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TO THE QUESTION OF MODELING OF WHEELS AND RAILS WEAR PROCESSES

Purpose. There is a need of wear process modeling in the wheel-rail system. This is related to the fact that the wear processes in this system are absolutely different in the initial and final stages. The profile change of rail and, especially, of the wheels caused by the wear significantly affects the rolling stock dynamics, traffic safety and the resource of the wheels and rails. Wear modeling and the traffic safety evaluation requires the accounting of the low frequency component forces (including the modeling of transitional areas) affecting the wheel on the side of the rail and carriage in motion of rolling stock, so the statistical analysis is not possible. **Methodology.** The method of mathematical modeling of the wheel set and the rail interaction was used during the research conducting. **Findings.** As a result of the modeling of the wheel set motion on the rail track, the mathematic model with 19 freedom degrees was obtained. This model takes into account the axle torque and studies wheels constructions as the components of the mechanical systems, consisting of a hub and tire. **Originality.** The mathematic model allows evaluating the wear degree of the wheels and rails when using on the rolling stock not only all-metal wheel sets, but also compound ones with the use of spring wheels and independent rotation of semi-axes with the wheels. **Practical value.** The development of the improved mathematical model of freight car wheel set motion with differential rotation of the wheels and compound axles allows studying the wear processes of wheels and rails.

Keywords: wear; modeling; traffic safety; wheel set oscillations; rolling stock dynamics

Introduction

The most common existing models of railway vehicle oscillations are maladapted to solving the problems related to the wear of railway wheels and tracks and to the forming of traction and braking forces. These models describe in detail the movement of vehicle body and bogies, perturbed by kinematic assignment of the wheels and rails irregularities or by wheel center accelerations [1, 12, 15]. Such models allow considering the low-frequency region of the oscillation spectrum on the sufficiently long track section and the influence of the bogie constructive parameters on the car body oscillations. In this case the high-frequency components of the wheels and rails oscillation spectrum are out of consideration. One should pay a tribute that these problems are reflected in investigation of the noises occurring in the motion of vehicle [13], but not in investigation of the wear of these important system elements. In these cases, we think it would be correct to describe in detail oscillations in the system "wheel set-rails" (hereinafter referred to as – ws-r) caused by their irregularities at the given comparatively low frequency dynamic forces into the points of the wheel centers. These forces affect the ws-r on the side of the bogie elements due to the oscillations of the bogie and body of the vehicle. Previously various authors studied the mathematical model of oscillations of both the rail vehicle in general and its separate elements [2, 6, 7, 8, 9]. However, Professor De Pater [5] analyzed the wheel set movement including and excluding the rail tracks irregularities, although in simplified form.

Purpose

Thus, nowadays, there is a need of wear process modeling in the wheel-rail system. This is related to the fact that the wear processes in this system are absolutely different in the initial and final stages. The profile change of rail and, especially, of the wheels caused by the wear significantly affects the rolling stock dynamics, traffic safety and the resource of the wheels and rails. Wear modeling and the traffic safety evaluation requires the accounting of the low frequency component forces (including the modeling of transitional areas) affecting the wheel on the side of the rail and carriage in motion of rolling stock, so the statistical analysis is not possible.

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Methodology

During research the method of mathematical modeling of the wheel set and the track interaction was used. A simple analysis shows that in the case of the wheel motion with a real flat spot of the 20 mm length and the "depth" relative to the thread surface 0.1 mm the duration of the rolling wheel is 1 ms at a speed of 20 m/sec. It corresponds to the move frequency of the contact on the vertical of 0.5 kHz (assuming that the impact duration corresponds to half of the period of sinusoidal oscillation). Acceleration of the contact point in conditions of above mentioned impact interaction equals 1000 m/s^2. If the rim, approximate weight of which is 0.21 t. will move with such vertical acceleration, then inertial force of the rim only will equal 210 kN (taking into account that the static loading on the rail is 108 kN).

