Proceedings in Manufacturing Systems, Volume 10, Issue 4, 2015, 165−170 ISSN 2067-9238

CONTRIBUTIONS TO OPTIMIZATION OF PART PROGRAM IN PROCESSING AND MESUREMENT PHASES OF WHEELSET RUNNING PROFILE

Constantin SANDU[1], Adrian GHIONEA[2], Ionuţ GHIONEA[3,*], Daniela CIOBOATĂ[4]

1) Assoc. Prof., PhD, Eng., Department of Machine and Manufacturing Systems, University “Politehnica” of Bucharest, Bucharest, Romania
2) Prof., PhD, Eng., Department of Machine and Manufacturing Systems, University “Politehnica” of Bucharest, Bucharest, Romania
3) Lecturer, PhD, Eng., Department of Machine Manufacturing Technology, University “Politehnica” of Bucharest, Bucharest, Romania
4) Senior researcher, PhD. Eng, The National Institute of Research and Development in Mechatronics and Measurement Technique, Bucharest, Romania

Abstract: *The paper presents the running profile features of the railway wheels, profile representation and optimization possibilities in order to elaborate the part program for processing the wheelsets by turning. The segments of the profile, which require the analysis of the approximation error with line segments and arcs, were highlighted. For this purpose, the research focused on achieving a small number of phrases in the part NC program. The established methodology was applied to one of the standardized profiles. In the paper values of applying this optimization methodology for a curved zone of the profile are presented. The resulting data can be also useful for the system of measuring and control of the profile after processing on the machine tool. Thus, it is easily possible to determine the concordance between the resulted deviations and the allowable ones required by the standards. It is also presented a measurement system that can be integrated in the machine-tool, resulting in a closed-loop measurement and processing system.*

Key words: *railway wheel sets, turning, running profile, parametric equations, part program.*

1. INTRODUCTION

The wheelset is one of the most stressed components of the railway vehicles [1, 4], being subject of variable loads and of a continuous process of wear. The profiles were determined in kinematic and dynamic conditions of the vehicle movement. Operating conditions are variable, such as: loadings, change of the rails and of the tread surfaces profiles, speed and temperature variations, especially of the rails tracks, vibrations, etc. The tread profile of the railway vehicles wheels must fit within the geometrical characteristics governed by national and international regulations [2], being an important factor for the passengers’ comfort and decrease of the environmental impact by reducing the noise caused by the wheel-rail contact [8], according to the current standards.

The surface and profile of the railway vehicles wheels have a complex geometry that must fit within certain sizes [5, 13]. This paper proposes an applicative methodology for parametric representation of the tread profiles and surfaces respectively. The parameterized surface can be used in order to achieve digital templates for the turning process, measurement and analysis of the wheel profile.

* Corresponding author: Bucharest, Splaiul Independenţei 313, sector 6, 060042, Romania,
Tel.: 00400 722926249,
Fax: 0040 21 4029724,
E-mail addresses: *costel_sandu@yahoo.com* (C. Sandu),
adrianghionea@yahoo.com (A. Ghionea),
ionut76@hotmail.com (I. Ghionea),
cioboatadoina@yahoo.com (D. Cioboată).

It is also useful a functional model of a cutting process, measurement and analysis system of the rail wheel profile [20], on a shaping/reshaping technological system using a numerically controlled machine tool [6, 17] for wheel sets or wheels in mass production [5].

2. PROFILE PARAMETRIC EQUATIONS

Railway wheels are processed according to the railway established by international standards also adopted nationally.

The machining of the UIC/ERRI profile of the wheels is regulated by SR EN 13715 + A1-2011 [14], thus: the profile UIC/ERRI for wheel with diameter D = 1000 mm and d = 760 mm, having the flange height h = 28 mm, UIC/ERRI D = 760 mm, d = 630 mm, h = 30 mm and UIC/ERRI D = 630 mm, d = 330 mm, h = 32 mm (Fig. 1). The last profile is analyzed in the paper and it is rated according to standard as: EN 13715 -EPS / H32 / e28.5 / 10%. On the profile, there are marked the limit points delimiting its main zones and whose coordinates are essential for generating the correct profile (A1, A2, ...,F2, H1, H2) [13, 14]. Drawing and checking the profile is done based on the parametric equations (1) – (8) [13, 15].

