INTERACTION BETWEEN ROLLING STOCK AND RAILWAY TRACK WITH OF THE ELASTIC PROPERTIES OF THE BASE

Prof. Dr. Myamlin S. [1], Assoc. Prof. Dr. Bondarenko I. [1]
Dnipropetrovsk National University of Railway Transport named after academician V. Lazaryan, Ukraine[1]

sergeymyamlin@gmail.com

Abstract: *The main trend in considering the interaction of the railway track and the rolling stock is the studying of the parameters of the rigidity of the interaction. For the study, a model of the track design, described using the basic concepts of the theory of elasticity and the propagation of elastic waves was developed. The study of the peculiarities of the interaction of the rolling stock and the track, taking into account the elastic properties of the base, allows to expand the possibilities of solving the problems of ensuring their functionally safe operation with a certain level of operational efficiency.*

Keywords: DYNAMIC PROCESS, OSCILLATIONS, POWER WAVE, PHYSICAL AND MECHANICAL FEATURES OF THE INTERACTION

1. Introduction

The main trend in considering the interaction of the railway track and the rolling stock is the studying of the parameters of the rigidity of the interaction. It is necessary to use not only equivalent parameters obtained in the experiment, but also parameters related to specific interaction conditions. The parameters of the railway track and the rolling stock, are the key to obtaining effective solutions in the tasks of ensuring their functionally safe operation with a certain level of efficiency taking into account the real constructive physical and mechanical features of the interaction.

All the issues related to determining reliable, functional and safe railroad track operation imply the exploration of dynamic processes in the track design that occur under the influence of the rolling stock.

A study of the dynamic process interconnects the following tasks: determining the types and magnitudes of the forces acting on the track depending on the position of the wheelset in a track, location and types of the contact between wheels with rails which depend on the condition of the wheels and rails, as well as a change in the stressed-strained state of the track over time. When describing the dynamic process, the magnitudes of vertical forces that act on the track were determined as functions of the longitudinal compressive forces [1]. The magnitudes of transverse forces – by dependences of the calculation of the rolling stock aligning with the track [1, 2]. The question on the types of contact between wheels and rails required separate consideration. Typically, when analyzing the contact between a rail and a wheel, a rail is considered either new or with a side wear of 3.5 mm, at which the rail is believed to be little worn-out, and a side wear of 7.8 mm, at which the rail is considered to be medium worn-out. Papers [3, 4] present modern analysis of the wear of wheels for different profiles. A separate research was conducted by the results of these articles, the outcomes of which are given in [5].

The time of influence of the rolling stock on the railroad track depends on the motion speed. The duration of these processes depends on the physical and structural characteristics of the elements of design of the railroad track. The existing methods for the calculation of parameters of the stressed strained state of the track by the influence of the rolling stock by canons of the method of finite elements or boundary elements describe physical and structural characteristics of the track design elements in full. But they do not take into account such phenomena as the period of the load passage over the elements of the track, the time of occurrence of reactions to the load from these elements, and the correlation of load action time and the duration of processing of this load by elements of the track design. The lack of a temporal component does not allow to describe the dynamic processes in full. The use of quasi dynamic methods changes the essence of dynamic processes. Thus, the application of quasi dynamic forces causes the track deformation, at which the sagging of rails and anchor system shifts along with the motion of the train despite the divergence of occurrence, over time, of maximum sagging in the elements of track design.

In the course of such studies, the calculations are performed for different values of frequency of quasi dynamic excitation, defined as the ratio of speed to the magnitudes of distances between the wheels of one bogie and adjacent bogies, or distance between the supporting elements of the track. And though all acknowledge that the speed of motion affects the frequency of excitation but the magnitude of frequency of excitation, determined by the ratio of the length of the contact area of the rail with the wheel to the duration of dynamic load action on the track (motion speed to length of the contact area) is not used in these calculations. In the physical essence, excitation frequency, inversely proportional to the geometric lengths of position of the wheels in the train, characterizes the recurrence of load occurrence in the examined track intersection. And for static calculations, it characterizes part of the force that acts in the examined track intersection in a certain point in time. When moving the load, the distance between the force application place and the examined intersection changes. Thus, not only the part of the magnitude of forces that acts in the examined intersection also the vector of force changes. And the frequency of excitation, inversely proportional to the period of action of the load by physical essence is characterized by an impulse of load, which acts on the track and allows to apply the basic equation of dynamics.

