Main aspects of establishing the machining parameters of the railway wheelset's rolling surfaces

I G Ghionea¹,², A L Ghionea¹, N Predincea² and E Balazs³

¹ University Politehnica of Bucharest, Manufacturing Engineering Department, Splaiul Independentei Street No. 313, Romania
² University Politehnica of Bucharest, Machine and Production Systems Department, Splaiul Independentei Street No. 313, Romania
³ Wagons Factory Aiud, Wheels Workshop Department, Vulcan Street No. 2-10, Aiud, Romania

Email: ionut.ghionea@imst.pub.ro

Abstract. In the rolling subsystem of the railway vehicles, the wheelset is the main component. This is subject to large and variable loads and to a continuous wear-off process. The wheels' rolling surfaces of the wheelset are processed on specialized lathes under precision conditions (profile, roughness) defined by specific rules. The geometric elements defining the tread profile are rigorously defined in norms and standards, which implies specific precision conditions. Profiling and re-profiling are performed by simultaneously turning both wheels of the wheelset. The technological parameters are determined considering the material to be machined, the material of the cutting tool (recommended by the catalogues), the quality and the roughness of the processed surfaces, the rigidity of the lathe, the power and torque of the electric motors used or driving the generating kinematic chains (main, feed). Also, the status and dimensions of the machining allowance, number of passes and the type of NC program used, are very important. In the paper are presented as examples some geometrical characteristics of the wheels and wheelset and are recommended values of the technological parameters, which are set numerically or experimentally. Based on these, values of speed, forces, moments and cutting power could be calculated.

1. Introduction

Many research projects in the field of machine tools remanufacturing involve different stages of their analysis on the technical characteristics, the kinematic structure, the improvement of the functional and precision parameters.

The working parameters could be adjusted corresponding to the values of the cutting forces and torques. We can calculate and measure their influence on surface precision and vibration behavior. These are important for evaluating kinematic and dynamic precision, extension of some design calculations and CAD modeling. The behavior of the tool's cutting edge during the cutting process is also analyzed.

The evolution of the working parameters causes chips to change their shapes and tools' durability. The main purpose of these determinations is to establish the optimum kinematic and constructive solution of the remanufactured machine tool. Thus, more and more old machine tools without CNC capabilities are being remanufactured in the Industry 4.0's new vision [1].
The development of the actual railway transport [2] emphasizes the increased reliability of the rolling stock and the traffic safety, on the reduction of operating costs. Their purpose is to reduce noise and wear during operation. Manufacturing, control and maintenance technologies are also improved. Framing the wheel rolling surface profile in the geometric and functional characteristics is rigorously established by national and international standards [3, 4, 5].

The precision of the rolling surface profile of the wheels and of the rail has been and is increasingly being studied and improved with the increase in rolling stock speed and wheelset load. Thus, wheels are among the most loaded components of these vehicles and are subject to a continuous wear-off process. By measuring and analyzing the noise and vibrations, it is found that the wheels have reached a critical wear level at a certain moment. They are evaluated on the basis of specific methodologies and procedures, and are then to be reshaped or replaced. The amount of wear is determined by calculations [6], based on the measurement of the rolling profiles [4]. Then it is calculated and indicated the thickness of machining allowance and the number of passes necessary to remove it. The machining allowance on the width of the worn wheel is not uniform. The profiling and reshaping of the wheels of the wheelset is carried out by the technological process of turning on specialized lathes [7]. Due to the high cost of purchasing such a modern machine tool, it is also possible to modernize some of the existing ones. This may be accomplished by implementing driving and control systems for the part and tools movements and improved control and measurement systems.

2. Aspects regarding the evaluation of rolling surfaces for reshaping

The wear of the rolling surfaces is presented in various forms (figure 1): profile and flange deformations, flattened areas, bumps, exfoliations, cracks, craters, etc. [5, 7]. These wears reduce operating safety, produce noise, wear the rails surface. As a result, the wear of the wheel-rail coupling increases. Thus, it becomes necessary to dismount the wheelset and reshape the rolling surfaces.

