

# Validating the durability testing method for large-sized vehicles based on dynamic characteristics of shock absorbers-extended tests

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## ABSTRACT

Road simulators are one of the methods of conducting durability tests. The article evaluates the methodology developed by the authors and described in earlier publications for durability tests on road vehicles using the Road Simulator. This evaluation was conducted by comparing the dynamic characteristics of road shock absorbers from 49 semi-trailers of different forwarders and five such vehicles after durability testing. As a benchmark, the characteristics of new shock absorbers were determined in the same way. The authors also verified the effect of shock absorber operating temperature on the effectiveness of the damping force. Tests were conducted for temperatures of -20 °C, 20 °C and 110 °C. The relationship between the maximum damping force of the shock absorber and the mileage of the vehicle in which it was installed was also determined.

**Keywords:** methodology of durability test, semi-trailer, damping force.

## INTRODUCTION

The service life of motor vehicles is a key engineering parameter that determines the safety of use, reliability and transport economics. Analysing aging processes and predicting the time to wear of components as early as at the design stage or during the testing stage of vehicle prototypes is particularly important for vehicle manufacturers. Understanding the dynamics of changes in the parameters of equipment and its components is essential for designing more robust components and for accurate assessment of their correct operation as well as for optimising maintenance schedules.

Other factors that also affect the service life of vehicles include the condition of the road surface [1], the habits of vehicle users, the natural

environment and the social environment. The literature now also recommends to use the results of user habit studies in the preparations for durability tests [2].

Time is crucial in vehicle durability testing, so manufacturers use special test tracks, road simulators or chassis dynamometers, where vehicles travel specific distances with purposely increased loading factors to accelerate the wear process and assess durability of the structure. Doddsa and Plummer [3] conducted an overview of road simulators. Suresh et al. [4] compared two basic methods for durability testing – test tracks and mechanical road simulators. Proving ground tracks are most often used for testing buses and trucks. This method of accelerated testing is described by Kepka [5], confirming that about 100 000 km on a proving

ground tracks may replicate about 1 000 000 km in real conditions. Kosobudzki [6], on the other hand, using test tracks, analysed the durability of suspension components to estimate their fatigue strength. Haiqiang [7] presents a fatigue analysis of vehicle element based on a test track. Azrulhisham [8] analysed fatigue strength of a passenger car wheel suspension knuckle using data from the British Millbrook proving ground.

Correlation between the results of accelerated durability tests and the consequences of actual vehicle operation is a key element of such tests. Achieving the best possible compatibility between accelerated vehicle wear and wear under normal operation is crucial and may significantly reduce the time it takes to launch production of a new vehicle or its component. For example, Ferry [9] combined vehicle modeling using the Automatic Dynamic Analysis of Mechanical Systems (ADAMS) software package with physical road tests and laboratory tests on a servohydraulic road test simulator (RTS) to determine the durability properties of a vehicle being designed vehicle various road conditions. Ledesma et al. [10] described the development of multi-axis, accelerated durability tests for commercial vehicle suspension systems that have well-defined correlation with customer usage. The procedure defines the vehicle's duty cycle based on the expected operational parameters, such as: road profile, vehicle speed and warranty life.

This study uses shock absorbers for comparative analysis of vehicle component wear after simulation tests versus actual vehicle usage. They are used in most road vehicles and their technical condition is important for the driving characteristics [11], the stability of the vehicle's movement and the effectiveness of active safety systems [12], as demonstrated by Zwosta et al. in their paper [13]. During operation shock absorbers are subject to gradual degradation caused by mechanical wear of their parts, which is manifested by a reduction in the damping force exerted by the shock absorber [14]. A procedure to determine the dependence of the level of damper degradation on the distance covered by the vehicle was prepared and presented by Cu et al. [15].

Thus, a comparison of the characteristics of shock absorbers from vehicles after simulator tests and those used in vehicles on real roads can be used to evaluate abbreviated durability

tests. It is also possible to relate the characteristics obtained to those of the same new parts or the characteristics of the manufacturer.

The authors, through their relations with the semi-trailer manufacturer, have access to one type of vehicle operated by different customers. Therefore they know the mileage of the semi-trailers from which shock absorbers were removed. In addition, the trailer manufacturer, with information from the after-sales service, has information on the loads of the operated semi-trailers.

The relationship between the shock absorber temperature and the vehicle's driving safety (road grip) and driving comfort was presented by Pavlov [16]. The author used the determined temperature characteristics of shock absorbers in numerical simulations of car models. The results indicate a strong impact of the shock absorber temperature on the vibration of sprung and unsprung masses. Therefore, the paper also describes additional tests of shock absorbers removed from vehicles with different mileages. The impact of low temperatures on the characteristics of shock absorbers depending on mileage was verified.

A method for assessing the technical condition of the shock absorber based on actual characteristics was developed by Gardulski and Warczek [17]. In the test method the damping power of a shock absorber was used as a quantitative parameter describing its technical condition. About 30 shock absorbers from passenger cars with known operating mileage were examined. Brand new shock absorbers with intentionally introduced defects were also tested. The results confirmed the effectiveness of the method for diagnostic purposes.

This paper presents a study the purpose of which was to determine the dumping characteristics for 114 shock absorbers. 98 of them were removed from 49 vehicles operated by different forwarders. 10 shock absorbers were removed from semi-trailers after durability tests and the reference points for testing were determined using 6 new shock absorbers.

Also the effect of the shock absorber operating temperature on its dynamic characteristics was tested. Based on the test results, the durability testing method for semi-trailers on the MTS Road Simulator was evaluated, which was already described in detail in earlier publications by the authors of this paper.

### TESTING METHODOLOGY

The assessment of the applied durability testing method for vehicles like semi-trailer was based on tests in which the damping force values of shock absorbers were compared depending on the speed at which the tested shock absorber was compressed and stretched. Tested were shock absorbers used in commercial semi-trailers. Information on semi-trailer mileage was obtained by downloading data using the Operation Data Recorder or ODR for that semi-trailer. Apart from user-sourced semi-trailers, also shock absorbers removed from vehicle tested on the road simulator were examined. In addition, new shock absorbers were tested to determine reference characteristics. The second stage of the research was to determine the effect of temperature on shock absorber characteristics. These characteristics were determined for temperatures between -20 °C and 110 °C. Refer to Figure 1 for a block diagram of the research methodology described above.

