A COMPUTATIONAL FLUID FLOW ANALYSIS OF A DISC VALVE SYSTEM

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Abstract

Noise concerns in shock absorbers can be divided into two categories. The first is fluid flow noise, or "swish noise", caused by the oil being forced through openings in the valves. The type and temperature of the oil, its velocity and the orifice geometry all have an effect on this. In addition, the structural design of the shock absorber shell may either reduce or amplify the noise. The second type of shock absorber noise is often described as regular operational noise or "chuckle noise". It can be observed in vehicles during low-displacement, higher-frequency events, such as driving over a slightly rough road. This effect measurable as a force discontinuity into the vehicle and can come from a number of sources in the shock absorber, e.g. hydraulic transitions. It is often traceable to the valve discs closing and opening, but can also be caused by cavitation/aeration in the oil and air being pulled through the valves. The work on noise improvement reported in this paper has been started using conventional shock absorbers to be extended and will cover in the future variable damping shock systems as well. The paper gives an overview about the configurations of a typical valve system including three basic regimes of operation, which correspond to the amount of oil flowing through a valve cavity. The aim of this work was to propose a finite element fluid flow model, which can be used in order to reduce the velocity of fluid flow through a cavity of a shock absorber valve. High flow velocity can cause high-content frequency vibrations and, in turn, audible noise. The model will be used for initial screening of new valve concepts and on the other hand to improve the currently use ones.

Keywords: *valve system, computational fluid flow analysis, simulation*

1. Introduction

Noise is the audible effect of structural and forced vibrations, and its reduction is carried out at shock absorber manufacturers as a product design and optimization activity. Recently, the subject has increased in importance for two reasons. Firstly, the unquestionable growth in quality demands in the automotive sector has created a requirement to significantly prolong warranty periods, and there is a clear tendency towards lowering the level of radiated noise and produced vibrations. Secondly, in the 1980s the first computer controlled variable damping systems were launched into the passenger car market. These systems require more effort to optimize noise and vibration because of controllable changes in damping force corresponding to road conditions, whose effect is not present in conventional shock absorbers. The noise of a hydraulic shock absorber includes friction noise, air current noise, liquid current noise and structural noise. Research work and experiments indicate that abnormal noise is related to high-frequency vibrations ranging from 0.1 to 2 kHz on the piston rod assembly, during the alternation of the rod travel direction. Although the causes of the noise of hydraulic shock absorbers have not been well explained by theory, there is a clear correlation between the sound emission of a shock absorber and its vibrations. The process of generating audible noise is complicated. It is necessary to first understand the mechanisms of vibrations and their transfer through a shock absorber, and then to investigate aspects of audible noise generation in order to attenuate its impact on shock absorber quality. The main vibration and harshness contributors inside the shock absorber are mechanical and fluid perturbations frequently occurring during the switching of valves. Hydraulic resonance and the instability of fluid-flow systems is widely reported in the literature [1-2]. The consequence of resonance in fluid systems can be instability, noise and vibrations. This paper therefore focuses on modelling fluid flow through a cavity of a shock absorber valve. CFD (computational fluid dynamics) allows flow paths to be visualized and analyzed in order to reduce the flow velocity. CFD analysis was performed at two characteristic points located on the operational curve of a valve. The first point corresponds to an opening of a valve, while the second point corresponds to the maximal opening of the valve.

2. Shock absorber system

A conventional double-tube hydraulic damper consists of interconnected chambers and a piston that is kinematically forced to move inside a liquid-filled cylinder [3]. The pressure differential builds up across the piston and forces the liquid to flow through restrictions (orifices) and valves located in the piston and the base assembly (Fig. 1).

