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РУХОМИЙ СКЛАД ЗАЛІЗНИЦЬ І ТЯГА ПОЇЗДІВ

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EVALUATION OF LONGITUDINAL LOADING OF TANK TRAINS DURING MOTION IN LONGITUDINAL CHANGES OF GRADIENT

Purpose. To research the tank train longitudinal loading during motion by track sections with changes of gradient. The trains of different length that consist of bogie tank wagons should be examined. Influence of cargo type on longitudinal loading of train during motion in concave section of track should be evaluated. **Methodology**. The level of the largest longitudinal forces was estimated by mathematical simulation. It was assumed that change of gradient is formed by two grades with baffle platforms, length 50 meters, so that the algebraic difference of limiting grades vary from 10 to 40 ‰, pitch 10 ‰. The initial speeds were 40, 60, 80, 100, 120 km/h. For evaluation of the longitudinal loading the regulating braking and motion «by coasting» was considered. For evaluation of buffing loads the entry to the concave gradient change of expanded train is considered, and in order to determine the quasi-static forces the compressed train is considered. **Findings**. As a result of calculations the dependencies of maximal longitudinal forces in the trains on the cargo type, the algebraic difference of the grades, the number of tank wagons, the initial speed, motion modes, and initial gaps condition in the train were obtained. **Originality.** The longitudinal loading of freight cars of different length formed by the similar bogie tank wagons with one locomotive was obtained. The locomotive is placed in the train head during motion in concave track sections with various algebraic difference of the grades «on coasting» and during the regulating braking mode. The obtained results can be used for parameters standardization of profile elevation of the track. **Practical value**. The obtained results show that during operation of tank trains on track sections of complex breakage the most dangerous is regulating braking of preliminary compressed trains during entering on concave parts of track. Level of the greatest buffing and quasi-static longitudinal forces is almost independent of cargo and slightly depends on the initial speed.

Keywords: longitudinal forces; mathematical simulation; changes of gradient; tank trains

Introduction

With increasing masses and especially lengths of trains the values of longitudinal forces affecting cars and weights they transport, and their accelerations as well acquire a considerable growth. These forces reach their maximum values in cases of transient or unstable modes of motion when, in general, multi-mass considerably non-linear mechanic system «train» transfers during short time intervals from one state into another [1, 3, 6, 8, 9, 11, 13].

Particular attention should be paid to the traffic of freight trains consisting of tank cars on changes of gradient that can lead to the origin of such longitudinal forces, which can affect the safety of railway traffic in general. As it is known, the maximal longitudinal compressing forces appear at the entering of extended tank train on concave part of track and the maximal extending forces appear at the entering of compressed tank train on convex track profile [1, 6, 9].

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Purpose

As it is shown in the paper [1] you can analyze only one of two tasks on the train movement in concave and convex track sections, because the results of solving received in both cases are the same, the only difference is sign (negative). The same work shows that in statistically inhomogeneous train the maximum expected values of forces exceed the corresponding values of forces in homogeneous train (with the same mass) no more than on 20 %. That is why the entry of extended homogeneous train on concave changes of gradient is being analyzed below for estimation of buffing loadings and the entry of compressed train – for determination of quasi-static forces.

It is also interesting to analyze influence of cargo types on longitudinal forces at motion by changes of gradient during research of longitudinal dynamic of tank trains.

Methodology

During estimation of longitudinal loading the train that consists of 80 bogie tank wagons with mass 84 t with one locomotive VL-8 in the head was analyzed. Mass of tank wagon was chosen in such manner, so that the volume of transported liquid does not exceed the usable storage of tank shell. During mathematical simulation it was assumed that tank wagons were filled with diesel fuel or carbamide-ammoniac blend (CAB) with density accordingly $p = 0.85$ t/m^3 and $p = 1.31$ t/m^3. Since, the volume of liquid underfill depends on its density the level of liquid free surface from the top inner surface of tank shell is located on distance 0.11 m for diesel fuel and on 1.17 m for carbamide-ammoniac blend [4, 8].

Solving the task of estimation of maximal longitudinal forces it was assumed that tank wagons were equipped by air distributors with arbitrary no. 483 turned on medium mode and composition brake shoes and the inter-car connections were equipped by elastic-friction draft gear Sh-1-TM [5, 7].

For estimation of longitudinal loading of trains the motion «by coasting» and regulating braking by II stage were analyzed.