The standard UIC 510-2 contains also a table with 261 pairs of points, with an increment of 0.5 mm on the X axis. The respective coordinates on the Y axis are given by the formula corresponding to A, …, H zones. The limit points of the profile are found among those calculated, also having a role of verifying the precision of the equation.

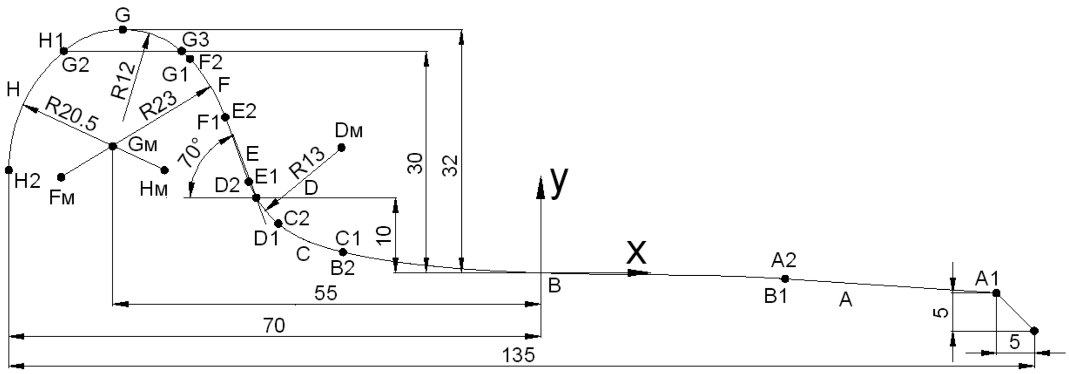

Fig. 1. Coordinates of the standard profile for wheels with a diameter between D = 630 mm and d = 330 mm.

Thus, for the wheels having the diameters D = 630 mm and d = 330 mm, the equations are (1)−(8):

Zone A $y = 1.364323640 - 0.066666667 \cdot x$, (1)

Zone B $y = 0 - 3.358537058 \cdot 10^{-2} \cdot x + 1.565681624 \cdot 10^{-3} \cdot x^2 - 2.810427944 \cdot 10^{-5} \cdot x^3 + 5.844240864 \cdot 10^{-8} \cdot x^4 - 1.562379023 \cdot 10^{-8} \cdot x^5 + 5.309217349 \cdot 10^{-15} \cdot x^6 - 5.957839843 \cdot 10^{-12} \cdot x^7 + 2.646656573 \cdot 10^{-13} \cdot x^8$, (2)

Zone C $y = -4.320221063 \cdot 10^{+3} - 1.038384026 \cdot 10^{+3} \cdot x - 1.065501873 \cdot 10^{+2} \cdot x^2 - 6.051367875 \cdot 10^{0} \cdot x^3 - 2.054332446 \cdot 10^{-1} \cdot x^4 - 4.169739389 \cdot 10^{-3} \cdot x^5 - 4.687195829 \cdot 10^{-5} \cdot x^6 - 2.252755540 \cdot 10^{-7} \cdot x^7$, (3)

Zone D $y = +16.446 - \sqrt{13^2 - (x + 26.210665)^2}$, (4)

Zone E $y = +93.576667419 - 2.747477419 \cdot x$, (5)

Zone F $y = +12.568005262 + \sqrt{23^2 - (x + 63.109590233)^2}$, (6)

Zone G $y = +20 + \sqrt{12^2 - (x + 55)^2}$, (7)

Zone H $y = +13.519259302 + \sqrt{20.5^2 - (x + 49.5)^2}$. (8)

These equations were determined by theoretical and experimental studies.

