ЗАЛІЗНИЧНА КОЛІЯ ТА АВТОМОБІЛЬНІ ДОРОГИ

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INVESTIGATION OF THE INFLUENCE OF THE ROLLING STOCK DYNAMICS ON THE INTENSITY OF USING THE RAILWAY TRACK ELEMENTS

Purpose. The main purpose of this work is to research deformability parameters of the railway track under various operating conditions as the initial data for the formation of forced oscillations of rolling stock and the trackform use intensity. **Methodology.** For the research, an original model of the trackform, described with using the basic concepts of the theory of elasticity and the propagation of elastic waves was developed. **Findings.** It has been established that the ratio between the intensity of work of elements and the trackform, as criteria for deformability, can be used as the estimated parameters of the functionally safe operation of the track. It can be the basis for the classification of critical track states under which it had to perform work to restore its working capacity in order to ensure the required level of efficiency of use construction during the service life. **Originality.** Trackform and parameters of the elements of the track superstructure and substructure can be described using the railway tracks deformability behaviour. In the future this conclusion will help to increase the efficiency of the dynamic properties of rolling stock when designing and maintain in readiness the infrastructure while in operation. **Practical value.** Changes in the regulatory framework of rail transport in recent years provide for the observance of its functional safety, therefore, the question of the need to assess the impact of rolling stock on the way to be regarded as a dynamic process with consideration to the deformability resistance track. This research provides a basis for record of the stiffness of deformation that allows creating the regulatory framework for the functional safety of the railway track in Ukraine.

Keywords: trackform; deformability parameters; oscillation; deformability of the railway track

Introduction

The issue of providing the reliable and safe operation of the railway track and rolling stock during their interaction has existed since the introduction of railway transport. The requirements for the said objects of interaction were forming gradually and depended on the level of knowledge and technologies. Thus, before introduction of rails of P50, UIC60, P65 types and reinforced concrete sleepers in the trackform, the main requirements were the provision of railway track element strength and the track panel stability under the influence of increasing loads and speeds of the rolling stock. The use of the aforesaid track structure components completely provided the superstructure strength under the weight of a rolling stock. From 70s of the last century, the new requirements were forming, and it has resulted in approving the international standards such as IEC 62278:2002, EN 50126-1-2017, EN 50126-2-2017 and IEC 60300-3-3:2017.

The modern requirements for transport system maintenance strategy are directed for minimizing the lifecycle cost, and for maximizing the reliability, availability, maintainability and safety (RAMS) of the transport systems. All the issues related to defining the functionally safe operation

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of transport systems imply the study and evaluation of dynamic processes resulting from the interaction in time between the railway track and rolling stock. The influence of dynamic processes in time becomes decisive while assessing the functionally safe operation of modern speed projects such as «Aero Train» (Yasuaki Kohama), «Hyperloop» (Elon Musk). In order to ensure the functionally safe operation of any transport system, it is required to know which changes occur in its elements in time and how the functionally safe status of each element as well as their aggregate affect the system's operation. Indeed, in order to predict the operation of subgrade under actual climate and service conditions, it is required to consider in time the process of permanent deformation accumulation in it. In other words, it is required to figure out the following issues: a) which changes occur in the subgrade as a result of multiple force impact by a rolling stock with respect to the change in temperature and soil moisture; b) how the process of change in temperature and moisture in the subgrade occurs under the influence of force, electromagnetic and gravitational fields.

The influence of force fields in the hard texture elements is researched insufficiently. The study of stress-strain state of the railway track elements results in identifying the peak stresses and deformations while using the full force value. The deformability of the railway trackform as the aggregate of deformations and shifts is presented as an influence line (field, when the finite element method is used). It is considered that the influence line shifts together with the force motion. In all the mathematical models of railway track calculation, it is taken that the influence of force field spreads evenly in all directions, i.e. the principle of force field transfer is used due to longitudinal waves how it occurs in liquid and gaseous media. The influence of longitudinal waves is not taken into account in the models. It may cause the error during calculation because it does not allow reflecting the physical process of transferring the force fields in the solid bodies and between them.

