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# Checking load sensing valves at vehicle inspections stations

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**Abstract –** On a commercial vehicle, braking force is controlled by pressure limiting valves, which are responsible for distributing the braking force to individual axles of the vehicle depending on the load. Due to the importance of this system in vehicle safety, we propose a new universal inspection method that complies with Directives 2009/40/EC and 2010/48/EC and Regulation UN/ECE No 13-H, for vehicles in service based on load simulation techniques. The method can be applied during periodical inspections, and is able to detect any malfunction of the system as a whole, regardless its action mode. The test results obtained with real vehicles validate the method.

**Key words:** Road safety / periodic technical inspection / UN/ECE No. 13 regulation / load sensing valve / brakes

## Nomenclature

| | |
|---|---|
| $dp$ | Driving pressure (bar) |
| $F_i$ | Brake force in the tyre circumference on axle $i$ (N) |
| $F_{M\max}$ | Maximum static reaction of the vehicle (N) |
| $F_{R\max}$ | Maximum static reaction of all the axles of the semitrailer (N) |
| $L$ | Lever length (mm) |
| MAM | Maximum authorized mass (kg) |
| $p_1$ | Input LSV pressure (bar) |
| $p_2$ | Output LSV pressure (bar) |
| $p_{41}$ | Pressure of the left suspension diapress (bar) |
| $p_{42}$ | Pressure of the right suspension diapress (bar) |
| LSV | Load Sensing Valve |
| $z_{M\text{lad}}$ | Braking effectiveness of laden vehicle (%) |
| $z_{R\text{lad}}$ | Braking effectiveness of laden trailer or semitrailer (%) |

## 1 Introduction

### 1.1 Operating systems of the load regulation function

The differences in the weight supported by individual axles during the normal use of a commercial vehicle can be sufficiently great to present serious braking problems, which must be taken into account by project designers.

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When commercial vehicles operate unladen, excessive pressure in its brake cylinders may cause the brakes to lock, leading to a dangerous loss of stability. On the other hand, brakes that are correctly calibrated for driving empty may turn out to be insufficient when the vehicle is driven under full load, which may be equally dangerous [1].

To solve this problem, Directive 70/320/EEC [2] and Regulation UN/ECE No 13-H [3] consider two solutions:

- Load sensing valves (LSV) installed on the axles, which perceive the applied braking according to the individual axle load.
- Anti-lock braking systems (ABS), which are responsible for avoiding wheel locking.

By itself, an automatically regulated LSV system regulates the distribution of braking force to the vehicle's axles. However, in the case of overbraking, this system cannot avoid wheel lock, which can only be prevented by an anti-lock braking system (ABS), since such systems control braking as a function of skidding.

For this reason, according to Directive 70/320/EEC [2], Annex II, Appendix 1, load sensing valves (LSV, or ALB in German) are not binding when vehicles are provided with ABS, because braking lock is better achieved by ABS than by LSV itself. Regardless of this, the presence of LSV is highly recommended, since this valve is responsible for limiting air pressure in circuits under low

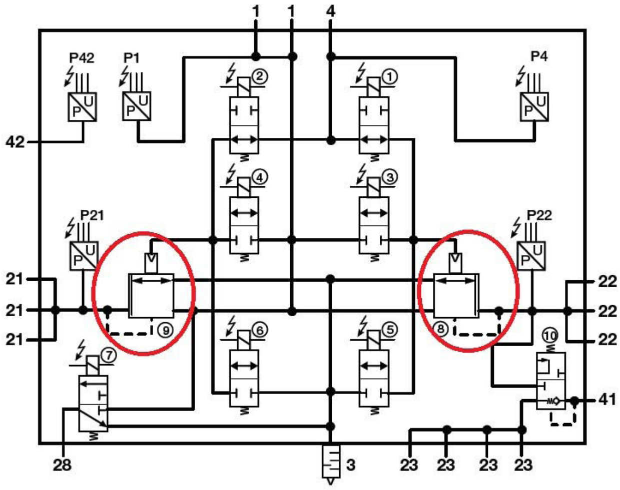


**Fig. 1.** Load sensing valves in an EBS system [4].

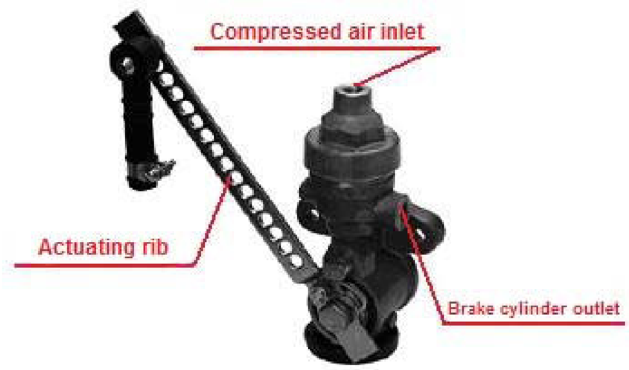


**Fig. 2.** Mechanical Load Sensing Valve (LSV) [5].

load conditions, preventing the unladen wheel from locking and the ABS system from coming into operation.

With no valve, almost every attempt to brake with no load, even in good grip conditions will result in wheel lock and the ABS will be forced to act. This involves a high consumption of compressed air from the reservoirs and very high tyre wear, because ABS begins to operate when slippage has just started, tyre wear due to friction in each cycle being unavoidable.

LSV and ABS are complementary systems, which optimize braking. This is why electronic braking systems (EBS) incorporate pressure control circuits in their control unit, which act on the relay valves installed (see Fig. 1).

Nowadays, we can find in the following two cases:

1. Brake control systems depending on load with an LSV (with or without ABS system), which can be one of these two types:
   - Vehicles with mechanical suspensions (spring): a pneumatic valve with a cam which is activated when the crossbow undergoes a deformation caused by the load (see Fig. 2).