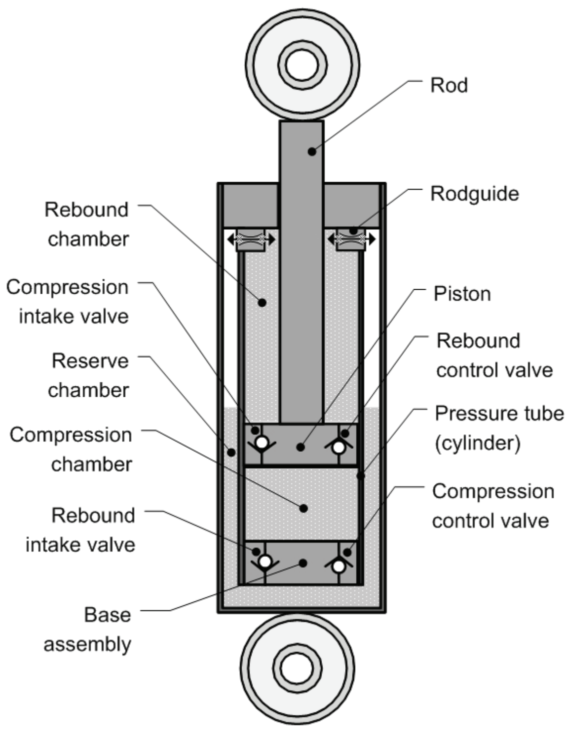

Fig. 1. An example of the influence of the number of thermal shocks on the piston sample deformation

The piston divides the cylinder space into two chambers; the rebound chamber, i.e. the portion of the cylinder above the piston, and the compression chamber, i.e. the portion below the piston. Movement of the piston rod transfers the liquid surrounding the cylinder to and from the reserve chamber through the base valve located at the bottom of the compression chamber. The rod guide consists of a self-lubricated bearing, and the controlled bypass from the rebound chamber to the reserve chamber. The function of the bypass is dearation of the rebound chamber since the presence of entrapped air results in a large piston displacement during the oil compression stroke. Two types of valves, intake valves and control valves are used in a shock absorber. Intake valves are check valves providing low resistance to flow in one direction and, upon reversal of the differential pressure, preventing the flow in the opposite direction. A valve spring is used to preload control valves and to prevent their opening until a specified pressure differential has built up across the valve; stiffness of the valve spring controls the height of the opening. Depending on the required force-displacement range and tolerance, coil or disc springs are used. Orifices in a disc, or notches in the valve seat, are used to provide a highly restricted flow path between two chambers when the connecting valves are closed.

3. Valve System of a Shock Absorber

The paper considers a specific type of shock absorber valve, i.e. the clamped piston valve presented in Fig. 2. Such a valve system consists of a combination of disc springs, referred further in the paper as a stack of discs or a disc stack, designed to withstand varying pressure load across the valve system. The number of discs, their diameters and thickness, directly affects the operational characteristics of the valve system.

A valve system operation can be split into three regimes. In the first regime, there is only a small flow through bleeds of a very small area below 1 mm2 in the so-called orifice disc while the stack of discs is completely closed (Fig. 2a). The damping forces produced by the valve are therefore very small, similar to a drive along a smooth road such as a highway. The stack of discs starts opening in the second regime providing a typical range of damping forces (Fig. 2b).