The variables that are mapping the profile have a very good accuracy up to nine decimal places, their compliance is important, being determined by satisfying the cinematic and dynamic conditions. The curves' centers that define the profile, denoted $D_M, \ldots, H_M$, are represented in Fig. 1. Their coordinates are:
D_M (x = –26.210665, y = 16.446),
F_M (x= –63.109590233, y = 12.568005260),
G_M (x = – 55, y = 20),
H_M (x = – 49.5, y = 13.519259302), in mm.

The actual standards [14], in order to check the profile, impose some validity zones:
A (x = +60 to +32.15796), B (x = +32.15796 to –26),
C (x = –26 to – 35), D (x = –35 to –38.426669071),
E (x = –38.426669071 to –41.496659950),
F (x = –41.496659950 to –46.153174292),
G (x = –46.153174292 to –62.764705882),
H (x = –62.764705882 to –70), in mm, as seen in Fig. 1.

Table 1

Coordinates of the limit points and distances between them

Zone	Points	x, [mm]	y, [mm]	Tangent angle, [^{0}]	Distance, [mm]	
O origin		0.0	0.0		Points	Value
Zone A	A1	60	–2.635676360	– 3.814		
	A2	–32.15796	–0.779540292	– 3.814	A2-B1	0.000000009
Zone B	B1	–32.15796	–0.779540302	– 3.814		
	B2	–26	2.741043365	– 13.587	B2-C1	0.009178071
Zone C	C1	–26	2.741006816	– 13.587		
	C2	–35	6.867385430	– 42.540	C2-D1	0.000036549
Zone D	D1	–35	6.867502904	– 42.540		
	D2	–38.426669071	11.999737284	– 70.000	D2-E1	0.000117474
Zone E	E1	–38.426669071	11.999738211	–70.000		
	E2	–41. 49665950	20.434468833	– 70.000	E2-F1	0.000000290
Zone F	F1	–41. 49665950	20.434468543	– 70.000		
	F2	–46.153174292	28.107630688	– 47.496	F2-G3	0.000000029
Zone G	G3	–46.153174292	28.107630658	–47.496		
	G2	–62.764705882	29.155217062	40.276	G2-H1	0.009178071
Zone H	H1	–62.764705882	29.149280987	40.320		
	H2	–70	13.51925945	90.000		

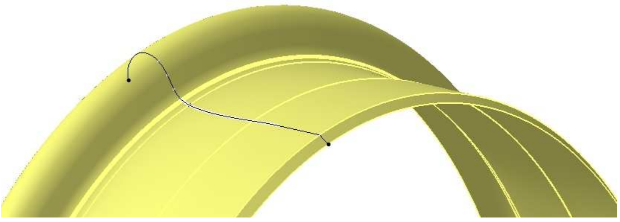

Fig. 2. Wheel surface obtained based on the parametrically drawn profile.

The limit point coordinates of the profile are also identified. These points are mandatory and will be considered in the process of establishing the part program, corresponding to the numerically controlled equipment. For the analysed case, these points coordinates are given in Table 1.

The data presented in Table 1 leads to the observed fact that where the distance is not zero it indicates a discontinuity of the analyzed profile. Later, these gaps/ discontinuities are taken into account in the elaboration of the part program.

The profile may undergo some changes as a result of the shaping/reshaping on the lathe, but it must comply with the recommendations of the limit deviations specified in UIC norms and standards [13].

The representation of the tread surface of the wheel is possible by revolving the profile around the axis of the axle, located at the coordinate y = 300 mm related to the point B in Fig. 1. The profile and surface are continuous and correct represented in Fig. 2.

There is no need to model the other elements of the wheel, the simulation of the shaping/reshaping machining and the creation of CNC code are possible based on this surface.

3. ASPECTS CONCERNING THE DEVELOPMENT AND OPTIMIZATION OF THE PART PROGRAM

Analysis of the data from Table 1 shows that there are some discontinuities at the borders between areas of the profile that must be corrected. In the phrases of the part program that is inserted into the machine-tool CNC equipment [3], the movement quotas, in mm, for the controlled axes, have a precision of only three decimal places.

To generate trajectories that more closely resembles the shape and position imposed by the engineer, it is necessary that from the set of many points of curves to choose only those that by writing in the CNC part program phrases to result deviations smaller compared with the curve defined by the engineer.