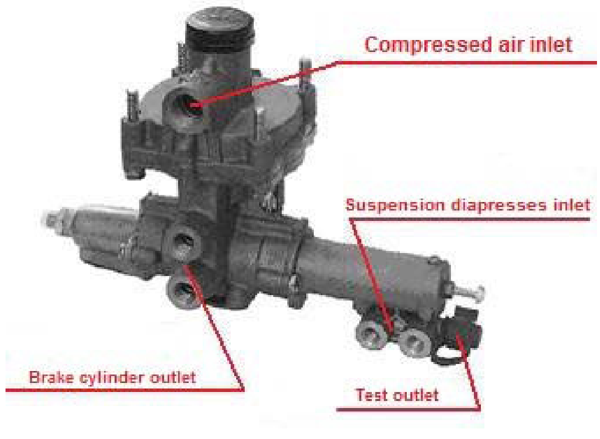


**Fig. 3.** Pneumatic LSV [6].

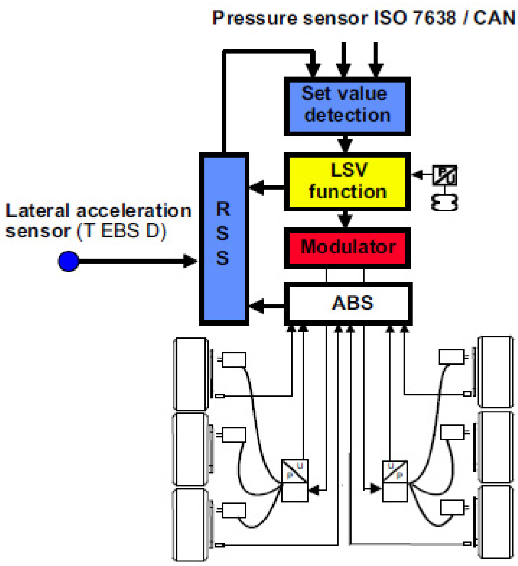


**Fig. 4.** Diagram of EBS system [6].

   - Vehicles with pneumatic suspensions (suspension diapress): a pneumatic valve with a pneumatic control power point which permanently reads the suspension pressure (see Fig. 3).
2. Load-dependent brake control systems for an EBS system (see Fig. 4) can also be one of these two types:
   - Vehicles with mechanical suspensions (spring): a potentiometer with a lever, which is activated when the spring undergoes a deformation caused by the load. The potentiometer sends a continuous input signal to the electronic EBS system.
   - Vehicles with pneumatic suspensions (suspension diapress): the EBS module has a pneumatic control input which integrates a pressure transducer.

In the case of semi-trailers, the load-dependent braking regulation has two differentiated parts (see Fig. 5):

- **Area A: Start-up**. When driving pressure (*dp*) increases up to 0.7 bar, the cylinder braking pressure increases up to 0.4 bar without activating the brake

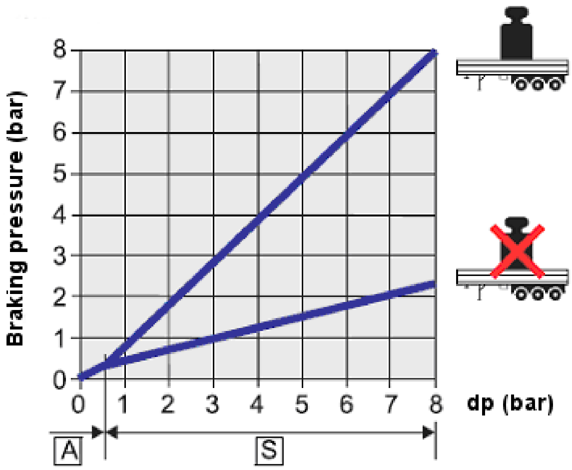


**Fig. 5.** LSV function in a semi-trailer [5].

mechanism. This pressure is used to overcome the return spring pressure of the brake cylinder.

– **Area S: Operation**. When driving pressure reaches 0.7 bar, brakes start to act according to the cylinder pressure, which increases according to official regulations. With the vehicle loaded, braking pressure follows the characteristic straight line, passing through the manufacturer's established value ($dp = 8$ bar), and remains constant.

## 1.2 Current method for periodic inspection of load sensing valves

The procedure presented below is only applicable to vehicles with a LSV equipped with an outlet for simulation or a test outlet. This type of inspection is recommended by the International Motor Vehicle Inspection Committee (CITA) [7].

Note that vehicles equipped with electronic braking systems, where braking force is electronically controlled, cannot be inspected in the way described below.

### 1.2.1 Pneumatically operated LSV valves

The inspection method consists of checking that the LSV characteristics agree with those given on its nameplate. According to the regulation, LSV nameplate must contain at least the following information:

– Valve input pressure.
– Diapress suspension pressure and its LSV output pressure for at least two points (e.g., the pressure corresponding to the laden and unladen vehicle).

To do this, manometers and pressure reducing valves must be connected in several areas of the brake circuit, depending on whether a trailer, a semi-trailer or a tractor is being inspected (see Figs. 6 and 7).

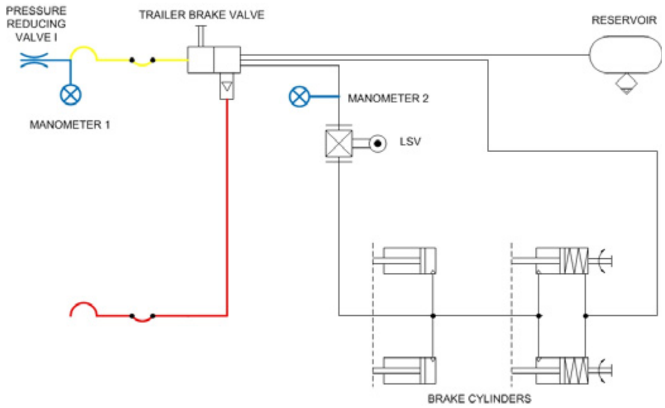


**Fig. 6.** Trailer/semi-trailer manometer connection diagram [8].

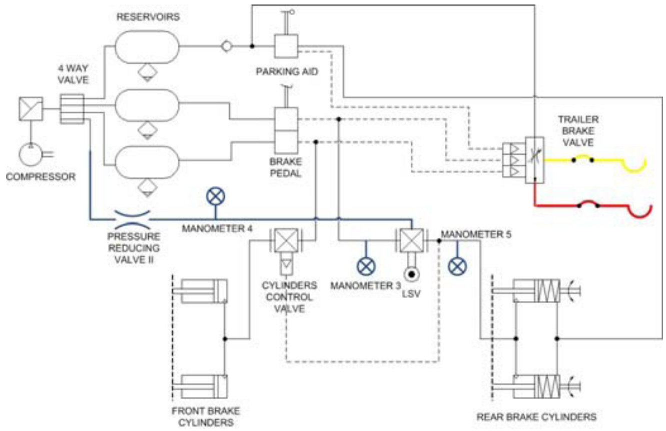


**Fig. 7.** Tractor vehicle manometer connection diagram [8].

Then, different pressures are simulated on the suspension diapresses so that the LSV is checked in, at least, three operating points.