#### Object of the research

Shock absorbers considered in this were from vehicles with air suspension. In semi-trailers with air suspension the front axle lifts automatically when transporting small loads (of light weight). This feature helps reduce resistance to movement. It eliminates the rolling resistance of the wheels of this axle reducing fuel consumption and tire wear. The third axle on the trailer, on the other hand, is overloaded when pressed by forklift truck during loading from a ramp. For this

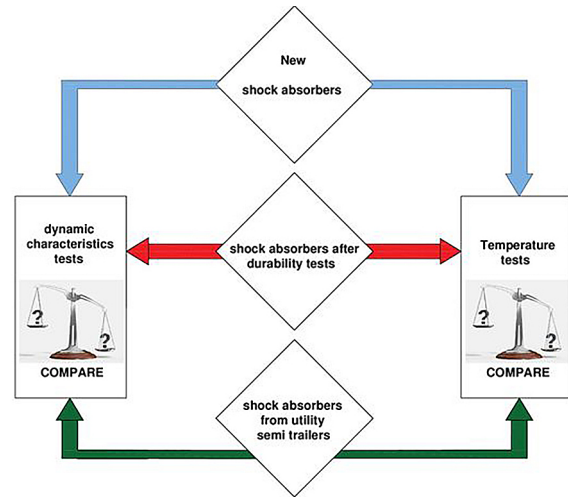


Figure 1. Block diagram of road shock absorber tests

reason, and also to reduce the cost of the project funded by the National Center for Research and Development in Poland, only shock absorbers from axis II were used for the research. All tested shock absorbers were of the same type and from the same manufacturer. M are shown in Refer to Figure 2 for model dynamic characteristics of a shock absorber of such type.

A total of 118 shock absorbers were tested. These included shock absorbers from 49 semi-trailers operated by different carriers, as well as shock absorbers from 5 semi-trailers after durability testing plus 6 new shock absorbers. Refer to Table 1 for a summary of all tested shock absorbers.

The table above suggests a very wide spread in the mileage of commercial semi-trailers. The lowest number of kilometres travelled, according to the documentation received by the user, was

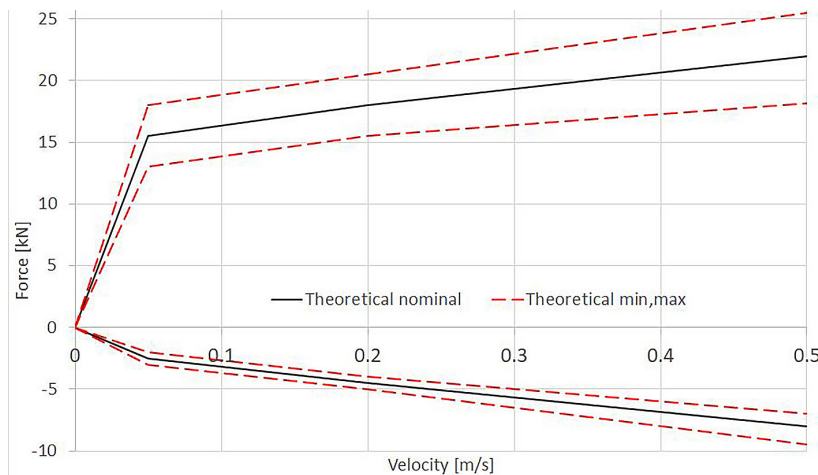


Figure 2. Data from the shock absorber manufacturer

**Table 1.** Summary of tested shock absorbers

Description of shock absorber	Name in the article	Distance [km]	Quantity [pcs.]
New	N	0	6
MTS tests	DT_MTS_1	Simulation 257 000	2
MTS tests	DT_MTS_2	Simulation 352 000	2
MTS tests	DT_MTS_3	Simulation 400 000	2
MTS tests	DT_MTS_4	Simulation 502 000	2
MTS tests	DT_MTS_5	Simulation 510 000	2
semi-trailer „1”	1	633 114	2
semi-trailer „2”	2	448 426	2
semi-trailer „3”	3	479 111	2
semi-trailer „4”	4	665 852	2
semi-trailer „5”	5	458 000	2
semi-trailer „6”	6	247 569	2
semi-trailer „7”	7	410 012	2
semi-trailer „8”	8	925 920	2
semi-trailer „9”	9	826 111	2
semi-trailer „10”	10	556 704	2
semi-trailer „11”	11	658 469	2
semi-trailer „12”	12	817 977	2
semi-trailer „13”	13	644 040	2
semi-trailer „14”	14	1 230 011	2
semi-trailer „15”	15	547 698	2
semi-trailer „16”	16	798 120	2
semi-trailer „17”	17	613 952	2
semi-trailer „18”	18	618 489	2
semi-trailer „19”	19	868 452	2
semi-trailer „20”	20	911 904	2
semi-trailer „21”	21	873 040	2
semi-trailer „22”	22	952 438	2
semi-trailer „23”	23	748 365	2
semi-trailer „24”	24	674 365	2
semi-trailer „25”	25	319 221	2
semi-trailer „26”	26	196 231	2
semi-trailer „27”	27	327 160	2
semi-trailer „28”	28	265 026	2
semi-trailer „29”	29	297 272	2
semi-trailer „30”	30	279 073	2
semi-trailer „31”	31	284 859	2
semi-trailer „32”	32	240 729	2
semi-trailer „33”	33	309 192	2
semi-trailer „34”	34	316 209	2
semi-trailer „35”	35	359 752	2
semi-trailer „36”	36	95440	2
semi-trailer „37”	37	415 019	2
semi-trailer „38”	38	73285	2
semi-trailer „39”	39	387 278	2
semi-trailer „40”	40	394 306	2
semi-trailer „41”	41	394 484	2

semi-trailer „42”	42	352 730	2
semi-trailer „43”	43	373 322	2
semi-trailer „44”	44	606 330	2
semi-trailer „45”	45	649 279	2
semi-trailer „46”	46	287 722	2
semi-trailer „47”	47	330 819	2
semi-trailer „48”	48	361 259	2
semi-trailer „49”	49	387 111	2

