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# NC PARAMETERIZATION IN RAIL WHEEL SET RE-PROFILING MACHINING

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***Abstract:*** *The paper deals with Computer Aided Manufacturing (CAM) in the processing by turning on a lathe machine tool type, which is subject to a process of remanufacturing. The feed drives of the lathe are redesigned being associated with numerical control equipment. Moreover, on the machine tool is adapted a specific measurement system. The paper presents the most common defects and necessity of reshaping the wheel, which have suffered a process of wear, by turning on specialized machines. The paper presents a methodology and a case study for parameterization of a NC program for automation of a re-profiling turning process for a rail wheel set. The NC parameters are defined based on the nominal profile and the real damaged profile. The algorithm calculates the machining offset, depth of cut and number of passes based on the coordinates of the measured points.*

***Key words:*** *Rail Wheel, Defects, Re-profiling, Turning, NC Parameterization.*

## 1. INTRODUCTION

Rail wheel is a type of wheel specially designed for use on rail tracks. A rolling component is typically pressed onto an axle and mounted directly on a rail car or locomotive or indirectly on a bogie. Wheels are cast or forged (wrought) and are heat-treated to have a specific hardness. New wheels are trued, using a lathe, to a specific profile before being pressed onto an axle. All wheel profiles need to be periodically monitored to ensure proper wheel-rail interface [1].

A rail wheel is usually made from steel, and is typically heated for remaining firmly as it shrinks and cools [2].

Depending on the destination (train, tram, metro) and also on different countries there are different types of rail wheel profiles.

The wheels are the most loaded components of railway vehicles. Due to intensive hard work condition, different type of defects can occur in the wheels. Defective wheels can cause damage to both the track and the vehicle or can lead to derailment.

The types of defects of the wheel of the railway vehicles are shown in Fig. 1 [1, 3, 4 and 5]:

Thermal cracks (Fig. 1,*b*) are the result of alternating heating and cooling of the wheel tread and rim area, and originate from metallurgical changes in the wheel material. Thermal cracks are the most severe form of wheel defects.

Rolling contact fatigue (Fig. 1,*a*) are caused by repeated contact stress during the rolling motion.

Subsurface fatigue initiate from metallurgical defects in the wheel. The cracks generally develop 3 to 25 mm below the tread surface in the region of maximum shear stress in the wheel/rail contact area.

Fatigue cracks generally originate from a defect in the wheel.

Spalling or shelled tread (Fig. 1,*c*, *e*) occur when pieces of metal break out of the tread surface in several places more or less continuously around the tread circumference.

Skidded wheels (Fig. 1,*f*) occur when a wheel *locks up* while the vehicle is moving.

Arise (Fig. 1,*d*) is formed when flange metal has rolled towards the tip of the flange causing a step with a sharp point at the flange tip.

A flange is considered to be steep when the flange face angle in this area is 5 degrees or less to the vertical.

Damaged wheels generally occur on the wheel web and can result in a fatigue crack, which propagates circumferentially around the web, or in an impact with a foreign object.

Some of railways defects can be remediated through reshaping the profile by turning.

This type of defect correction (turning) will change some geometrical parameters of the wheel such as diameters and rim thickness [5].

A rail vehicle cannot remain in service if it has a wheel rim thickness less than the limits specified below:

- freight vehicles up to 25 tons axle load − 20 mm;
- freight vehicles over 25 tons axle load − 22 mm;
- passenger vehicles − 25 mm;
- locomotives − 22 mm; locomotive wheel rim thickness are imposed by bogie component distances, such as gearboxes, above the rolling stock outline.

The railway wheel profiles are based on directive 2008/57/CE. The classification and indication of the geometric parameter limits for the railway vehicle wheels are indicated by EN 15313 standard [6, 14].