At the same time, according to the paper [10] natural frequency of the wheel rim rotation “relative to the axle, which is perpendicular to the center line of the wheel” is only 187 Hz, the natural frequency of central displacement of the rim is 340 Hz and the lowest forms of the rim bending – are 366 and 947 Hz. The natural frequencies of the wheel set torsional oscillations with drive elements of electric locomotive of the type E120 equal 16 and 50 Hz [3, 7]. On the other hand, for example, in case of the wheel-rail adhesion break or in case of wheel sliding there appear torsional oscillations of the wheel set with relatively high frequency and the bearing point vibration of the wheel relative to the rail in the longitudinal direction. Considering that on these vibrations can be imposed the vertical forces, which can both unload the contact or load it, then these movements of the wheel and contact can have a substantial role on the movement resistance of the certain wheel set, on the level of traction force being realized by the wheel and on the erosion and wear, including the corrugations of the rails. In the case of excitation of torsional oscillations of wheel set or rims, the frictional force occurring in motion will have the wearing influence on the rail at a frequency twice as much as the frequency of the natural torsional oscillations. Fluctuations of the vertical force will modulate the friction force of the friction oscillations. Owing to this modulation in the friction force spectrum wearing the rail will be the components of a double frequency of wheel set torsional oscillations and of frequencies, which are equal in the sum and difference of the doubled frequencies of torsional oscillations and the frequencies of vertical force changes of the interaction between wheel and rail. Oscillations with the smallest differences Ω_{min} (in Hz) of these frequencies determine maximum length λ_{max} of corrugations in the track section with the given average velocity $\bar{v}$ of car movement. The wavelength λ_{max} is calculated by the ratio $\lambda_{max}=\bar{v}/\Omega_{min}$. Certain rail defects run the mechanism of the wearing oscillations at the given track section, which causes the wearing of rails and all the wheels of train.

On the other hand, during the wheel motion on the tracks occur the surface waves of sufficiently high frequency. These waves occur as a result of unavoidable sliding of the contact patch relative to the rail and vertical interaction forces. The most interesting waves among them are probably the Rayleigh and Love waves [11]. The Rayleigh wave causes the displacement of the rail surface points in horizontal (along the rail) and vertical direction. If the vertical displacement of the rail surface can be neglected because of its smallness, the horizontal displacement, despite of its smallness, has a significant velocity of displacement due to the high frequency of oscillations. This will certainly have an impact on the relative sliding velocity of the wheel contact point relative to the rail, so it will have an impact on the wear of the wheel and the rail surface. If the Rayleigh surface waves occur in the isotropic body, the surface Love waves causing the horizontal displacement of the surface points perpendicular to the direction of motion, occur in bodies with the blanket. This blanket is formed in the rails and on the wheel thread during processing treatment. Oscillations corresponding to the Love waves are also high frequency. They can lead to significant velocity of points displacement in the transverse direction and hence to the wear. Furthermore, in this case the surface curvature of rail bearing and wheel thread can somehow influence integrally the lateral forces and motion resistance, which is an independent task and requires a special consideration.

Findings

Excitation of the surface waves during the rolling stock motion results in the formation of standing waves in certain track sections, which are lim-

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ited by the clinches or surface defects. In the antinodes of displacement velocities the high frequency wheel slides relative to the rails occur. They provoke rapidly changing friction forces and intense wear relative to the other sections of the rails, which in turn leads to the wavelike shortwave rail wear. At this wavelike wear the wavelength should be twice shorter than the length of the standing wave.

Thus, the above-described cases of the wheel set dynamic loading lead to the need of more detailed study of the formation of wheel set fluctuations in the interaction with the rails.

In this paper the movement of the wheel set is generally presented (Figure 1) as a spatial motion in the following manner:

1. The translational motion of the wheel rims relative to the wheel hub.
2. Spatial translational movement of the wheel set axle with the hubs of the wheels and axle boxes.
3. Rotational movement of the wheel set relative to the vertical and longitudinal axes.
4. Rotational (including torsion) motions of the wheels, combined with the half of the axle of the wheel set relative to its axis.
5. Reduced masses of the track defining starting resistance of the track during its high frequency interaction with the wheels.

As a result of modeling of the road wheel pair motion on the track the mathematical model with 19 freedom degrees is obtained. This model allows accounting the axle torsion, as well as studying the wheel design as a complex mechanical systems consisting of a hub and tread.

Originality and practical value

Parameters of connection of two parts of the wheel set during its rotation around its axle can be defined as the parameters of the wheel set axle torsion. These parameters can be changed with time depending on the boundary conditions of the torsion. The conditions are defined by the wheel slide relative to the track. In case only one wheel is in adhesion with the rail, the parameters correspond to the torsion form of the wheel set with a choked right or left wheel and free opposite wheel. In case both wheels slide, the parameters are chosen on the basis of the torsion form with two free wheels. If there is no sliding on both wheels, the parameters are chosen on the basis of the torsion form with two choked wheels.

In order to exclude the value gaps of the generalized forces in the moments of changing of the wheel set torsion parameters during the integration of the motion differential equations, the generalized forces are calculated at the each time stage of numerical integration by adding of their change at the stage to the strength value at the previous stage.

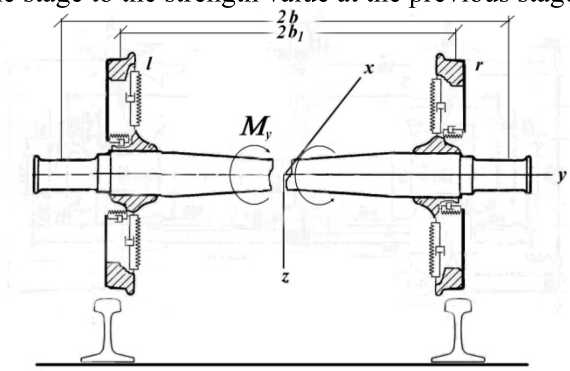

Fig. 1.