It was assumed that change of gradient is formed by two grades with baffle platforms, length 50 meters so that the algebraic difference of limiting grades vary from 10 to 40 ‰, pitch 10 ‰. The initial speeds of motion were $V_0 = 40$, 60, 80, 100, 120 km/h.

Estimation of longitudinal forces was made by numerical integration of nonlinear differential equations of train motion [8].

Findings

Below on the Figures 1 and 2 are illustrated the dependencies of maximal buffing longitudinal forces on values of grades difference during motion «by coasting» and during regulating braking by II stage accordingly. The given graphs are obtained during simulation of train movement with initial speed $V_0 = 80$ km/h.

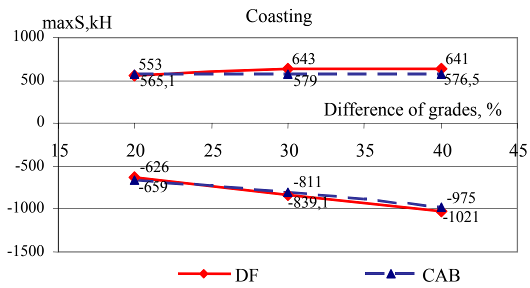

Fig. 1. Dependence of maximal buffing longitudinal forces on value of grade difference during motion «by coasting»

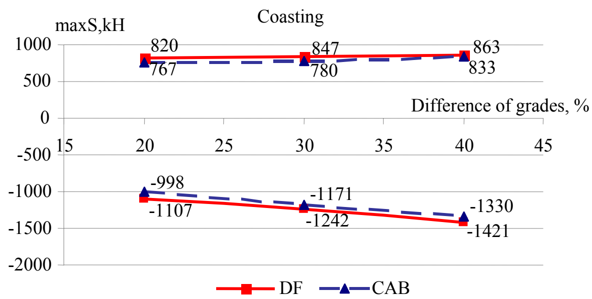

Fig. 2. Dependence of maximal buffing longitudinal forces on value of grade difference during regulating braking by II stage

On the presented Figures the full lines correspond to the tanks filled with diesel fuel and the dashed lines – to the tanks with CAB.

As we can see from the Figures 1 and 2 the maximal buffing longitudinal forces grow with increase of algebraic difference of grades and during both the motion «by coasting» and during regulating braking by II stage. The level of maximal longitudinal forces during for different types of cargo (diesel fuel and carbamide-ammoniac blend) differed less by 10 %.

As a comparison, the similar motion modes («by coasting» and regulating braking by II stage) for train consisting of 80 open cars during entering on concave track section were simulated. The initial speed of motion was 80 km/h.

In the Table 1 are listed the maximal buffing extending and compressing forces for analyzed motion modes and different algebraic difference of grades.

Table 1

Maximal values of buffing compressing and -extending forces (in kN) in trains consisting of tank wagons and open cars for different algebraic difference of gradient changes during motion «by coasting» and regulating braking by II stage with initial speed 80 km/h

Algebraic difference of gradient changes, ‰	Coasting			Braking by II stage		
	Tank wagons		Open cars	Tank wagons		Open cars
	DF	CAB		DF	CAB	
20	553 / –626	565 / –659	90 / –748	820 / –1107	767 / –998	90 / –1295
30	643 / –839	579 / –811	150 / –897	847 / –1242	780 / –1171	135 / –1425
40	641 / –1021	576.5 / –975	180 / –1035	863 / –1421	833 / –1330	180 / –1515

As we can see from the results listed in the Table 1, the level of maximal compressing forces in train consisting of open cars is higher than similar values in the train consisting of tank wagons only.

It should be noted that during freighting of cargo with higher density (CAB) the level of compressing forces was somewhat lower.

It is caused by the fact that with the same mass of car the level of underfill is different.

As was mentioned above the level of maximal compressing forces depends on mass of stationary liquid that is determined by density of transported cargo [4, 6, 9].

Value of stationary mass for diesel fuel is 44.93 tons and for CAB is 39.51 tons. That is why the level of longitudinal loading for tank wagons with carbamide-ammoniac blend was the lowest and for the open cars (all cargo of which is considered as the stationary one) – was the highest.

The moving part of liquid affects the level of maximal extending forces that is why this value in trains consisting of tank wagons exceeds the same values for trains consisting of open cars.

The dependencies of maximal buffing longitudinal forces for different modes of motion during freighting of diesel fuel and carbamide-ammoniac blend in tank wagons are illustrated on Figures 3 and 4.

