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Challenges and Opportunities of Tram Wheel Profile Design

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Abstract

This paper presents the challenges and opportunities for designing a new wheel profile for polish tramways. Due to the lack of specific regulations and standards in this field, authors propose their own methodology, based on both numerical and experimental approach.

Keywords: tramway, wheel, profile, wheel-rail interaction.

1 Introduction

Urban transport is supposed to be efficient and sustainable. This can be achieved by a thoughtful handling of rolling stock and infrastructure, which includes, among others, many challenges of the wheel-rail interface. This topic is very up-to-date in the whole railway market, but there is very small number of research concerning light rail vehicles, for example [1], [2]. Comparing the wheel-rail interface expertise for trains and tram, the first one is definitely better explored, mainly because of interoperability and unification of rail systems in specific countries or continents. Tramways run also on Vignole rails, but there are some differences in the operation conditions, e.g. different axle loads, shallow-grooved crossings, small radius curves, worse track technical condition and very frequent accelerations and decelerations. Tram networks are generally not connected with each other and do not make up one domestic system. This leads to setting of vast numbers of various wheel-rail pairs, some of which are incorrect in the matter of proper interaction. Here came the motivation for the research project – to design a new wheel profile for polish cities.

This required the development of a complex operating methodology, taking into account both the analysis of the current state, as well as simulation calculations and experimental tests, both in terms of the behavior of the wheel on the rail and the material properties of the friction pair. Selected challenges and opportunities of this process are presented in this paper.

2 Methods

In order to define the new wheel (or rail) profile it is important to obtain information on the trends of their mutual wear (Fig. 1). They result from the design of the vehicles running gear, as well as the geometry and wear of the track.

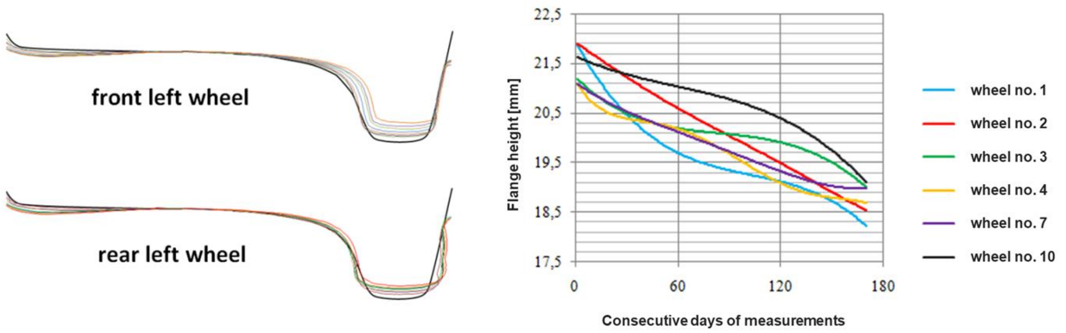

Figure 1: An example of the wheel wear for a vehicle with non-pivoting bogies.

An important element of a new wheel profile design process is its geometric adjustment to the existing rail profiles. An important role is played in this case by the non-measurable parameter of the conformality of the shape of the wheel and rail profile. Figure 2 shows the possible contact areas of the wheel and rail for two different profiles of tram wheels.

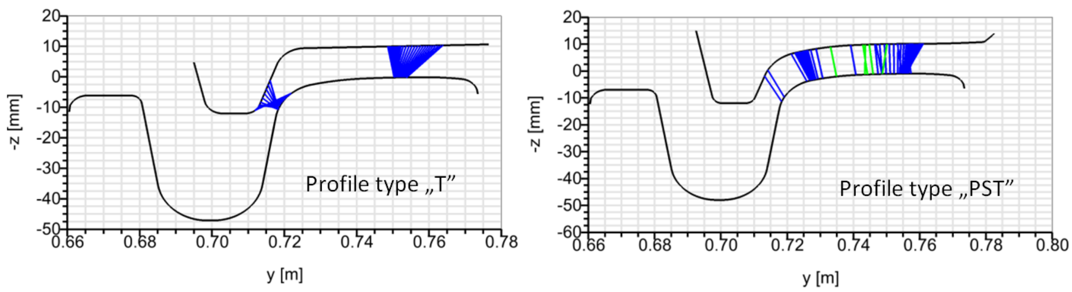

Figure 2: Contact point distribution.

