International Journal of Modern Manufacturing Technologies
ISSN 2067–3604, Special Issue, Vol. XI, No. 3 / 2019

ANALYSIS OF THE IMPACT OF THE PRELOAD DISC THICKNESS OF THE UPPER VALVE OF THE DOUBLE TUBE SHOCK ABSORBER ON DAMPING FORCES

Katarzyna Białas, Katarzyna Machera

Silesian University of Technology University, Faculty of Mechanical Engineering, Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Konarskiego 18A, 44-100 Gliwice, Poland

Corresponding author: Katarzyna Białas, katarzyna.bialas@polsl.pl

Abstract: Nowadays, vehicles travel on various carriageways. For every case and means of transport, the suspension system is needed to ensure proper contact of the wheel and the surface as well as relative comfort of travel of passengers [14]. The integral part of the suspension is the damper. Hydraulic vibration dampers of every manufacturer are based on the same physical effects. The differences are usually in the design of valves and seals. Each of these details affects the most important properties for the consumer: durability, vibration damping and price [18]. The subject of this article is to analyze the double-pipe hydraulic damper and determine the relations between the initial load disk thickness on the damping forces in relation to other parameters of valve adjustment. DoE analysis is performed to find out for which input parameter the sensitivity within medium movement rates of the damper piston rod is the highest. The analysis is done for two types of upper valves: MTV CL and RV+.

Key words: Suspension, double-pipe hydraulic damper, damper upper valve, calculating damping forces, DoE method, Pareto diagram

1. INTRODUCTION

Suspension may at first seem like a simple vehicle subassembly. However, the intense developmental research is being conducted and valuable innovations are being implemented. Suspension is a great challenge for current designers since it should provide many functions, which often exclude one another. It is of major effect on the driving comfort, control and safety – technical condition and settings determine the turning efficiency, braking distance and operation of electronic systems responsible for driving support [14].

Dampers are one of the main vehicle suspension elements. They are responsible for supporting the operation of spring suspension that is, reducing vibration occurring as a result of uneven surface. With the dampers, a car leans out from the natural position when driving along an obstacle and then returns to the initial position [13].

The comfort arising from dampening vibrations is not the only function of the suspension system. We believe that the basic function is to ensure contact of the vehicle with the surface so safety while driving. If the suspension system had no dampening element, the wheels would jump on any uneven points of surface. It is undesirable and very dangerous. This may cause a loss of control of the driver and the incorrect operation of electronic systems such as ABS [13].

The valves which are a part of the suspension have a direct impact on the damper's operation. Engineers choose valve characteristics for a specific vehicle to achieve the best driving properties and stability in a wide range of driving conditions. Their selection of valve components controls the flow of fluid in the damper which determines the comfort and vehicle operation [2, 5, 12].

An important thing that needs to be considered is that all the forces absorbed by the suspension are processed into the heat which is then dispersed by the oil and the damper body. Every damper has a limited force that can be absorber for a specific time before the generated heat will cause breaking or expansion of impact oil to the cavitation point at which the piston is blocked. Therefore, not only the proper setting of impact valves is important but also making sure that the damper is compatible and well-fitted to the vehicle performance [5, 12]. The piston valves and the bottom valves directly affect the damper's operation. These are made of the unit of spring disks, bodies with dampening holes and screw springs. By changing the tuning parameters such as the number of disks per valve, their thickness and diameter, we can quickly affect the change in distribution of the dampening forces [17]. One of the disk groups used in the upper valves of the double-piped damper are the so-called initial load disks. These are commonly used in two most popular valves in the market: MTV CL and RV+. One of the businesses that manufacture dampers for automobile industry started to experience some issues with repeated dampening forces for the scope of medium speeds. Upon installation of all suspension components, damping forces are measured for each damper. Too high discrepancy made that the dampers did not live up to the customer's specification resulting in the increased percentage discarding of final products. The detailed analysis of valve sensitivity was conducted to identify the reason for issues with differences of the dampening forces.

2. BASIC INFORMATION ON SUSPENSION AND DAMPERS

Suspension is considered the mechanism connecting wheels with the frame or body of a vehicle (Figure 1). With the suspension, it is possible to transfer the component forces from both wheels, so: reaction of wheels to any unevenness of the surface, driving and braking forces, proper part of car weight, lateral inertial forces that occur while making turns [5, 12]. The basic functions of the suspension system are to mitigate the vibration that occur as a result of unevenness of the carriageway the vehicle is driving on and protecting loads against these shocks and vibrations. The protection also affects the durability of vehicle mechanisms and the human health [6].

