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DYNAMIC AND STATIONARY TESTING OF VEHICLE BRAKING SYSTEMS

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The paper deals with the dynamic and stationary testing of vehicle braking systems for a selected set of eight intercity buses in an unloaded state. In case of the dynamic test carried out on a defined test area, a decelerometer is used to record the braking deceleration of a set of vehicles, which is placed in the vehicle during the course of test. According to the methodical procedure, the vehicle is accelerated to a speed of 40 km·h^{-1} and subsequently braked with the maximum braking deceleration. Braking deceleration values recorded by the decelerometer were used to calculate vehicle braking. During the stationary test, a roller brake tester was used, on which the maximum braking forces on the front and rear axles of the vehicle are measured, and then, the braking of the vehicle is calculated from these values according to the methodical procedure. The calculated braking values of vehicles during the dynamic and stationary test are subsequently compared, where it is possible to observe the percentage difference of these values, which may be caused by several factors taken into account in the results of the paper.

Keywords: stationary test; dynamic test; decelerometer; roller brake tester; vehicle braking

During the technical safety inspection of vehicles, the task is to assess whether the braking effect of the vehicle is sufficient, or whether there is a malfunction in the braking system that could affect the movement and braking of the vehicle, and thus also vehicle´s road traffic safety (Rybicka et al, 2023). An extended and universally applicable diagnostic device suitable for this purpose is a roller brake tester. All technical inspection stations and many car repair shops are equipped with it. In addition to operating instructions for these devices, there are detailed methodological instructions for their use and processing of measurement results. As stated by Janoško and Kuchar (2017) and Kulaç (2019), measuring on a stationary device cannot directly determine the deceleration that a vehicle would achieve by braking, as it is in case of a dynamic test using a decelerometer. According to Angelov and Draganov (2018), a roller brake tester is a complex diagnostic device which, in addition to measuring the braking force on each wheel, also allows examining its course depending on control force on the pedal of the hydraulic brake system or depending on pressure in case of an air pressure system. In this way, for example, fluctuations in the effect of brakes caused by the ovality of brake drums or tossing of discs can be detected (Senabre et al., 2012a; Rybianský et al., 2014). As stated by (Šešera et al., 2013; Kuchar et al., 2022) roller brake testing facilities are used in most countries to legally demonstrate that braking forces are sufficient to achieve the prescribed deceleration, despite the fact that direct tests could be used for this purpose. The reason for this is that a stationary test on a roller brake tester is faster, safer, independent of weather conditions, and requires less space compared to a dynamic test (Li et al., 2011). The measurement result of stationary measurement is repeatable and less influenced by the subjective influence of a controlling person or the environment (Rybianský et al., 2009; Muthoriq et al., 2020).

The aim of this work is to perform the dynamic and stationary tests of braking systems and subsequent braking calculations, which will prove whether the vehicles meet the legislatively established corrosion resistance values. This contribution demonstrates the differences in calculated braking between dynamic and stationary vehicle tests and provides demonstrable conclusions from which it follows that the results of dynamic tests have a higher predictive value of demonstrable braking.

Material and methods

The aim of this work was to perform the dynamic and stationary test of the brake system of vehicles and then compare the calculated braking values during these tests of the vehicle´s brake system. The measurements were carried out on eight intercity buses, the technical parameters of which are listed in Tables 1–8.

Table 1 Technical parameters of vehicle 1

Make	SOR
Trade name	CN 12.3
Kind	intercity bus
Type/variant	SOR 12.3/6ND2D21FX
Year of manufacture	2021
Category	M3
Brake system	pneumatic
Mileage status	96,100
Operating weight (kg)	10,140
The largest permissible total weight (kg)	16,500
The largest permissible weight per axle 1/2 (kg)	5,800/10,700

Table 2 Technical parameters of vehicle 2

Make	SOR
Trade name	C 10.5
Kind	intercity bus
Type/variant	SOR C 10.5/1CD2DM1FX
Year of manufacture	2017
Category	M3
Brake system	pneumatic
Mileage status	492,548
Operating weight (kg)	9080
The largest permissible total weight (kg)	15,000
The largest permissible weight per axle 1/2 (kg)	5,500/9,500

