Для оцінки роботи залізничної колії з умов її надійної та функціонально-безпечної роботи створено алгоритм розрахунку динамічних процесів зміни деформативності колії. Запропоновано передачу динамічних навантажень описати шляхом передачі імпульсів. Наведено особливості передачі динамічного навантаження від рухомого складу: два види частот, змінну направленість в часі та зв'язок між амплітудами коливань при переході з одного елементу в інший

Ключові слова: динамічне навантаження, амплітуда коливань, частота збудження імпульсом сили, розповсюдження коливань

Для оценки работы железнодорожного пути из условий его надежной и функционально безопасной работы создан алгоритм расчета динамических процессов изменения деформативности пути. Предложено передачу динамических нагрузок описать путем передачи импульсов. Приведены особенности передачи динамической нагрузки от подвижного состава: два вида частот, переменную направленность во времени и связь между амплитудами колебаний при переходе из одного элемента в другой

Ключевые слова: динамическая нагрузка, амплитуда колебаний, частота воздействия импульсом силы, распространения колебаний

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DEVELOPMENT OF ALGORITHM FOR CALCULATING DYNAMIC PROCESSES OF RAILROAD TRACK DEFORMABILITY WORK

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1. Introduction

All the issues related to determining reliable and 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 depending on 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 [2]. A 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 as 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].

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. 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 in full physical and structural characteristics of the track design elements. 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 this load by elements of the track design. The lack of a temporal component does not allow describing 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 cart and adjacent carts, or distance between the track's supporting elements. 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 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 force magnitude of forces that acts in the examined intersection changes but the vector of force. 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 applying 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, design of the track, or measures related to its strengthening with the provision of certain resource of its work.

2. Literature review and problem statement

By the term dynamic deformability we shall understand the changes that occur in the track design, due to the changes that occur in the elements of track design when loaded. By the process of deformative work of the track we shall understand the phenomena of dynamic deformability that take place under the influence of the rolling stock.

In order to correctly describe dynamic loading, we studied the experience of theoretical modelling. Thus, article [6] considers the pliability of railroad lines using the model of beams on the half-space and using the method of finite elements. Paper [7] compared calculations of vibrations in subway, performed for the model that is described by the method of boundary elements, and by the proposed method of "pipe in a pipe". In the proposed method, the wall tunnel and the ground that surrounds it are modeled in the form of two concentric pipes using the principles of the theory of elasticity continuum. Articles [8, 9] are the continuation of the solid-state research that is developed due to the improvement of characteristics obtained by the experiments and using the method of finite elements. Paper [10] performed numerical dynamic simulation that combined two techniques: three-dimensional model of the motion of wagons and the method of finite elements. This method solved the problem of determining the magnitudes of loads on the track. Article [11] collected analysis of the obtained empirical data and evaluated the models that are used in the calculation of oscillations in the track base on the rolling stock influence, as well as recommendations for further corrections of the models. Papers [6–11] expanded the topic regarding the simulation of oscillations in the track design, but there is an unsolved issue yet of determining the changes in the stressed-strained state of the track under the influence of the rolling stock. Based on the experience gained, a model was developed for determining the processes of deformative operation of a railroad track [12]. Thus, it describes underlying theoretical positions and principles for determining the stressed-strained state in a particular element of the track applying the principles of theory of elasticity and wave propagation. But it is not explained in which way the dynamic loads are transferred from one element of the structure to another one. Thus, this makes us compile a detailed description of the algorithm of dynamic processes in the change of deformability of the track, which would allow us to explore the question regarding reliable conditions of the railroad track performance.

3. The aim and tasks of the study

The research we conducted intended to create an algorithm of dynamic processes of the change in deformability of the track, which would make it possible to examine the question regarding reliable conditions of the railroad track performance.

To achieve the set goal, the following task had to be solved: to describe the peculiarities of the interaction between external and internal forces of the process of deformative work of a railroad track by considering propagation of oscillations in the design of the railroad track.

4. Positions and methods of research into the influence of action of rolling stock on the deformative work of the railroad track

4. 1. The impact of the track design on the algorithm of propagation of the process of track deformability

When examining deformative work of a railroad track, a dynamic process is considered, in which the following tasks are interrelated: determining the types and magnitudes of the forces that act on the track depending on the position of a wheelset in a track, location and types of contacts between wheels depending on the condition of wheels and rails. The magnitudes of vertical forces are determined as functions of longitudinal compressive forces by procedure [1]. The magnitudes of transverse forces are determined by dependences of the calculation of the rolling stock alignment with a track. An analysis of influence of condition of rails and wheels on the parameters of contact of their interaction demonstrated that in the fluctuating process, there are single-point, point-to-point and conformal single-point, point-to-point contacts. The physical process of oscillation is determined by two types of waves. Volumetric waves characterize oscillation of the system due to the action of external influence. The geometry of design determines the process of propagation of volumetric waves. These are the fastest waves. Amplitude of force determines the amplitudes of oscillation of the points of elements and geometrical parameters of the structure firm involved in the process of oscillation. But it is necessary to consider that volumetric waves significantly reduce the part of transverse waves while propagating in wetted materials, reducing its value to zero in water and in the air. That is, the existence of pipes, bridges and other artificial structures considerably affect the presence of transverse waves and the propagation of volumetric waves. Surface waves characterize oscillations of free and tangential surfaces due to the action of elongation forces. They have local effect, lower propagation velocity and their propagation does not depend on the presence of water or air.