Figure 1. Dismounted wheelsets and aspects of the rolling surfaces’ wear.

The evaluation of the rolling surfaces' wear is done for the two wheels of the wheelset by specific instrument measurements according to the *Instruction for repair of wheelsets mounted on railway vehicles 931/1986*. The data are then synthetically presented in a measurement file [7] and are based on some conditions for wheelset replacement on the bogie. The rolling surface profile S78 (STAS 112 / 3-90) is a stabilized wear profile in contact with the rail. It is adapted to rail gauge from the CFR network. In operation, the wheel profile must be kept to the dimensions indicated in the UIC 510-2 [5] regulations.

In order to establish the data required for the reshaping, it is necessary to analyze some basic aspects concerning: the main forms of wear of the wheels rolling surfaces, the increase of the surfaces' hardness in contact (up to 45 HRC) due to the sudden heating and cooling of the wheels during the successive brakes, by deforming the flange (the normal height is $S_h = 26$ mm, but it can also reach 30 mm). This results in additional machining before the proper reshaping.

The tilt of the active flank of the flange (increasing the angle $\delta$ over $70^\circ$, figure 2) between the axis of the wheelset and the tangent in a defined point to the profile produces numerous other changes in the rolling surface, like: deformations, material flows, hardening, various damage, etc., which lead to a reduced operational safety. For assessment of the profile flange, two important dimensions are defined: flange thickness ($S_d$), admissible limit size (minimum 26 mm and admissible 24 mm), flange
A flange height $Sh$ too small may lead to an increased risk of derailment of the wheelset. Also, the flange gradient is important: $qr \leq 6.5$ mm. For the reshaping process, this dimension is 10.794 mm for the S78 CFR profile. Some other intermediate profiles [5] are used, for example: $qr = 9.5$ mm and $Sd = 30$ mm for passenger coaches, or $qr = 8.5$ mm and $Sd = 28.5$ mm for freight wagons.

The wear evaluation stages are established to assure the requirements of national and international norms [3], thus: the two widths of the wheels bandage should be equal (135 mm); the distance between the rolling circles to be 1500 mm, with admissible deviations; the minimum thickness of the bandages in the plane of the rolling circle after reshaping should be equal with minimum 35 mm; the distance between the inner faces minimum 1360 mm, the minimal width of the bandage to be at least 26 mm.

![Figure 2. The forms of the rolling profile: a - initial, b - worn, c - reshaped.](image)

![Figure 3. Measurement of $Sh$ and $Sd$ parameters of the flange after reshaping.](image)

Figure 2 shows various shapes of the rolling profile of a wheel in the three stages, thus: a - profile in the initial condition after the wheelset production according to STAS 112 / 3-90; b - the resultant profile due to the wearing process and c - reshaped profile. The dimensions of the three profiles correspond to the mentioned standard, respectively, to the data recorded in the measurement sheet by the specialized operator of the Wagons Factory Aiud.

Figure 3 shows the measuring process with a special calliper under the workshop conditions of the height and thickness of a wheel flange after reshaping.

3. Establishing the machining scheme and the cutting parameters

The machining allowances $ap$ for reshaping of the wheels profiles are determined according to the size of the surface wear. The difference between the machined surfaces of the wheels regarding the diameters of the rolling circles must not be greater than 1 mm [3, 5].

In order to accomplish the quality requirements and precision conditions of these surfaces, it is recommended that the machining (figure 4) to be done in two or more passes [6], with cutting depths specific to roughing, semi-finishing and finishing. The cutting tool performs two rectilinear movements in the directions of the X and Z axes.

The size and state of the machining allowance, the geometry and wear of the cutting tool edge, the cutting speed $v_c$ and the feed speed $v_f$ parameters influence the chip formation and detachment manner. The chips can be continuously (figure 4) and/or fragmented (figure 5).

