PIMR-EBS BRAKING SYSTEM AND ITS TESTING IN AUTOMOTIVE ROAD UNITS

ADAM P. DUBOWSKI[1], ALEKSANDER RAKOWICZ, SYLWESTER WEYMANN, KRZYSZTOF ZEMBROWSKI, TADEUSZ PAWŁOWSKI, RADOSŁAW KARBOWSKI

Summary

Electrical diagram of the new PIMR-EBS (PEBS) braking system and its main parts are described in the article. The PIMR automotive road unit tests range is described in the article. The tests were carried out within the framework of N R10-0006-04/2008 R&D Project. The results of the bench tests for the road unit consisting of Mitsubishi L200 research vehicle and the PIMR N1 semi-trailer (GVWR 4.3 t) are presented in the paper. The PEBS braking system is designed for interoperation with the semi-trailers / trailers fitted with the air cushion suspension system. A way of mounting an additional mechanical pneumatic valve, which makes it possible to use the PEBS braking system in the vehicles fitted with the suspension systems with the leaf springs or with the rubber torsion shafts, is presented in the paper. During servicing the PEBS braking systems mounted in PIMR road units, which is being continued in 2011, it was stated that it is necessary to replace: a) two gel non-spillable batteries with the traditional acid ones, and b) unreliable air compressors manufactured in Taiwan with Thomas compressors made in the USA. The new PEBS electro-pneumatic-hydraulic braking system stands a chance of being used it 03 category gooseneck semi-trailers.

Keywords: brake, system, electric, pneumatic, hydraulic, test approval, light truck, gooseneck trailer

1. Introduction

R&D work carried out at Industrial Institute Of Agricultural Engineering (Przemysłowy Instytut Maszyn Rolniczych, Polish acronym: PIMR) at Poznan, Poland, concerning transport safety and quality improvement for the agricultural and forest sector made it possibleto develop a new PIMR-EBS (PEBS) braking system [1] and to put forward a patent application [2]. R&D work on PEBS systems was being realized within the framework of N R10 0006 04/2008 R&D Project [3]. Testing their functionality, efficiency and reliability during the road tests and in the test off-road vehicles was the goal of the work. The PEBS system type-approval testing and the tests of the system conformity to the actual EU Directives were carried out within the framework of the project. The type-approval tests of 02 category trailer and semi-trailer confirmed correct functioning of the new braking systems developed at PIMR and ended with the type-approval certificates issuing. Tests of the PEBS braking system

[1] Industrial Institute of Agricultural Engineering, Starolecka 31 Street, 60-963 Poznan, ad@man.poznan.pl, ad@pimr.poznan.pl, ph.: +48 61 871 22 30, ph.: +48 601 453 602

mounted in 03 category (GVWR 10 t) semi-trailer / trailer confirmed its correct functioning during the road tests and enabled us to find that it was possible to use it in the middle-size gooseneck semi-trailers with GVWR up to 12 t (up to 10 t for the suspension axle and up to 2 t for the catch ball).

2. PEBS Braking System Description

The PEBS braking system is a hybrid design containing electrical, pneumatic and hydraulic systems [6]. The electrical diagrams of the PEBS braking system of the towing vehicle and the towed vehicle braking system are shown in Figures 1 and 2 respectively.

There are two electrical pressure transducers (Keller PA21Y) in the towing vehicle. The transducers are mounted at the master brake cylinder hydraulic system [Fig. 3]. Following the brake fluid pressure variation the pressure transducers provide current signals (0 – 20 mA) to a comparator [Fig. 4]. The comparator compares the signals and transmits the higher one to the PEBS piece mounted in the towed vehicle.

