

Tomasz STAŚKIEWICZ*

Bartosz FIRLIK*

(Date of receipt of the article: 02.09.2016, Date of acceptance of the article for publication: 10.11.2016)

VERIFICATION OF A TRAM WHEEL NEW PROFILE DYNAMIC BEHAVIOR

This paper is concerned about verification of a tram wheel new profile on multi-body simulation basis. The profile was obtained in an optimization process, which objective function was reduction of gaps occurring between points of contact with rail. The following parameters were checked: derailment coefficient Y/Q , wheelset lateral displacement, number of contact points and wear index. The aim of this work was to determine whether the new wheel profile is suitable for Polish tram networks and if its performance is enhanced in comparison to other profiles being applied. Simulation rides were carried out on tracks with measured geometry. It was found out, that the new profile had significantly better wear properties, but the ride safety was controversial.

Keywords: wheel/rail interaction, multi-body simulation

1. INTRODUCTION

Tram wheel profile is a rather rare topic in Poland. By now three of the profiles are in use: T, PST and TW (modification of T profile, originating from Warsaw). The first is an obsolete one, with conical wheel tread and very small flangeway clearance (2,5 mm). Profile PST is the newest one, however it was designed over 25 years ago.

Wheel profile has significant influence on ride quality by participation in formation of wheel/rail interface. One is able to steer ride safety, intensity of wheel and rail wear, ride stability and noise emission by altering wheel profile with regard to phenomena occurring in the wheel/rail. Controlling the wear process of wheel (and rail) may lead to a considerable reduction of maintenance spendings and work [Shev-

* Poznan University of Technology, Faculty of Machines and Transport.

tsov, Markine, Esveld 2008, Polach 2010]. The authors believe that knowledge gathered during the whole project will be a plentiful source for tram operators to adjust local maintenance guidelines and improve tram systems efficiency.

2. METHODOLOGY

2.1. Tram model

The object of simulation was a three-section, partly low-floor tram model supported on four motor, pivoting bogies with classic wheelsets. Low floor was situated in the middle car. Topology of multi-body model was presented in Fig. 1. All bogies were similar, therefore topology was simplified. The abbreviation WS means: “a wheelset” and WS1R means: “the right wheel of the first wheelset”.

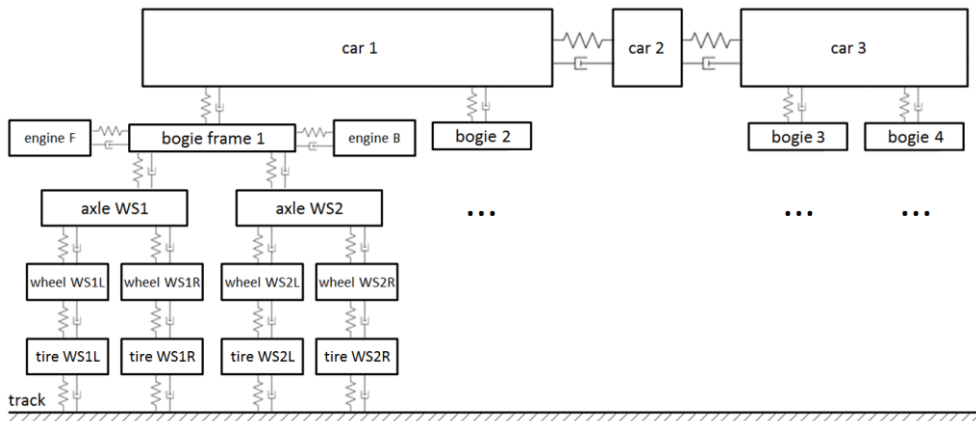


Fig. 1. Topology of the model

Metal-rubber elements were used as primary springs, whereas conical springs and metal-rubber elements (serial connection) were used as secondary springs. Wheel diameter was equal to 654 mm.

2.2. Wheel profiles

Two wheel profiles were used in the simulation: PST and PP1. Outline of PST profile was presented in Fig. 2.