In figure 4, a cutting tool was used for profiling, re-profiling and semi-finishing using a single tool holder with two rectangular inserts tangential mounted. This type of cutting tool ensures an effective inserts' durability during the machining of wheels of 4 to 6 wheelsets, optimal chips' formation and detachment, but at higher cost.

The values of the geometric parameters of the tool cutting edges and the physical and machinability characteristics of the processed material are important factors in the quality of the rolling surface.
Considering the available power of the electric motors in the main driving rotating motion of the wheelset, a cutting depth \( a_{p\text{max}} = 5 \ldots 10 \) mm can be chosen. Thus, it is reduced the reshaping time. Depending on the size of the machining allowance, on the shape and dimensions of the insert's cutting edges and of its degree of wear, there are situations when the processing can be done in a single pass.

**Figure 4.** Machining of the rolling surface and continuous chips formation.

**Figure 5.** Forms of fragmented chips.

Figure 6, a. shows the shape and orientation of the active part of a rectangular insert [6, 8], according to figure 4, in two successive positions corresponding to the longitudinal feed motion with the parameters feed rate \( f_L \) and cutting depth \( a_p \).

**Figure 6.** Geometric elements of the cutting edges, a) cutting parameters; b) detail of the tool's cutting edge.

The cutting tool has continuous longitudinal and radial feed motions with \( v_L \) and \( v_R \) speeds respectively on CNC controlled Z and X axes. The generatrix of the machined surface (profile c, figure 2) is geometrically defined by specific equations [5].

The insert is oriented in the tool body (figure 6, a.) at a position angle of 84\(^\circ\) [6]. In contact with the wheel surface, the insert has a main side cutting edge (approach) angle \( \Theta_r \), which determines a chip section defined by the parameters cutting depth \( a_p \) and chip thickness \( h \). The shape of the chip is also determined by the radius \( r \) of the active part of the insert's cutting edge. According to the catalogue data [8], the insert has the following dimensions: \( r = 4 \) mm, \( l = 19.05 \) mm and \( iW = 10 \) mm, values that also influence the shape of the chip and the size \( R_e \) (figure 6, b.) of the surface roughness.

The strategy and the cutting parameters for machining the rolling surface of the wheelset wheels are established according to the state of the wheel's stock, thus: castings made of steels (alloyed with C, Si, Mn, Cr, Cu, Ni, Mo, etc., having a maximum content \% specified in [3]) for new and damaged wheels with flattens, exfoliations, thermal cracks.

The materials used in manufacturing of wheels and rail in Europe are steels with pearlitic structures containing hard cementite lamellae guarantee high resistance to wear; slightly worn wheels for
which CNMX [8] rhombic inserts are recommended for finishing processings; usually, the rolling surfaces are processed in one pass, in other cases, the machining allowance is removed in several passes (2 - 3) to obtain the correct profile [1, 5, 6]. The technical processing conditions prescribed are: dimensional precision, surfaces quality, deviations on the shape and position of the curves that define the surfaces.

It is very important to analyze the state of wear of the rolling surfaces. For example, it is considered the case of a worn wheel having the profile S78. The measurement methodology, according to the data sheet prepared for each wheelset being in the Wagons Factory Aiud current manufacturing, contains numerous data established in the following steps: measuring the distance between the planes of the rolling circles (1501.7 mm), measuring the diameters of the wheels in the median planes of the rolling circles (895 mm and 896 mm), the minimum flange thickness \(S_d\) (25 mm and 26 mm, respectively) and the height of the flange \(S_h\) (30 mm, after reshaping it results in 28 mm).

For reshaping, based on the measured data, it is established a machining allowance \(a_{p_{\text{max}}} = 10\) mm. Thus, the diameters of the rolling circles on both wheels become 871 mm. For this, two or three passes are established: one for roughing \((a_{p_1} = 7\) mm\) and one for finishing \((a_{p_2} = 3\) mm\) or two for roughing \((a_{p_1} = 4.5\) mm and \(a_{p_2} = 3\) mm\) and one for finishing \((a_{p_3} = 2.5\) mm\).

