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METHOD AND SYSTEM FOR MEASUREMENT OF RAILWAY WHEELS ROLLING SURFACE IN RE-SHAPING PROCESS

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Abstract: *Train wheelsets must be periodically inspected for possible or actual failures. The wheels are the most loaded components of railway vehicles and are subject to continuous wear. Framing the rolling profile of the railway vehicle wheels into the geometric and dimensional features, regulated by national and international norms and standards, is a key factor for traffic safety. When the wheel reaches a certain critical level of wear, it must be re-profiled or replaced. This paper presents some considerations on the development of an automatic wheel profile measurement and computer analysis system integrated in a CNC profiling/re-profiling machine-tools. Measurement is done by contact, in two rectangular coordinates.*

Key words: *wheel set; railway wheel profile measurement; railway wheel wear; numerical model; in-workshop inspection, railway wheel reshaping*.

1. INTRODUCTION

In recent years, higher train speeds and increased axle loads have led to larger wheel/rail contact forces. Also, efforts have been made to optimize wheel and rail design and maintenance [3].

The wheels are the most loaded components of railway vehicles and are subject to continuous wear. When the wheel running profile reaches a certain critical level of wear, it must be readjusted or replaced [9].

The importance of improving the wheel sets re-profiling technology results not only from the need to reduce maintenance costs, but also from the need to enable modern high speed trains to use their potential under conditions of reliability and safety of transport [1].

Re-profiling involves a loss of material from the whole wheel profile. So, after re-profiling, the wheel has a smaller diameter. When the wheels on a wheelset are re-profiled independently, there is a risk of differences in diameter between them. If the difference between wheels exceeds the permissible limit, the danger of derailment increases. Another consequence of differing sizes is that smaller wheels wear faster than larger ones.

Using wheels with appropriate profile reduce the risk of derailment and minimizes the dynamic interaction between the vehicle and the track, reducing noise, vibration and wear.

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Simultaneous measurement and re-profiling of wheelsets, on the same machine-tools, reduces the risk of using wheels with different profiles and sizes.

The choice of the shape and size of the profile to be reshaped is still mostly based on the worker intuition after measurement with manual gauges.

During the last decades a number of efforts have been made to use numerical methods in wheel design, measurement and manufacturing processes.

In these days, CNC technology offer a number of new possibilities including improved part measurement, automatic tool measurement, tool force monitoring, intelligent machining cycles, remote diagnostics and simplified operator interface [7].

2. WHEEL PROFILES

Figure 1 shows the railway wheels profile regions [7]. More than 20 dimensional and geometric parameters must be kept within strict tolerances to guaranty the safety of the train.

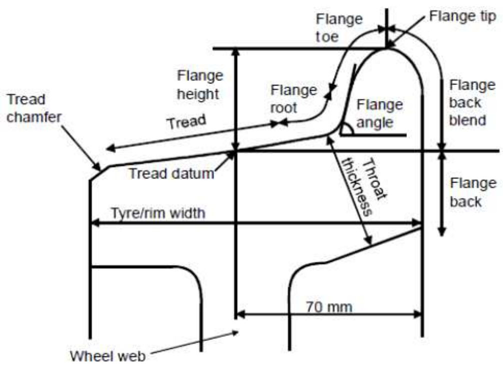


Fig. 1. Definition of the profile regions [7].

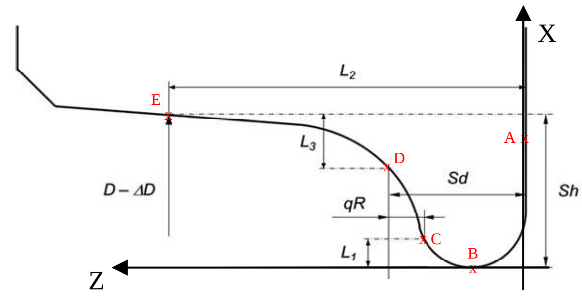


Fig. 2. Definition of wheel profile parameters: Flange thickness (*Sd*), flange height (*Sh*) and flange inclination (*qR*).