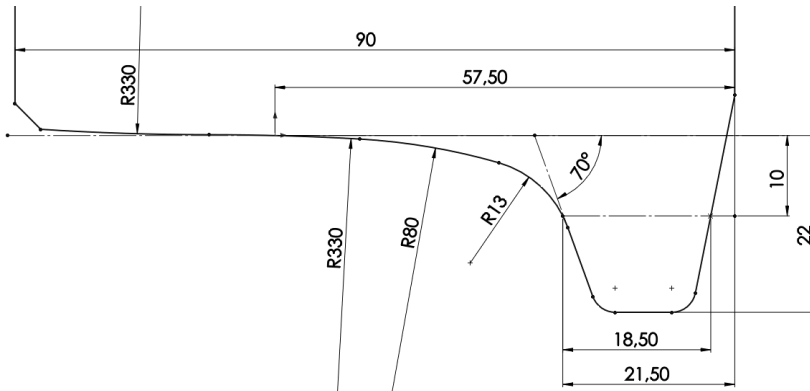


Fig. 2. PST profile

The flangeway clearance of this profile is around 5 mm per wheel (measured 14 mm under the top of rail), which is two times more than for T profile (2,5 mm). PST profile was designed to interact, among others, with 60R2 rails and some railway types: 49E1, 60E1. Some examples of interaction of misconfigured wheel/rail pairs were noticed in previous research [Staśkiewicz, Nowakowski 2016]. PST profile is commonly called as adjusted to wear, because its outline was designed on basis of observation of worn profiles.

PP1 profile was shown in Fig. 3.

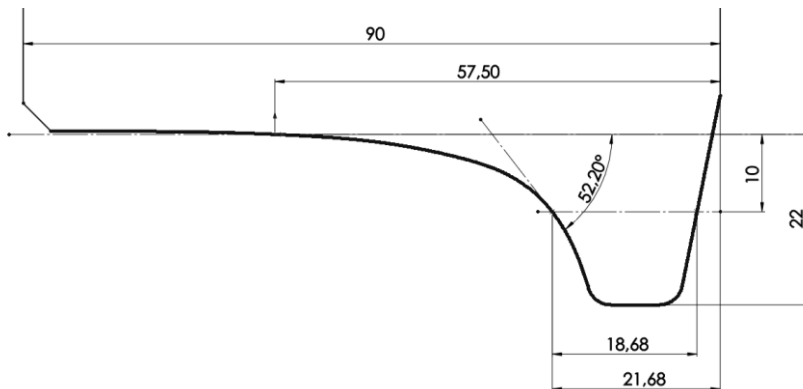


Fig. 3. PP1 profile

PP1 profile is an effect of computational optimization of PST profile. The objective function was to reduce width of gaps between particular points of contact. Comparison of both profiles potential points of contact with 60R2 rail was shown in Fig. 4. There are more than one contact patch in the figure for particular wheelset lateral displacements, so additional contact lines were printed in different color (grey).

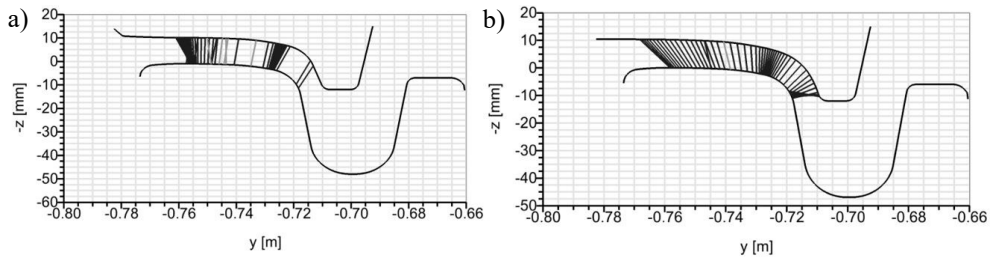


Fig. 4. Comparison of potential points of contact: a – PST, b – PP1

The main change in relation to PST profile is continuous distribution of contact points, bigger flangeway clearance (6 mm per wheel) and smoother transition from wheel tread to flange. It was still not clear how to measure flange inclination for profiles with curved outer side of flange. Authors adopted method used by [PKP Intercity 2010], which was shown in Fig. 3. PP1 profile flange inclination is small, as well Nadal's criterion, which may cause problems with ride safety.

2.3. Tracks

Following, different track sections were utilized in the simulations:

- straight track with excitations, speed limit 30 kmph, 330 m long,
- curved track with excitations, speed limit 15 kmph, 220 m long, topology in

Fig. 5.

