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MODIFICATION OF THE WHEEL PROFILE TO IMPROVE VEHICLE EFFICIENCY DURING RIDE IN SMALL-RADIUS CURVES

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ВДОСКОНАЛЕННЯ ПРОФІЛЮ КАТАННЯ КОЛЕСА ДЛЯ ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ВПИСУВАННЯ ТРАНСПОРТНОГО ЗАСОБУ В КРИВІ МАЛОГО РАДІУСУ

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The process of ride in curved track sections is a serious problem of railway transport that requires high attention. Vehicle as well as track parameters have to be taken into account. Special attention is taking place in the environment of mass transit, for which higher amount of small radius curves being apllied is specific. The outcome of such operation of vehicles is an increase in vehicle's effects on the track in the rail-wheel contact resulting in increased ride resistance, creep in the rail-wheel contact patch, speeding up the process of wear in the contact-pair as well as noise generation. At present, a variety of technical solutions for the vehicle bogie design as well as rail designs focused on decreasing of these negative effects exists. Their use in smaller radius curves however, cannot give acceptable results and often causes complications in bogie design. The authors give a concept of creep reduction in rail-wheel contact in this paper, which doesn't require complicated bogie design. The proposed solution is supported by dynamcial analysis simulation of the vehicle ride.

Keywords: *creep in wheel-rail contact, track curves of small radius, wheel profile.*

Introduction. Currently used solutions for reducing the wear of rail-wheel pair and especially noise include lubricating devices installed in the rail or the vehicle, widening of the track free channel [13], setting the bogie axles to radial position, independent mount of the wheels on the axle [8], optimalization of the ride surface of the wheel [14], adding mechatronic parts into bogies, placing noise-absorbing rubber parts in the bogie and in the rail seating. [3, 4, 6] These solutions are focused on reducing the negative effects, but do not eliminate its cause in sufficient measure, or their application leads inevitably to complicated design of the bogie.

Creep in the rail-wheel contact emerges in lateral and longitudinal direction. The creep in lateral direction reaches higher values in curves with smaller radius. However, it is possible to effectively eliminate it by using bogie design, which allows setting of the axles to a radial position. [7] The aim of the work is to find a solution, which would eliminate the cause of longitudinal creep in the wheel-rail contact and still not make the design too complicated. The presented solution is supported by a dynamical analysis simulation of a vehicle ride.

The problem analysis. Curve radius, at which the axle is able to ride through without creep can be determined using the equation:

$$R \geq \frac{2Sr}{\Delta r},\ [\text{mm}] \qquad (1)$$

where:

2S is contact circles distance, mm;

R is wheel radius, mm;

Δr is the value of the wheel profile delta function at the moment the clearance provided by the track channel is completely reduced, mm [5].

For a tram axle designed for a gauge of 1000 mm, with a wheel radius of 340 mm, KP-1 profile, contact circles distance 2S = 1061.9 mm and value Δr 5.5 mm, the minimal value of the curve radius, that can be run theoretically without creep is 65.64 m. For example in Bratislava the city railways vehicles commonly operate on tracks with radiuses starting from 17 m. It is therefore necessary to examine the options of increasing the Δr value in formula (1). The relation of the desired Δr value to the track radius can be expressed, based on the formula (1) as shown in Fig. 1.

Increase in the Δr value by increasing the value of the ride surface conicity cannot be seen as a suitable solution. Such intervention in the wheel profile geometry would lead to a more significant undulatory movement and thus worsening the vehicle ride stability at higher velocities. Thereby a conflicting requirement on increasing the Δr value without intervening in the existing wheel profile ride surface geometry.

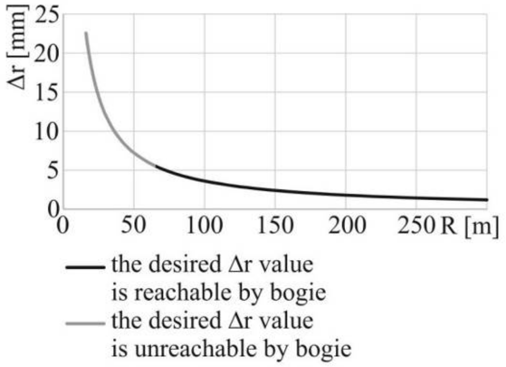

Fig. 1. Desired value Δr necessary for ride in curve without creep

Proposed solution. Described requirement can be fulfilled by creating new point of rail-wheel contact. We suggest solving this situation by using a wheel profile with an extended ride surface designed for a ride in small radius curves, located on the outer side of the wheel profile. A schematically picture of the axle with an extended profile and the principle of its ride through track curve is given in Fig. 2.