Throughout this procedure, it must be taken into account that LSVs in trailers and semitrailers work statically: that is, during braking, the LSV output pressure is not adjusted according to the control pressure (diapress pressure), which is why the vehicle load transfer during braking is not taken into account. To simulate different braking forces at different diapress pressures, the brake pedal must be released and pressed again.

### 1.2.2 Mechanically operated LSV valves

The inspection method consists of checking that the LSV characteristics are those given on its nameplate. As above, it should contain at least the following information:

– Input pressure.
– Spring movement in mm (The spring flexing value with the laden vehicle should be supplied by the axle manufacturer).
– Lever length, $L$, in mm.
– The axle load and the output pressure corresponding to the LSV for at least two positions; for example, with an unladen axle and with full load.

The load can only be simulated if the mechanical lever is adjusted manually or by using an external load simulation system. If the lever is moved to maximum load position, the valve output pressure can be measured and compared with the value indicated on the nameplate. This cannot be checked in tractor units, where only the lever length, $L$, can be verified.

#### 1.2.3 Vehicles equipped with ABS/EBS brakes

The inspection procedure which is currently followed for periodic inspections is limited to visual checks that can easily be made for any vehicle without using any special equipment. The method is also recommended by the International Motor Vehicle Inspection Committee (CITA) [7].

Technical inspectors must follow these points:

- Check that the ABS/EBS system warning signal comes on when the engine is started, and then goes off. The way to test the signal varies from one vehicle model to another, but the light usually goes off after a short period of time or when the vehicle reaches a certain speed. It is important that the inspector knows the different operation modes of this signal. If the warning device stays on, the vehicle should be rejected.
- A visual check should be made for signs of damage in the electrical system, such as damaged cables or connectors that may affect the proper operation of the system.
- Check that there are no leaks in the pneumatic or hydraulic system.
- A visual inspection should be made of accessible mechanical parts in a search for defects which could affect the system's proper operation.

Only a few references dealing with LSV behaviour, and no reference to LSV inspections, have been found in journals because this is a very specific subject, whose knowledge remains mostly with the manufacturers.

## 2 Results of inspections based on current method

Based on this methodology, a study was made of the first 55 725 periodic inspections of commercial vehicles during year 2012 in the province of Murcia (CARM), Spain, which possesses 20% of the total refrigerated lorry fleet of the country (see Tab. 1).

A total of 42 758 defects (minor, serious and negative), which are broken down into inspection groups, according to the ITV station Inspection Procedures Manual [10], are shown in Table 2.

Figure 8 shows percentage of failures per group.

As can be seen, 43% of the defects found concern the brakes. To determine the incidence of the load control valve in the set of defects, the group "brakes" was divided into subgroups, giving Table 3.

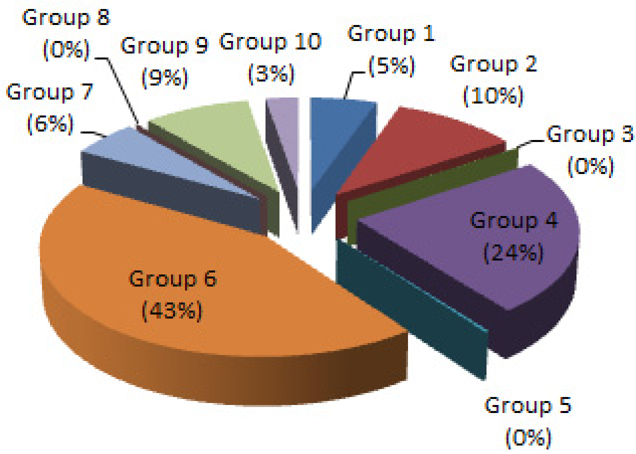


**Fig. 8.** Percentage of defects per inspection group in commercial vehicles with a MAM > 3500 kg during 2012 (Source: CARM).

As can be seen, load sensing valve was only responsible for 0.1% of the defects relating to the brake system. In fact, these 17 defects were due to the absence of this valve in the vehicles which were legally obliged to have one.

This low incidence is probably due to the fact that the inspection process, as indicated in Section 1.2 of this article, is very complex and laborious, and it is only viable in vehicles with a pneumatic LSV, but not in vehicles with a mechanical valve or vehicles with an electronic brake system (EBS), where this function is embedded in the electronics.

In fact, there is no procedure for checking the points indicated in Directive 2010/48/EC [11] regarding the load sensing valve operation test, the procedure devised by CITA [7] focusing on other regulatory requirements, such as checking the existence of compulsory nameplate, the readability of its data and the existence or not of the load sensing valve. In addition, as shown in Section 1.2.3, this check is non-existent in vehicles equipped with ABS/EBS, where the inspection is limited to verifying the system operation as a whole by means of the warning signal. Because of this, it is necessary to create a procedure which is easier to use and also applicable to all types of vehicles.

## 3 Materials and methods

In view of the above, it is evident that a new inspection method is needed in order to check all the load regulation systems on the market.

We propose a new inspection method based on a new device which can simulate load on commercial vehicles [12]. Although it was initially designed to obey Directive 2010/49 in terms of braking effectiveness, as we will see, it can be used to check the load control system on commercial vehicles.

**Table 1.** Number of inspections of commercial vehicles with a maximum authorized mass (MAM) > 3500 kg during 2012 (Source: CARM).

| Classification by construction according to RD 2822/1998 [9] | Description | Inspections during 2012 |
|---|---|---|
| 21 | Lorry with a 3500 < MAM $\leq q$ 12 000 kg | 4149 |
| 22 | Lorry with a MAM > 12 000 kg | 13 655 |
| 23 | Tractor-trailer | 15 347 |
| 25 | Van with a 3500 kg < MAM $\leq$ 12 000 kg | 57 |
| 26 | Van with a MAM > 12 000 kg | 49 |
| 42 | Trailer and semitrailer with a 3500 kg < MAM $\leq$ 10 000 kg | 155 |
| 43 | Trailer and semitrailer with a MAM > 10 000 kg | 22 313 |
| | TOTAL | 55 725 |

**Table 2.** Number of defects per inspection group in commercial vehicles with a MAM > 3500 kg during 2012 (Source: CARM).