In order to increase clarity of markings, tracks were named respectively: track 1 and track 2.

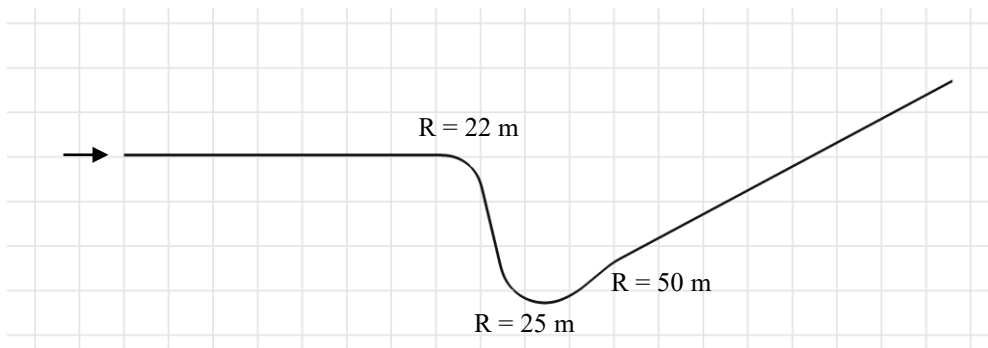


Fig. 5. Curved track with excitations (track 2) topology

All track stretches originate from a real tram system. Track irregularities were measured using gauge trolley. Track curves were accompanied with appropriate transition curves due to [Minister Administracji... 1983].

2.4. Simulation process

SIMPACK software was used to carry out the simulations. The following parameters were gathered: derailment coefficient Y/Q , wheelset lateral displacement y , ride index in lateral and vertical direction (y_{max} , z_{max}), number of contact points np and wear index I_w , which is calculated according to the formula [Shevtsov 2008]:

$$I_w = F_x \xi + F_y \eta \quad (1)$$

Where F_x is longitudinal creep force, ξ is longitudinal creepage, F_y is lateral creep force; and η is lateral creepage.

3. RESULTS DISCUSSION

3.1. Track 1

Ride safety is undoubtedly one of the most important factors describing ride conditions. Optimization criteria are various through the literature, but verifying the derailment coefficient Y/Q value is present in each publication [Persson, Iwnicki 2004, Novales, Orro, Bugarín 2007, Shevtsov 2008, Öberg, Hartwig 2012, Choi, Lee, Lee 2013].

Figure 6 presents relationship between Y/Q quotient and traveled distance s for PST and PP1 profiles (WS1R).

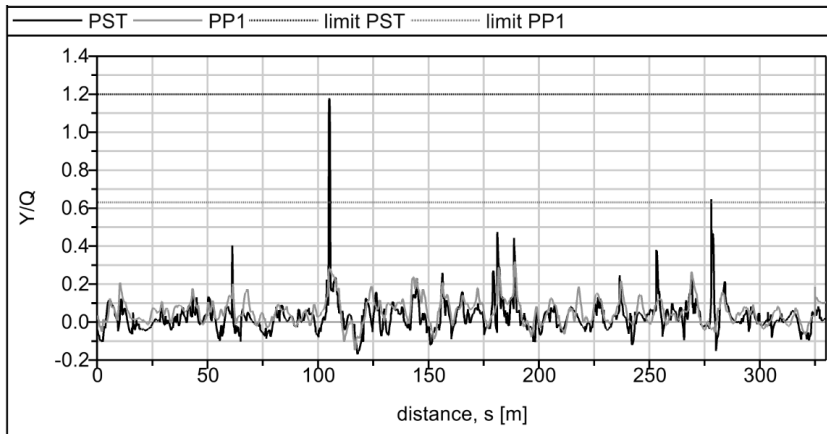


Fig. 6. Relationship between derailment coefficient Y/Q and travelled distance s

The above figure indicates that local maximum values were bigger for profile PST. This is an important change, because exactly those immediate growths generate

higher risk of derailment. Limiting values came from Nadal's criterion calculation according to [Nadal 1896]. Eventual transgression may cause increase of derailment probability. Although no transgressions were spotted.