In order to verify contact patches occurrence and distribution in several situations typical for light rail vehicles, thermographic and high speed cameras were used, as shown in Fig. 3.

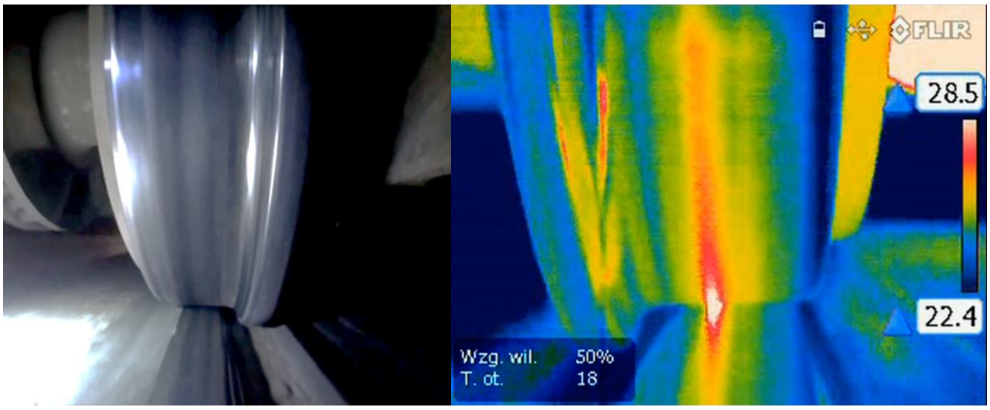

Figure 3: Images from high speed and thermographic cameras showing wheel-rail interaction.

High friction and in consequence wear is present during multi-patch contact, which is very common for tramways, but have to be avoided to cut the maintenance cost.

The wear of wheels and rails, in addition to the geometric adjustment, is also influenced by the material adjustment, including the hardness of the both elements. Hardness measurements were carried out according to Vickers method (Fig 4).

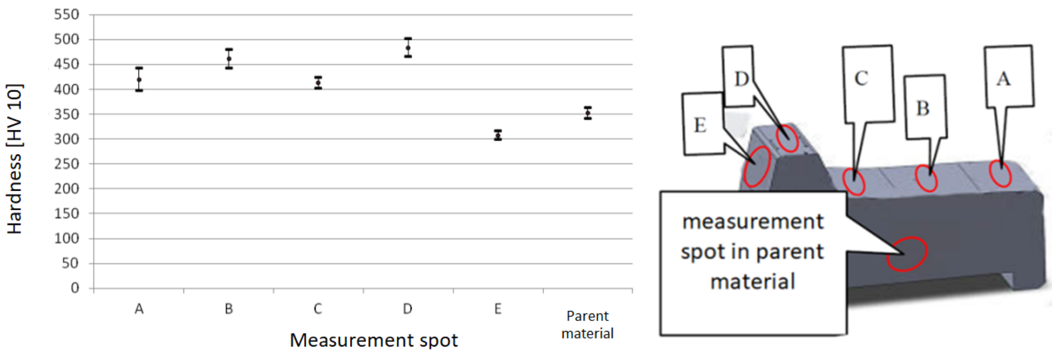

Figure 4: Results and schematic layout of measurements of hardness of HV 10 and the surface roughness profiles for the test samples of the rim (A, B, C – running surface D – top of the rim, E – the plane internal face) [3].

The wheel tread becomes hardened during operation and the hardness of the material thus decreases towards the core. In the later process of wheel reprofiling, the top layer (hardened) is collected and the nominal hardness of the wheel rim is recreated in a way.

In section D, white etching layer was observed on the rolling surface of the wheel rims, giving introduction to fatigue cracking. It is due to the fact, that the flange tip contacts the rail while passing shallow-grooved rail crossings, contaminated with sand, water and accumulated wear products. Moreover, the interaction between flange tip and rail crossing groove is rather violent, increasing the surface roughness.

3 Results

CMA-ES optimization algorithm. During the optimization process more than 50 000 correct (feasible) wheel profiles were generated and evaluated. The design criteria were chosen regarding literature [2], [5–9] and research carried out during the identification of tram wheel-rail phenomena [10] and were as follows:

- wear index – product of creep force and creepage as in [6] (to be minimized),
- Y/Q ratio – quotient of max. simulated Y/Q over Nadal criterion (to be minimized),
- static, minimum wheel/rail contact area for lateral displacements ± 5 mm (to be maximized).