Table 3 Technical parameters of vehicle 3

Make	IVECO
Trade name	Crossway Low Entry
Kind	intercity bus
Type/variant	CBLE 400/4C
Year of manufacture	2015
Category	M3
Brake system	pneumatic
Mileage status	470,084
Operating weight (kg)	10,675
The largest permissible total weight (kg)	17,900
The largest permissible weight per axle 1/2 (kg)	6,300/11,600

Table 4 Technical parameters of vehicle 4

Make	SOR
Trade name	CN 12.3
Kind	intercity bus
Type/variant	SOR CN 12.3/6ND2D21FX
Year of manufacture	2021
Category	M3
Brake system	pneumatic
Mileage status	50,583
Operating weight (kg)	10,140
The largest permissible total weight (kg)	16,500
The largest permissible weight per axle 1/2 (kg)	5,800/10,700

Table 5 Technical parameters of vehicle 5

Make	SOR
Trade name	C 10.5
Kind	intercity bus
Type/variant	SOR C 10.5/1CD2DF1FX
Year of manufacture	2012
Category	M3
Brake system	pneumatic
Mileage status	816,032
Operating weight (kg)	8,750
The largest permissible total weight (kg)	15,000
The largest permissible weight per axle 1/2 (kg)	5,500/9,500

Table 6 Technical parameters of vehicle 6

Make	SOR
Trade name	C 12
Kind	intercity bus
Type/variant	–
Year of manufacture	2010
Category	M3
Brake system	pneumatic
Mileage status	896,809
Operating weight (kg)	8,500
The largest permissible total weight (kg)	16,500
The largest permissible weight per axle 1/2 (kg)	5,800/10,700

Table 7 Technical parameters of vehicle 7

Make	SOR
Trade name	C 12
Kind	intercity bus
Type/variant	2/C
Year of manufacture	2009
Category	M3
Brake system	pneumatic
Mileage status	567,631
Operating weight (kg)	8500
The largest permissible total weight (kg)	16,500
The largest permissible weight per axle 1/2 (kg)	5,800/10,700

Table 8 Technical parameters of vehicle 8

Make	IVECO
Trade name	Crossway
Kind	intercity bus
Type/variant	CBCW 300/3C
Year of manufacture	2019
Category	M3
Brake system	pneumatic
Mileage status	244,041
Operating weight (kg)	11,300
The largest permissible total weight (kg)	18,000
The largest permissible weight per axle 1/2 (kg)	7,100/12,600

Roller brake tester MAHA MBT 4200 LON W Classic

The stationary measurements of the maximum braking forces were carried out by the MAHA MBT 4200 LON W Classic roller brake tester. Table 3 shows the technical data of the roller brake tester.

The resulting values of braking forces of the service brake are recorded in a protocol from the roller brake tester. These values are further processed according to the valid methodical procedure for the indicative calculation of service brake effect, with the expression of the percentage braking of the vehicle.

The percentage braking of the vehicle at test weight is calculated according to Slovak methodical instruction no. 74/2018.

$$Z = 10.2 \cdot \frac{\sum B_{vi}}{m_s} \quad (\%) \qquad (1)$$

where: $\sum B_{vi}$ – the sum of braking forces on the circumference of the wheels of axles i (N); m_s – the test weight of the vehicle (kg)

Table 9 Technical data of the roller brake tester MAHA MBT 4200 LON W Classic

Parameter		Value
Axle load (kg)		4000
Driving power (kW)		2 × 11
Test speed (km·h-1)		4.6
Length of rollers (mm)		1,000
Diameter of rollers (mm)		202
Axial distance of rollers (mm)		400
Voltage supply (V; Hz)		3–400; 50
Protection (A)		63
Coefficient of friction of the rollers	**dry/steel**	0.9
	wet/steel	0.7
Dual analogue display (mm)		870 × 910 × 300; scale Ø 2 × 350
Switchboard (mm)		800 × 950 × 300
Differential display		digital/optical
Display range (kN; mm)		0–4/0–40; 0–100

If the roller brake tester does not allow the test weight of the vehicle to be determined, it is assumed that the test weight of the vehicle without load is equal to either curb weight increased by 75 kg or operating weight, depending on which of these data is indicated in the vehicle document submitted. If for braking Z compared to the prescribed minimum braking Z_{min} for the service brake:

$$Z \geq Z_{min} \quad (\%) \qquad (2)$$

then, it is considered proven that the vehicle is able to achieve the prescribed minimum braking effect with the service brake.

Otherwise, if"

$$Z < Z_{min} \quad (\%) \qquad (3)$$

the vehicle does not achieve the minimum braking effect prescribed by the service brake. For category M3, which includes buses, the minimum braking value is 50% according to the applicable legislation.

Decelerometer VMZ 300

Braking deceleration measurements during the dynamic test were carried out with a VMZ 300 decelerometer, which records the time course of vehicle´s deceleration during the dynamic test so that the deceleration value can then be determined as a quantity that must be calibrated. Table 10 shows the technical parameters of the decelerometer.

From the value of mean full braking deceleration detected from the decelerometer, the equivalent braking value is calculated according to Slovak methodical instruction no. 25/2020 as:

$$Z = \frac{a}{g} \times 100 \quad (\%) \qquad (4)$$

Table 10 Technical data of Decelerometer VMZ 300

Parameter	Value
Value of maximum deceleration ($m \cdot s^{-2}$)	0–10
Display range ($m \cdot s^{-2}$)	0–22
Recommended measurement speed ($km \cdot h^{-1}$)	20–40
Calibration error limit ($m \cdot s^{-2}$)	±0.1
Tilt speed ($° \cdot s^{-1}$)	40
Measurement ranges	automatic determination
Memory of measured values	7 registers with 1,000 measurement points, or 14 registers with 500 measurement points
Reading of measured values (Hz)	100
Power supply (V/Ah)	Batery 6/1.8
On-board power supply (V)	10–24 DC
Connector (V)	230 V/15 AC; 25
Printer	24 points, 8 needles

where: a – the mean full braking deceleration of the vehicle achieved by the service brake ($m \cdot s^{-2}$); g – gravitational acceleration (9.806 $m \cdot s^{-2}$)

If the vehicle deceleration meter directly indicates the braking value, then the indicated value is used and calculation is not performed. If braking Z calculated according to Eq. 4 is compared with the prescribed minimum braking for the service brake, the following applies:

$$Z \geq Z_{min} \quad (\%) \tag{5}$$

then, it is proven that the vehicle is able to achieve the prescribed minimum braking effect with the service brake.

Otherwise, if:

$$Z < Z_{min} \quad (\%) \tag{6}$$

the vehicle does not achieve the minimum braking effect prescribed by the service brake. For category M3, which includes buses, the minimum braking value is 50% according to the applicable legislation.

Results and discussion

During the stationary test of the brake system, the braking forces on the front and rear axles of the vehicles were measured using a roller brake tester. Based on Slovak methodical instruction no. 74/2018, the indicative values of percentage braking of the vehicle were subsequently calculated from these forces during technical inspections. Table 11 shows the calculated braking values during the stationary test of the braking system. As can be seen for vehicle 1, the braking value is 47.33%, which is considered insufficient. According to the current legislation, the minimum value of the achieved braking is 50%. The same situation applies to vehicle 4, where this value of calculated percentage braking is 42.25%. For other vehicles, the percentage braking value is higher than 50%, thus meeting the legislatively determined condition of minimum braking. During the measurement of the brake system by a dynamic test using the VMZ 300 decelerometer, braking deceleration values were determined, on the basis of which the percentage braking of the vehicles was calculated according to the methodical procedure. During the dynamic

Table 11 Braking force values from the roller brake tester and calculated braking during the stationary test

Vehicles	Max. braking force on the 1st axle (kN)	Max. braking force on the 2nd axle (kN)	Brake deceleration ($m \cdot s^{-2}$)	Braking – stationary test (%)	Braking – dynamic test (%)	Difference (%)
Vehicle 1	15.08	32.32	7.41	47.33	75.57	28.24
Vehicle 2	19.10	30.70	7.74	55.51	78.93	23.42
Vehicle 3	21.29	32.37	6.85	51.51	69.86	18.35
Vehicle 4	10.65	31.89	7.88	42.25	80.36	38.11
Vehicle 5	16.22	34.03	7.82	58.07	79.75	21.68
Vehicle 6	17.39	28.99	6.97	55.17	71.07	15.90
Vehicle 7	16.99	31.76	7.79	57.99	79.44	21.45
Vehicle 8	20.14	36.00	6.15	50.34	72.72	22.38

