# MEASUREMENT OF BRAKING UNIFORMITY OF TRAILERS AND SEMI-TRAILERS FOR COUPLING WITH VEHICLES WITH A GVW OF UP TO 3.5 T AND ABOVE

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## Abstract

As part of the work, an analysis of scientific literature and legal acts was conducted, and the assumptions for the operation of the device and its concept were prepared. The construction of the device, in accordance with the developed guidelines, was entrusted to an external company. After receiving the device, it was tested using sample measurements of the effectiveness and uniformity of trailer brake operation. This article describes the principle of operation of the device and presents the results of exemplary tests on the effectiveness and uniformity of braking performed using the device developed.

## Keywords:

braking efficiency, braking uniformity, measurement of brake operation, vehicle braking process

## Citation:

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## 1. Introduction

At vehicle inspection stations in Poland, during periodic technical inspections, a mandatory activity is to check the effectiveness and uniformity of braking. The test is usually performed on stationary devices. In cases where the design features of the vehicle (oversized vehicles) make it impossible to check the brakes this way, it is allowed to test the braking effectiveness by measuring the braking delay in real conditions. A delay counter is then used.

## 1.1. Review of scientific literature

Among the recent studies on the effectiveness and uniformity of braking, it is worth mentioning at least a few of the most interesting ones.

The article [11] presents integrated control of the vehicle's longitudinal and lateral dynamics using an active front steering system (AFS) and an active braking system. Since the effectiveness of ABS in shortening braking distances depends on the optimal tire slip coefficients, an adaptive neuro-fuzzy inference system (ANFIS) was proposed to obtain their optimal values. The results obtained indicate high precision in estimating the friction coefficient and optimal wheel slip, significant shortening of the stopping distance and time, and improvement in lateral and torsional stability compared to a vehicle without the estimator. The above work presents in an interesting way the problem of lateral stability of the vehicle and minimization of its deflection using integrated control.

The article [12] emphasized the influence of the uniformity of brakes operation on vehicle stability during braking. Various braking intensities were considered, taking into account both wheel locking and non-locking. It was found that for different types of braking, the permissible non--uniformity of brake operation should be determined.

In [13], a mathematical model of car braking was developed using differential equations. To evaluate the car's steering behaviour, a driver's control action function was introduced into the mathematical model, imitating the driver's action algorithm. The angular speed of the steering wheel is limited by the driver's capabilities. If the heading angle decreased with the introduction of the driver control action feature, then the slip was considered controlled.

The article [14] presents a simulation of a vehicle braking manoeuver in various road conditions. The aim of the article was to answer the question whether random road surface irregularities can shorten the vehicle's braking distance. Different left and right wheel profiles and a road surface with different friction coefficient were assumed.

The article [15] presents research on the braking stability of autonomous vehicles on bends in various road conditions. Taking into account the adhesion properties of the surface, a braking model for autonomous vehicles was built in Simulink, and then the braking effectiveness on curved sections was analysed using CarSim/Simulink co-simulation. The simulation results indicate that both the maximum lateral offset distances and the maximum tire lateral forces decrease with gradually increasing corner radius under various road conditions. It can also be concluded that the distribution of vertical forces in the tire is relatively uniform when the arc radius is not less than 100 m, and the terminal speed of the vehicle changes parabolically as the arc radius increases.

There are, of course, many more articles describing the issue of vehicle stability during braking and systems that improve the uniformity of braking and vehicle stabilization. However, tests of this stability are based on: simulation, inference using the uniformity of braking forces or by assessing whether the vehicle has not been outside the designated area during braking.

There are however, no devices that would allow to easily measure braking irregularities while driving on any road. Therefore, the aim of this work was to develop such a tool.

## 1.2. Review of legal acts

Based on a review of European and Polish legal acts, it was determined that the following provisions apply to the check the effectiveness and uniformity of brake operation by measuring the braking delay of motor vehicles and trailers.

- Commission Directive 2010/48/EU of 5 July 2010 adapting the Directive 2009/40/EC of the European Parliament and of the Council to the technical progress on roadworthiness tests for motor vehicles and their trailers.
- Regulation of the Minister of Transport, Construction and Maritime Economy of June 26, 2012, as later amended, on the scope and method of conducting technical tests of vehicles and templates of documents used for these tests.