The tram model for the simulation process of the wheel rail behaviour was a five section fully low floor tram with three stiff bogies and independent wheels. For wheel-rail contact we used the FASTSIM algorithm due to a high number of simulations to be calculated. More details about the method of the deign process can be found in [10].

A set of best, non-dominated profiles was found which can be conveniently embedded and visualized as a set of simulation results in 3D space and shown in Fig. 4 (best original results). Red color indicates results for existing European wheel profiles (for comparison). There is very clear trade-off between Y/Q ratio and wear index, hence there have to be worked out a compromise among these two parameters. The calculated wheel profiles dominated every evaluated European wheel profile in case of Y/Q ratio, wear index and contact area. The design algorithm proposed mainly wheel profiles with narrower wheel flange than for reference profile PST (21,5 mm) due to better simulation results. On the contrary this parameter should not be decreased significantly in order to preserve a necessary margin for flange wear. Although it was possible to select one wheel profile (indicated with black arrow on Fig. 5, also on Fig. 6 as a blue outline), with almost the same value of flange width. Flange height was set constant to provide proper interaction with shallow-grooved crossings and fair margin for wear. Moreover the flange tip was rounded with radius equal to 240 mm to lower the contact stress, basing on other work done within the project, involving finite element method.

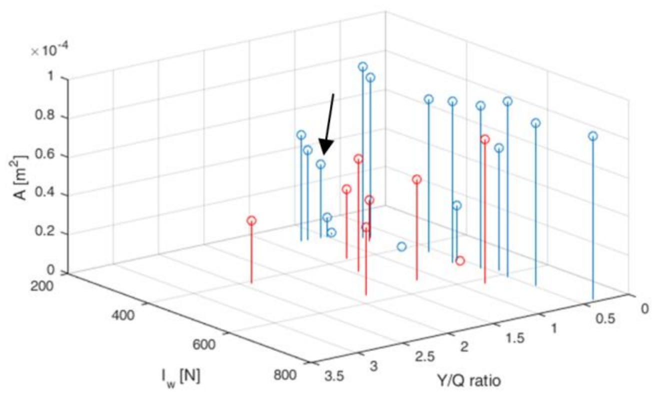

Figure 5: Distribution of results (description in text).

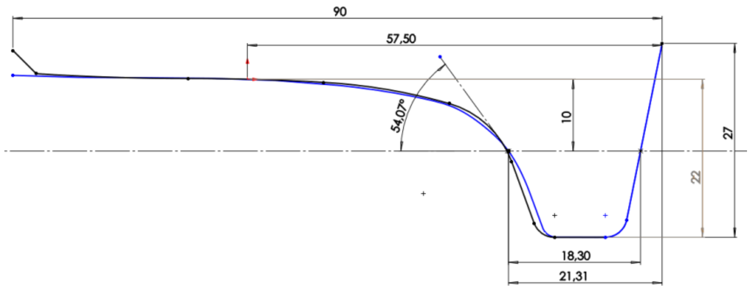

Figure 6: Proposed new wheel profile outline (blue line) and common PST profile (black line).

4 Conclusions and Contributions

Many aspects of tram wheel-rail interface were investigated within the research project, that were among others: tendencies of tram wheel wear basing on repeating wheel profile measurements, influence of the wheel profile on vehicle dynamic response, wheel and rail shapes conformity, contact patch formation, interaction while curving (including thermographic imaging of the wheel-rail interface), wheel and rail surface hardness and roughness development during operation, distribution of tangential tractions, contact stress (two approaches: finite element method and CONTACT), frictional power density and slip relative velocity in the wheel-rail contact patch. Due to the form of publication, only selected studies have been presented in this short paper.
The described results of the new tram wheel profile design process shows that the upgrade is possible. One best wheel profile was selected among around 50000 others and directed to empirical verification. Two tram operators agreed to test the new wheel profiles, their wheel lathes are fitted with the new programs and consequently in the forthcoming months the new profiles will be machined and evaluated on supervised test rides and then during regular operation.

The above results refer to a fully low floor tram with stiff bogies and independent wheels. The similar design process, but using different multibody model was adopted for design of new wheel profile for a partly low floor tram, with pivoting bogies and classical wheelsets.

Acknowledgements

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