In the process of moving, the contact area between a wheel and a rail has variable load from the rolling stock that acts over certain time depending on the motion speed. Therefore, there is a cycle of transferring the load from the wheel to the rail along a certain plane, which is repeated all along the length of the rail. There is also a cyclical movement along the length relative to the supports, where the contact area of the wheel and the rail is in the section from the middle of one support to another one. In this case, there is the symmetry of transmission of oscillations from the rail to the support relative to the middle of the sleeper box. When transferring the loads from the rail to the supports, there is also a cycle, at which the load that is applied to one contact area is passed on to a certain number of supports. And, consequently, it will cause two more cycles: in the first one, the load is transmitted to the ballast layer, while in the second one – to the ground layer. Therefore, if one considers propagation of the process of deformability of the track, we have the following positions.

First, each dynamic load has two types of frequencies: the first type of frequency represents the frequency of the force pulse, and the second one – the frequency of force application per one intersection. The first one accounts for the density and intensity of force pulse transmission in a particular oscillation. And the second one – the density and intensity of force pulse transmission in the totality of oscillations.

Second, each oscillation has its frequency and the area of action. A transfer of the load from the rolling stock to the track is formed by the following oscillation processes:

– the wheels transfer the load to the track through the contact area over a period that depends on the motion speed. At the motion speeds of rolling stock from 10 to 120 km/h, the time of action of the load t ranges from 0.00462 to 0.00044 s. In this case, the frequency of force pulse excitation of intersection of rail ω_f ranges from 1361.6204 to 14266.598 s^{-1}. Geometric zone of action of the wheel depends on the location of the contact area. Transferring the load from the wheel is the oscillation repeated along the length of the rail. The spread (range) of parameters of oscillation depends on the motion speed and contact parameters;

– the influence of wheelsets is a oscillation of the aggregate action of two wheels with their frequency of transferring load pulse ω_f (frequency of excitation of intersections of the rails) and with the aggregate action area. A range of parameters of this oscillation along the length of the track depends on the motion speed and position of the wheelset in a track;

– the impact of carts on the track generates oscillations with the frequency of transferring the force impulse to rails ω_t (frequency of excitation of rails by cart), which depends on the motion speed and geometry of the cart. A range of parameters of this oscillation along the length of the track depends on the motion speed and position of cart relative to the track;

– the impact of carriages on the track generates two types of oscillations. The first one is with the frequency of excitation of the rail by adjacent carts of adjacent carriages ω_w (frequency of excitation of rails by carriages), the second one – with a cycle of excitation of the rail by adjacent carriages of train ω_{rs} (frequency of excitation of rails by train). Both depend on the motion speed and geometry of the carriages. The ranges of parameters of oscillation along the length of the track depend on the motion speed and position of the carriages relative to the track;

– the impact of carriages on the rails creates three processes of oscillation. The first one is the rail's own oscillations with its frequency that depends on the characteristics of hardness of the material and the weight of the rail. The second one is the oscillations of supports with frequency that depends on the motion speed and curve of sleepers ω_{sl} (frequency of excitation of supports by carriages). The latter oscillations form both the process of oscillation of the group of supports and the third process – oscillations of rails caused by reactions of the group of supports;

– the influence of rails on supports forms four processes of oscillation. The first one is the supports' own oscillations with their own frequency of oscillation. The second one and the third one are the oscillations of the base by the group of supports and the process of oscillation of supports, caused by the reactions of the base. The fourth one is the base's own oscillations.

Thus, a general form of the load that acts from the rolling stock side on the track in one rail intersection is

$$F = F_0 \sin(\omega_f t)\left(k_{it}\sin(\omega_t t) + k_{iw}\sin(\omega_w t) + k_{irs}\sin(\omega_{rs} t)\right), \quad (1)$$

where F_0 is the maximum value that the force gains in the intersection; k_i is the coefficient that considers attenuation of force by the corresponding direction.

Third, every element of design has its own frequency, amplitude, cycle and oscillation speed, which are resultant of the oscillations that act on them.

Fourth, each structure has its own frequency, amplitude and oscillation speed, which are resultant of the oscillations of constituent elements.