Table 1

The requirements for wheelsets [9]

Part of the wheelset	Criterion	Diameter of the wheel	Limit value [mm] Min.	Max.
Flange	Flange height (*Sh*)	330≤d≤630	31.5	36
		630≤d≤760	29.5	
		760< d	27.5	
	Flange thickness (*Sd*)	330≤d≤760	27.5	33
		760≤d≤840	25	
		840< d	22	
	Flange inclination (q_R)	≥ 330	6.5	–
Wheelset/ Wheel rim	Wheelset back-to- back distance A_R	330≤d≤760	1359	1363
		760≤d≤840	1358	
		840< d	1357	
	Wheelset front-to -front distance S_R	330≤d≤760	1415	1426
		760≤d≤840	1412	
		840< d	11410	
	Rim-wheel width		135 140	Tolerance −2, +1

These parameters must be inspected in the manufacturing and maintenance processes. The main parameters of the wheels are presented in Fig. 2.

For most railway wheels, the default values of the parameters are $L1$ = 2 mm, $L2$ = 70 mm and $L3$ = 10 mm. The main requirements for wheelsets and their acceptance criterion are presented in Table 1[8].

3. WHEEL WEAR MECHANISM

Many wear mechanisms exist and there are several dominant in the wheel-rail contact: oxidative wear, adhesive wear, abrasive wear, fatigue wear, plastic deformation [2].

The location of the highest wear on a wheel profile depends on the type of railway network the train is running on. The possible types of wheel wear are shown in Fig. 3.

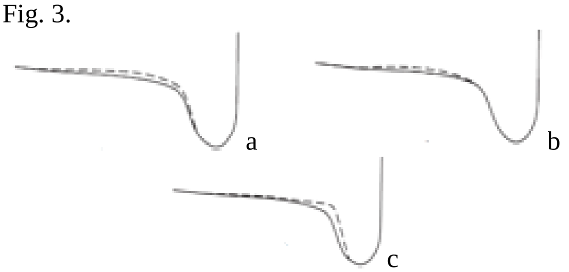


Fig. 3. Worn wheel profile and new wheel profile: *a* – evenly distributed wear on the tread and flange; *b* – mainly tread wear, *c* – mainly flange wear.

Table 2

Wheel steel requirements according to UIC 812-3 and EN 13262

Steel category		Carbon content	Yield strength (N/mm^2)	Tensile strength (N/mm^2)	Elongation (%)
UIC 812-3	EN 13262	UIC/EN	EN 13262	UIC/EN	UIC/EN
R1N	–	≤0.48	–	600…720	≥ 18
R2N	–	≤0.58	–	700…840	≥ 14
R3N	–	≤0.70	–	800…940	≥ 10
R6T,E	ER6	≤0.48	≥500	780…900	≥ 15
R7T,E	ER7	≤0.52	≥520	820…940	≥ 14
R8T,E	ER8	≤0.56	≥540	860…980	≥ 13
R9T,E	ER9	≤0.60	≥580	900…1050	≥ 12

To determine the worn status of a wheel profile, are used the parameters defined in Fig. 2 (*Sd, Sh, qR, D*).

These are internationally accepted measures of wheel tread profiles. The advantage of using these parameters is the standardisation of measuring equipment, the ability to compare performance and the ability to use standard gauges.

Flange wear results in reduced flange thickness (*Sd*) and increased flange inclination (*qr* decreases) [2]. Wheel tread wear results in increased flange thickness (*Sd*) and increased flange height (*Sh*).

4. WHEEL MATERIALS

In order to deal with the demands imposed by the severity of the wheel/rail contact conditions, for wheels and rails construction are used materials with high resistance to wear, which have predominantly pearlitic structures and containing hard cementite lamellae. Technical Specification UIC 812-3 lists for solid wheels seven types of steel, which mainly differ in carbon content, heat treatment state and therefore strength. EN 13262 contains only four types of steel. R7 is by far the most commonly used material (Table 2) [10].