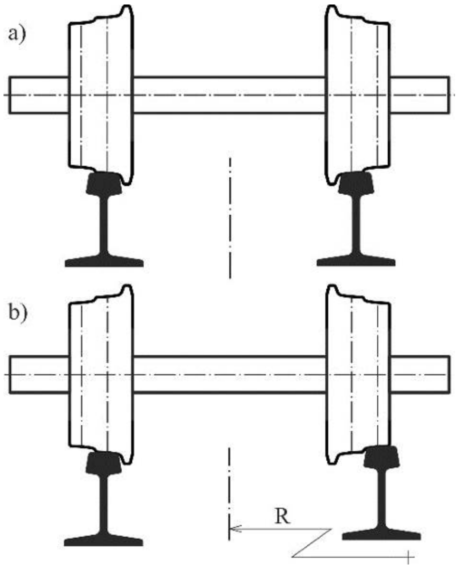

Fig. 2. Wheelset equipped with an additional tread
a – during ride on a straight track, b – during ride in track arc

The inner part of the wheel profile is identical with the former profile. Ride characteristics of the vehicle during ride on a straight track or in curved track with a large radius therefore stays unchanged. An additional tread is designed on the outer part of the profile for ride of the axle on curved track with small radius. In curved track the outer wheel therefore rides on the additional tread of a smaller radius, allowing the required shift in delta r function curve to be achieved.

For an effective use of the additional tread, it is necessary to determine its displacement from the original profile in lateral and vertical direction appropriately, defined using the dimensions y and z on Fig. 3. For creating the geometry of the secondary tread, it is possible to use a segment of the original wheel tread.

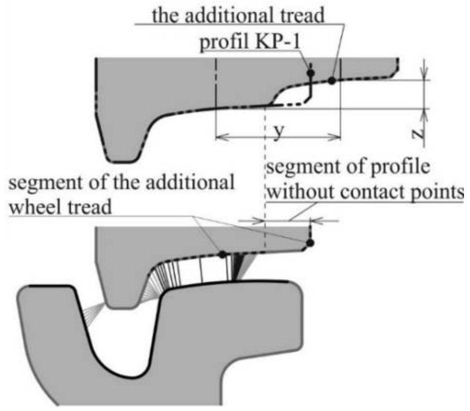

Fig. 3. Placement of the additional tread on the wheel profile

The displacement in lateral direction should be minimal, to avoid significant increase in material volume and thus the mass of the wheel rim. However, its minimal value is limited by the distribution of the given wheel-rail pair contact points. For placing the additional tread, we suggest using the outer part of the original wheel profile, where the profile doesn't have any contact points with the rail. A certain widening of the wheel profile is necessary nevertheless. In the considered case of profile KP-1, a lateral displacement of the additional tread from the original one y = 50 mm was chosen.

The displacement in vertical direction is dependent on the wheel profile delta r function value at the moment the clearance provided by the track channel is completely reduced. For an effective use of the additional tread to be provided, following formula can be derived for the value z:

$$z = 2\Delta r + \frac{y.\Delta r}{2S}, \text{ [mm]} \qquad (2)$$

In the considered case of the original profile KP-1, the vertical displacement of the additional wheel tread value z is 11.5 mm. The required and achieved Δr value curve (as given in Fig. 1) is therefore changed in a way shown in Fig. 4.

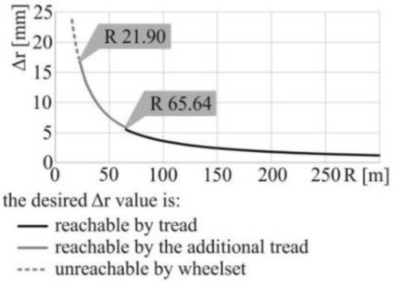

Fig. 4. Desired and attainable Δr value for ride of the wheelset in curve without creep

Based on the given theoretical consideration it is possible to expect more favorable ride in curve with a radius smaller than 65.64 m thanks to the use of an additional tread. A theoretical prerequisite for a wheelset ride without creep is created for a track curve radius of up to 21.9 m.

