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EXPERIMENTAL DIAGNOSIS OF CAVITATION FOR A HYDRAULIC MONOTUBE SHOCK ABSORBER

Giulia MORETTINI, Nicola BARTOLINI, Davide ASTOLFI, Lorenzo SCAPPATICCI, Matteo BECCHETTI, Francesco CASTELLANI
University of Perugia, Department of Engineering, Perugia, Italy, e-mail: morettinigiulia@gmail.com

Abstract

Hydraulic shock absorbers are mechanical devices responsible of vibration damping. Although a high level of development and tuning has been carried on, in order to ensure high performance standards in almost every situation, some dynamic phenomenon affecting internal fluid may reduce the damping capacity. In hydraulic shock absorbers, the energy is dissipated forcing the internal fluid through calibrated orifices; this energy is converted in heat and dispersed outwards from the external walls. Hydraulic fluid has therefore a fundamental role for the proper functioning of the overall device, and the most important variations of its chemical-physical properties have to be considered. One of the most dangerous phenomena involving the internal fluid is cavitation, which could affect performances and generate structural damages of the internal components of the damper. The aim of this work is to diagnose the phenomenon of cavitation using experimental data from a prototype of monotube shock absorber equipped with transparent walls and developed for research purposes. The identification of force and displacement parameters is carried out through experimental tests on the prototype, which is a totally adjustable device equipped with pressure and temperature transducers for every chamber. The optical access provided from the transparent wall allows to collect images from a high-speed camera, which could be related to the signals coming from the transducers. This approach is valuable for analyzing the occurrence and the time development of dynamic phenomena of cavitation of the flow or the motion of the main valve blades. Finally, the acquisition of the optical images, coupled with evidences from experimental data, allows to characterize the dynamic events of cavitation, from his onset.

Keywords: Shock absorber, cavitation, shock transparent.

1. INTRODUCTION

The main function of shock absorbers is to dissipate the vibrational energy coming from dynamic loads acting on the mechanical elements. In this way the duration and the amplitude of the vibrations are reduced. In the automotive field, the shock absorbers are one of the most important components of the suspension system for a wide range of vehicles. The main task of a suspension system is to reduce the entity of vibrations coming from the terrain to the chassis through the connection components (tyres, suspension links, joints). This leads to two relevant advantages, such as the improvement of the comfort for passengers and the possibility to adjust the dynamic behaviour of the vehicle [1]. For these reasons, the correct design and tuning of a suspension system is fundamental in order to ensure the adequate level of safety and handling for various vehicles, from means of transport to competition cars and motorbikes. There are different methods used to dissipate the energy, but hydraulic shock absorbers are nowadays the most used kind of damper, primarily for the automotive sector. For this reason, it is fundamental to investigate the behavior of the internal fluid and the most important phenomena to which it is subject. The response of the shock absorber to external stresses is strongly non-linear and characterized by hysteresis phenomena. For this reason, numerical modeling is challenging and vastly addressed in the literature, both with parametric [2-4] and physical [5-9] approaches. Cavitation [10] occurs when the oil vapour pressure exceeds the local static pressure. This is analogous to boiling, but it happens because of the pressure reduction rather than because of temperature and vapour pressure increases. Nevertheless, at high temperature the oil vapour pressure is higher, and cavitation is somewhat easier to create. When cavitation happens, numerous pockets of oil vapour are created throughout the oil. A small increase of pressure can easily turn them back into liquid, with a severe slam shock, causing bad noise and possible damage to the internals of the damper. Cavitation may be avoided by correct design, in such a way that the pressure at all points in the damper exceeds the vapour pressure [11].

For a pressurised single-tube damper, cavitation occurs earlier in the extension chamber when the pressure drop through the piston exceeds the pressure in the compression chamber (Figure 1). In this paper, we define “incipient cavitation” when the phenomenon involves only a small region of space in the rebound camber; It is called “evolved cavitation" when it involves the entire compressed chamber. Finally, it is called "complete cavitation", when it involves also the chamber which is in compression phase [12].