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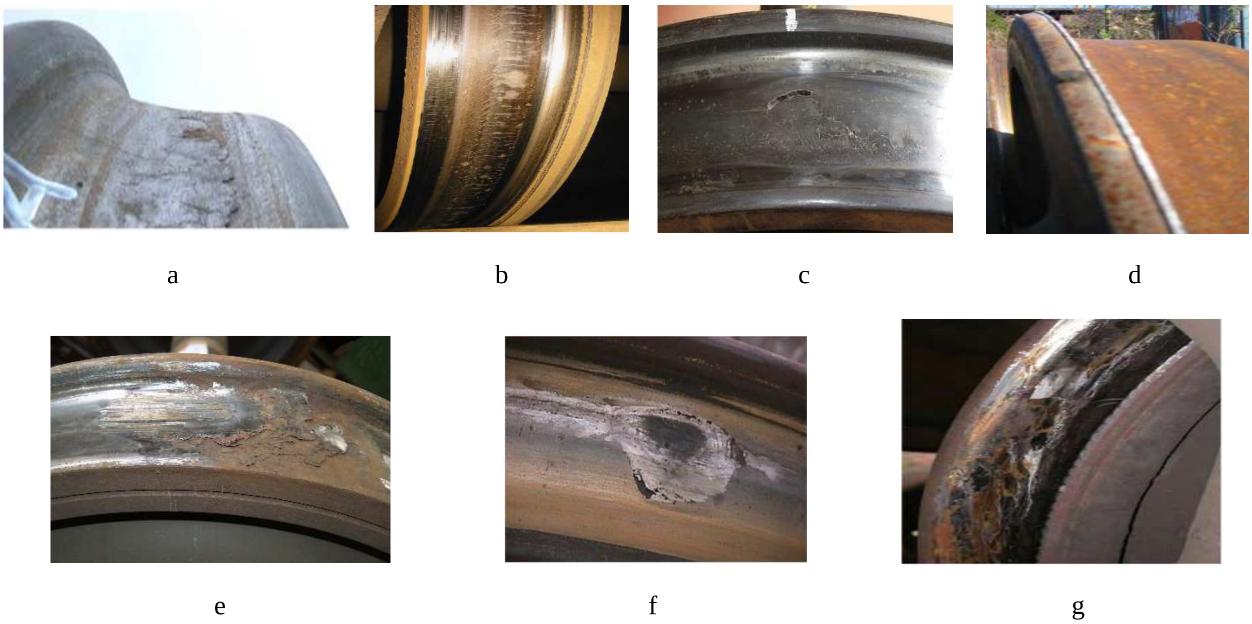



**Fig. 1.** Wheel ser defects: *a* – slight hollow wear and some fatigue cracking [2]; *b* − thermal cracks [1]; *c* – shell [3]; *d* – arise [4]; *e* − spalling or shelled tread [4]; *f* − skidded wheels [4]; *g* − scaled wheel [4].

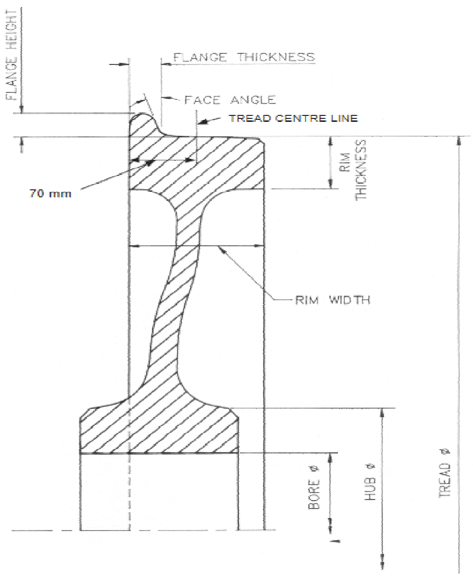



**Fig. 2.** Location of limiting dimension [5].

On locomotives, locomotive hauled passenger cars and multiple unit rolling stock, the diameter variations on wheels should be in accordance with directive 2008/57/CE, but they should not exceed the limits in dot points 2 and 3 (Fig. 2) [2].

## 2. ALGORITHM FOR TURNING PROCEDURE PARAMETERIZATION OF RAILWAY WHEELS PROFILE

Machining and re-machining of the rail wheels profiles in order to eliminate the defects due to hard work conditions involve a series of constraints imposed by actual Standards.

In this paper we proposed an algorithm for turning machining of the rail wheels profiles on a NC dedicated machine tool. There are several aspects which have to be taken into account.

1. There are several types of profile based on EU standards as (UIC D760, UICORE 1000 760 UICORE 630 330) etc. [6].
2. The cutting tool inserts can have different profiles as circular or rectangular inserts. In Table 1 a few aspects considering recommendation for depth of cut in turning process for rectangular and circular inserts are presented [4].