Also, another important requirement is that the length of the curve sector described in a phrase to be as large as possible. It was taken into account that most of the CNC equipment use linear and circular interpolations. For complex curves (polynomials, splines), the generation of the CNC part programs lead to the creation of the processing trajectory only of line segments and arcs.

Thus, the part programs result with a large number of phrases. These types of programs lead to large running times and to significant variations of speed while the profile contouring.

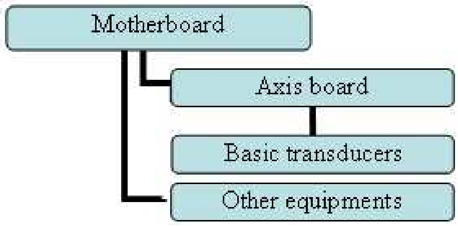

Fig. 3. CNC simplified structure.

The profile of the wheel tread surfaces consists of line segments and curves [2, 9, and 14] defined geometrically and by the position and dimensional accuracy. The profile processing is performed on specialized lathes fitted with mechanical, electrical [16], hydraulic or CNC copy (Co) systems. The CNC equipment performs many functions, among which the most important are command, control, and communication [3].

Regarding the profile processing, it is done by part programs (Pp). The analyzed profile is defined in a plane containing the rotation axis of the axle. The profile is processed by rectilinear movements on two axes directions, numerically controlled, with defined speeds. The profile is processed by the interpolation of the Z and Y axes of the CNC lathe. The Z axis, respectively, the X axis of the lathe are considered to become X axis, respectively, Y axis in the equations (1) – (8) to define the profile (Fig. 1).

The CNC simplified structure is represented in Fig. 3 which shows the basic composing elements. These elements are important for what is presented in the paper.

The CNC motherboard with its processor realizes screens, functions F1, ..., F8, part drawing, processing simulation, editing, communications and warning messages about the program running and machine-tool behavior.

The phrases of the part program are transmitted for execution to the axis board for movement purpose, indicated by the current phrase and a number of phrases in anticipation.

The processor transmits the movement parameters to the electric motors of the CNC axes. For this, there is an axes board that contains a number of slave type processors. Some of them are activated corresponding to the controlled axes. To each slave type processor a transducer is connected for the axis position.

By the previous phrase of the current phrase is set the initial point of the running trajectory. By the current phrase there are indicated the following data: the end point of the trajectory, trajectory type (G1 linear, G2 and G3 – circular) and some other known data (S, F, I, J, R, F, G, etc.).

The internal program of the axes board determines a number of intermediary points on the trajectory. During the trajectory execution to achieve these points, there are determined the running errors, corrected if possible, up to the next point on the curve.

Also, for completing the trajectory, in the CNC parameters there are defined: acceleration, deceleration and the error to achieve the target point.

Functions defined in the part program indicate if the target point specified in the phrase is reached exactly or not. If yes, the trajectory described in the current phrase is executed with high accuracy, by an accelerated start from the initial point until the feed speed (F) value is achieved. Near the target point, the deceleration of the movement begins for achieving with accuracy the point.

If the touch function is inaccurate, the endpoint speed is not zero and the program goes to the next phrase. The start speed on the next trajectory, which becomes the current trajectory, is final of the deceleration period.

The real time of execution the trajectory described from the start and the end point will be higher than the ratio between the distance between the two points and the feed speed *F*. As a result, when the number of phrases that describe the movement on trajectory is large, the difference between the real time and scheduled time is correspondingly higher. It is important that the part program to contain a minimum number of phrases.

Therefore, it is necessary that the generated trajectory to be described by linear and circular interpolation phrases with initial and final points more distanced. The part programs for spatial surfaces lead to a large number of phrases with small distances between points and with errors from the surface to be processed.

The optimization of the running trajectory is done through phrases of type G1, G2 and G3 with large distances between the initial and the final points. Phrases of type G2 or G3 are specific to the movements on circular curves with arc lengths that are large as well.