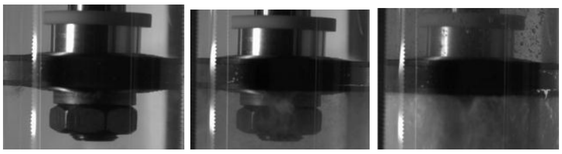

Fig. 1. The evolution of cavitation

Although the phenomenon is highly investigated in volumetric compression machines, scientific literature regarding shock absorbers is at its early stages. For this reason, this work has the objective to evaluate the beginning and the evolution of phenomenon, when the shock absorber is subject to variations in pressure and temperature. Further objective is to understand how the variation of these parameters affects the overall performances.
This discussion is organized in two Sections: in the first, the influence of the pressure on the phenomenon of cavitation is addressed; in the second, the influence of the temperature is discussed. In Section 3, the results are collected. The conclusions are drawn, and some further direction is sketched in Section 4.

2. EXPERIMENTAL SETUP

The Department of Engineering at the University of Perugia provides an instrumental set, for capturing the test data. The test bench (Figure 2) is constituted by a static solid structure and by a road crank actuated by an electrical motor. This stresses the shock absorber with sinusoidal displacement at variable frequency from 1 to 6 Hz.

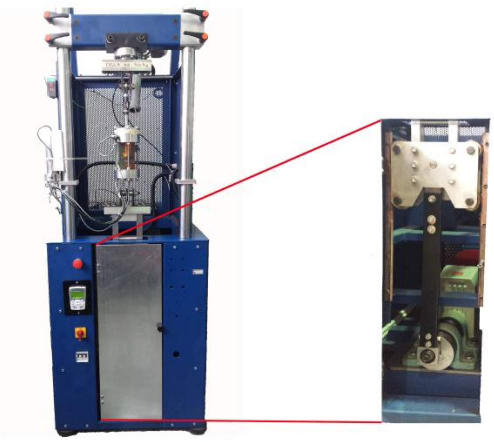

Fig. 2. The test bench and a detail of its road crank

The excursion of the piston road is 16 mm both in compression and return phase. The test bench is equipped by:

- pressure sensor, recording variations of the absolute pressure in each chamber of the shock absorber;
- thermocouple, recording oil temperature;
- load cell, recording the force
- displacement sensor, allowing to follow the piston in its movement.

The central element of the experimental set up is the transparent monotube shock absorber (Figure 3), with a separate compensation chamber, where a floating piston separates oil from nitrogen.

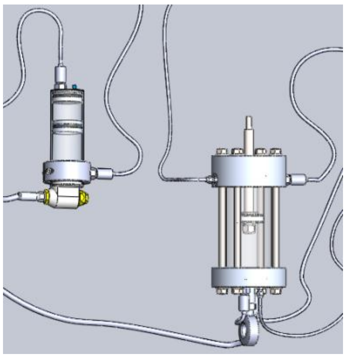

Fig. 3. Render of the transparent monotube shock absorber

The walls of the principal chamber are transparent: this makes it possible to observe the cavitation phenomena with a high-resolution camera (Phantom V700). The optical acquisition system allows to capture the phenomena related to the oil cavitation also for low variation of pressures.
The classic test, for extracting the features of a shock absorber, is based on submitting a sinusoidal motion with fixed amplitude to the system and then measuring the force transmitted by the damper to the structure. The synchronized data of force, displacement and velocity are collected, in order to generate the two characteristic graphs in output from the analysis, which are the force-displacement and force-velocity diagrams (Figure 4).

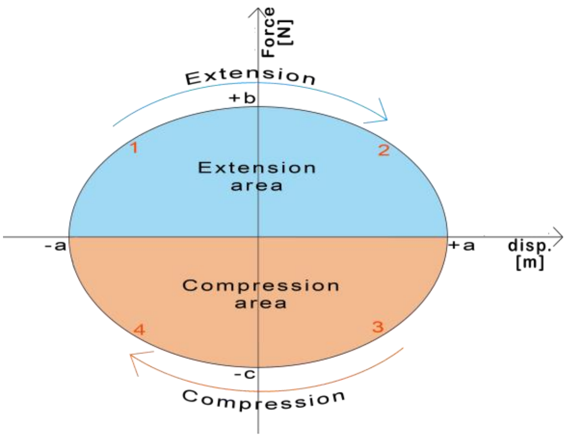

Fig. 4. Example of Characteristic Curve

The area of the underlying Characteristic Curve represents the energy that the shock absorber is able to dissipate. During the cavitation, this area is greatly reduced: the complete cavitation phase generates two "bites" which reduce the performance of the shock absorber.