It should be noted that the separation of the wheel rims into separate solids in the design scheme of wheel set is described in [1] and in [14] in relation to the locomotives with rubberized wheels. Thus, the presented mathematical model allows evaluating the wear degree of the wheels and rails when using on the rolling stock not only all-metal wheel sets, but also the compound ones with the use of spring wheels and independent rotation of semi-axes with the wheels.

Conclusions

The feature of the work is research of the similar model in relation to the wheel sets with steel wheels. In the paper [4] the wheel rim displacement relative to their hubs is partially studied. In general, the wheel set movement of the freight car is described by the 19 freedom degrees.

Thus, an improved mathematical model of the freight car wheel set motion is presented. The model allows one to research the wear processes of the wheels and rails.

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ЩОДО ПИТАННЯ ПРО МОДЕЛЮВАННЯ ПРОЦЕСІВ ЗНОСУ ЗАЛІЗНИЧНИХ КОЛІС І РЕЙОК

Мета. Існує необхідність моделювання процесу зношування в системі колесо-рейка. Це пов'язано з тим, що процеси зношування в цій системі на початковій та кінцевій стадіях протікають істотно по-різному. Причому зміна профілів рейок і, особливо, коліс, викликана зношуванням, суттєво позначається на динаміці рухомого складу, безпеки руху, ресурсі коліс і рейок. Моделювання зношування і оцінка безпеки руху екіпажу вимагає врахування низькочастотних складових сил (у тому числі при моделюванні перехідних ділянок), що діють на колесо з боку рейки і екіпажу при русі рухомого складу, тому статистичний аналіз неможливий. **Методика**. При виконанні досліджень застосовується метод математичного моделювання взаємодії залізничної колісної пари і рейкового шляху. **Результати.** У результаті виконаного моделювання руху дорожньої колісної пари по рейковому шляху отримано математичну модель з 19-тьма ступенями свободи, що дозволяє враховувати кручення осі, а також розглядати конструкції коліс як складових механічних систем, що складаються з ступиці і бандажа. **Наукова новизна.** Представлена математична модель дозволяє оцінювати ступінь зношування коліс і рейок при використанні на рухомому складі не тільки суцільнометалевих колісних пар, а й складових, з використанням підпружинених коліс і незалежним обертанням піввісей з колесами. **Практична значимість.** Створення вдосконаленої математичної моделі руху колісної пари вантажного вагона з диференційованим обертанням коліс і складовими осями дозволяє досліджувати процеси зносу коліс і рейок.

Ключові слова: знос; моделювання; безпеку руху; коливання колісної пари; динаміка рухомого складу

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К ВОПРОСУ О МОДЕЛИРОВАНИИ ПРОЦЕССОВ ИЗНОСА ЖЕЛЕЗНОДОРОЖНЫХ КОЛЕС И РЕЛЬСОВ

Цель. Существует необходимость моделирования процесса износа в системе колесо-рельс. Это связано с тем, что процессы изнашивания в этой системе на начальной и конечной стадиях протекают существенно по-разному. Причём изменение профилей рельсов и, особенно, колёс, вызванное изнашиванием, существенно сказывается на динамике подвижного состава, безопасности движения, ресурсе колёс и рельсов. Моделирование износа и оценка безопасности движения экипажа требует учёта низкочастотных составляющих сил (в том числе при моделировании переходных участков), действующих на колесо со стороны рельса и экипажа при движении подвижного состава, поэтому статистический анализ невозможен. **Методика.** При выпол-нении исследований применяется метод математического моделирования взаимодействия железнодорожной колесной пары и рельсового пути. **Результаты.** В результате выполненного моделирования движения дорожной колесной пары по рельсовому пути получена математическая модель с 19-тью степенями свободы, позволяющая учитывать кручение оси, а также рассматривать конструкции колес, как составных механических систем, состоящих из ступицы и бандажа. **Научная новизна.** Представленная математи-ческая модель позволяет оценивать степень износа колес и рельсов при использовании на подвижном составе не только цельнометаллических колесных пар, а и составных, с использованием подпружиненных колес и независимым вращением полуосей с колесами. **Практическая значимость.** Создание усовершенствованной математической модели движения колесной пары грузового вагона с дифферен-цированным вращением колес и составными осями позволяет исследовать процессы износа колес и рельсов.

Ключевые слова: износ; моделирование; безопасность движения; колебания колесной пары; динамика подвижного состава

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