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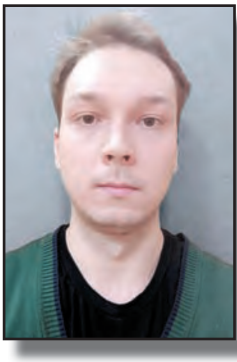
Evaluation of the Danger of Wheel Lift for Empty Cars in Heavy Trains during Shunting Collisions and Transient Modes of Movement

Gennady I. PETROV

Viktor N. FILIPPOV

Nadezhda M. KURZINA



Ivan K. SERGEEV

Gennady I. Petrov [1]***, Viktor N. Filippov*** [2]***, Nadezhda M. Kurzina*** [3]***, Ivan K. Sergeev*** [4]

[1, 2, 3, 4] *Russian University of Transport, Moscow, Russia.*

✉ [3]*kurzina.nadia@gmail.com.*

ABSTRACT

The increase in the transit and carrying capacity of cargo intensive sections and directions of railways is achieved by introducing into circulation of cargo trains of increased weight and length, which in turn leads to a change in longitudinal dynamics of movement and emergence of additional loads on rolling stock and the railway track.

In this regard in relation to Russian conditions, to ensure the required volumes of transportation with a preset level of safety, it is necessary to revise the current standards designed for maximum longitudinal compression forces of 50 tf, which are currently more than doubled in heavy trains.

Based on the analysis of existing regulatory documents, domestic and foreign experience, it was possible to substantiate the necessity to improve the longitudinal dynamics of trains and to propose some ways to achieve it. are proposed. The simulation of collision of a free running platform wagon with standard draft gears of Sh-1-TM type with a gondola cars' cut also equipped with standard draft gears of Sh-1-TM type was carried out to identify accident modes. The study has allowed to conclude on the expediency of increasing the energy intensity of draft gear through new design solutions, as well as on reducing longitudinal forces through adoption of floating centre beams.

Keywords: railway cargo wagons, train longitudinal dynamics, calculation of parameters of shunting collisions and transient modes, draft gear, floating centre beam.

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INTRODUCTION

A growth in transit and carrying capacity of cargo-intensive sections and routes of Russian and some foreign railways is currently achieved by introducing cargo trains of increased weight and length, which in turn leads to a change in the longitudinal dynamics of movement and to the emergence of additional loads on rolling stock and the railway track.

The first regulatory documents, adopted on Russian railways in relation to cargo trains of increased weight and length, defined them as trains weighing more than 6000 t, with a length of more than 284 axles, with one or more operating locomotives located at the head of the train, at the head and tail, at the head and in the last third of the train. As of January 1, 2015, in accordance with classification and profiling of railway lines developed by JSC Institute for Transport Economics and Development, a railway line with heavy cargo traffic was defined as a line with traffic of cargo trains weighing 6300 t and more, including cars with axle load up to 25 tf [1]. At present, to describe the heavy haul traffic, mass of cargo trains from 7000 t and more is increasingly mentioned [2]. Consequently, the mass of heavy trains increased by at least 17 %.

It is worth noting that, in accordance with classification of International Heavy Haul Association (IHHA), a railway for such transportation must meet at least two of the following three criteria [3]:

• Regularly operates or is contemplating the operation of unit or combined trains of at least 5 000 metric tons.

• Hauls or is contemplating the hauling of revenue freight of at least 20 million gross tons per year over a given line haul segment comprising at least 150 km in length.

• Regularly operates or is contemplating the operation of equipment with axle loadings of 25 tons or more [3].

Consequently, foreign colleagues operate with significantly smaller masses of trains, which increases the level of safety of the transportation process.

If the length of the segments of circulation of heavy haul trains in the Russian Federation as of January 1, 2015, was 9,76 % of the operational length of the road network, then the planned length by 2025 should reach 33,6 %. Moreover, circulation of trains weighing 7100 t, with an axle load of 25 tf takes place mainly at the «Eastern polygon» [Eastern part of the network] to ensure transportation of bulk export cargo to the ports of the Far East, China, as well as from the coal mines of Kuzbass [Kuznetsk Basin]. This part of the rail network is characterised by a complex terrain with many mountain passes, curves of small radius and harsh climate.