3. EXPERIMENTAL ANALYSIS

3.1. Influence of the airlock pressure variation on the cavitation

The first analysis is aimed at evaluating the influence of the pressure of the gas in the airlock on the phenomenon of cavitation and consequently on the performance of the shock absorber.

24 tests are carried out by varying the relative pressure among predetermined values [0 - 0.2 - 0.5 - 1 MPa] and changing the stress of the frequency bank from 1 to 6 Hz, by 1Hz steps. The temperature is kept constant and equal to 20°C. The working fluid is never replaced; it has a SAE 5W viscosity and the settings of the valves are unchanged for all the tests. Starting from the highest frequency, the output data from the test are processed through a Matlab script, reconstructing the Characteristic Curve (Figure 5).

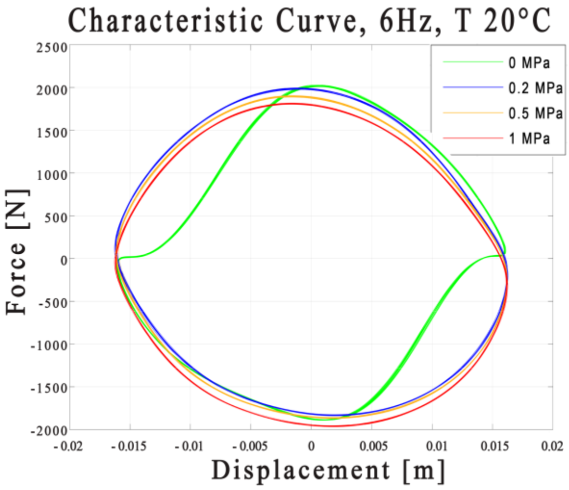

Fig. 5. Characteristic Curve, 6Hz, [0 - 0.2 - 0.5 - 1 MPa]

Apparently, the cavitation phenomenon occurs only for relative pressure near to zero bar. Yet, analysing further through optical acquisitions, it is possible to verify that the phenomenon is clearly present in many tests. For example, at 0.5 MPa pressure, an incipient cavitation is observed (Fig. 6).

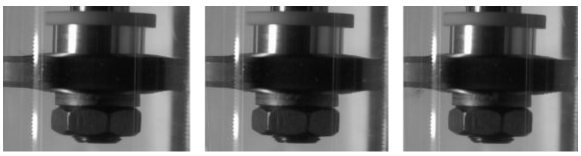

Fig. 6. Images acquisition of the test, 6Hz, 0.5 MPa

At 0.2 MPa pressure, an evolved cavitation arises (Figure 7); at 0 MPa, a complete cavitation is observed (Figure 8).

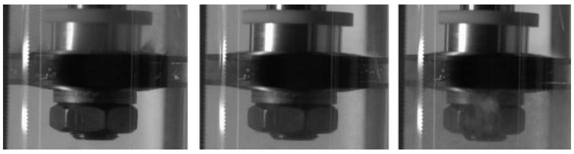

Fig. 7. Images acquisition of the test, 6Hz, 0.2MPa

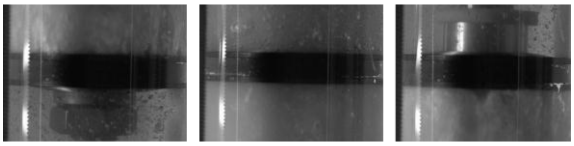

Fig. 8. Images acquisition of the test, 6Hz, 0MPa

Only at a gas pressure of 1 MPa, bubbles are not observed. Decreasing the frequency of the stress, cavitation occurs only for low values of pressure.