4. 2. Peculiarities of geometry of loading the forced oscillations

As noted [12], oscillatory process propagates according to the equation, which contains free and forced oscillations. Forced oscillations are propagated by waves that in their shape are close to the ellipsoid. Ellipsoid that is built for every moment of time of the propagation of oscillations characterizes wave surfaces – surfaces of constant phase. But each impulse has a period of its action, so it characterizes the wave front – those surfaces that separate the points of the medium of those at rest from those activated in a certain time by a forced pulse. Thus, the Huygens principle is implemented. This principle allows us to determine the wave front at non-stationary wave process that occurs when the source of oscillations moves in a stationary medium, and possesses the Doppler Effect at its registration in the experiments. When examining the process of deformability of a track, we have a case when the source of oscillations (wheel) that moves along the rail has the lower speed than the propagation speed of oscillations in the elements of the track. That is, the wave front will have an ellipsoid form while the speed in the direction of propagation is

$$u(r) = \frac{(C_t - V\sin\beta)C_l}{\sqrt{(C_t - V\sin\beta)^2\cos^2\alpha + C_l^2\sin^2\alpha}}, \quad (2)$$

where C_t, C_l are the transverse and longitudinal wave propagation speeds in a particular medium; α is the angle between the radius of wave propagation in a certain point of the medium to the direction of propagation of a forces pulse (angle in the vertical plane); β is the angle between the radius of wave propagation in a certain point of the medium to the positive horizontally transverse of force propagation direction (angle in the horizontal plane).

A local system of force coordinates for each propagation of oscillations is always positioned in such a way so that the x axis coincides with the direction of force motion and the z axis – direction of force action. An explanation to the directions and angles is given in Fig. 1.

Components of the wave vector along the axes of coordinates that define the plane of equal phases and amplitudes of oscillatory motion depend on the position of a local coordinate system of force relative to the basic coordinate system of the structure. Thus, the position of a local coordinate system of force relative to the basic coordinate system of the structure defines both the directions of propagation of longitudinal and transverse waves and polarization of these waves. Since the impulse of oscillations is the ellipsoid with parameters of propagation described in (2), which causes both ordinary and non-uniform volumetric waves, then in the transition of oscillatory process from one element of the design to another one, the character of wave processes of these elements will also depend on the position of a local coordinate system of force relative to the basic coordinate system of the structure.

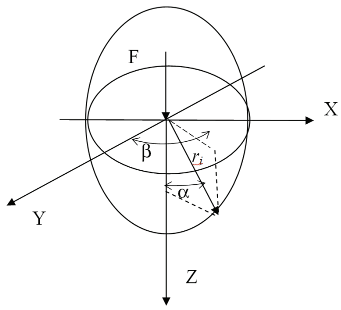

Fig. 1. Determining the directions and angles of oscillations propagation

4. 3. Consideration of connection between the amplitudes of oscillations in the transition of waves from one element to another one

Since the amplitudes of oscillations are dependent on the physical characteristics of elements and, in line with the law of conservation of energy, they are interconnected, then, by physical and structural characteristics, it is possible to explore in what way the oscillations of the track design depend on the oscillations of the track elements. The value and direction of the oscillations amplitude motion depend on the force vector that causes them.

General values of the amplitudes are formed in the process of propagation of oscillation pulse and are the result of the superposition of all oscillations.

From the law of conservation of energy, intensity of a refracted wave is equal to the difference in the intensities of the waves of incidence and reflection $I_{inc}-I_{refl}=I_{refr}$, thus

$$A_{refl}=A_{inc}\frac{\rho_1 u_1-\rho_2 u_2}{\rho_1 u_1+\rho_2 u_2}, \quad (3)$$

$$A_{refr}=A_{inc}\frac{2\rho_1 u_1}{\rho_1 u_1+\rho_2 u_2}, \quad (4)$$

where A_{inc}, A_{refr}, A_{refl} are the amplitudes of waves of incidence, refraction and reflection, respectively; $\rho_i u_i$ is the impedance (resistance of medium); u_i is the speed of the wave.

By physical essence, amplitude of incidence is the amplitude that defines displacement of a particular point of the internal medium at a certain time from the influence of external load F_{ext} taking into account forces of elasticity and friction of the medium F_{inc}. Amplitude of reflection characterizes how at each point in the medium in a certain time, the displacement of a particular point of the internal medium changes due to the reaction of external medium F_r. Amplitude of refraction is the amplitude of incidence for a different external medium. Thus, consequently, the amplitude of refraction characterizes the impulse of force of external load, and the amplitude of reflection – the impulse of force of reaction of the external medium, and for each object:

$$F_{ext}=\sum F_{int}+\sum F_r. \quad (5)$$

When the elastic wave of incidence (inc) of any type (longitudinal – p or transverse – s) meets a free surface relative to the displacement boundary, there occurs four waves. Two of them are refracted (p-refl – refracted longitudinal wave with refraction angle α and s-reflr – transverse refracted wave with refraction angle β) into the lower medium with density ρ_b and two are reflected in the upper medium with density ρ_a (p-refl – longitudinal wave of reflection and s-refl – transverse wave of reflection). In this case, it is necessary to satisfy four boundary conditions under which, on both sides of the boundary, the normal and tangential displacements and stresses must match. These boundary conditions will be satisfied if these waves are exposed to the Huygens principle, which leads to the implementation of the Snell's laws. Thus, using the solutions of systems of equations (6)–(8), we received parameters of oscillations of the examined point.

