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RESEARCH ON THE COMPATIBILITY OF THE CALCULATION METHODS OF ROLLING-STOCK BRAKES

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Abstract. One of the main tasks approached by the European Union is the liberalisation of railway transport service market. The foremost problem solved in this paper is the interoperability of various railway systems in the countries of the European Union. Thus, the immediate goal is to solve the problem of the interoperability of different railway systems used in the European Union. A distinction between railway track gauges (from 1435 to 1668 mm), particular couples of wagons, various clearances of rolling stock, different systems of infrastructure etc. are the main impediments. One of the problems in the nearest future will be the evaluation of the brakes of different wagons produced in Western Europe and the former Soviet Union. Freight trains in Lithuania consist of these two types of wagons, and therefore some problems of correcting the results of calculating braking distances and brake force may arise. The main object of this research is to investigate the methods evaluating the brakes of rolling-stock and to assess the possibilities of integrating and harmonizing these different methods. The reliability of the methods evaluating the brakes of rolling-stock is one of the most important components enabling the interoperability of railway transport in the EU network. The brakes of Russian wagons are calculated by MPS *Rules for Traction Calculations*, approved by the Russian Ministry of Transport (till 2004 – Ministry of Communication Ways of Russia)). On the other hand, the brakes of the wagons produced in Western Europe should be calculated applying TSI (*Technical Specifications for Interoperability*) methodology. The main parameter following TSI (Technical Specifications for Interoperability) methodology is braked mass and following MPS (Railway Transport Ministry of Russia) method – a pressing force of the brake shoes. The questions of determining the braked mass of wagons and correcting mean braking distance are presented. The compatibility of two different evaluating methods is discussed. Finally, the basic conclusions are given.

Keywords: railway interoperability, passengers and freight wagons, braking distance, braked mass, methods of calculating brakes, improvements to calculation correctness.

1. Introduction

One of the main tasks approached by the European Union is the liberalisation of railway transport service market. Thus, the immediate goal is to solve the problem of the interoperability of different railway systems used in the European Union. These wide-ranging problems are analyzed by Bessenyei (2008); Butkevičius (2007). The problems of rolling stock technical stability are investigated by Kisilowski *et al.* (Kisilowski and Zalewski 2008). The factors of the deterioration of railway vehicles are estimated by Lingaitis and Vaičiūnas (2008) and the particularities of railway switches wearing are explored by Gailiene *et al.* (2008). A distinction between railway track gauges (from 1435 to 1668 mm), particular couples of wagons, various clearances of rolling stock and different systems of infrastructure are the main impediments. According to the *European Union Council Directive 2001/16/EU*, all member states should attempt to eliminate these disadvantages in their railways. One of the problems in the nearest future will be the evaluation of the brakes of different wagons produced in Western Europe and the former Soviet Union. Freight trains could consist of two types of wagons, and thus some problems of correcting the results of calculating braking distances and brake force may arise. The brakes of Russian wagons are calculated by *MPS* (Russian version МПС – Министерство путей сообщения) *Rules for Traction Calculations*, approved by the Russian Ministry of Transport (till 2004 – Ministry of Communication Ways of Russia). The principal research on rolling stock traction in Russia has been made by Grebenyuk (Гребенюк 2003), Grebenyuk *et. al.* (Гребенюк и др. 1987) and Krylov *et al.* (Крылов и др. 1991). A number of

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scientists including Bureika and Subačius (2002); Bureika *et al.* (2004); Vaičiūnas *et al.* (2004); Liudvinavičius and Lingaitis (2007) are investigating this issue in Lithuania. On the other hand, the brakes of the wagons produced in Western Europe should be calculated following TSI (*Technical Specifications for Interoperability*) methodology referring to the resolution approved by the EU Commission on 28 July 2006 (2006/861/EC). The reliability of the methods evaluating the brakes of rolling-stock is one of the most important components enabling the interoperability of railway transport in the EU network. Under TSI methodology, braked mass is the main parameter, whereas MPS method points to a pressing force of the brake shoes.

