ASSESSING THE RELIABILITY OF TESTING METHODS USED FOR FLUID TELESCOPIC SHOCK ABSORBERS IN CARS

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Abstract

Shock absorbers in modern cars have asymmetric damping characteristics corrected by overflow valves. Their indicator diagrams are far from being elliptical. Defective shock absorbers may lead to excessive amplitudes in vibration accelerations, excessive car body rolls, both lateral and longitudinal, excessive braking distance and destruction of the car components or road surface. The paper discusses methods of testing shock absorbers mounted or removed from the car. Advantages and disadvantages of the methods are used as basis for the assessment. It is pointed out that the methods should not assume linear characteristics of springs and damping elements. Testing methods can be divided as follows:
- those referring to shock absorbers removed from the car,
- those referring to shock absorbers mounted in the car.

Methods used for testing shock absorbers removed from the car are those performed on indicator test rigs provided with mechanical-electric or electrohydraulic extortion system. Such test rigs have measuring devices to enable recording of indicator diagrams relative to the absorber damping force in function of piston stroke with deflection and reflection. Among a variety of testing methods, those requiring no removal are by far preferred by Vehicle Control Stations or diagnostic lines. The methods can be divided as follows:
-free vibration type,
-forced vibration type.

Keywords: *transport, road transport, safety of transport, testing methods, shock absorbers*

1. Introduction

Defective shock absorbers may lead to excessive amplitudes in vibration accelerations, excessive car body rolls, both lateral and longitudinal, excessive braking distance and destruction of the car components or road surface. From the point of view of car users, there are two important factors connected with technical state or characteristics of shock absorbers, namely safety and comfort of travel. Any car is a complex material system having discrete-continuous design and containing a large number of resonance frequencies (including unsprung masses 8-18 Hz and sprung masses 1-3 Hz) joined together with springs (coil springs) or damping elements (most often fluid telescopic shock absorbers) of non-linear, progressive characteristics. Testing technical state is difficult. The methods are numerous, and nearly each of them has a different diagnostic reliability.

2. Methods of testing shock absorbers

Testing methods can be divided as follows:
- those referring to shock absorbers removed from the car,
- those referring to shock absorbers mounted in the car.

Among the methods used for testing shock absorbers removed from the car are those performed on indicator test rigs provided with mechanical-electric or electrohydraulic extortion system. Such test rigs have measuring devices to enable recording of indicator diagrams relative to the absorber damping force in function of piston stroke with deflection and reflection.

In indicator test rigs it is usually the crank-shaft unit that extorts plane-backward movement of the lower absorber holder and the body. Upper holder, connected to piston rod, is mounted to the rig frame through force converter. An example of such test rig, included in PTP Laboratory outfit, Department of Transport, Silesian Technical University, is shown in fig.1 in the form of kinematic diagram.

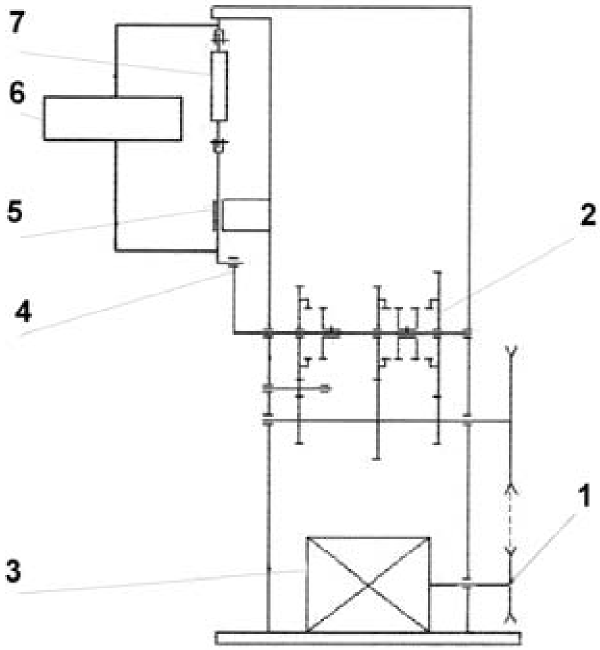

Fig.1. Kinematic diagram of the test rig:
1-belt transmission, 2-gear transmission, 3-electric motor, 4-crank-shaft unit,
5-sliders, 6-measuring device, 7-shock absorber under testing