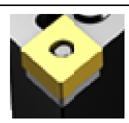
   For the depth of cut it was established the fallowing relation:

$$a_p = T * c1 + c2, \quad (1)$$

   where: $T$ – total depth of cut established by the operator; $c1$ − depth coefficient of each cut; $c2$ − coefficient for depth of cut established by machine state based on dynamic machine behaviour [4, 12].
3. The measuring points are important for automated measurement system [13, 15], but at the same time the decision should be of the operator due to variety of defects types. In Fig. 3, a schema for theoretical profile of a rail wheel based on US patent US 7669906 B2 [7] is presented.

*Table 1*

**Coefficient selection [3]**

| No | Tool insert type | T [mm] | C1 |
|---|---|---|---|
| 1 |  | 11-15 | 0.3 |
| 2 | | 6-10 | 0.5 |
| 3 | | <=5 | 1 |
| 4 |  | 11-15 | 0.2 |
| 5 | | 6-10 | 0.3 |
| 6 | | 2-5 | 0.5 |
| 7 | | <=2 | 1 |

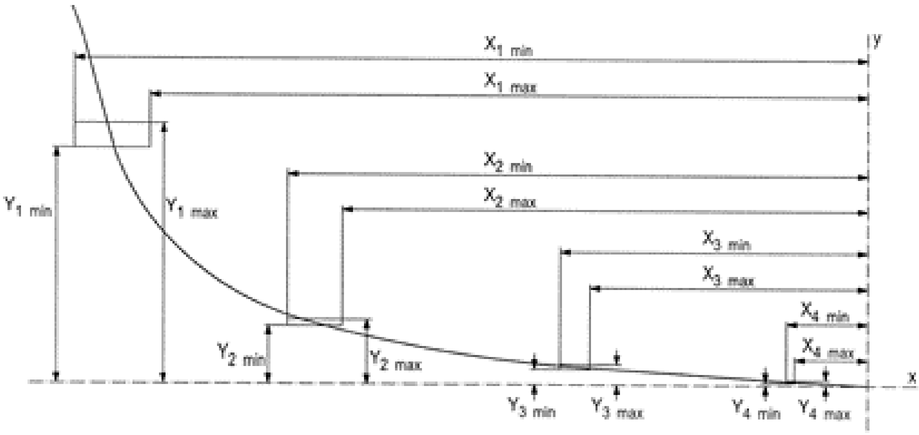



**Fig. 3.** Rail wheel profile important dimensions.

A general schema for the machining application is presented in Fig. 4.

The machining systems is a complex one composed of special turning machine, measuring systems which will generate input data to the NC algorithm, machine controller type which will define the programming NC language, a data base with rail wheel profile theoretical dimension values, mathematical algorithm for calculation of the final rail wheels re-machine dimensions, a cutting tool library defined based on insert and body dimension and of the established cutting parameters.

Based on this information, the system will generate automatically the NC file needed for machining [10, 11].

From the point of view of profile definition, in NC file two ways can be met:

1. The profile is defined through points as results of equation system calculation (Fig. 5). The result is a more accurate profile, while the NC file has more points and the tool movement is linear interpolation.
2. Approximation of the profile is done through circle arcs (Fig. 6). The resulted profile is less accurate than the theoretical profile, while having fewer lines in the NC file. The tool movement is made in both linear and circular interpolation.

In order to achieve the best quality, the algorithm was made for profile defining through points.

The profile point coordinates are obtained based on theoretical profile such that to take into account cutting tool radius compensation in the NC file. The tool radius compensation codes G41 and G42 are used for the NC controller based on G code as in Fanuc or Sinumerik [8].

Since on the machine a wheel set (pair of wheels) is processed, from the point of view of NC, two different trajectories (left and right) are considered (Fig. 7), so that the controller should be able to run in the same time both files. On the right side, the compensation is done by G41 and on the left side by G42 [9].