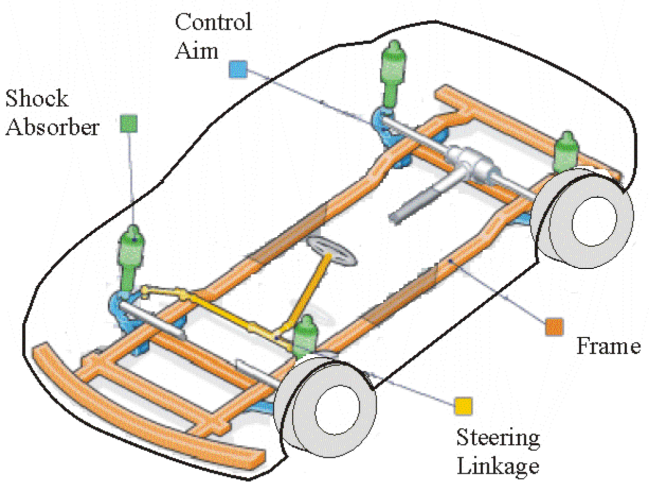

Fig.1. Car suspension [4]

Improper operation of the suspension system may cause premature wear of tires, wheel bearings, joints of the driving system and suspension and the body fixing elements of the car [5,12].
The suspension system can be divided into three basic groups given the connection of wheels within the same axle. These are:
- dependent,
- independent,
- semi-dependent suspensions [14].

Every company has its individual design solutions. Frequently, seemingly similar suspensions may differ by few details [3].
Damper is one of the suspension elements whose main goal is to damp the vibration of its body and spring-less masses. It is located between the undercarriage and the wheel [10, 11]. Wheels are constantly pressed with proper force against the carriageway which improves stability and driving safety [7]. The element is an oil pump inside which a piston is moved which is fixed on one side to the piston rod. During the piston up and down movement, oil is pushed through small gaps on the valve piston. The holes let through a small amount of hydraulic oil, which automatically slows down the movement of the piston, spring and suspension [15]. The resistance generated by the damper depends on the rate of the suspension, number and size of piston holes and the number and thickness of disks in the valve. The piston generates higher resistance if the suspension moves faster. The most important functions of the damper include:
- controlling spring and suspension movement,
- ensuring smooth control and braking of the vehicle,
- counteracting premature wear of tires,
- facilitating contact of tires and the carriageway,
- maintaining dynamic setting of the tires,
- controlling problematic movement of the body,
- reducing wear of the elements,
- improving even wear of the brakes and the tires,
- reducing driver's fatigue [15].

Double-pipe hydraulic damper is composed of the working cylinder, the piston and the piston rod (these elements are interconnected), bottom valve, compensation tank and the piston rod guide [11]. During the compression (bending) due to the pressure on the piston rod, the oil flows through the piston channels into the space over it. The space for the oil in the cylinder becomes limited. The excess of the fluid is pressed through the bottom valve to the compensation tank (filled with air or gas such as nitrogen) [11] (Figure 2).

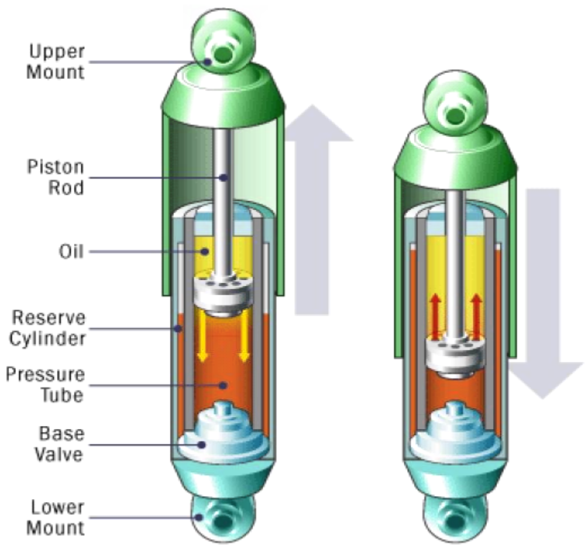

Fig. 2. Double-pipe hydraulic damper in deflection and bending movement [4]

The stretching (deflection) phase consists in pulling out the piston rod from the cylinder. The oil pressure over the piston is increased. The flow of dampening fluid is started with resistance through the channels and valves that cause dampening during the deflection phase. The oil accumulated in the surge chamber flows through the bottom valve to level up the volume of the piston rod pulled out from the working cylinder [11].

Valves are the basic elements of double-pipe dampers responsible for damper operation. They are divided into:

- upper valves (decompressed)
- bottom (compressed) valves.