The rig is driven by an alternating current electric motor. The motor drive is transmitted through belt transmission onto the two-ratio gearbox and reversing gear. The drive is further transmitted onto the eccentric crank-shaft unit having variable length. The extortion is transmitted from crank-shaft unit onto lower end of the absorber through slider mechanism. Upper mounting of the absorber is connected to the rig casing through force converter. Relationship between the crankweb length „R” and the rotation angle „α” is:

$$z = R[(1-\cos\alpha) + \frac{\lambda}{4}(1-\cos 2\alpha)], \tag{1}$$

where $\lambda = \dfrac{R}{l}$ crankthrow-to-connecting rod length ratio,

and upon differentiation the form is:

$$\dot{z} = R \cdot \omega(\sin\alpha + \frac{\lambda}{2}\sin 2\alpha), \tag{2}$$

where:
ω-crank angular velocity,
ω=π n/30[rad/s],
n-shaft rotational speed [r.p.m.].

If tests are performed on shock absorbers having linear symmetric characteristics with no correction valves, the damping force equation in function of piston shift is a parametric elliptic equation. In case of linear system, damping coefficient is stable and equal to linear characteristic pitch angle tangent in the absorber velocity diagram.

Shock absorbers in modern cars have asymmetric damping characteristics corrected by overflow valves. Their indicator diagrams are far from being elliptical. Assessment of their technical state is usually based on comparison between the indicator diagram form and control results obtained for new absorbers. The consequent closed diagrams show a change in damping force in function of the absorber piston stroke. Their differentiation results in new forms, called velocity diagrams, to describe damping power in function of piston relative velocity. If tests on the indicator test rig are performed with various extortion frequencies, a set of closed characteristic curves will be obtained for damping. This can also be presented in the form of expanded (opened) diagrams. Examples of damping characteristic curves (new vs. used absorbers) are shown in figs. 2,3,4,

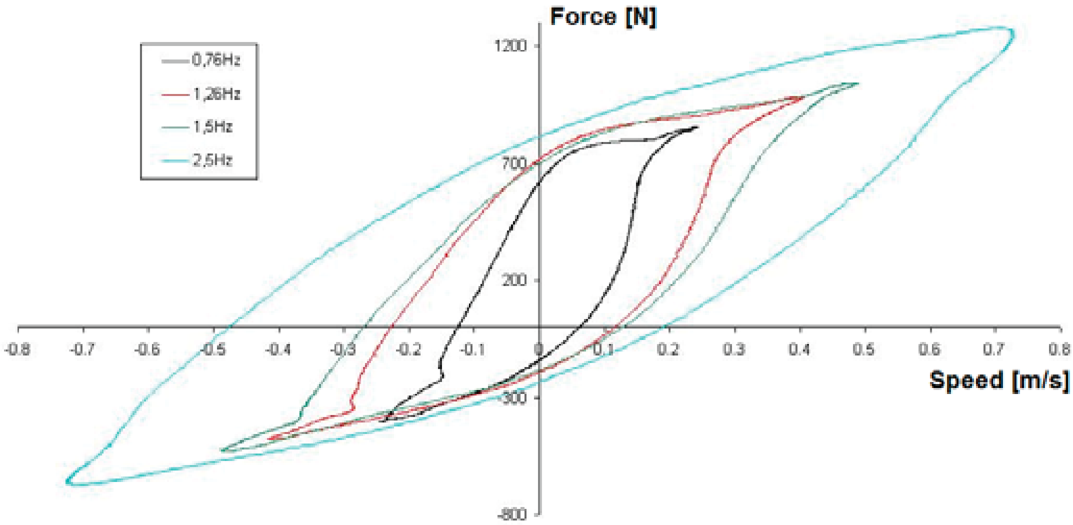

Fig.2. A set of characteristic curves for a new shock absorber with various extortion frequencies.