78,000 and the highest was 1,230,000. Also, their service life varies as the newest trailers were two years old and the oldest were 10 years old. In contrast, shock absorbers removed from vehicles after testing on the Road Simulator, the lowest simulated mileage was 257,000 km and the highest was 510,000 km. Importantly, the durability tests carried out by the semi-trailer manufacturer, due to the very high cost of testing, are simulated up to 500,000 km. Based on surveys of large truck fleet users, a semi-trailer accumulates an average of 90÷120,000 km per year. This corresponds to a period of about 4 years of vehicle operation where the manufacturer’s warranty for the semi-trailer under standard conditions is 2 years. Also, these surveys show that semi-trailers are 70% of time operated expressways and motorways, 20% on national roads and 10% on local roads with the worst quality. However, these figures are very general and largely depend on the forwarder’s size and the type of transportation services performed.

On the other hand, the mileage of semi-trailers that were used in durability testing, carried out as per the methodology described in [18], was converted to 500,000 km. It takes about 6 weeks of simulations to accumulate this mileage. Hence, the shock absorbers, following durability testing, from their first use, were only operated for about 7 weeks including the time needed to measure reference data from semi-trailer runs in real conditions.

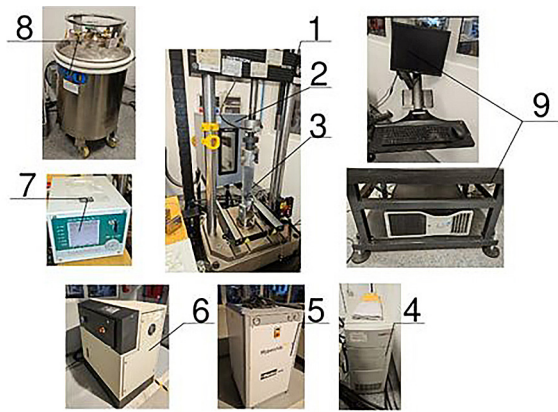
**Measurement test station**

Damping characteristic of shock absorbers were determined using the test station shown in Figure 3. The main component of the test station is testing machine INSTRON (1) which features an operating range of up to ±25 kN with an accuracy of 0.5%. The hydraulic system (6) is cooled by water using a chiller (5). Placed on the frame of the machine was an (2) INSTRON environmental

test chamber to support tests temperatures of -160 °C to +600 °C. Obtaining a temperature change in the chamber was possible with liquid nitrogen stored in a tank (8) that was integrated into the test station. The heaters in the chamber generate above zero temperatures. During testing, road shock absorbers (3) were mounted on the machine. Parameters such as force and displacement on the testing machine were measured with a PC (9) running on INSTRON software dedicated to the testing machine. The shock absorber’s temperature was measured with an ALMEMO recorder (7) with the thermocouple.

During the tests, the displacement of the shock absorber was forced by a sinusoidal signal. The displacement amplitude was 30 mm. The displacement was tested for 6 different frequencies varying from 0.1 Hz to 1.1 Hz. 10 cycles of sinusoidal movement of the shock absorber piston rod were performed for each frequency. This is how a change in the stretching/compression speed of the piston rod in shock absorbers was achieved. The range of speed achieved was 0.017 m/s to 0.205 m/s. As seen in Figure 2. manufacturers of shock absorbers determine their characteristics for speeds in the range of 0÷0.5 m/s. Achieving speeds in excess of 0.205 m/s was impossible due to the limitation of the induction head, which has an operating range of ±25 kN. For 0.205 m/s the forces recorded on the head reached 22 kN. Figure 4 shows an example of the time waveform of the excitation signal during stretching/compression of the tested shock absorbers. All shock absorbers were tested in their middle operating range. All measurements were taken at 50 Hz.

In addition to measuring the damping force as a function of the speed of the shock absorber piston rod for 20 selected shock absorbers, their characteristics were examined as a function of operating temperature. For this purpose each shock absorbers was placed in a thermal chamber where the temperature was set at -30 °C.



**Figure 3.** View of the measurement test station:  
 1) INSTRON 8872 testing machine,  
 2) INSTRON CP124804 environmental chamber,  
 3) tested shock absorber, 4) 8800 series testing machine controller, 5) ICEP010 industrial chiller,  
 6) 3520 series hydraulic power system,  
 7) ALMEMO 5690-M2 series recorder,  
 8) liquid nitrogen tank, 9) data acquisition PC

Shock absorbers were kept in this temperature for 2 hours. They were then removed from the chamber and placed on a testing machine to determine their characteristics. The temperature of the shock absorber during the test was measured with a K-type thermocouple, attached at the bottom of the piston rod, to its housing. The temperature was measured at a frequency of 1 Hz. After two hours of cooling, the temperature reading on the shock absorber housing was between  $-15 \div 20$  °C. This temperature was considered a baseline temperature at which determined were the characteristics of the shock absorbers with a cycle identical to that of the shock absorbers tested at room temperature. Upon completion of the measurement cycle the shock absorber was forced with the maximum speed value possible on the testing machine for a piston rod amplitude of 30 mm. The movement of the piston rod

was continued until the temperature of the shock absorber measured on the housing reached 110 °C. Then, at 110 °C, considered a baseline temperature, a measurement cycle was performed. This way the authors obtained dynamic characteristics of the shock absorbers for three temperatures, i.e. -20 °C, room temperature and 110 °C. An example of the time waveform of the excitation force during the test from negative temperatures to extremely positive temperatures is shown in Figure 5.