5. WHEELSETS REPROFILING PROCESS

The performance of rolling stock maintenance will have a great influence on transport safety and passengers comfort. Wheel re-profiling process is an important step in the maintenance of the rolling stock. Three major aspects require special attention in wheel re-profiling process [7]: choosing the appropriate profile; framing prescribed tolerances; compliance with surface quality.

Improving the wheelsets reshaping technology is a requirement of the need to reduce maintenance costs and to enable modern high speed trains to use their potential in safety conditions.

Unfortunately, in most railway workshops for turning the profiles of the wheelsets are used old machine-tools [5] whose performances no longer meets current requirements of precision and productivity. The purchase and installation of new modern machines is too expensive for these workshops. Under these conditions, extensive research has taken conducted on the development of cost-effective solutions for improving technologies for re-profiling the wheel tread.

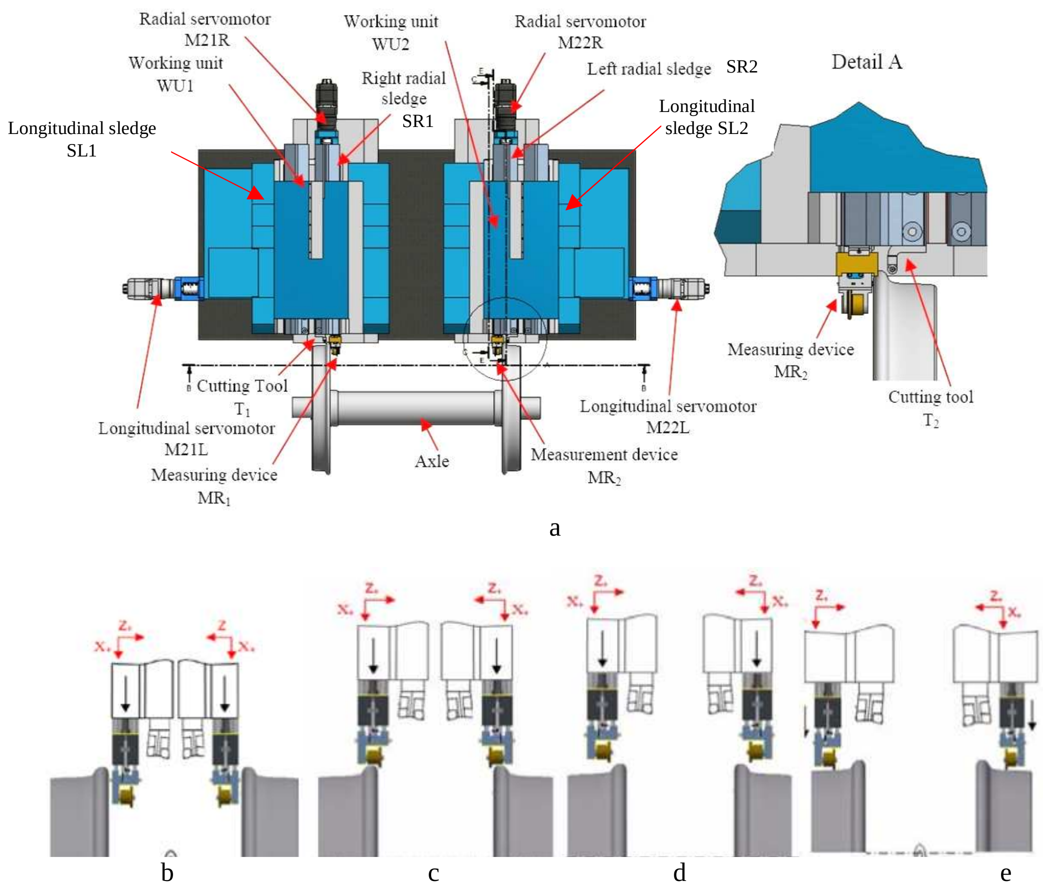


Fig. 4. Modernized structure of the wheel reshaping lathe [4 and 7]: *a* – lathe with measurement devices integrated ; *b* – measurement of internal frontal faces and axial run out; *c* – measurement of flange height; *d* – measurement of flange angle and thickness; *e* – Measurement of running diameter and out of roundness.