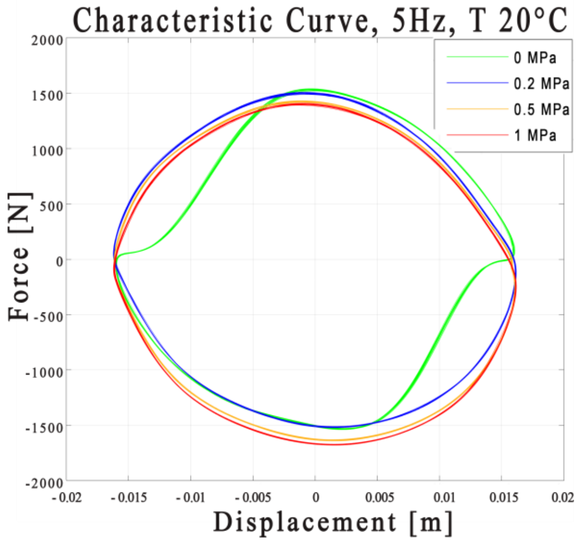

Fig. 9. Characteristic Curve, 5Hz, [0 - 0.2 - 0.5 - 1 MPa]

From the Characteristics Curves (Figure 9), one can see that, when there is no cavitation, curves come closer, until they finally overlap. Lowering the stress frequency again, for values close to 2 and 1 Hz, the cavitation does not occur. The performance of the shock absorber returns to normality.

3.2. Influence of the temperature variation on the cavitation

This analysis aims at evaluating the influence of the temperature of the oil in the cavitation phenomena. 96 tests are performed varying the temperature among four established values [20 °C, 30 °C, 40 °C, 50 °C]. This temperature range is selected because in this way it is possible to consider the relevance of the variation of the viscosity of the oil. At the same time, no excessive dilatation of the main chamber is caused. Maintaining a constant temperature, the stress frequency and the pressure are varied, in order to generate a general map of the onset of the cavitation and its evolution. Through the map of Figure 10, one can argue that the most challenging testing ground is the regime of low pressure – high frequency stress.

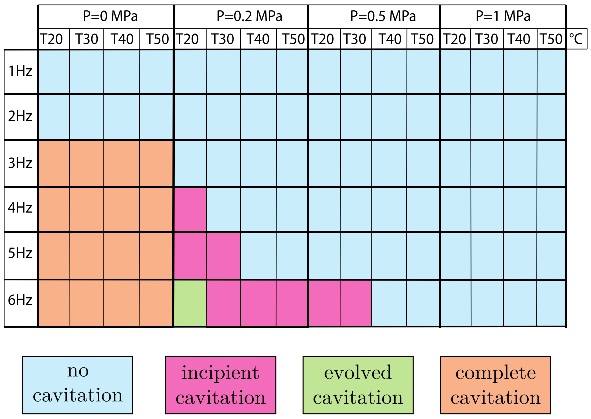

Fig. 10. Summary grid of an optical evaluation

From the grid (Figure 10) produced by the first analysis of the data made through the video capture, it is evident that the effect of temperature on the cavitation is the opposite of what one could expect. Evaluating the test carried out at [6 Hz, P = 0.5 MPa] of Figure 11, it arises that, in the captured frames at a temperature of T = 20 °C, the cavitation occurs in the incipient phase. As the temperature increases, it fades and ceases to exist.

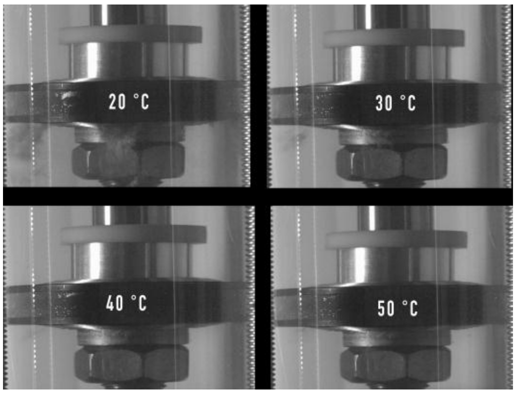

Fig. 11. Video acquisitions of piston, stressed 6 Hz, gas pressure 0.5 MPa, during the variation of the temperature

The analysis goes on through comparison of the data output coming from the bench. The force-displacement curves (Figure 12), at this point, confirm the data captured by the video.