The main object of this research is to investigate the methods evaluating the brakes of rolling-stock and to assess the possibilities of integrating and harmonizing these different methods.

2. Determining Vehicle Braking Force Fitted with UIC Air Brake for Passenger Trains

According to the resolution issued by the EU Commission on 28 July 2006 (2006/861/EC), the braked mass B_{br} of a wagon shall be established under calculation procedures considering the following conditions: maximum speed ≤ 120 km/h; the wheels are braked on both sides and have a nominal diameter from 920 to 1000 mm; the brake shoes are made of P10 cast iron; the blocks are type B_g (single) or B_{gu} (tandem); force applied by the shoes 5 to 40 kN with B_g and 5 to 55 kN with B_{gu} blocks.

The braked mass B_{br} shall be calculated using the following formula:

$$B_{br} = \frac{k \cdot \sum F_{dyn}}{g}, \quad (1)$$

where: k – a dimensionless factor that depends on the type of a shoe (B_g or B_{gu}) and on the contact force of each shoe; $\sum F_{dyn}$ – the sum of all forces applied by the shoes whilst the vehicle is moving.

$\sum F_{dyn}$ shall be calculated using the following formula:

$$\sum F_{dyn} = (F_t \cdot i - i^* \cdot F_R) \cdot \eta_{dyn}, \quad (2)$$

where: F_t – effective force at the brake cylinder, once the recoil of the cylinders and rigging has been deducted, kN; i – total increment for brake rigging; i^* – the increment after central rigging (normally 4 for two-axled wagons and 8 for bogie wagons); η_{dyn} – mean efficiency of rigging whilst the vehicle is moving, mean between two maintenance visits (can be up to 0.91, depending on the type of rigging); F_r – opposing force applied from the regulator (usually 2 kN).

The k curves used to calculate the braked mass are given by mathematical formulae of the following type:

$$k = a_0 + a_1 \cdot F_{dyn} + a_2 \cdot F_{dyn}^2 + a_3 \cdot F_{dyn}^3. \quad (3)$$

The values of coefficients a_i are given in Table 1.

The determination of the braked mass percentage to calculate braking distance using assessment graphics in Fig. 1 refer to EU Commission decision made on 28 July 2006.