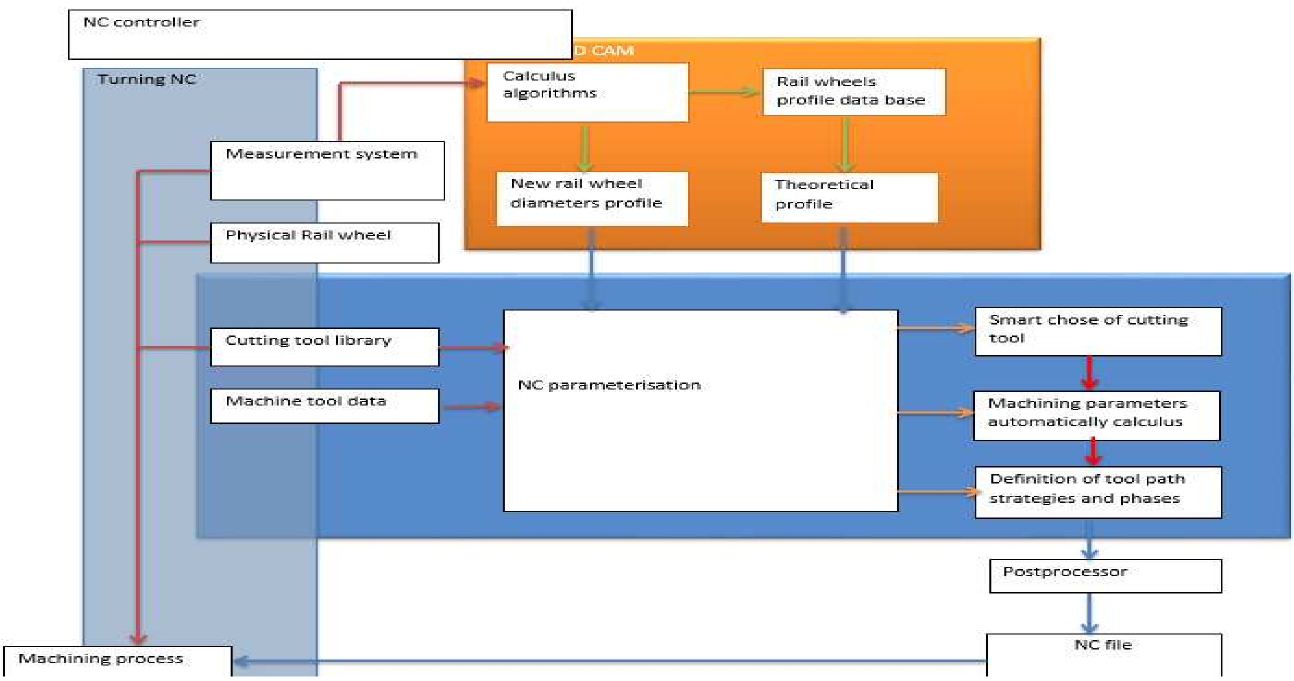



**Fig. 4.** Schema for the machining application.

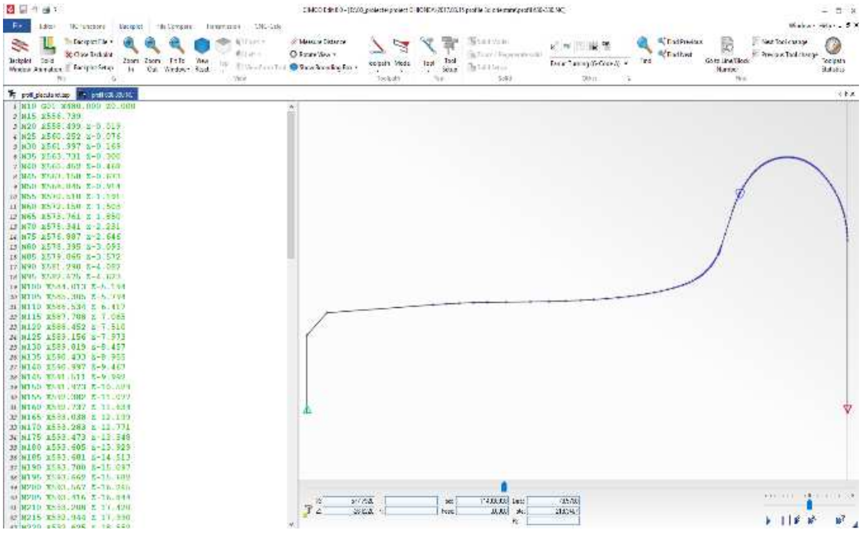


**Fig. 5.** Profile through points.

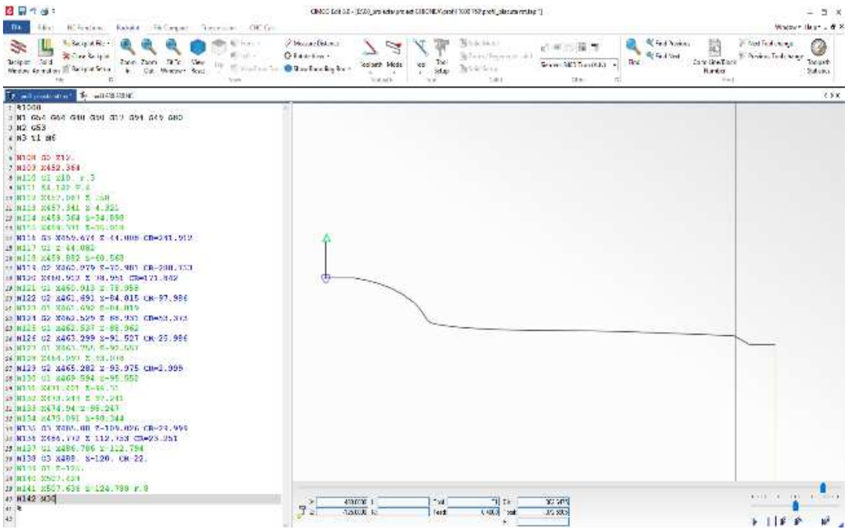


**Fig. 6.** Profile through arcs.

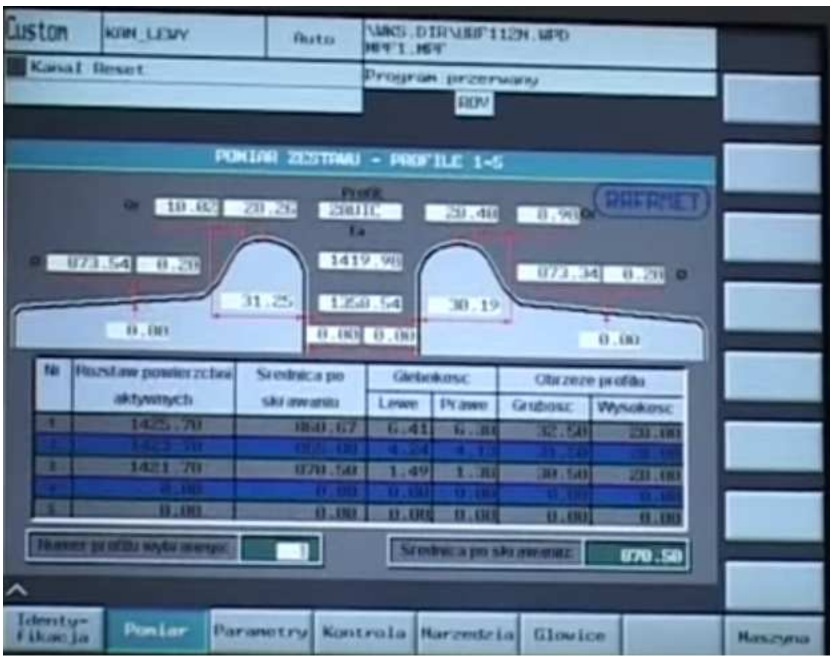


**Fig. 7.** Machining set up.

## 3. NC PARAMETERIZATION FOR MACHINING THE ROLLING SURFACE OF RAILWAY WHEELS

The algorithm will include a set of parameters in order to define the total depth of cut, depth of cut and also some iterative parameters for calculation.

A general logical schema for application in NC programs is presented in Fig. 8.

Based on this schema, a parametric NC application was developed for Fanuc controller as follows:

A set of variables was defined for measuring points (5 points #501 #502 #503 #504 and #505) in order to define the diameter of the real rail wheel.

The values of these parameters are read by the measuring system. Based on this and the type of defects, the operator decides the total depth of cut (*T*) and depth of cut (*Ap*).

