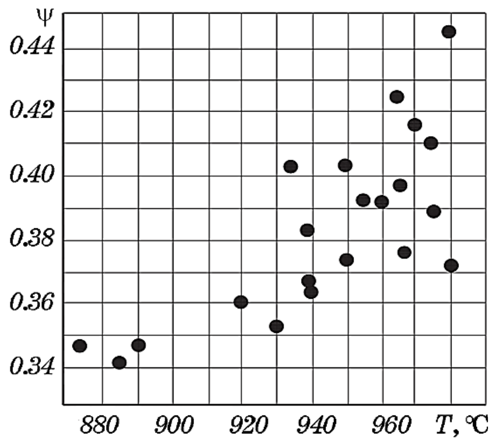

Fig. 7. Dependence of rolling torque arm ratio on temperature in finishing pass of profile 228G-020-01.

the required structure, to ensure that the energy costs of the process remain unchanged, while the rolling force can vary significantly.

The obtained result seems to be reliable, since it does not contradict the generally accepted provisions of the rolling theory. The validity of obtained experimental data, in addition to qualitative comparisons, should be assessed by quantitative indicators.

For the profiles, in addition to the parameters presented above, the motor armature current was measured using different measuring equipment. Then, the data from them were well correlated with each other after processing.

Processing of the obtained results by methods of mathematical statistics allowed obtaining empirical dependences of rolling force in the seventh pass.

For the profile 228G-020,
rolling force on motor armature current

$$P_7 = 3.007 + 238.257 I_7,$$

rolling force on strip temperature [in tons]

$$P_7 = 639.019 + 0.419 T_7, \tag{1}$$

torque arm ratio on strip temperature

$$\psi_7 = 0.00077 T_7 - 0.34300.$$

For the profile 228G-020-01,
rolling force on motor armature current

$$P_7 = 3.010 + 236.100 I_7,$$

rolling force on strip temperature [in tons]

$$P_7 = 651.594 + 0.412 T_7, \tag{2}$$

torque arm ratio on strip temperature

$$\psi_7 = 0.00081 T_7 - 0.37900.$$

The correlation ratios for currents are of 0.83 and 0.82, for temperature, they are of 0.67 and 0.74, and for torque arm ratio, they are of 0.79 and 0.71. At a temperature of 900°C, the torque arm ratio for the investigated profiles takes the corresponding value equal to 0.35. In this case, the resultant of forces is located closer to the outlet of the deformation zone.

High convergence of the studied data indicates the reliability of the obtained experimental results.

Comparing expressions (1) and (2), we make sure that they differ insignificantly in numerical values that confirms the same order of obtained experimental values on serial and experimental profiles. Using formulas (1) and (2) by measured values of current force, it is possible to determine the rolling force of profiles with toroidal flange of different weight. If the stiffness of the mechanical system is known, we can determine its elastic deformation and thickness of the yielding strip. By knowing the force and the arm ratio, we can get the rolling torque.

Comparison of data for profiles with toroidal and tapered flanges shows that there is a difference between them.

The temperature for profiles 7.0-20-03 and 8.5-20-03 is significantly lower than for profiles 228G-020. This is due to the greater weight of the profile, and the lower value of the torque arm ratio ψ for toroidal flanges compared to profiles with tapered flanges is due to the complex shape of the cross section. This also applies to the rolling force, which is greater on profiles with complex configurations. Such a comparison of experimental data for different geometrically shaped profiles is useful if there are general trends that confirm the same qualitative result, which includes the plastic flow effect. Comparison of experimental data on profiles indicates that temperature reduction on lightweight profiles does not lead to an increase in the energy parameters of the rolling process.

To develop the optimal weight of profiles at mill 550 of Petrovsky plant several modifications of profile 228G-020- 01 of different weight were rolled, with different parameters of wave central zone with depth of groove $h_{\text{groove}} = 0.8$, 1.0, 1.2 mm. The influence of the groove depth, *i.e.*, the profile weight, on the process parameters was studied.

Table 2 shows the values of the rolling process parameters obtained from the motor armature current at groove depths of 0.8 mm and 1.2 mm.

