XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

INFLUENCE OF HEAD WIND ON THE BRAKING DISTANCE OF SINGLE RAILWAY VEHICLE

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Abstract *– Train stopping distance during brake application is influenced by the brake system performance, longitudinal running resistance and presence of wind and its direction. This paper deals with influence of the wind conditions on the results of slip brake tests. The influence is more expressed in the case of single vehicles tests and less expressed for the trains. The tests with and without presence of head wind were performed on the tank car type Zacns. Depending on wind speed, measured stopping distances may differ significantly. Opposite from head wind, tail wind increases stopping distance and should be considered when calculating safety margin and setting service train speed depending on the wind conditions. The results may also serve for further analyses of aerodynamic characteristics of railway vehicles and for verification of numerical simulations.*

Keywords – stopping distance, slip brake tests, head wind, influence

1. INTRODUCTION

Influence of wind on railway vehicles can be considered from several aspects. As an effect influencing safety and stability of vehicles and as an effect that affects train running resistance and stopping distance. This paper deals with influence of the wind on the braking distance of the train during running service and influence on the test results during slip tests and measured stopping distance of single bogie wagon. Wind presence may cause these test results to be irregular. UIC 544-1 [1] describes regular atmospheric conditions as with the minimum wind and with dry rails. Influence of wind on the brake performance test is reported in [2] but without any binding limit values prescribed.

2. BRAKE PERFORMANCE TEST

This chapeter presents regular brake perfomance test methodology in the case of basic bogie wagons. That means without presence or with the minimum wind. Full scale test [3] was performed with single tank car type Zacns with K-block brake (Fig 1). When empty this wagon runs at 120 km/h and in the fully loaded conditions the maximum speed is 100 km/h.

Fig.1. Tank wagon Zacns

2.1. Test procedure

Determining the braking performance for freight wagons with top speed up to 120 km/h and K-brake blocks is performed with single vehicle slip tests [1]. The tested vehicle is accelerated up to the speed envisaged for braking. At this speed, an emergency (rapid) brake shall be applied, at the same time or short time after wagon uncoupling from the test train composition. The test speed for freight wagons with top speed up to 120 km/h is 100 km/h and 120 km/h. At least four valid tests shall be carried out at each test

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speed. The mean value of stopping distance shall be corrected for nominal test conditions and then braked weight percentage is determined using assessment graphs or formulae given in UIC [1].

2.2. Measuring equipment

During slip tests following braking parameters vs. time were recoreded:

- wagon speed;
- stopping distance;
- main brake pipe pressure and brake cylinder pressure.

Table 2 presents high perfromance measuring equipment used for these purposes.

Tab. 2 Measurement equipment

Item	Type	Manufacturer
Pressure tranducer	P8AP	HBM
	P8AP	HBM
Radar doppler transducer	Delta DRS1000	GHM Engeen.
Data aquisition system	Quantum MX840A	HBM
Contact thermometer	905-T2	TESTO
Notebook PC	E734	Fujitsu

Weather station (Fig. 2) served for checking the test conditions regularity. This station records: environmental remperature, atmospheric pressure, air humididty, wind speed and direction.

Fig.2. Weather station position

3. CORRECTING THE STOPPING DISTANCE

3.1. Correcting the measured stopping distance

The stopping distance obtained in test shall be corrected in order to take into account the following factors:

- nominal speed in relation to the initial speed measured in the test;
- gradient of the test track.

3.2. Correction of the mean stopping distance

After determining the mean stopping distance, its validity is checked using following statistical criteria that should be met at the same time:

$$\text{Criterion K1:} \quad \frac{\sigma_n}{\bar{s}} \leq 0.03 \quad (1)$$

$$\text{Criterion K2:} \quad \left| s_e - \bar{s} \right| \leq 1{,}95 \cdot \sigma_n \quad (2)$$

where:

$$\sigma_n = \sqrt{\frac{\left| s_j - \bar{s} \right|^2}{n}} \quad (3)$$

s_j [m] – stopping distance measured during test "j" and corrected using Formula (4) , expressed in m,
n [-] – number of valid test
σ [-] – standard deviation of test results;
$\bar{s}$ [m] – mean stopping distance, expressed in m;
s_e [m] – individual stopping distance furthest from mean value.

