Silesian University of Technology

DOCTORAL DISSERTATION

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Coupled Fluid-Structure Interaction Numerical Model of the Shock Absorber Valve

Sprzężony przepływowo-mechaniczny model numeryczny zaworu amortyzatora

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Abstract

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Automotive suspension systems have been refined for many years. Their key element is the shock absorber, whose task is to ensure passenger comfort, the car maneuverability and thus – driving safety. The automotive companies that are leaders in the design and manufacture of shock absorbers are involved in a range of research and development processes aiming to improve their products. To stay competitive in this field, they employ state-of-the-art computational tools that make it possible to provide faster and cheaper answers to issues related to the strength of the device components, its performance under various conditions, optimization of its shape and mass, and others. The challenge in this research area is to simulate the operation of the shock absorber valves to enable their in-depth analysis, which in turn will contribute to supporting the development of new technologies in the field.

The dissertation presents a study of the use of a numerical method that enables an analysis of the performance of different valve technologies. This objective was achieved using coupled 2-way Fluid-Structure Interaction modelling implemented in the ANSYS software. Due to the fact that the available valve technologies differ from each other significantly, it is impossible to propose one universal model for all of them. It was therefore necessary to prepare a model dedicated to a specific valve type. The dissertation describes methods of modelling two classical valves that cover a significant part of currently manufactured passive shock absorbers. These are the clamped disc stack valve and the sliding intake valve. In addition to the modelling methods intended for the classical valves found in popular solutions, the dissertation also describes a model of a special auxiliary valve that is being developed as part of an advanced premium passive valve. The description of its operation imposes different requirements for the numerical modelling method, in particular in relation to the fluid dynamic mesh adaptation.

The 2-way Fluid Structure Interaction modelling methods, being the focus of the work, are presented as a comprehensive description of the principles of the geometry model preparation, the application of boundary conditions, the physical model selection and the model discretization with special emphasis on the definition of the fluid deforming mesh. The description highlights the difficulties arising due to the limitations of the FEA/CFD methods and includes proposals for adequate solutions. The described approaches to modelling different types of valves were used in practice to analyse the behaviour of commercially used valves and confronted with the results obtained from measurements performed on a test stand.

The clamped disc stack valve type modelling method was validated based on three variants of the compression side of the piston valve. The numerical model showed a good correlation with the experiment, where the discrepancies between the obtained damping characteristics in the whole measuring range do not exceed 10%. The modelling was then used to identify the source of the characteristic curve hysteresis of this valve type. The analysis focused on the operation of a base valve with a high degree of the disc-stack stiffness. For this purpose,

measurements were carried out on a test stand and a numerical model corresponding to the valve geometric features was made. The presence of the characteristic curve hysteresis was identified as the effect of friction between the discs, which in the case of a multiple-disc stack combined with the discs being strongly pre-stressed resulted in a significant observable hysteresis field.

The sliding intake valve modelling method was used to simulate the rebound side of the base valve. For this purpose, two configurations of the valve were considered with two different values of the closing spring stiffness of 70N and 30N, respectively. Adequate numerical models were constructed, and then, for the model that showed a satisfactory correlation with the experimental data, several analyses were performed for excitations of flows with high frequencies and variable amplitudes included in the range of 0-150Hz and 0-80l/min, respectively. Strong pressure oscillations were observed during the valve opening, which were identified as the effect of the disc inertia.

The bleed valve modelling method was used to determine the tuning range of the valve characteristic curve using discs with different thicknesses and shapes. Simulations of the valve 12 assemblies were performed in its operating range, i.e. for the flow rate of 0-4l/min. The characteristics of the valve closing obtained from the FSI numerical models made it possible to evaluate the valve behaviour depending on the geometry of its components. For the cases under consideration, the valve tuning is possible in the flow rate range from 0.6 to 3.2 l/min. The delay in switching from the *open* to the *closed* characteristic can generate a pressure jump of up to 3.9bar depending on the thickness of the fulcrum and the check discs.

The presented applications of the described methods confirm that the proposed approach using the Fluid-Structure Interaction modelling makes it possible to obtain reliable results with a satisfactory degree of correlation with experimental data. The described physical models do not require the correlation of coefficients using experimental data. Due to that, they can be adapted to new designs with a limited risk of a correlation loss. By implementing the models in the process of developing or working out a new valve technology, the engineering team can optimize the design and validate a whole range of concepts without having to order physical prototypes and conduct many experiments.