The upper valves move within the working area which is divided into two separate sections: the decompression chamber (over the piston) and the compression chamber (beneath the piston). The basic function of valves is to damp the oil flow while the piston is being pulled out [9-11] (Figure 3).

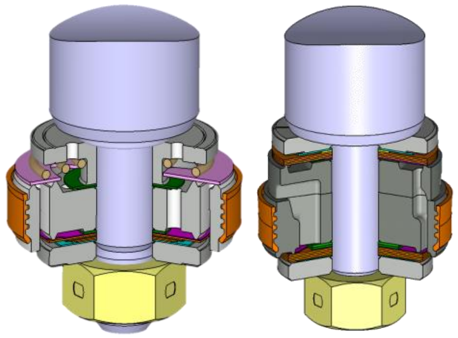

Fig. 3. RV valve + and MTV CL [19]

The typical valve characteristics are dependence of the force from the displacement (Figure 4). The diagram shows the amount of energy extracted by the damper while the differences for compression and deflection arise from the fact that a portion of energy is absorbed by the suspension spring and for different piston rod rates, the amount of extracted energy varies.

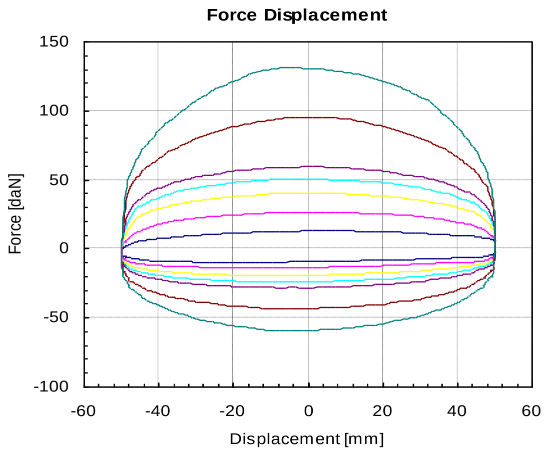

Fig. 4. Damping force – displacement diagram [19]

The preliminary load disk is a thin ring located between the piston and the hole disk. RV+ valve has the disk on the decompression side (Figure 5), while for MTV CL valve (Figure 6) the disk is located both on the compression and decompression side. Both valves require one preliminary load disk to be used.

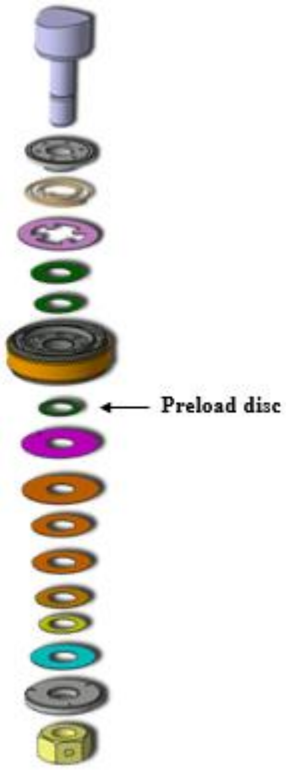

Fig. 5. Position of preliminary load disk in RV+ valve [19]

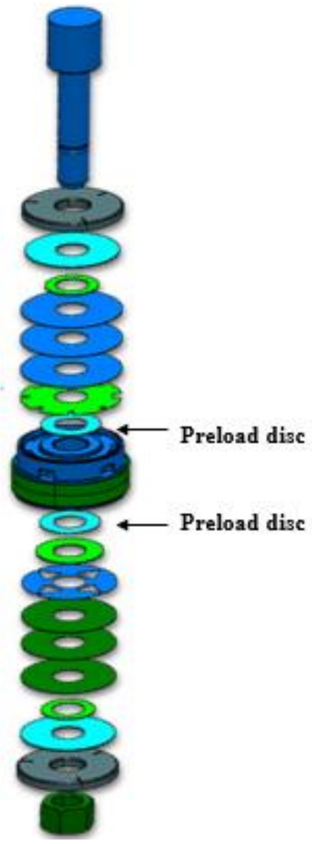

Fig. 6. Position of preliminary load disk in MTV CL valve [19]

The disk is used for initial deflection of the valve disks with the change of its thickness (Figures 7 and 8). The preliminary load affects the so-called disk breaking point – the flow increases with the higher rate and the orifice channels are not enough to handle it. The higher pressure at one point breaks the force of initial load and starts to raise the shields. The thicker shield of the initial load means lower initial load in the valve stack and vice versa.