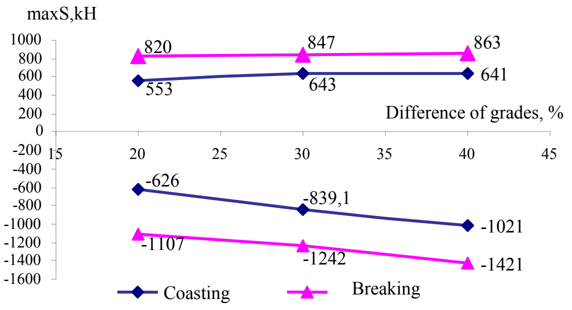

Fig. 3. Dependence of maximal buffing longitudinal forces on value of grade difference during the diesel fuel freighting

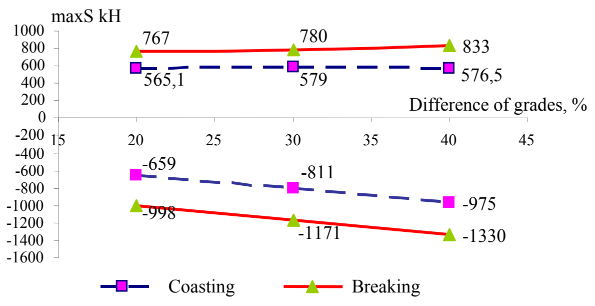

Fig. 4. Dependence of maximal buffing longitudinal forces on value of grade difference during the CAB freighting

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On the foregoing Figures the dashed lines resulted from the simulation of train motion «by coasting» and the full lines from the regulating braking simulation.

Solving task of regulating braking of initially extended and compressed trains during entering on the concave track section it was assumed that the start of braking happens at the moment of train entering on baffle platform with length 50 meters.

As expected, the longitudinal loading during the regulating braking was considerably higher than that during motion «by coasting»

The graphs of maximal buffing forces behavior in the train consisting of tank wagons (during freighting of CAB) depending on initial speed during motion «by coasting» on concave track section with different algebraic difference of gradient changes are shown on Figures 5 and 6. The maximal buffing extending forces are shown on Figure 5 and the compressing forces – on Figure 6. On the above mentioned graphs the lines 1 correspond to the algebraic difference grades difference $\Delta i = 10$ ‰, the lines 2 – $\Delta i = 20$ ‰, the lines 3 – $\Delta i = 30$ ‰, the lines 4 – $\Delta i = 40$ ‰.

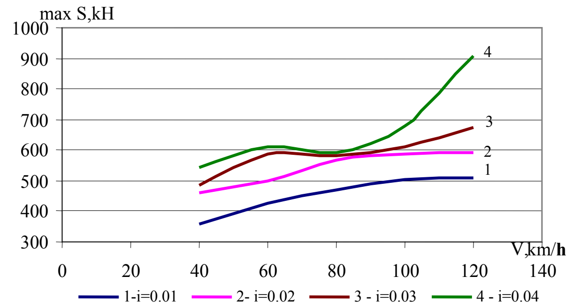

Fig. 5. Dependence of maximal buffing extending longitudinal forces on the initial speed during motion «by coasting» and CAB freighting

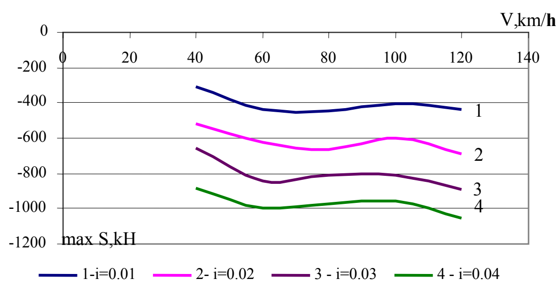

Fig. 6. Dependence of maximal buffing compressing longitudinal forces on the initial speed during motion «by coasting» and CAB freighting

As one can see from the Figures 5-6, as a rule, the level of maximal buffing longitudinal forces grows with the speed increasing. However in the range of initial speed V_0 the maximal compressing forces slightly decrease. It is caused by the fact that the longitudinal loading forming in the trains consisting of tanks depends on the moving liquid oscillation.

In case the liquid oscillations in two neighboring tank wagons are opposite in phase at the moment of maximal longitudinal forces occurring it can lead to the slight decrease of the maximal buffing force.

Dependencies of values of maximal buffing extending and buffing compressing forces on initial speed of motion for different types of transported cargo are shown on the Figures 7-8.

