

Research of Characteristics of Sports Cars' Shock Absorbers

P. Skačkauskas*, V. Žuraulis**

*Vilnius Gediminas Technical University, J. Basanavičiaus st. 28, 03224, Vilnius, Lithuania,

E-mail: paulius.skackauskas@vgtu.lt

**Vilnius Gediminas Technical University, J. Basanavičiaus st. 28, 03224, Vilnius, Lithuania,

E-mail: vidas.zuraulis@vgtu.lt

Abstract

In sports cars shock absorbers are a complex part of suspension that ensures the damping of a car's oscillations and a suitable grip of the wheels to a road surface, which is very important for a car's driver seeking to move in an optimal racing line on a race track. However, even using shock absorbers for auto sport in cars, their suspensions are not constructionally perfect because shock absorbers for sports cars are designed to be suitable in various situations, seeking to obtain acceptable characteristics. In order to adjust a specific sports car for a particular race type, considering the driver's mass, skills, specific requirements and the car's parameters, it is very important to obtain suitable characteristics of a shock absorber's oscillatory damping and to determine them precisely. In this thesis, an original method of a monotube shock absorber's modification is reviewed, changing the construction of a shim valve of piston used in shock absorbers, which (method) is designed for getting the desirable characteristics of damping. Test results of modified and not modified monotube shock absorbers got using the specialised shock absorbers' test stand are presented and the influence of the modified construction of the piston valve on the change of a F_d-v characteristic's form, which describes the shock absorber's oscillatory damping during exploitation, is discussed.

KEY WORDS: *shock absorber, sports car, damping force, characteristics, shim valve*

1. Introduction

Seeking to move in an optimal racing line with a sports car, without the movement in the driving direction, being affected by additional external and internal forces, the car oscillates around transverse, longitudinal and vertical axis. Oscillations of sprung and unsprung masses appearing due to the additional movements of a car have negative influence on the dynamics and safety of driving [10], therefore shock absorbers of different and also of partly adjustable characteristics are used in cars. Different specific features of shock absorbers' constructions have influence both on operation characteristics of shock absorbers and a suspension [1], that is why, in order to ensure optimal and precise dynamic and safety characteristics of a specific sports car, a modification of shock absorbers is done, based on different specifics.

The main method of shock absorbers' modification researched in scientific works is improvement of separate elements of shock absorbers' construction. In the source of literature [3] a method of modification of a shock absorber's construction, which consists of two stages, is researched: 1) The changing of metal powder pistons with engineering plastic (PPA) pistons. Advantages of the engineering plastic piston mentioned in the publication: lesser mass of a piston and a high temperature resistance (PPA piston starts to melt when it reaches a temperature of 300°C, under complex conditions in shock absorbers of exploited vehicles a temperature of ~120°C predominates); 2) Research of optimizing alternatives of parameters of engineering plastic piston's forms, which have influence on the dependency of shock absorber's damping characteristic. In the work it is stated that, during exploitation under different pressures between working chambers and a high temperature, deformations form in the construction of the piston which determine inefficient work of a shock absorber. After determining optimal PPA piston's orifices' measurements and avoiding the forming of deformations, using the mentioned piston a F_d-v characteristic (this characteristic indicates how the force varies with compression and rebound velocities) is obtained, the form of which is close to the form of the characteristic, which is obtained when exploiting metal powder piston in a shock absorber. A disadvantage of the mentioned method – an unsuitable technology of production of metal powder pistons, they can only be produced using injection molding manufacturing process. In the paper [5], a method of modifying monotube shock absorbers by assembling an original construction gas chamber is presented. The construction described in the presented work is peculiar because of the additional gas (nitrogen) movement orifices, which are equipped in the gas chamber of a shock absorber. With these orifices an additional gas flow movement during exploitation is formed. The author of the publication indicates that because of the additionally formed gas movement flows, when the amplitude of oscillations is growing so is the maximal damping force, the shock absorber damps oscillations more effectively when their frequency is 5-10 Hz. The results obtained during the laboratory tests of a shock absorber of such construction are presented in the work, however practical tests in the suspension of a vehicle, during which named propositions would be validated and the actual effectiveness of the operating of such shock absorbers would be tested, were not done. The same author has published another work [6], in which an original method of modifying a working chamber of a shock absorber is described too,

