Comparison of Same Aftermarket Monotube Shock Absorbers Manufactured by Different Brands

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Abstract. Suspension keeps the wheels of the vehicle in contact with the road surface, dampens various vibrations that arise due to road surface irregularities and ensures adequate control of the vehicle. The performance of the suspension is directly related to shock absorbers, which are an integral part of the suspension. As there are many options of various aftermarket shock absorbers, quality and price are the main factors that define the driver's choice. However, the main question is how different can the same aftermarket monotube shock absorbers be, which were designed for a specific vehicle, but were manufactured by different brands? To answer this question, further described research presents the experimental analysis and comparison of damping characteristics of the same aftermarket monotube shock absorbers, which were manufactured by different brands. During the analysis, in total, 8 completely new shock absorbers manufactured by 4 different brands were compared, and the effects of the initial shock absorber temperature were also taken into account.

Keywords: Vehicle · Monotube · Aftermarket · Shock absorber · Damping force · Force vs. velocity · Graph · Knee-point · Comparison

1 Introduction and Literature Review

Active and passive safety systems are crucial to the safety of any vehicle; however, other factors, such as the general technical condition of vehicle, the quality of the used aftermarket parts or the performance of other vehicle systems also play a significant role. In terms of safety and performance, vehicle suspension is not an exception. Since the change of the shock absorber damping characteristics greatly affects ride and handling of the vehicle [1], it can be stated that the shock absorber damping characteristics is the main indicator that defines suspension performance. A shock absorber, which does not generate enough damping force or a shock absorber that is too stiff and generates too much damping force, is going to negatively affect the safety of any vehicle. According to [2], worn shock absorbers can reduce braking efficiency or they can directly affect

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loss of handling and control of the vehicle. Therefore, the impacts of the shock absorber damping characteristics on the ride and handling of the vehicle is a relevant topic, frequently discussed by the researchers. This section further provides a concise review of how the relation between the performance of shock absorbers and the safety of the vehicle is analysed in various research works.

A number of scholars are analysing the relation between the performance of the shock absorber and the safety of the vehicle and, respectively, the relation between the performance of the shock absorber and its damping characteristics. The influence of the wear of the shock absorber on vehicle braking performance is analysed in [3]. On the basis of the performed analysis, the authors concluded that the shock absorber status has no influence on the vehicle's braking performance when the vehicle is moving on a smooth road profile. However, in the case of a rough road profile, the state of the shock absorber has a significant influence on the braking distance [3]. The influence of worn shock absorbers on the braking performance on a rough road was also analysed in [4]. In this reference it was shown that when the ABS is activated, the brake pressure fluctuations are affected by the changes in shock absorber damping capacity. After performing similar experimental tests with worn and new shock absorbers, it was determined that the braking distance obtained with the worn shock absorbers is approximately 21% longer than with the new shock absorbers [4]. Regarding the relation between the ABS braking and shock absorbers, in [5] the effects of variable shock absorber damping settings induced brake pressure oscillations on axle and wheel oscillations during the ABS braking are discussed. In their work, the authors showed that the brake pressure is distinctly changed by variable shock absorber damping settings and that it is possible to damp the axle and wheel oscillations by setting wheel load effect at high and low piston velocities of different shock absorber settings. The authors in [6] have shown that the performance of shock absorbers also adversely affects the handling and stability of the vehicle. Worn shock absorbers increase roll and pitch motions, leading to a less stable vehicle response. The possibility to increase vehicle stability by regulating the damping force characteristic, while vehicle is moving on a sharp road curve with deteriorated pavement edge, was analysed in [7]. It was determined by the authors that suspension with higher damping force characteristic showed better vehicle stability results. While further considering steerability and stability problems, an analysis of the influence of the worn shock absorbers on steerability and stability of the vehicle motion is presented in [8]. The presented analysis of the worn shock absorbers showed that: 1. The damage of the shock absorber increases the vehicle understeering phenomena; 2. The inefficiency of the worn shock absorber causes the wheels to disconnect from the road surface, thereby worsening the steerability of the vehicle. The author of [8] in one of his more recent works [9] once again supported the observation that the reduced damping of the shock absorber generally results in the understeering phenomena of the vehicle during various manoeuvres. What is more, similarly to the research works [3] and [4], the author of [8] also noted that the damage of the shock absorber influences the increase in the braking distance.

