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Procedia Engineering 100 (2015) 1724 – 1731

Procedia Engineering

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25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014

High Speed Flexible Transport System

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Abstract

Development of railway transport strongly depends on reliable, energy effective cars. This paper shows the simulation results of with designed wheel pair for a new cars generation. Using the new design of a wheel will halve the power consumption for train traction; it will become possible to raise the axial load up to 35 tons and double the motion speed. Article investigates design and modeling of new wheel pair movement. Comparative mock-up runs of the three models of wheel pairs with changing the parameters of the wheel set-track system are performed. Research of wheel pair was conducted using behavior prototype (scale 1 to 20) and simulation model.

Peer-review under responsibility of DAAAM International Vienna

Keywords: wheel pair; power effective cars; increase axial loading; reduce wear; analysis; simulation

1. Introduction

Railway transport in Russia provides great field for innovations. Through the analysis of technical and economic performance of Russian rail transport during the last 30 years, no dramatic changes could be observed. For example: the service speed is 37-40 km/h, the axle load is 23-25 t, the weight of the train is 5000-7000 t, and the average weight is 3500-3800 t. The empty car mileage is 39-42%. The design speed of freight cars is 90 km/h. The maximum speed of passenger traffic does not exceed 200 km/h. The maximum capacity of a double-track line is 120-130 pairs of trains per day [1].

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Peer-review under responsibility of DAAAM International Vienna
doi:10.1016/j.proeng.2015.01.548

By 2010, it is planned to increase the service speed up to 43 km/h, the axial load and the weight of trains will remain the same. In addition, over the past 15 years, despite the traffic decrease by half, the deterioration of the track structure and rolling stock wheel pairs has increased 10 times. The operating costs of railways increase year by year. The dynamics of traffic growth is low [1].

Transportation by rail begins to compete with road transportation in the distances of over 2000 km. All this happens despite the tenfold excess of fuel consumption at road transportation if compared to rail transportation. Delivery of cargoes from the Far East to the European part takes a month; therefore, 25% of the total products of the economy of Russia is inside rail cars. As a result, the transport costs in the cost of the final products range from 30 to 50%. In western countries, the indicator is equal to 10% [2]. Obviously, Russia currently needs a new ideology of transportation, which would take into account the two key factors. The first one is the international transport corridors and operation in them. And the second one is the container traffic growth. Currently, the industry has started to produce new rolling stock, whose physical characteristics are improved by 10-20% compared with the one in operation. It is planned that the use of the rolling stock will allow increasing the speed of cargoes delivery from 13 to 14 km/h by 2030, and the increase in capacity will be achieved by the construction of second, third, and fourth tracks [2].

The reality of the current situation in the transportation can be demonstrated by the example of Omsk railway enterprise. For example, the enterprise's products are delivered from Omsk to Kaliningrad by road rather than rail, because it is cheaper. This situation is a nonsense, because the fuel costs of motor vehicles for 1 ton/km of track is ten times greater than of the rail transport. A significant increase in freight traffic is planned to achieve through the construction of the third and fourth tracks, but it requires considerable time and costs, and makes 70% of the cost of the entire project. This situation is caused by the existing system of rail transportation, the design of the rolling stock and the track structure, and it will continue as long as the railway transport will be using the existing rolling stock and the existing transport management system. The growth of transport performance indicators by just one percent requires serious capital investments.

The design of the existing rolling stock is technically outdated and economically inefficient. For example, the current wheel pair design was used as far back as in the Cherepanovs' steam train, the freight car design was developed in the 1920s, and the design of electric locomotives – in the 1950s. Currently, high-speed rolling stock is purchased from abroad; however, this rolling stock needs to be adapted to following conditions: the 1520-mm gauge, the track stiffness, which is four times higher, and the seasonal variations in ambient temperature, which is nearly three times wider.