which is used in order to obtain the most possible accurate adjusting possibilities of damping characteristic of a shock absorber. Both in sources [5] and [6] mathematical models are presented, based on which supposed damping characteristics of F_d-v and F_d-x (damping force – position of the piston) of modified shock absorbers are predicted, however the results got theoretically and during laboratory tests do not match. In the conclusions of both papers it is stated that the main reason which determined the differences in the results is the simplifications which were done during mathematical modelling, i.e. physical characteristics (compressibility) of the oil used in a shock absorber which were not introduced. A method of modifying shock absorbers for vehicles prepared for rally races, developing and using a spring of original construction, which would be used in the suspension of a car together with a coilover, is analysed in the paper [8]. In the indicated work, a cylindrical spring is described which is made of three different parts of variable number of coils, which's cross-section form of a wire is a rectangular, however the measurements of all the parts are different. The researched construction of the course of uneven winding and the variable wire measurements theoretically has influence on the nonlinear characteristic of a spring, however the actual benefit of the spring of such construction for the suspension of a vehicle is not proved: dynamical quarter modelling of the vehicle, while the suspension of the vehicle is equipped with these springs, is not done, also the changes in the oscillation damping of the body and a comparison when the suspension of the vehicle is equipped with the described springs and the standard springs are not presented. In various papers different methods of modifying shock absorbers are also researched: shock absorbers are modified by researching and eliminating the defects in them that show during the exploitation [4, 8], possibilities of using amplitude-selective-damping (ASD) valves are researched [2], magneto-rheological (MR) and electro-rheological (ER) fluids have been widely studied to control the damping force of shock absorbers by replacing the mechanical valves [9]. In the source of literature [9] a possibility to improve the performance of shock absorbers by using a MR accumulator, that consists of a gas accumulator and a MR device is researched. The level of damping is continuously variable by means of control of the applied current in an MR device that is fitted to a floating piston in a shock absorber. The MR device is used to resist the movement of the floating piston.

Various scientific works are published, in which methods of modifying shock absorbers are presented and analysed, however in such works, as well as in the reviewed ones, only the prototypes of the modified shock absorbers and the theoretical possible alternatives of modifying shock absorbers, which are complex and not designed to apply to actual shock absorbers used in auto sport, are presented. In this work, a method of modifying shock absorbers, by changing the construction of a shim valve of a piston used in a shock absorber, is reviewed, designed for obtaining the desirable damping characteristics in monotube shock absorbers for auto sport. The test results of not modified and modified monotube shock absorbers got from a specialised shock absorber test stand are presented and compared. The influence of the modified construction of a valve of a piston on the changing of the form of a F_d-v characteristic, describing the oscillation damping of a shock absorber during exploitation, is discussed.

2. Modification method and experimental procedure

In a shim valve construction (Fig. 1), the main bleed orifices in a piston which are designed for the flowing of the oil during compression and rebound are covered by special shim stack. When the sprung mass oscillations are forming and because of that the rod of the shock absorbers is moving, a difference in pressures, which deforms the shims, forms between the working chambers of the shock absorber. The rate of the oil that flows through the piston and the form of a F_d-v characteristic of a shock absorber depends on the extent of the deformation of these shims and the resistance to the pressure. The amount of the shims of the valve and their geometrical proportions in the shock absorber are not limited, various variations of positioning these shims on the piston, forming different geometrical forms, are possible (Fig. 1).