The researches focused especially on the upgrading of technological processing systems to increase the productivity and profiling/ re-profiling accuracy, the improvement of machined surfaces quality by using appropriate tools and the improvement of the interoperable and final measurement methods.

Modernizing the existing machine-tools is a less expensive solution than buying new ones. CNC technology provides opportunity for retrofitting and automation the existing lathes used by railway maintenance workshops for re-profiling the wheels. Implementation of CNC on existing machine-tools offers a number of new possibilities including improving wheel profile measurement before and after turning, maintaining a database with measured profiles and with normalized profiles, wheel profile optimization, intelligent machining cycles and simplified operator interface.

The goal of the research was to modernize such a modernized machine-tool, which include a wheel profile measurement system. The modernized technological measurement and manufacturing system includes: two devices for wheelsets profiles measurement before and after machining; a CNC system with four translation axis integrated in structure of a horizontal lathe with two working units (type UB 150 - RAFAMET-Poland), for driving and control of reshaping and measurement processes; intelligent machining cycles for wheel turning and measurement [6 and 7]. The two working units WU1 and WU2 have identical structures and driving systems.

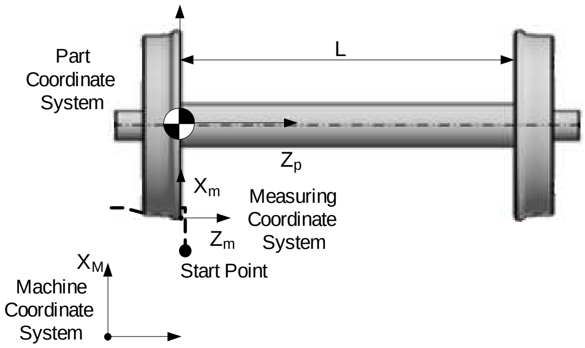
The following aspects were considered in the design and technical realization of the kinematic chain in radial and longitudinal directions:

- adaptability to the constructive and kinematic structure of the lathe in the conventional version;
- providing cutting parameters (movement speed and range, feed precision, force and torque);
- redesign the hydraulic circuit for CNC machine adapted to the existing lubrication circuit on the original machine;
- reduced noise and vibrations by reconditioning the guides and using silent drive systems;
- simple and compact structure;
- the use of flexible couplings to compensate for possible non-alignment of the motor with the ball screws.

6. WHEELSETS PROFILE MEASUREMENT SYSTEM

Due to the wear that occurs during the operation, the profile and diameter of the railway wheels have to be inspected regularly. For these inspection operations there were developed a series of measurement and control gauges and equipments. But wheels geometry measurement is also part of the reshaping operation [7]. Measurement must be done before and after turning. The common methods used in wheels manufacturing technologies involved measurements with various manual gauges (Fig. 5). These measurements may introduce human errors [12] and do not allow the storage and processing of measured data.

Fig. 5. Measurement gauges for railway wheels.



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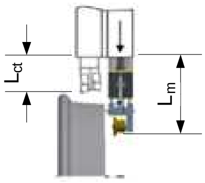


b

Fig. 6. Integration of the mesuring coordibate systems in the machine and part coordinate systems: *a* – coordinate systems; *b* – dimensions used for length compensation.

The modernized lathe integrates numerical controlled axes along X and Z on both working units (left and right) and also a measuring system. They work on the basis of specific reference systems (Fig. 6,*a*), as follows:

- Machine Coordinate System (MCS) or Machine Origin is the default coordinate system assumed during power-up.
- The Programmer Coordinate System (PCS) is independent with regard to the MCS and usually is belonging to the part.
- Measuring Coordinate System that belongs to the part and more specifically to the wheel profile.