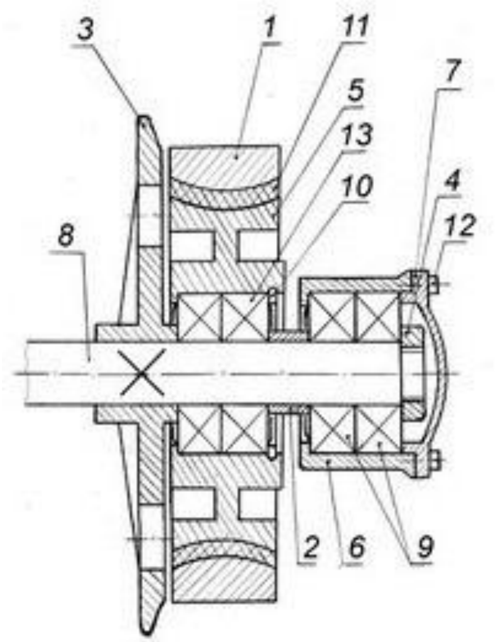
The degree of backwardness of the domestic railway designs from the world level is significant. For example, on conversion to 1 ton of the transported cargo, Russian cars are 1.5 times heavier. Domestic freight cars are inferior to the best world standards also by reliability. For example, the time between overhaul of domestic cars is 110000 km, whereas the modern foreign cars have about 500000 km. All of the above confirms that the existing designs of the rolling stock and the rail traffic management system have exhausted their capacity of effective adoption of high-tech solutions. The use of the existing rail transport cannot provide the necessary intensity of the freight traffic growth and its effectiveness, which would correspond to the planned pace of development of the country's economy.

Radical increase in technical and economic performance of rail transport can be achieved by solving one of the key issues – improvement of the interaction of the wheel pair and the rail gauge. Also it is preferred to use local resources. Foreign experience is currently considered expensive and not always effective [7].

2. Practical options and approaches to solving the problem

2.1. Technical aspects

The Omsk State Transport University has developed and patented new design of a wheel for railway rolling stock wheel pairs. The wheel of new design (Fig. 1) consists of two discs (3 and 5) rotating independently from each other. The first disc is hard-mounted on the axle (8), which is capable of rotating in the axle bearings (9). Along the perimeter, the disc (3) has the shape of the flange and takes up the horizontal guiding forces from the side surface of rails. The second disc (5) is mounted on the wheel pair axle (8) by means of a pair of bearings (13) and transmits the vertical load of the rolling stock weight on the tire (1), which rolls on the rail tread. The space between the second disc (5) and the tire (1) is filled with elastic material (11), which may be rubber or new generation materials – elastic composites and nanocomposites. Use of the new generation high-tech materials can significantly improve the performance of this design, but its implementation is also possible with the use of existing materials, which provides ample opportunities for further gradual modernization.



1. Elastic Tire
2. Bearing Race
3. Disc Flange
4. Axial Lock Nut
5. Wheel Disc
6. Journal Box Casing
7. Journal Box Lid
8. Wheel Pair Axle
9. Journal Bearing
10. Stop Ring
11. Elastic Gasket
12. Journal Box Lid Bolts
13. Wheel Bearings

Fig.1. The new wheel pair design

The new design of a wheel allows all points on the surfaces of the tires and flanges of both wheels of a wheel pair, which are in contact with the surfaces of rail heads, to rotate freely and independently of each other. Additionally, the sprung elastic tire has 30 times less unspring weight in the wheel-rail contact point. Thus, the new design does not have any rigid coupling at rotation of all points of the surfaces of wheel tires, which can contact with the surfaces of rail heads.

To estimate the parameters of the new wheel pair, mock-up models of two bogies were manufactured at a scale of 1 in 20 with two different versions of the wheel pair design. The wheel pair with flexible wheels and the wheel pair with locked wheels (screws are used to rigidly connect both wheel discs (3 and 5) – Fig. 1) are presented in the photo of Fig. 2, the standard wheel – on the photo of Fig. 3, and the layout of the railway track in the same scale – in the photo of Fig. 4.