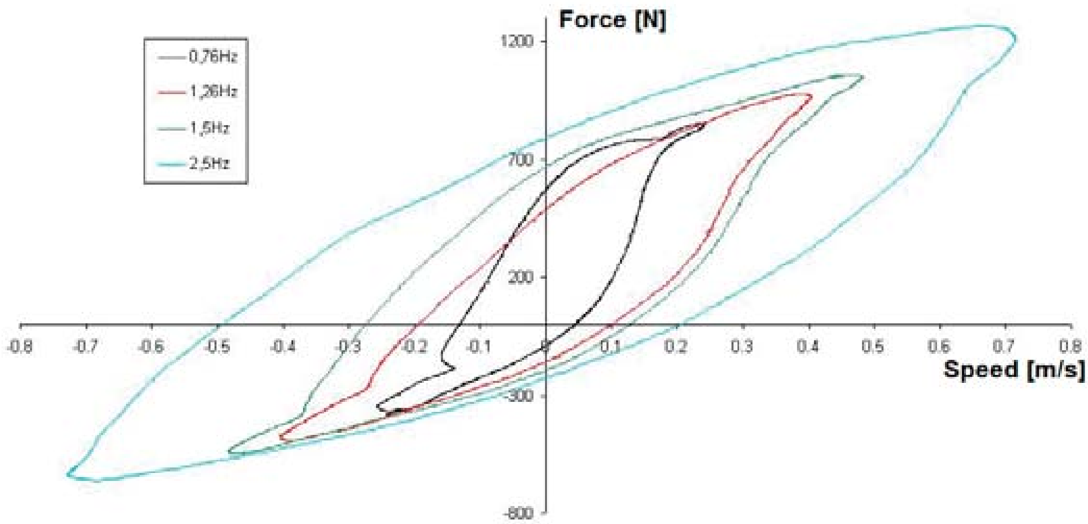

Fig.3. A set of characteristic curves for a shock absorber with 25% fluid loss.

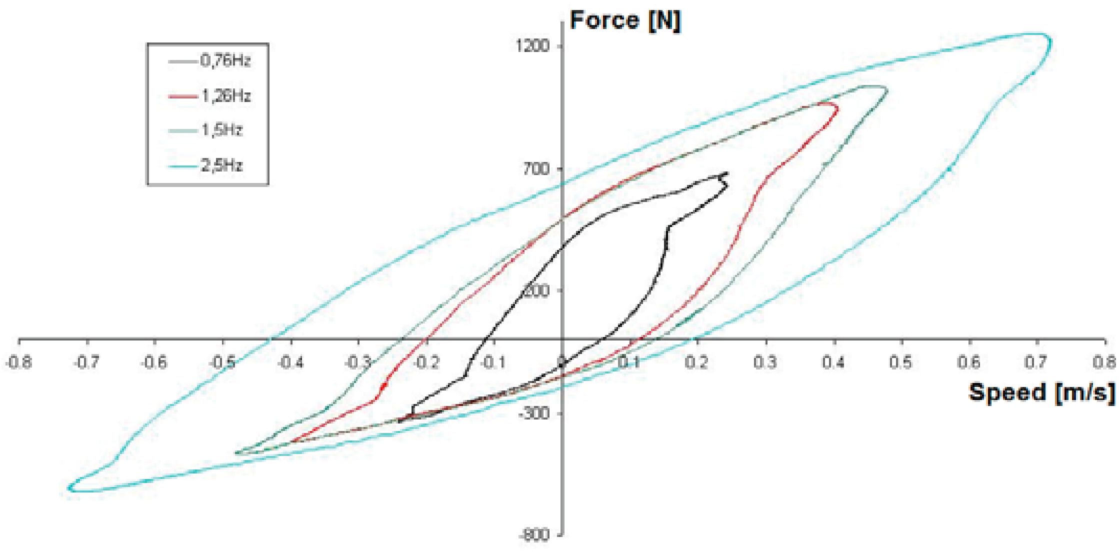

Fig.4. A set of characteristic curves for a shock absorber with a defective valve.

An estimator widely used for assessing technical state of shock absorbers was based on maximal and minimal damping force rates which were compared with those in a new absorber. The author introduced a new diagnostic parameter to the assessment process, namely damping power. This enables more accurate identification of damages. Another method to analyze the recorded results on the indicator rig is a system based on neural network.