Figure 7 shows plot of wheelset lateral displacement y against travelled distance s for PST and PP1 profiles (WS1).

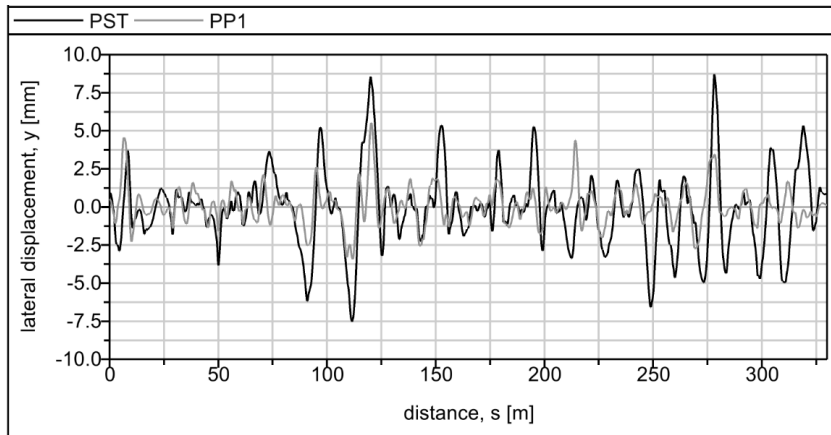


Fig. 7. Relationship between lateral displacement y and travelled distance s

It is clearly visible from above, that PP1 profile was behaving calmer – lateral displacements of wheelset were smaller. One may state that PP1 profile provides better ride stability in conditions prevailing on track 1.

There was no noticeable change in ride index values, neither in lateral direction, nor in vertical. For all tracks maximum values were low (around 0,3–0,5 m/s^2) and its spread was negligible.

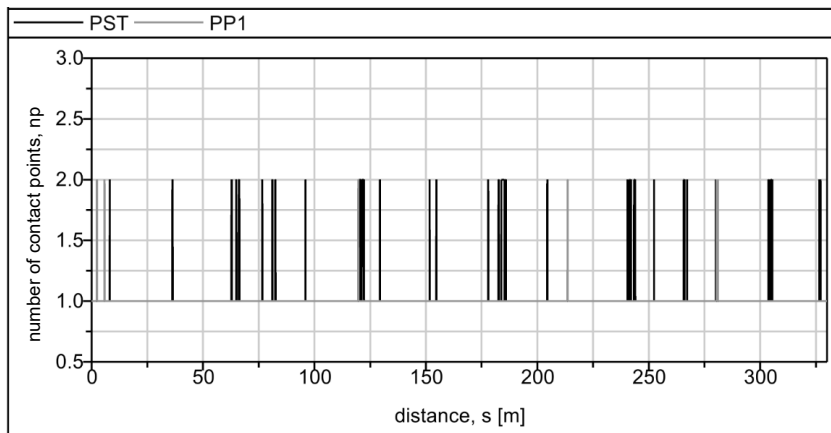


Fig. 8. Relationship between number of contact points n_p and travelled distance s

Next analyzed parameter was number of contact points np . In practice, there are no points of contact but there are patches. Points were introduced as a simplification. Figure 8 presents plot of number of contact points np versus travelled distance s , for PST and PP1 profiles (WS1R). Proper contact, with reduced and stable wear rate, is a single-point, conformal contact in whole range of wheelset's lateral displacement [Shevtsov 2008].

Both wheel profiles formed mainly single-point contact with rail. Double-point contact appeared for PST 2–3% more often than for PP1 profile, which is a slight difference, hence both profiles during the ride on track 1 may be considered as similar in the field of number of contact points.

Wear index is a parameter of high interest of tram systems operators because of it's big influence on operation cost. Both wheels and rails are being worn by each other, but the rate of the process can be steerable – for instance, by wheel profile geometry as in publications [Shevtsov 2008, Shevtsov, Markine, Esveld 2008]. Figure 9 shows mean values of wear indexes I_w for respective wheels and wheel profiles.

