Wheel-rail contact issues on railway and light-rail transportation

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Abstract: The evolution in time of the wheel profiles conduce to some important technical solutions for the tram wheel in the city of Timisoara (400.000 inhabitants, western side of Romania). Nowadays, an original wheel called Timis 2, especially designed for velocities around 50 km/h is usually used for the public transportation. The maintenance problems imposed a correlation between the wheel profile and the wear. Among the four types of wear (abrasive wear, adhesion wear, corrosive wear and fatigue wear) only the first and the second types of wear are active on the wheel-rail contact. The analysis of the worn profiles of the tram wheels is correlated with the state of the stress in the wheels, according to the most recent wheel-rail contact theories. Now-days, the rolling profile of the wheel is indicated, as a recommendation for every romanian public transportation operator and is not strictly settled. This recommendation allows to choose the suitable wheel profile according to the own working conditions. As a conclusion, our research is focused on processing a wheel profile, in order to obtain the minimum wear.

Key-Words: - wheel, rail, transport, wear, railway wheel-profile, rail profile.

1. Introduction

In the city of Timișoara the most important characteristics and their tolerances for the tram wheel and rail are presented in figure 1 and table 1.

Fig.1. Dimensions of the rail line in Timisoara

In function of the real working conditions, the transportation companies impose their own tolerances, between the limits prescribed by U.I.C.. The most important conditions to be reached are: \( k + n < v' \) and \( q_R > 6,5 \) mm.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Character name</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k )</td>
<td>Distance between rolling circles</td>
<td>135</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7</td>
<td>65</td>
</tr>
<tr>
<td>( i )</td>
<td>Wheelset gauge</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>( n )</td>
<td>Thickness of the rim</td>
<td>20</td>
<td>33</td>
</tr>
<tr>
<td>( q_R )</td>
<td>Distance to the critical contact point</td>
<td>6,5</td>
<td>-</td>
</tr>
<tr>
<td>( r' )</td>
<td>Rail gauge</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>43</td>
<td>70</td>
</tr>
<tr>
<td>( v' )</td>
<td>Distance to added rail line</td>
<td>1</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>-</td>
</tr>
</tbody>
</table>

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2. Problem Formulation

The influence of the relative conicity of the rolling surface \( \lambda = \frac{\Delta r}{2q} \) about the critical velocity for different values of the stiffness coefficient of the suspension is presented in figure 2. As a result of the increasing of the longitudinal and the transversal stiffness (\(1/c_x; 1/c_y\)), the critical velocity will also increase till a certain limit. Unfortunately, the rigid fixation of the wheel sets conduces to the decreasing of the critical velocity. When an elastic fixation is adopted, the value of the critical velocity is proportional with \(1/\sqrt{\lambda} \). When a significant increasing of the stiffness is reached, the relation will qualitatively change and the maximum value of the critical velocity will be reached.

Fig.2. The relative conicity of the rolling surface function of the critical velocity

The evolution of the wheel profiles has been imposed as a result of the conditions to reduce the noise and the vibrations of the tram wheels. The evolution followed some important stages:

a) The use of the rubber instead of steel for the rim. The method conduced to bad practical results, because the intense wear of the rubber profile as a result of small contact surfaces, high forces on the rim and long traffic distances.

b) The use of the suspension with a rubber layer instead of the metallic springs covered by rubber. The technical solution was important because it functioned like a vibration isolator.

c) The assembly of some cast iron rings on the internal part of the wheel based on the principle of the dynamic friction dampers

d) The covering of the rolling equipments and of the lateral parts of the wheels with vibration damping layers.

So, the evolution of the wheel profiles conduce to an important technical solution for the tram wheel in the city of Timisoara, as there is presented in figure 3:

Fig.3. Elastic tram wheel solution used in Timisoara

In accordance with BO-STRAB requirements, the elastic wheels must present a perfect guidance instead of their elasticity. A distance of maximum 5 mm is imposed between the body of the wheel and the internal side of the rim.

For the same normal load there are comparatively plotted the dependences between the above mentioned distance and deformations (radial, tangential and axial).

Fig.4. Axial, radial and tangential deformations of the elastic tram wheels

The best characteristics and the most silent public transportation is ensured by the Timis 2 wheel (figure 5).
The technical wheel solution for trams with tyres instead of wheels, in order to decrease the level of noise and to increase the adherence coefficient, conducted to an imperfect guidance. For this case, a special guidance system must be implemented.