Thus, in order to examine the dynamic processes of deformability of the track, it is necessary to take into account the differences between static and dynamic characteristics of loads. The changes proposed will make it possible to evaluate the work of a railroad track under the influence of the rolling stock depending on the design features of the track structure over particular period of time. This will allow us to compare characteristics of the track operation, obtained by actual parameters, to characteristics of its work and to determine actual period of its operation. The changes proposed will also provide for the possibility under the assigned operating conditions to define, by the criteria of reliability, the design of the track or measures related to its strengthening with the provision of certain resource of its work.

2. Problem discussion

Currently, many research have been devoted to the study of the mathematical description of the impacts acting from railway track to the rolling stock. In all studies it was believed that the reaction of the railway track to the impact of the rolling stock is instantaneous. In addition, the results of the recorded disturbance obtained on the rolling stock in the experiment are not classified according to the constructions characteristics of the railway tracks. It is assumed that the elastic and dissipative characteristics of the path determine the amplitude-frequency characteristics of the oscillations. But they are yet not classified according to the physical-mechanical and geometric characteristics of railway track construction elements. To create such classification, it is necessary to study the mechanism for transferring force from the rolling stock to the elements of the track in time. This problem will be theoretically investigated within this work. The problem can be formulated as follows: how do the physic-mechanical properties of railway track elements affect the process of propagation of force from the rolling stock to the construction of the track?

3. Objective and research methodologies

The main purpose of this work is to study the process of transferring force from the rolling stock to the elements of the track in time.

For the study, a model of the track design, described using the basic concepts of the theory of elasticity and the propagation of elastic waves was developed [6, 7].

The mechanism of action of the rolling stock on the track is represented by pulses that excite the contact areas of the rails with wheels located along the track. The excitation of contact areas takes place taking into account the time of occurrence and the effect of loads in them. The specified intervals of the action time of the pulse depend on the speed of the trains. The impulse along the construction of the path is propagated by the power waves. The propagation of a power wave in the elements of the track structure is described as the process of excitation and propagation of volume longitudinal and transverse spherical waves, taking into account their properties.

These introductions made it possible to obtain analytical dependencies to determine the features of dynamic load propagation. These include: two types of transmission frequencies of dynamic load, variable directivity in time, the relationship between the amplitudes of oscillations both within the elements and during the transition from one element to another. That allows us to describe the process of propagation of a power wave in the construction of a track in time, taking into account the inverse reaction of the elements on them.

Underlying this modeling is the existence of wave processes that are caused by both external and own oscillations.

All oscillations generated by the contacting surfaces, which, up to the given point, have not touched or have renewed their contact after a break, propagate by spherical waves. They characterize the main direction of propagation of the wave process from a new or renewed contact between surfaces and account for the contact and local concentrations of stresses and deformations.

All oscillations generated by the contacting surfaces, which, up to the given point, have touched and established contacts, propagate by quasi spherical waves. They characterize the basic direction of propagation of the wave process from the contact point of the surfaces and account for the non-uniformity of oscillating. But one spherical wave of incidence that carries the longitudinal and transverse mode causes four quasi spherical refracted waves: two longitudinal and two transverse. Each of them is heterogeneous, as it has vivid dependence of the change in characteristics in its direction and carries the consequences from the neighboring refracted waves in other directions.

Since in the process of propagation there is the superposition of waves, it characterizes the non-uniformity of the whole process of oscillating. Thus, in every point of the design in a certain period of action, one will observe either homogeneous spherical and (or) non-uniform quasi spherical waves. In general, the oscillations that propagate by quasi spherical waves cannot be predicted based on approximation.

The use of wave properties in the propagation of force in the elements of the track structure allows:

a) to establish that the deformability process in the design of the track is due to the presence of wave processes, the nature of which depends on the physic-mechanical and geometric properties of the track elements.

In order to consider the transfer of force between the elements, let us consider the contact pair of a rail-gasket with the characteristics given in Table 1.

Table 1. *Physical-mechanical characteristics the contact pair of the rail - gasket*

Element	Density, кг/м^3		Poisson's coefficient		Young's module E, МПа		C_l,м/с [1]		C_t,м/с [2]	
rail	7830	7830	0,24	0,3	2,1x10^5	2,1x10^5	5622	6008	3288	3211
gasket	918	935	0,3	0,485	100	200	382	1572	204	268

1 - the speed of longitudinal; 2 - the speed of transverse waves in the material.