The above mentioned dependencies for the case of train motion «by coasting» are shown on the Figure 7, and the dependencies for the regulating braking are shown on the Figure 8.

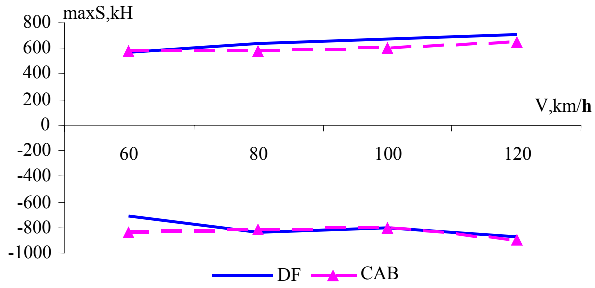

Fig. 7. Dependence of maximal buffing longitudinal forces on initial speed during motion «by coasting»

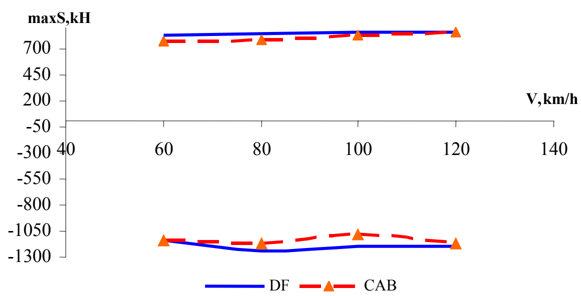

Fig. 8. Dependence of maximal buffing longitudinal forces on initial speed during regulating braking by stage II

Graphs shown on the Figures 7 and 8 are obtained for motion of the trains consisting of 80 tank cars in the concave track section with algebraic difference of grades $\Delta i = 30$ ‰.

Full lines correspond to the variants when the tank wagons transport diesel fuel and the dashed lines when the tank wagons transport the carbamide-ammoniac blend.

According to the obtained results the values of maximum longitudinal forces for analyzed modes of motion insignificantly grow during the increase of initial speed for analyzed types of cargo.

The dependencies of maximal values of longitudinal forces on the train length are researched below.

To do this, the motions of trains consisting of 60, 70, 80, and 100 tank cars, which transport either the diesel fuel or carbamide-ammoniac blend were simulated. Firstly the results of mathematical simulation of train motion «by coasting» should be analyzed.

As an example the above mentioned dependencies received in case of entering compressed (Fig. 9a and 9b) and extended (Fig. 11) trains «by coasting» on the concave track sections with initial speed 80 km/h were shown.

On the Figures 9 and 11 the lines 1 correspond to the concave track section with algebraic difference of grades equal to 20 ‰, lines 2…30 ‰, lines 3…40 ‰. Full lines are obtained for the case of simulation of the CAB transportation in tank wagons and the dashed lines for diesel fuel (DF) transportation.

As it is commonly known, that during entering of preliminary compressed trains on the concave profile track sections in the inter-car connections appear the quasi-static forces. In case these forces exceed the accepted value – 1000 kN, they can lead to extrusion even of loaded car.

As example the oscillograms of longitudinal forces in the inter-car connections during entering «by coasting» of preliminary compressed train consisting of 100 tank wagons, which are filled with carbamide-ammoniac blend on the concave track section with algebraic difference of grades 30 ‰ and initial speed 80 km/h are shown on the Figure 10.

As we can see from the listed oscillograms, the quasi-static forces in inter-car connections of the analyzed train appear even during motion «by coasting». These forces are close to the dangerous values from the position of motion stability.

As an example the dependences of maximal longitudinal forces on the number of tank wagons in the train for different initial speeds during entering «by coasting» of preliminary extended trains on concave track section with algebraic difference of gradients equal to 30 ‰ are shown on the Figures 12 and 13.