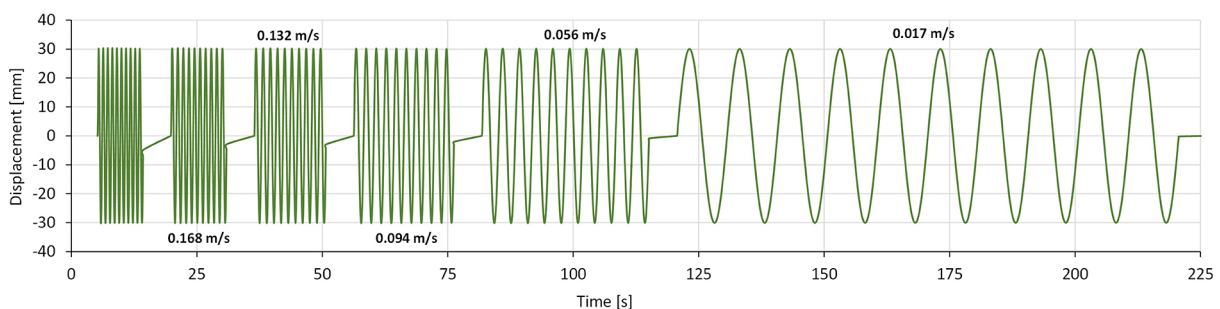
The original research assumptions were to determine characteristics for shock absorber cooling temperatures of -50 °C. However, as the shock absorber were cooled to this temperature for two hours, the measured temperature on its housing was -28 °C. After installing the shock absorber on the testing machine it was not possible to move the shock absorber piston rod, most likely due to the oil being too viscous. The maximum force on the induction head was exceeded and the test was interrupted for safety reasons. Hence, it was necessary to revise the original research plan.

### DURABILITY TESTING – METHODOLOGY

Some of the shock absorbers were from vehicles tested at MTS. The testing methodology used by manufacturers is confidential. Particularly in terms of preparing road profiles-i.e. the way actuators move during tests, generating structural behaviour that corresponds to their daily operation.

Therefore, it was necessary to develop an original method [18] for carrying out durability tests for this type of vehicles like trailer or semi-trailer on these stands [19]. Refer to Figure 6 for a flowchart of the procedure for durability testing.

At the beginning of the test vehicle must be prepare. It involves placing on the vehicle, mainly on the frame (as a supporting structure) depending



**Figure 4.** Shock absorber excitation signal during the test

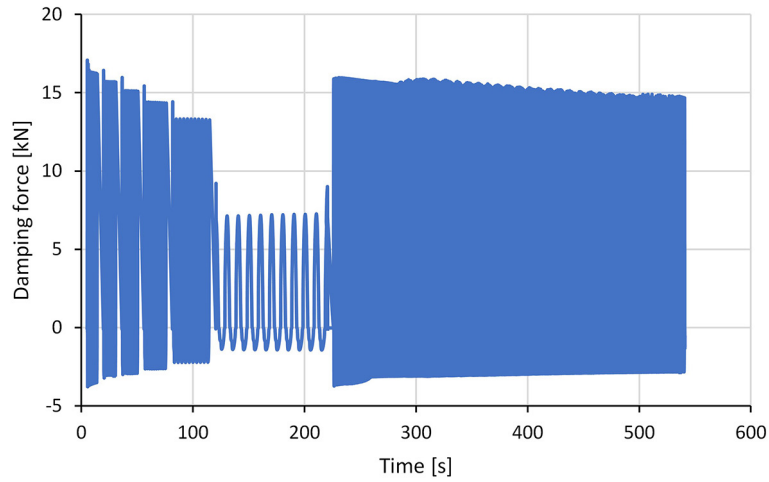


Figure 5. Time waveform of shock absorber excitation during the cycle at -30 °C and its heating to 110 °C

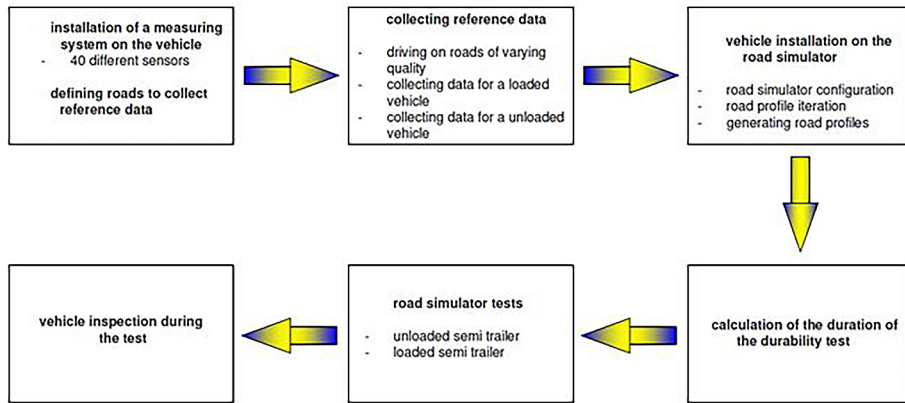


Figure 6. Durability testing methodology

on the type of semi-trailer, 30–40 different sensors such as displacement sensors, pressure sensors, acceleration sensors or Wheatstone bridge circuit strain gauges. Then the tested vehicle with the installation moves on different types of roads, which are divided by quality into local roads, national roads and expressways (highways). The total distance travelled is about 500 km. The method of selecting routes is described by Stembalski [20]. The semi-trailer covers this route empty and fully loaded, which, depending on the type of semi-trailer (its tare weight), ranges from 24–27 tonnes. The next stage of testing is installing the trailer on the Road Simulator. It involves connecting the measurement system installed on the vehicle to the test station controller via an EtherCat card. A further step involves generating road profiles. These profiles are the input signals to the test station, used by the hydraulic actuators to generate excitations in a way that reflects the movements of the semi-trailer that coincide with those of the

reference runs. Road profiles are generated based on the data from runs on local roads. The reason behind selecting local roads is that these roads, being of the worst quality, generate the highest amplitudes of the signals measured with the measurement sensors. Selected from this data pool are only the data showing the largest amplitudes. Following appropriate signal processing, the length of road profiles is predominantly between 40–250 seconds. Each semi-trailer tested this way is subject to excitation with several road profiles, the number of which varies from 3–8. Upon extracting the data with the highest amplitude, or energy value, the next step of the process involved creating a system model. The model is based on determining the relationship between the input signals which are those responsible for controlling the hydraulic actuators, called DRV (Drive), and respond- the signals from sensors called RSP. The system model is the FRF (frequency response function) [21] shown in Figure 7.