While running the test on the rolling stock's influence on the railway track, a huge number of statistical data on strain-stress state of the track have been obtained. They describe different deformability of the same length of the track under the influence of the same rolling stock. The different statistical data are conditioned by the process of mutual influence of the rolling stock and the railway track. We consider next the issue of analyzing the parameters of railway track deformability under various operating conditions as the initial data for forming the forced oscillations of the railway rolling stock and the intensity of using the trackform elements.

Purpose

The main purpose of this work is to study deformability parameters of the railway track under various operating conditions as the initial data for the formation of forced oscillations of rolling stock and the intensity in the use of elements of the trackform. The object of the study is the process of mutual influence of the railway rolling stock and the track. The subject of the study is the deformability of the railway track under various operating conditions as a factor in the formation of dynamic irregularities.

Methodology of investigation

The main macro indicators of the operation of the railway transport infrastructure are the availability and economic efficiency coefficients. Currently, many studies have been devoted to the problems of studying the mathematical description of perturbations acting on the track and the crew during their interaction [2-3, 5-23]. Each article adds an important part of the overall process of the track and rolling stock interaction. Articles [2, 5-6, 10, 12, 13, 15-17, 20, 21-23] focus on analysing the simulation results delivered with implementation of the mathematical models of the rolling stock: for transport carriages [2, 5, 22], for real locomotives [6, 13, 16, 20, 21], for locomotive-roller rig coupled system [9], for general rail vehicle [10, 12, 15, 17, 23]. Paper [3] describes the mechanism of transferring force from the rolling stock to the trackform. The simplified method to determine a vertical impact force of the wheel with flat and rail interaction is presented in this article. This article demonstrates the influence of the wheel with flat geometrical parameters, speed of a vehicle to maximum contact force and its distribution in the contact zone. Articles [7, 11,

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14, 16, 18, and 19] are dedicated to studying the track and the rolling stock interaction.

The numerical model [7] is subsequently used to determine the track vertical and lateral stiffness. The work [11] proposes a computational methodology to study how the varying vehicle component characteristics, on normal and degraded conditions, impact on the vehicle/track interaction loads and on the track damage. The paper [14] proposes an approach for the validation of railway vehicle models based on on-track measurements. The tasks that are addressed in the research [18]: to perform tests at track irregularities of symmetrical sinusoidal shape running both along straight and curved tracks, as well as driving over the junctions along the straight and curved tracks, and compare the results. A novel wheel–rail contact model [19] is proposed to be implemented for multi-body dynamics simulation, in order to facilitate accurate online calculation of damage phenomena such as wear and rolling contact fatigue.

The above articles studies are very important issues, but they apply some of the approaches that restrict their research. Modern theoretical models, which study the track and rolling stock interaction, means and methods of recording oscillations used in experiments, while studying the track and rolling stock interaction, or assessing geometrical track states, have no mechanism for determining the source of vibration and the nature of the process of transferring these vibrations to the «rolling stock-track system». Consequently, the oscillograms of the railway track contain the superposition of both the impact of the rolling stock on the track and the response of the track, taking into account its deformability. The oscillograms on the rolling stock contain a superposition of both the impact of the rolling stock on the track and the other way round. These perturbations are not classified according to physic-mechanical and geometric characteristics of railway track construction elements that determine its deformability. Thus, changes in the conditions of rails and wheels contact with their tortuous motion remain unconsidered. Therefore, firstly, it has become necessary to study the mechanism of transferring force from the rolling stock to the trackform and vice versa in time. Secondly, there was a need to study the physics of the oscillation process and to differentiate the vibrations from the

physical-mechanical and geometric characteristics of the elements of the construction of the railway track, which determine its deformability.

Based on the experience gained, a model was developed for determining the processes of deformative operation of the railroad track [1, 4, 8].

The original model was created for investigating the dynamic problem of railway track deformability under the influence of the rolling stock. It applies the basic provisions of the theories of elasticity and propagation of elastic waves.