Another requirement is the achievement accuracy of the measured trajectories on each CNC axis. Usually, it is limited to three or four decimal places. Because of this, the end values of linear or circular trajectories must be precisely determined by this order of magnitude.

In the considered case of the profile generation of train wheels, the profile consists of line segments, arcs, but also of two trajectories described by polynomials of the eighth order. A polygonal trajectory is required to be precisely followed, and for another one larger deviation is allowed.

In fact, by various reasons, some indicated in the literature [3], the exact generation is not possible and permissible deviations are specified.

Thus, to achieve the precision requirements it is necessary to transform the polynomial function of the eighth order in a series of replacement functions G1 (line) and G2 or G3 (arc), while keeping the continuity expressed by the common tangent line to the endpoints of the different areas of the replacement functions.

Zone *C* will be taken as an example in order to better understand the part program optimization. A polynomial curve of the eighth order defines the zone *C* profile. To highlight how the optimizing part program is done, it is considered the zone *C* example, where the profile is defined by a polynomial function of the eighth order.

Usually, the first degree and second degree (only arcs) curves are interpolated in the CNC equipment. Other curve types on the trajectory are approximated with lines or arcs, while fulfilling the conditions of continuity and tangency with adjacent curves.

The standard UIC 510-2 OR [13] also includes tables with 260 discrete point coordinates of the wheel profile to be processed. The part program can be developed by

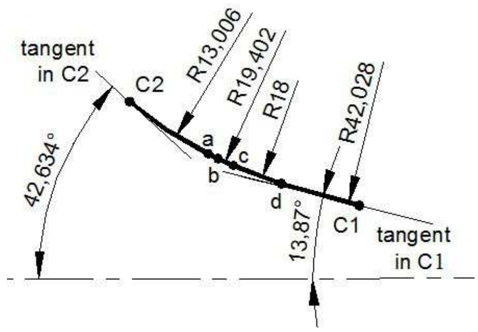

Fig. 4. Function replacement in zone *C* of the profile.

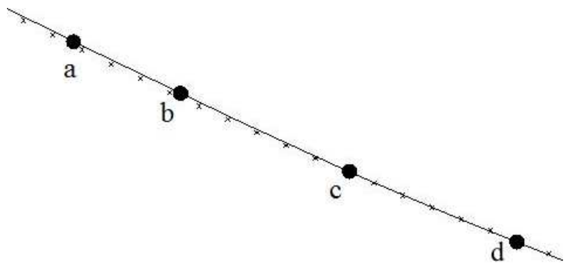

Fig. 5. Detail of zone *C* of the profile.

using those coordinates thanks to line segments from point to point. This results in 259 part program phrases.

The same condition of continuity and tangency with the curve of zone *B* and zone *D*, respectively, is applied in points *C*1 and *C*2 (Fig. 4).

A drawback of this solution is that the processing profile time is higher than the ratio between the length of the processing path and the feed rate trajectory.

Another drawback is that since acceleration and deceleration are necessary for each of the 259 line segments, the speed on the path fluctuates; moreover, it may not be even reachable as programmed by F.

Therefore, the optimization of the processing path time has to be done by the decomposition of polynomials of the eighth order into several line segments and arcs called replacement curves.

For Zone *C*, those segments are arcs *C*1-*d*, *d*-*c*, *c*-*b*, *a*-*C*2, while *b*-*a* is a line segment. This is repeated for zone *B* of the profile. Zones *A*, *D*, E, *F*, *G*, *H* are defined by their equations as line segments or arcs.

Figures 4 and 5 show a polynomial curve of the eighth order (zone *C*) that is marked by × between points *C*1 and *C*2 (Fig. 5).

The tangent lines in points *C*1 and *C*2 are shared with the adjacent curves to the wheel profile. The polynomial curve zone *C*, located between points *C*1(*x*1, *y*1) and *C*2(*x*2, *y*2) is of polynomial type.

For CNC, the points become *C*1 (*Z*1, *X*1) and *C*2 (*Z*2, *X*2). Z and *X* are axes of the CNC lathe.