| Group | Description | Minor | Serious | Negative | Total |
|---|---|---|---|---|---|
| 1 | Identification | 1620 | 448 | 0 | 2068 |
| 2 | External reconditioning, body and chassis | 2428 | 1519 | 5 | 3952 |
| 3 | External reconditioning | 5 | 9 | 0 | 14 |
| 4 | Lighting and signalling | 6749 | 2386 | 0 | 9135 |
| 5 | Polluting emissions | 0 | 101 | 0 | 101 |
| 6 | Brakes | 9235 | 7329 | 113 | 16 677 |
| 7 | Steering | 967 | 1127 | 0 | 2094 |
| 8 | Axles, wheels, tyres, suspension | 1742 | 2593 | 35 | 4370 |
| 9 | Engine and transmission | 2948 | 395 | 0 | 3343 |
| 10 | Other | 0 | 1031 | 0 | 1031 |
| | TOTAL | 25 694 | 16 938 | 153 | 42 785 |

**Table 3.** Number of defects in Group 6 (brakes) during 2012, broken down into inspection subgroups (Source: CARM).

| Subgroup | Description | Minor | Serious | Negative | TOTAL |
|---|---|---|---|---|---|
| 6.1 | Service brake | 9104 | 5316 | 75 | 14 495 |
| 6.2 | Secondary brake (emergency) | 0 | 0 | 0 | 0 |
| 6.3 | Parking brake | 82 | 1373 | 0 | 1455 |
| 6.4 | Inertia brake | 0 | 0 | 0 | 0 |
| 6.5 | Anti-lock device | 8 | 14 | 0 | 22 |
| 6.6 | Deceleration device | 2 | 1 | 0 | 3 |
| 6.7 | Braking device pedal | 3 | 1 | 0 | 4 |
| 6.8 | Vacuum pump or compressor and tanks | 0 | 52 | 0 | 52 |
| 6.9 | Low pressure indicator | 0 | 0 | 0 | 0 |
| 6.10 | Hand brake control valve | 0 | 7 | 0 | 7 |
| 6.11 | Braking valves | 6 | 292 | 5 | 303 |
| 6.12 | Accumulator or pressure tank | 14 | 38 | 0 | 52 |
| 6.13 | Trailer brakes connection | 0 | 3 | 0 | 3 |
| 6.14 | Servo brake. Master cylinder (hydraulic systems) | 0 | 4 | 0 | 4 |
| 6.15 | Rigid tubes | 0 | 8 | 0 | 8 |
| 6.16 | Flexible tubes | 3 | 44 | 1 | 48 |
| 6.17 | Brake lining | 0 | 33 | 1 | 34 |
| 6.18 | Brake drums and discs | 0 | 112 | 30 | 142 |
| 6.19 | Cables, ribs, levers, connections | 0 | 4 | 0 | 4 |
| 6.20 | Braking system cylinders | 13 | 9 | 1 | 23 |
| 6.21 | Load sensing valve | 0 | 17 | 0 | 17 |
| 6.22 | Automatic slack adjusters | 0 | 1 | 0 | 1 |
| | TOTAL | 9235 | 7329 | 113 | 16 677 |

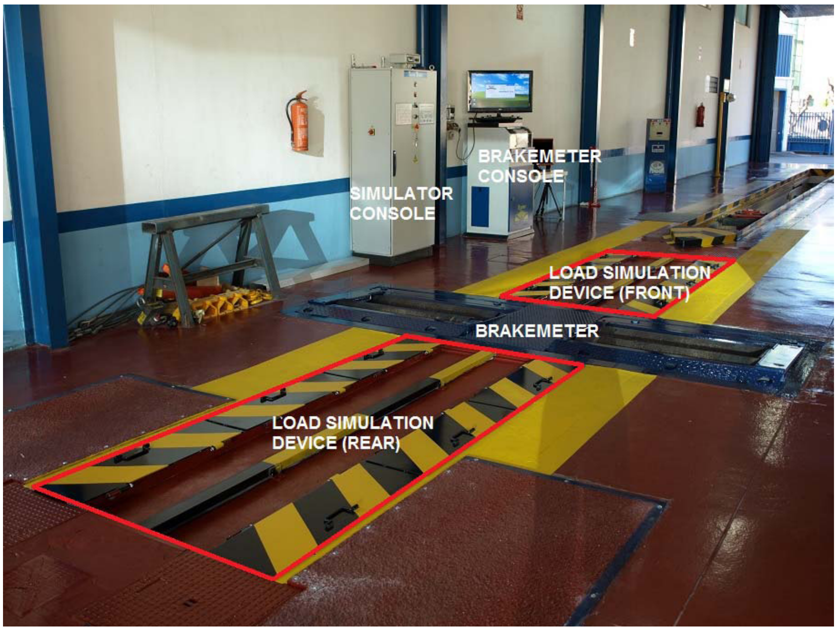


**Fig. 9.** Load simulation device for vehicles with a MAM > 3500 kg.

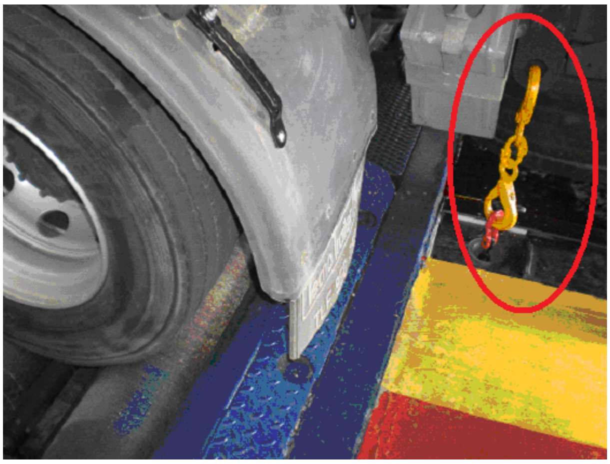

**Fig. 10.** Pulling point for load simulation.

### 3.1 Load simulation device

The load simulation equipment consists of four rails, two located in front of the brake testing equipment (brakemeter) and two behind where the four hydraulically operated traction pulling elements are located (see Fig. 9). Pulling elements are controlled by the simulator console which regules the pulling force.

These pulling elements, once connected to the chassis by templates, flanges or any equivalent system, apply a downwards traction force (see Fig. 10). This force, when it is applied on the chassis, activates the load sensing valve by simulating load [13].

For effective load simulation, the traction must occur on the vehicle frame, so that rings (see Fig. 11) are arranged on it to allow the pulling force to be applied safely.