From the results of experimental studies, it was found that the vertical forces acting from the wheel on the rail in a heavy haul train increase in proportion to the axial load, and the longitudinal forces can be 2,0–2,5 times greater than the maximum traction force of the locomotive in terms of adhesion [4]. According to JSC VNIKTI data, the maximum longitudinal compression forces in cargo trains exceeded the standard of 50 tf and reached 120 tf in a train weighing 12600 tons and 140 tf in a train weighing 14200 tons [5]. Therefore, at present, to ensure required volumes of transportation with a specified level of safety, it is necessary to revise the current standards and propose options for reducing the negative impact of existing excess loads on rolling stock and the railway track. If in recent years many works by domestic researchers have been devoted to strengthening the roadbed, the superstructure of the railway track, bridge structures on lines with heavy traffic, then insufficient attention has been paid to improvement of the longitudinal dynamics of rolling stock, so this issue is relevant.

The global features of organisation of heavy haul traffic [6] also indicate the expediency of specialisation of the sections of the railway, on which trains of optimal length and weight will run at a certain speed [7], consisting of the most convenient, uniform rolling stock suitable for quick loading and unloading of cars. For this purpose, research is carried out on the conditions of interaction between the carriage and the track, the wheel and the rail, on the longitudinal dynamics of the train, speed modes, the profile and plan of the track of a particular section.

The process of operation, especially incorrect actions of the personnel, can provoke the occurrence of excess dynamic modes, which are particularly dangerous during shunting operations and driving of heavy trains of great length on sections of the track of a complex profile with slopes. The current standards [8] establish the main standardised design modes of loading of various types of rolling stock (Table 1).

However, the existing standards do not establish limit values for longitudinal forces

Table 1

Values of longitudinal design mode loads in the assessment of the strength of different types of cars [8]

	Value of longitudinal load, MN			
	Design modes			
Name of cars	I		III	
	Quasi-static force	Impact, jerk	Quasi-static force	Impact, jerk
Cargo cars of main types	-3,0 +2,5	-3,0 +2,5	-1,0 +1,0	-1,0 +1,0
Isothermal cars, hopper-dispenser, dump cars	-2,5 +2,5	-3,0 +2,5	-1,0 +1,0	-1,0 +1,0
Passenger cars of all types, including mail, baggage, and mail-luggage cars	-2,5 +1,5	-2,5 +2,0	-1,0 +1,0	-1,0 +1,0

when driving trains through the sections with complex profiles, considering recuperation modes, and they also do not contain limit values for longitudinal forces, upon reaching which empty cars' wheels can be lifted from the track.

For the first time, the problems of empty cars' wheel lift arose when the cargo fleet began to be equipped with cars with a different number of axles (of two and more). Moreover, two-axle cars had a short base and low tare weight. With appearance of powerful locomotives, cars' wheels were lifted from the track more frequently, which led to accidents. To eliminate this problem, it was necessary to carefully monitor assembling of the train by installing empty cars at the end of the train, which created certain difficulties in performing marshalling and shunting operations. However, later-on, the two-axle cars were taken out of service, and the problem of wheel lift lost its relevance.

With appearance of specialised cars that transported dangerous goods, the issues of the longitudinal dynamics of the train, strength, stability of cars, loading of their elements during shunting collisions and various emergency situations again came to the fore [9; 10]. Various computational simulation models were used, displacements, speeds and accelerations of nodes were analysed along with the forces in individual elements, to study loading of tanks under emergency conditions of collisions.

In the early 2000s, methods were developed for calculating longitudinal dynamic forces in automatic couplers of cargo cars of long and heavy haul trains [11], considering the characteristics of the features of brake devices and draft gears that were widely used at that time, as well as modelling movement of long heavy haul trains along the curve down-slope in the braking mode to identify the area of possible derailment of the car [12].