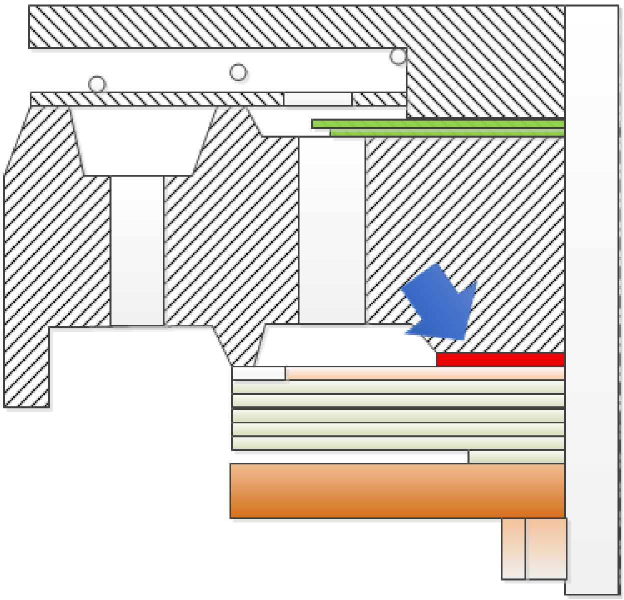

Fig. 7. Thick disk – low initial load of valve disks [15]

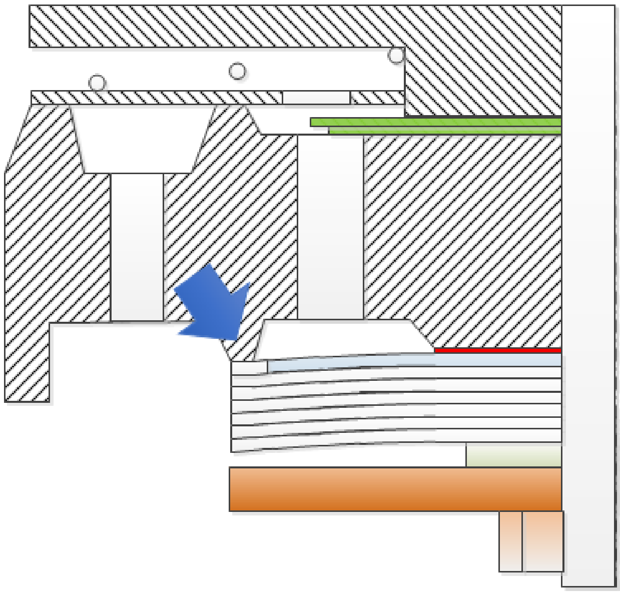

Fig. 8. Thin disk – high initial load of valve disks [15]

3. MEASURING DAMPING FORCES OF DOUBLE-PIPE DAMPER – DOE ANALYSIS

The current automobile industry uses many tools to solve issues of product quality. As commonly known, there are not many issues that can be explained by only one cause. It is common to think that the process cannot be configured as there are too many parameters. But most of them are the derivative of the other and those that are dependent, have no direct effect on the process. Therefore, it is crucial to understand these relations [1].

One of the quality tools is DoE analysis which is widely used when comparing the effect of factors on the given product. It allows to determine the effect of specific input parameters on the output. It is relatively frequent that by changing a given parameter we affect the other. In this case, we are talking about interdependent parameters [1].

The theoretical DoE analysis was done with the special calculator in Excel and Minitab. The tests were conducted to obtain the data on what are the important parameters affecting damping forces within mean speeds.

The following six basic parameters were considered: distance H – L of valve piston, valve disk thickness of 0.15mm, valve disk thickness of 0.20mm, initial load disk thickness, support surface diameter, support disk diameter (Figure 9).

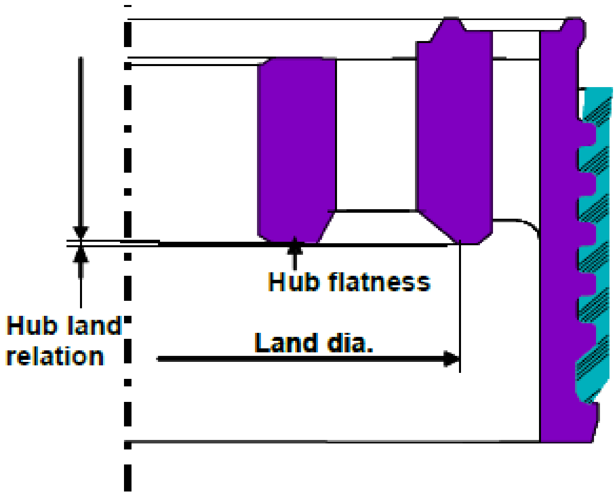

Fig. 9. H – L distance for valve piston [15]

Nominal values were determined for each of the above input parameters.

Afterwards, scopes of tolerances of input parameters were determined that will be considered during DoE analysis (Table 1).

The first step was to introduce random values of input parameters from the tolerance field into Minitab.

Then, dimensions for specific rows were introduced into the special calculator in Excel for calculating theoretical damping forces. Each valve has its individual calculator. After receiving damping forces for five speeds and specific input parameters, these were filled into the columns in Minitab (Figures 10 and 11).

Table 1. Nominal values of input parameters within DoE analysis

DOE	A	B[kN]	C[mm]	D[mm]	E[mm]	F[mm]	G[mm]	H[mm]
1	MTV CL	1-1.5	12.4/30	0.02	0.88	0.9	20.2	11.1
2	MTV CL	1-1.5	12.4/30	0.1	0.8	0.9	20.2	11.1
3	MTV CL	1-1.5	12.4/30	0.14	0.76	0.9	20.2	11.1
4	MTV CL	1-1.5	12.4/30	0.15	0.75	0.9	20.2	11.1
5	MTV CL	1-1.5	25/35	0.02	0.88	0.9	25.48	16
6	MTV CL	1-1.5	25/35	0.1	0.8	0.9	25.48	16
7	MTV CL	1-1.5	25/35	0.14	0.76	0.9	25.48	16
8	MTV CL	1-1.5	25/35	0.15	0.75	0.9	25.48	16
9	RV+	1-1.5	12.4/30	0.02	0.38	0.4	19.815	11.1
10	RV+	1-1.5	12.4/30	0.05	0.35	0.4	19.815	11.1
11	RV+	1-1.5	12.4/30	0.1	0.3	0.4	19.815	11.1
12	RV+	1-1.5	12.4/30	0.15	0.25	0.4	19.815	11.1
13	RV+	1-1.5	25/35	0.02	0.38	0.4	24.2	16
14	RV+	1-1.5	25/35	0.05	0.35	0.4	24.2	16
15	RV+	1-1.5	25/35	0.1	0.3	0.4	24.2	14

The symbols from Table 1 means: A - Valve type; B - Blow off force [kN]; C - Rod / Bore diameter [mm]; D - Nominal preload [mm]; E - Nominal thickness of preload disc [mm]; F - Nominal distance hub-land [mm]; G - Nominal land diameter [mm]; H - Nominal fulcrum disc diameter [mm].

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
	StdOrder	RunOrder	CenterPt	Blocks	Piston H-L	0.15mm Disc TH	0.2mm Disc TH	Preload Disc TH	Land Diameter	Fulcrum Disc Diam
1	1	1	1	1	0.894	0.145	0.194	0.862	20.16	11.05
2	2	2	1	1	0.906	0.145	0.194	0.862	20.24	11.05
3	3	3	1	1	0.894	0.155	0.194	0.862	20.24	11.15
4	4	4	1	1	0.906	0.155	0.194	0.862	20.16	11.15
5	5	5	1	1	0.894	0.145	0.206	0.862	20.24	11.15
6	6	6	1	1	0.906	0.145	0.206	0.862	20.16	11.15
7	7	7	1	1	0.894	0.155	0.206	0.862	20.16	11.05
8	8	8	1	1	0.906	0.155	0.206	0.862	20.24	11.05
9	9	9	1	1	0.894	0.145	0.194	0.898	20.16	11.15
10	10	10	1	1	0.906	0.145	0.194	0.898	20.24	11.15
11	11	11	1	1	0.894	0.155	0.194	0.898	20.24	11.05
12	12	12	1	1	0.906	0.155	0.194	0.898	20.16	11.05
13	13	13	1	1	0.894	0.145	0.206	0.898	20.24	11.05
14	14	14	1	1	0.906	0.145	0.206	0.898	20.16	11.05
15	15	15	1	1	0.894	0.155	0.206	0.898	20.16	11.15

Fig. 10. Entering data into Minitab

C11	C12	C13	C14	C15
DF @ 0.13	DF @ 0.26	DF @ 0.39	DF @ 0.5	DF @ 1
272	395	507	598	1017
291	411	519	608	1020
299	433	553	651	1096
339	475	597	697	1149
287	416	532	627	1060
325	456	574	670	1111
312	451	576	677	1135
336	470	592	691	1140
202	330	444	538	965
221	346	458	550	970
208	340	459	555	992
240	375	496	594	1040
201	328	443	536	962
231	361	478	573	1007
227	371	499	603	1070

Fig. 11. Entering damping forces calculated by calculator

Figure 12 shows the distribution of damping forces for fifteen cases with various input parameters, subjected to DoE analysis.

As evidenced by the diagram damping forces comparison (Figure 12), the selection of various input parameters combinations gives a very wide difference in the obtained damping forces.

The Minitab analytic and graphic tool was used to calculate the effect of parameters which enables: selection from among possible project experiments, creating and saving a project after defining its properties, displaying and saving diagnostic statistics to simplify results interpretation, generating auxiliary diagrams for easier interpretation and results presentation [16] (Figure 13).

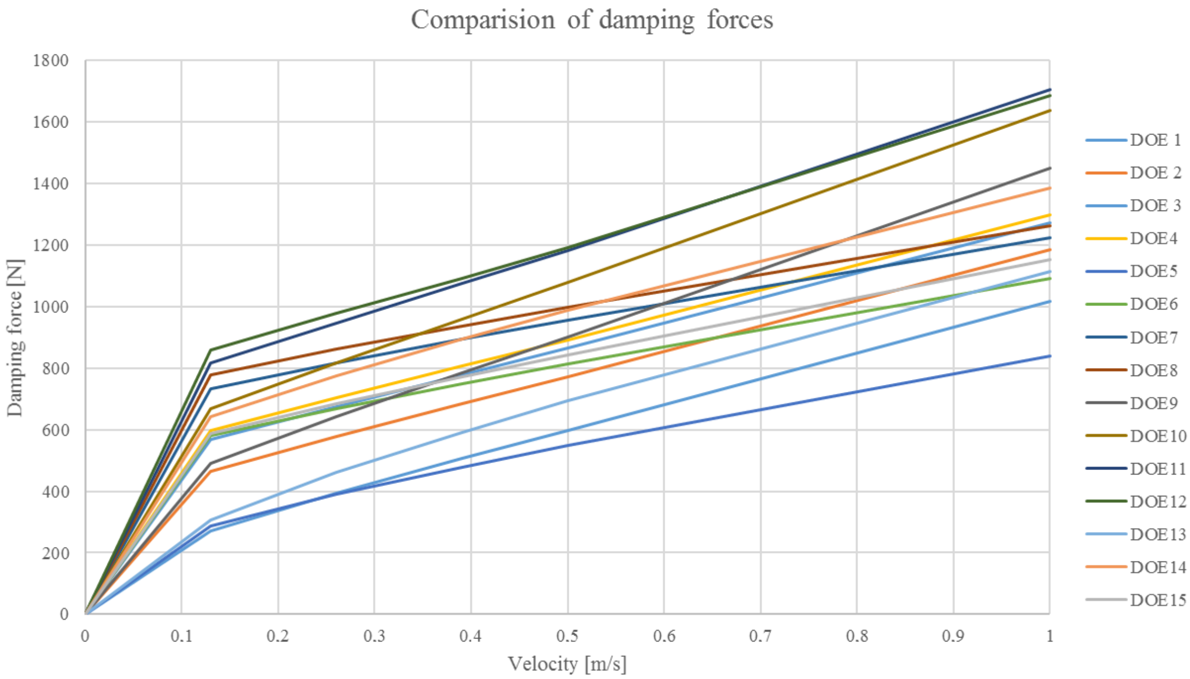

Fig. 12. Damping forces comparison

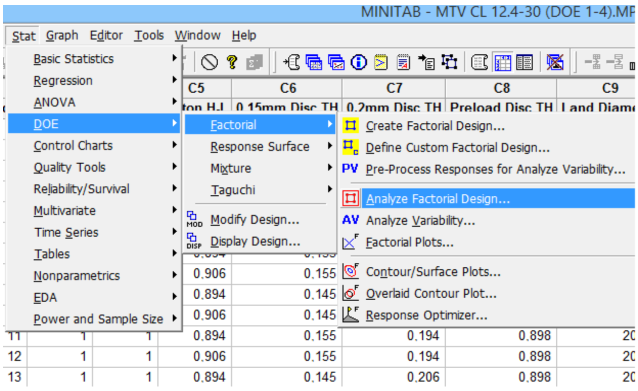

Fig. 13. DoE analysis in Minitab

The results are presented as a Pareto diagram (Figures 14 – 17). The diagram is a rather frequently used tool that allows to set a hierarchy of parameters affecting the given effect. It is a graphic image showing the relative and the absolute distribution of types of issues and errors with their causes. It allows to show data as a column diagram highlighting the elements of greatest contribution for the issue [8].

The diagram of Pareto is also known as the 20-80 right or the ABC method. The Pareto principle claims that 20% of the factors is responsible for 80% of effects. Therefore, we should note that in case of corrective measures against 20% of the most important causes of incompatibility [8].