Angles characterizing the process of transmission of power waves for the contact rail-gasket pair are given in Table 2. Where p-inc –longitudinal wave of incidence and s- inc – transverse wave of incidence, p-refl – refracted longitudinal wave and s-refl – transverse refracted wave, p-refl – longitudinal wave of reflection and s-refl – transverse wave of reflection.

Table 2. *Characteristics of the angles of the wave process in the contact pair of the rail - gasket*

Contact pair	Angles, degree							
	incidence	reflection		refraction		critical		
						I	II	III
longitudinal wave								
	p- inc	p-refl	s-refl	p-refl	s-refl			
rail - gasket	10	10	5,33-5,83	0,68-2,788	0,34-0,47			
	20	20	10,53-11,54	1,33-5,49	0,67-0,94			
	30	30	15,50-17,00	1,95-8,04	0,98-1,37			
	40	40	20,10-22,08	2,51-10,36	1,25-1,76			
	50	50	24,17-26,62	2,9-12,379	1,50-2,10	-	-	-
	60	60	27,58-30,43	3,38-14,02	1,69-2,37			
	70	70	30,15-33,34	3,67-15,24	1,83-2,57			
	80	80	31,76-35,17	3,85-15,99	1,92-2,69			
transverse wave								
	s- inc	s-refl	p-refl	p-refl	s-refl			
rail - gasket	10	10	17,27-18,96	1,16-4,88	0,62-0,83			
	20	20	35,79-39,78	2,28-9,64	1,22-1,64			
	30	30	58,74-69,30	3,3-14,174	1,78-2,39			
	40	40	-	3,88-16,52	2,07-2,78	-	-	32,3-35,8
	50	50	-	5,12-22,03	2,73-3,67			
	60	60	-	5,79-25,09	3,09-4,15			
	70	70	-	6,28-27,39	3,35-4,50			
	80	80	-	6,58-28,83	3,51-4,72			

The results shown in Table 2 demonstrate the collecting ability of the gasket. That is, if different forces act on the same surface at angles of 10-80^0, the gasket processes them and combines them, directing the common beam characterizing the p-refl angles (0,68-28,83^0) for longitudinal waves and s-refl (0,34-4,72^0) for transverse waves further. These angles characterize the angles of the reflection process from the edge of the gasket. Knowing the values of the reflection angles at the boundary of the gasket-sleeper contact and the thickness of the gasket, it is possible to form a geometric pattern on the surface of the gasket to improve its damping properties and extend the service life.

For example, Poisson's coefficient for the material (Table 1) of the gasket can vary from 0.3-0.485. If the value of the Poisson coefficient is less than 0.4, the transverse waves will not affect the work of the gasket. Consequently, with values of the Poisson coefficient, less than 0.4 rail will accept loads transmitted by reflected transverse waves, and the gasket will perceive loads carried only by longitudinal waves. The loads transmitted by longitudinal and transverse waves will be transmitted to gaskets when the values of the Poisson factor are more than 0.4. Consequently, the characteristics of the gasket material will impact the possibility of the destruction of the gasket. In addition, the consideration of these questions in time allows us to predict the concentration of waves in the middle of the gasket, characterizing the concentration of its stress-strain state in time.

b) to determine the direction and amplitudes of oscillations in the elements of the track and their displacement from the impact of the rolling stock considering in time.

The oscillation direction of the particle depends on the direction of propagation and the type of wave (Fig. 1). If the wave is a longitudinal *P*, it forces a particle to move in the direction of its propagation. If the wave is transverse to the vertical mode of *SV*, then it forces the particle to move in the plane of propagation, but perpendicular to the direction of propagation. If the wave is transverse to the horizontal mode of *SH*, a particle oscillates in a plane that is perpendicular to the propagation plane.

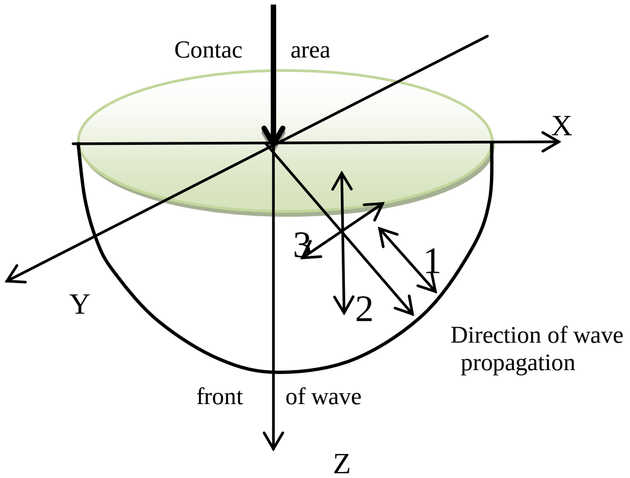

Fig. 1 The scheme of the front of the wave propagation and the directions of oscillation of the particles relative to the direction of propagation of the wave: 1 - direction of propagation of longitudinal waves *P*; 2 and 3 - directions of propagation of transverse waves *S*, respectively *SV* and *SH*

Thus, the direction and amplitude of oscillation of particles in time are formed.