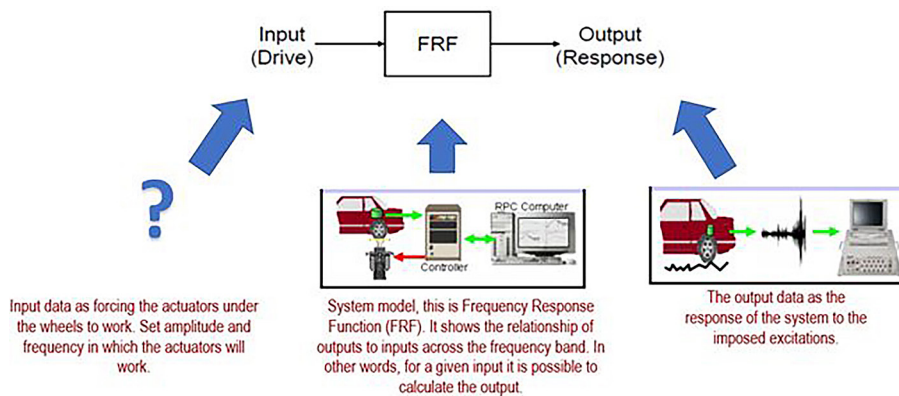


Figure 7. System model creation diagram

One of the final stages of the durability testing methodology is learning the bench, or iteration. This is done by checking the level of reproduction of the signal acquired from reference runs. Using the iteration method, the forces on the actuators are selected to best reproduce the signals collected during the reference runs.

The degree of data convergence of the values received to those collected from the road can be determined, for example, by the RMS error value. An example of the error for several iterative steps is shown in Figure 8. As shown, the error value for the displacement sensors does not exceed 12%. The sensors are located near the wheel of the semi-trailer, that is, they are near the excitation point (above the hydraulic actuator). Therefore the RMS error is small.

## TEST RESULTS

### Damping characteristic

The first stage of the research was to determine the damping characteristics of all tested shock absorbers. These characteristics define the relationship between the displacement of the piston rod and the force generated by the shock absorber when it is stretched/compressed. Refer to Figure 9 for some sample characteristics for a new shock absorber on a commercial semi-trailer and a shock absorber after durability testing. These characteristics were obtained for excitations at a frequency of 1.1 Hz, which corresponds to a piston rod displacement speed of 0.205 [m/s]. As shown in the Figure 9, the shapes of the characteristics are very similar. The largest obtained values refer to a new shock absorber. Disturbances in the shape of the characteristics

marked with a circle in the Figure 9, according to the authors, are due to the work of the test station. Namely, they were caused by a slight play between mounting adapters of the shock absorbers and the components of the measuring machine. Therefore, when the direction of work of shock absorber was changed, its characteristics were disturbed.

The next step of the research determined the dynamic characteristics that describe the relationship between force and speed of shock absorber. These characteristics were related to the catalogue characteristics shown in Figure 2. Figure 10

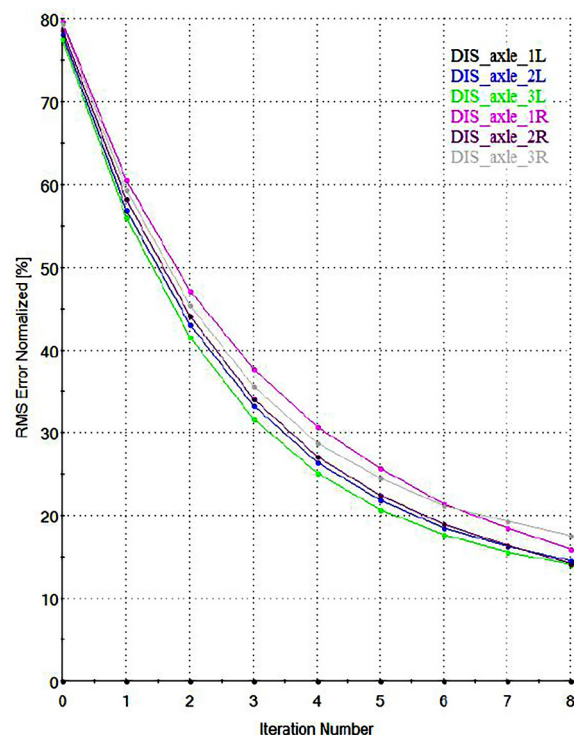
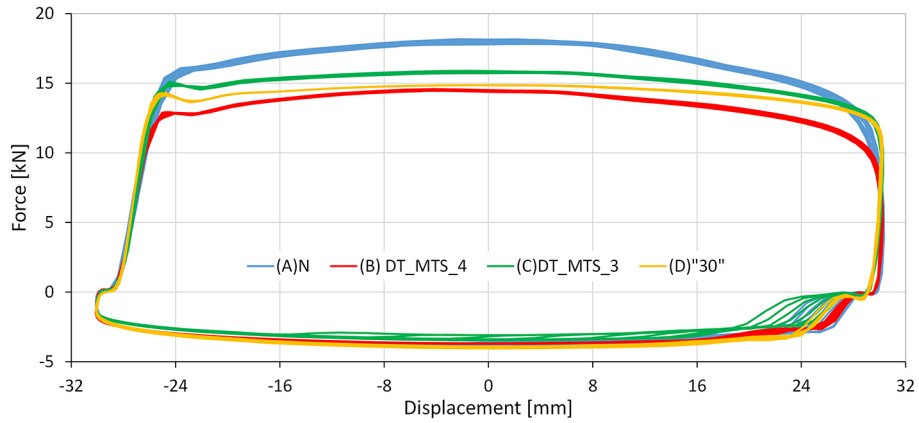


Figure 8. Normalized RMS error for the displacement sensors



**Figure 9.** Sample damping characteristic of four shock absorbers – two after MTS test, one new shock absorber, one sample shock absorber removed from a commercial semi-trailer