The vertical axis of each diagram generated within Minitab has input parameters that may affect the distribution in damping forces. The vertical axis, on the other hand, shows the effect of a parameter on the forces. The values for 0m/s rate were subjected to graphic analysis.

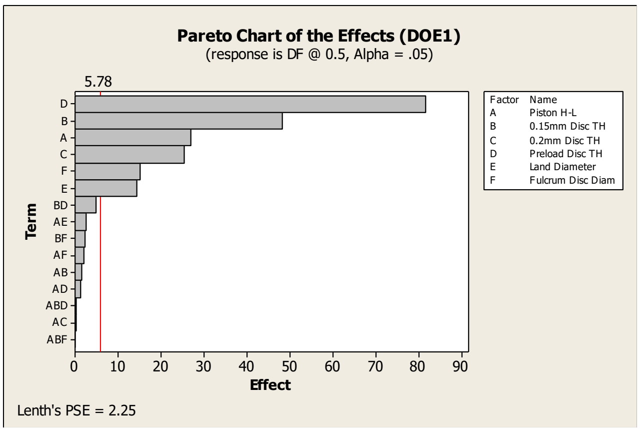

Fig. 14. Pareto diagram for DoE 1

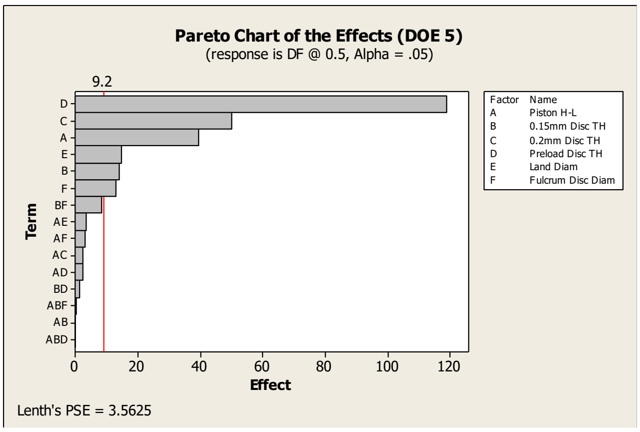

Fig. 15. Pareto diagram for DoE 5

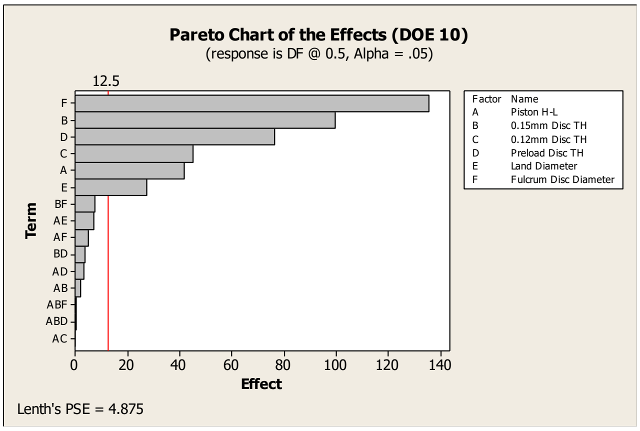

Fig. 16. Pareto diagram for DoE 10

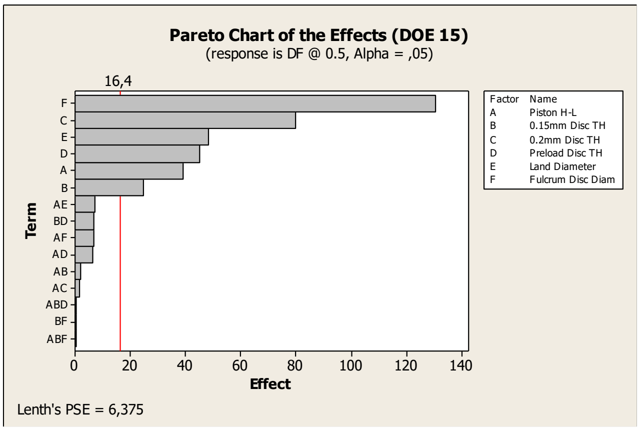

Fig. 17. Pareto diagram for DoE 15

As a result of the DoE analysis, information was obtained about which of the input parameters has the greatest impact on the damping forces for medium speeds. It turned out that the most important parameter is the thickness of the pre-load disk.