4. Setting the cutting speed, spindle speed and the feed rates

To optimize the cutting speed parameter, we consider the chemical composition, the mechanical characteristics of the recommended steels, the rigidity of the technological processing system, the geometry of the active part and the effective durability of the tool.

SR EN 13262 contains four types of steel: ER6 and ER7 are the most used grades for all freight wagon wheels and on most passenger coaches. These wheels are commonly supplied with lower carbon contents (<0.55% C) which often puts them in the lower strength tolerance range. For driven wheels on locomotives and motor coaches, ER8 (<0.56% C) is increasingly the used grade. ER9 (<0.60% C) is limited to niche applications, like construction vehicles and combined transport systems. Materials used for railway wheels in Europe are largely restricted to unalloyed steels and, after an appropriate heat treatment (fine pearlitization) of the tread, they have tensile strengths of at least 820 MPa (ER7) to 980 MPa (ER8) in maximum.

The main mechanical feature of the wheels stock’s material, that defines the cutting process, is the tensile strength and, accordingly, the hardness (255 to 310 HB). Depending on this, the specific cutting resistance \(k_c\) (ER6, ER7: 2600 N/mm² and ER8, ER9: 2850 N/mm²) is set being dependent on the main parameters of the cutting regime.

These data are important for choosing the optimal cutting speed \(v_c\). Also, other parameters are taken into account, the most important being: the effective tool durability \(T_{ef}\), the cutting depth \(a_p\) and the longitudinal feed rate \(f_l\). According to [9] the calculus relation is established:

\[
v_c = C \cdot a_p^F \cdot f_l^E \cdot T_{ef}^G \cdot K_g, \text{ [m/min]}
\]

where: the constant \(C\) and the \(F, E, G\) exponents depend on the wheels material processing group, the couple of materials cutting tool - wheel, \(K_g\) - correction factor taking into account the machinability and rigidity of the technological system: machine tool - cutting tool - fixture device - part (wheel). For the effective durability, \(T_{ef} = 55\) min is considered, giving the possibility to process the rolling surfaces of a 4 - 5 wheels with normal wear, requiring 1 - 2 machining passes for each wheel.

Thus, for the processing of alloyed steels with the tensile strength \(R_m = 820 \ldots 980\) N/mm² [3] using a TopRail TRWL 50-55 TG tool with sintered metal carbide inserts with applied layers (LNMX 19 19 40-PM, grade ISO-P GC 4215) [8], there are indicated [9, 10] the following values: \(C = 168; E = -0.45; F = -0.12\) and \(G = -0.16\), which are replaced in relation (1).

We considered two examples with the most used parameters for the machining conditions: roughing \(a_p = 7\) mm; \(f_l = 3.5\) mm/rev and a value of the correction coefficient \(K_g = 0.75\). Through replacements and calculations it is obtained the value of \(v_c \approx 29.9\) m/min (figure 5). For finishing processing, the considered parameters are: \(a_p = 3\) mm; \(f_l = 1.2\) mm/rev and a correction coefficient \(K_g\)
= 0.8. By replacing in relation (1), it is obtained: \( v_c \approx 57.2 \) m/min. Considering the cases of two wheels of 630 mm and 1300 mm diameters, processed with the above parameters, the spindle speeds result: \( n_{c\_rough} = 15.11 \) rev/min, \( n_{c\_finish} = 28.9 \) rev/min and \( n_{c\_rough} = 7.3 \) rev/min, \( n_{c\_finish} = 14 \) rev/min. These values are in the range of programmable spindle speeds of the lathe: 9, 11.2, 14, 18, 22.4, 28, 35.5 rev/min. Thus, for each machining it is chosen the spindle speed nearest to the calculation result. Also, in the roughing process results a roughness value \( R_{e\_rough} \approx 0.21 \) mm and for finishing \( R_{e\_finish} \approx 0.04 \) mm (figure 6, b).