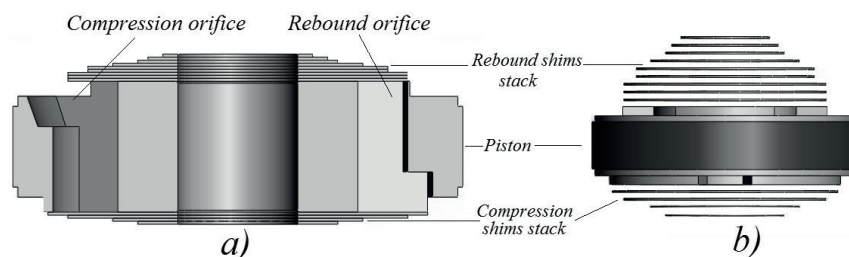


Fig. 1 Model of the researched piston: a - piston and shim valve construction; b - outspread positioning of shims stack on the piston and their formed geometrical form

On both sides of the piston using a different amount of these shims, when the shims are of different diameters and with this forming a different stiffness of a shims group and different geometrical forms, different desirable damping characteristics for both compression and rebound processes are obtained separately. An example of the named method of modifying shock absorbers is presented in this work. In the Fig. 2 compression and rebound sides of a linear type piston of the tested shock absorbers and the samples of the valve shims used during modifying are presented.



Fig. 2 Parts of the researched shock absorber: a - piston compression side; b - piston rebound side; c - samples of the valve shims used for tests

External diameters and the positioning order of the shims used before modification and during modification are presented in the Table 1 (in the table from left to right, the positioning order of a shim from the closest to the farthest from the piston). The thickness of all the shims used in the research – 0.3 mm, internal diameter – 20/12 mm, mass – 1–3 g.

Table 1

External diameters and positioning of the used valve shims during tests

Position of the shim			1	2	3	4	5	6	7	8	9
External diameters of the shims, mm											
Shock absorber of front suspension	Before revalving	Compression	38	34	32	30	27.5	25	22.5	-	-
		Rebound	34	32	30	27.5	25	-	-	-	-
	After revalving	Compression	38	38	38	38	38	30	26	16	17
		Rebound	34	34	34	30	25	17	20	-	-
Shock absorber of rear suspension	Before revalving	Compression	38	38	34	32	30	27.5	25	-	-
		Rebound	34	32	30	27.5	25	22.5	20	-	-
	After revalving	Compression	38	38	34	34	30	26	17	-	-
		Rebound	34	30	27.5	22	16	17	-	-	-

Main information of the monotube shock absorbers used for the tests and conditions of the test are presented in the Table 2. F_d - v characteristic of the researched shock absorbers is determined using electromechanical tester (Fig. 3), operating of which is based on the principle of the “Scotch Yoke” mechanism. The Shock absorber is fixed at one end of the testing stand, and attached to a vertical shaft on its opposing end.

Table 2

Information of the researched shock absorbers and test conditions

Model	XYZ Super Sport Coilover
Used oil	Castrol Fork Oil 10W
Initial pressure of rebound, compression and gas chambers, MPa	~1.5
Diameter of the rod (Front/Rear suspension), mm	20/12
Diameter of the piston, mm	40
Stroke length of the rod of the shock absorber during the processes of rebound/compression, mm	15/15
Maximal velocity of the compression and rebound of the rod, during which the test is done, mm/s	400
Duration of the test of the shock absorber using the stand, s	80

In order to imitate the process of compression and rebound, DC electric motor is used in the stand. From the DC motor, drive is brought to a gear reducer whose gear reduction ratio is 4:1. Variation of stroke is possible by disassembly of the apparatus, i.e. connecting rod can be fixed in any of the appropriate holes, which are made in the disk type flywheel, to select the stroke length. As the DC electric motor turns, the shaft displaces vertically for a set distance. The shock absorber damping force is measured by load cell, which is equipped in the used stand. The data of the damping force F_d formed by the shock absorber and piston movement velocity v obtained using the stand are sent to a computer, in which they are processed.