The ratios of amplitudes of the wave process at the incidence of longitudinal wave are defined as:

$$\begin{cases} \left(A_{p-inc}-A_{p-refl}\right)\cos\alpha_{p-inc}+A_{s-refl}\sin\beta_{s-refl}-A_{p-refr}\cos\alpha_{p-refr}-A_{s-refr}\sin\beta_{s-refr}=0; \\ \left(A_{p-inc}-A_{p-refl}\right)\sin\alpha_{p-inc}+A_{s-refl}\cos\beta_{s-refl}-A_{p-refr}\sin\alpha_{p-refr}+A_{s-refr}\cos\beta_{s-refr}=0; \\ \left(A_{p-inc}+A_{p-refl}\right)c_{p-inc}\cos 2\beta_{s-refl}-A_{s-refl}c_{s-refl}\sin 2\beta_{s-refl}-\frac{\rho_b}{\rho_a}A_{p-refr}c_{p-refr}\cos 2\beta_{s-refr} \\ -\frac{\rho_b}{\rho_a}A_{s-refr}c_{s-refr}\sin 2\beta_{s-refr}=0; \\ \rho_a c_{s-refl}^2\left[\left(A_{p-inc}-A_{p-refl}\right)\sin 2\alpha_{p-inc}-\frac{c_{p-refl}}{c_{s-refl}}A_{s-refl}\cos 2\beta_{s-refl}\right]- \\ -\rho_b c_{s-refr}^2\left[\frac{c_{p-refl}}{c_{s-refl}}A_{s-refr}\sin 2\alpha_{s-refr}-\frac{c_{p-refl}}{c_{s-refr}}A_{s-refr}\cos 2\beta_{s-refr}\right]=0. \end{cases} \quad (6)$$

The ratios of amplitudes of the wave process at the incidence of transverse waves of vertical polarization are determined as:

$$\begin{cases} \left(B_{s-inc}-B_{s-refl}\right)\sin\beta_{s-inc}+B_{p-refl}\cos\alpha_{p-refl}+B_{p-refr}\cos\alpha_{p-refr}-B_{s-refr}\sin\beta_{s-refr}=0; \\ \left(B_{s-inc}+B_{s-refl}\right)\cos\beta_{s-inc}+B_{p-refl}\sin\alpha_{p-refl}-B_{p-refr}\sin\alpha_{p-refr}-B_{s-refr}\cos\beta_{s-refr}=0; \\ \left(B_{s-inc}+B_{s-refl}\right)c_{s-inc}\sin 2\beta_{s-inc}-B_{p-refl}c_{p-refl}\cos 2\beta_{s-refl}+\frac{\rho_b}{\rho_a}B_{p-refr}c_{p-refr}\cos 2\beta_{s-refr}- \\ -\frac{\rho_b}{\rho_a}B_{s-refr}c_{s-refr}\sin 2\beta_{s-refr}=0; \\ \rho_a c_{s-refl}\left[\left(B_{s-inc}-B_{s-refl}\right)\cos 2\beta_{s-inc}-\frac{c_{s-refl}}{c_{p-refl}}B_{p-refl}\sin 2\alpha_{p-refl}\right]- \\ -\rho_b c_{s-refr}\left[\frac{c_{s-refr}}{c_{p-refr}}B_{p-refr}\sin 2\alpha_{p-refr}+B_{s-refr}\cos 2\beta_{s-refr}\right]=0. \end{cases} \quad (7)$$

The ratios of amplitudes of the wave process at the incidence of transverse waves of horizontal polarization are determined as:

$$\begin{cases} B_{s-inc} + B_{s-refl} - B_{s-refr} = 0; \\ \rho_a \left(B_{s-inc} - B_{s-refl} \right) \sin 2\beta_{s-inc} - \rho_b B_{s-refr} \sin 2\beta_{s-refr} = 0. \end{cases} \quad (8)$$

Thus, by the values of amplitudes of reflection and refraction and angles of reflection and refraction, defined at certain incidence angles, characteristics of the oscillations are determined, at which the propagation of the rolling stock impact on the track's design occurs.

5. Results of research into creation of the dynamic processes algorithm for studying the deformative work of a railroad track

We examined vertical oscillation of the center point of the rail sole that rests on a support, at the central effect of vertical force. Reaction time of the track design on the influence of the rolling stock depends on its motion speed and physical and structural parameters of the track. That is, it is necessary to clearly define by the term "time delay" between the impact of load and reaction of the track design. Since the quasi dynamic calculations lack this difference, in line with the adopted theoretical assumptions, there are attempts at taking it into account as the difference between the time the force action starts and the period of realization of maximum sagging of the rail at the deformation of the track structure in the vertical plane in the cross-section of the applied load. If we consider the problem with this definition of the term "time delay", then, first, it is necessary to take into account the time it takes to reach the maximum value of force in the examined intersection. Second, it is necessary to take into account the time of adoption of load impulse, with regard to the reactions to it, elements of the track design, by depth.

Fig. 2 displays the ratio of oscillations force pulse for a freight carriage at different motion speeds. We accepted the load at motion speed 10 km/h as unity.