In the model, it is taken that the track and rolling stock interaction occurs by means of impulses. The impulses are transmitted via bond pads conditioned by the position of a wheel set along the track. The impulse duration is characterized by the time of transferring the load from the rolling stock to the rail and depends on the rolling stock speed. Any dynamic force is characterized by the impulse transmission frequency on a particular bond pad and by the impulse repetition frequency in particular section [1, 4, 8]. The impulses are characterized by the law of force change and the law of force intensity change in a contact time. 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.
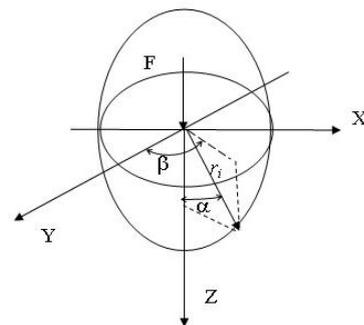

Fig. 1. Determining the directions and angles of oscillations propagation

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 the force relative to the basic coordinate system of the structure. Thus, the position of a local coordinate system of the force relative to the basic coordinate

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system of the structure defines both the directions of propagation of longitudinal and transverse waves and polarization of these waves.

The impulses are transmitted by the force waves. The process of force wave propagation is described by using the propagation properties of transverse and longitudinal waves. 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 ones. Each of them is heterogeneous, as it has vivid dependence of the change in characteristics on 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 structure in a certain period of action, one will observe either homogeneous spherical or non-uniform quasi spherical waves. Their availability and velocity of propagation are conditioned by stress-strain properties of element materials. Each wave affects the particle in different directions with respect to the direction of wave propagation. Each wave, while transiting from one element to the other, changes its properties. So, the calculation in the model is done with respect to the directions of force wave front propagation (r_i). The main dependences of motion-direction are shown in [1, 4]. As a result, the shift of structural particles in time has been obtained (s_i) (see Fig. 2-5).

We compared the values of the stresses at the rail base edge and head and the rail deflections caused by running of ChS8 locomotive at a speed of 155 km/h. The experiment was carried out on a single-track section. The trackform elements: UIC60 rail track, reinforced concrete sleepers with KPP-5 type fastening, 40 cm ballast depth, the roadbed is a sandy loam subgrade. The modulus of the track elasticity in the vertical plane for calculation by the existing method was taken from the experimental data and made $U = 69.2\ MPa$. Table 1 shows the data calculated by the existing method «Track strength calculation», the proposed method and the experiment obtained ones.

Table 1

**Data of the track stress-strain state
obtained using various methods
and experimentally**

Method	Stresses (MPa) in rail		Rail deflection, mm
	Base edge	Head	
The existing method	115.7	120.69	1.56
The proposed method	159.5	145.9	2.81
Experiment	163.3	146.1	2.5

Based on the strain-stress properties and geometrical characteristics of the elements, the use of wave properties allows establishing: a) the reaction of elements to the force impact with respect to the time of its propagation; b) time ratio of impulse impact and its propagation along the length and depth of the trackform; c) change in amount of energy in any point of the structure in time. The aforementioned parameters allow changing the deformation processes by altering the element geometry and material properties.

Based on the described mathematical model, it is proposed to take as a composite index the deformable work of trackform elements (A_i):

$$A_i = \int_{t1}^{t2} P \cdot y\, dt, \qquad (1)$$

where P – force that affects the element; y – shift caused by the force during the action [$t1$, $t2$].

The amounts of shift have three-dimensional nature even for one section of the trackform. So, it

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was proposed to define the deformable work of trackform (A) as the sum of works performed by all the track elements in one section under the influence of the rolling stock with respect to the time of perception and reaction of the elements:

$$A = \sum_{i=1}^{n} \int_{t1}^{t2} A_i dt, \qquad (2)$$

n – a number of elements getting a force impact.

For evaluating and comparing the use of trackform and elements under different operating conditions, it was proposed to use I – the intensity of deformable work of the elements or the structure (deformable work in the unit of time).

The investigation is carried out for the trackform model consisting of the following elements such as rails of R65 type, concrete sleepers of SB3 type, fastenings of KPP-5-К, ballast stone of 40 *cm* thick, subgrade. They are given in Table 2.