Usually, in order to run the trajectory made up of $n-1$ line segments, corresponding to *n* points on the trajectory, the phrases are as follows:

```
. . .
G1 Z1 X1 Ff
G1 Z2 X2
. . .
G1 Zn Xn
. . .
```

Zone *C* is meshed (by choice) in this case by 90 points, namely: (–35, 6.86738539); (–34.9, 6.77657890); ... (–26.1, 2.76528192); (–2, 2.74100733).

The part program phrases for those points, become:

G1 Z–35. X6.867 F0.6
G1 Z–34.9 X6.776
. . .
G1 Z–26.1 X2.765
G1 Z–26. X2.741

The practical implementation of the methodology of replacing the polynomial curves by arcs and line segments led to writing only six command phrases, corresponding to arcs *C*1-*d*, *d*-*c*, *c*-*b*, *a*-*C*2 and line segments *b*-*a* (Fig. 5).

The part program phrases are as follows:

G1 Z–35. X6.867 F0.6
G2 Z–28.535 X3.536 R42.028
G2 Z–30.357 X4.224 R18.0
G2 Z–30.953 X4.49 R19.402
G1 Z–31.301 X6.867
G2 Z–26. X2.741 R13.006

4. MANUFACTURING AND MEASUREMENT SYSTEM STRUCTURE

The methods for measuring the profile include mechanical devices (Fig. 6), contact [11] or contactless portable mechatronic devices (Fig. 7). All these devices are able to determine the geometrical characteristics of the profiles defined in the national and international normative.

A few years ago, usually, the design and processing of profiles of train wheels were done manually, based on the wear analysis and experience of designers and manufacturer [12]. Today, the progress in IT has made possible the use of numerical methods in the design and processing of the wheel profile. In these circumstances, the systems for shaped/reshaped wheels profile measurement and validation must be updated and adapted to the specific numerical control machine tools.

Thus, it must be used a measuring equipment mounted on the machine-tool, which enables to measure the wheel's profile before processing, comparing it with a digital template. The purpose is to choose the optimal profile to be processed and measure the profile after processing for validating its conformity.

In Fig. 9 it is presented such a measurement system, designed to be mounted on radial sledge of the lathe with two working stations [7].

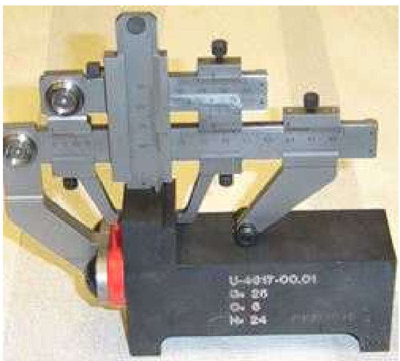

Fig. 6. Mechanical measurement.

Fig. 7. Portable device for contactless measurement.