Additionally, the following provisions, directly or indirectly related to the measurement of braking delay, are helpful in developing the concept of a delay counter model.

- Directive 94/20/EC of the European Parliament and of the Council of 30 May 1994 relating to mechanical coupling devices for motor vehicles and their trailers and their attachment systems to those vehicles.
- Regulation No 13 of the United Nations Economic Commission for Europe (UN/ECE) – Uniform provisions concerning the type-approval of vehicles of M, N and O categories with regard to braking.

- Regulation No. 55 of the Economic Commission for Europe of the United Nations (UN/ECE) – Uniform provisions concerning the type- approval of mechanical coupling components of vehicle combinations.
- Regulation of the Minister of Transport and Construction of February 10, 2006, as later amended, on detailed requirements for stations conducting technical tests of vehicles.
- Regulation of the Minister of Transport, Construction and Maritime Economy of December 15, 2016, as later amended, on the technical conditions of vehicles and the scope of their necessary equipment.

## 1.3. Objective of the work

The practical objective was to design and produce a prototype of a mobile measuring device for measuring the uniformity of braking of trailers and semi-trailers to be connected to vehicles with a GVW of up to 3.5 T and above.

The device described was developed as part of statutory work no. 06/22/ZDO/007 at the Motor Transport Institute, in cooperation with an external company, and extended the functionality of the CL177 delay counter with additional measurement functions. A patent application number P.442902 has also been filed.

## 2. Methodology

In the design process, the analysis of legal requirements regarding the method of measuring braking effectiveness and uniformity was crucial.

## 2.1. Analysis of the requirements for measuring the effectiveness and uniformity of braking

Measurement of vehicle braking delay of the service, emergency and parking brakes is described in §3 of the Regulation of the Minister of Transport, Construction and Maritime Economy of June 26, 2012, as later amended, on the scope and method of conducting technical tests of vehicles and document templates used for these tests. The measurement should be performed under the following conditions:

- the test can only be carried out on a section of the road where it will not pose a threat to road traffic safety (for example by sudden braking of the vehicle),
- tire pressure cannot differ from the nominal one by more than ±0.1 bar for a motorcycle, a moped and a passenger car and ±0.2 bar for other vehicles,
- braking should be performed only with the brake being tested, however the engine clutch may be engaged and, in vehicles equipped with a servo mechanism, the engine may be running,
- the pressure on the brake pedal (lever) cannot exceed the values specified in the regulation,
- the vehicle should be evenly loaded with a load equal to its permissible load capacity; passenger cars and motorcycles may only be tested with a driver; it is prohibited to test buses and trolleybuses on a public road, unless instead of passengers, ballast is placed in the vehicle, corresponding to the weight and load capacity of the vehicle in question,
- the road on the section selected for measurement should be horizontal, with a hard surface (bituminous, concrete), even, dry and clean,
- during the measurement, the vehicle should be driven by the driver of the tested vehicle or an employee authorized to perform technical tests,
- the vehicle driver should brake only with the brake being tested, but the clutch may be engaged,
- the measurement should be performed at an initial speed of approximately 30 km/h according to the speedometer readings, and in the case of vehicles not achieving this speed: at maximum speed,
- braking until the vehicle stops is not required,
- measurement of braking delay should be made using a delay counter calibrated in $m/s^2$ or in % of gravitational acceleration, mounted in the tested vehicle in the manner indicated by the manufacturer of the device.

The method of determining and assessing the effectiveness and uniformity of braking is described in §4 of the Regulation on the scope and method of conducting technical tests of vehicles and templates of documents used for these tests. Pursuant to the provisions of this paragraph, braking performance shall be deemed to meet the requirements if the following conditions are met:

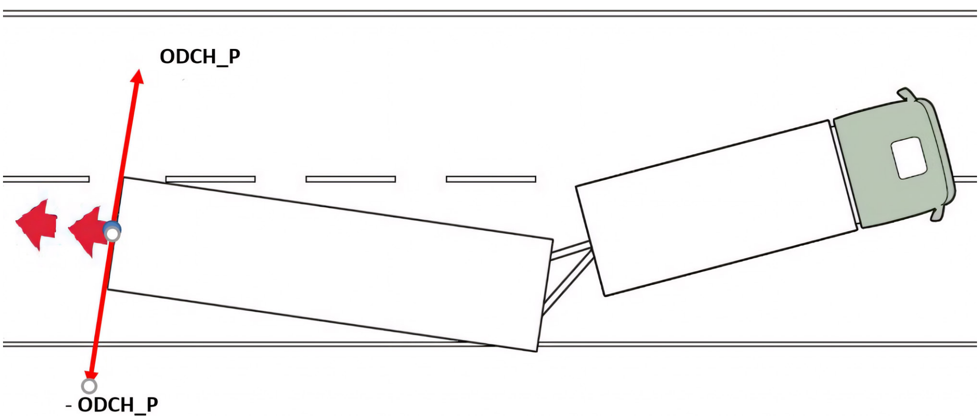
- the braking efficiency indicator measured based on the braking delay measurement is not less than that specified in § 16 section 2 and 4, § 51 section 1 and 2 of the Regulation on the technical conditions of vehicles and the scope of their necessary equipment,
- the measured braking delay is not less than the required one, determined based on the braking efficiency indicator,
- there was no change in the position of the axis of the vehicle's direction of movement during braking by more than 0.5 m relative to the initial direction (with the steering wheel not correcting the direction of travel).

## 2.2. Device concept

The general concept of the device is to place the acceleration sensor in the rear of the trailer or semi-trailer and locate it in a horizontal plane, perpendicular to the direction of travel. This sensor will capture the lateral accelerations of the trailer or semi-trailer and transmit them to the module processing the sensor data. There, the lateral acceleration course will be double integrated and, on its basis, the total displacement of the trailer or semi-trailer in the direction perpendicular to the direction of travel will be determined. Based on this, it is possible to assess the uniformity of braking.

Fig. 1 shows the behaviour of the trailer during uneven braking.