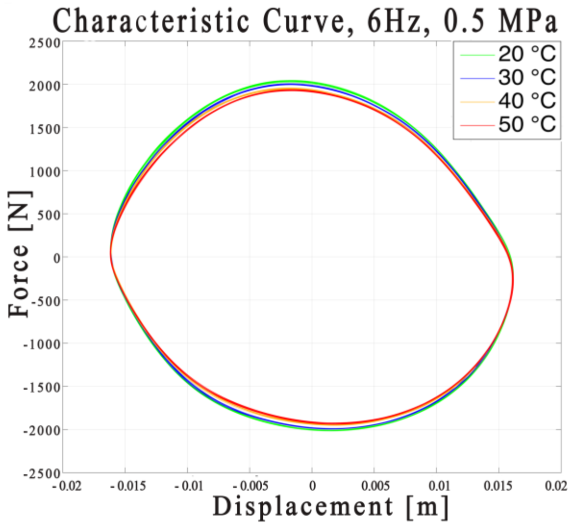

Fig. 12. Characteristic Curve, 6Hz, 0.5MPa, [20-30-40-50 °C]

Also the test, where the cavitation is present in incipient or evolved phase (pink and green colour of Figure 10), presents the same trend.

The situation changes when, at the start of the test, a complete cavitation phase is present (orange colour of Figure 10). In this condition, during the variation of the temperature, the cavitation phenomena decreases, as arises from the Characteristic curve (Figure 13).

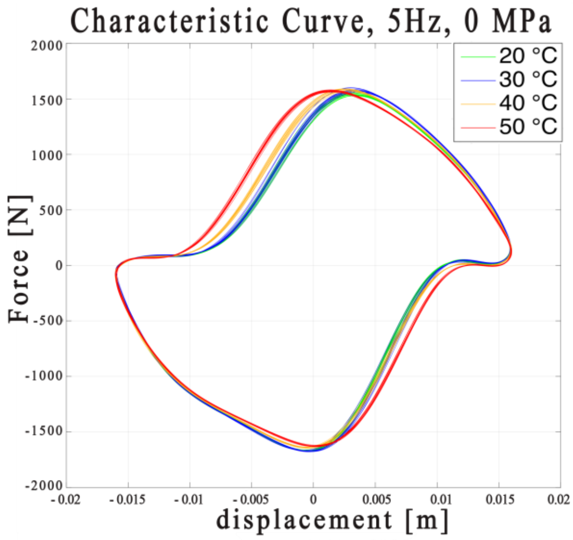

Fig. 13. Characteristic Curve, 5Hz, 0MPa, [20-30-40-50 °C]

4. RESULTS

In the following, the results of the experimental analysis are presented.

4.1. Results: influence of the airlock pressure

All the experimental tests display the same response to pressure variation: if the pressure decreases, cavitation occurs for lower stress values.

It is possible to summarize this trend through a plot, illustrating the variation of the performances of the shock absorber. They are expressed in Joules, and in Figure 14 they are shown as function of the pressure and of the stress of the frequency bench.

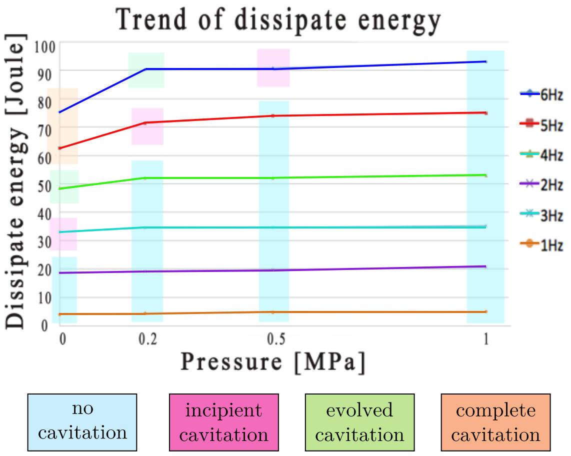

Fig. 14. Variation the performance of the shock absorber

For high degrees of stress and low pressure, the cavitation is present in a complete form: this causes a sharp reduction of energy that the shock absorber is able to dissipate.

For a frequency of 6Hz, the loss is about the 20% of energy between no cavitation phase and the complete cavitation phase.

4.2. Results: influence of the variation of the temperature

From the data collected for the temperature experimental analysis, it arises that two cases must be distinguished:

1- If the increase of temperature occurs when the cavitation is in incipient or evolved phases, it generates a decrease of the cavitation phenomenon. This leads to an expected increase of forces, but an opposite behaviour is caused by the reduction of the oil viscosity. In this situation, the weight of the second phenomenon is larger and the amount of energy dissipated per cycle decreases with the increasing of temperature.