The rail infrastructure consists in concrete girders covered by rubber or in iron or wood beams. The evolution in time of the tram rail profiles in the city of Timisoara is presented below.

3. Problem Solution

The technical solutions for rails and wheels shape profiles are confirmed both by the exploitation and by the finite element analysis.

3.1. Rail profiles

The first tram line in Timisoara used the Vignole rail profile (figure 6) with a linear weight of 20 kg/m settled on an oak settlement as in figure 6:

Because of the deterioration after a relative short time period, with the Vignole rail profile has been replaced with a rail profile with a linear weight of 33.6 kg/m or 23.6 kg/m, as in figure 8.

After that the tram line profile with a linear weight of 51.2 kg/m (figure 9) was used for the local transport. This type of rail presents a relative reasonable specific feature regarding the wear due also to the electric welding of the rail coupons.
Nowadays, in different areas of the city of Timisoara, the following profiles are used (figure 9). The profiles are similar with rail types 180 S and 180 P (used in Poland), respectively rail types Tv 60 and Tv 65 (used in Russia, figure 10).

3.2. Finite element analysis to optimize the wheel profile

Boundary and loading conditions leads to the following results regarding the state of stress both in the wheel and in the rail, and according to [3], [4], [5] and [6].
3.3. Wear appreciation of the contact surfaces wheel-rail

The intensity of the lateral wear is expressed [1], [2], for the leading wheel “i” as:

\[ \Phi_i = \mu_i P_i v_{ri} \]  

(1)

where: \( \mu_i \) - the friction coefficient between the rail and the wheel rim

\( P_i \) - the leading lateral force on the \( i \) wheel

\( v_{ri} \) - the relative sliding velocity on a perpendicular direction on the rail axis (OY) for the \( i \) wheel expressed by the analytic expression

\[ v_{ri} = \frac{w_{yi}}{v} \]  

(2)

where: \( w_{yi} \) - the sliding velocity on the OY direction

\( v \) - the running velocity on the OX direction

but:

\[ w_{yi} = p_i \omega_z \]  

(3)

\[ v = R \omega_z \]

so:

\[ v_{ri} = \frac{p_i}{R} = \sin \alpha_i \approx \tan \alpha_i \approx \alpha_i \text{ [rad]} \]  

(4)

For some comparative calculus, there is conventionally considered \( \mu_i=1 \) and the practical (for a general calculus) value of the wear index will be:

\[ \Phi_i = P_i g \alpha_i \approx P_i \alpha_i \]  

(5)

If \( \Phi_i \) exceed the limit value, the wear became too intense, and in order to reduce it the lubrication of the rim became as necessary and is practically performed with special lubrication push-carts (on the lateral side of the rim).

The appreciation of the wear imposes some coefficients which must be experimentally appreciated for particular technical conditions. So, in function of the wear type, there are considered studied:

- for the abrasion wear, because of some hard particles on the wheel-rail contact interface, the wear intensity “\( I_h \)” is estimated as:

\[ I_h = \frac{K_a p L_f}{H_B} \]  

(6)

\( p \) - average vertical pressure on the contact patch

\( L_f \) - “distance” of friction (“contact line”)

\( H_B \) - Brinell hardness

\( K_a \) - wear coefficient (2,8 \( \times 10^2 \) …4\( \times 10^2 \))

- for the adherence wear, because the presence of welded cracked particles, temperature and materials conditions, the total worn material volume is estimated as:

\[ V_w = K_c \frac{N L_f}{\sigma_c} \]  

(7)

\( N \) – normal (vertical) load

\( \sigma_c \) - yield point of the most soft material (wheel material or rail material)

\( K_c \) - friction coefficient (1\( \times 10^4 \) …\( \times 10^4 \))

According to the theoretical calculus and experimental measurements the relative dependence between wear resistance and hardness is presented in figure 15.
4. Conclusions

- The axial, radial and tangential deformations of the elastic tram wheels present relative small values, according to figure 4.

- The state of stresses both in the elastic wheels and in the rail, according to figures 12, 13, 14, is under the BO-STRAB limits and regulations.

- For different types of alloyed steels, the wear resistance is minimum for a hardness range between 180-200 HB, according to figure 15.

- In order to optimize the minimum state of contact stress and the minimum wear represents a challenge of some future researches.

References:


