sciendo CzOTO 2019, volume 1, issue 1, pp. 670-677

SIMULATIONS OF SAFETY VALES FOR FLUID POWER SYSTEMS

doi: 10.2478/czoto-2019-0085
Date of submission of the article to the Editor: 27/11/2018
Date of acceptance of the article by the Editor: 14/01/2019

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Abstract: Hydraulic power systems are widely used in heavy machinery. Safety of such a systems have a major importance due to the fact that any failure may cause environmental contamination or serious injury. One of the component which protects hydraulic drive systems against excessive rising of working pressure is a safety valve which aim is to maintain pressure in the systems below acceptable level. Pressure control valves which plays important role in a hydraulic systems may have very simple or complex structure. Even in case of the simplest structure of such valve modeling is not an easy task. The new quality in designing hydraulic valves bring CFD method and FSI (Fluid Structure Interaction) methods.

Keywords: hydraulic power system, CFD, fluid structure interaction, FSI

1. INTRODUCTION

Fluid power systems during decades have been implemented in many applications from heavy industry to agriculture and marine industry. Despite the progress in development in material sciences and design methods a mineral oil is still main working medium for fluid power systems. There are attempts of using environmental friendly medium, which is also fire resistance based on water with additives, but have found few applications only (Pobedza and Sobczyk, 2014). Therefore, safety of hydraulic systems have a major importance because theirs failure may cause environmental contamination of serious injury of machine operators. There are conducted research on hydraulic system failures and its causes (Fabis-Domagala, 2011; Fabis-Domagala et al., 2018) which shows that one of the cause of failure might be inappropriate working conditions: higher working pressure than it was assumed. Hydraulic power systems are protected against excessive pressure rise by safety valves. The aim of such valves is to maintain pressure in the system on set level.

Pressure control valve which plays an important role in a hydraulic systems may have very simple or complex structure. We can distinguish two main types of pressure control vales: direct acting and with a pilot.

Modelling and simulation of pressure control valves is not an easy task even in case of the simplest structure valve. Modeling of these valves may be performed on many ways, using mathematical model which consists of equation of motion and general purpose simulation tool (Lisowski et al., 2015) or by the use of computational fluid dynamics (CFD) or by combining both tools. One of the unknown factor during modelling of pressure control valve are flow forces which are difficult to evaluate or predict during fluid flow. There are, however, conducted research which allows to measure flow forces directly on the working components, but that has been made for fixed position of working components not during the fluid flow (Lisowski et al., 2016; Lisowski et al., 2018). Computer modelling tools allows also for simulating other causes of valve failures like erosion or cavitation which is presented in work (Domagala et al., 2018a) and (Domagala et al., 2018b).

This paper presents a simulation of direct acting pressure valve with the use of Fluid-Structure Interaction (FSI) method.

2. DIRECT ACTING RELIEF VALVE

Direct acting relief valve is perhaps one of the most simplest hydraulic component, however, its modeling is not easy task due to the difficulties in evaluating of flow forces. There are, however, analytical formulas, which can be used for calculation of flow forces, but theirs application may be very limited and may not be acceptable nowadays. New capabilities gives computer simulation tools: computational fluid dynamic, which allows to simulate fluid flow during valve operation.