The measurements (see Fig. 4,*b*) are done using initial displacements on controlled axes with regard to Programmer Coordinate System, and after that in the Measuring Coordinate System. Figure 6,*b* shows the dimensions that are subject to length compensation for both cutting tool and profile measurement system, L_{ct} and *Lm*, respectively.

For wheels profiling/re-profiling technology, it is more effective to use a measurement system mounted on the machine-tool which has the same coordinate system with the cutting tools. By positioning two measuring heads on the radial sledges in the near proximity of the tools (Fig. 6), the axial position of the lateral faces, the diameter of the wheels and the wear of both wheels on a wheelset profiles are determined in a coordinate system with a known position relative to the position of cutting tool [7]. Both measurement heads and tools are displaced by the same driving systems, directly governed by the numerical control unit of the machine-tools. In this way, machining is more efficient and accurate. Wide range of programming possibilities guarantee easy adapting of the turning process to dimensions and profile of the wheels. The axial position of the lateral faces of the wheel, the running diameter and the geometrical parameters of the profiles of both wheels on a wheelset are determined before reshaping, to choose appropriate profile to be reshaped and determine the starting point for turning process and after reshaping to determine the conformity of reshaped wheels surfaces.

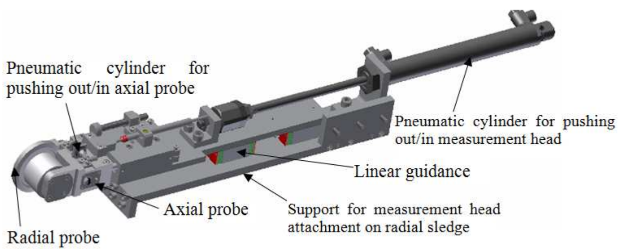
Measurement can be done by contact-scanning the whole profile of the wheels or by measuring the coordinates of the A ... E points (Fig. 2) and determine the specific parameters of the profile (flange height –*Sh*; flange width –*Sd*; flange gradient - *qr*; running diameter - D; out of roundness of running diameter; back to back distance - *L*; axial run-out of lateral faces).

Figure 7 shows a measurement system, designed to be mounted on radial sledge of the lathe presented above.

The measurement is made in the radial and axial direction relative to the wheel axle. Displacement of the measurement probes to the characteristic points of the profile is carried out by moving the radial and longitudinal sledges (see Fig. 4,*a*), numerically controlled. The measurement of deviations from the theoretical profile is done with incremental transducers with ± 10 mm range and 2 µm accuracy, for radial direction and inductive transducers with ± 2 mm range and 0.25% linearity for the axial direction.

For frontal or radial run out measurement, the axle with wheels rotates at a constant speed. The values measured with displacement transducers are analysed with FFT, synchronized with the wheels rotary speed. The speed of the wheelset is measured with an optical sensor (tachometer).

The acquisition and transmission of the data from measurement transducers is done through an interface Sensoray 826 installed in the computer Sinumeric PCU 50.5-C of the machine-tools (Fig. 8).



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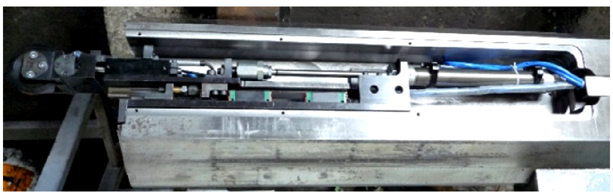

b

Fig. 7. Profile measurement system: *a* – measurement system structure; *b* – measurement system positioned on radial sledge.