Also, in NC file the parameter #700 memorizes the limit of the wheel remaining diameter. For safety reasons, if the machining process is done below this diameter, the program stops and the wheel cannot be recovered. On the real wheel, this diameter is marked by a groove (Fig. 9).

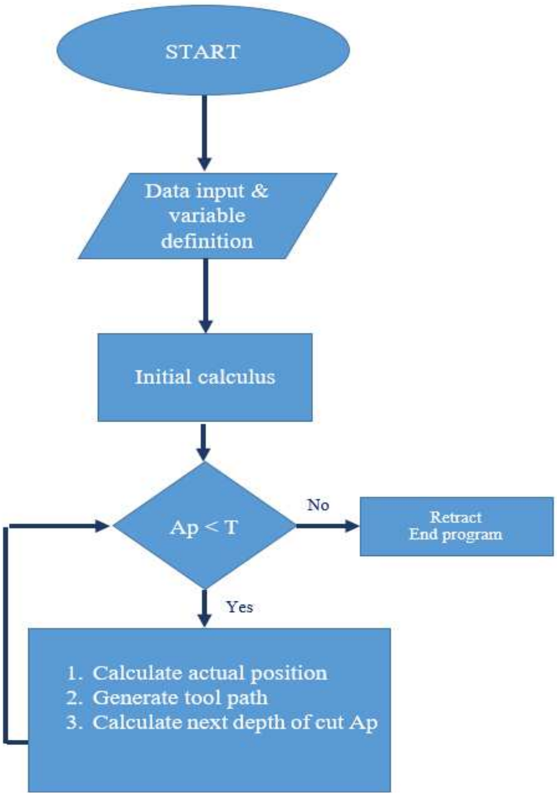



**Fig. 8.** Logical schema.

**Fig. 9.** Wheel safety groove.

For a Fanuc controller, the fallowing variables were defined:

#500 (real diameter of the wheel);

#600 (nominal diameter of the wheel based on type of wheel);

#700 (safety groove diameter);

#400 (diameter offset based on difference between real and nominal wheel diameter);

#110 No of passes – operator input;

#120 total depth – operator input;

#125 depth of cut;

#126 current depth of cut;

#130 current position in Z;

#101 final position.

The first condition is to check if after machining the diameter of the wheel is under the safety diameter (grove diameter). In NC file, the minimum diameter is calculated with the following relation:

$$\#130 = \#500 - \#126. \quad (1)$$

The condition is

$$\text{IF [\#130 LE \#700] GOTO 2,} \quad (2)$$

where 2 is the label of the end program line N2 M30.

Initial calculus is based on the fallowing relation:

$$\#400 = \#600 - \#500. \quad (3)$$

The offset diameter related to the nominal diameter is used for calculating each cutting point coordinates of the NC file.

$$\#125 = \#120 / \#110. \quad (4)$$

The depth of cut is calculated automatically by the Eq. (3). For further version of the NC file for this calculus the cutting toll geometry will be taken into account. In this stage, a circular insert was considered for machining.

This variable is a constant in the NC file and represents the increment for each step of calculation.

The current depth of cut is calculated with relation (4)

$$\#126 = \#126 + \#125. \quad (5)$$

The initial depth of cut #126 is the same with the depth of cut #125.

The condition of machining process for each step is that the actual depth of cut #126 is lower than the total depth of cut #120:

$$\text{IF [\#126 GT \#120] GOTO2.} \quad 6)$$

The current position of the cutting tool on diameter is calculated by relation (6)

$$\#130 = Z_i - \#126 - \#400, \quad i = 1...112, \quad (7)$$

where $Z_i$ represents the coordinate of nominal diameter in each point of the profile.

The calculus program algorithm is presented in Fig. 10.