Vehicle ride simulation. For the purpose of verifying this prerequisite, a series of vehicle ride dynamics simulation analysis was performed in simulation program SIMPACK with the aim of finding the dependency of the monitored quantities from the track curve radius [1, 2, 9, 10, 12]. From among the examined quantities, the power dissipation arising from the vehicle ride resistance in track curve represents the effectiveness of the vehicle ride in curved track well. The curves of this quantity in three different situations are compared in this article. In the first case, a vehicle without the possibility of steering the wheelsets nor the wheel profile with additional tread is considered. In the second case we consider a vehicle with a steering wheelsets possibility and without the proposed wheel profile design. The third case considers a vehicle with steering wheelsets equipped with the described new wheel profile design. The vehicle parameters basically resemble the ones of a T3 tram.

For obtaining an overall view of the vehicle behaviour it is necessary to evaluate the monitored quantities in dependence on the track curve radius. One of the ways to achieve such dependence is a simulation of vehicle ride along a track transition curve of a sufficient length. A track transition curve is a track section, where the radius of the curve is continously changed. It can have various shapes. According to the TNŽ 73 63 61 standard [13], a transition curve in the shape of a clothoid is allowed to be used in the track. In case the clothoid connects a straight track section with a circular curve, it is possible to calculate the values of its virtual radius in the considered place with the use of the following formula:

$$R = \frac{R_2 . l}{s} \text{ [m]}, \qquad (3)$$

where

R is the track curve virtual radius, m;

R_2 is the radius of the circular track curve on the end of the transition curve, m;

l is the overall length of the transition curve, m;

s is the transition curve length measured from its beginning to the considered place, m.

In case the radius changes smoothly enough, the track section on which the vehicle is located currently can be considered as an curve with a constant radius. Therefore, the distance travelled along the track represented on the horizontal axis of the considered quantity curves can be calculated with the use of formula (3) for the track curve radius in the considered place.

In the subsequent simulation, a ride on a track composed from a straight section designed for consolidation of the vehicle ride, a track transition curve in the shape of a clothoid with a length of 10 km and a circular arc with a radius of 17 metres. The shape of the track is shown in the Fig. 5.

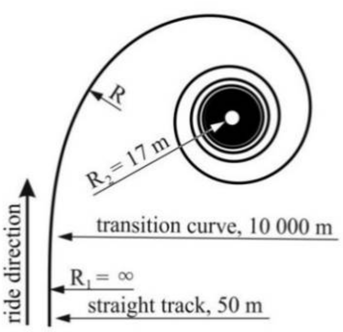

Fig. 5. Track in the shape of a transition curve

Results. Comparison of the vehicle power dissipation during a ride at the speed of 10 km.h^{-1} is given in Fig. 6. Because of a big amount of the calculated values, only power dissipation curves for the curve radius interval from 17 to 100 m, hence the area, where an effective application of the proposed design can be expected are presented. Power dissipation needed to cover the creep in longitudinal direction P_x and in lateral direction P_y are given separately, but the vehicle covers both power dissipations at the same time.

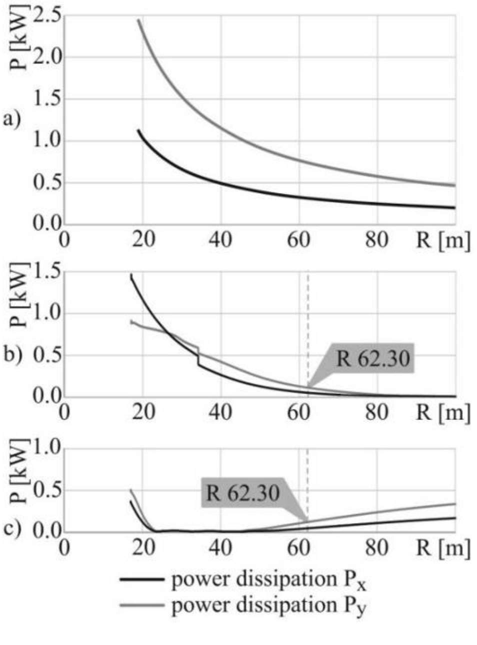

Fig. 6. Power dissipation of the vehicle:
a – without the possibility to steer the wheelsets and additional tread, b – with the possibility to steer the wheelsets and without additional tread, c – with the possibility to steer the wheelsets and with the use of additional tread

Based on the simulation analysis of a ride in track transition curve it can be concluded, that in the case of vehicle ride in track curve with a small radius, it is possible to achieve more favorable ride parameters in a wider track curve radius interval.