According to results in Fig. 2, we observe dependence, at which an increase in the motion speed of leads to the increase in value of force and the decrease in the time of force action, oscillations pulse frequency, and the value of oscillation pulse. Dependence between the amplitudes of forced oscillations in the rails on the motion speed caused by loads (Fig. 2) is depicted in Fig. 3. According to the represented results in Fig. 3, we observe dependence, at which an increase in the motion speed leads to the decrease in the values of amplitudes in the rails in the direction of propagation and the decrease in the time if implementing these amplitudes.

Results of the second condition for the same unit of the rolling stock are demonstrated in Fig. 4–7.

Values of amplitudes of the load oscillations in the gaskets when transferring the load on the sleeper are displayed in Fig. 4. The process of gaskets oscillation from direct action of the force in the intersection starts by 0.000032 s later than the moment of applying the pulse to the rail. The starting time of the gasket oscillation process does not depend on the trains motion speed and is determined by the properties of material and geometrical dimensions of the rail. The ending time of the gasket oscillation process depends both on the trains' motion speed and the properties and geometrical dimensions of the under-rail base. Operation period of the gaskets when transferring the load on the sleeper depends on the motion speed of trains, the properties of material and geometrical dimensions of gaskets. As the reaction of gaskets depends on their thickness and properties of the material, then there is a delay between the work of the rail and gaskets in the form of positive oscillations (Fig. 4).

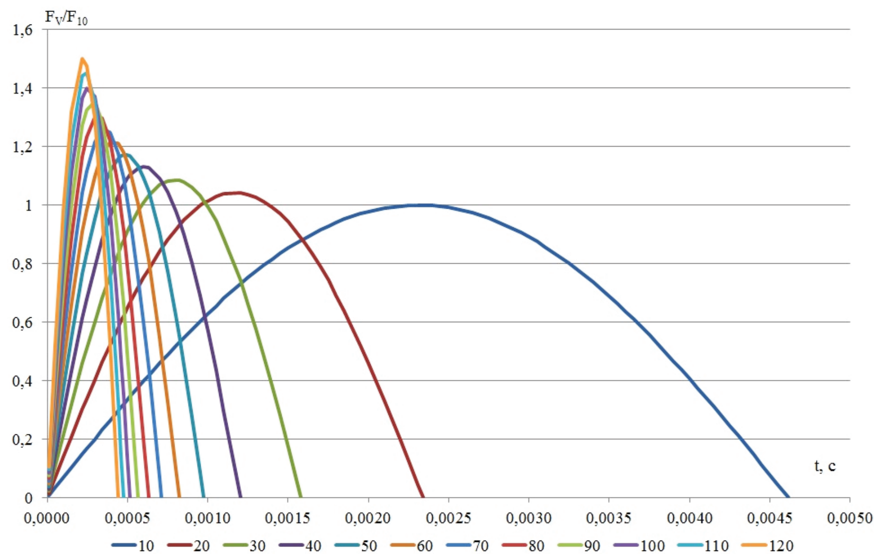

Fig. 2. Ratio of oscillations force pulse depending on the motion speed of the rolling stock

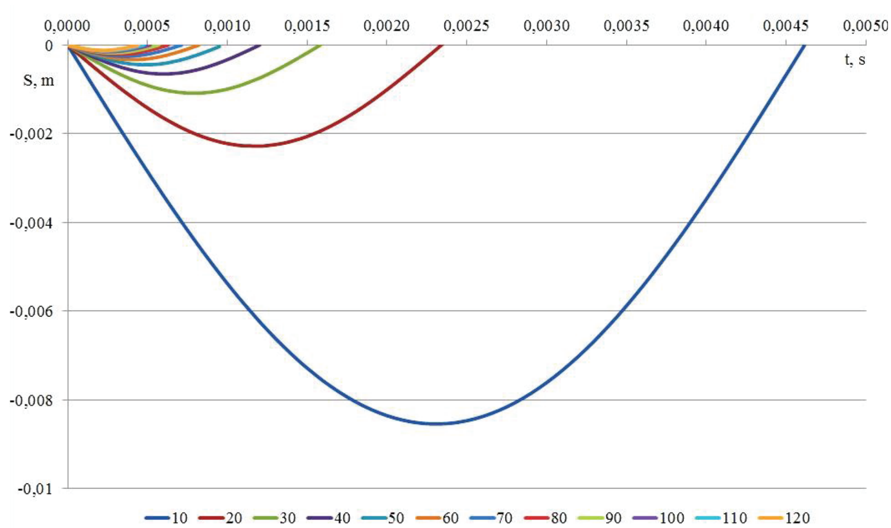

Fig. 3. Dependence of amplitudes of load oscillations in the rails on the motion speed of the rolling stock