The next step is correction of the mean stopping distance by following criteria:

- basic principle - adaptation of the existing condition of the test vehicle to the actual characteristics of design series,
- additional correction - the actual filling time shall be corrected in relation to the nominal value.

$$s_{corr} = t_e \cdot v_{nom} + \frac{F_{test} + W_m}{F_{corr} + W_m} \cdot (\bar{s} - v_{nom} \cdot t_e) \quad (4)$$

$$t_e = t_o + \frac{t_s}{2} \quad (5)$$

$$F_{test} = m \cdot \rho \cdot \frac{v_{nom}^2}{2(\bar{s} - v_{nom} \cdot t_e)} - W_m \quad (6)$$

$$F_{corr} = F_{test} \cdot \frac{\eta_{dyn}}{\eta_{dyn,test}} \cdot \frac{d_{test}}{d_m} - \left[\frac{p_{nom} - p_{feder}}{p_{test} - p_{feder}} \right] \quad (7)$$

s_{corr} - corrected mean stopping distance [m],
$\bar{s}$ - mean stopping distance of test [m],
t_e - equivalent time for development of brake force [s],
t_s - mean measured brake cylinder filling time [s],
v_{nom} - nominal initial speed during tests [m/s] ,
F_{corr} - corrected brake force [kN],
F_{test} - mean brake force during the test [kN],
W_m - mean value of resistance to forward movement (on the straight track and without wind presence) [kN],

d_{test} - mean wheel diameter on test wagon,
d_m - diameter of semi-worn wheel [mm]; for block brakes $d_m = d_{test}$
η_{dyn} - mean efficiency of brake rigging during journey,
$\eta_{dyn,test}$ - efficiency of brake rigging during test,
p_{nom} - nominal brake cylinder pressure,
p_{test} - brake cylinder pressure on test vehicle,
p_{feder} - pressure of retaining springs relative to the effective brake cylinder piston surface area,
v_o - initial braking speed [m/s].

The mean value of resistance to forward movement W_m is represented by a formula (8):

$$W_m = F_{Ra,m} = A + \frac{2}{3} \cdot B \cdot v + \frac{1}{2} \cdot C \cdot v_0^2 \qquad (8)$$

which consists of:

- one term independent of vehicle speed;
- one term proportional to the speed, dealing mostly with the mechanical components resistance (train and track);
- the third term proportional to the square of the speed (aerodynamic resistance), where

A, B. C are specific coefficients depending on vehicle type according to [4] or obtained by measurement [5].

4. RUNNING RESISTANCE

Running resistance is total force acting on a train against its direction of travel. It consists of several components: mechanical resistance, aerodynamic resistance, grade resistance and inertia resistance. Grade and inertia resistance are partially recoverable during train motion. Mechanical resistance is mainly due to wheel rolling on the rail (increases during curves negotiation). Aerodynamic resistance is proportional to the square of the speed and is additionally influenced by wind speed and its direction. Assuming that for one wagon tested on the same track section all test conditions are the same, this paper focuses on presence or absence of wind against vehicle travel direction.

Running resistance of freight trains is reported in [6]. Running resistance of passenger coaches was analyzed in ORE C179 [7]. Hara 1967 in Japan investigated influence of the aerodynamics on high-speed Shinkansen trains [8]

Running resistance is possible to determine using different test methods:

1. Tractive effort methods,
2. Dynamometer drawbar methods,
3. Coasting methods [5].

For assessment of wind drag during slip test the most appropriate method is Coasting method. This method implies that the wagon or train is accelerated to a certain speed. Then the traction power and brakes are switched off and from that moment starts recording of speed vs. time on the track section without gradient or with known gradient along tracks. Coasting train will start to reduce speed and kinetic energy. Decelerations calculated from the speed vs. time function serves for estimation of train running resistance. Also, it is possible directly to measure longitudinal deceleration vs. time for this purpose.