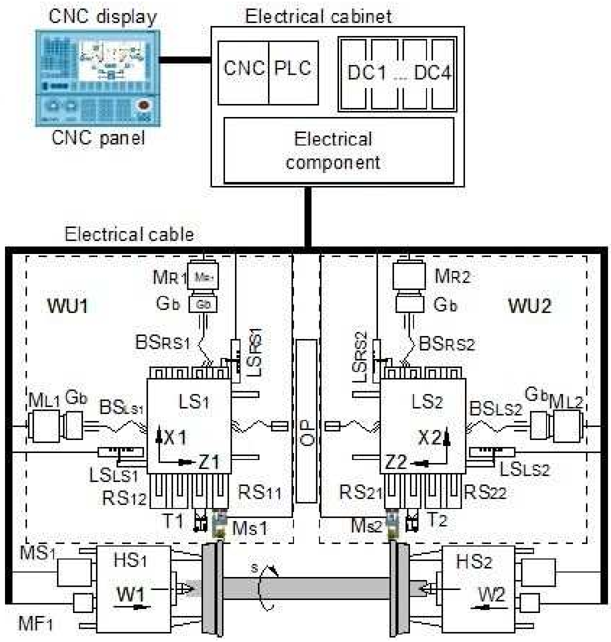

Fig. 8. The structure of mechatronic system for processing and measurement wheels profile (*MP*1, *MP*2 – spindle motor; *MF*1, *MF*2 – feed motor; *HS*1, *HS*2 – head stock; *WU*1, *WU*2 – working units *T*1, *T*2 – tool; M_{R1}, M_{R2} – motor for radial slide movements; M_{L1}, M_{L2} – motor for longitudinal sledge movements; R_{S11}, R_{S12}, R_{S21}, R_{S22} – radial slides; L_{S1}, L_{S2} – longitudinal slides; LS_{LS1}, LS_{LS2} – longitudinal positional measurement; LS_{RS1}, LS_{RS2} – radial positional measurement; *Gb* – gearbox; BS_{LS1}, BS_{LS2} – ball screws for radial slide; BS_{RS1}, BS_{RS2} – ball screws for longitudinal slide).

The structure of the closed loop measuring and processing system with CNC is shown in Fig. 8.

The machine tool evaluates a blank profile, comparing it with the given profile and profile measured after processing to validate its conformity.

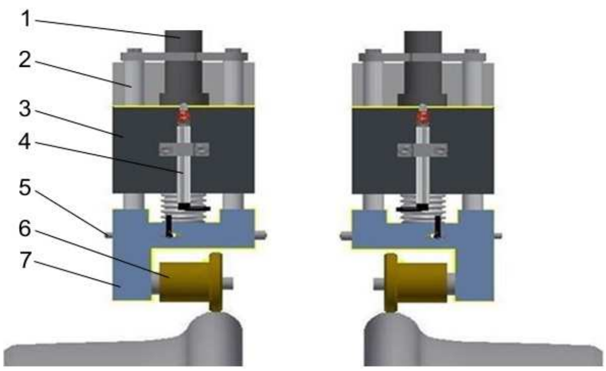

Fig. 9. Measuring the wheelset profiles.

The components of the system in Fig. 9 are: 1 – pneumatic cylinder, 2 – guiding columns, 3 – body of the measuring system, 4 – measurement transducer for the radial profile, 5 – two way transducer for frontal measurements, 6 – roll probing profile, 7 – roller and transducer support for the measuring probe.

A system of this type is adapted on each radial slide R_S where is also placed the cutting tool T [10, 18 and 19] (Fig. 8), that has different shapes and fields of application.

5. CONCLUSIONS

The analysis presented in this paper is a part of the authors research results achieved in the second phase of the project PN II-PT-PCCA-2013-4-1681.

In order to optimize the preliminary steps for processing the part program, it is proposed the replacement of some profile's zones by line segments and arcs. The profile and the wheels tread were drawn using parametric equations according to standards.

The paper exemplifies how this was done for the zone *C* of the profile. As a result, there was observed a reduction of the number of phrases, from 89 to 6 in the part program. Also, it was considered the requirement that the replacing curves should accomplish the continuity and tangency conditions. The other zones of the profile, according to the equations, are defined by line and arc segments. For the evaluation by measuring of the profile points and zones, there were used specific methodologies and tools.

The paper proposes, also, a basic structure of a measuring mechatronic system in order to be used in the profile evaluation after the processing on the machine-tool, versus the theoretic drawn profile.

ACKNOWLEDGEMENTS: This technological system is being developed under Partnerships in Priority Areas Programme - PNII supported by MEN-UEFISCDI, in the 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*.

The work of Ghionea Ionuţ has been supported by the Sectorial Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/138963.

REFERENCES

[1] T. Mazilu, M. Dumitriu, *Manufacturing technology and repair of railway rolling stock*, Matrix Rom, Bucharest, 2013.

[2] R. Talambă, M. Stoica, *The wheelset* (*Osia montată*). Editura ASAB, Bucureşti, 2005.

[3] H. B. Kief, H. A. Roschiwal, *CNC-Handbuch*, Carl Hanser Verlag GmbH & Co. KG, Germany, DOI: 10.3139/9783446437180, 2013.

[4] I. Sebeşan, Cr. Tudorache. *Dynamics of the railway vehicles. Study of the wheel-rail contact. Applications* (*Dinamica vehiculelor de cale ferată. Studiul contactului roata-sina. Aplicaţii*), Matrix Rom, Bucharest, 2014.