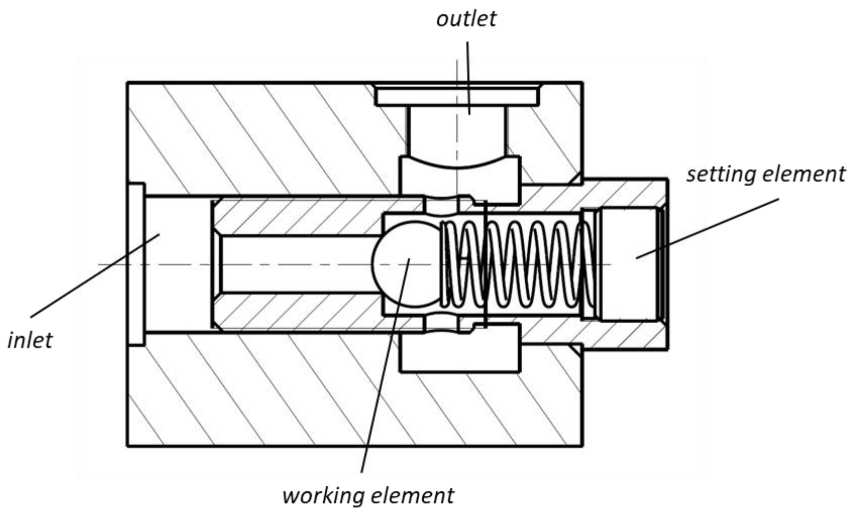

Fig. 1. Simplified drawing of direct acting relief valve

Simplified drawing of direct acting relief valve is presented in Fig. 1. Working components might be sphere, conical shape spool or a piston. Flow forces which appears during fluid flow is a key factor in modelling of such valves and are evaluated by the use of CFD tools. Then the values are used in lumped parameter models for simulation dynamic behavior of the valve. One of the latest possibilities of simulation dynamics of valves is combination of CFD and FSI methods, which allows to investigate valve during operation much with much more accuracy than in case of lumped parameters models.

3. MODELLING DYNAMICS OF VALVE USING FSI

Modelling of valve dynamics (valve operation) with the use of CFD method gives new quality in modelling of hydraulic valves, however, it requires taking some assumptions and preparing calculation model which have to fulfill specific requirements. There are few methods which allows for modelling valves during operations which differs the way which computational model has to be created. The oldest possibilities which were available in CFD methods was deformable grid in which grid of fluid domain may be deformed (stretched, extended, some of cells may be switched off). However, such approach may lead to problems with quality of the grid, which is presented in Fig. 2.

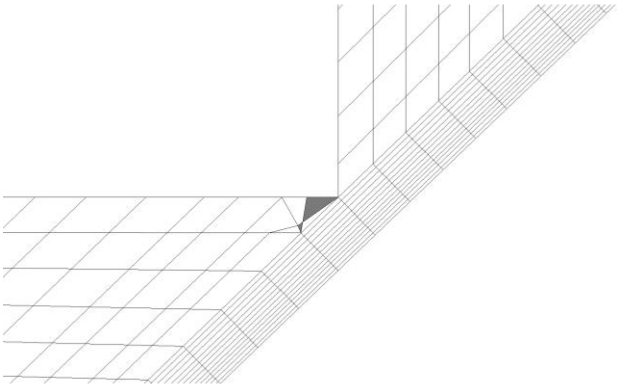

Fig. 2. Problem with quality of cells (cells distortion) during grid deformation (Domagala, 2008)

There are study which shows that such a method may be used for modelling of a pressure valves (Beune et al., 2012) with properly created grid. Another approach is simulation of valve operation by the use of "immersed solid" method in which solid grid and fluid grid overlap each other (Domagala, 2015). Such approach has however some disadvantageous which do not allows its using for simulation of components which motion is determined by fluid flow.

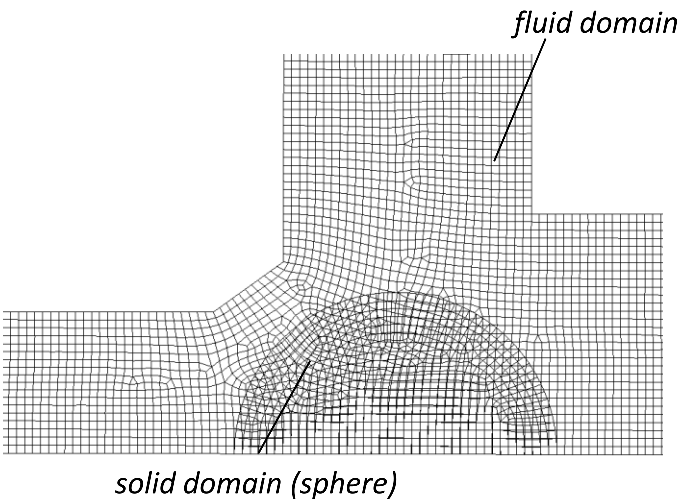

Fig. 3. Lattice nodes for direct operating relief valve (Domagala, 2016)

Development of CFD tools brings new possibilities in modelling of hydraulic valves. One of the latest achievement, not only in modelling component in motion, but generally in CFD modelling are meshless methods. Preliminary studies (Domagala, 2016) on conical shape working component shows that it is very promising method for simulating hydraulic valves, however, lattice nodes have to be created in a proper way for modelling geometry of valve component in a proper way. Meshless methods are not widely implemented in CFD simulation software's yet and methods of creating computational nodes sometimes do not allows for describing complex shape geometry of hydraulic valves. But it has to be underlined, that such methods eliminate the weaknesses of deforming grid which is quality of grid during component motion, which would have to require remeshing the model or using few models with grid adequate to cover all range of valve component motion. Model of direct acting relief valve of meshless method is presented in Fig. 4.