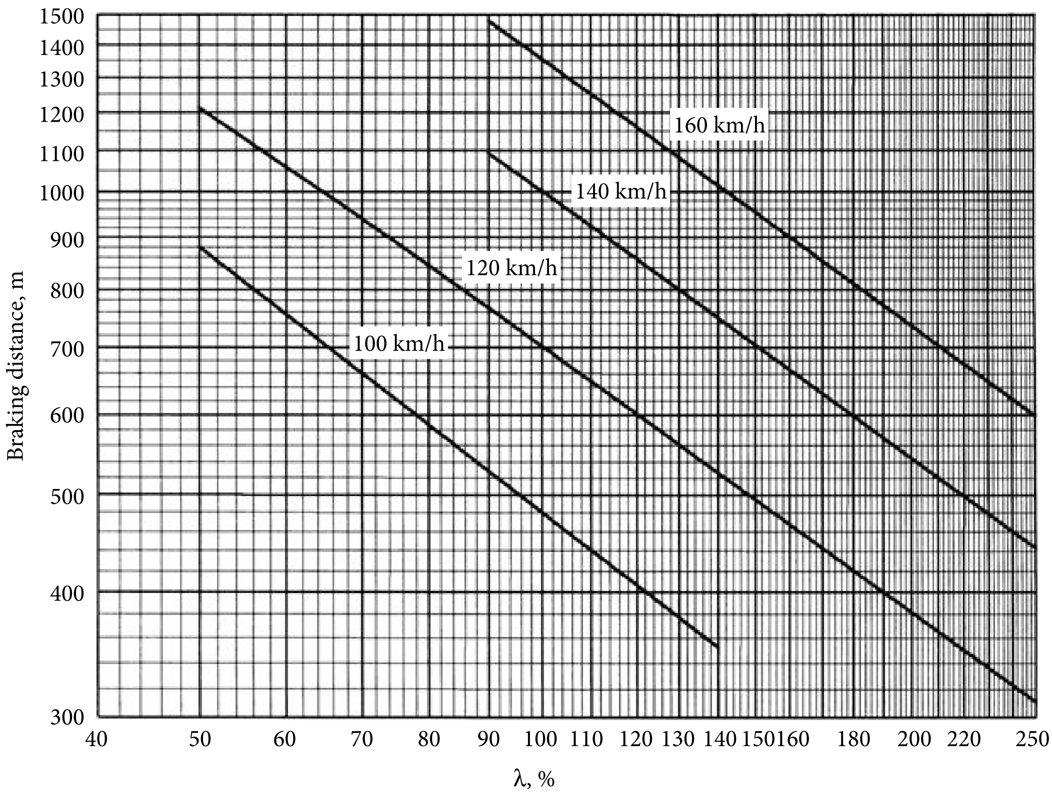

Fig. 1. Assessment graphics of the braked mass percentage λ of passenger wagons

Table 1. Values of coefficients in formula (3)

Coefficient	a_0	a_1	a_2	a_3
k_{Bg}	2.145	$-5.38 \cdot 10^{-2}$	$7.8 \cdot 10^{-4}$	$-5.36 \cdot 10^{-6}$
k_{Bgu}	2.137	$-5.14 \cdot 10^{-2}$	$8.32 \cdot 10^{-4}$	$-6.04 \cdot 10^{-6}$

The results of minimum braked mass B_{br} shall be taken:

$$S = \frac{C}{\lambda + D} \tag{4}$$

and

$$\lambda = \frac{C}{S} - D. \tag{5}$$

Calculation results are given in Table 2.

Table 2. Calculation of braked mass percentage λ

v, km/h	*C*	*D*
100	52 840	10
120	83 634	19
140	119 179	19
160	161 280	19

NOTE. Formulae (4) and (5) are valid inside the limits corresponding to the extremities of the lines in Fig. 1.

3. Determining Wagon Braking Force Fitted with a UIC Air Brake for Freight Trains

3.1. Number of Tests

At least 4 valid tests shall be carried out to calculate the mean. All braking distances obtained shall be corrected.

The mean shall be accepted if meeting the following simultaneously checked criteria:

- Criterion 1

$$\frac{Standard\ \ deviation\ of\ \ sample\ (\sigma_n)}{Mean\ of\ \ sample\ (\bar{S})} \leq 3.0\ \%;$$

- Criterion 2:

$$|Extreme\ value\ (S_e) - mean\ (\bar{S})| \leq 1.95 \cdot \sigma_n,$$

where: S_e – braking distance furthest from the mean.

NOTE. If one of the two criteria is not met, then a supplementary test shall be carried out (rejecting the extreme value S_e if criterion 2 is not met and $n \geq 5$).

With the new values thus obtained, criteria 1 and 2 shall then be checked where: S_i – braking distance measured in test '*i*', after correction, m; *S* – mean braking distance, m; *n* – the number of tests; σ_n – the standard deviation of the sample *6* and it is equal:

$$\sigma_n = \sqrt{\frac{\sum |S_i - \bar{S}|^2}{n}}. \tag{6}$$

3.2. Method of Evaluating the Results of Testing Brakes

Braking distance obtained in test '*j*' shall be corrected to take into account the following factors: nominal speed in relation to the initial speed measured in the test and a gradient of the test track.