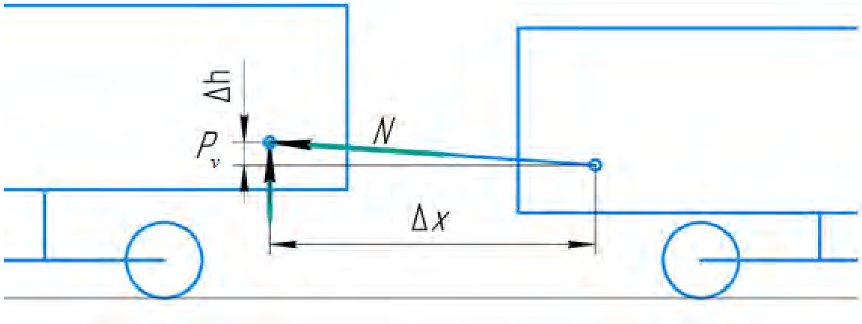
The *objective* of the study was to substantiate the need and suggest a general assessment of possible ways to improve the longitudinal dynamics of trains. Main *methods* of the study comprised content analysis of scientific publications, physical and mathematical calculations, and modelling.

RESULTS

Modern Approaches to the Analysis of the Dynamics of Heavy and Long Trains

Currently, the problem has again become relevant due to a next stage of a significant increase in length and weight of trains. Several international works consider mathematical models of inter-car couplings used in a long and heavy train, taking into account the elastic-frictional properties of draft gears and gaps in automatic couplers connecting train cars.

Modern computational methods make it possible to model each car as a separate mass, that can be further combined into a train through not only elastic, but viscoelastic connections in accordance with the type of draft gear. The work [13], using a mathematical model of a long train consisting of 107 cars with a distributed load, compared different variants of system's coupling. It was demonstrated that reducing slack of coupler results in diminishing internal force and fatigue damage. The nature of friction in the draft gear proved to be an important factor in controlling internal train forces and minimising fatigue damage. It was shown that the fatigue damage occurs mostly in the middle of the train, while in the head part it is minimal due to softer dynamics, and in the tail of the train it is also minimal due to the action of stable forces with rare strong bursts.



Pic. 1. Scheme of action of forces in the automatic coupler node [compiled by the authors].

The work [14], based on a simulation model, studied the effect of emergency braking of heavy trains in curves of different radii on safety and smoothness of train run. Reducing the radius of the curve to 500 m, as well as its length, increases the coefficient of wheel derailment from the outer rail under the condition of braking, significantly reduces the safety and can lead to an emergency. Therefore, it is necessary to choose the optimal train route. The most important factor affecting the efficiency of heavy train control is the increase in the number of cars, and, consequently, weight, length, and axle load, which significantly increases the braking wave during movement of a heavy train and changes its dynamic characteristics.

However, it should be noted that the operating conditions of domestic heavy trains are much tougher than of foreign ones, and are associated with a larger mass of cars, length of routes, a complex plan and profile of the track, as well as the condition of the railway track.

Situation Modelling

Let us consider the factors affecting distribution of forces in the automatic coupler assembly (Pic. 1).

As can be seen from the scheme, vertical force, lifting the car, can be found according to the formula:

$$P_v = N \cdot \frac{\Delta h}{\sqrt{\Delta h^2 + \Delta x^2}}. \quad (1)$$

According to the values presented in Table 1, the longitudinal force during train running can reach 3 MN (300 tf). It is easy to estimate the value of the vertical component of the inter-car reaction, knowing the required geometric dimensions. The maximum allowable difference in heights of automatic couplers when assembling a train is $\Delta h = 100$ mm, and the distance between the ends of the automatic couplers of adjacent cars does not exceed $\Delta x = 2000$ mm.

In this case, the vertical component P_V is determined using expression (1):

$$P_v = 300 \cdot \frac{100}{\sqrt{100^2 + 2000^2}} \cong 15 \text{ tf}. \quad (2)$$

Since four-axle cars with a tare weight of not more than 25 tons are most common on the railway network, the force pressing the body to one bogie in the centre plate area will not exceed 12,5 tf, which is less than the calculated value of the vertical component of P_V. Consequently, an empty car that is not equipped with special centre plate fixing devices will be lifted from the track under the given conditions.

Calculations have shown that when an empty platform with draft gears Sh-1-TM rolls from a hump onto a train of five gondola cars with the same draft gears Sh-1-TM at a speed of 3,6 m/s, the longitudinal forces in a collision increase by 2,5 times, and acceleration by 2,7 times compared to the standard mode, which will lead to damage to the automatic coupler of the tail car. And in the case of collision with a half-loaded tank car, the bogie of the head car will roll out.