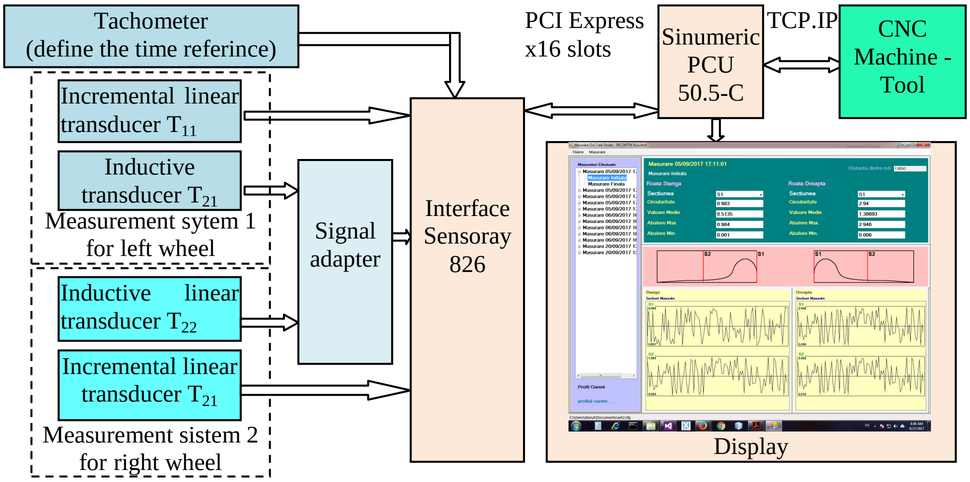

Fig. 8. Measurement acquisition and transmission data.

During the cutting process, the measuring systems are retracted into the radial sledges seats being protected by articulated covers from the chips. The two measuring heads can be operated individually or simultaneously, with individual pneumatic driving systems. The pneumatic cylinders for push/ pull the measurement heads are equipped with end-of-travel sensors at both ends of the race.

According to UIC510-2 normative, a good approach for the geometric characterization of the wheels wear is based on the measurement of the profile parameters [11].

The measurement program defines the coordinates of the measuring points in the wheel coordinate system and defines the measurement sections. The measurement system determines the deviations between the real profiles and the theoretical profiles in these sections.

According to the measurement results, the operator will decide if the wheels are in the functional parameters, they must be re-profiled or replaced.

The measuring system can be operated manually or automatically. Manual mode allows adjustment of transducers in the measurement range and testing of measurement functions. Automatic measurement mode allows simultaneous or independent measurement of both wheels. To measure the wheels before re-profiling must be performed the following steps:

- The wheelset is fixed between peaks;
- The measuring heads are pushed by the pneumatic cylinders (Fig. 7,*a*) to a fixed stop;

The coordinate system of the wheels is determined in relation to the machine-tool coordinate system. For this, the measuring heads are displaced by longitudinal and radial sledges so that the axial probes touch the inner faces of the wheels in points A. These points are reference points for Z direction (Fig. 2). The wheelset is rotated with constant speed and is determined the axial run out. The measuring heads are moved by longitudinal and radial sledges so that the radial probes touch the wheels profiles in the highest point of the wheels flanges (points B). These are the second reference points for defining the wheel coordinate system XOZ (Fig. 2). The points A and B are considered to be points of the theoretical profile. The X axis is parallel to the radial displacement direction and Z axes are parallel to the longitudinal displacement.

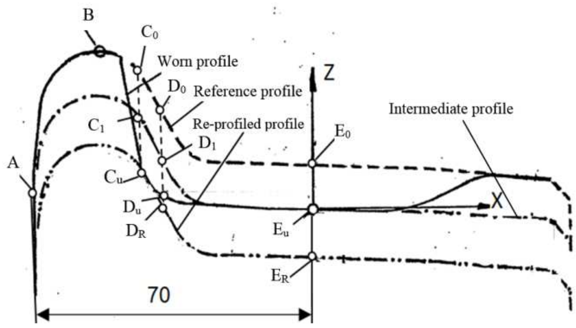

Fig. 9. Determination of the re-profiled profile translation.

- The measuring heads are moved on Z direction with (S_d - q_R) and on X direction with L1, and the radial probe measure the deviation of C point on radial direction.

Similarly are determined the deviations of points D and E on the measured wheels relative to theoretical profile.