Table 2

The properties of trackform elements

Element	Density, kg/m³		Poisson's coefficient		Young's module E, MPa		Cl, m/s [1]		Ct, m/s [2]	
rail	7 830	7 830	0.24	0.3	2.1×10^5	2.1×10^5	5 622	6 008	3 288	3 211
pad	918	935	0.3	0.485	100	200	382	1 572	204	268
sleeper	2 200	2 500	0.1	0.15	36 000	40 000	4 090	4 110	2 727	2 637
ballast	1 900	2 200	0.2	0.2	100	400	241	449	148	275
ground base	170	175	0.3	0.35	30	40	487	605	260	290

1 – the speed of longitudinal; 2 – the speed of transverse waves in the material

The rolling stock influence on the track was considered with respect to the central position of the wheel set. As a result of investigation, the following dependences were obtained, which are shown in Fig. 2-3.

The upper part of the diagram demonstrates the dependence of forces having an impact on the track with respect to the time at various motion speeds. The values of forces are given against the force value at the speed of 10 *km/h*. The lower part of the diagram demonstrates the dependence of oscillation amplitudes of the trackform section in time with respect to different motion speeds under the single force impact on the section.

In the existing models, it is assumed that the trackform deformability as a result of the rolling stock influence occurs instantly. Figures 2 and 3 clearly demonstrate the falsehood of such assumption, depending on the time of impulse impact conditioned by the motion speed of the rolling stock.

The time of occurrence of the deformability process in the railway trackform due to the rolling stock impact depends on two constituents. The first constituent is the time of impulse impact that depends on the motion speed. Its value decreases together with the increase in motion speed. The second constituent is the time of propagation of force impact in the trackform elements. It depends on stress-strain and geometrical characteristics of trackform elements. For the same trackform, in case of the same-type force impact (the equal

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direction of force and place of its application), this value is constant. Therefore, in case of increase in motion speed, the time of deformability process running in the trackform approaches the value of

second constituent. With increase in motion speed, we may observe the increase in temporary delay value between the time of impact on the trackform and the time when deformability occurs.
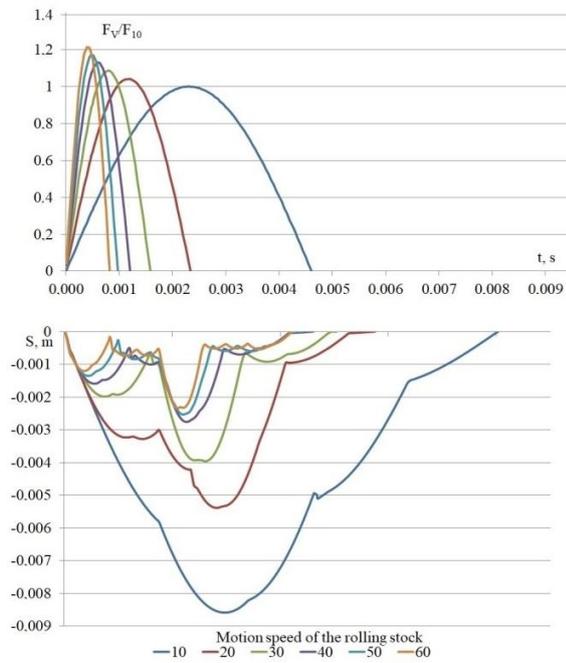

Fig. 2. The dependence of oscillation amplitudes of the trackform section in time with respect to different motion speeds under the impact on the section of single force $F = 225\ kN$
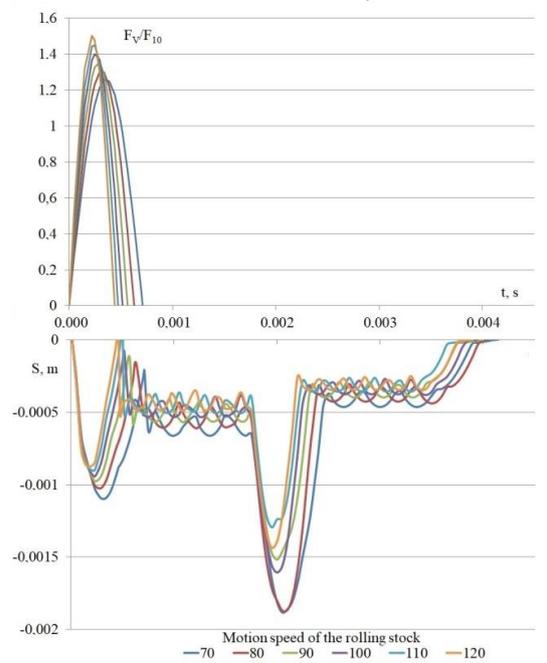