Problem Solution Options

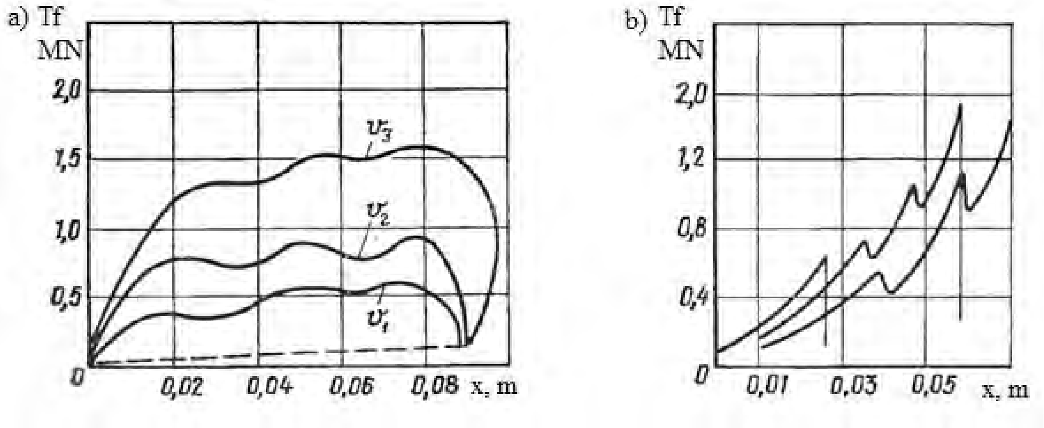
There are several possible solutions to this problem:

1. Changing the characteristics of draft gear to reduce the value of longitudinal forces.

2. Increasing the distance between the ends of the shanks of the automatic couplers of cars by means of some new design solutions.

3. Creation of a rigid connection between the bogie and the body in the centre plate area by using locking pivot. Such a solution is currently implemented in the design of passenger car bodies.

It should be noted that the value of the inter-car reaction is largely affected by the stroke of the draft gear. Due to the fact that the design of



Pic. 2. Types of power characteristics of draft gears [15]. a – soft characteristic, b – hard characteristic.

the automatic coupler was developed in the 1930s, the overall dimensions of the internal part were chosen in such a way as to ensure effective operation of draft gears designed at that time. However, this design of the apparatus, which provides a maximum stroke of the apparatus of 120 mm, has not been improved since those times, which imposes significant geometric restrictions on the developed models of modern draft gears.

The value of irreversibly absorbed energy in the apparatus depends on the area of the power characteristic, the most common variants of which are shown in Pic. 2 [15].

One of the options for solving the problem of reducing the longitudinal force in the train is the use of devices with a soft characteristic instead of those that have a hard force characteristic. The former mainly include elastomeric and hydraulic draft gears, as well as other promising designs being developed (for example, hydro-gas apparatuses, where liquid and gas under pressure are used as a working body).

Foreign experience of previous years [16] also showed the feasibility of using draft gear with a soft power characteristic, which is achieved not only by choosing the type of working fluid (friction, elastomeric, hydraulic, or combinations thereof), but also by increasing the maximum stroke due to changes in dimensions (primarily length) of the absorbing apparatus. Design solutions for various American draft gears from 18 to 43 inches long are shown in Pic. 3.

Recently, researchers have carried out a comparative assessment of influence of a type of power characteristic of draft gears on the maximum longitudinal forces arising in inter-car connections of trains [17]. Based on the results obtained, the main positive and negative properties of the rigid, linear and soft power characteristics of draft gears of automatic couplers are determined.

To calculate various situations of shunting collision and transient modes of train movement, domestic specialists have developed a general mathematical model that describes operation of an elastomeric draft gear, which is the dependence of the response of the gear on its deformation and speed of such a deformation, considering initial tightening of the device and the properties of working bodies [18].

The criterion of power consumption is proposed to be used as a parameter characterising the efficiency of draft gears of various types [19].

Thus, the widespread use of elastomeric draft gears (or others with a soft characteristic), as well as an increase in their maximum working stroke, will reduce the value of inter-car dynamic forces and solve the problem of wheel lift of empty cars in a train.