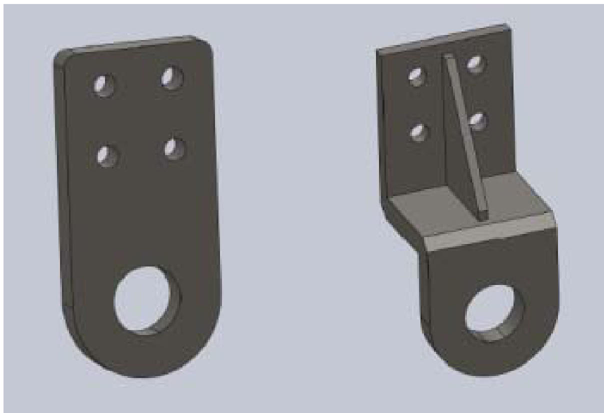

**Fig. 11.** Fastening rings of the frame-pulling elements.

The rings, whose optimal design has been studied, should be connected with the pulling elements before performing the test.

Table 4 shows the characteristics of the new device.

### 3.2 Material used in data collection

For data collection, an axle-weighing scale (see Tab. 5) and a brakemeter (see Tab. 6) were used, both of which are commonly available at any vehicle inspection station. Those used in these tests have a calibration certificate from the National Accreditation Entity of Spain (ENAC).

### 3.3 Software

Specific software has been developed in order to make the procedure easier and automatic. Earlier works [14,15] were taken into account in this task.

**Table 4.** Characteristics of the load simulation device.

| | |
|---|---|
| Load (minimum/maximum) | 630/18 000 kg |
| Electrical power | 8 kW–380 V |
| Width between rails | 1035 mm |
| Effective length of rails | 2700 mm (on each side of the brakemeter) |
| Internal tyre width (minimum) | 1250 mm |
| Width (minimum/maximum) of the vehicle frame | 750/1350 mm |
| Tensioning height | 300 mm |
| Applicable to triaxial tandem with wheelbase: | 1400 mm |

**Table 5.** Characteristics of the axle-weighing scale.

| | |
|---|---|
| Capacity | 15 t |
| Platform dimensions | 3 × 1 m |
| Weight transmission | 4 digital load cells |
| Weight display | Model D800, axle-weighing programme |
| Installation | Built in a trench of 69 cm |

**Table 6.** Characteristics of the brakemeter.

| | |
|---|---|
| Maximum load per axle | 20 t |
| Electric motor power | 2 × 11 kW |
| Test speed | 3 km/h |
| Voltage | 630/400 V–50 Hz (3F + N) |
| Protection fuse | 3 × 50 A |
| Thermal protector | 2 × 25 A |
| Roller diameter | 270 mm |
| Roller length | 1150 mm |
| Distance between centres | 485 mm |
| Rear roller superelevation | 50 mm |
| Measurement indication error | 1% |
| Coefficient of friction | Dry: 0.9<br>Wet: 0.7 |
| Maximum braking force | 3000 N |
| Measuring step | 10 N |

### 3.4 Simulation data collection protocol

For the simulation data, proceed as follows.

In the control console, choose the type of vehicle where braking force is going to be measured. Next, the values of the tare weights and the MAM per axle are inserted and also the total load percentage desired.

The operator selects the frame points where the load is going to be applied and moves the pulling elements along the rails until they are placed vertically below the selected points, always on the axle where the LSV valve acts.

Then, the joining accessories (rings) are set in place and load is applied slowly at various points. The system emits a warning signal when the prescribed load has been reached and, at this moment, the axle on the brakemeter is braked.

If a vehicle has more than one rear axle, the joining accessories are released, the vehicle is moved to another position on the brakemeter, the pulling elements are moved again, and the braking test is repeated.

**Table 7.** MERCEDES load intervals.

| Load interval | Mass (kg) |
|---|---|
| N1 (unladen vehicle) | 10 655 |
| N2 | 13 724 |
| N3 | 16 793 |
| N4 | 19 862 |
| N5 | 22 931 |
| N6 (laden vehicle) | 26 000 |

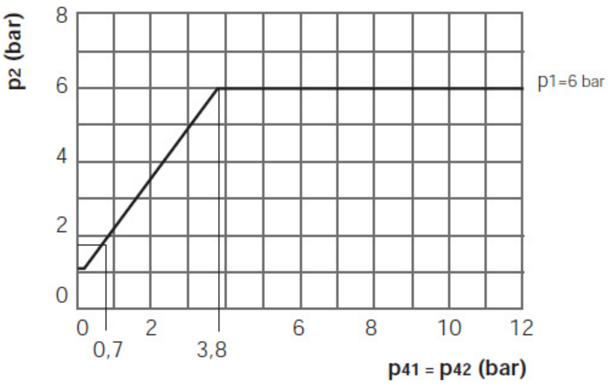


**Fig. 12.** EBS performance depending on load [6].

## 4 Validation of the new device

### 4.1 Tests on sample vehicles

To validate the test, we used three vehicles: (i) a Mercedes commercial vehicle, Model 2535 with 6 × 2 configuration and an electronic braking system (EBS) with an integrated load control function, (ii) a NISSAN lorry with a MAM of 8000 kg, and (iii) an IVECO lorry.

The theoretical operating graph is (Fig. 12).

This graph shows how, by increasing the load of the vehicle, the pressure on the suspension diapress ($p_{41}$) is increased. The output valve pressure ($p_2$) increases linearly until the vehicle reaches a laden state and, when the diapress pressure reaches 3.8 bar, the valve opens completely, equalizing and stabilizing the output ($p_2$) and input ($p_1$) pressures at 6 bar.

Once the theoretical operation of the load control system is known, in order to check the behaviour of the LSV, a graph which matches brake force and vehicle load is made, and later compared with the theoretical value.

For this, we first divide the total vehicle load interval into six parts, as can be seen in Table 7. The first point

**Table 8.** Braking values per payload interval (kN) for a MERCEDES lorry.

| | Braking data (kN) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Test 1 | | Test 2 | | Test 3 | | Test 4 | | Test 5 | |
| | Right | Left | Right | Left | Right | Left | Right | Left | Right | Left |
| N1 | 11.74 | 11.33 | 11.48 | 11.97 | 11.56 | 11.27 | 11.50 | 11.37 | 11.60 | 11.43 |
| N2 | 17.13 | 18.03 | 16.56 | 20.04 | 18.24 | 18.50 | 16.96 | 18.57 | 18.00 | 17.15 |
| N3 | 24.77 | 25.08 | 26.5 | 25.55 | 26.7 | 25.9 | 26.00 | 25.45 | 25.34 | 25.56 |
| N4 | 30.00 | 27.71 | 29.71 | 28.69 | 29.71 | 26.78 | 29.69 | 27.77 | 29.71 | 28.68 |
| N5 | 29.55 | 27.38 | 29.59 | 27.62 | 29.82 | 27.75 | 29.57 | 27.65 | 29.71 | 27.70 |
| N6 | 31.05 | 30.99 | 31.06 | 30.89 | 31.54 | 31.00 | 31.06 | 31.00 | 31.05 | 30.98 |

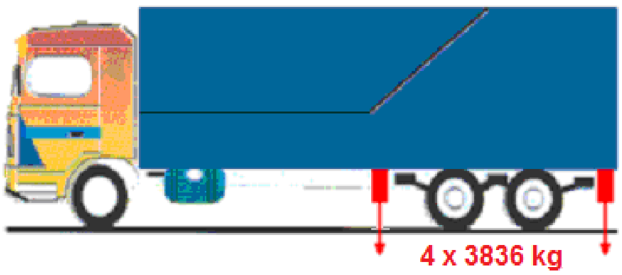


**Fig. 13.** Load distribution for a MERCEDES lorry.

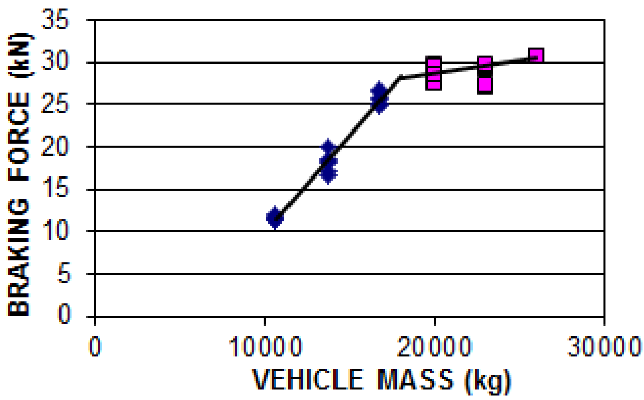


**Fig. 14.** LSV system behaviour for a MERCEDES lorry.

corresponds to the unladen vehicle and the last point to the laden vehicle.

When the desired load is reached, the braking force of one of the axles on which the valve operates is measured. For this, the third axle is placed on a roller brake tester (see Fig. 12), making three tests for each braking point [16], as in Table 8.

Representing these values for each wheel where the LSV valve operates, gives, as can be seen in Figure 14, the load-dependent behaviour of that valve.

This behaviour, as can be seen, is analogous to the theoretical behaviour shown in Figure 12, because braking force increases linearly up to 20 000 kg of mass, after which it remains constant. Braking force only slightly increases because the friction of the pneumatic-roll brake tester increases and the force depends on a normal reaction to this.

**Table 9.** NISSAN load intervals.

| Load interval | Mass (kg) |
|---|---|
| N1 (unladen vehicle) | 3980 |
| N2 | 4784 |
| N3 | 5588 |
| N4 | 6392 |
| N5 | 7196 |
| N6 (laden vehicle) | 8000 |

As mentioned above, these tests were repeated with two more vehicles, one of them a NISSAN lorry with a MAM of 8000 kg, a configuration of 4 × 2, with a hydropneumatic braking system and an electronic braking system (EBS). The other was an IVECO tractor unit with a pneumatic braking system and a regulation braking system (EBS). The results obtained are shown in Tables 10 and 12, and Figures 15 and 17.

As can be seen in the last case, the maximum braking force was reached at 100% MAM, which means that load-dependent braking regulation system is calibrated to obtain maximum braking at the vehicle's MAM, not, as in previous cases, at 70% MAM and 75% MAM, respectively. This is because each manufacturer calibrates the regulation system according to the characteristics of its vehicle. Furthermore, in this case, we were dealing with a tractor unit with a self-loading crane which overloads the front axle and, as a result of these changes; the braking regulation of the EBS has been calibrated differently.

### 4.2 Braking effectiveness

In order to validate the measurement system, the braking effectiveness of all the vehicles with real load was measured with the ultimate purpose of comparing real results with those obtained with the new system by means of a statistic study. It should be pointed out that this effectiveness only applies to the service brake, but not to the parking or safe brake.

Part I of ISO 21069 specifies how to establish in a coil brakemeter the brake efficacy of road vehicles with a MAM of more than 3500 kg and equipped with pneumatic brake systems. It applies also to electronic brake systems (EBS). Its purpose is to establish an action protocol that ensures standardized measuring results, leading to a reliable evaluation of the service brake effectiveness.

**Table 10.** Braking values per payload interval (kN) for a NISSAN lorry.

| | Braking data (kN) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Test 1 | | Test 2 | | Test 3 | | Test 4 | | Test 5 | |
| | Right | Left | Right | Left | Right | Left | Right | Left | Right | Left |
| N1 | 6.04 | 5.38 | 6.38 | 5.38 | 5.79 | 5.11 | 6.35 | 5.38 | 6.00 | 5.47 |
| N2 | 8.83 | 8.57 | 9.30 | 9.30 | 9.08 | 9.39 | 9.05 | 9.35 | 8.93 | 8.76 |
| N3 | 11.33 | 11.62 | 12.01 | 12.30 | 11.39 | 12.25 | 11.36 | 11.89 | 11.56 | 12.25 |
| N4 | 13.75 | 13.73 | 14.57 | 15.08 | 14.10 | 15.78 | 13.95 | 13.75 | 14.27 | 15.00 |
| N5 | 15.76 | 16.00 | 14.40 | 14.30 | 15.40 | 15.10 | 15.50 | 15.10 | 15.40 | 15.20 |
| N6 | 14.80 | 13.90 | 15.70 | 13.90 | 14.50 | 14.30 | 14.90 | 13.99 | 15.40 | 14.20 |