**Fig. 1. Trailer behaviour during uneven braking**

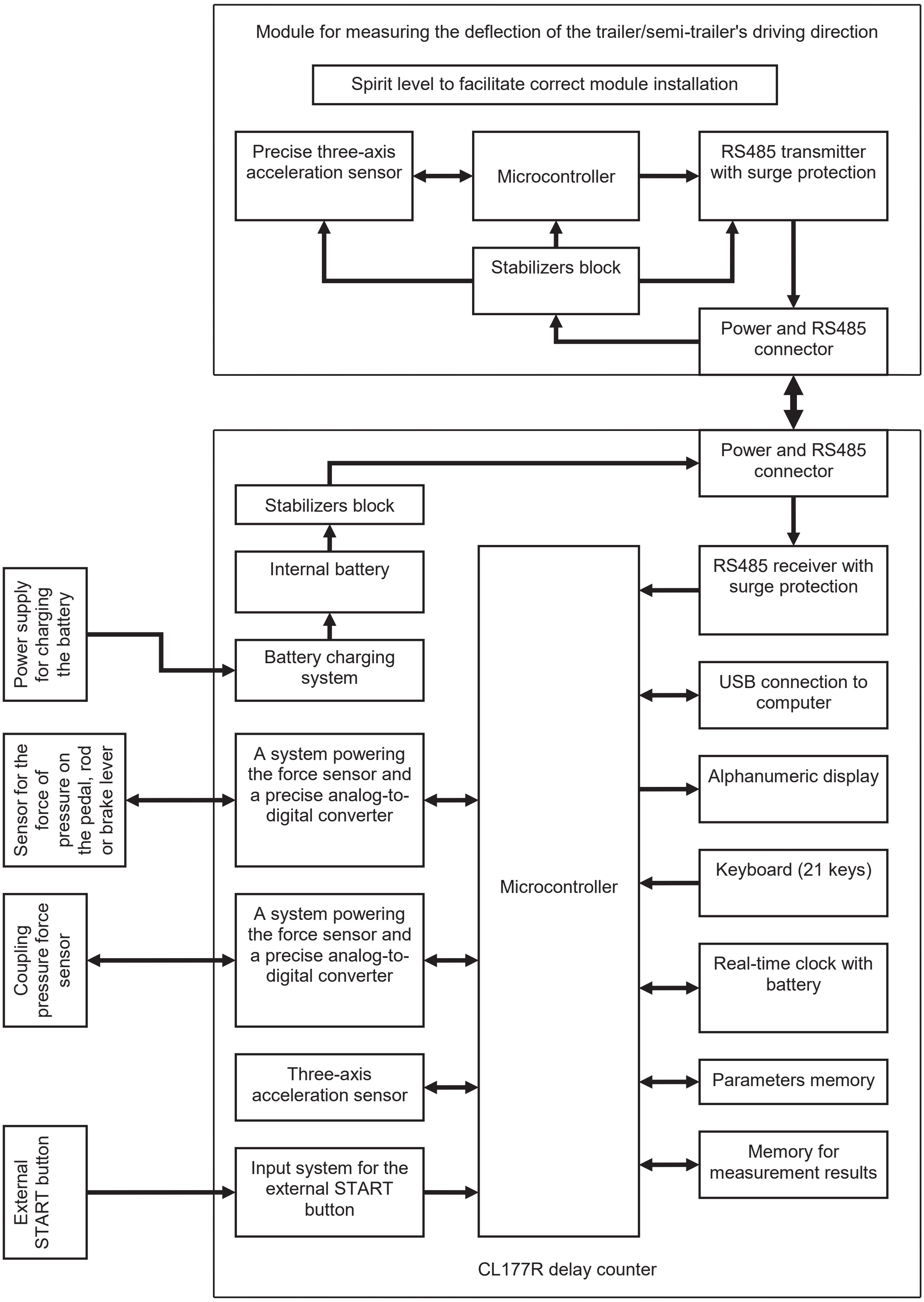


The construction of the device in accordance with the adopted assumptions and concept was entrusted to an external company.

## 3. Construction and operation description of the device

The operation of the device is described using the diagram presented in Fig. 2.

Fig. 2. Module for measuring the deflection of the trailer or semi-trailer's driving direction



The module for measuring the deflection of the direction of travel of a trailer or semi-trailer measures acceleration values in three axes and transmits pre-calculated values to the CL177R delay counter. The CL177R delay counter receives the results from the directional deflection measurement module and performs their final conversion into natural units ($m/s^2$). The values of these accelerations are used to check the correct mounting of the module for measuring the deflection of the trailer or semi-trailer's direction of travel before measuring the effectiveness and uniformity of braking.

## 3.1. Determining deflection from the driving direction

When measuring the effectiveness and uniformity of braking, the CL177R delay counter records acceleration values from the module for measuring the deflection of the trailer or semi-trailer's direction of travel. After braking, based on the acceleration course in the horizontal axis perpendicular to the vehicle axis, the driving deflection of the trailer or semi-trailer is calculated according to formulas (1.) and (2.):

$$BUF_{VP}[n] = \sum_{i=nh1}^{nh2} (BUF_{AP}[i] \times tp) \quad (1.)$$

$$ODCH_P = \sum_{i=nh1}^{nh2} (BUF_V P[i] \times tp) \quad (2.)$$

where:

- $BUF_{AP}$ – buffer with recorded instantaneous values of the acceleration of the trailer or semi-trailer in the horizontal axis perpendicular to the vehicle axis ($m/s^2$),
- $BUF_{VP}$ – buffer with calculated instantaneous values of the speed of the trailer or semi-trailer in the horizontal axis perpendicular to the vehicle axis (m/s),
- $ODCH_P$ – calculated value of the deflection of the trailer or semi--trailer's driving direction (m)
- nh1 sample number (in $BUF_{AP}$) for the beginning of braking (when the measured vehicle braking delay increases to the value closest to 0.05 $m/s^2$ but not greater than 0.05 $m/s^2$),
- nh2 – sample number (in BUF_AP) for the end of braking (when the measured vehicle braking delay drops to the value closest to 0.05 $m/s^2$ but not greater than 0.05 $m/s^2$),
- sample number in the BUF_VP buffer (in the range from nh1 to nh2),
- tp – sampling period during recording (in CL177R it is 0.01 s).

Example:
During braking process, the acceleration of the trailer in the horizontal axis perpendicular to the vehicle axis is 0.20 $m/s^2$ and the braking time is 2.00 s.