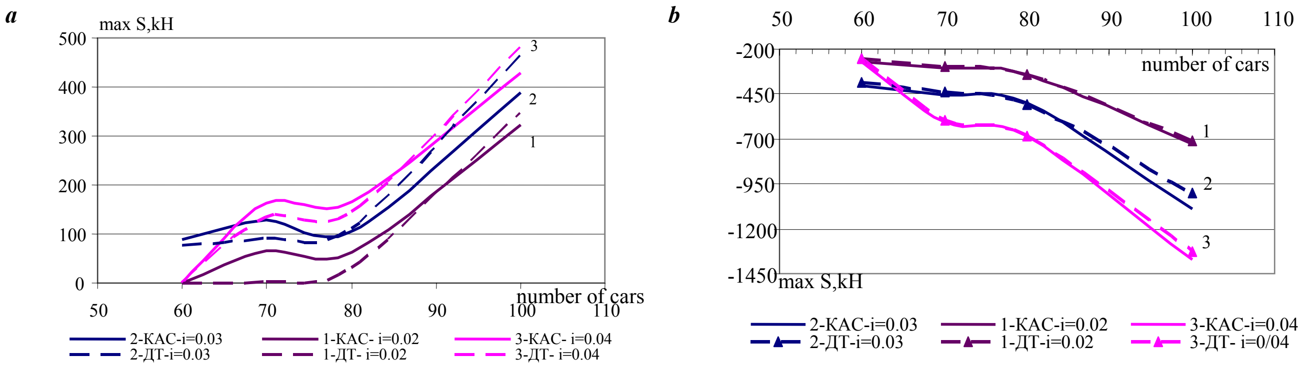

Fig. 9. Dependence of maximal extending (a) and compressing (b) longitudinal forces on the number of tank wagons during entering «by coasting» of preliminary compressed trains on the concave track section

As a result of the presented graphs, the level of maximal longitudinal forces grows with increasing of tank wagons number, insignificantly grows in case of increasing of initial speed and significant accepted below value from a perspective of tank wagons durability.

Since during regulating braking the level of maximal longitudinal forces is significantly higher than during motion «by coasting» further we are going to estimate the longitudinal loading of trains with different length for the specified mode.

Dependencies of maximal compressing forces on initial speed for different algebraic difference of grades during regulating breaking by II stage on the concave track section of preliminary compressed trains transporting the diesel fuel are shown on the Figures 14-17.

On the Figures 14-17 the lines 1 correspond to algebraic difference of grades $\Delta i = 10$ ‰, lines 2 – $\Delta i = 20$ ‰, lines 3 – $\Delta i = 30$ ‰, lines 4 – $\Delta i = 40$ ‰.

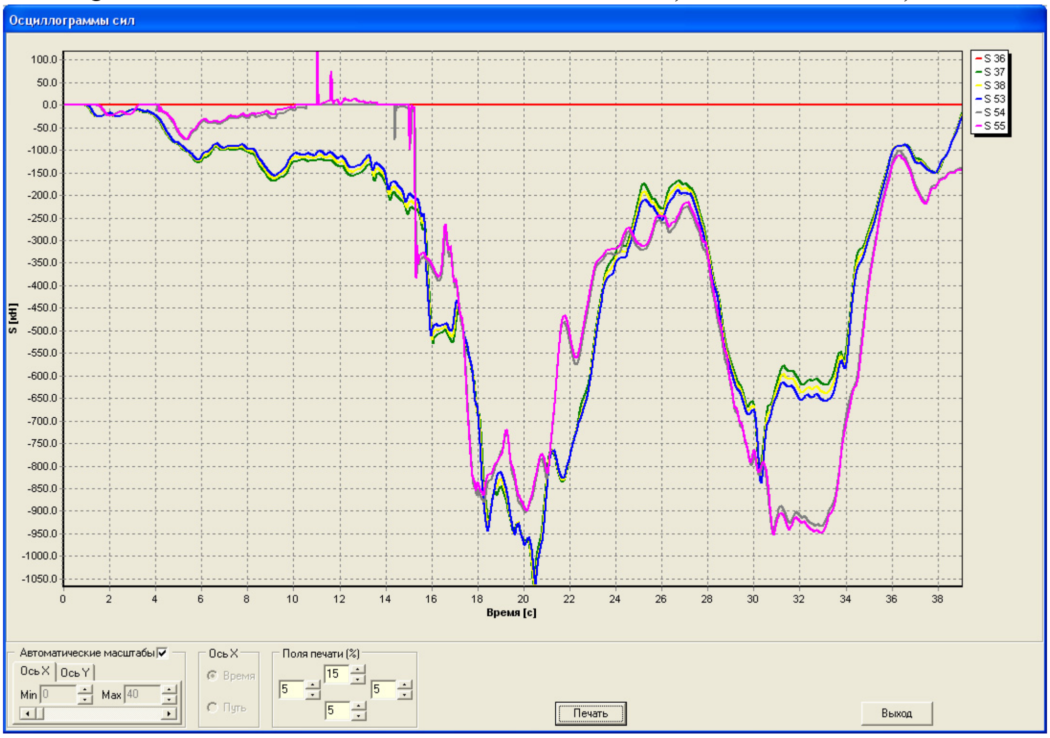

Fig. 10. Oscillograms of longitudinal forces in 36th, 37th, 38th, 53 th, 54th and 55th sections of preliminary compressed train consisting of 100 tank wagons, which are filled with carbamide-ammoniac blend during motion «by coasting» in the concave track section with algebraic difference of grade difference 30 ‰ and initial speed 80 km/h