Applying the following formula shall make the correction:

$$\frac{v_{jnom}^2}{2 \cdot 3.6^2 \cdot S_{jcorr}} = \frac{v_{jmeas}^2}{2 \cdot 3.6^2 \cdot S_{jmeas}} - \frac{g}{\rho} \cdot \frac{i}{1000}. \tag{7}$$

Transformation gives the following:

$$S_{jcorr} = \frac{3.933 \cdot \rho \cdot v_{jnom}^2}{3.933 \cdot \rho \cdot v_{jnom}^2 - i \cdot S_{jmeas}} \cdot S_{jmeas}, \tag{8}$$

where: S_{jcorr} –corrected braking distance (corresponding to the nominal speed in test *j*), m; S_{jmeas} – braking distance measured in test *j*, m; v_{jnom} – nominal initial speed in test *j*, km/h; v_{jmeas} – initial speed measured in test *j*, km/h; *i* – mean gradient over S_{jmeas} on the test track which is positive (+) for an upgrade and negative (–) for a downgrade, mm/m ‰; ρ – the coefficient of the inertia of 'rotating masses' defined as follows:

$$\rho = 1 + \frac{m_r}{m}, \tag{9}$$

where: *m* – the mass of a tested train or vehicle, m_r – the equivalent mass of rotating components (wheel-sets, shafts, etc.).

NOTE. In case no exact value is known ρ = 1.15 for locomotives and ρ = 1.04 for wagons shall be used.

4. Correcting Mean Braking Distance

Mean braking distance $\bar{S}$ shall be corrected taking into account the following factors:

a) The dynamic efficiency of brake rigging tested as compared with mean in-service value and, for disc brakes, mean wheel diameter on the vehicles tested as compared to the diameter of the half-worn wheel. For wagons with P10 block brakes and conventional brake rigging dynamic efficiency shall be corrected.

b) Mean braking distance shall be corrected using the following formulae:

$$F_{corr} = F_{tset} \cdot \frac{\eta_m}{\eta_{test}} \cdot \frac{d_{test}}{d_m} \tag{10}$$

and

$$\bar{S}_{corr} = t_e \cdot v_{nom} + \frac{F_{test} + W_m}{F_{corr} + W_m} \cdot \left(\bar{S} - v_{nom} \cdot t_e\right), \tag{11}$$

where: $\bar{S}_{corr}$ –corrected mean braking distance, m; $\bar{S}$ – mean braking distance in the test, m;

t_e – equivalent build-up time for braking force, s; v_{nom} – nominal initial speed in the test, m/s; d_{test} – mean wheel diameter on the vehicles tested, mm; d_m – the diameter of the half-worn wheel, mm; F_{corr} – corrected braking force, kN; F_{test} – mean braking force in the test, kN; η_m – the efficiency of brake rigging in average service conditions; η_{test} – the efficiency of brake rigging in the test; W_m – mean resistance to forward motion.

c) Real filling time in relation to nominal is 4 s. This correction shall only be applied to tests with an isolated vehicle.
The following correction formula shall be applied:

$$\bar{S}_{corr} = \left(2 - \frac{t_s}{2}\right) \cdot v_{nom} + \bar{S}, \quad (12)$$

where: $\bar{S}_{corr}$ – corrected mean braking distance, m; $\bar{S}$ – mean braking distance, m; t_s – measured mean filling time for the brake cylinders, s; v_{nom} – nominal initial speed in the tests, m/s.

5. Compatibility of TSI and MPS Methods

The braked mass B_{br} of Russian freight wagons shall be calculated:

$$B_{br} = \frac{10}{7} \cdot \sum K \cdot \gamma, \quad (13)$$

where: K – a total pressing force of the brake shoes, tf; γ – the empirical coefficient determined as a function of brake cylinder filling time, initial pressure rising level and a total pressing force of the shoes (see Fig. 2).