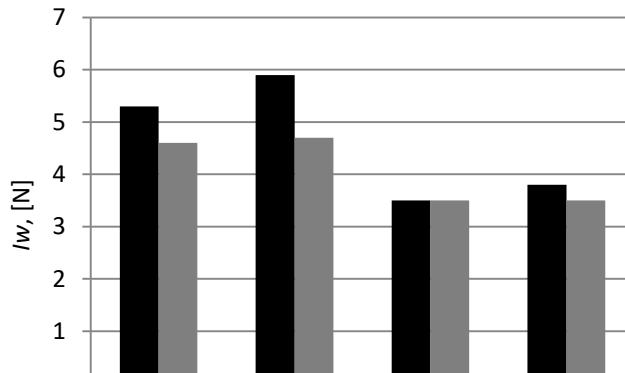


Fig. 9. Mean values of wear index I_w

The above graph indicates that wear process of wheels with profile PP1 may be, for assumed ride conditions, less intense in comparison to PST profile even about 20%. This regularity occurred even despite of known tendency to faster wear of wheels with bigger equivalent conicity parameter [Shevtsov 2008]. The possible reason of that behavior was even distribution of contact points through entire wheel profile.

3.2. Track 2

Second track incorporated a few narrow curves. Firstly, the ride safety was verified (Fig. 10, WS1R).

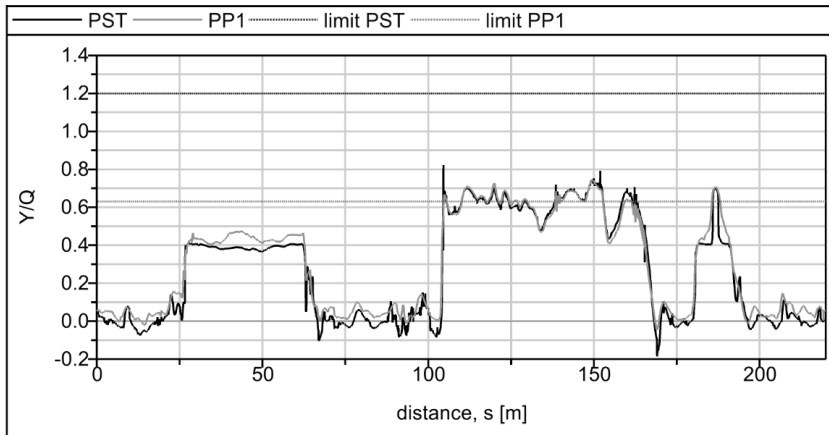


Fig. 10. Relationship between derailment coefficient Y/Q and travelled distance s

The above diagram indicates that values for both profiles were alike, but such a low limiting value as 0,63 for PP1 profile caused occurrence of transgressions while riding on the outer rail. It is an important piece of information, which should be taken into consideration while updating the optimization criteria. Increasing the flange inclination will raise the limiting value resulting of Nadal criterion. Furthermore, there were observed momentary peaks during entering the curves for PST profile. Nothing similar was observed in case of PP1 profile, probably due to its geometry (smooth transition curve).

Opposite tendency as regarding ride on track 1 occurred on track 2 considering wheelset lateral displacement y (Fig. 11, WS1).

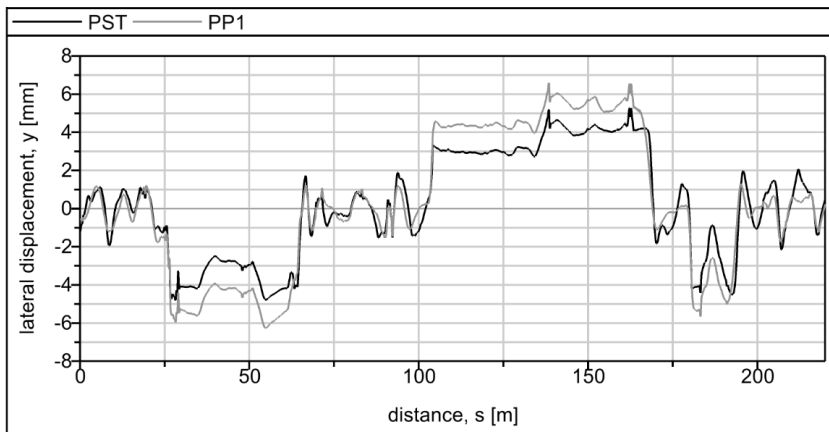


Fig. 11. Relationship between lateral displacement y and travelled distance s

As seen from above, the wheelset with PP1 profile wheels covered bigger range of lateral displacements. It is believed that increased flangeway clearance of PP1 profile was a reason of that behavior.