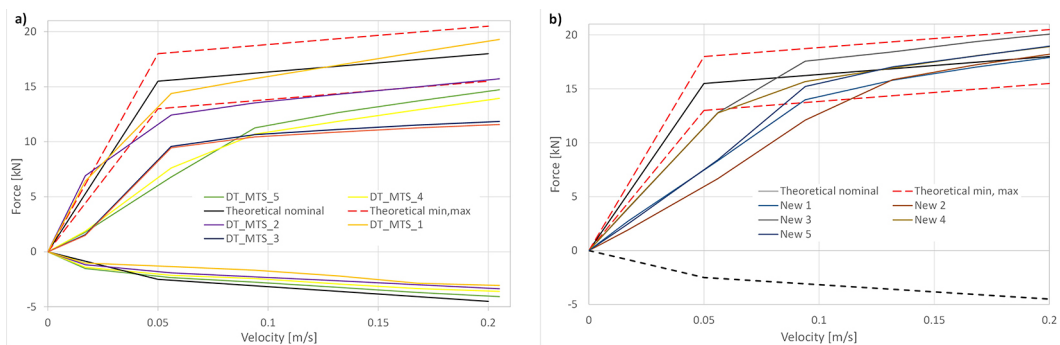
shows characteristic after MTS, while Figure 11 shows characteristics for selected shock absorbers from commercial trailers.

Damping characteristics in the compression phase do not differ regardless of the simulated course on the MTS station. As for the stretching phase, only the shape and values for relevant speeds of the characteristics of the shock absorbers after MTS designated DT\_MTS\_1 with a simulated mileage of 257 000 kilometers match the theoretical characteristics for new shock absorbers. Other semi-trailers from MTS, their characteristics deviate from the theoretical characteristics.

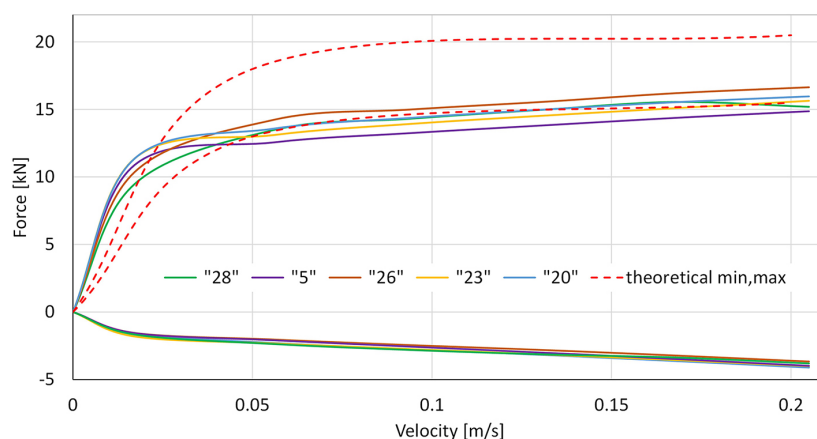
There was also a difference in damping force depending on the side on which the shock absorber was mounted. Shock absorbers from the right side featured a lower damping force value than those from the left side. The difference was 2–5%. The reason for this difference was that the reference data were collected from roads in Poland, an RHT country. The lower value of the damping force on the right side is due to the fact that, most of the time, the right side of the roadway is

of poorer quality than the center of the roadway (unevenness, potholes, cavities in asphalt).

Of the 49 commercial semi-trailers, the graph above shows 5 examples of shock absorber characteristics removed from semi-trailers. The mileages of these semi-trailers ranged from 196 000 km to 911 000 km. Analysing the results, it is to be noted that for the stretching phase of the shock absorber, all the values of the measured forces for velocities above 0.05 [m/s] are within the lower tolerances provided by the manufacturer. At lower speeds, the force values measured on the shock absorbers during their operation are above the upper limits permitted by the manufacturer. This is also confirmed by authors' observations, who found during their tests that shock absorbers removed from commercial semi-trailers require, for very low speeds (in the first phase of movement) significantly higher forces to move the piston rod than new shock absorbers or shock absorbers after MTS. According to the authors, this is caused the internal friction of the shock absorber between the piston rod, seals



**Figure 10.** Dependence of force and speed: a) shock absorbers from five vehicles after MTS tests, b) new shock absorbers



**Figure 11.** Characteristics of shock absorbers removed from 5 selected commercial semi-trailers

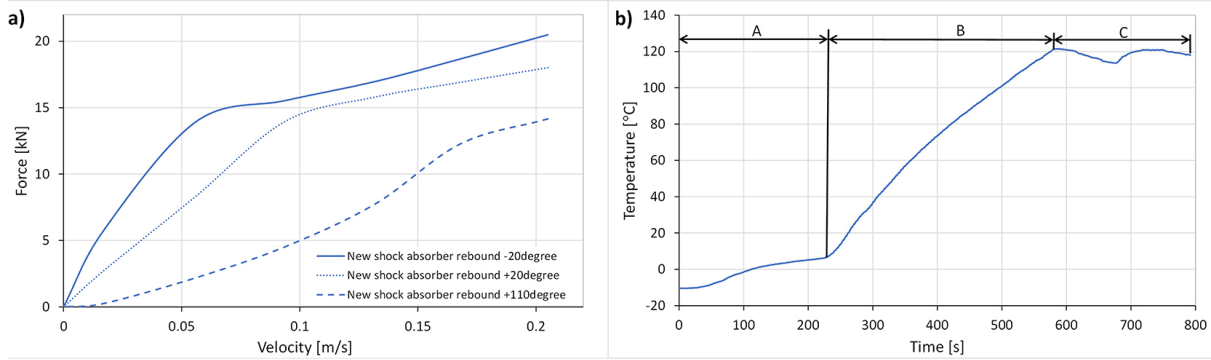
and the piston. In addition, many of the tested shock absorbers showed traces of corrosion on the housing, but also on the shock absorber piston, due to friction. In addition to corrosion, it is important to consider aspects associated with the aging of components inside the shock absorber, such as the seals, which are most often made of rubber, a material particularly susceptible to aging. The shock absorbers removed from commercial semi-trailers were operated over a period of 3–10 years in very different weather conditions. In contrast, shock absorbers removed after durability testing are only a few to several months old. Aside from reference runs during road data collection, these shock absorbers were never exposed to factors such as sub-zero temperatures, humidity or road salt.