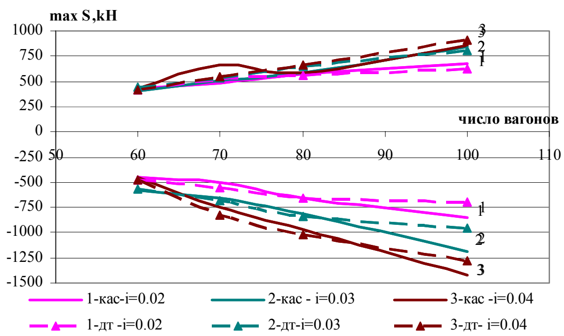

Fig. 11. Dependence of maximal longitudinal forces on the number of tank wagons during entering «by coasting» of extended trains on concave track section

From the presented Figures it can be concluded that maximal values of compressing longitudinal forces practically don't change when the initial speed increases and grow up when the algebraic difference of grades increase.

As can be seen from the Figure 15, the maximal values of compressing longitudinal forces in train that consists of 80 tank wagons are very close to the limiting value – 1000 kN.

Dependencies of maximal compressing quasi-static longitudinal forces on number of tank wagons during regulating braking of preliminary compressed trains on concave track section are shown on the Figure 16 and 17.

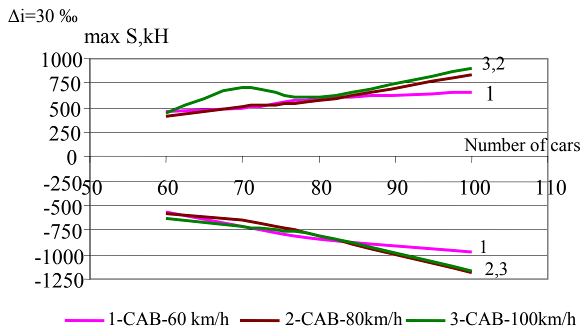

Fig. 12. Dependence of maximal longitudinal forces on the number of tank wagons during entering «by coasting» of extended trains transporting CAB on the concave track section for different initial speeds

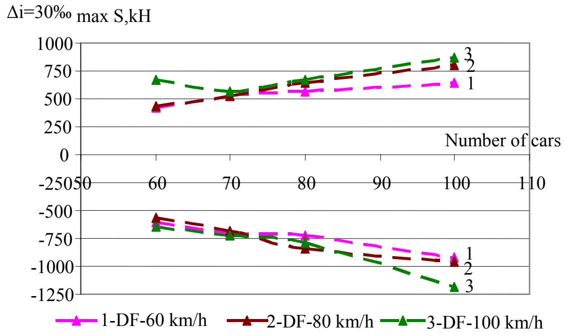

Fig. 13. Dependence of maximal buffing longitudinal forces on number of tank wagons during entering «by coasting» of extended trains transporting diesel fuel on concave track section for different initial speeds

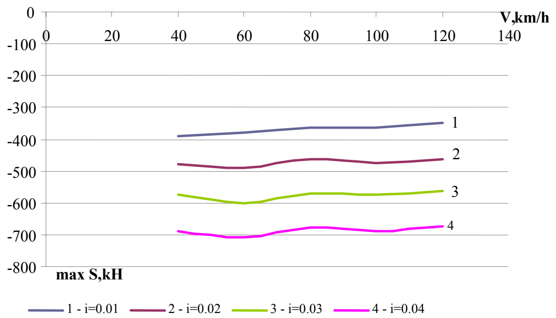

Fig. 14. Dependence of maximal longitudinal forces on the speed for different values of algebraic difference of grades during regulating braking of preliminary compressed trains consisting of 60 tank wagons on concave track section