4. CONCLUSIONS

Based on all the analyses, it can be found that the tolerance of initial load disk thickness is the most important parameter responsible for generating damping force in most of the cases. Therefore, it is so important to improve the quality of thicker initial load disks to achieve higher damping forces with small initial deflection. This is caused by possible loss of tightness of the vale with high deflection and too high distribution in damping forces. If this parameter was not important in several cases, it will always be in the group of three most important values along with the valve disk thickness of 0.15 mm and the support disk diameter. For MTV CL valve, the effect of initial load disk thickness on damping forces is greatest. For RV+ valve, the support disk diameter has a high impact. Therefore, load disk thickness is always within the group of three most important parameters for all analyses in the group.
Another stage of testing is to conduct a detailed analysis of valve sensitivity composed of two parts to determine what may be the reason for issues with differences in damping forces:
- Disk quality analysis: analyzing tolerance of the upper valve disk which has the greatest effect on the damping forces, arising from DoE analysis. We aim for the percentage value of disk tolerance on the nominal deflection of valve rings which in turn may affect the generated damping forces.
- Measuring damping forces on MTS machine: obtain the information how the forces vary depending on set rate, initial deflection and type of valve used.
After conducting the analysis and finding the cause of too high dispersion in damping forces, corrective measures will be taken to reduce too high dispersion on the production line and consequently, to minimize financial losses.

5. REFERENCES

1. Anderson, M. J., Whitcomb, P. J. (2010). *DOE Simplified Practical Tools for Effective Experimentation*, Third Edition CRC Pres (New York)
2. Białas, K., (2012). *Mechanical and Electrical Subsystems as Implementation of Active Reduction of Vibration*. International Journal of Modern Manufacturing Technologies, IV, 1: 29-34
3. Fundowicz, P., Radzimierski, M., Wieczorek, M., (2010). *Konstrukcja pojazdów samochodowych*, WSiP Publishing House, (Warsaw)
4. Harris, W., (2005). Automotive Damper System. Available from: http://auto.howstuffworks.com/carsuspension2.htm., Accesed:4/02/2019
5. Niziski, S., (1999). *Diagnostyka samochodów osobowych i ciężarowych* Bellona Publishing House (Warsaw)
6. Orzełowski, S., (2009). *Budowa podwozi i nadwozi samochodowych*, WSiP Publishing House, (Warsaw)
7. Próchniewicz, H., (2017). *Kierowca doskonały B*, Wydawnictwo Grupa IMAGE sp. z o. o., publisher, (Warsaw)
8. Prywata, M., (2010). *Zarządzanie ryzykiem w małych przedsiębiorstwach*. Polish Agency for Enterprise Development (PARP) (Warsaw)
9. Reimpell, J., Betzler, J., (2004). *Podwozia samochodów : podstawy konstrukcji*, 3rd Edition, trans. Andrzej Reński, Communication and Connectivity Publishing House (Warsaw)
10. Reński, A., (2004). Budowa samochodów: układy hamulcowe i kierownicze oraz zawieszenia, 3rd Edition Publishing House of Warsaw University of Technology (Warsaw)
11. Sikorski, J., (1984). *Amortyzatory pojazdów samochodowych*, 3rd Edition, Communication and Connectivity Publishing House (Warsaw)

12. Sitek, K. (1999). *Diagnostyka samochodowa – układy odpowiedzialne za bezpieczestwo jazdy* AUTO Publishing House (Warsaw)
13. Sowiński, D., (2015). *Jak działaja amortyzatory*, Available from: https://allegro.pl/artykul/jak-dzialaja-amortyzatory-68017, Accesed:4/02/2019
14. Witowski, S., (2011). *Układy zawieszenia w samochodach osobowych*. Available from: https://autokult.pl/14518,uklady-zawieszenia-w-samochodach-osobowych, Accesed:4/02/2019
15.Own materials of the research laboratory of Tenneco Automotive Eastern Europe Sp. z o.o.
16. (2010). *Poznaj Minitab 16* Available from: https://www.mgx.com.pl/users/PL16_MeetMinitab.pdf, Accesed:4/02/2019
17. (2011). *Amortyzatory dwururowe – budowa i zasady działania,* Available from: https://motofocus.pl/technika/7835/amortyzatory-dwururowe-budowa-i-zasady-dzialania, Accesed:4/02/2019
18. (2014). *Amortyzatory TRW – budowa i działanie*. Available from: https://motofocus.pl/specjalne/12480/amortyzatory-trw-budowa-i-dzialanie, Accesed:4/02/2019
19. (2014). *Rodzaje zawieszenia*, Available from: https://www.bopss.pl/rodzaje-zawieszen,0,242.htm, Accesed:4/02/2019

Received: March 27, 2019 / Accepted: December 20, 2019 / Paper available online: December 25, 2019 © International Journal of Modern Manufacturing Technologies