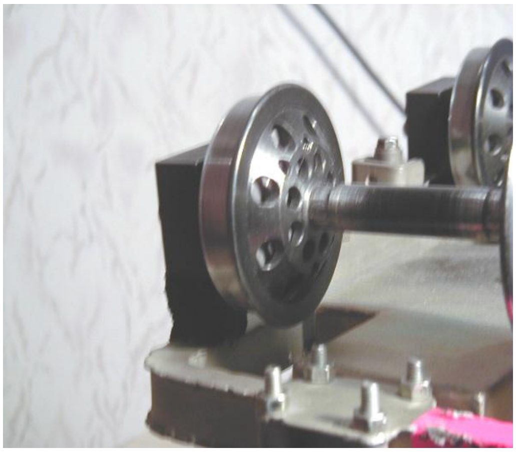


Fig. 2. A wheel pair with independently rotating flexible tires

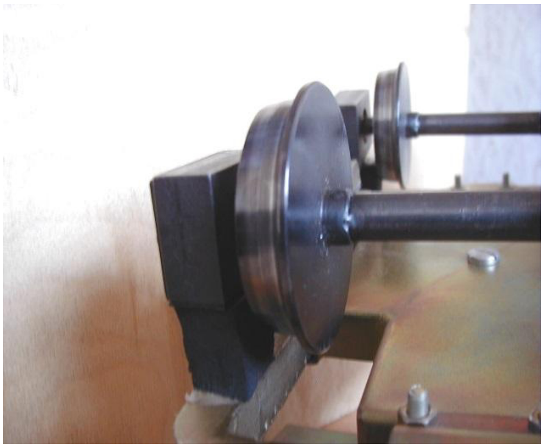


Fig. 3. A standard wheel pair

Fig. 4. Layout of the test site

The comparative mock-up runs of the three models of wheel pairs is performed. Following parameters of the wheel pair-track system are varied:

- The value of the gauge width on tangent track (Fig. 7),
- The number of horizontal irregularities on one of rails on tangent track (Fig. 5),
- The presence of corrugated rail wear on two rail lengths on tangent track,
- The value of elevation with regard to the level of the external rail on curved track,
- The value of misalignment of axles (the difference of wheelbases) of wheel pairs in the bogie when moving on curved track (Fig. 6).

For these variants of the mock-up tests, the comparison of the wheel pair designs was performed by the length of traversed track (Fig.s 5-7), the amplitude of vibration acceleration – Fig.s 8, 10, and the noise level – Fig. 9.

The length of traversed track was used for evaluation of the resistance to movement of the bogies, which were driven by accelerating from humps. With multiple races, the discrepancy of the recorded parameters was equal to 1-2%, which indicates the high reliability of the data obtained using the mock-up model.

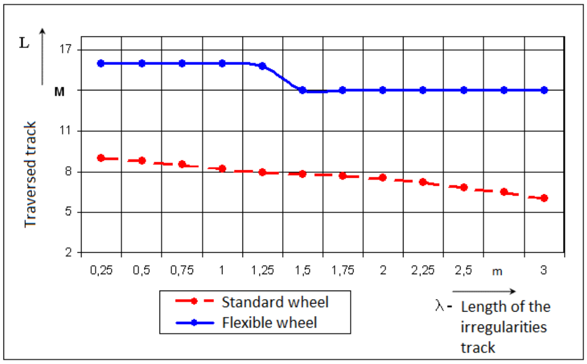


Fig. 5. Dependence of the length of the track traversed by bogies on the number of horizontal irregularities