Table 2 shows that the force and rolling torques at groove depth of 1.2 mm have increased in comparison with the data of Table 1. From the technological point of view, it has complicated the process of obtaining the profile in shape and size, increased energy consumption, mill downtime associated with its readjustment, consumption of rolls. There were problems with obtaining the specified roll thickness in finishing passes. From the technological point of view, the profile weight with groove depth of 1.0 mm was more preferable.

Rolling of the profile with depth $h_{\text{groove}} = 0.8$ mm did not cause concerns; however, such a 'sinusoid' was worn out faster.

4. CONCLUSION

All the data given in this article indicate that the manufacture of pro-

TABLE 2. Values of rolling force and torques obtained by motor armature current for profile 228G-020-01.

Process parameters	Pass Nos.	
	6	7
	Groove depth of 0.8 mm	
Rolling force, MN	1.85–2.40	2.00–3.20
Rolling torque, MNm	0.023–0.028	0.025–0.041
	Groove depth of 1.2 mm	
Rolling force, MN	1.88–2.56	2.52–3.44
Rolling torque, MNm	0.023–0.031	0.031–0.046

files with a wave-shaped central part in real production conditions confirms the effects of plastic flow and allows realizing the process of stable rolling of thin-walled products with reduced metal intensity. The wavy shape of the central part of the finishing profile increases the web width, which reduces the partial drawing of the heavily reduced element. Redistribution of partial drawings across the strip width changes the nature of the stress state.

As a result, we have a new quality associated with the rolling of thin-walled products; the process of plastic deformation (rolling) can be controlled, improving its technological capabilities. On the other hand, the features of shape change determine the design of the profiles themselves, and there is a possibility of their technological design. This problem has been successfully solved for special profiles for wheels of trucks, buses and trolleybuses.

REFERENCES

1. A. A. Nester, O. S. Drobot, and O. O. Nikitin, *Metallofiz. Noveishie Tekhnol.*, **44**, No. 4: 471 (2022) (in Ukrainian).
2. I. E. Volokitina, *Prog. Phys. Met.*, **24**, No. 3: 593 (2023).
3. I. E. Volokitina, A. V. Volokitin, M. A. Latypova, V. V. Chigirinsky, and A. S. Kolesnikov, *Prog. Phys. Met.*, **24**, No. 1: 132 (2023).
4. A. Denissova, Y. Kuatbay, and Y. Liseitsev, *Case Studies in Construction Materials*, **19**: e02346 (2023).
5. I. E. Volokitina, *Prog. Phys. Met.*, **24**: No. 3: 593 (2023).
6. A. Bychkov and A. Kolesnikov, *Metallogr. Microstruct., Anal.*, **12**: 564 (2023).
7. V. V. Chigirinsky, Y. S. Kresanov, and I. E. Volokitina, *Metallofiz. Noveishie Tekhnol.*, **45**: No. 4: 467 (2023).
8. N. V. Ruzanov, M. A. Bolotov, V. A. Pechenin, and E. R. Matek, *Key Eng. Mater.*, **769**: 242 (2018).
9. V. V. Chigirinsky, Y. S. Kresanov, and I. E. Volokitina, *Metallofiz. Noveishie Tekhnol.*, **45**: No. 5: 651 (2023).
10. Yu. Ya. Meshkov and G. P. Zimina, *Metallofiz. Noveishie Tekhnol.*, **44**, No. 6:

807 (2022) (in Ukrainian).
11. V. Chigirinsky and O. Naumenko, *East.-Eur. J. Enterp. Technol.*, **5**: 27 (2019).
12. O. I. Gorbatov, Yu. N. Gornostyrev, P. A. Korzhavyi, and A. V. Ruban, *Phys. Met. Metallogr.*, **117**: 1293 (2016).
13. N. V. Ruzanov, M. A. Bolotov, V. A. Pechenin, N. D. Pronichev, and E. R. Stepanova, *Procedia Eng.*, **176**: 529 (2017).
14. B. Sapargaliyeva, A. Agabekova, G. Ulyeva, A. Yerzhanov, and P. Kozlov, *Case Studies in Construction Materials*, **18**: e02162 (2023).