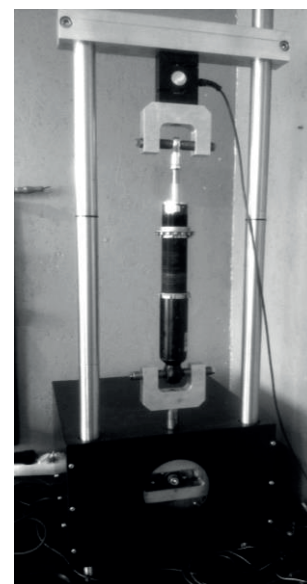


Fig. 3 The shock absorber test stand used for research and the „XYZ Super Sport“ shock absorber mounted in it

3. Results

The characteristics obtained during tests are linear type and have two different phases (slopes) (Fig.4). The first slope is the low speed phase of the characteristic (shaft velocities between 0 mm/s and 50 mm/s, velocities from 50 mm/s upwards – normal and high speeds). In this stage, due to the insufficient difference in pressures between the working chambers for the deformation of the shim stack, the shim stack does not have influence on the size of the forming damping force. An increasing rate of damping for slow velocities is provided and controlled by an adjustment needle, the diameter of which during exploitation is constant. Because of this reason, the size of the damping force formed by the shock absorber of the front suspension before and after modification, as well as by the shock absorber of the rear suspension before and after modification, and the characteristic shape in the first slope is close, though they do not match completely. The forming of the differences is determined by the fact that during the tests of the shock absorbers before and after modification, different operation materials were used. Before modification – materials which were used since the beginning of the exploitation of the tested shock absorbers. After modification – new operation materials (oil, o-rings, etc.).

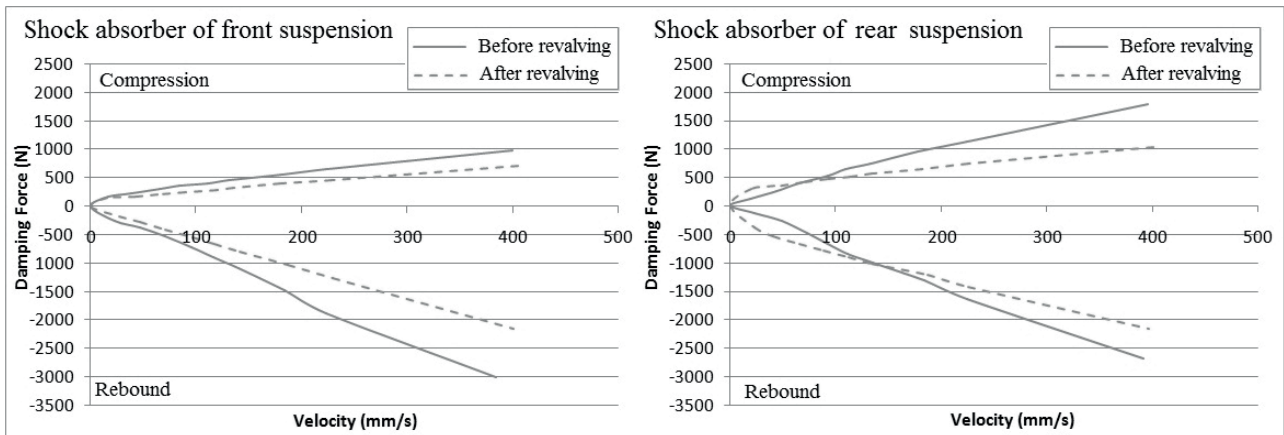


Fig. 4 F_d - v characteristics obtained during tests

The point of transition from the low speed characteristic to the high speed characteristic is “knee” point. An example of a “knee” point is presented in Fig. 5. During the tests it was observed that the shims against the piston affect the preload on the whole shim stack and that has influence on the location of the „knee“ of the characteristic. It was also observed that as the bleed adjuster of the needle is opened to the maximum, the „knee“ point of the characteristic drops significantly. When the amount of oil flowing through the adjusting needle is minimal, greater damping force forms at the lower shaft velocities, for example, during rebound when shaft velocity is ~ 30 mm/s and the adjuster is opened to the maximum, the damping force is 100 N, when the adjuster is opened to the minimum – 600 N (Fig. 5). In this case, by changing the shims against the piston and adjusting the needle, the „knee“ point location can be controlled.