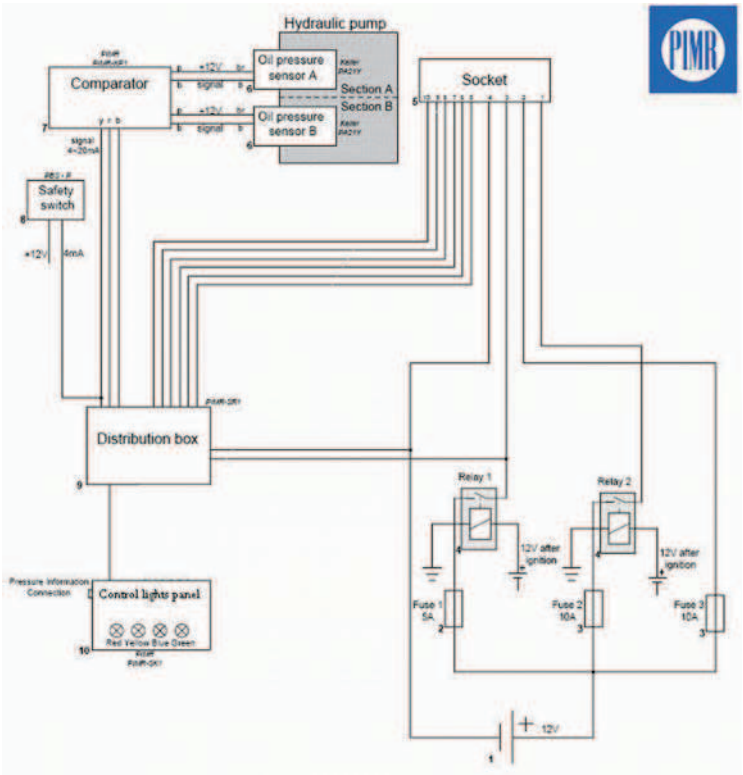

Fig. 1. Electrical diagram of the towing vehicle PEBS braking system.

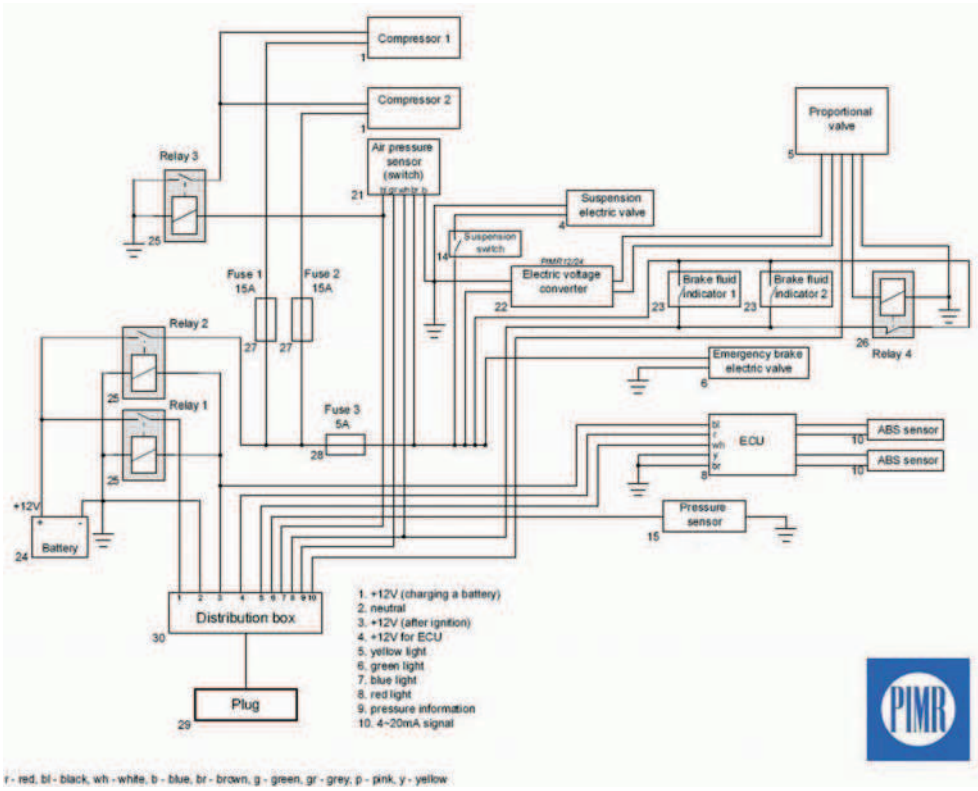

Fig. 2. Electrical diagram of the towed vehicle PEBS braking system.

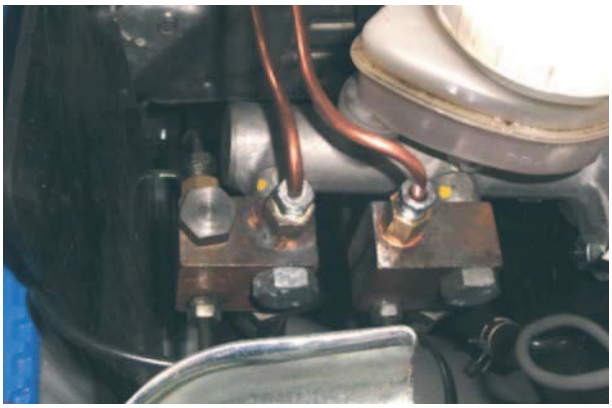

Fig. 3. View of the pressure transducers connections at Mitsubishi L200 vehicle master brake cylinder. The transducers are mounted at the bottom of each body.

Fig. 4. View of the electrical signals comparator. The signals are being transmitted from the brake fluid pressure transducers of the towing vehicle master brake cylinder systems.

There is a control panel with colour LEDs [Fig. 5] in a driver's cab of the towing vehicle. The red indicator signals too low pressure (below 4.5 bar) in the operating air tank, too low brake fluid level, and the lack of the proportional valve feeding. The yellow indicator signals the EBS modulator error and the operating air tank pressure below 4.5 bar. The green indicator signals correct functioning of the operating system of the towed vehicle,

Fig. 5. View of the control panel with LED indicators. The red safety brake push button is shown by the panel, and the counter of working time of the compressors in the semi-trailer / trailer is shown above.

and blue indicator, additionally mounted, signals switching on and operation of the air compressors.

The comparator electrical signal is being converted within the proportional valve in the towed vehicle into the air pressure that controls the EBS modulator operation. In dependence of the air pressure within the air bellows of the suspension system and the signals from the ABS sensors placed on the left and right sides of the semi-trailer / trailer, the modulator feeds pressure, appropriately corrected, to two pneumatic-hydraulic converters. The air pressure within the converters, which are being supplied by means of separate pneumatic pipes, is being converted into hydraulic pressure within independent systems placed on the vehicle right and left sides. The hydraulic fluid activates the hydraulic brakes of the semi-trailer / trailer wheels. The system is parametrized in the way that the vehicle brake pedal maximum pressing corresponds to 5.25 ±0.05 bar control pressure behind the proportional valve.

The anti-blocking system operates in the way that the EBS modulator analyses the axle "2" wheels rotational speeds and makes it possible to modulate the brake servomotors pressure independently for the two axles, when the wheels under measure have a tendency to block. The additional merit of the system is the function of preventing a vehicle against capsizing during turning when a driver does not efficiently reduce the vehicle speed.

The automatic emergency brake switches on the semi-trailer / trailer brake in case of unintentional vehicle road unit disconnection. The safety valve voltage dropout causes feeding the air pressure into the converter by the EBS modulator and braking the trailer with approximately 2.5 bar pressure (about 50% of the operating tank nominal pressure).

The PEBS system is fitted with a safety brake which is being activated electrically with the use of the safety push button at the driver's seat [Fig. 3]. Pressing the safety push button causes the electrical signal transmission to the proportional valve and activation of the semi-trailer / trailer braking system, even in case of the towing vehicle hydraulic braking system failure. The electrical signal transmission takes place when the safety push button is being pressed and held down by a driver.

The pneumatic system includes two air compressors which feed the main air tank independently and turn on when the pressure drops down to 6 bar, and turn off when the main tank (2 x 4.6 dm^3) pressure reaches 8 bar. The operating tank (4.6 dm^3) is being fed with 5.25 bar pressure from the main tank, via the reducing valve. The working time counter for the semi-trailer / trailer compressors is placed within the driver's cab, next to the control panel with LED indicators, near the safety brake push button [Fig. 5].

The control connectors [Fig. 6] for servicing and diagnostics of the PEBS braking system are placed in the front part of the semi-trailer.

The PEBS braking system has been designed for using in agricultural and forest vehicles which operate under hard conditions. Such vehicles should facilitate transport work, and be reliable and easy to service. Hence the PEBS braking system design includes, e.g., two pressure transducers on the vehicle master brake cylinder, two compressors with the

From the left:
- Connector 1 – control of the EBS modulator control air pressure
- Connector 2 – control of the suspension system air pressure
- Connector 3 – control of the pneumatic-hydraulic converter servomotor air pressure
- Connector 4 – control of the main tank air pressure
- Connector 5 – electrical control connector for the electronic circuits of the EBS modulator

Fig. 6. Position of the control connectors in the PIMR N1 semi-trailer front part.

circuits protected with non-return valves on the main tank side; two-section master brake cylinders are used in each pneumatic-hydraulic converter, and the two circuits of each cylinder are connected. In case of failure of any section of the cylinder the second one feeds the semi-trailer / trailer hydraulic brakes with the hydraulic pressure.