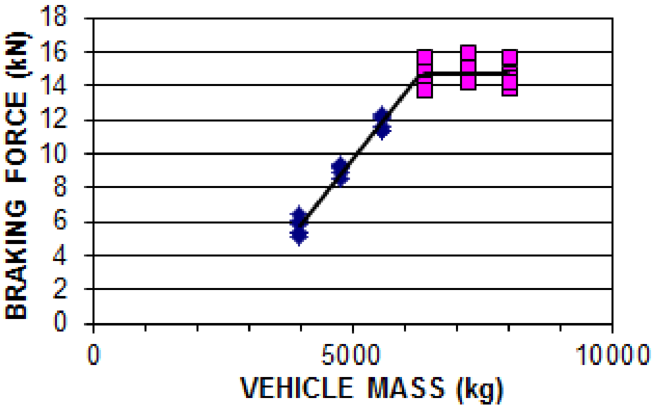


**Fig. 15.** LSV system behaviour for a NISSAN lorry.

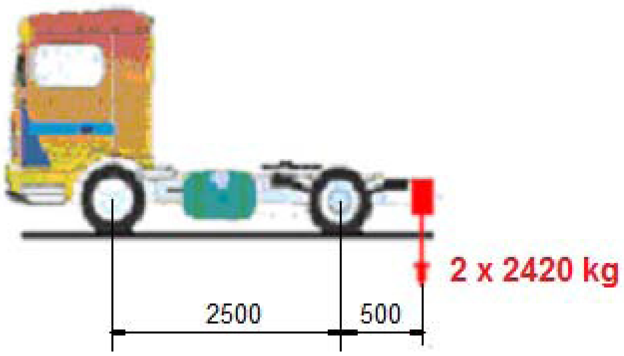


**Fig. 16.** Load distribution for an IVECO lorry.

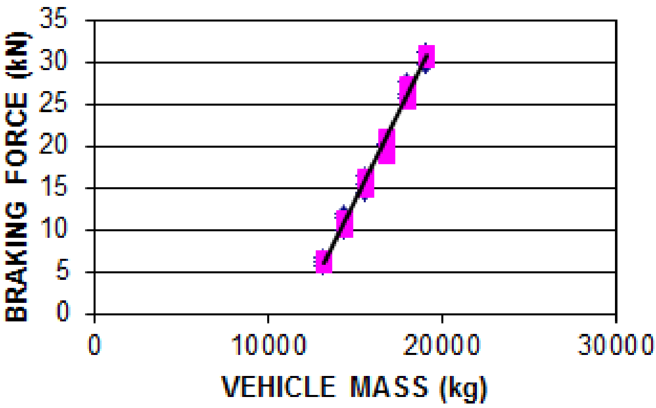


**Fig. 17.** LSV system behaviour for an IVECO lorry.

**Table 11.** IVECO load intervals.

| Load interval | Mass (kg) |
|---|---|
| N1 (unladen vehicle) | 13 160 |
| N2 | 14 352 |
| N3 | 15 544 |
| N4 | 16 736 |
| N5 | 17 928 |
| N6 (laden vehicle) | 19 120 |

Brake effectiveness can be calculated from the experimental data of the vehicle brake force, as follows:

$$z_{M\text{lad}} = \frac{\sum F_i}{F_{M\max}};\ \text{for engine vehicles} \qquad (1)$$

$$z_{R\text{lad}} = \frac{\sum F_i}{F_{R\max}};\ \text{for trailers and semitrailers} \qquad (2)$$

where:

- $z_{M\text{lad}}$ : Braking effectiveness of laden vehicle
- $z_{R\text{lad}}$ : Braking effectiveness laden of trailer or semi-trailer
- $F_i$ : Brake force in the tyre circumference on axle $i$ (N)
- $F_{M\max}$ : Maximum static reaction of the vehicle (N)
- $F_{R\max}$ : Maximum static reaction of all the axles of the semitrailer (N).

Table 13 shows the results obtained with this mathematical expression applied to the tested vehicles.

It is important to point out that the software modifies the load to be applied in order to avoid in the simulation a non-zero torque in the axle to which braking is applied, which could produce an overload. This feature must be provided in order to adjust simulation results to real behavior.

The low differences between the laden and simulated conditions can be seen in Figure 18.

Furthermore, braking effectiveness on rear axle is less than on front axle, but bigger than standardized, so this procedure allows the inspector to check whether the vehicle correctly brakes.

## 5 Proposal of a new method of inspection

To develop an inspection method applicable to periodic regulatory inspections, the first thing to be taken into

**Table 12.** Braking values per payload interval (kN) for an IVECO lorry.

| | braking data (kN) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Test 1 | | Test 2 | | Test 3 | | Test 4 | | Test 5 | |
| | Right | Left | Right | Left | Right | Left | Right | Left | Right | Left |
| N1 | 5.66 | 5.89 | 6.25 | 6.55 | 6.68 | 6.56 | 6.00 | 6.56 | 6.65 | 6.55 |
| N2 | 9.88 | 10.02 | 11.30 | 11.50 | 11.90 | 11.40 | 10.01 | 11.50 | 11.50 | 11.30 |
| N3 | 14.50 | 14.80 | 15.50 | 15.80 | 16.30 | 16.40 | 15.03 | 15.80 | 15.50 | 14.80 |
| N4 | 18.90 | 19.00 | 20.23 | 21.10 | 20.10 | 20.20 | 20.14 | 20.30 | 19.98 | 20.20 |
| N5 | 27.54 | 27.29 | 26.13 | 26.41 | 25.55 | 25.47 | 26.45 | 26.47 | 25.60 | 25.74 |
| N6 | 31.25 | 29.59 | 31.21 | 30.31 | 31.17 | 31.09 | 31.23 | 29.97 | 31.20 | 31.21 |

**Table 13.** Test results in sample vehicles.

| Type of vehicle | | MAM | effectiveness loaded | Effectiveness in simulation |
|---|---|---|---|---|
| N Class: Engine vehicles designed and manufactured primarily for transporting goods | | | | |
| N2 | NISSAN | 12 t | $55 \pm 8\%$ | $56 \pm 6\%$ |
| N3 | MERCEDES | 26 t | $60 \pm 2\%$ | $56 \pm 2\%$ |
| N3 | TRACTORA IVECO | 18 t | $56 \pm 4\%$ | $55 \pm 4\%$ |