From the comparison of the given simulation analysis can be evaluated, that a ride of a vehicle with use of an additional tread is more favorable in a curve with a radius smaller then 62.3 m in terms of power dissipation curves. From the given graphs it is evident, that it comes to significant reduce of negative effects in the monitored area when using the additional tread. In the track curve radius range of 23.55 to 44.88 m the power dissipation is practically eliminated.

For the described way of vehicle ride in track curves with small radius to be able to be put to use, it is necessary to focus on creating an altered regime of wheel rolling during ride as well as examining vehicle response to such change. The authors are currently dealing with the problem.

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Хаусер В., Лоулова М., Ноженко О.С., Кравченко К.О. Вдосконалення профілю катання колеса для підвищення ефективності вписування транспортного засобу в криві малого радіусу

Важливим питанням, що вимагає додаткових досліджень, є процес проходження кривих ділянок колії. Особливої уваги вимагає дане питання в умовах організації міського руху на залізничному транспорті, особливістю якого є наявність великої кількості кривих малого радіуса, що призводить до виникнення підвищеного впливу в контакті «колесо-рейка», підвищенню опору руху, зносу і шуму, збільшується швидкість ковзання в контакті «колесо-рейка». Авторами розглядається можливість зменшення поздовжньої швидкості ковзання шляхом модифікації поверхні катання колеса і рейки. Розроблено технічне рішення, яке спрямоване на усунення швидкості ковзання в контакті «колесо-рейка» - причини виникнення підвищеного впливу транспортного засобу на колію - без значного ускладнення конструкції візка. Запропонована модифікація профілю колеса шляхом створення додаткової поверхні катання, призначеної виключно для проходження кривих ділянок колії малого радіуса. Запропоноване технічне рішення відповідно до результатів моделювання руху рухомого складу в кривій малого радіусу дозволяє проходити криві радіусом від 65,64 до 21,9 м без проковзування, що призведе до зменшення опору руху, зниження зносу в контакті «колесо-рейка» і шуму, також дозволить поліпшити ходово-динамічні якості екіпажу при проходженні кривих малого радіусу.

Ключові слова: *відносна швидкість руху в контакті колеса з рейкою, крива малого радіусу, профіль колеса.*

Хаусер В., Лоулова М., Ноженко Е.С., Кравченко Е.А. Усовершенствование профиля катания колеса для повышения эффективности вписывания транспортного средства в кривые малого радиуса

Важным вопросом, требующим дополнительных исследований, является процесс прохождения кривых участков пути. Особенного внимания требует данный вопрос в условиях организации городского железнодорожного движения, особенностью которого является наличие большого количества кривых малого радиуса, что приводит к возникновению повышенного воздействия в контакте «колесо-рельс», повышению сопротивления движения, износа и шума, увеличивается скорость скольжения в контакте «колесо-рельс». Авторами рассматривается возможность уменьшения продольной скорости скольжения путем модификации поверхности катания колеса и рельса. Разработано техническое решение, направленное на устранение скорости скольжения в контакте «колесо-рельс» - причины возникновения повышенного воздействия транспортного средства на путь - без значительного усложнения конструкции тележки. Предложенена модификация профиля колеса путем создания дополнительной поверхности катания, предназначенной исключительно для прохождения кривых участков пути малого радиуса. Предложенное техническое решение в соответствии с результатами моделирования движения подвижного состава в кривой малого радиуса позволяет проходить кривые радиусом от 65,64 до 21,9 м без проскальзывания, что приведет к уменьшению сопротивления движению, снижению износа в контакте «колесо-рельс» и шума, также улучшаться ходово-динамические качества экипажа при прохождении кривых малого радиуса.

Ключевые слова: *относительная скорость скольжения в контакте колеса с рельсом, кривая малого радиуса, профиль колеса.*

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