The results shown in Table 3 demonstrate coefficients of reflection and refraction of the wave process in a contact pair of rails with gaskets. The values of the coefficients characterize the change in the magnitude of the amplitudes of the reflection and refraction of the wave processes relative to the amplitude of the wave process of the incidence.

Table 3. *Coefficients of reflection and refraction of the wave process in a contact pair of rails with gaskets*

longitudinal wave				
Angles p- inc, degree	K p-refl	K s-refl	K p-reflr	K s-reflr
10	0,941	0,392	1,950	0,380
20	0,820	0,727	1,852	0,732
30	0,646	0,963	1,701	1,047
40	0,450	1,081	1,512	1,302
50	0,272	1,085	1,302	1,482
60	0,148	0,997	1,083	1,558
70	0,131	0,835	0,855	1,485
80	0,318	0,573	0,569	1,120
transverse wave				
Angles s- inc, degree	K p-refl	K s-refl	K p-reflr	K s-reflr
10	0,847	0,389	0,378	1,943
20	0,467	0,712	0,722	1,824
30	0,029	0,968	0,965	1,725
40	0,708	5,656	0,064	6,964
50	0,799	5,960	0,383	4,774

As indicated above, if the value of the Poisson coefficient is less than 0.4, the transverse waves will not affect the work of the gasket. According to the results shown in Table 3 these conditions correspond with angles s- inc more than 50^0.

c) to regulate energy transfer and the process of oscillation in the elements of the track design by adjusting the physic-mechanical and geometric characteristics of the elements of the track design.

The results shown in Table 3 prove that the ratio of the amplitudes of reflection and refraction amplitude varies depending on the angle of incidence for one and the same material.

Since the energy transferred by the wave is proportional to the square of the amplitude, then the ratio of energy values in the reflected and refracted waves is different at different angles of incidence. This fact provides the possibility of directed forecasting of the deformability of the elements of the railway track by changing the characteristics of materials and the construction of the elements of the railway track by studying the process of the origin and propagation of power waves.

4. Conclusion

The study of the peculiarities of the interaction of the rolling stock and the track, taking into account the elastic properties of the base, allows to expand the possibilities of solving the problems of ensuring their functionally safe operation with a certain level of operational efficiency.

Literature

1. Сокол, Э.Н. «Классический» сход рельсов подвижного состава / Э. Н. Сокол, А.А. Переймыбида, Д.А. Радкевич, под общ. ред. Э.Н. Сокол; К.: Феникс, –2006. –168 с.

2. Myamlin, S. Mathematical Model of Wheelset Oscillations with Independent Wheel Rotation in the Horizontal Plane / S. Myamlin, O. Kirilchuk, V. Metyzhenko // Наука та прогрес транспорту. — 2016. — № 4 (64). — P. 134—140.

3. Ушкалов В. Ф. Типовые формы изношенных профилей колес / В. Ф. Ушкалов, И. В. Подъельников // Техническая механика. – 2009. – № 1. – С. 50 – 55.

4. Ушкалов В. Ф. Увеличение ресурса колесных пар за счет использования износостойких профилей колес / В. Ф. Ушкалов, Н. В. Безрукавый // Техническая механика. – 2015. – № 1. – С. 97 – 103.

5. Бондаренко І. О. Аналіз впливу колісної пари на процес деформативної роботи колії / І. О. Бондаренко. // Тези XIV Міжнародної науково-практичної конференції «Проблеми механіки залізничного транспорту», 25-27.05.2016. Дніпропетровськ, 2016. – С. 26-27.

6. Myamlin, S. Modeling deformability work of the track in determining the dynamic loading of the rolling stock [Text] / S. Myamlin, I. Bondarenko // 6th International Scientific Conference “Advanced Rail Technologies”, 15-16.11.2017. Warsaw, 2017. – P. 79.

7. Bondarenko I. Development of algorithm for calculating dynamic processes of railroad track deformability work // Eastern-European Journal of Enterprise Technologies. – 2016. – №6/7(84). – С. 28–36.