For simplicity, we assume nh1 = 1, which results in nh2 = 200 (to obtain a time of 2 s with a sampling period of 0.01 s). As a result, n (the position number in the buffers) takes values from 1 to 200. $BUF_{AP}$ therefore contains 200 acceleration samples (from $BUF_{AP}[1]$ to $BUF_{AP}[200]$) with a value of 0.20 $m/s^2$ each. Calculating $BUF_{VP}[n]$, we obtain the form described by formula (3.):

$$BUF_{VP}[n] = 0,20 \times n \times 0,01 = 0,002 \times n[\mathrm{m/s}] \quad (3.)$$
$$\text{(for n of the interval from 1 to 200)}$$

Calculating ODCH_P gives the result described by formulas (4.) and (5):

$$ODCH_P = \sum_{i=1}^{200}(0,002 \times i \times 0,01) = \sum_{i=1}^{200}(0,00002 \times i) = 0,00002 \times \sum_{i=1}^{200} i \quad (4.)$$

$$ODCH_P = 0,00002 \times 200 \times 201/2 = 0,402[\mathrm{m}] \text{ after rounding: 0,40 m} \quad (5.)$$

To check, using formula (6.) for a distance in uniformly accelerated motion:

$$(s = a \times t^2/2) \quad (6.)$$

we will obtain formula (7.):

$$ODCH_P = 0,20 \times 2,002/2 = 0,40 \text{ m}. \quad (7.)$$

## 3.2. An example test performed with the device

Fig. 3 shows a set of vehicles on which the trailer braking uniformity was measured.

**Fig. 3. A set of vehicles for measuring the uniformity of trailer braking**

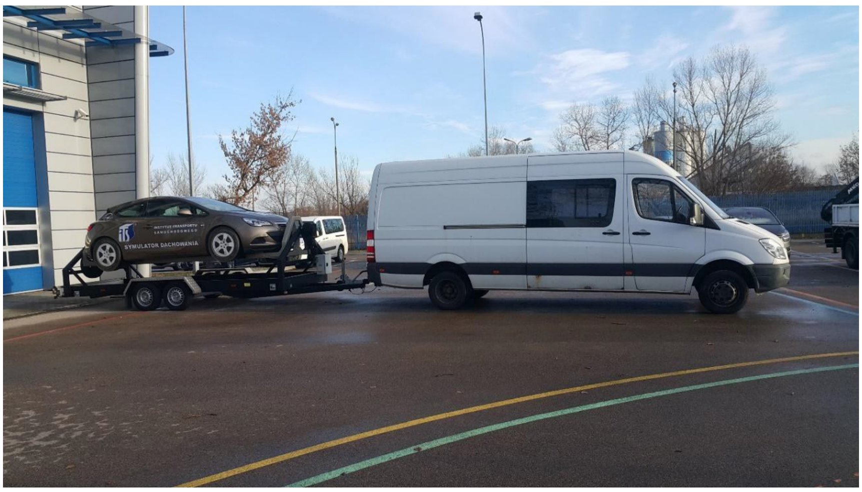


Fig. 4 shows how to attach the measuring module to the rear of the trailer.

**Fig. 4. Method of mounting the measuring module**


Fig. 5 shows the course of: braking delay, brake pedal pressure and trailer deflection from the direction of travel during an example test of the effectiveness and uniformity of the brakes.

**Fig. 5. Graph illustrating the deflection of the trailer's direction during braking.**

**Foot operated brake**
**Braking delay, brake pedal pressure and trailer deflection:**

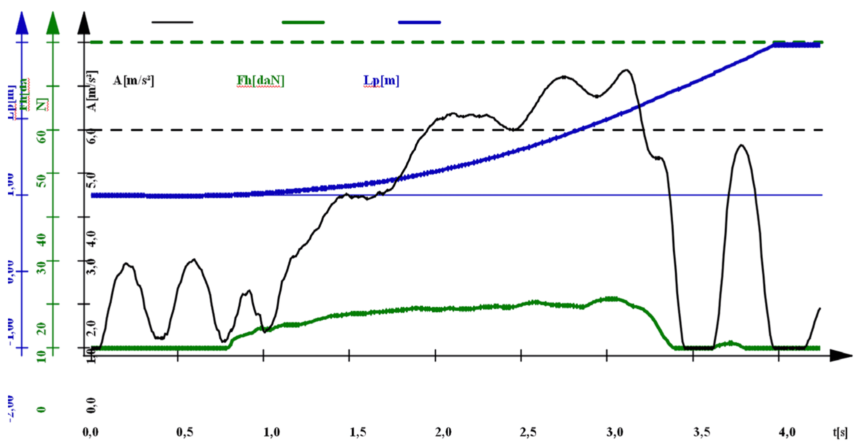


Fig. 6 shows the measurement report generated by the device during an example test of the effectiveness and uniformity of brake operation.