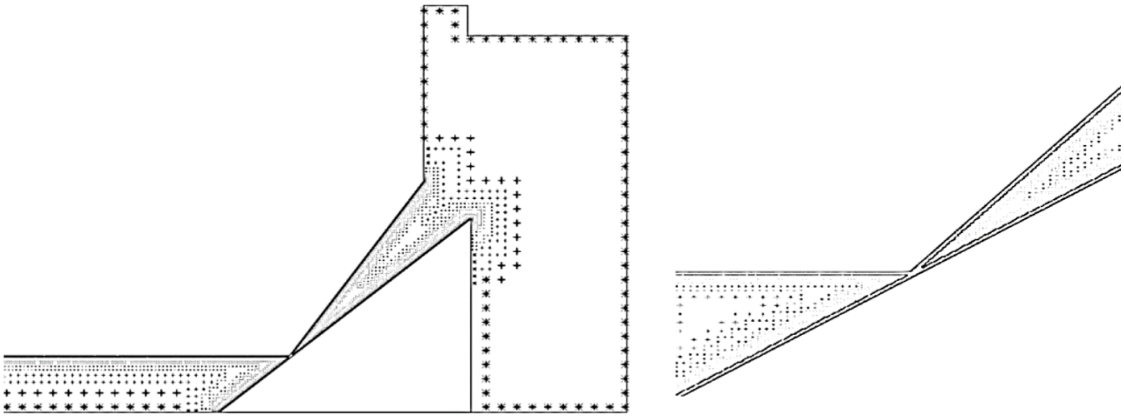

Fig. 4. Lattice nodes for direct operating relief valve (Domagala, 2016)

Lastly introduced "overset mesh" techniques is similar by principle with "immersed solids" by creating interface between two domain, however, in this case both domains are fluid domains, which allows to create grid at the component with appropriate quality. Model with overset mesh for safety valve presented in Fig. 1 is shown on figure below.

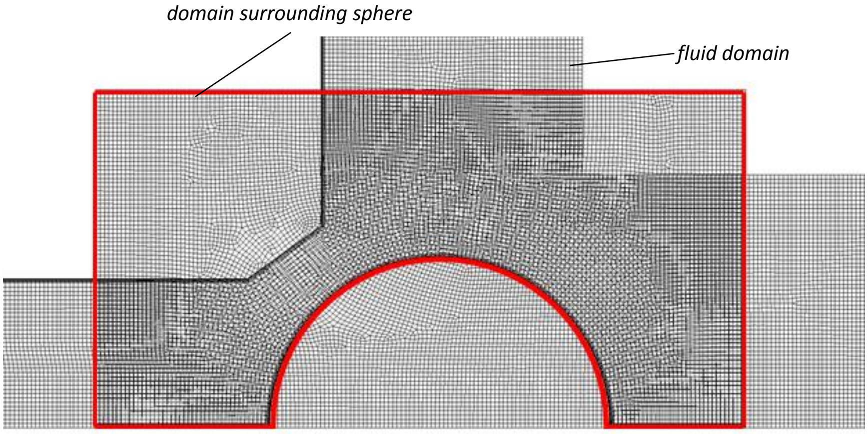

Fig. 5. Overset mesh model for safety valve presented in Fig. 1.

Interface between both domain is presented in Fig. 6 what allows for simulating sphere motion in the full range of motion without problems with grid quality.

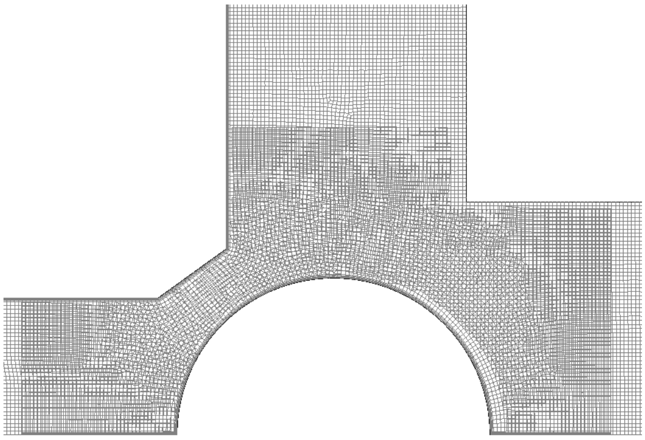

Fig. 6. Overset mesh model for safety valve presented in Fig. 1.