5. AERODYNAMIC RESISTANCE CAUSED BY WIND

Apart from the aerodynamic resistance included in the total running resistance, additional force acting on the vehicle is induced by wind blowing on the vehicle frontal side. Head wind generally helps braking system and decreases stopping distance. Opposite, tail wind increases stopping distance. The following formula calculates drag force [9]:

$$F_D = \frac{1}{2} \cdot \rho \cdot A_f \cdot C_D(\beta) \cdot v_{rel}{}^2 \qquad (9)$$

In the case of direct head wind (β=0°):

$$F_D = \frac{1}{2} \cdot \rho \cdot A_f \cdot C_D(0°) \cdot (v_n + v_{wind})^2 \qquad (10)$$

where:
ρ - air density [kg/m^3] ,
C_D - air drag coefficient [kg/m^2],
β - yaw angle of wind [°],
A_f - drag area [m^2],
v_{rel} - relative wind speed [m/s],
v_{wind} - wind speed [m/s],
v_n - nominal initial speed at test start [m/s].

Use of this equation for additional wind resistance, requires third term in the equation (8) to be excluded and replaced with equation (10).

Head wind with magnituded v_{wind} = 7 m/s reduces calculated stopping distance for about 7 m from v_n=100 km/h and from speed v_n=120 km/h it reduces stopping distance for 13 m.

6. TEST RESULTS

This analysis focuses on pure head wind. The yaw angle β between wind direction and train travel direction during experiments was less than 6° and could be neglected. In total, consequent side component of the wind force may cause additional running resistance related to mechanical components, but this was not included in the analysis.

This paper deals only with head wind component, considering that all other influences are known and equal during all tests. The main difference is presence or absence of wind. One series of tests was performed without wind and one with head wind having magnitude 7 m/s.

Table 3 presents test results for stopping distance in the case of wind presence and absence [0].

Tab. 3. Measured stopping distance

Initial speed (km/h)	Stopping distance (m)	
	Wind 7 m/s	No wind
100	337.44	370.25
	340.86	378.33
	340.03	381.18
	342.19	350.66
120	473.22	507.97
	471.37	526.99
	476.16	508.62
	479.67	515.50

Table 4 presents hypothetical difference in estimation of the brake performance, if the wind influence was neglected.

Tab. 4. Corrected stopping distance, brake weight percentage and brake weight

Initial speed (km/h)	Wind 7 m/s			No wind		
	s_{corr} (m)	λ (%)	B (t)	s_{corr} (m)	λ (%)	B (t)
100	373.6	131.4	28.6	400.8	121.8	26.6
120	525.9	140.0	30.5	579.9	125.2	27.3

Test results show that in the case of Zacns tank wagon, head wind with magnitude v_{wind} = 7 m/s reduces stopping distance for about 27 m from initial speed v_n=100 km/h and from speed v_n=120 km/h for about 54 m. Consequently, determined brake weight B, if the wind was neglected, differs for 2-3 tonns, which is unacceptably false result.

7. NUMERICAL SIMULATIONS

There are many computer programs around the world dealing with train resistance simulations. They are power tools, serving for estimation of the energy consumption, determining trains running time etc. The computer programs specialized for running resistance including aerodynamic forces, use CFD and include wind magnitude, wind yaw angle, wind speed distribution, flow around the vehicle [5, 9]. These programs may help solving different problems and performance of vast number of simulations.

8. CONCLUSION

Wind causes additional running resistance force that acts on the vehicle. In order to obtain reliable indicators of the validity of applied analytical expressions and numerical simulations, more experimental tests are needed under different wind magnitudes and directions of blowing.

Difference between the calculated and measured stopping distances identified during this research, requires further investigations. According to test results, wind influence is greater than it shows the calculations. Newer editions of valid European standards [4, 5], for any further analyses related to aerodynamics, suggest use of CFD and experimentally determined resistance coefficients for each vehicle and not to use coefficient from the database for similar vehicles [10].

As required in reference standard [1], when testing brake performance, the influence of wind should be excluded, by choosing test site and time of the test without presence of wind. Presence of wind will further complicate already complex procedure for correcting measured stopping distance and reduce reliability of measurements.

Based on the available informations from railway practice and service, significant problems related to wind influence on braking process are not reported.

ACKNOWLEDGEMENT

Authors express gratitude to Ministry of Education, Science and Technological Development of Republic of Serbia.

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