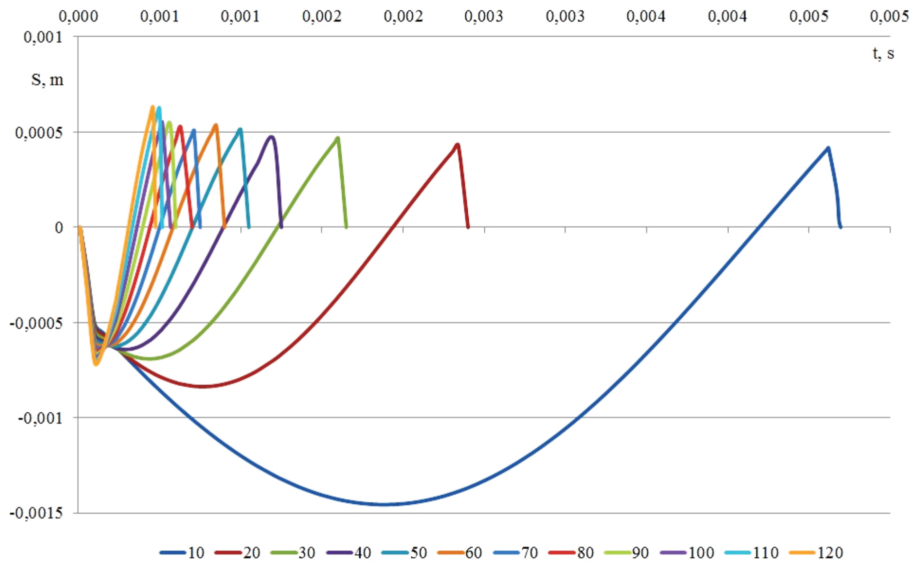

Fig. 4. Dependence of amplitudes of load oscillations in the gaskets on the motion speed of the rolling stock

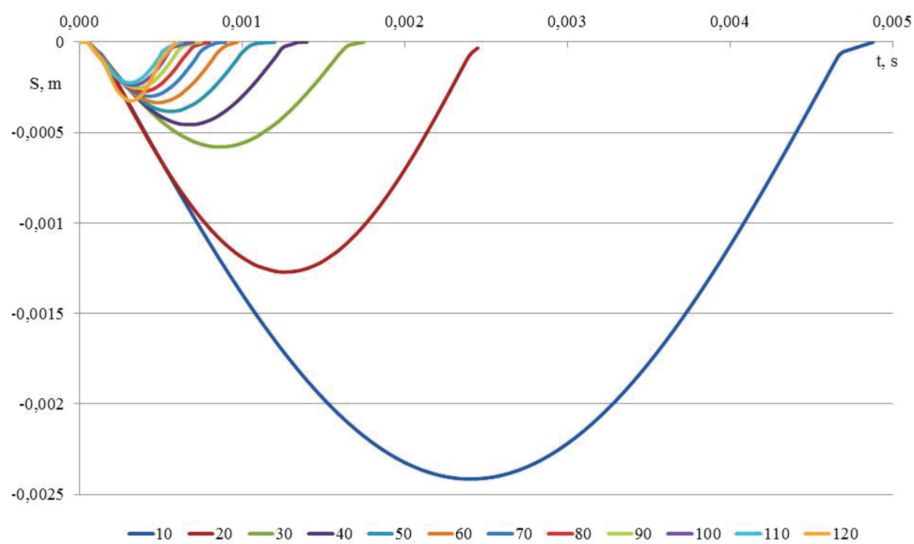

Fig. 5. Dependence of load oscillations amplitudes in sleepers on the motion speed of the rolling stock

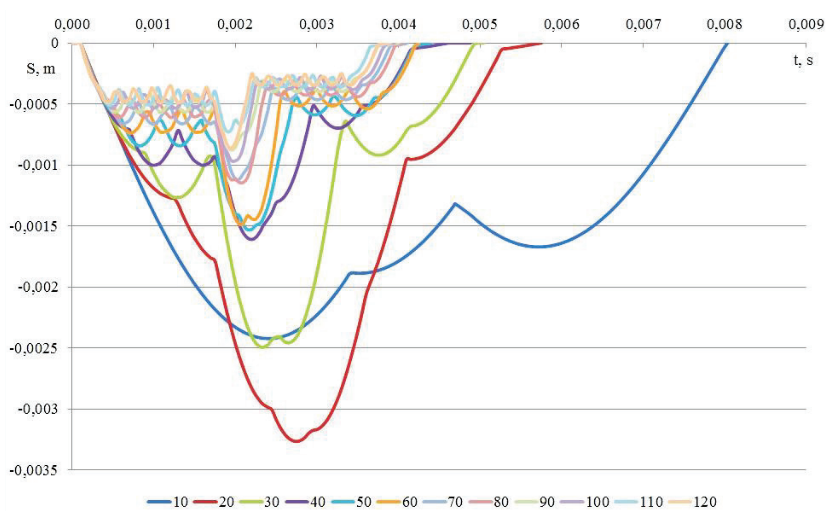

Fig. 6. Dependence of load oscillations amplitudes in the ballast layer on the motion speed of the rolling stock

Values of load oscillations amplitudes in the sleepers whose attainment time regardless of the motion speed for the specified design of the track is 0.0000738 s are presented in Fig. 5. The time of sleepers' operation when transferring the load to the ballast load depends on the motion speed of trains, properties of the material and geometrical dimensions of sleepers.

Values of reactions oscillations amplitudes in the ballast layer, the attainment time of which regardless of the motion speed for the specified design of the track is 0.000171575 s, are displayed in Fig. 6. The time of ballast work when transferring the load to the ground depends on the motion speed of trains, properties of the material and geometrical dimensions of the ballast.