Interface of fluid domains is presented in Fig. 7 for two stages: valve opening and valve which is fully opened.

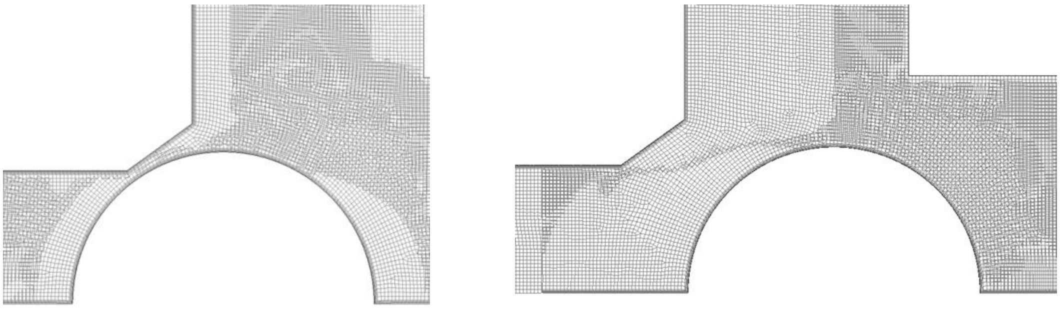

Fig. 7. Grid interface between two fluid domains.

Presented above model with overset mesh allows to simulate valve dynamics and obtain flow characteristics directly and eliminates all weaknesses of deformed grid.

4. CONCLUSIONS

Simulation of safety valve for hydraulic systems have a significant meaning in scope of safety for machine operators or environmental protection. Results of simulation may be used as a input data for process of improving safety and reliability of hydraulic systems. This study shown some aspect of modelling safety valve with the use of CFD method. There was presented few approaches of Fluid-Structure Interaction capabilities in scope of simulation of safety valve dynamics. The latest achievement of simulation of interaction between fluid and solids (hydraulic oil and valve component) which is named “overset mesh” looks very promising method which eliminates all weaknesses of deforming grid. It allows to simulate valve dynamics directly without using any additional simulation tool and may increase safety of newly designed valves.

Presented methods may be useful in many areas of the simulation-based engineering and science, e.g. temperature fields (Styrylska and Pietraszek, 1992) or the statistical estimation of an uncertainty (Pietraszek and Gadek-Moszczak, 2014; Goroshko and Royzman, 2015; Kozien and Kozien, 2017a), especially with non-parametric (Pietraszek et al., 2017a; Pietraszek et al., 2017b) or even fuzzy (Pietraszek and Skrzypczak-Pietraszek, 2014; Pietraszek et al., 2016) approach.

Such simulations require systematic approach usually based on the design of experiments methodology (Montgomery, 2008) which is applied widely from biotechnology (Skrzypczak-Pietraszek et al., 2018a; Skrzypczak-Pietraszek et al., 2018b) and phytochemistry (Skrzypczak-Pietraszek and Pietraszek, 2009; Skrzypczak-Pietraszek et al., 2017) through materials science (Scendo et al., 2014; Klimecka-Tatar et al., 2015), the machining (Dwornicka et al., 2017; Radek et al., 2018a; Radek et al., 2018b), the technical stereology (Gadek-Moszczak, 2017; Gadek-Moszczak and Matusiewicz, 2017) up to a large scale research facilities (Baussan et al., 2014; Singh et al., 2016; Singh et al., 2017), a commercialization of scientific research (Kozien and Kozien, 2017b) and a factory lean management (Ulewicz et al., 2013; Ulewicz, 2016; Maszke et al., 2018).

Last but not least, it should be very useful in a hydraulic development e.g. manufacturing (Pobedza and Sobczyk, 2013; Guzowski and Sobczyk, 2014; Walczak and Sobczyk, 204; Krawczyk et al., 2018)

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