The PEBS hydraulic system model was fitted with two gel batteries (14 Ah) placed in the confined space of the trailer made of the bottom of the oval main tank and a cover, or in a small plastic case in 02, 03 category semi-trailers, placed directly behind the rear stationary axle of the semi-trailer. Such location of the case makes it possible to access the braking system parts easy. For the next PEBS braking system versions it is planned to design the bracket members in the way that access and servicing will be much easier without removing other parts.

View of the PEBS braking system in the trailer is shown in Figure 7, and the system in the semi-trailer – in Figure 8.

The merit of the braking system compact design, especially in case of the small segments

Fig. 7. The PEBS braking system in the PIMR P1 trailer (March 2010) with gel batteries within the space made of the main tank tube.

Fig. 8. The PEBS braking system mounted in the PIMR N1 semi-trailer; the main tank (2 x 4.6 dm3) is shown on the left.

of the air pipes connecting the pneumatic circuits, is very short response time which, for the pneumatic circuit of the system, is equal to 0.25 s. The response time, measured from pressing the brake pedal until 125 bar maximum pressure within the hydraulic pipes is reached, is equal to 0.30 s and is much shorter than in case of the Sense A Brake braking system from New Zealand, tested previously, the response time of the front axle servomotor (0.62 – 0.77 s), and the response time of the rear axle servomotor (0.65 – 0.84 s) fed from a single pipe pneumatic braking system used yet in the agricultural trailers in Poland [7].

The PEBS braking system meets the demands of 72/245* 2006/28EC EU Directive [8]. The EMC tests, ordered by Idiada, Spain/Poland [10], were carried out at VTUPV [9].

3. Tests of the Automotive Road Units Fitted with the PEBS Braking System

The new PEBS braking systems were mounted in the test vehicles constructed or modernized within the framework of the R&D Project [3]. The 02 PIMR P1 trailer type-approval tests were being carried out from November 2008 until March 2010, and the PIMR N1 semi-trailer was tested in the middle of 2010. The results of measurements of the braking efficiency for the empty N1 semi-trailer are shown in Fig. 9, and the results for the fully loaded trailer – in Fig. 10.

The GN5000 semi-trailer (on the basis of the GN2000 undercarriage) with 5 t stationary axle suspended on the leaf springs, with disc brakes and drum parking brakes (IVECO DAILY 65C), and 03 category semi-trailer / trailer were the other research vehicles. The frame bearers, for the two categories, were designed as single universal frames for the semi-trailers and trailers. It made it possible to carry out the functional, field and durability tests

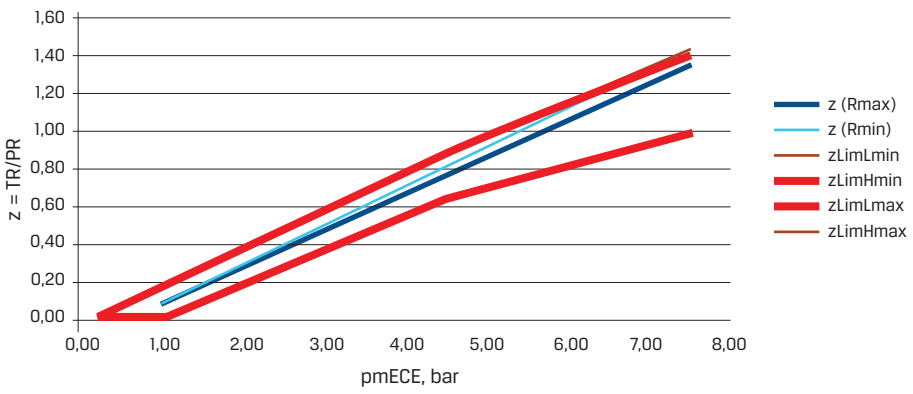

Fig. 9. Results of measurements of the braking efficiency for the empty N1 semi-trailer.