**Fig. 6. Report for measuring the uniformity of trailer braking**

**Official report for measuring braking delay WX/151**
**Motor Transport Institute**
**03-301 Warsaw, ul. Jagiellońska 80**
**DATE, TIME: 2022-12-08, 12:13**

VEHICLE DATA:

| | | |
|---|---|---|
| Vehicle type/category: | Category N1 | |
| Date of first registration: | 2010-07-28 | |
| Registration number: | | |
| Make: | | |
| Type / model: | | |
| Registration number: | | |
| Mileage in km: | | |
| Trailer type / category: | Trailer – Category O | |
| Date of first registration: | 2010-07-28 | |
| Registration number: | | |
| Make: | | |
| Type / model: | | |
| Identification number: | | |
| Measurement method: | trailer braking only | |
| Real trailer weight [t]: | | 1,900 |
| Actual vehicle weight [t]: | | 3,000 |
| Delay due to rolling resistance [m/s²]: | | 0,30 |

| MEASUREMENT RESULTS | | WSH [%] |
|---|---|---|
| Foot operated brake | | |
| - maximum braking delay [m/s²]: | 6,37 | |
| - average braking delay [m/s²]: | 5,26 | 52 |
| - brake pedal pressure [daN]: | 11,2 | |
| - vehicle direction deflection [m]: | right 0,15 | |
| - average trailer braking delay [m/s²]: | 13,09 | 130 |
| - trailer travel direction deflection [m]: | right 1,97 | |

| FINAL EVALUATION | |
|---|---|
| Foot operated brake | |
| Braking delay [m/s²]: | ≥5,0 |
| Brake pedal pressure [daN]: | ≤70 |
| Vehicle driving direction deflection [m]: | ≤0,5 |
| Trailer braking delay [m/s²]: | ≥5,0 |
| Trailer travel direction deflection [m]: | >0,5 |

INSPECTION RESULT: negative

1. The deviation of the trailer's travelling direction is too large.

Vehicle ID: 11111115

## 4. Summary

As part of the work, an analysis of scientific literature and legal acts was conducted, and the assumptions for the operation of the device and its concept were prepared. The construction of the device in accordance with the developed guidelines was entrusted to an external company. After receiving the device, it was tested using sample measurements of the effectiveness and uniformity of trailer brake operation.

The device works thanks to an acceleration sensor placed in such a way that the measurement direction is transverse to the direction of travel and is in a horizontal plane. Thanks to this, the measured acceleration values correspond to the lateral displacements of the trailer and indicate uneven braking.

The acceleration sensor is placed in the rear of the vehicle and the measured values are transferred to the computing module. There, the acceleration course is double integrated and the units are agreed upon.

The device records the results and generates a graphic form of the course: braking delay, brake pedal pressure and trailer deflection from the direction of travel. It also creates a test report in which the measured values are compared to the normative values and provides information whether the vehicle meets or fails to meet the requirements.

The device can be used at vehicle inspection stations to test the effectiveness and uniformity of braking in the field. Its design is protected by the patent office under the number: P.442902.