In relation to the fact that the damping characteristics of the shock absorber directly affect the safety and performance of the vehicle, scholars are paying quite a lot of attention to the diagnostics and failure analysis of the shock absorbers. In [10] the authors analysed the failure characteristics of a twintube shock absorber and the proposed virtual prototyping technology, designed to investigate dynamic properties of shock absorbers. An application of the vibration test in order to evaluate the technical condition of shock absorbers built into the vehicle is described in [11]. In [12] a sound metric approach based on the Wigner–Ville distribution was developed to investigate the shock absorber rattling noises. It is also important to mention that, in the research works, the changes in shock absorber damping characteristics are being analysed from many different points of view. For example, in [13] a comparative analysis of monotube shock absorbers with different valve systems is performed. Investigation of the relation between the cavitation process in the monotube shock absorber and its damping characteristics is presented in [14]. In [15] a non-linear analysis of shock absorbers with amplitude-dependent damping characteristics is described. Based on the described research works it is clear that the importance of the shock absorber and the damping force generated by the shock absorber cannot be ignored when considering the safety of the vehicle.

This research work proposes to look at the damping characteristics of shock absorbers from a slightly different point of view. Currently there are more than 25 major shock absorber manufacturers [16]. According to the Global Industrial Hydraulic Shock Absorber Market Report [17], the global industrial hydraulic shock absorber market size is projected to reach USD 304.9 million in 2022 and is forecast to a readjusted size of USD 357.7 million by 2028. The passenger vehicle holds the largest share in the shock absorber market share, accounted for 74.6% in 2018, with a market value of USD 11,873.4 million [16]. Thus, while seeking to replace faulty shock absorbers, the consumer – the driver of the vehicle has a significant number of different options. The main question that arises is: if the driver should expect that the same shock absorber, designed for a specific vehicle, but manufactured by a different brand, can actually have different damping characteristics, which would differently affect the performance and safety of the vehicle? Due to this reason, the main aim of this work is to answer this question by comparing the damping characteristics of the same aftermarket monotube shock absorbers, designed for specific vehicles, but manufactured by different brands.

2 Experimental Research

In order to compare the damping characteristics of the same aftermarket monotube shock absorbers manufactured by different brands, an experimental research was performed. While seeking to obtain more reliable and detailed results, the experimental research was performed by testing entirely new shock absorbers, designed for two different specific light vehicles (the same class and year of manufacture). The exact brands and models of the light vehicles, for which the tested shock absorbers were designed, were selected randomly. In total, 8 shock absorbers, manufactured by 4 different brands, were tested, i.e., 4 shock absorbers manufactured by 4 different brands for vehicle No. 1 and 4 shock absorbers manufactured by the matching 4 different brands for vehicle No. 2 were experimentally tested. The tested shock absorbers were designed for the rear suspension of both vehicles. The rear suspension was selected due to the more simple mounting joints design. The brands of the tested shock absorbers were selected based on the price of the single shock absorber, from lowest to highest. Respectively, further in the work, "Brand 1" represents the shock absorber brand with the lowest price and "Brand 4" represents the shock absorber brand with the highest price. It is important to note that when considering the price of the tested shock absorbers, in the cases of both vehicles, the actual brands of the tested shock absorber lined up in a similar order. All tested shock absorbers are shown in Fig. 1.

Fig. 1. Monotube shock absorbers, which were tested during the experimental research.

The experimental research was performed while using the *LABA*[7] *Featherlight Shock Dyno* shock absorber test stand (Fig. 2). All shock absorbers were tested at a maximum compression/rebound velocity of 600 mm/s, i.e. the amplitude of the compression/rebound velocity was equal to 600 mm/s. The amplitude of compression/rebound strokes was 50 mm. When considering research work [18] and the importance of the shock absorber temperature, two-stage testing was used: 1. Testing with an initial shock absorber temperature of 25 °C; 2. Testing with an initial shock absorber temperature of 50 °C. Such values of the initial shock absorber temperature were selected as the "normal" and "relatively high" values, while taking into account that shock absorbers must be able to properly perform up to 100 °C temperature [18]. The initial temperatures of the shock absorbers were measured by using an IR temperature sensor, mounted on the test stand. A remark must be made that the specific initial temperatures (25 °C and 50 °C) of the shock absorbers were achieved by primarily performing compression/rebound strokes and warming up the shock absorbers in the test stand. The experimental testing of each shock absorber started only when the specific initial temperature was achieved accurately. During the experimental tests, the initial temperature was not maintained, as the shock absorbers continued to slightly warm up, while their damping characteristics were measured.