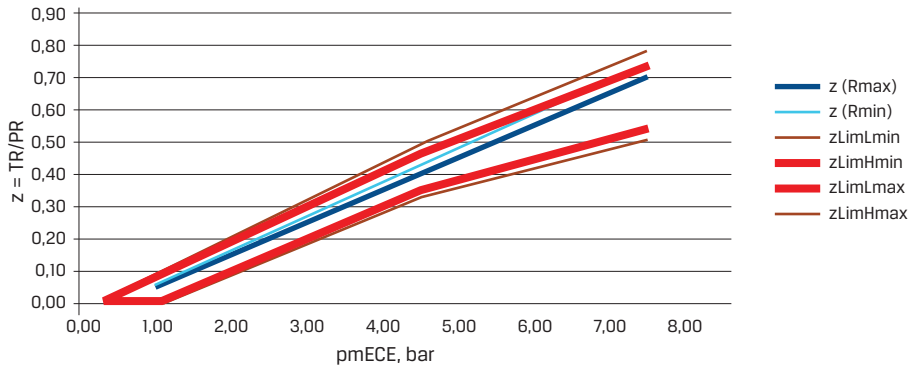

Fig. 10. Results of measurements of the braking efficiency for the fully loaded N1 semi-trailer.

for the undercarriage and the braking system continuously – irrespective of used drawbar: the gooseneck or the classic one.

Mounting additional parking brakes inside Dexter Axle, USA, axles [11], with hydraulic disc brakes of Kodiak, USA [12], was a significant problem. In the USA there is no obligation to mount such brakes in vehicles. The only obligation is that the service brake is operable for minimum 15 minutes after the vehicle stoppage, i.e. for the time needed for securing the wheels with wedges.

In a tow dolly loaned by JMR Boopark [13] the brackets of a service brake system were mounted on each suspension axle with 1780 kg load capacity, and additional brackets of the Kodiak parking brake were mounted on the rear axle. However, there were problems with matching electrical sensors for measurements of the semi-trailer / trailer cargo, which could interoperate with the EBS modulator and be easy mounted in light semi-trailers / trailers. We resigned from the tests of this tow dolly with the PEBS braking system until reengineering the suspension system into the air bellows system.

In order to meet the needs of the PEBS braking system it was decided that the axles with 1800 kg load capacity, with the hydraulic drum brakes and ABS sensors, loaned by KNOTT [14] for the previous tests, would be reengineered. The tandem arrangement rigid axles were placed on the suspension levers with air bellows in the PIMR P1 (GVWR 3400 kg) trailer and the PIMR N1 (GVWR 4300 kg semi-trailer, including 800 kg for the ball coupler and 3500 kg for the stationary axles). The vehicles were tested in this configuration during type-approval testing, and road and field tests as well. The braking system tests carried out during the road drives and testing ground tests of the GN5000 semi-trailer on the airstrip at Bednary airfield, near Poznan, demonstrated easiness of driving, manoeuvring and moving at the speeds of about 100 km/h for the new road units, and efficient and safe braking [15]. The demonstration results of the testing ground tests of a double lane-change (ISO TR 3888) and braking of the research vehicle unit are shown in Figure 11.

Fig. 11. Demonstration records of the testing ground tests at Bednary, Pobiedziska District, made with the use of VIDEO VBOX Racelogic [14] double camera system. The active measurement data channels are marked on the left, and 6.41 m/s^2 result for MFDD, generated automatically, is shown in the centre of the table.

Correct interoperation of the PEBS braking system mounted in the GN5000 semi-trailer with IVECO 5 t axle was achieved by mounting an additional LSV valve. Its mechanical-pneumatic mechanism, by the air pressure change, was signalling any changes of the load transported by the semi-trailer, and, this way, the braking force correction was possible [Fig. 12] [17].

03 category semi-trailer / trailer tests were limited to the road drives of the unit with Mistubishi L200 research vehicle, because the necessity to build models of the new PIMR braking system brought serious problems with reference to the project schedule. In the same way as for the GN5000 semi-trailer, the LSV valve was mounted in the PIMR-03 semi-trailer. The valve was mounted before the front suspension axle, in the middle of the coupler fastened to the both suspension levers [Fig. 13]. In the third quarter of 2011 PIMR bought IVECO Daily 35S17 vehicle with intention to mount a bracket for the ball catch with 60 mm ball in diameter, for coupling 03 category new generation gooseneck semi-trailers with the PEBS braking systems, and to continue the tests.

Fig. 12. LSV valve in the GN5000 semi-trailer.

Fig. 13. LSV valve in 03 category semi-trailer.