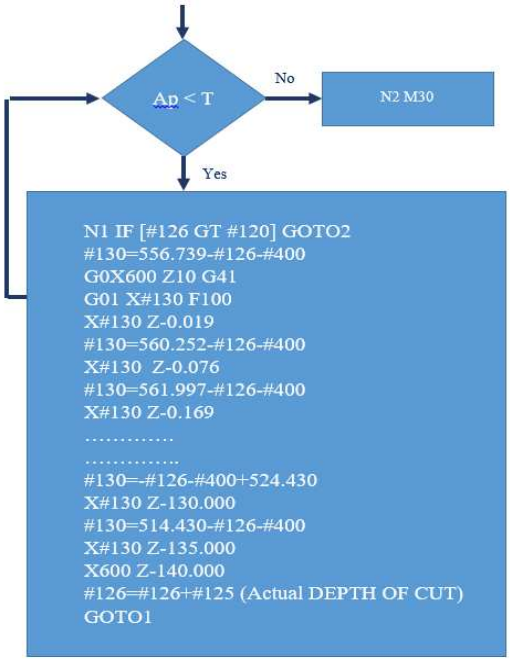



**Fig. 10.** Program algorithm.

Based on relations 1−6, the NC program was generated using CIMCO software. This software allows defining and running parametric NC programs for the most common controllers like Fanuc, Sinumerik, and Heidenhein. In this way, the best solution can be achieved for the optimal NC program for re-machining of the rail wheel.

In Fig. 11, the tool path generated for a Fanuc controller in Cimco Edit by a parametric NC file is presented.

It was taken into account the nominal diameter for the profile Uicore 630-330, real measured diameter for a rail wheel, total depth of cut and depth of cut established by the NC operator.

It can be observed that in NC file besides the cutting points and cutting tool path, rapid retract trajectory was defined in order to avoid any collision.

The cutting points were generated based on the CAD model developed in CATIA using parametric Eq. (13).

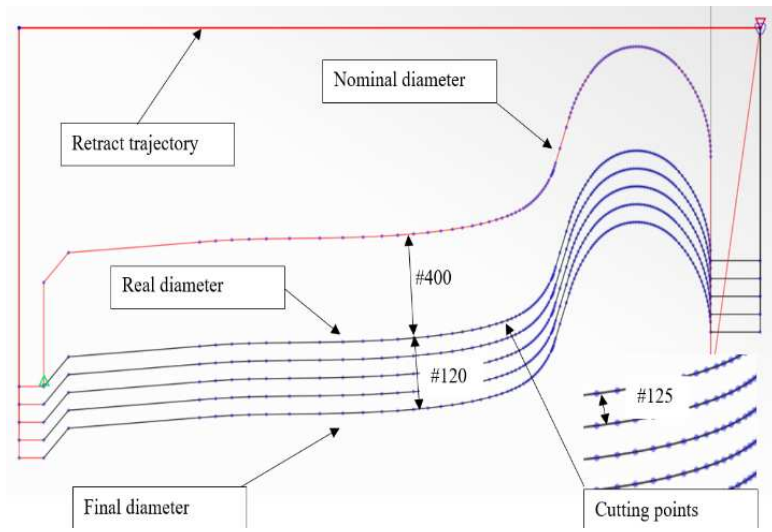



**Fig. 11.** CIMCO study case for UICORE 630-330.

The task flow of implementing the accurate profile in NC file is the following (Fig. 12):

- generate CAD model;
- extract profile of the wheel;
- export it in dxf format;
- import in CIMCO CALC software;
- generate NC coordinates.

The next step is to add the parameterization algorithm around the set of coordinate obtained in step 6 and simulate the results for validation.

## 4. CONCLUSIONS

Today, the CAD-CAM software is advanced and can solve complex 2D and 3D models.

The latest machine tool controllers allow complex parameterization of the NC file direct on the machine.

In many ways, Macro Programming is the highest level of G-code Programming. It offers the most flexibility and the greatest potential power of any of the G-Code Programming Techniques. Without Macro Programming, G-Code is not really a full-fledged computer language, being more a recording of a series of manual steps. That is useful, but computers and CNC controllers are capable of much more.

You may have noticed that different companies often develop the CNC Controller according to an actual machine tool. In fact, this is nearly always the case. There is a collection of settings inside the controller that are called *parameters* used to perform that configuration of the controller to the machine tool. For example, the travels, spindle speed range, rapid traverse rate, and many other types of information that is critical to make the control working right with the machine.