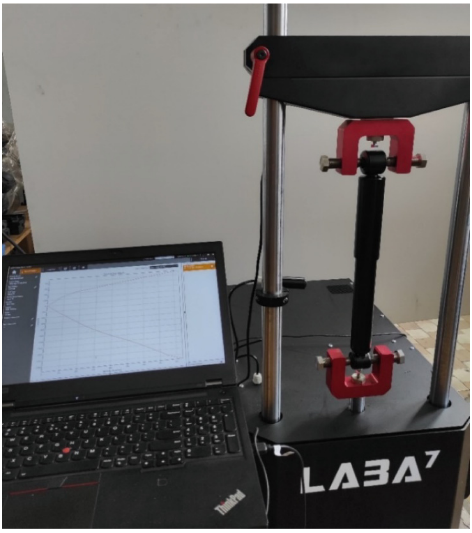

Fig. 2. The *LABA[7] Featherlight Shock Dyno* shock absorber test stand used for the experimental research and the monotube shock absorber mounted in the test stand.

3 Analysis of the Results and Remarks

The results of the experimental research – damping force vs. average velocity graphs are provided in the Fig. 3 and Fig. 4 (vehicle No. 1 and vehicle No. 2 respectively). The generalised maximum damping force values and knee-point characteristics of each of the experimentally tested shock absorbers are provided in Tables 1, 2 and 3.

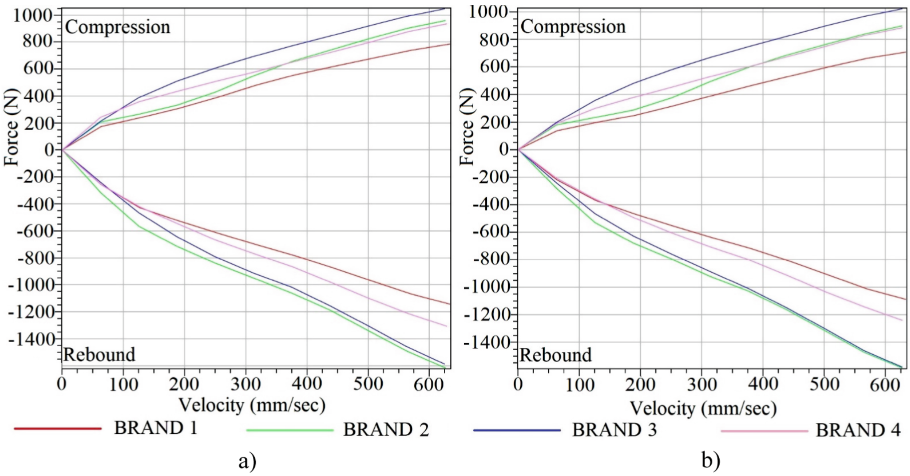

Fig. 3. Experimental results of the tested shock absorbers (vehicle No. 1): a) Initial shock absorber temperature of 25 °C; b) Initial shock absorber temperature of 50 °C.

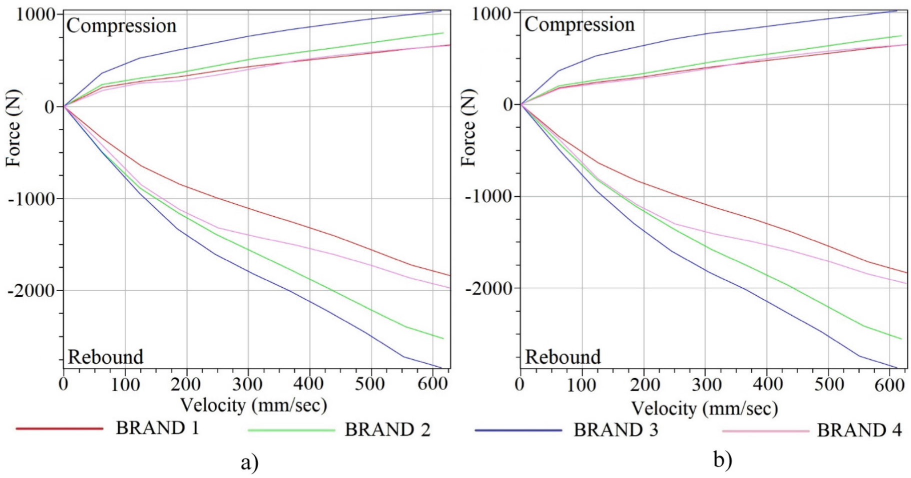

Fig. 4. Experimental results of the tested shock absorbers (vehicle No. 2): a) Initial shock absorber temperature of 25 °C; b) Initial shock absorber temperature of 50 °C.

Table 1. Maximum damping forces generated by the tested shock absorbers.