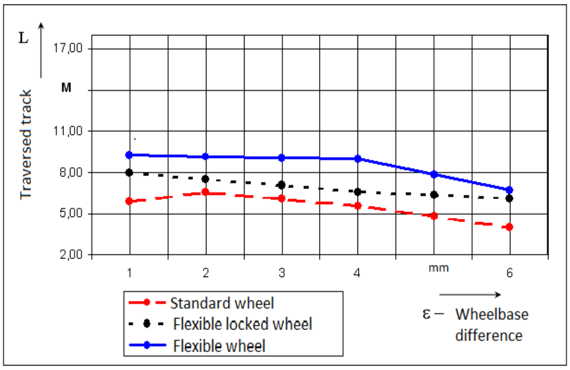


Fig. 6. Dependence of the track passed by bogies on the value of the gauge widening

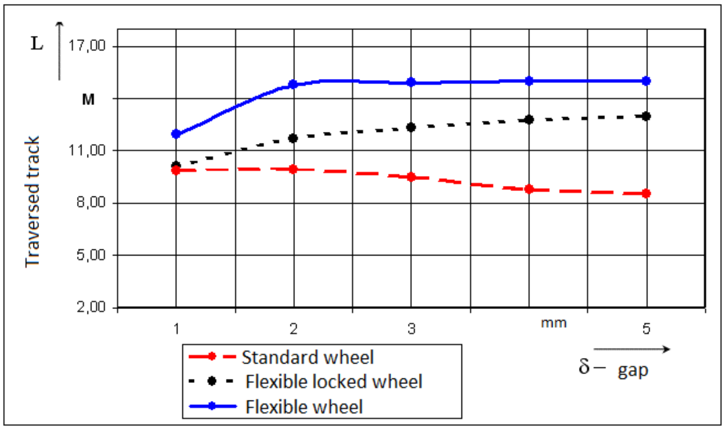


Fig. 7. Dependence of the track traversed by bogies on the value of the wheel pairs misalignment

As seen on the graph of Fig. 5, on tangent track, the traversed distance of the bogie with flexible wheels is twice larger than the distance of the bogie with standard wheels. As the number of horizontal irregularities increases, the traversed distance of the bogie with wheel pairs with flexible tires does not change, whereas the distance of the bogie with standard wheel pairs is constantly decreasing. Change of the gauge widening within the range of 2 to 5 mm has no effect on the the distance traversed by the bogie with flexible tires (Fig. 7).

The same pattern is observed in case of non-parallel installation of wheel pairs in the bogie when passing curved tracks (Fig. 6). In addition, by using a laser recording device, it is confirmed that during the rectilinear movement, the new wheel pair did not demonstrate meandering movement, whereas the standard wheel pair did.

In the case of the flexible wheel, all elements of the "wheel pair-track" system demonstrated a 1.5 times lower level of amplitudes of vibration acceleration at high frequencies, than in the case of the standard wheel (refer to Fig. 8, 10). The sound pressure level at the movement of bogies with flexible wheels is lower by 5 dBA (refer to Fig. 9). Thus, the basic parameters of the new design of the wheel pair demonstrate a combination of the advantages of the rail and road wheels.

Based on the above data of the mock-up comparative tests, it is predicted that the use of wheel pairs with flexible tires in freight cars will halve power consumption for traction. By reducing the unspring weights and the level of high frequency oscillations in the "wheel-rail" system, it is possible to increase the axial load up to 35 tons, and double the translational velocity. At that, the deterioration of track and rolling stock for 1 t/km gross of the cargo run through will be less than the current level.

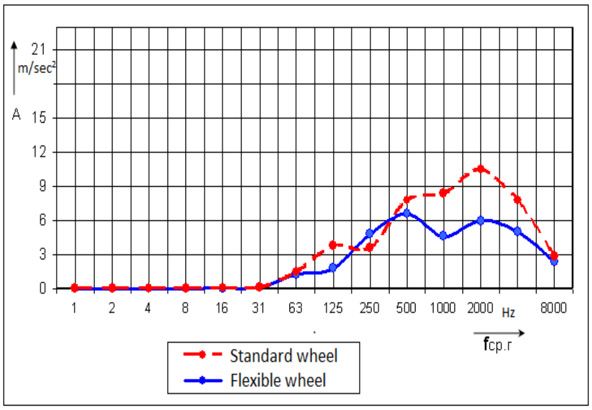


Fig. 8. The frequency spectrum of natural oscillations of the flexible and standard wheels