Besides, since the vertical component of the inter-car reaction depends on the location of the ends of automatic couplers, the design in which the parameter Δx will be larger compared to traditional implementation, will reduce the value of the lifting force. This effect can be achieved through the use of automatic couplers of increased length in the design of the draft. Such options were implemented on US railways in the second half of the 20th century. Some designs of such automatic couplers are shown in Pics. 4–6.

a)

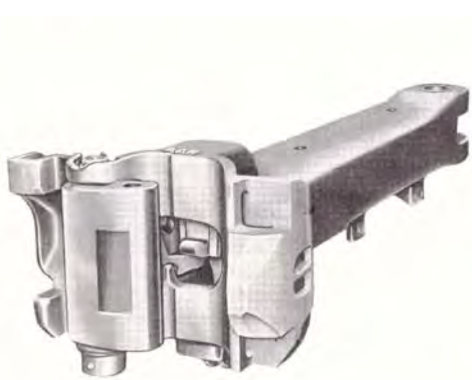
b)

c)

Pic. 3. Types of draft gear used on American railways: a) friction; b) hydraulic-friction; c) rubber friction [16].

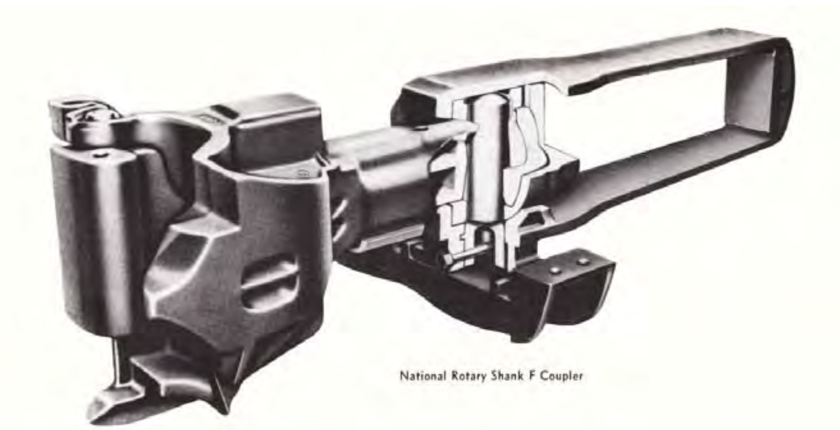
However, the use of automatic couplers of increased length entails coupling problems in curves and requires the use of devices with a large elastic stroke. In addition, considering the latest trends in the growth of axial loads of rolling stock, the values of longitudinal accelerations in trains can reach 12g. To solve this problem, special end stops were used on American railways (Pic. 7). This design makes it possible to prevent the cargo from leaving the body of rolling stock at a high level of longitudinal accelerations.

It should be noted that the use of design that allows not only to prevent the load from rolling out, but also to reduce the level of longitudinal accelerations is also relevant. Such solutions include the use of floating centre beams, which were first introduced on US railways in the second half of the 20th century. The first experiment involved the procedure for introducing a hydraulic damper into the central part of the main beam (Pic. 8). As a result of the experimental studies, data were obtained



Pic. 4. AAR (H) type automatic coupler [16].

Pic. 5. AAR (H) type automatic coupler with yoke [16].



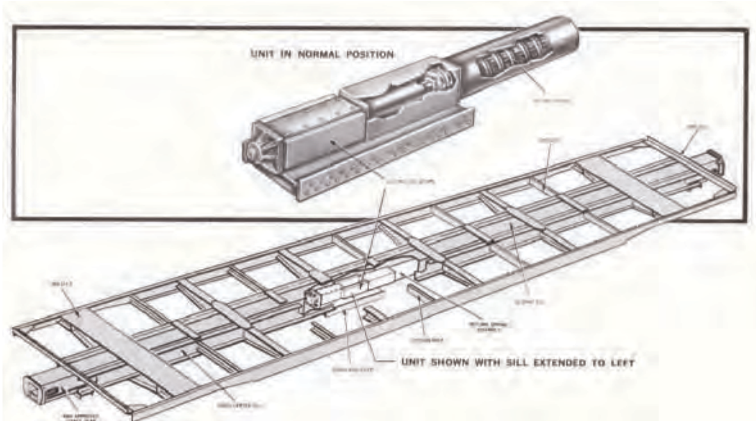
Pic. 6. National E-F automatic coupler with swivel shank [16].