[5] I.Y. Shevtsov, *Wheel/Rail Interface Optimisation*, Delft University of Technology, The Netherlandes, 2008.

[6] A. Ghionea, I. Ghionea, D. Cioboată, M. Savu, *Preliminary Considerations Regarding Modernization of the Driving, CNC Control and Measurement Systems of a Lathe Model UBC 150 RAFAMET*, International Multidisciplinary Conference, Baia Mare – Nyiregyhaza Romania-Hungary, Bessenyei Publishing House Nyiregyháza, 11th Edition, 20–22 May, 2015, pp. 65–72.

[7] D. Cioboată, A. Abălaru, D. Stanciu, Cr. Logofătu, I. Ghionea, S. Szekely, *Technolgical system for profiling/reprofiling railway wheelset*. The Romanian Precision Mechanics, Optics&Mechatronics, No. 47, 2015, pp. 79−85.

[8] S. Zakharov, V. Bogdanov, et al., *Problems of wheel and rail profiles selection and optimization*, Proceedings of 7th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2006), Brisbane, Australia, 24–26 September, 2006, pp. 697–703.

[9] I. Sebeşan, *About the synthesis of the rolling surfaces profiles of the railway vehicles wheels*. The 7th IFToMM (Vol. 4) International Symposium on Linkages and Computer Aided Design Methods, Theory and Practice of Mechanisms, SYROM'97, in TCMM, Vol. 30, Technical Publishing House, Bucharest, Romania, 26–30 August, 1997, pp. 195–200.

[10] T. Mikolajczyk, *Mechatronics Tools for Turning*, Applied Mechanics and Materials 783, August 2015, pp. 115–125, DOI: 10.4028/www.scientific.net/AMM.783.115.

[11] Z. F. Zhang, Z. Gao, Y. Y. Liu, F. C. Jiang, Y. L. Yang, Y. F. Ren, H. J. Yang, K. Yang, X. D. Zhang, *Computer Vision Based Method and System for Online, Measurement of Geometric Parameters of Train Wheel Sets*, Sensors Journal, 2012, 12, pp.334–346, www.mdpi.com/journal/sensors.

[12] J. Santamaria, J. Herreros, E. G. Vadillo, N. Correa, *Design of an optimised wheel profile for rail vehicles operating on two track gauges, Vehicle System Dynamics*, Vol. 51, 2013, pp. 54–73.

[13] *** UIC 510–2 OR *Trailing stock-wheels and wheelsets. Conditions concerning the use of wheels of various diameters*, 4th edition, May 2004.

[14] *** SR EN 13715+A1:2011 Romanian standard, *Railway applications − Wheelsets and bogies − Wheels – Tread profile*.

[15] *** SR EN 13262+A2:2011, *Railway applications and bogies. Wheels. Product Requirements*.

[16] *** *Technical instructions for function of the lathe UBC 150 (Instructiuni tehnice de functionare a strungului, model UBC*150, Rafamet-Kuzina Raciborsc, Poland, 1978.

[17] *** Contract 250/2014, Project PN-II-PT-PCCA-2013-4-1681, *Phase I Report. Studies and analyzes on technological system of profiling / reprofiling and measurement of railway wheels processed surfaces.* (*Raport Etapa I. Studii şi analize privind sistemul tehnologic de profilare / reprofilare si măsurare a suprafeţelor prelucrate ale roţilor de tren*), 2014.

[18] ***, *ISCAR's Machining Solutions for Railroad Car Wheels Re-Turning*, 2014, available at: http://www.iscar.com, accessed: 21.09.2015.

[19] ***, Technical Guide. Turning-Milling-Drilling-Boring-Toolholding. Sandvik Coromant, 201, C–2900:7, ENG/01: available at: http://www.sandvik.coromant.com, accessed: 16.08.2015.

[20] ***, APTA PR-M-S-017-06, Standard for Definition and Measurement of Wheel Tread Taper, 2007, Apta Press Task Force, www.apta.com.../standards.../APTA-PR-M-S-0.