Vehicle	Vehicle no. 1		Vehicle no. 2	
Shock absorber brand	25 °C	50 °C	25 °C	50 °C
	Maximum damping force, N (Compression/Rebound)	Maximum damping force, N (Compression/Rebound)	Maximum damping force, N (Compression/Rebound)	Maximum damping force, N (Compression/Rebound)
Brand 1	785/−1,144	709/−1,088	667/−1,837	650/−1,832
Brand 2	959/−1,617	898/−1,580	799/−2,523	747/−2,502
Brand 3	1,046/−1,589	1,023/−1,587	1,038/−2,840	1,018/−2,837
Brand 4	935/−1,308	885/−1,240	661/−1,972	649/−1,949

Firstly, while comparing the damping force vs. average velocity graphs and the values of the generated maximum damping forces, a general tendency can be formulated; although in some of the cases there are similarities in the damping graphs, it can be seen that the shapes and slopes of the graphs, i.e., the changes of the damping force and maximum damping force values, which are generated by the same aftermarket monotube shock absorbers manufactured by different brands, differ quite significantly. In the case of vehicle No. 1, at the initial shock absorber temperature of 25 °C, during the compression of the shock absorbers, the largest difference observed between the damping forces was 28.5% (brands 1 and 3), the lowest difference observed between the damping forces was 2.5% (brands 2 and 4). During the rebound of the shock absorbers, the largest difference between the damping forces was 34.3% (brands 1 and 2), the lowest difference between the damping forces was 1.7% (brands 2 and 3). Respectively, in the case of vehicle No. 2, at the initial shock absorber temperature of 25 °C, during the compression of the shock absorbers, the largest difference observed between the damping forces was even greater and reached 44.4% (brands 1 and 3), the lowest difference observed between the damping forces was 0.9% (brands 1 and 4). Similarly, during the rebound of the shock absorbers, the largest difference between the damping forces was also greater and reached 42.9%, the lowest difference observed between the damping forces was 7.1% (brands 1 and 4). The tendency can be seen that the differences between the maximum damping force values are higher during the rebound of the shock absorber and lower during the compression. What is even more important from the comparison point of view, as can be seen from the provided figures (Fig. 2 and Fig. 3), the increase of the initial shock absorber temperature up to 50 °C did not have any significant influence on the shape and slope of the damping force vs. average velocity graphs. Due to this reason the difference between the maximum damping force values, generated by the same aftermarket monotube shock absorbers manufactured by different brands, remained approximately the same as in the case of the initial shock absorber temperature of 25 °C.

Secondly, while further taking into consideration the effect of the initial shock absorber temperature increase up to 50 °C, it was observed that, in all of the tested different brand shock absorbers, the increase of the initial temperature affected the decrease of the generated maximum damping force. This remark can be easily explained by the fact that, as the temperature of the shock absorber increases, the viscosity of the shock absorber oil decreases, leading to a decrease of the generated maximum damping force [18, 19]. It should be noted that the decrease of the maximum damping force in the shock absorbers of different brands was approximately similar, but not entirely equal. After the increase of the initial shock absorber temperature up to 50 °C, the average decrease in the maximum damping force in each of the tested different brand shock absorbers was (based on the data provided in Table 1): in brand 1 for the compression 6.4% and for the rebound 2.6%; in brand 2 for the compression 6.6% and for the rebound 1.5%; in brand 3 for the compression 2.1% and for the rebound 0.1%; in brand 4 for the compression 3.7% and for the rebound 3.3%. Based on these results it can be stated that, although the changes in the maximum damping force of different brand shock absorbers are not entirely equal, these changes and differences in the maximum damping force, which emerged as a result of the temperature change, were not significant. Thus, a general remark can be made that all of the tested different brand shock absorbers react similarly to the change of the initial temperature.

Thirdly, while comparing the performance of the shock absorbers, it is important to consider the knee-point characteristics (location of the knee-point), i.e., the transition point from the low-velocity compression/rebound strokes range (piston valve system is closed) to the high-velocity compression/rebound strokes range (piston valve system is opened to a specific level). The location of the knee-point must be considered as an important characteristic because: 1. It shows at which point of the damping curve the piston valve system of the shock absorber actually starts to open; 2. It allows to make assumptions about the differences between the performance of the valve systems, used in different shock absorbers. The knee-point characteristics recorded during the experimental tests are provided in Table 2 and Table 3.

It is very interesting to note that actually, in most of the tested different brand shock absorbers, the knee-point appeared approximately at the same compression/rebound velocities: for the compression between the 60–64 mm/s and for the rebound between

Table 2. Knee-point characteristics of the tested shock absorbers (vehicle No. 1).

Shock absorber	Initial temperature of 25 °C		Initial temperature of 50 °C	
	Damping force (Compression) at velocity, N at mm/sec	Damping force (Rebound) and velocity, N and mm/sec	Damping force (Compression) and velocity, N and mm/sec	Damping force (Rebound) and velocity, N and mm/sec
Brand 1	173 N at 63.8 mm/s	−429 N at 126.7 mm/s	136 N at 63.3 mm/s	−219 N at 63.3 mm/s
Brand 2	206 N at 62.5 mm/s	−566 N at 125.3 mm/s	179 N at 62.7 mm/s	−531 N at 125.4 mm/s
Brand 3	*Not visible clearly*	−465 N at 125.1 mm/s	*Not visible clearly*	−465 N at 125.4 mm/s
Brand 4	242 N at 62.8 mm/s	−420N at 125.7 mm/s	189 N at 62.7 mm/s	−207 N at 62.7 mm/s

Table 3. Knee-point characteristics of the tested shock absorbers (vehicle No. 2).

Shock absorber	Initial temperature of 25 °C		Initial temperature of 50 °C	
	Damping force (Compression) and velocity, N and mm/sec	Damping force (Rebound) and velocity, N and mm/sec	Damping force (Compression) and velocity, N and mm/sec	Damping force (Rebound) and velocity, N and mm/sec
Brand 1	206 N at 62.7 mm/s	−646 N at 125.5 mm/s	181 N at 62.8 mm/s	−636 N at 125.5 mm/s
Brand 2	236 N at 61.7 mm/s	−886 N at 123.5 mm/s	201 N at 61.9 mm/s	−820 N at 123.9 mm/s
Brand 3	360 N at 61.4 mm/s	−943 N at 122.8 mm/s	354 N at 61.2 mm/s	−936 N at 122.3 mm/s
Brand 4	173 N at 62.7 mm/s	−852 N at 125.5 mm/s	172 N at 60.7 mm/s	−809 N at 125.4 mm/s

the 122–126 mm/s. What is more, during the experimental tests, the increase of the temperature also did not have any significant effect on the compression/rebound velocities at which the knee-point appeared. Noticed exception: in the case of vehicle No. 1, after the increase of the initial shock absorber temperature up to 50 °C, in the brand 1 and brand 4 shock absorbers the rebound velocity at which the knee-point appears decreased by 50%. This phenomenon was not noticed in the case of vehicle No. 2, while testing brand 1 and brand 4 shock absorbers. Thus, it can be assumed that the brand of the shock absorber and the temperature have no significant influence on the compression/rebound velocity at which the knee-point appears. However, the damping force at the knee-point in all of the tested different brand shock absorbers was noticeably different. In the case

of vehicle No. 1, at the initial shock absorber temperature of 25 °C, during the compression of the shock absorbers the largest difference observed between the damping forces at the knee-point was 33.3% (brands 1 and 4). In the case of vehicle No. 2, the largest difference observed between the damping forces at the knee-point was 70.2% (brands 3 and 4). Regarding the increase of the temperature – similarly to the already described effect of the temperature on the damping force, the increase of the initial shock absorber temperature affected the decrease of the damping force value at the knee-point. The largest noticed decrease of the damping force value at the knee-point during the compression was 25% (vehicle No. 1, brand 4 shock absorber). During the rebound the largest decrease of the damping force value observed at the knee-point was 67%, also in the case of the vehicle No. 1, brand 4 shock absorber. Nevertheless, in some of the cases the increase of the initial shock absorber temperature did not have any effect at all on the damping force value at the knee-point (vehicle No. 1, brand 3 shock absorber) or the effect was minimal (vehicle No. 2, brand 1 and brand 3 shock absorber). It can be generalized that the knee-point characteristics of the same aftermarket monotube shock absorbers, manufactured by different brands, are also different and react differently to the changes of the initial shock absorber temperature.

4 Conclusions

This research paper raised an important practical question, related to the safety and performance of any vehicle, which should be taken into consideration during the maintenance of the suspension – if the driver of the vehicle should expect that the same aftermarket shock absorber, but manufactured by a different brand, can actually have different damping characteristics? Based on the performed research an initial answer to this question can be proposed – it is highly possible that the same aftermarket shock absorber, manufactured by a different brand, is going to have relatively or even significantly different damping characteristics. After conducting an experimental research it was observed that, during the compression of the shock absorbers, the differences between the generated maximum damping force reached approximately 29% and during the rebound the differences between the generated maximum damping force reached almost 45%. It was also observed that the damping force values at the knee-point of the same aftermarket monotube shock absorbers, manufactured by different brands, can also be different and can even reach the difference of approximately 70%. It should be noted that this is only the initial research and comparison of the same aftermarket shock absorbers, manufactured by different brands, which could serve as a base for further investigation. To more thoroughly support the described observations, more detailed and sophisticated research should be performed.

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