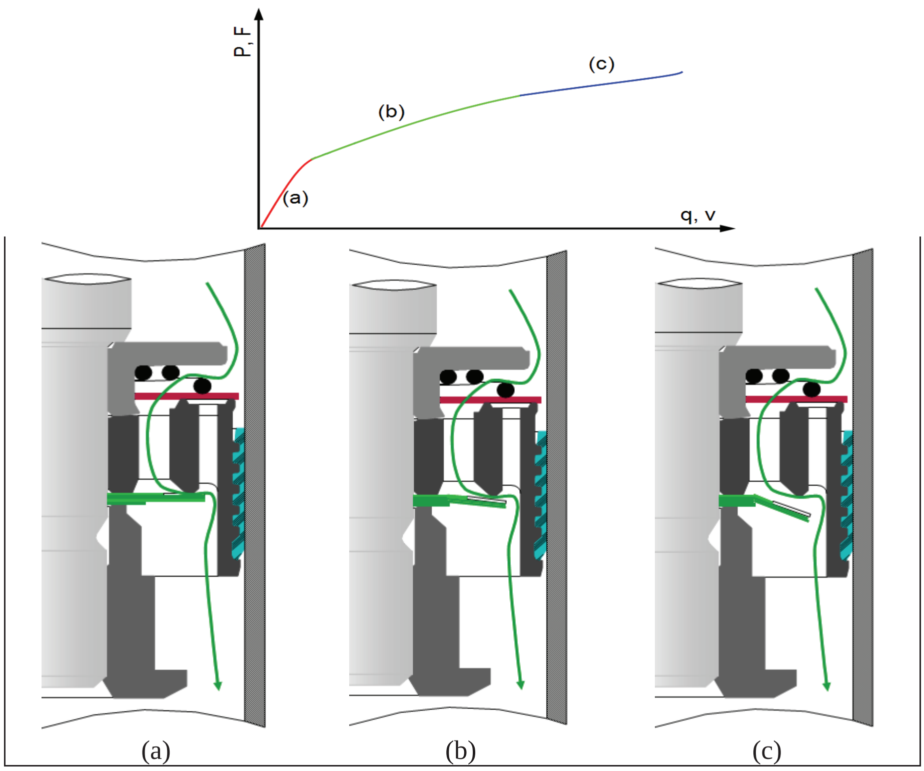

Fig. 2. Pressure-flow or force-flow characteristics and its regimes: a) bleed operation; b) normal operation; c) high-damping operation

The last regime corresponds to the case when the stack is fully opened and the restriction is provided by the profiled channels in the piston (Fig. 2c). This regime represents off-road conditions or violent manoeuvres on the road.

This work focuses on the second regime, where the initial opening and maximal opening points are taken into account.

4. Valve System of a Shock Absorber

A CFD model has been created in the ANSYS CFX v11 program. The model consists of two million nodes in the case of the minimal disc stack opening. Nevertheless, the number of nodes in the grid is greater in the case of maximal opening where the cavity volume is larger due to lifted discs.