Subsequently, number of contact points np was investigated for the right wheel of the first wheelset (Fig. 12).

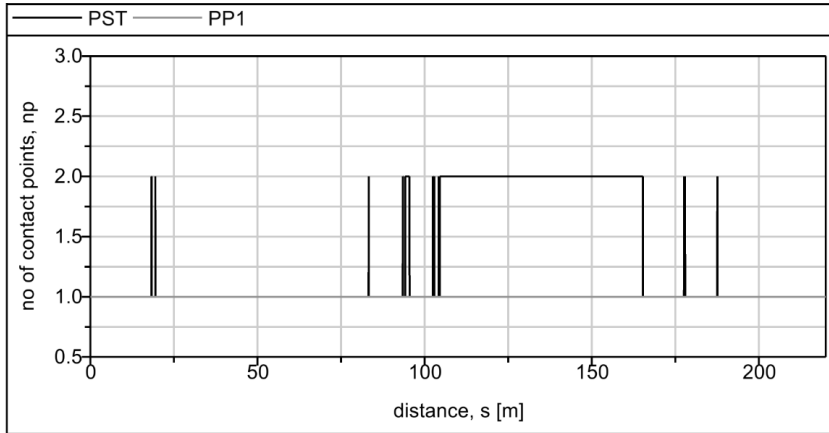


Fig. 12. Relationship between number of contact points np and travelled distance s

The above figure indicates that profile PP1 formed single-point contact during the whole ride on track 2. This is a positive feature, which may lead to reduction of wear intensity as multiple-point contacts contribute to increase equivalent conicity and to occurrence of creepage [Shevtsov 2008, Polach 2010]. The curving behavior of PP1 profile resembles performance of rail profiles in wide curves. PP1 profile was optimized due to continuous distribution of contact points along rim width, which effect was keeping single-point contact on entire route.

Furthermore, geometries of the wheel profiles were verified regarding wear index I_w . Results of this comparison were set together in Fig. 13 (mean values).

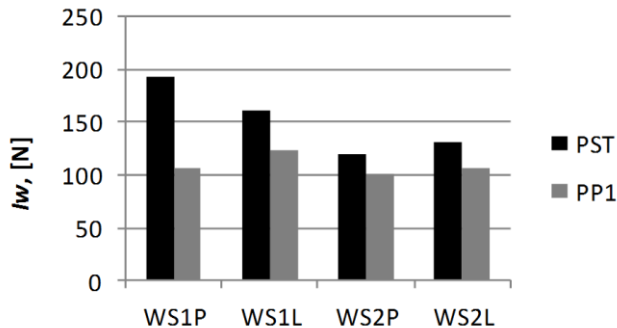


Fig. 13. Mean values of wear index I_w

Wear index I_w was up to 44% smaller for wheels with profile PP1 than for wheels with profile PST. There was a significant improvement of wear performance of optimized wheel profile during riding in curves. Differences were the most noticeable on first wheelset, where angles of attack are usually the highest [Andersson, Berg, Stichel 2014].

4. CONCLUSION

New wheel profile PP1 presented in this paper is definitely not a final one in the project. The optimization process have just began to calculate thousands of them. Even at this stage of work important information was gathered, which was useful to improve the optimization assumptions. The conclusions drawn from the new profile dynamic behavior verification were as follows:

The Y/Q derailment coefficient was generally similar for both wheel profiles on track 1, but the local peaks were significantly lower for profile PP1. There were no transgressions of limiting value (due to Nadal criterion) for PP1 profile. The situation repeated on track 2, where Y/Q quotients were close to each other, but the peaks (while entering curves) were much lower for profile PP1. It is most likely that such peaks were due to rapid movement of contact patch from wheel tread to flange (profile PST), with accompanying jerk. It is worth to consider increasing profile's PP1 flange inclination to raise the Y/Q limiting value.

Bigger values of wheelset lateral displacement y occurred for profile PST on straight track, and for PP1 on curved track. New profile is more stable on straight track sections.

Profile geometry change had negligible influence on ride index.