## Bibliography:

### Legal acts:


1. Dyrektywa 94/20/WE Parlamentu Europejskiego I Rady z dnia 30 maja 1994 r. odnosząca się do mechanicznych urządzeń sprzęgających pojazdów silnikowych i ich przyczep oraz systemów ich mocowania do tych pojazdów (Dziennik Urzędowy Unii Europejskiej L 195/1 z 29.7.1994).
2. Dyrektywa Komisji 2010/48/UE z dnia 5 lipca 2010 r. dostosowująca do postępu technicznego dyrektywę Parlamentu Europejskiego i Rady 2009/40/WE w sprawie badań zdatności do ruchu drogowego pojazdów silnikowych i ich przyczep (Dziennik Urzędowy Unii Europejskiej L 173/47 z 8.7.2010).
3. Zalecenie Komisji z dnia 5 lipca 2010 r. w sprawie oceny usterek w trakcie badań zdatności do ruchu drogowego zgodnie z dyrektywą Parlamentu Europejskiego i Rady 2009/40/WE w sprawie badań zdatności do ruchu drogowego pojazdów silnikowych i ich przyczep (2010/378/UE) (Dziennik Urzędowy Unii Europejskiej L 173/74 z 8.7.2010).
4. Zalecenie Komisji z dnia 5 lipca 2010 r. w sprawie oceny ryzyka związanego z usterkami stwierdzonymi podczas kontroli drogowych (pojazdów użytkowych) zgodnie z dyrektywą 2000/30/WE Parlamentu Europejskiego i Rady (2010/379/UE) (Dziennik Urzędowy Unii Europejskiej L 173/97 z 8.7.2010).
5. Regulamin nr 13 Europejskiej Komisji Gospodarczej Organizacji Narodów Zjednoczonych (EKG ONZ) – Jednolite przepisy dotyczące homologacji pojazdów kategorii M, N i O w zakresie hamowania (Dziennik Urzędowy Unii Europejskiej L 257/1 z 30.9.2010), obejmujący wszystkie obowiązujące teksty, w tym:
   - Suplement nr 5 do serii poprawek 10 – data wejścia w życie: dnia 15 października 2008 r.,
   - Sprostowanie 1 do wersji 6 – data wejścia w życie: dnia 10 marca 2009 r.,
   - Sprostowanie 2 do wersji 6 – data wejścia w życie: dnia 24 czerwca 2009 r.
   - Regulamin nr 55 Europejskiej Komisji Gospodarczej Organizacji Narodów Zjednoczonych (EKG ONZ) – Jednolite przepisy dotyczące homologacji mechanicznych elementów sprzęgających zespołów pojazdów (Dziennik Urzędowy Unii Europejskiej L 227/1 z 28.8.2010);
6. Rozporządzenie Ministra Transportu i Budownictwa z dnia 10 lutego 2006 r. w sprawie szczegółowych wymagań w stosunku do stacji przeprowadzających badania techniczne pojazdów (Dz. U. Nr 40 z dnia 10 marca 2006 r., poz. 275);
7. Rozporządzenie Ministra Transportu, Budownictwa i Gospodarki Morskiej z dnia 26 czerwca 2012 r. w sprawie zakresu i sposobu przeprowadzania badań technicznych pojazdów oraz wzorów dokumentów stosowanych przy tych badaniach (Dz. U. z 2012 r. z dnia 7 września 2012 r., poz. 996);
8. Rozporządzenie Ministra Transportu, Budownictwa i Gospodarki Morskiej z dnia 3 sierpnia 2012 r. zmieniającego rozporządzenie w sprawie warunków technicznych pojazdów oraz zakresu ich niezbędnego wyposażenia (Dz. U. z 2012 z dnia 7 września 2012 r., poz.997).
9. Technical Report ISO/TR 13487:1997(en) Braking of road vehicles — Considerations on the definition of mean fully developed deceleration.
10. Warunki techniczne nr WT-ITS 23/99-ZDO. Maszyny i urządzenia do diagnostyki i kontroli pojazdów. Opóźnieniomierze do kontroli działania hamulców. Wymagania i badania. Wydanie 3.


### Papers:


11. Abbas Soltani, Shahram Azadi, Reza Nakhaie Jazar: Integrated control of braking and steering systems to improve vehicle stability based on optimal wheel slip ratio estimation, Journal of the Brazilian Society of Mechanical Sciences and Engineering, 2022.
12. Omil Kasimov: Method for regulation of permissible irregularity of brake forces on front axle, Tashkent State Transport University, 2022.
13. Omil Kasimov, Sobit Tukhtamishov: Mathematical model of braking process of car, Tashkent State Transport University, 2022.
14. Jarosław Zalewski: Simulation of a Motor Vehicle Braking on a Randomly Uneven Road, Journal of KONBiN, 2022.
15. Binshuang Zheng, Xiaoming Huang, Junyao Tang, Jiaying Chen, Runmin Zhao, Zhengqiang Hong, Tao Tang, Meiling Han: Evaluation on Braking Stability of Autonomous Vehicles Running along Curved Sections Based on Asphalt Pavement Adhesion Properties, Journal of Advanced Transportation, 2022.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