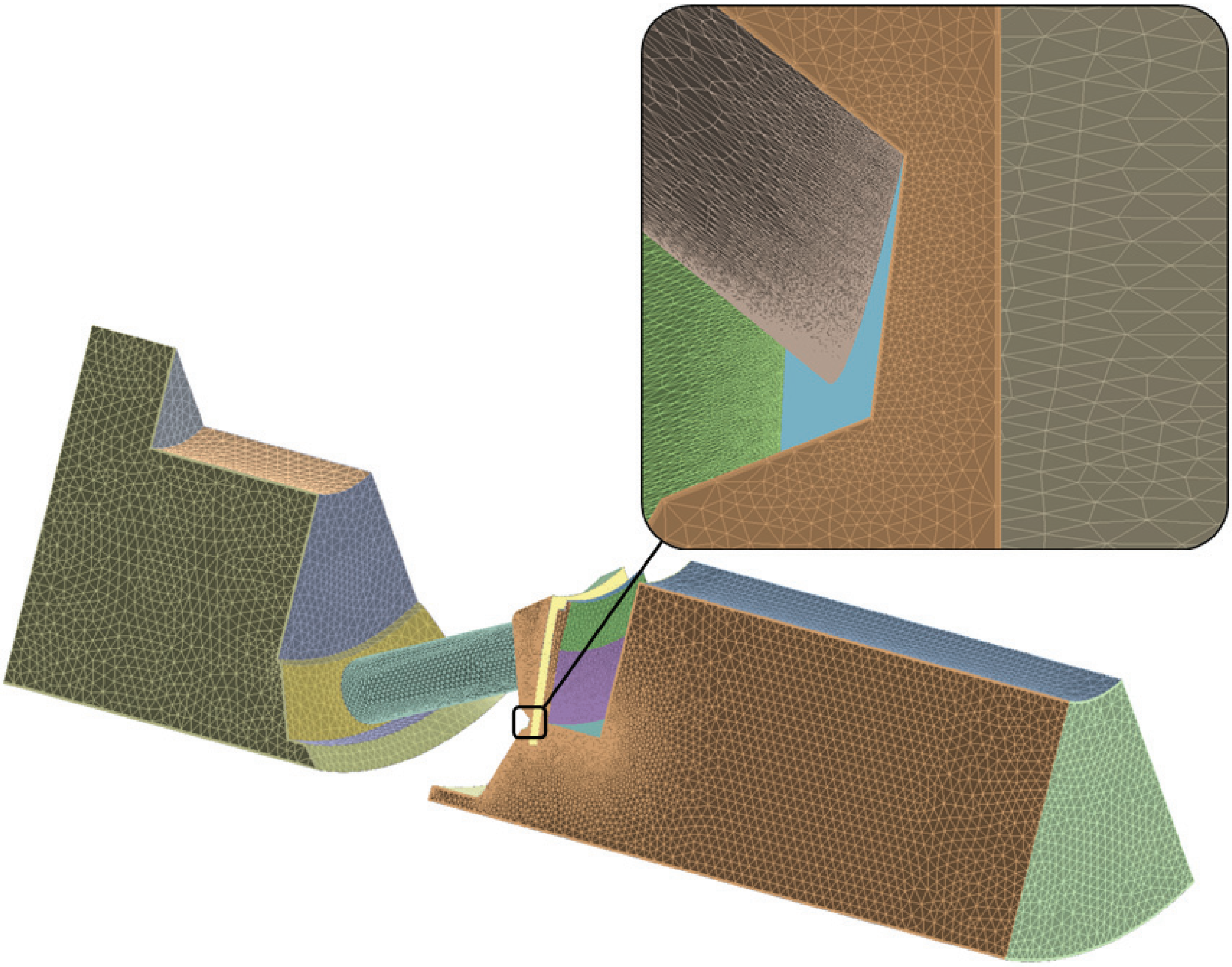

Fig. 3. Numerical model geometry of the valve and the grid of finite elements

A similar study aimed towards development of a CFD model of a valve system is presented in [4].

5. Discussion of simulation results

Figure 4 presents flow streams in the case of minimal and maximal valve opening. The flow patterns are more organized for a small opening compared to a large opening. Our simulations confirmed that higher velocity corresponds to a higher opening of the stack of discs (Fig. 5). These differences are clearly noticeable in the channels below the stack of discs.