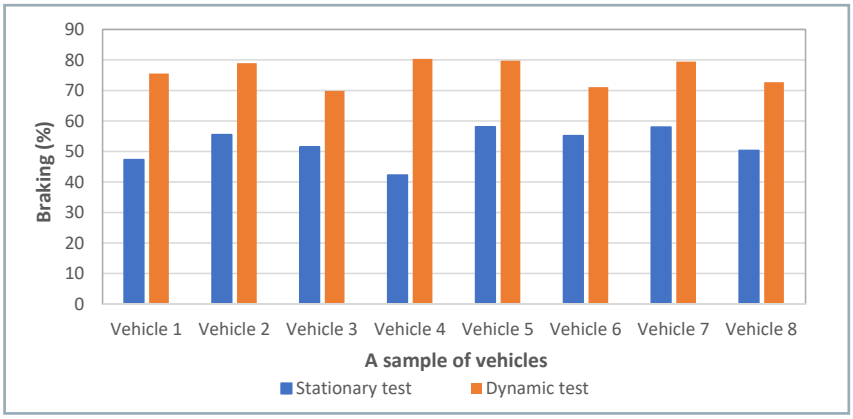


Fig. 1 Graphical comparison of calculated braking during the stationary and dynamic testing of the braking system

test, sufficient braking was calculated for each vehicle and resulting braking is satisfactory for each vehicle.

Figure 1 shows the calculated vehicle braking values during the stationary and dynamic testing of the vehicles.

From the results achieved, it can be concluded that vehicles 1 and 4 had insufficient braking values during the stationary test due to lower braking forces measured on the cylinder brake test bench. According to García-León et al. (2021) and Gurumoorthy et al. (2021), insufficient values of braking forces can be caused by malfunctions of the vehicle´s brake system, such as excessive wear of brake discs and brake linings, insufficient pressure in the brake system, which is caused by air leak on the master brake cylinder. In another case, the insufficient values of braking forces can also be caused by the pollution of vehicle´s tires or the cylinders of the brake seat and, last but not least, by insufficient pressure in the tires, as stated by Senabre et al. (2012b) They indicate that by changing the tire pressure, it is possible to obtain incorrect braking force results on the brake cylinder test bench, which implies that tire pressure is a determining factor in assessing the condition of the vehicle´s braking system. If braking forces caused by the above-mentioned problems in the dynamic test are lower, there would be also insufficient braking deceleration values. From Table 11 and Figure 1, it can be seen that the braking values during the dynamic test are higher for all the examined vehicles, and thus meet the condition of the minimum braking value. Based on the comparison of braking values during the dynamic and stationary test of the vehicle brake system, it can be claimed that the vehicle brake system, the elements of the brake system, are in a technically satisfactory condition, and the insufficient results for vehicles 1 and 4 during the stationary test are caused by the insufficient accuracy of orientation calculation. Since this is only an indicative calculation method, it is possible to evaluate that with the use of a more accurate method of calculating braking with the help of exploration, it would be possible to achieve higher percentage braking values for these vehicles.

Conclusion

This scientific contribution deals with a dynamic and stationary test of eight intercity buses with different mileage. When calculating the percentage braking value in the stationary test (the braking forces on both axles of the vehicles were measured using a roller brake tester), it is possible to see the insufficient percentage braking values for vehicles 1 and 4. Based on the results of the dynamic test (braking deceleration was detected using a decelerometer and subsequently calculated percentage braking), it is possible to state that braking values are satisfactory for all the vehicles. For this reason, it is possible to claim that the insufficient braking values in case of the stationary test for vehicles 1 and 4 are not caused by insufficient braking forces caused by the wear of the braking system elements, or by a failure of the braking system. Since this is only an indicative calculation method, it is possible to state that using a more accurate method of braking calculation using the extrapolated constants of all axles (in which the braking of the vehicle is calculated extrapolated to the theoretical state corresponding to the maximum braking pressure when the vehicle is loaded to the largest total permissible weight), it would be possible to achieve higher percentage braking values for these vehicles (higher than the legislatively established minimum percentage braking values for this category of vehicles).

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