Pic. 7. Evans Products platform with end stops [16].

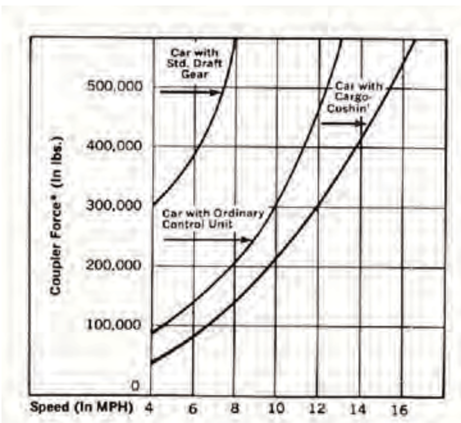
confirming the decrease in the value of the horizontal component of the traction force in the automatic coupler assembly (Pic. 9).

Table in Pic. 9 shows the various impact speeds and the corresponding forces in the coupler. During test number 3 (third line), the maximum force in the automatic coupler of a standard centre beam car was 600000 pound-forces, while in the test of a car with a floating centre beam, the force value decreased by more than four times and amounted to 144000 pound-forces.

On domestic railways, attempts to use car designs with floating centre beams [20] took place only as part of testing special-purpose cars, for example, car models 11-9960 of JSC TVZ [20].



Pic. 8. Centre beam with hydraulic damper in the central part [16].



Dynacoupler Force (Maximum Peak in Lbs.)

	With Cargo Cushin'		With Ordinary Control Unit		Car with Standard Draft Gear	
Run No.	Impact Speed MPH	Max. Force at Impact (Lbs.)	Impact Speed (MPH)	Max. Force at Impact (Lbs.)	Impact Speed (MPH)	Max. Force at Impact (Lbs.)
1	4.25	40,000	4.1	96,000	4.2	310,000
2	6.20	84,000	6.4	180,000	6.5	430,000
3	8.10	144,000	8.5	195,000	8.0	600,000
4	9.90	210,000	10.3	322,000	9.2	980,000
5	11.75	295,000	11.7	480,000	–	–
6	13.20	360,000	12.2	496,000	–	–
7	14.20	425,000	13.0	575,000	–	–

Pic. 9. Results of testing the loading test of a car with and without a floating centre beam [16].

CONCLUSIONS

Thus, the solution of issues related to the study of the longitudinal dynamics of trains in modern conditions of their operation (a significant increase in the part of long and heavy trains running along curved and mountain-pass sections), as well as to updating relevant regulatory documents, is a very urgent task.

Preliminary calculations showed that an increase in speed of free running an empty platform with Sh-1-TM draft gears from a hump up to a collision with a cut of five gondola cars with the same devices by more than 3 m/s significantly increases the longitudinal forces during a collision and acceleration, which could lead to damage to the automatic coupler of the tail car, and in the case of a half-loaded tank car – to the derailment of the bogie of the head car. For more accurate assessment of emergency situations, it is necessary to simulate a larger number of options on various types and models of cars.

Based on the studied domestic and foreign experience in improving longitudinal dynamics of trains, it is advisable to increase energy intensity of draft gears of the automatic coupler not only by improving the working fluid, but also by increasing the maximum working stroke by changing the distance between the ends of the shanks of the automatic couplers, as well as to develop design for serial cars of various types with floating centre beams.

The development of specific recommendations can be carried out in the course of further in-depth studies of this issue.

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Information about the authors:

Petrov, Gennady I., *D.Sc. (Eng), Professor, Head of the Department of Cars and Car Facilities of Russian University of Transport, Moscow, Russia, petrovgi@gmail.com.*

Filippov, Viktor N., *D.Sc. (Eng), Professor at the Department of Cars and Car Facilities of Russian University of Transport, Moscow, Russia, filipovvn@gmail.com.*

Kurzina, Nadezhda M., *Ph.D. student at the Department of Cars and Car Facilities of Russian University of Transport, Moscow, Russia, kurzina.nadia@gmail.com.*

Sergeev, Ivan K., *Ph.D. student at the Department of Cars and Car Facilities of Russian University of Transport, Moscow, Russia, sergeev.workmail@yandex.ru.*

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