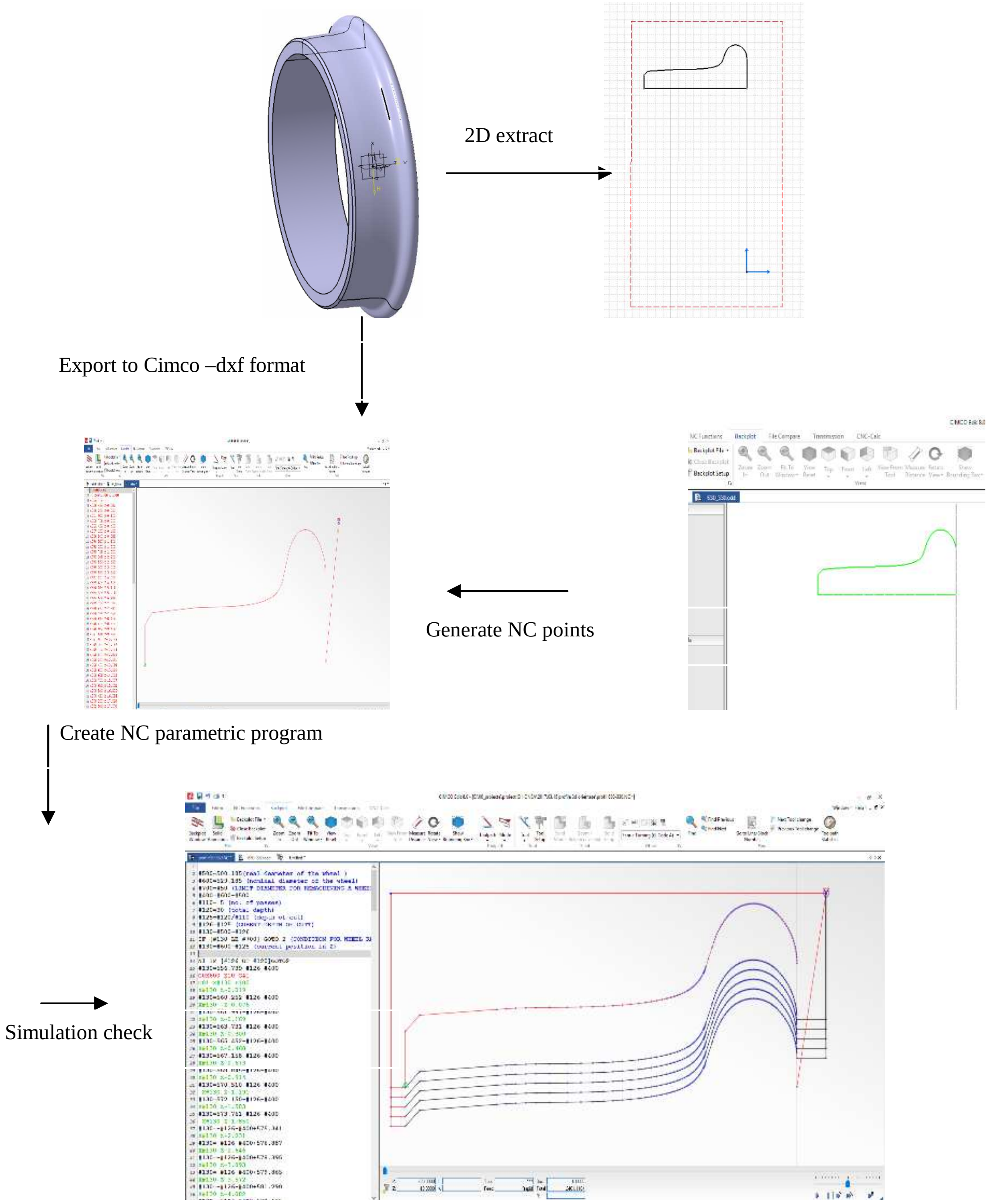



**Fig. 12.** Application flow for profile Unicore 630-330.

The paper analyses the importance of the profile shape and the rolling surface quality of the railway vehicle wheels in accordance with the Standard regulations in the field.

The parametric drawing methodology of the wheel profile allows improving the shaping/reshaping NC file for the cutting process on a specialized machine tool.

Applicative algorithm and methodology for parameterization the machining process of the rolling surface of railway wheels aim to improve the operating behaviour of the wheel-rail coupling.

Following the modelling stages of the rolling surface, model transformation into NC points, implementing of a parameterization method in the NC file, ensure the creation of machine NC program database with complex information on the profile shape, machining parameters, and cutting tool parameters with multiple choice for achieving an optimal process.

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