Number of contact points np was similar for both profiles on track 1. Difference emerged on curved track (track 2), where profile PP1 formed single-point contact on entire route. It was an expected result since profile PP1 was optimized due to even and continuous distribution of contact points.

It can be stated that profile PP1 is more efficient regarding wear than profile PST. The profit was the biggest on curved track, where relative difference was around 44%. It is likely that profile PP1 may achieve bigger mean mileages between turning works. Above discussion confirms that wear intensity is correlated with number of contact points, but there are others, considerate parameters such as equivalent conicity, suspension stiffness, forces in the interface in combination with creepages, friction coefficient, wheel diameter, etc. [Shevtsov, Markine, Esveld 2008, Andersson, Berg, Stichel 2014].

REFERENCES

- Andersson E., Berg M., Stichel S., 2014, Rail Vehicle Dynamics, Railway Group KTH, Stockholm.
- Choi H.Y., Lee D.H., Lee J., 2013, Optimization of a railway wheel profile to minimize flange wear and surface fatigue, *Wear* 300.
- Minister Administracji, Gospodarki Terenowej i Ochrony Środowiska, 1983, Wytyczne techniczne projektowania, budowy i utrzymania torów tramwajowych, Warsaw.
- Nadal M.J., 1896, *Theorie de la Stabilite des locomotives*, Part II: mouvement de lacet, *Annales des Mines*, 10.
- Novalés M., Orro A., Bugarín M.R., 2007, Use of a genetic algorithm to optimize wheel profile geometry, *Proceedings of Institution of Mechanical Engineers*, Vol. 221, Part F: *Journal of Rail and Rapid Transit*.
- Öberg J., Hartwig P., 2012, Wheel profile optimization for the iron ore wagons on Malmbanan, MiW Konsult AB, Stockholm.
- Persson I., Iwnicki S.D., 2004, Optimisation of railway wheel profiles using a genetic algorithm, Rail Technology Unit, Manchester.
- PKP Intercity, 2010, Bt-11, Instrukcja pomiarów i oceny technicznej zestawów kołowych pojazdów trakcyjnych, Warsaw.
- Polach O., 2010, Wheel profile design for target conicity and wide tread wear spreading, *Wear* 271.
- Shevtsov I.Y., 2008, *Wheel/Rail Interface Optimisation*, praca doktorska, Delft.
- Shevtsov I.Y., Markine V.L., Esveld C., 2008, Design of railway wheel profile taking into account rolling contact fatigue and wear, *Wear* 265.
- Staśkiewicz T., Nowakowski T., 2016, Analiza współpracy koła tramwajowego z szyną w warunkach rzeczywistej eksploatacji, *Problemy Kolejnictwa* (publication in progress).

ACKNOWLEDGEMENTS

All the presented work is realized within the framework of a research project „Identification and modeling of nonlinear phenomena at the wheel/rail contact area for the development of a new tramway wheel profile” (LIDER/20/521/L-4/12/NCBR/2013), that has been started with a financial support from the Polish National Centre for Research and Development.

WERYFIKACJA ZACHOWANIA DYNAMICZNEGO KOŁA TRAMWAJOWEGO O NOWYM PROFILU

Streszczenie

Niniejszy artykuł jest poświęcony symulacyjnej weryfikacji dynamicznych własności kół tramwajowych o nowym profilu, który opracowano na drodze optymalizacji kształtu, której funkcją celu była redukcja rozmiarów przerw między punktami kontaktu koła z szyną. Sprawdzono następujące wielkości: współczynnik bezpieczeństwa przeciwko wykolejeniu, przesunięcie poprzeczne zestawu kołowego, spokojność biegu, liczbę punktów styku oraz współczynnik intensywności zużywania. Celem pracy było określenie czy nowy profil może być wdrożony do eksploatacji w polskich sieciach tramwajowych oraz czy jego własności dynamiczne uległy poprawie względem profili obecnie eksploatowanych. Przejazdy symulacyjne były prowadzone na torach o rzeczywistej, zmierzonej geometrii. Zauważono, że nowy profil miał znacznie lepsze właściwości zużyciowe, lecz bezpieczeństwo jazdy było dyskusyjne.

Słowa kluczowe: współpraca koła z szyną, symulacja układów wielomasowych