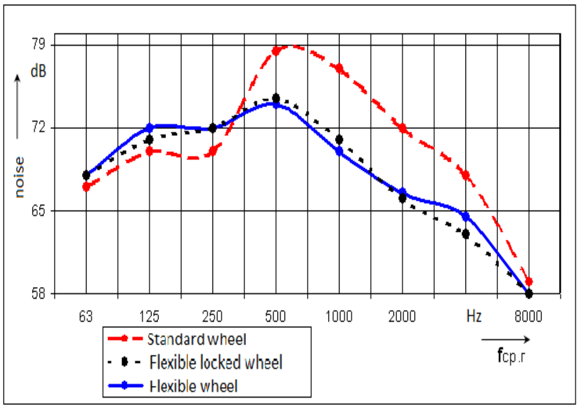


Fig. 9. The frequency spectrum of the sound pressure amplitudes for the three versions of wheels

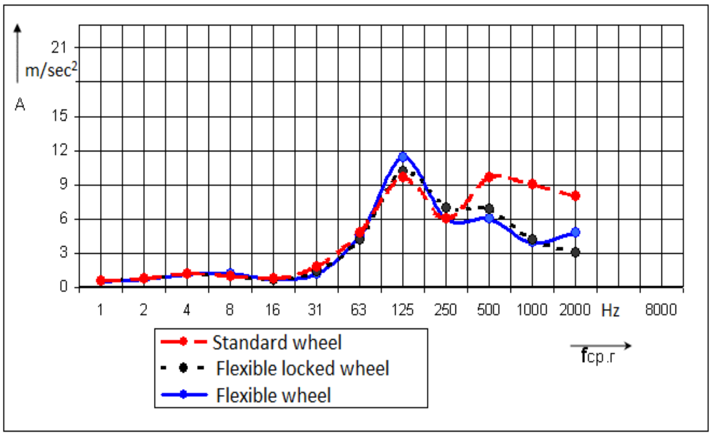


Fig. 10. The spectrum of vibration acceleration amplitudes on the journal box for the three versions of wheel pairs

The peculiar features of the new design also greatly improve the train traffic safety, as its factor of safety against wheel derailment is much higher than that of a conventional wheel pair. In addition, the proposed wheel design and the rolling stock using such wheels are less sensitive to rails defects. For example, the presence of 10-20-cm long chips on the rail surface on both rails simultaneously (which is common for rail joints) will not result in train derailment.

The strategic goal of the project: creation of a flexible transport system that will allow 7-fold increase in the carrying capacity of the rail transport. The set goal will be achieved through the implementation of the wheel pair of new design. The estimated main technical parameters of the new transport system are provided in the table. For reference, Table 1 shows the technical parameters of the existing transport system. Since a wheel pair with flexible tires has significantly lower dynamic impact on the track structure and its specifications are close to such support systems as magnetic levitation or air cushion, these technical parameters of transportation will be implemented on the existing track structure. This path of development of rail transport makes reconstruction of the transport system much cheaper and provides high economic benefits in a short period.

Table 1. Main specifications of the existing and flexible transport systems

No.	Description of parameter	The existing transport system	The flexible transport system
1	Axial load	23.5 t	35 t
2	Design speed	90-110 km/h	500 km/h
3	Service speed for freight traffic	35-40 km/h	120-200 km/h
4	The speed of cargo delivery "sender to receiver"	12-16 km/h	90-120 km/h
5	Passenger traffic speed	90-140 km/h	250-400 km/h
6	Experimental speeds	250 km/h	450-600 km/h
7	Speed limit depending on the track condition.	15 km/h	100 km/h
8	Weight of the train	4000-8000 t	40000-70000 t
9	Lengths of run	150-300 km	4000-6000 km
10	The daily mileage of rolling stock	400-550 km	2000-3500 km
11	Mileage between maintenance	110000 km	1500000 km