It should be noted that for the design of the track with the rails of the R65 type, coupling KPP-5-K, thickness of the ballast layer 0.4 m, the period from the force action start to the occurrence of oscillations in the ground base is 0.003479747 s regardless of the motion speed. And it takes place later compared to the time of action of maximum values of forces in the rails. Fig. 7 displays result of oscillations of the ground base from the action of loads of the rolling stock.

Dependence of values of general oscillation amplitudes of the structures of the track on the motion speeds is depicted in Fig. 8 – for the motion speeds of 10–60 km/h, and in Fig. 9 – for the motion speeds of 70–120 m/h. As demonstrated by results in Fig. 8, 9, maximum values of sagging in the structure do not coincide with the action of maximum values of loads of the rolling stock. And under the action of rolling stock on the track at any motion speeds, amplitudes take maximum values when the loads are received by the ground base and the ballast layer.

It should also be emphasized: there is not only a different depth of acceptance of loads by time, but also different length of the track and rail design that accept these loads by time. The load that acts on the track structure is accepted by elements of its design depending on the design's structure and the speeds of deformation of the elements themselves. The action of the load in the intersection of the track design varies from zero to the maximum value, and vice versa, during contact period. In addition, the time of impact of the load in the intersection of the track decreases with increasing motion speed, and the period of transferring the load to elements of the track design remains constant for a particular track design. This leads to the fact that the lower the motion speed, the larger the length and depth of the part of the track design engaged in the acceptance of load. But the larger the motion speed, the larger is the length of the track that is in contact with the wheel over certain time. In this case, the perception of loads by all elements of the structure occurs much later than the force manifests itself in the intersection of the track. Thus, the ratios of maximum values of the track design's sagging at different motion speeds do not correspond to the ratios of maximum force values at the same motion speeds. An analysis of the amplitudes of oscillations of the elements separately and the track design in general revealed the pulse of the forced oscillations causes parametric oscillations of both the elements and the track design.

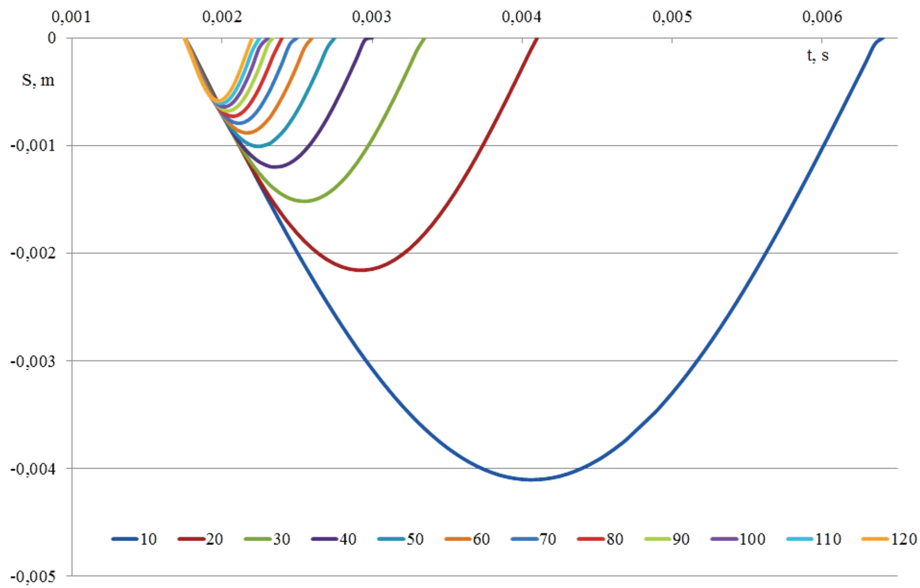

Fig. 7. Dependence of load oscillations amplitudes in the ground base on the motion speed of the rolling stock

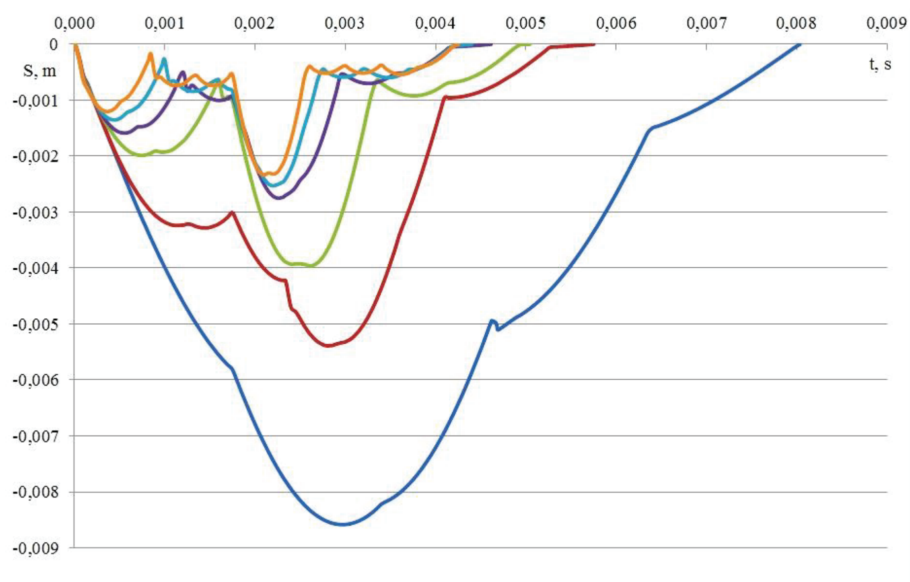

Fig. 8. Dependence of amplitudes of general oscillations of the design on the motion speed of the rolling stock