In Fig. 9, the measured points (A, B, C_u, D_u, E_u) are represented. The re-profiled profiles of the wheels must be the same as the initial (theoretically) profile, before the wear occurs, but translated in the radial direction. The way of determining the radial displacement of the re-profiled profile is shown in Figs. 9 and 10. The new profile must be tangent to at least one of the measured points with the worn profile, and no measured point should be within the re-profiled profile. In Fig. 9, the intermediate profile is the profile translated in radial direction, considering only the wear on the tread. It can be seen that there are points on the wheel flange which are inside this profile. The correctly chosen profile for re-profiling is the one that is tangent in the C_u point with the worn profile.

To achieve precision measurements, the machine tool shall have: high accuracy tools/ measurement heads positioning system; drive and control system, less vibration and noise level [4].

7. CONCLUSIONS

This paper presents some considerations regarding modernization of a lathe for wheelsets profiling/re-profiling, by implementation a CNC system with four translation axis for driving and control of reshaping and an intelligent measurement system for profile measurement before and after turning.

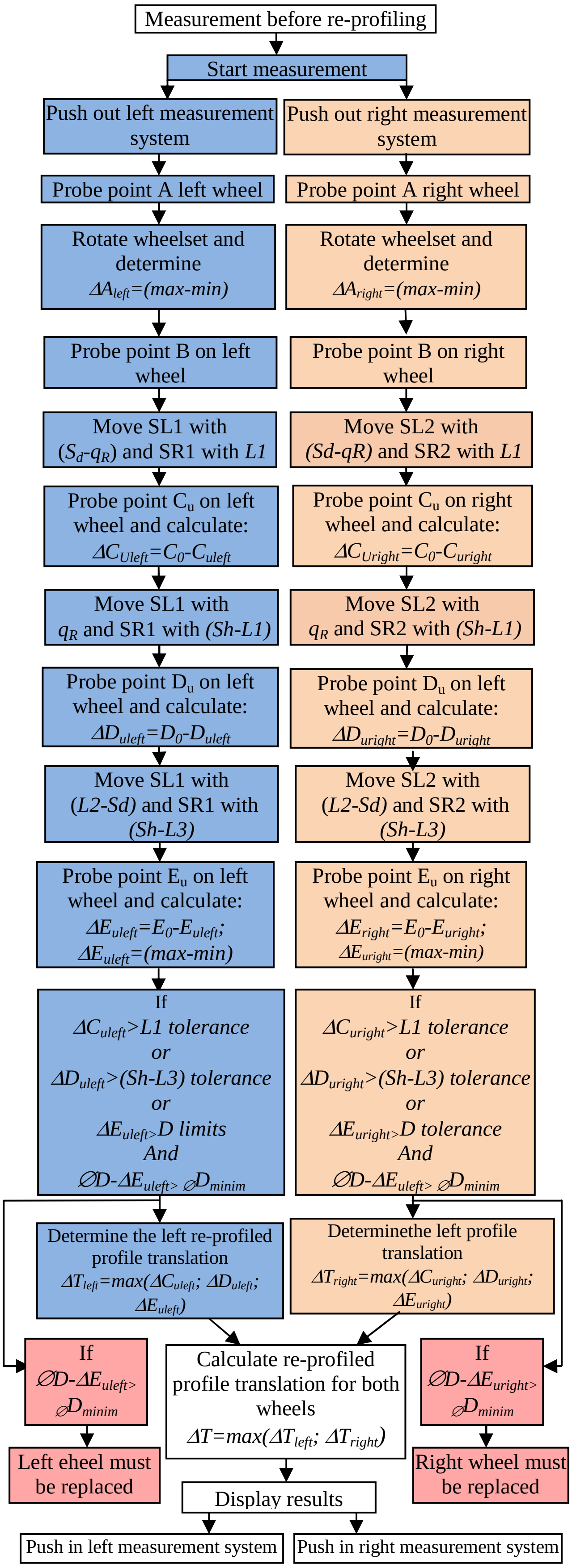

Fig. 10. Logical scheme for measuring the worn profiles.

The measurement system allows automation of the measurement process and optimal determination of the re-profiled profile. The measurement systems have a triple role: determine the coordinate system; determine the degree of wear of the wheels; determine the conformance of the re-profiled profiles with specifications.

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