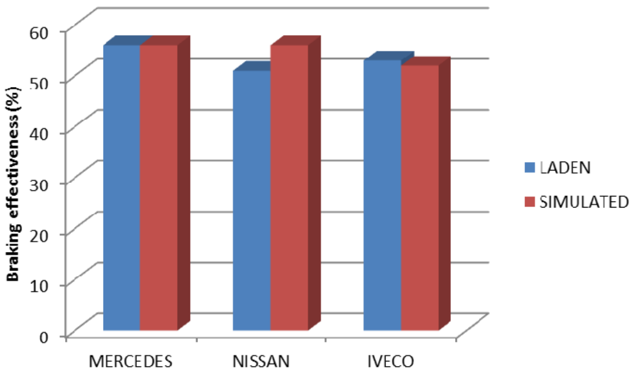


**Fig. 18.** Braking effectiveness comparison.

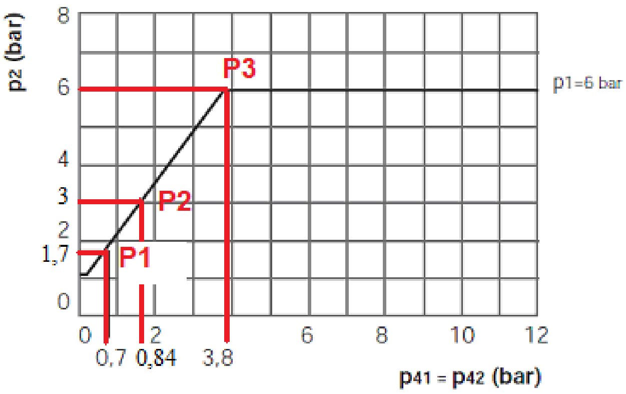


**Fig. 19.** LSV check points with the third point in the proportionality area.

account is paragraph (6) of Directive 2009/40/EC [17], which indicates that the technical inspection of vehicles "should be relatively simple, fast and cheap". This was not easy, because the vehicles studied were "real" working vehicles, whose owners allowed us to carry out our two-hour tests during the inspection period.

The current method proposed by CITA [7], which is applicable to all countries where the technical inspection of vehicles is mandatory, is too slow, since it is necessary to connect vehicles to five manometers in different positions of the pneumatic braking system, not all of them easily accessible and not easy to identify. This and the fact that not all vehicles have pressure outlets in the indicated places, and also that not all the valves have a test outlet for carrying out the recommended tests, means that what is written in Annex II of Directive 2010/48/EC [11] is, in most cases, impossible to implement.

Taking into account the correlation between the sensing valve pressure and the braking force, as verified in this article, we propose the following method of inspection for load-dependent braking regulation systems, which is valid for all vehicles.

### 5.1 Checking the LSV

In order to comply with the recommendation of CITA, which indicates that, at least three load points are necessary to check the LSV, it is not enough to check the unladen and laden vehicle, so measurements must be made at the following points (see Fig. 19).

- **Point 1:** Measure the braking force with the unladen vehicle.
- **Point 2:** Using the load simulator, measure the braking force after increasing the vehicle's load by 20%. The braking force should also increase by 20%, with a certain amount of tolerance. The figure 20% is chosen so that the second point is in the area where pressure increases are proportional to braking force. In this way, we can confirm that braking force depends on load.
- **Point 3:** Using the load simulator, measure the braking force at the MAM of the vehicle.

This third point can be at the end of the proportionality zone or in the zone where the maximum opening of

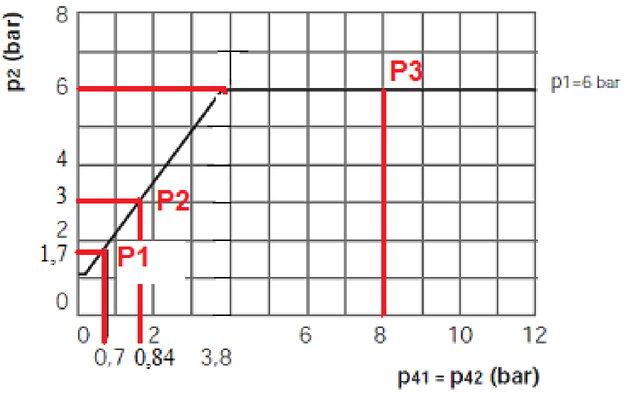


**Fig. 20.** LSV check points with the third point outside the proportionality area.

the valve occurs and where pressure and braking force do not change (see Fig. 20).

## 6 Discussion

Currently, there are no procedures for checking all the braking regulation systems on the market, because the procedures proposed by CITA are only valid for pneumatically operated LSVs, and there is no direct verification procedure for mechanically operated LSVs or ABS/EBS systems.

Several user tests have been carried out with the device and method presented here to study the convergence of the model in terms of user satisfaction, but also in terms of data acceptance. The results were in all cases very satisfactory and provide interesting information:

- Users (technical inspectors) were satisfied with the new method because it is very reliable as was demonstrated.
- Technical inspectors do not carry out tests with the current method because they tend to be unawared of it.
- This method, or any similar method, is not applied anywhere else in Europe.
- The results did not differ from one user to another.

The method also provides the three load points necessary to check the LSV valve.

## 7 Conclusions

Following the mandatory international standards on braking systems security and their inspection procedures for transport vehicles, this paper presents an innovative inspection method for load sensing valves. Based on a new load simulation device, it offers to technical inspectors the possibility to check LSVs and determines braking effectiveness by using a new device that complies with Directive 2010/48/EC.

Tests were conducted on three different transport vehicles, initially unladen, where the proposed device applied a force equivalent to that of the laden condition on the individual axles. The correlation between the sensing valve pressure and the braking force was verified.

The tests provided very satisfactory results, not only from a technical point of view, but for the ease of application and the satisfaction of the inspectors who carry out the inspections. Of particular interest and importance is the fact that the procedure enables inspections and can simulate laden conditions so that vehicles can go to the inspection unladen, which will be of particular economic interest for transport fleet managers.

If we also take into account the progress made in recent years regarding the braking technology of commercial vehicles, which has led to the introduction of electronic and integrated systems, it is clear that the current inspection procedure for load-dependent braking regulation systems is obsolete, both from a regulatory and methodological point of view. This problem will become worse in coming years because technology will increase the presence of these electronic systems in vehicles since they are much more reliable and compact.

Now let us turn our attention to the inspection of a vehicle's electronic systems: although there are currently several lines of research aimed at monitoring the electronics based on reading the error messages stored in the memory of EBS modules, the problem is that the different systems used by manufacturers, as well as their complexity, make it difficult for a reliable method to be developed in the near future. What is more, it will always be a system that simulates the operation of the electronics, without taking into consideration the state of pneumatic or mechanical elements of different systems, which are of basic importance for the functioning of the whole system.

The method presented in this work is valid for all commercial vehicles which incorporate an electronic, pneumatic or mechanical load-dependent braking regulation system and it complies with the relevant legislation of all European Union countries. Our method only very slightly increases the inspection time, but it still fulfils the requirements of being simple, fast and cheap. Most importantly, it simulates with a high degree of reliability the real braking capacity of these vehicles.

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