Indicator testing method is very accurate. The results have a high level of reliability. However, it can only be used for absorbers that have been removed from the car.

Among a variety of testing methods, those requiring no removal are by far preferred by Vehicle Control Stations or diagnostic lines. The methods can be divided as follows:

-free vibration type,

-forced vibration type.

Free vibration type consists of car vibration caused by a single impulse. Car body will vibrate, but the higher damping force in the suspension, the sooner the vibration will disappear. The impulse to cause vibration may include: free fall, drop from a moderately high level, single load on the body. If ground load as induced by the wheel is measured, damping effectiveness may be based on the ratio of least wheel load on the ground during vibration to static wheel load, recorded in the form of diagrams in time function (CARTEC method). If the diagnosing device is to measure body deflections from the ground, damping effectiveness value may be based on four successive amplitudes throughout the body vibrating time (Mtronic GmbH). Testing methods based on free vibrations require previous records of the car model to refer to.

Another method (deflection type) consists of tests on the undercarriage movements upon stimulation by an impulse. This method involves „dropping" the car from a movable bearer. The procedure is as follows: The car should be brought up in such a way that the wheel is placed on the movable bearer. Then the car is brought further up by means of a compound lever. When the latter is unlocked, the car drops onto the rig plate causing unsprung and sprung masses to vibrate. Technical state of the absorber is shown bay mean damping rate (negative amplitude-to-positive amplitude ratio during the first swing).

Among methods requiring no removal of the absorbers, EUSAMA and BOGE types or their derivatives are most popular, and both involve forced vibration. The methods are based on harmonic, mechanical vertical vibration inductors stimulating vibration in the wheel which has been placed on the test rig plate. Original vibration frequency is higher than resonant frequency of the unsprung mass. The stimulation cycle has three phases. As soon as the inductor is switched on (phase 1), the test rig will run up to receive the frequency higher than resonant frequency of the suspension. Phase 2 imposes stimulation on the suspension with stable frequency (approx.21 or 26 Hz). When the inductor is switched off (phase 3) the vibration begins to disappear in result of damping process on the absorber, suspension elements and tyre. Vibration amplitude and frequency become reduced. When vibration frequency is the same as suspension resonant frequency, the vibration amplitude will increase indicating technical state of the absorber. Damping effectiveness is defined on the basis of vibration analysis:

- in function of time (BOGE method),
- in function of wheel load on the plate (EUSAMA method).

The BOGE method assumes that absorber quality indicator is damping decrement considered as double amplitude of resonance vibrations. Course of vibration in the test plate is recorded (usually by means of an ultrasonic probe) and compared with reference courses in the absorbers of respective car model. A modified BOGE method,
used for MAHA equipment enables assessment of suspension-mounted absorbers in percentage terms. The method assumes linear relationship between extortion amplitude and the car mass load on the plate as well as linear relationship between damping efficiency (in %) and the plate vibration amplitude.

The EUSAMA method, developed by The European Association of Shock Absorber Manufacturers, attempts to asses (in %) the adhesive force of the wheel on the plate. Damping effectiveness is indicated by EUSAMA WE factor as follows:

$$WE = \frac{Q_{\min}}{Q_{st}} \cdot 100\%, \tag{3}$$

where:
Qmin - minimal value of apparent wheel load on the plate when resonance occurred; assumed stable frequency 16Hz,
Qst - static value of wheel load on the plate as defined for motionless plate.

Technical state of shock absorbers is assessed by analysis of the result as per the four-stage scale shown in table 1.

Tab. 1. Technical state of shock absorbers

WE [%]	Quality assessment of damping effectiveness
0 - 20	Bad
21 - 40	Satisfactory
41 - 60	Good
60 - 100	Very good

Assessment criteria are the same for all types of vehicles. Difference in WE values between left and right side when measuring one axis should not exceed 20%.

However, the method raises doubts when used to test vibration damping effectiveness in rear axle suspension in light cars with front-wheel drive. In many cases damping effectiveness in such cars was shown to be on the verge of „good-bad”, and sometimes even „very good” (the latter upon loading the car).