### Temperature measurement

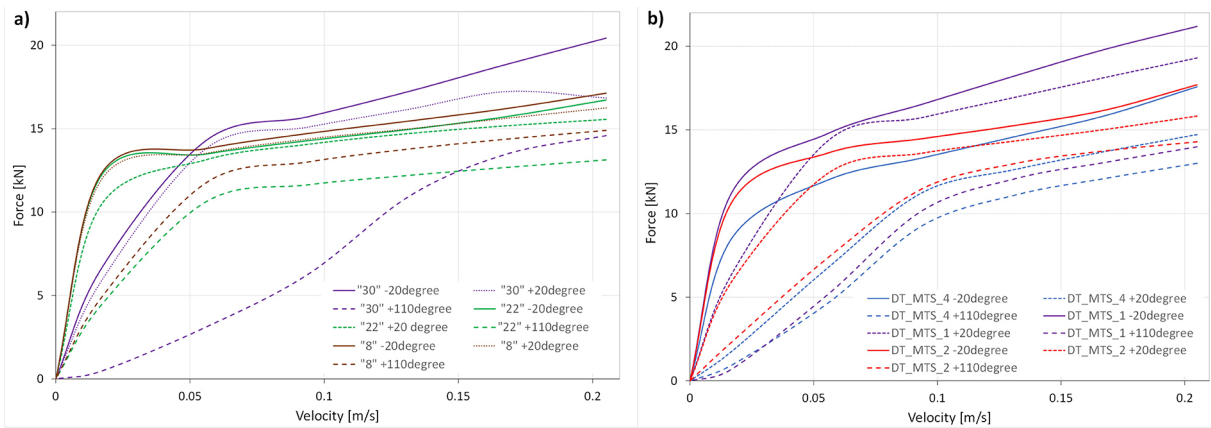
The second field of tests of the shock absorbers to was to verify the effect of temperature on their dynamic characteristics. The exact method of these tests is described in Section 2.2. 20 shock absorbers were selected for tests. They were cooled in a thermal chamber in a constant temperature of  $-30\text{ }^{\circ}\text{C}$ . After two hours the temperature of cooled shock absorbers ranged from  $-10\text{ }^{\circ}\text{C}$  to  $-18\text{ }^{\circ}\text{C}$ . Importantly, these differences may have been due to the fact that the shock absorber, when removed from the thermal chamber, was placed on the machine to then have a K-type thermocouple was attached to its housing, and the thermocouple needed a while to read the temperature of the shock absorber (the entire procedure took about 4 minutes). For this baseline temperature, the research tested the shock

absorber damping force variations depending on the speed of its piston rod. Then, after studying the characteristics, the shock absorber was excited with a 30 mm amplitude at the maximum speed for the testing machine. During this excitation the shock absorber reached a temperature of  $110\text{ }^{\circ}\text{C}$  in a short time (in about 170 seconds). The damping characteristics of the tested shock absorbers were then redetermined for this temperature considered as the baseline temperature. This way dynamic characteristics were determined for the selected shock absorbers for three different baseline temperatures. Refer for Figure 12, 13 for representative force-velocity graphs for selected shock absorbers.

New shock absorbers showed a change in the shape of the dynamic characteristics of the shock absorber (Figure 12a)). For the baseline test temperature of  $-20\text{ }^{\circ}\text{C}$ , an increase of 13% in force in the stretching phase was recorded for a shock absorber working maximum speed compared to the same speed at  $+20\text{ }^{\circ}\text{C}$  and 44% for  $+110\text{ }^{\circ}\text{C}$ . On the other hand, for the tested speed, i.e. 0.017 m/s, the increase in this force was 111%. Also to be noted is the significant decrease in forces for the baseline test temperature of  $110\text{ }^{\circ}\text{C}$ . In contrast, for the lowest speeds the value of the damping force at this temperature was close to 0 N. Referring to Figure 12b), it is to be noted that the shock absorber in the first cycle of determining the dynamic characteristics heated up from  $-10$  to  $+8$  in 235 seconds (area A) followed by the shock absorber cooling phase (area B), of 299 seconds. Next a cycle of shock absorber excitations was carried out for temperature of  $+110\text{ }^{\circ}\text{C}$  (area C). During this time the shock absorber increased its temperature by  $11\text{ }^{\circ}\text{C}$ .



**Figure 12.** Influence of temperature on the dynamic characteristic of shock absorber: a) dependence of the damping force on the speed of operation for a new shock absorber for three different baseline temperatures, stretching phase, b) temperature over time chart divided into areas: A- determination of characteristics for sub-zero temperature, B- shock absorber heating, C- determination of characteristics for +110 °C



**Figure 13.** Dynamic characteristics for different shock absorber temperatures: a) removed from commercial semi-trailers, b) removed from vehicle after MTS tests

In all considered cases the characteristics are similar. To better illustrate the results, Table 2 shows the percentage changed in the damping force of the shock absorber, for a speed of 0.205 m/s in the stretching phase for +20 °C and 110 °C compared to -20 °C.

Shock absorber manufacturers specify the permissible shock absorber operating temperature to be 120 °C. If the actual temperature is higher, shock absorber cooling systems are recommended. Such temperatures are possible when performing very dynamic tests, i.e. on test tracks [5] or road simulators [19].

### Relationship between damping force and semi-trailer mileage

The influence of the vehicle mileage on the change in the shock absorber damping force was

determined on the basis of its characteristics for the maximum tested speed (Figure 14). Data on the semi-trailer mileage were obtained from documentation (ODR) provided by users. Whereas data on the mileage of semi-trailers after durability tests were worked out from simulation calculations. The initial damping force shown in the graph represents the force generated by new shock absorbers (an average force for the 6 absorbers tested) at 0.205 m/s.

When analysing the graph below, it is to be noted that the shock absorbers from users featured a damping force ranging from 93–76% of the nominal force. On the other hand, the value of the measured force after durability tests was 88–75%.