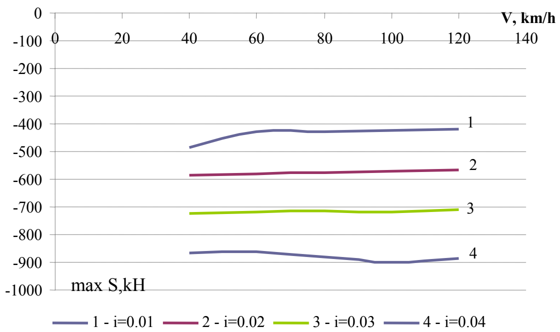

Fig. 15. Dependence of maximal longitudinal forces on motion speed for different values of algebraic difference of grades during regulating braking of preliminary compressed trains consisting of 80 tank wagons on the concave track section

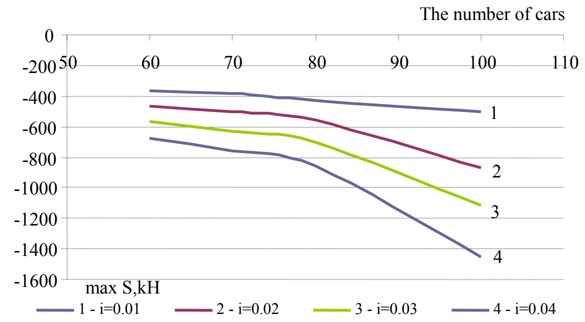

Fig. 16. Dependence of maximal longitudinal forces on number of tank wagons for different values of algebraic difference of grades during regulating braking of preliminary compressed trains with initial speed 60 km/h on concave track section

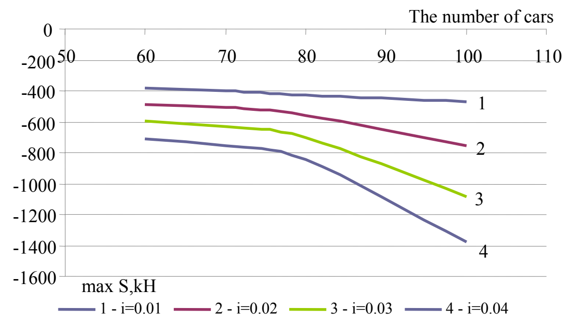

Fig. 17. Dependence of maximal longitudinal forces on number of tank wagons for different values of algebraic difference of grades during regulating braking of preliminary compressed trains with initial speed 80 km/h on concave track section

Using the obtained dependencies (Figures 16, 17) the level of maximal quasi-static compressing longitudinal forces should not exceed the acceptable value, according to the car stability conditions of extrusion (for loaded freight cars this force equals 1000 kN [2]). On the basis of the above mentioned, it can be concluded that during motion in the compound track sections (with grade difference $\Delta i = 30$ ‰ or more) one can make up the train with locomotive in the head using no more than 95 tank cars.

Originality and practical value

The paper researched the longitudinal loading of freight cars of different length formed by identical four-axial tank cars with one locomotive in the head during motion in the track section with different algebraic difference of the grades «by coast-

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ing» and in the mode of regulating braking. The obtained results can be used during parameter standardization of the longitudinal profile of the track.

Conclusions

Results show that if it is necessary to operate the train in the compound track sections the most dangerous is the regulating breaking of the preliminary compressed trains during entering the concave profile sections. In the trains consisting of more than 90 tank wagons during motion in concave track section with algebraic difference of grades more than 30 ‰ these forces can reach the dangerous values from the point of car extrusion.

The values of obtained forces exceed the similar values of quasi-static longitudinal forces in train consisting of open cars only.

As for the level of maximal buffing compressing forces in trains consisting of open cars is higher than that in the same trains consisting of tank wagons. Oscillations of the moving part of liquid reduce the maximal level of compressing forces and provide extending longitudinal forces.

Level of the greatest buffing and quasi-static longitudinal forces is almost independent from the transported cargo and insignificantly depends on the initial speed and grows with the increase of algebraic differences of grades.

As expected the longitudinal loading in case of regulating braking was higher than that in case of motion «by coasting».