Some companies, e.g. Hoffmann, extended the original scale by another parameter i.e. natural mass of vehicle, changing the range limits accepted by EUSAMA system and defining maximum difference in WE values for the axle.

Beissbarth introduced a new method called EUSAMA plus, using fluent control of extortion frequency. Measurement process comprises two stages:

– preliminary stage - to warm-up the absorbers; this stage takes about 10s. and runs with low vibration frequency; air pressure in tyre is checked automatically basing on tyre deformations in result of variable load;
– to measure the damping coefficient.

The measurement process is accompanied by changes in vibration frequency, the latter being fluently reduced by 1 Hz from 30 Hz to 8 Hz. Careful analysis of resonance range is done for unsprung masses (13-18 Hz). Apparent weight of unsprung masses when loading the rig plate during squeezing and stretching the absorber is measured for the entire frequency range. This enables assessing the sprung and unsprung mass sizes and defining the ratio of these masses to the car. Then a relationship between damping coefficient and sprung mass-unsprung mass ratio is determined. Final assessment of the absorber technical state is based on a three-stage scale.

Another modification of the harmonic test used to diagnose shock absorbers mounted in cars is Hunter Engineering Company method. Assessment of suspension technical state
is chiefly based on phase angle. Physically, a phase angle is considered as phase shift between signal of test rig plate dislocation and signal of variable wheel pressure on the plate. The difference in comparison with EUSAMA method is that an additional vibration signal parameter, i.e. the plate shift, is measured. Dislocation of the unsprung mass against the plate is proportional to actual value of the pressure between them. Therefore both dislocation and acceleration of the unsprung mass is greatest when the phase angle value is zero (no damping). As soon as damping is brought into the system, dislocation of the wheel becomes reduced and value of the phase angle increases. Value of the phase shift within frequency band between sprung mass resonance and unsprung mass resonance is called the smallest phase angle. It should be approx.90^o if the absorber is in good condition.

3. Summing-up

Reliability of testing methods used for fluid telescopic shock absorbers was assessed basing on analysis of their advantages and disadvantages.

1 An advantage of indicator tests on shock absorbers is high reliability of the results. Damping power or neural network used as estimator enables easy identification of damages. Principal disadvantage of the method is that shock absorbers must be removed from the car suspension. The method is expensive and time-consuming. This disadvantage excludes the method from diagnosing procedure used for shock absorbers by Vehicle Control Stations.

2 Free vibration methods used for testing shock absorbers mounted in cars are simple and relatively cheap. However, they have numerous disadvantages. They are not enough sensitive to changes in damping coefficients, but are very sensitive to changes in the suspension dry friction and changes in the car service load. More advantages are noted with the „drop" method. One of them is that the method can discover damages affecting vibration amplitudes (loss of fluid, damages to non-return valve). Disadvantages include little sensitivity to overflow valve damages and assumption that damping characteristics are linear in form.

The EUSAMA method, developed by The European Association of Shock Absorber Manufacturers, has become a standard among methods based on forced vibrations, and practically superseded other methods. Advantages of this method include a standard test rig, large statistical material and no necessity of having previous records to refer to. Disadvantages include as follows: assumption that damping characteristics are linear in form and that resonance frequency in the suspension is stable, practically two-state, school-like system of shock absorber assessment, excessive ranges allowed for specific states, no identification of damages, ambiguous results for rear axle absorbers and „satisfactory" absorbers. EUSAMA recommendations are that they should be examined on indicator test rig upon removal from the car.

Other methods (BOGE, MAHA, Hoffmann) have practically no applications now. They require previous records to refer to and assume linear characteristics for shock absorber damping. Methods proposed by Beissbarth or Hunter Engineering Company are not used by Vehicle Control Stations in spite of their advantages.

Conclusions

The methods used for diagnosing fluid shock absorbers in cars do not explicitly define their technical state and do not identify the type of damage. The accepted assumption that characteristics of damping or elasticity are linear informs that it is false and inconsistent with design solutions used for such elements nowadays. The results must be treated as approximate. Therefore it seems reasonable to make special effort in order to develop more reliable methods which could have wide application in practice.

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