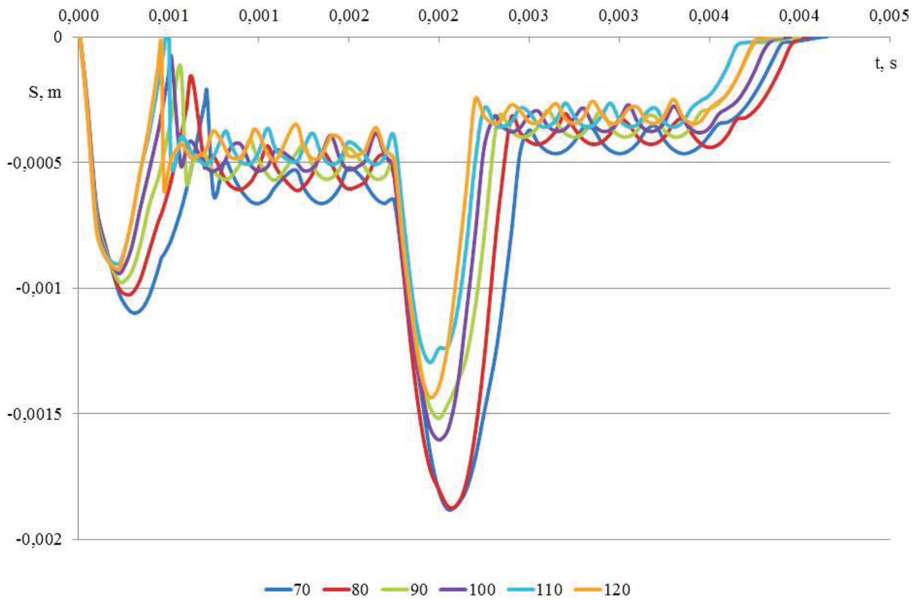

Fig. 9. Dependence of amplitudes of general oscillations of the design on the motion speed of the rolling stock

4. Introduction of initial conditions (characteristics of changes in the contact area and force of influence over time) for determining the basic characteristics of the pulse.

5. Construction of the spatial propagation of the pulse with regard to the conditions of pulse transition from one element to another one.

6. Determining the magnitude of displacements and stresses in the elements of the track.

7. Evaluation of the stressed-strained state of the track design.

The developed algorithm allows us to take into account the dependence of oscillations of elements and the track design on:

– period of action that depends on the motion speed;

– characteristics of materials and structure of the elements and the track design.

The algorithm presented complements the research on modeling for the purpose of establishing assessment of conditions of functional safety of a railroad track [12]. Based on the developed algorithm, further studies may be conducted for determining the mechanical performance of elements of the track and the track design itself from the influence of the rolling stock for the purpose of evaluating and predicting the terms of operation of the elements and design of the track.

6. Discussion of results of research into creation of algorithm for the dynamic processes of changing the track deformability

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 algorithm for the calculation of dynamic processes of changing the track deformability is as follows:

1. Mapping a geometrical model of the track design.

2. Determining physical characteristics of elements of the track design.

3. Introduction of boundary conditions.

7. Conclusions

In the course of research we conducted, an algorithm is developed for the calculation of dynamic processes of changing the track deformability. It is a method for the description of transfer of impact of the rolling stock on the track. It is proposed, as a dynamic influence of the rolling stock on the track, to consider a parametric impact of the pulses that act in the point of contact between rails and wheels and propagate maintaining the properties of elastic waves. Characteristic features of the algorithm are the application of principles of the theory of wave propagation in solid materials. Due to these peculiarities, the possibility is provided for the determination of a wave front at a non-stationary wave process that occurs when the source of oscillations moves in a motionless environment and possesses the Doppler Effect with its registration in the experiments. We took into account that the special features of the transfer of dynamic load are:

– the period of load action on the track that defines the frequency of pulse oscillation that is transferred to the track design;

– variable directivity of the oscillation pulse over time, which is predetermined by changes in mode, polarization and waves shape at propagation. This allows us: to obtain spatial parameters of propagation of the process of deformability in the track design; to predict the change in the stressed-strained state of the elements of design and the design itself depending on the characteristics of materials and structure elements of the track design; to solve the problems on interaction between the contacting surfaces at the propagation of loads with regard to relations between the amplitudes of oscillations in the transition of waves from one element to another one.

Thus, our research demonstrated the possibility of directed regulation of the process of deformability of a railroad track by changing the characteristics of materials and design of the elements of a railroad track.

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