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ОЦІНКА ПОДОВЖНЬОЇ НАВАНТАЖЕНОСТІ НАЛИВНИХ ПОЇЗДІВ ПРИ РУСІ ПЕРЕЛОМАМИ ПОДОВЖНЬОГО ПРОФІЛЮ КОЛІЇ

Мета. Дослідити подовжню навантаженість наливних поїздів при русі по ділянках шляху ламаного профілю. Розглянути поїзди різної довжини, що складаються з чотиривісних цистерн. Оцінити вплив типу вантажу, що перевозиться, на подовжню навантаженість поїзду при його русі по увігнутій ділянці шляху. **Методика**. Рівень найбільших подовжніх зусиль оцінювався за допомогою математичного моделювання. Передбачалося, що перелом профілю утворений двома ухилами з розділювальним майданчиком довжиною 50 метрів таким чином, що алгебраїчна різниця керівних ухилів змінювалась від 10 до 40 ‰ з кроком 10 ‰. Початкові швидкості руху приймалися рівними 40, 60, 80, 100, 120 км/год. Для оцінки подовжньої навантаженості розглядалися регулювальні гальмування і рух «на вибіганні». Для оцінки ударних навантажень розглядався в’їзд на увігнуту ділянку розтягнутого однорідного поїзда, а для визначення квазістатичних сил – стислого. **Результати**. У результаті розрахунків були отримані залежності найбільших подовжніх сил в поїздах від типа вантажу, що перевозиться, алгебраїчної різниці ухилів, кількості вагонів-цистерн, початкової швидкості руху, режимів руху, початкового стану зазорів у поїзді. **Наукова новизна.** Досліджено подовжню навантаженість вантажних поїздів різної довжини, сформованих з однакових чотиривісних вагонів-цистерн з одним локомотивом, розташованим в голові при русі по увігнутим ділянках колії з різною алгебраїчною різницею похилів на «вибігу» і режимі регулювального гальмування. Отримані результати можуть бути використані при нормуванні параметрів поздовжнього профілю колії. **Практична значимість.** Отримані результати показують, що при необхідності водіння наливних поїздів по ділянках колії складного профілю найбільш небезпечним виявилось регулювальне гальмування попередньо стиснутих поїздів при в'їзді на ділянки увігнутого профилю. Рівень найбільших ударних і квазістатичних подовжніх сил практично не залежить від вантажу, що перевозиться, і трохи залежить від початкової швидкості руху.

Ключеві слова: поздовжні зусилля; математичне моделювання; переломи подовжнього профілю; наливні поїзди

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ОЦЕНКА ПРОДОЛЬНОЙ НАГРУЖЕННОСТИ НАЛИВНЫХ ПОЕЗДОВ ПРИ ДВИЖЕНИИ ПО ПЕРЕЛОМАМ ПРОДОЛЬНОГО ПРОФИЛЯ ПУТИ

Цель. Исследовать продольную нагруженность наливных поездов при движении по участкам пути ломаного профиля. Рассмотреть поезда различной длины, состоящие из четырехосных цистерн. Оценить влияние типа перевозимого груза на продольную нагруженность поезда при движении поезда по вогнутому участку пути. **Методика**. Уровень наибольших продольных сил оценивался с помощью математического моделирования. Предполагалось, что перелом профиля образован двумя уклонами с разделительной площадкой длиною 50 метров таким образом, что алгебраическая разность руководящих уклонов варьировалась от 10 до 40 ‰ с шагом 10 ‰. Начальные скорости движения принимались равными 40, 60, 80, 100, 120 км/ч. Для оценки продольной нагруженности рассматривались регулировочные торможения и движения «на выбеге». Для оценки ударных нагрузок рассматривается въезд на вогнутый перелом растянутого однородного поезда, а для определения квазистатических сил – сжатого. **Результаты**. В результате расчетов были получены зависимости наибольших продольных сил в поездах от типа перевозимого груза, алгебраической разности уклонов, количества вагонов-цистерн, начальной скорости движения, режимов движения, начального состояния зазоров в поезде. **Научная новизна**. Исследована продольная нагруженность грузовых поездов разной длины, сформированных из одинаковых четырехосных вагонов-цистерн с одним локомотивом, расположенным в голове при движении по вогнутым участкам пути с различной алгебраической разностью уклонов на «выбеге» и режиме регулировочного торможения. Полученные результаты могут быть использованы при нормировании параметров продольного профиля пути. **Практическая значимость.** Полученные результаты показывают, что при необходимости вождения наливных поездов по участкам пути сложного профиля наиболее опасным оказалось регулировочное торможение предварительно сжатых поездов при въезде на участки вогнутого профиля. Уровень наибольших ударных и квазистатических продольных сил практически не зависит от перевозимого груза и незначительно зависит от начальной скорости движения.

Ключевые слова: продольные усилия; математическое моделирование; переломы продольного профиля; наливные поезда

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