Fig. 3. The dependence of oscillation amplitudes of the trackform section in time with respect to different motion speeds under the impact on the section of single force $F = 225\ kN$

The dependences of oscillation amplitudes of trackform section in time for various motion speeds under the single force impact on the section are shown in Fig. 4 and 5, which are similar to Fig. 2. The difference in diagrams is caused by the difference in force values having an effect on the track. With increase in action force, the direct variation of dependences of oscillation amplitudes of trackform section in time is not traced in diagrams. The form of oscillations changes together with the change in oscillation amplitudes. The form of oscillation towards the direction of force impact propagation changes in propagation time and is connected with the correlation between the force action time and the time of deformability process propagation in the trackform elements.

The number of energy transferred by the wave is proportional to the square of oscillation amplitudes. The change in energy occurs due to the following conditions: a) changes in oscillation characteristics towards directions of wave propagation; b) changes

in oscillation characteristics with respect to the wave properties during their transition from one element to the other; c) friction forces in the very oscillation propagation medium; d) friction forces arising during interaction of element contact pairs. For the same trackform and with the same-type force action, the change in energy occurs due to condition a; the rest of conditions change proportionally to the change in force. This condition a preconditioned the change in the depth of trackform required for taking up a load. Conditions b, c, d are changing the form of dependences only in case of changing the trackform. However, condition b is decisive for choosing the number of elements and characteristics of element materials in the trackform.

The aforesaid shows that the change in power loads and motion speeds of the rolling stock directly affects the process of track deformability. This process is one of the main factors for the formation of dynamic track irregularities which

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serve as disturbance effect for forming the three-dimensional vibrations of the rolling stock. Each variety of trackform has its own time of force impact propagation in the trackform elements. The change in number of trackform elements, stress-strain properties, geometrical and inertial characteristics of the trackform elements can cause the change in time of propagation of the deformability process. Therefore, we can trace the interdependence of the rolling stock dynamics and the process of track deformability.
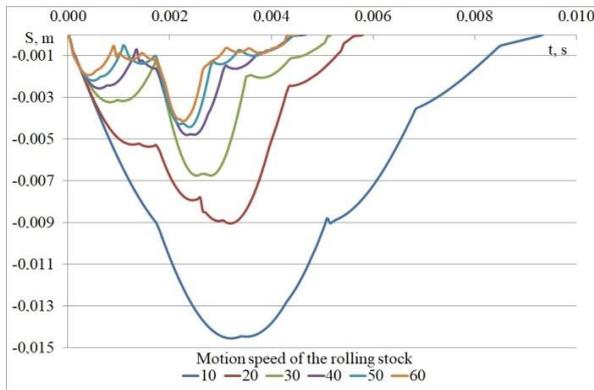

Fig. 4. The dependence of oscillation amplitudes of the trackform section in time with respect to different motion speeds under the impact on the section of single force $F = 294\ \kappa N$
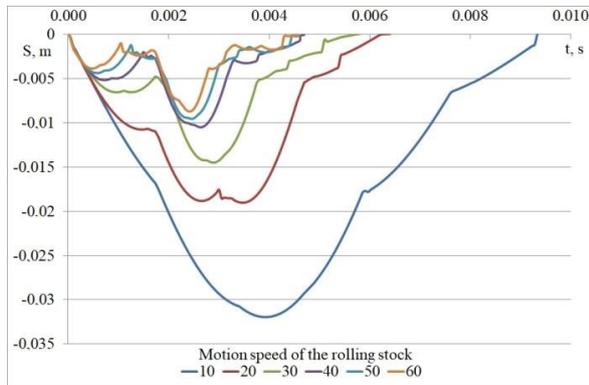

Fig. 5. The dependence of oscillation amplitudes of the trackform section in time with respect to different motion speeds under the impact on the section of single force $F = 450\ \kappa N$

The track deformability is accompanied by the trackform element work to take up the force impacts from the rolling stock and to react to this impact. Each element engages in the process of deformability from the moment the force waves begin impacting on it. Each element has its own

time of propagation and transformation of force waves which is conditioned by the stress-strain properties and geometrical characteristics of the material. The trackform structure characterizes the time of direct presence of force waves in the trackform elements. Therefore, there exists the time when the element directly takes and transforms force impacts, and the time when the element becomes deformed due to deformations and shifts of the other elements. In other words, the structure elements can work «actively» (by transforming the force impacts) and «passively».