5. Conclusions
The simultaneous machining of the rolling surface of the wheels of the wheelset is processed on a specialized lathe in conditions of dimensional accuracy, of shape conformity and quality. The characteristics of the material to be machined, the surface condition and the unevenness of the machining allowance make the cutting process to produce vibrations, wear of the cutting edge and some unevenness of the surface quality. Taking into account the theoretical and experimental researches done in the frame of the project for the remanufacturing and NC equipment of the RAFAMET UBC 150 lathe, some specific data resulted for its optimal use, necessary in the running phases of this lathe. The research team has carried out a wide range of studies, proposed and applied technical solutions. Many results of these researches are published and already in use in the daily activity of the wagons factory of Aiud, Romania.

Thus, on the improvement of the cutting parameters, there are defined range values of feed, feed rate, cutting depth and cutting speed. These machining parameters can be chosen, depending on the different wear conditions of the wheels’ rolling surfaces. The cutting process is performed simultaneously on both wheels, so it needs to be examined by measurements of the initial dimensions of the worn surfaces. The data obtained are stored and analyzed, based on them being determined: the rolling surface wear condition, the machining allowance, the number of processing passes required for reshaping, the cutting parameters and the NC program. In the most cases, it is necessary to adapt the working parameters for each wheelset. This study takes into account the mechanical characteristics of the wheels’ materials, the type, inserts grade and position of the cutting tool, proposing recommendations for the parameters of the cutting process. Also, the project contains technical solutions and experimental results regarding the improvement of the technological system by remanufacturing, already proven in the use of the lathe.

Acknowledgement
The paper presents researches in the frame of Partnerships in Priority Areas Programme – PNII supported by MEN-UEFISCDI, in project PN II-PT-PCCA-2013-4-1681, Mechatronic system for measuring the wheel profile of the rail transport vehicles, in order to optimize the reshaping on CNC machine tools and increase the traffic safety, 2014 - 2017.

References
[1] Ghionea I, Ghionea A, Cioboată D, Ćuković S 2016 Lathe Machining in the Era of Industry 4.0: Remanufactured Lathe with Integrated Measurement System for CNC Generation of the Rolling Surfaces for Railway Wheels 13th IFIP WG 5.1 Int. Conf. on Prod. Lifecycle Manag. (Univ. of South Carolina, Columbia, USA) (Springer Ch. 27, Vol. 492) 296-308.
[2] Okagata Y 2016 Design Technologies for Railway Wheels and Future Prospects, (Nippon Steel & Sumitomo Metal Technical Report).
[3] SR EN 13262+A2 2011 Romanian standard, Railway Applications - Wheelsets and Bogies – Wheels, Product Requirements.
[4] UIC 812-31984 Technical Specification for the Supply of Rolled Solid Wheels of Non Alloy Steel for Traction and Rolling Stock, 5th edition.
[5] UIC 510-2 2004 Trailing Stock: Wheels and Wheelsets. Condition Concerning the Use of Wheels of Various Diameters, 4th edition.
[6] Ghionea I, Ghionea A, Predincea N 2018 Cutting Parameters and Analysis by FEA Simulation of Their Influence on the Re-Profilation of the Wheels of the Railway Wheelset Acta Technica Napocensis, Series: App. Math., Mech. and Eng. 61 I, Technical University of Cluj-Napoca, Cluj-Napoca, Romania, 73-84.

[7] Contract 250/2014, PN-II-PT-PCCA-2013-4-1681, 2015 – 2017, Scientific reports 1 – 4.

[8] Sandvik 2014 Railway Turning, Re-turning and New Wheel Turning, Application Guide.

[9] Perovic B 2006 Handbook Werkzeug-maschinen. Berechnung, Auslegung und Konstruction - Machine tools guide. Calculation and Construction (Munchen – Wien: Carl Hanser Verlag)

[10] Degner W, Lutze H, Smejkal E 2009 Spanende Formung. Theorie, Berechnung, Richtwerte. (Munchen- Wien: Carl Hanser Verlag).