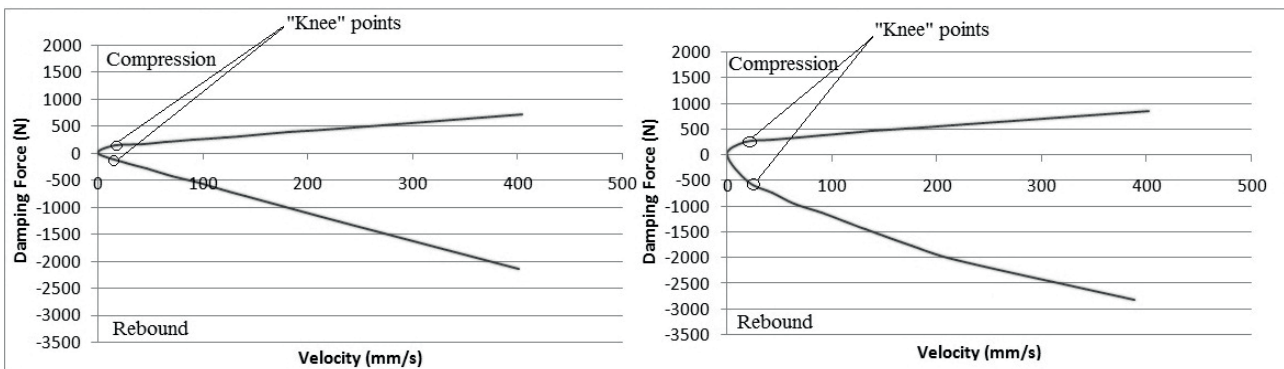


Fig. 5 Damping characteristics of the shock absorber of the front suspension, when the bleed adjuster of the needle is opened to the maximum and minimum: a) adjuster opened to the maximum; b) adjuster opened to the minimum

During the normal/high speed phase of the F_d - v characteristic, the flow through the adjusting needle is obstructed and the pressure forms on the shim stack. In this phase, the damping force is controlled by the shim stack preload and the index of the shims stack mentioned in the chapter 2. The last set of shims (5-9 shims) adjusts the damping force of the high speed region of the characteristic. In the obtained characteristics, which show the tendency of the changing of the damping force after revalving, forming the shim stack during modification, the stiffness of which is greater than the stiffness of the shim stack before revalving, it is seen that both in the position of compression and rebound, the growth

of the damping force, when the shaft velocity is increasing, and its maximal size are lower, for example, the maximal damping force in the shock absorber of the rear suspension in the compression process before modification is 1800 N and after modification – 1000 N (during the maximal 400 mm/s velocity). In the presented characteristics (Fig. 4), it is seen, that the shock absorbers with the modified shim stack, using the positioning of the shims presented in the Table 1, are much softer than the shock absorbers with the original shim stack.

4. Conclusions

The presented method of modification of shock absorbers is suitable for monotube shock absorbers, in which shim valves are used. On analysing the results of the experiment, modifying shim valves of coilovers for sports cars, it was found that it is possible to get the desirable characteristics of the low speed phase, using suitable shims against the piston, as well as adjusting the needle and with this controlling the „knee“ point location in the F_d-v characteristic. This allows to make quick changes of the damping characteristics, when the vehicle is exploited on different tracks, to enhance grip in bumpy corners or provide more support on smoother tracks, without the repeated revalving of the shim valve of the shock absorbers.

Splitting characteristic into two phases (slopes) leads to a more balanced and better performing vehicle suspension. Based on the obtained results, it is clear that each shim in the shim stack performs a different function that influences the characteristic shape, however it is difficult to predict what kind of influence each shim will have on the performance of the shock absorber and the form of the made damping characteristic, therefore the future work is to create a mathematical model, able to predict the forms of F_d-v or F_d-x damping characteristics, before and after revalving.

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