A new clamp mechanism bracket design is a problem to solve. The mechanism is needed for braking a semi-trailer when it is parked. An alternative suggestion is to use an entirely new technological solution from DEXTER AXLE: AIRFLEX™, a new suspension system offered since 2010, patent [18], [Fig. 14].

The essence of the solution is that an axle with the suspension levers placed on the rubber torsion shafts is placed on the suspension levers of an air suspension assembly. The hybrid suspended axles are fitted with the hydraulic drum brakes, ABS sensors and a parking brake.

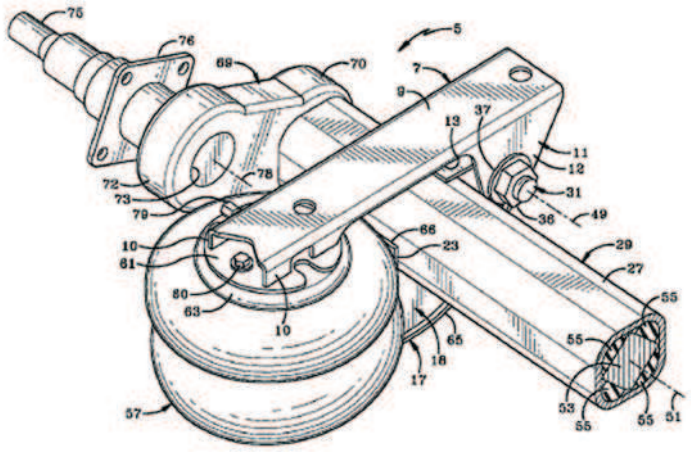

Fig. 14. In the figure from the US patent No. US 7,726,674 (FIG-3), a new suspension concept is shown. The concept was developed at Dexter Axle and is designed for 2.45 – 4.45 t load capacity axles.

4. PEBS Braking System Changes Made After the Tests Carried out at PIMR

The PEBS braking systems were functioning correctly during the tests carried out by the end of 2010. The double sub-assembly system turned out to be a good solution, the brakes were functioning correctly and provided safe transport despite the fact that a compressor failed during some road drive. During running inspections it was found that the operation of consecutive All First Corp. compressors was being disturbed. The compressors were replaced with the new ones from the same manufacturer. After some consecutive replacements it was stated that it was necessary to replace the faulty compressors with high quality devices from Thomas, USA [20]. The PEBS braking systems with Thomas compressors, taken out from the Sens A Brake systems tested previously, operate without failure and fill tanks with compressed air a dozen or so seconds quicker than the systems with the compressors from Taiwan, and they operate more quietly.

The tests carried out at the turn of 2010 and 2011 demonstrated the necessity to replace two gel batteries with a single one, classic. During long-lasting stops outdoors the gel batteries were discharging partially, and one of the batteries, that had not been charged during winter, had four casing walls damaged. Replacing the gel batteries (14 Ah) with the classic ones (44 Ah) made it easy to service the PEBS system. The only inconvenience is the necessity to place a larger battery outside the case, although it is probable that the electrical and electronic circuits separation from the battery vapours may result in the system operational reliability increase.

5. PEBS Braking System Tests Summary

1. The PEBS braking system mounted in 02 category vehicles got the type-approval certificates for the semi-trailer (GVWR 4300 kg) and the trailer (GVWR 3400 kg).

2. The PEBS system hybrid construction provides control simplicity (Brake-By-Wire) by means of electrical signals, significant shortening of the pneumatic sub-assemblies response time, and easiness of hydraulic pipes placement in the towed vehicles.

3. The sub-assembly equipment changes, particularly using new compressors, significantly increased the PEBS system operation quality and operational reliability.

4. Using the Airflex™ system in 02, 03 category semi-trailers should provide reliable interoperation of the air suspension system with the EBS modulator, ensure drive comfort, increase transport safety by means of using an integrated and compact hydraulic drum brake construction with a parking brake and ABS sensors.

5. Using the drum brakes in a new generation of the semi-trailers may improve the exploitation safety and durability under conditions of agricultural and forest transport.

6. Experience acquired during the PEBS braking system in 02 category semi-trailers and trailers tests should ease carrying out 03 semi-trailers type-approval testing. At present ECE Regulation No. 13 documents do not take into consideration the structure of similar hybrid braking systems for the middle-size semi-trailers. These documents require electrical and pneumatic signals proportional control, although it seems that the braking systems certificated until now do not meet this requirement with reference to the electrical signals proportional control.

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