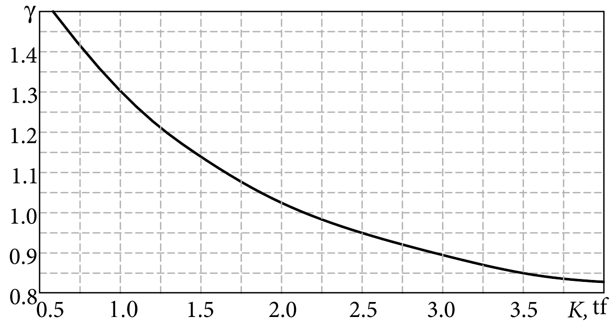

Fig. 2. Nomogram of empirical coefficient γ

Braking coefficient ϑ_{br} (by MPS) is calculated by formula:

$$\vartheta_{br} = \frac{\sum K}{m_w}, \quad (14)$$

where: $\sum K$ –a total pressing force of the brake pads of the wagon, tf; m_w – the gross mass of the wagon, t.

The values of the gross masses of Russian freight wagons, the pressing forces of the brake pads K and the number of the brake pads of the wagon are taken from a technical manual of Grebenyuk *et al.* [Гребенюк, Долганов, Скворцова 1987]. If $\sum K$ and γ are known, it is possible to calculate the braked mass of freight wagons. If the braked mass B_{br} is known, there is an opportunity to choose the required pressure force of the brake shoes K for designing new wagons.

According to formula (13), it is possible to calculate the braked masses B_{br} of all types of Russian freight wagons. The calculation results and errors of the braking mass of freight wagons are presented in Table 3.

The TSI methodology affords to evaluate the braking distances of Russian rolling-stock by linear equations. It is supposed that when applying both methods,

Table 3. Braking parameters of Russian freight wagons with cast-iron brakes pads

State of wagon loading	Gross mass of wagons m_w, t	Pad's pressing force K, kN (tf)	Total pads' pressing force ΣK, kN (tf)	Braking coefficient ϑ_{br} by MPS	Conversion coefficient γ	Calculated braking mass B_{br}, t	Braking mass B_{br} received by MPS, t	Bias of braking mass determination, %
four axles wagons with 8 brake pads								
loaded	84	37.3 (3.8)	298.2 (30.4)	0.36	0.83	36.0	36	0
semi-loaded	42	22.6 (2.3)	180.5 (18.4)	0.43	0.97	25.5	–	–
empty	24	1.3 (1.3)	99.1 (10.1)	0.42	1.21	17.6	18	2.2
six axles wagons with 16 brake pads								
loaded	126	25.5 (2.6)	408.1 (41.6)	0.33	0.94	55.9	54	3.6
semi-loaded	63	15.7 (1.6)	251.1 (25.6)	0.41	1.13	41.3	–	–
empty	36	8.8 (0.9)	141.3 (14.4)	0.40	1.34	27.6	27	2.2
eight axles wagons with 16 brake pads								
loaded	168	34.3 (3.5)	549.4 (56.0)	0.33	0.85	68.0	72	5.5
semi-loaded	84	21.4 (2.18)	342.4 (34.9)	0.42	0.98	48.8	–	–
empty	48	12.2 (1.24)	194.2 (19.8)	0.41	1.22	34.6	36	3.8

NOTE. Braking mass received by MPS is 88 kN (9 tf) per wagon's axle.

the rank of the definition errors of the braking distance of rolling-stock is the same as the errors of the calculated braked mass $B_{br.}$.

6. Conclusions

1. The braking distance of rolling stock shall be corrected taking into account two factors: nominal speed in relation to the speed measured in the test and the gradient *i* of the tested track.
2. The differences (errors) between the values of the braked mass of Russian freight wagons estimated by *TSI* (Europe Union) method and calculated by *MPS* (Russian) method for 4 axle freight wagons with cast-iron brake shoes are (0–2.2)%, for 6 axle freight wagons with the brake shoes – (2–4)% and for 8 axle freight wagons – up to 5.5% (Table 3).
3. The values of braking coefficient ϑ_{br} for Russian freight wagons vary from 0.33 to 0.43 (Table 3).
4. In the nearest future, it is necessary to compile the tables for calculating the braked mass of Russian wagons exploited within EU railways.
5. The pressing force of the brake shoes *K* and coefficient γ (Fig. 2) are the initial data to correctly compile the conversion tables of the braked mass of Russian freight wagons.

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