It is possible to summarize this trend through a plot (Figure 15), illustrating the variation of the performances of the shock absorber. They are expressed in Joules, and they are function of the temperature for fixed values of frequency bench stress end pressure.

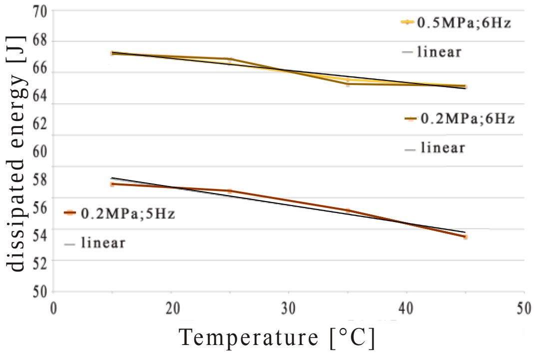

Fig. 15. variation of the performance of the shock absorber. Incipient or evolved cavitation

From Figure 15, it arises a decreasing trend: the different curves are only translated by the different stress level.

2- If the variation of temperature occurs when the cavitation is in complete phases, even in this case the influence of rising temperature generates a decrease of the cavitation phenomenon. In this situation, the force recovery due to this behaviour is higher with respect to the decrease generated by the reduction of oil viscosity, and the amount of dissipated energy per cycle increases.

It is possible to summarize this trend through the plot of Figure 16, illustrating the variation of the performances of the shock absorber. They are expressed in Joules, and they are shown as function of the temperature, for fixed values of frequency bench stress and pressure.

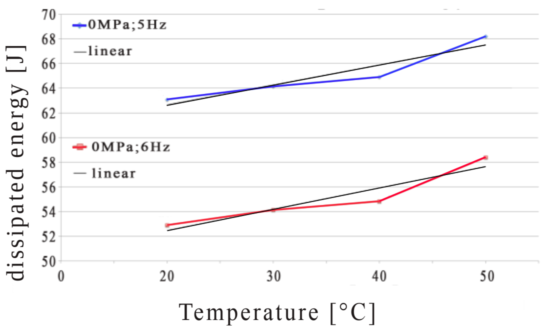

Fig. 16. Variation of the performance of the shock absorber. Full cavitation phase

From Figure 16, it arises that the increase trend is the same: the curve is only translated by the different stress level. For a variation of 40°C, the shock absorber retrieves an 8% of its performance.

5. CONCLUSIONS AND FURTHER DIRECTIONS

In this study, the importance of airlock pressure and oil viscosity on the phenomenon of cavitation for a monotube shock absorber has been assessed.

Focusing on the effect of airlock pressure, from the experimental tests it is evident that its increase limits the appearance of the cavitation phenomenon. However, the analysis highlighted the usefulness of the optical acquisition to diagnose the actual presence of the cavitation. In fact, from the classic data acquisition it is not possible to notice the onset of the phenomenon, which is revealed only from the optical acquisition in many cases.

Regarding the second stage of the work, oil properties and his treatments affect greatly the generation and the evolution of the phenomenon [13].

It has been observed that the variation of viscosity (caused by variation of temperature) can cause two effects:

1- A decrease of the maximum forces, produced by a lower viscosity: it generates a reduction of the possibility that the pressure drops below the values of the vapour pressure, and therefore generates cavitation.
2- A greater possibility of cavitation, produced to lower surface tension, caused by lowering oil viscosity.

The analysis of this tow bucking effect [14] is the main future direction of this work. The device developed for this work can be profitably used to better investigate other internal phenomena related to hydraulics shock absorbers. For instance, the knocking noise phenomenon [15] can be individuated and characterized exploiting accelerometric measurements and image acquisition of the inner behaviour of fluid and valves.

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Giulia Morettini is a Mechanical Engineer; she graduated with 110Lode/110 at the University of Perugia (ITALY). This work comes from the research for her thesis. During her academic career she has actively participated in many projects:

- Team Leader FSAE, during the construction RB11.1, best emerging team in Varano competition.
- Designer of the car suspensions group, RB12.1.
- Numerical simulation of condition monitoring and diagnosis of suspension motion.