Despite the fact that the parameters of the wheel pair movement on the rail track are fundamental to all the technical and economic features of the railway transport operation, numerous phenomena, which occur at the wheel-rail patch of contact, have been insufficiently studied so far. During the recent decades, the problems of interaction in the "wheel pair - rail gauge" system have been approached in an extensive manner (use of more durable metals for the manufacture of wheels and rails, increase in the hardness of their treads, which increases the mass per unit length of rails, enhances lubrication processes, etc.). The proposed system is aimed to switching to intensive development of the rolling stock technology, and moving to a brand new performance level of the entire industry.

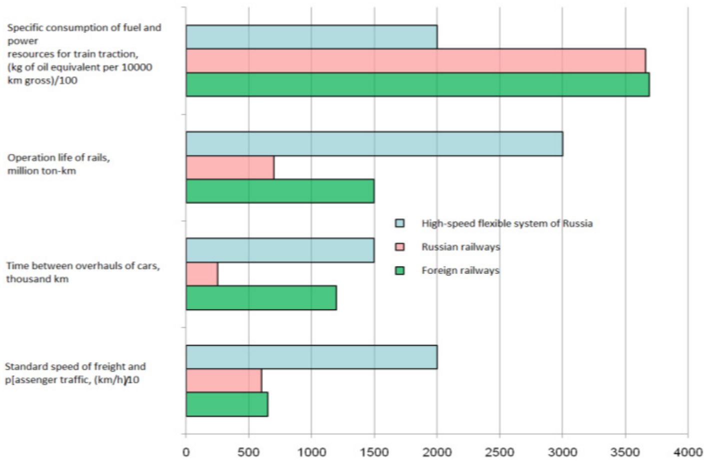


Fig. 11. The spectrum of vibration acceleration amplitudes on the journal box for the three versions of wheel pairs

Conclusion

A new design of a wheel for railway rolling stock wheel pairs was developed. It allows all points on the surfaces of both wheels of the wheel pair, which contact the surfaces of rail heads, to rotate freely and independently from each other. Using the new design of a wheel will halve the power consumption for train traction; it will become possible to raise the axial load up to 35 tons and double the motion speed.

The peculiar features of the new design also greatly improve the train traffic safety, as its factor of safety against wheel derailment is much higher than that of a conventional wheel pair. Economically new wheel pair implementation promises following benefits:

- The reduction of power consumption (by half) would save ~ 100 billion rubles a year
- The reduction of track deterioration (by half) would save ~ 10 billion rubles a year

The rail fleet will reduce by half, and as a result, there will be 2-fold decrease in the costs for repair/overhaul of the rolling stock. The proposed high-speed flexible transport system is unique in the world and, according to calculations, is 20-30 years ahead of the foreign transportation technology. Foreign firms show keen interest in the project. Significant saving of costs (up to 70%) for implementation of the new high-speed transport system will be achieved by using the existing track structure Future project implementation includes five stages:

1. Design development, manufacture, and test of the wheel pair of new design.
   - axial load increase by 3-4 tons,
   - elongation of mileage between overhauls with the current state of the track by 25-40%.
2. Development and manufacture of a new bogie uniform for all types of the rolling stock.
   - improvement of the technical and economic features of the railway transport operation.
   - 6-10-fold increase in the carrying capacity of the existing railways, and 2-3-fold decrease of the rail fleet.
3. Development of new bodies. This stage is the final one in the development of new rolling stock.
   - achievement of the expected performance parameters of the flexible high-speed railroad transport system (Table 1 - Basic technical and economic features of the project).
4. Development of new freight terminals.
   - The speed of cargo delivery from manufacturers to consignees will achieve the planned values of up to 90-120 km/h.
5. Creation of a new highly economical and efficient system of diagnostics and repair/overhaul of modernized and new rolling stock.

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