For the purpose of evaluating the operation of the above structure elements, we calculated the dependences of oscillation amplitudes of the elements and trackform section in time for various motion speeds during single force movement (wheel motion). Table 3 shows the relationship between the values of the deformability behavior of the elements and the trackform at various motion speeds.

Table 3

Deformability behavior ratios at various motion speeds

V, km/h	structure	pad	sleeper	ballast	ground base
V, km/h		$A_V\ /\ A_{V=10}$			
10	1	1	1	1	1
30	0.17	0.18	0.09	0.469	0.134
60	0.03	0.08	0.03	0.121	0.044
90	0.02	0.07	0.02	0.055	0.025
120	0.01	0.06	0.01	0.044	0.018
		$I_V\ /\ I_{V=10}$			
10	1	1	1	1	1
30	0.487	0.513	0.255	1.088	0.391
60	0.159	0.498	0.159	0.679	0.245
90	0.141	0.565	0.129	0.444	0.202
120	0.133	0.655	0.117	0.466	0.184

Following the results of data analysis given in Table 3, at lower motion speeds, the values of trackform amplitudes and load impact time exceed

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the similar values at higher motion speeds but the load-receiving track length is shorter. It results in different deformability behavior ratios at various motion speeds. The evaluation of the trackform and elements work intensity during the time of load action characterizes the trackform and elements work intensity at various motion speeds. The increase in motion speeds results in the intensity of using the rail pads and railway ballast due to increased load-receiving track length against the background of total decrease in the intensity of using the trackform.

Table 4 shows the relationship between the values of the deformability behavior of the elements and the trackform at various loads.

Table 4

**Deformability behavior ratios
at various loads**

Object	load		
	225 kN	294 kN	450 kN
A_F / $A_{F=264}$			
structures	1	2.21–2.34	7.1–7.63
pad	1	2.02–2.25	5.67–7.03
sleeper	1	2.17–2.19	6.25–6.83
ballast	1	2.18–2.43	6.49–8.13
ground base	1	2.18–2.48	6.42–6.85
I_F / $I_{F=264}$			
structures	1	2.01–2.13	5.79–6.02
pad	1	1.83–-2.06	4.47–5.57
sleeper	1	1.90–2.00	4.94–5.38
ballast	1	1.94–2.73	5.07–7.7
ground base	1	1.98–2.25	5.06–6.63

Following the results of data analysis given in Table 4, the railway track, under the influence of the rolling stock having the load of 225 kN, performs less work than the track having the loads of 294 kN and 450 kN respectively by 2.24 and 6.16 times. The intensity of using the elements and trackform having the loads of 225 kN is less than that of the tracks having the load of 294 kN and 450 kN respectively by 2.08 and 5.66 times. It allows establishing the interdependences of the rolling stock dynamics and the intensity of using the railway track elements.

The use of proposed evaluation parameters of deformability behavior will further allow us to define the effect of the aggregate change in the states of elements on the trackform operation and, in compliance with the current requirements for the trackform and its maintenance, to form the set of evaluation data of the track state in terms of acceptable deviations in the trackform elements.

Originality and practical value

Trackform and parameters of the elements of the track superstructure and substructure can be described using the railway tracks deformability behavior. In the future this conclusion will help to increase the efficiency of the dynamic properties of rolling stock when designing and provide availability of the infrastructure during operation. Changes in the regulatory framework of rail transport in recent years provide for the observance of its functional safety, therefore, the question of the need to assess the impact of rolling stock on the way to be regarded as a dynamic process which must be taken into account track deformability resistance. This study provides a basis which takes into account the stiffness of deformation to allow forming the regulatory framework for functional safety of railway track in Ukraine.

Conclusion

The paper presents the investigation of deformability parameters of the railway track under various operating conditions as the initial data for forming the forced oscillations of a rolling stock and the intensity of using the elements of a trackform. In paper, the theoretical provisions are proposed, and new analytical dependences of mutual influence of railway rolling stock and railway track are determined.