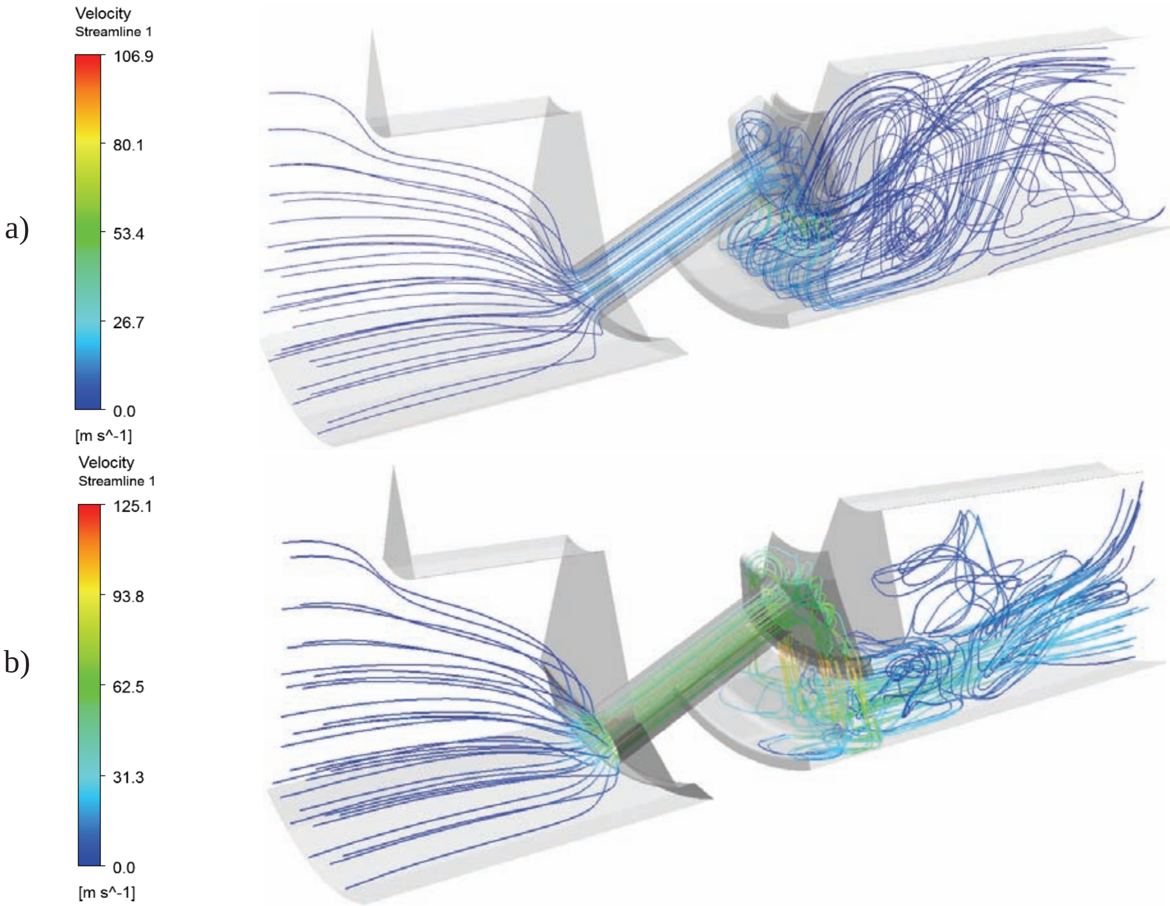

Fig. 4. Streams of flow: a) minimal opening; b) maximal opening

The pressure maps indicate the region of higher flow velocity where the highest pressure drops is in the channels transporting fluid under the stack of discs (Fig. 6). There are areas of high pressure gradient of the magnitude 4 MPa. This indicates regions where cavitation may occur.