The analysis of the distribution of the graph below reveals that for semi-trailer up to 600,000 km the decrease in the measured damping force is clear. However, for semi-trailers

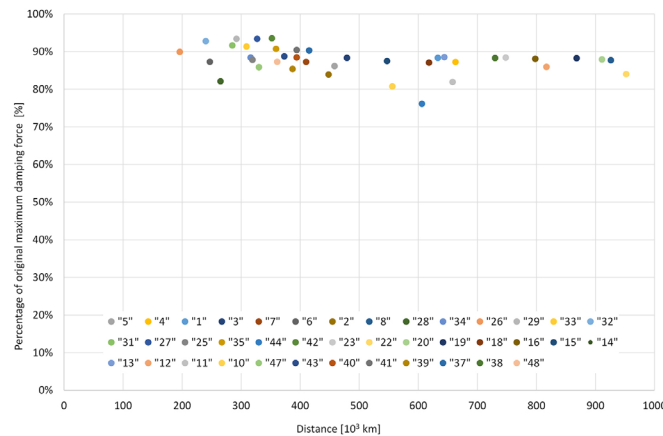
**Table 2.** Summary of the results of the damping force drop measurement of the shock absorber for a speed of 0.205 m/s at -20 °C compared to +20 °C and 110 °C

Shock absorber	Damping force drop [%]	
	Temperature 20 °C	Temperature 110 °C
"15"	8	16
"22"	7	16
"30"	16	40
"38"	14	24
"8"	5	15
"43"	17	29
DT_MTS_1	10	37
DT_MTS_2	12	24
DT_MTS_3	10	18
DT_MTS_4	19	35
DT_MTS_5	7	14

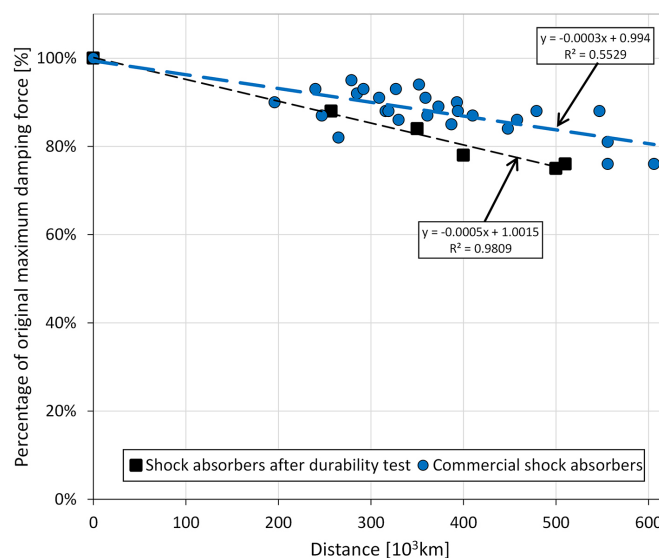
with higher mileage, the graph flattens out. It can be observed that the force values for these semi-trailers are comparable or even exceed the force values for semi-trailers with mileage of 200,000÷300,000 kilometres. The reason for this phenomenon may be increased internal friction in the shock absorber between its piston rod and seal following years of exposure to weather conditions.

For this reason semi-trailers older than 5 years with more than  $0.6 \cdot 10^6$  km travelled were excluded in further analysis. Points are marked with an ellipse in Figure 13 met the above conditions.

The next step of the analysis was to determine a trend line for the measured points of force values for shock absorbers from commercial vehicles and after MTS testing. Refer to Figure 15 for results of the analysis along with specific trend lines.



**Figure 14.** Relationship between semi-trailer mileage and maximum damping force determined for a speed of 0.205 m/s for shock absorbers removed from commercial vehicles, left side



**Figure 15.** Decrease in damping force depending on semi-trailer mileage

## CONCLUSIONS

The paper presents the dynamic characteristics of shock absorbers that were removed from semi-trailers used by different carriers (49 semi-trailers) and semi-trailers after durability tests (5 vehicles) conducted on Road Simulator. In addition, new shock absorbers were examined as benchmark. The damping characteristics of shock absorbers cooled at  $-30\text{ }^{\circ}\text{C}$  and heated to  $+110\text{ }^{\circ}\text{C}$  were also determined. From the presented investigation it can be concluded that:

- For a sub-zero temperature, 2.5 more damping force was observed than for a room temperature of  $+20\text{ }^{\circ}\text{C}$ . At  $-20\text{ }^{\circ}\text{C}$ , the force saw on average a 15% increase in its value for shock absorbers from commercial semi-trailers and 12% for shock absorbers after durability testing.
- Shock absorbers from commercial semi-trailers feature better damping efficiency. The user-sourced shock absorbers were characterized by a damping force ranging from 93÷76% of the nominal force. On the other hand, the value of the measured force for shock absorbers after durability tests was 88÷75%. Comparing the damping forces for semi-trailers with 500,000 km travelled, the difference in force between commercial shock absorbers and shock absorbers after durability testing is 10%. In contrast, for shock absorbers which travelled 400,000 km, the difference in forces is 9%.
- Better damping performance may also be due to the method of loading. During durability testing semi-trailers are loaded for 80% time of the simulation duration (i.e. 400,000 km) at 100% while the other 20% of the test duration is dedicated to durability of an unloaded vehicle. As for commercial semi-trailers, the loading method is up to the user and cannot be clearly defined. When evaluating the validation methodology, it is to be noted that the error in calculating simulated kilometres against actual runs is about 10%. The durability testing method developed by the authors give satisfactory results although subject to the above discrepancy. In addition, in all studied cases the shock absorbers removed from the left side of the semi-trailer featured higher damping forces than those on the right side.
- According to the authors, it would be very reasonable to check the characteristics of shock absorbers for higher speeds. Suspected that for maximum speeds, greater

differences would be observed depending on the mileage of the shock absorber.

## Acknowledgements

This research was funded in whole or in part by National Science Centre, Poland registered under number: 2024/08/X/ST8/00206, decision number: DEC-2024/08/X/ST8/00206 under the title “Validating the durability testing method for large-sized vehicles based on dynamic characteristics of shock absorbers”.

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