It is found that the ratio between the work intensity value of the elements and the trackform, as criteria for deformability behavior, may be used

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as the evaluation parameters of the functionally safe operation of the track. The given parameters will serve as the basis for classifying the critical track states when it is expedient to repair and maintain the track to ensure the required level of trackform use efficiency during its service life.

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ДОСЛІДЖЕННЯ ВПЛИВУ ДИНАМІКИ РУХОМОГО СКЛАДУ НА ІНТЕНСИВНІСТЬ ВИКОРИСТАННЯ ЕЛЕМЕНТІВ КОНСТРУКЦІЇ КОЛІЇ

Мета. Основною метою цієї роботи є дослідження параметрів деформованості залізничної колії за різних експлуатаційних умов як вихідних даних для формування вимушених коливань рухомого складу й інтенсивності використання елементів конструкції колії. **Методика.** Для дослідження було розроблено оригінальну модель конструкції колії, описану з використанням основних понять теорій пружності й поширення пружних хвиль. **Результати.** Установлено, що співвідношення між інтенсивністю роботи елементів і конструкцією колії як критерієм деформованості можна використати як оціночний параметр функціонально безпечної експлуатації колії. Це може бути основою для класифікації критичних станів конструкцій колії за яких необхідно проводити роботи з відновлення її працездатності, щоб забезпечити необхідний рівень ефективності використання конструкції протягом терміну служби. **Наукова новизна.** Конструкція колії й параметри елементів її верхньої та нижньої будов можуть бути описані з використанням поведінки деформованості. Надалі цей висновок допоможе підвищити ефективність динамічних властивостей рухомого складу під час проектування й забезпечити готовність інфраструктури під час експлуатації. **Практична значимість.** Зміни в нормативно-правовій базі залізничного транспорту за останні роки передбачають дотримання його функціональної безпеки. Тому

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питання про необхідність оцінки впливу рухомого складу на колію слід розглядати як динамічний процес, який повинен брати до уваги опір деформованості колії. Це дослідження становить основу для обліку жорсткості деформації, що дозволяє сформувати нормативну базу для гарантування функціональної безпеки залізничної колії в Україні.

Ключові слова: конструкція колії; параметри деформованості; коливання; деформованість залізничної колії

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ИССЛЕДОВАНИЕ ВЛИЯНИЯ ДИНАМИКИ ПОДВИЖНОГО СОСТАВА НА ИНТЕНСИВНОСТЬ ИСПОЛЬЗОВАНИЯ ЭЛЕМЕНТОВ КОНСТРУКЦИИ ПУТИ

Цель. Основной целью данной работы является исследование параметров деформированности железнодорожного пути при различных эксплуатационных условиях в качестве исходных данных для формирования вынужденных колебаний подвижного состава и интенсивности использования элементов конструкции пути. **Методика**. Для исследования была разработана оригинальная модель конструкции пути, описанная с использованием основных положений теорий упругости и распространения упругих волн. **Результаты**. Установлено, что соотношения между интенсивностью работы элементов и конструкцией пути как критерием деформированности можно использовать в качестве оценочного параметра функционально безопасной эксплуатации пути. Это может быть основой для классификации критических состояний конструкций пути, при которых необходимо проводить работы по восстановлению его работоспособности, чтобы обеспечить необходимый уровень эффективности использования конструкции в течение срока службы. **Научная новизна.** Конструкция пути и параметры элементов его верхнего и нижнего строений могут быть описаны с использованием поведения деформированности. В дальнейшем этот вывод поможет повысить эффективность динамических свойств подвижного состава при проектировании и обеспечить готовность инфраструктуры во время эксплуатации. **Практическая значимость.** Изменения в нормативно-правовой базе железнодорожного транспорта в последние годы предусматривают соблюдение его функциональной безопасности. Поэтому вопрос о необходимости оценки влияния подвижного состава на путь следует рассматривать как динамический процесс, который должен принимать во внимание сопротивление деформированности пути. Это исследование обеспечивает основу для учета жесткости деформации, что позволяет сформировать нормативную базу для обеспечения функциональной безопасности железнодорожного пути в Украине.

Ключевые слова: конструкция пути; параметры деформированности; колебания; деформированность железнодорожного пути

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