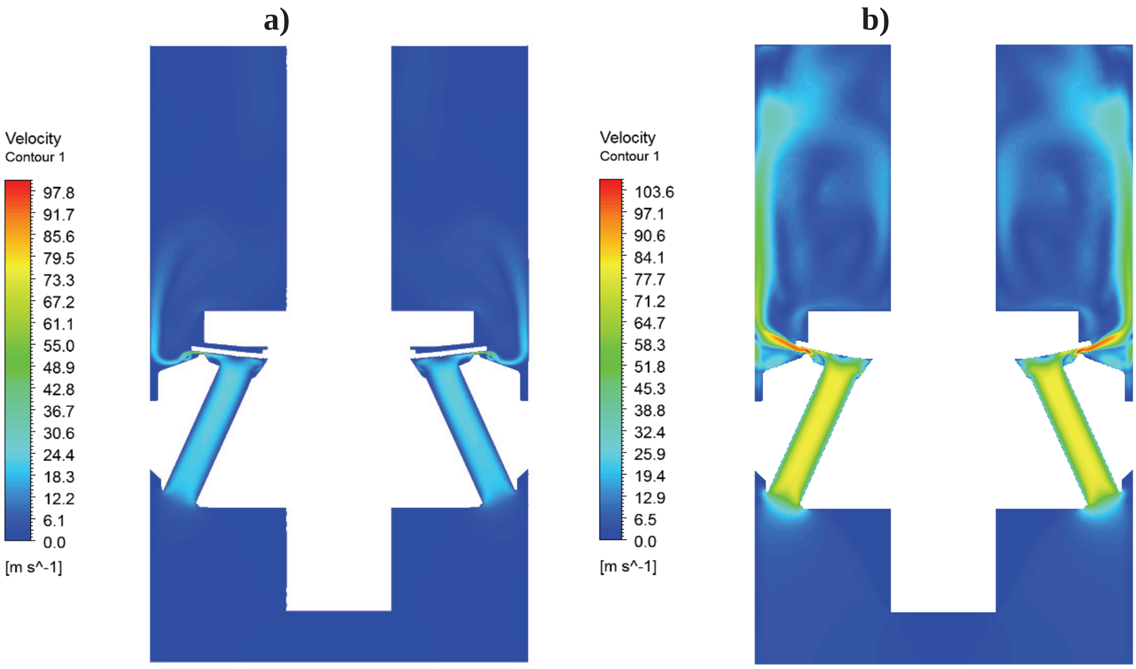

Fig. 5. Flow velocity: a) minimal opening; b) maximal opening

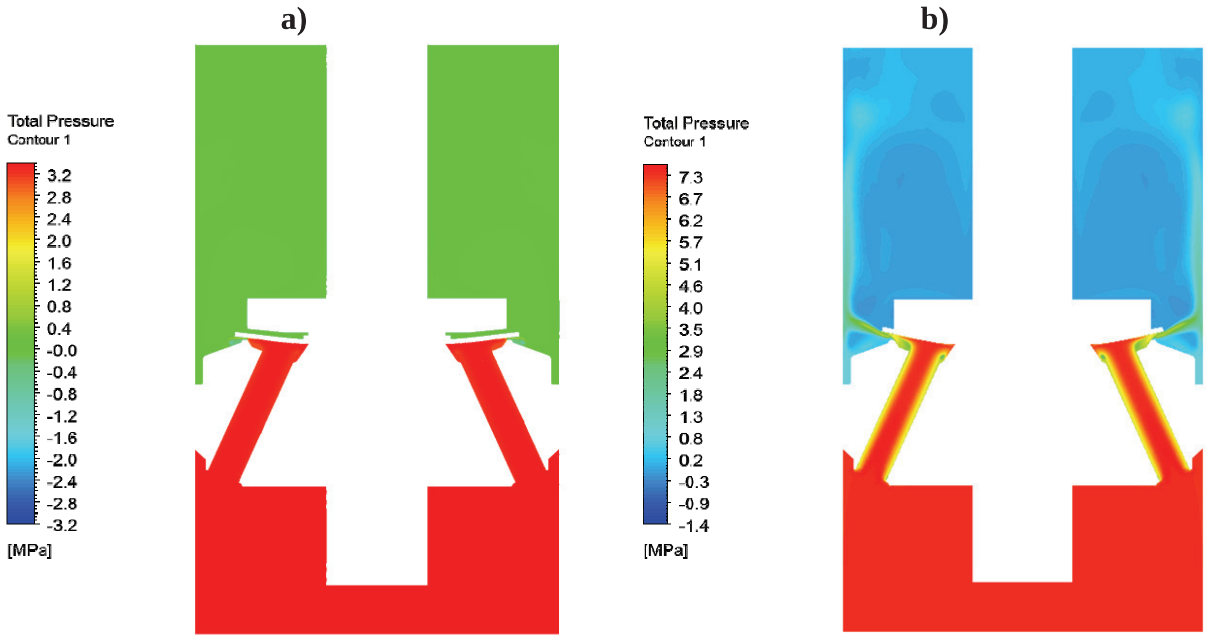

Fig. 6. Pressure distribution: a) minimal opening; b) maximal opening

6. Summary

This work indicates the possibility of improving a valve system by reducing velocity under the opened stack of discs. The improvement should focus on reshaping the rounding where the lower disc touches the valve seat. The initial optimization showed that the pressure drop could be decreased by 0.3 MPa, significantly reducing the turbulence flow effect.

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