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NUMERICAL SIMULATION OF FLUID FLOW INSIDE THE FLOW CONTROL VALVE

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Mariusz Domagała[1] – *orcid id: 0000-0001-9642-6142*
Hassan Momeni[2]
Joanna Fabis-Domagała[1] – *orcid id: 0000-0003-2811-1100*
Mariusz Krawczyk[1]
Grzegorz Filo[1] – *orcid id: 0000-0003-0848-6124*
Saeed Bikass[2]
[1]Cracow University of Technology, Institute of Applied Informatics, Jana Pawla II 37, 31-841 Cracow, **Poland**
[2]Western Norway University of Applied Sciences, Department of Mechanical and Marine Engineering, Inndalsveien 28, 5063 Bergen, **Norway**

Abstract. Hydraulic valves are widely used in many branches and they are still developed and improved. Due to the problem with verification of flow phenomena which appears during valves operation numerical simulations methods are tools which allows to improved valves design. This paper presents numerical simulation of fluid flow inside flow control valve.
Keywords: hydraulic system protection, safety valve, relief valve, numerical modelling, test bench experiments

1 INTRODUCTION

Fluid power components, particularly valves, are widely used in many industrial branches, from manufacturing to heavy machinery. Valves are used in a power and control systems. The latest tendency in fluid power technology is implementing electronic systems in hydraulic valves what allows to obtain new possibilities, mostly in control functions. Improvement of valves quality in aspect of control might be achieved by detailed modelling mechanical parts. However, it is a complex task due to the relatively small dimensions and complex phenomena which appears during fluid flow. One of the tool which might be used in modelling vales operation particularly is simulation of flow of working fluid is CFD (Computational Fluid Dynamics). This numerical methods use RANS (Reynolds Averaged Navier-Stokes) equations which defines scalars (e.g. velocity) as a mean values and fluctuations over this value. Such approach is very practical because in engineering practice information about each vortex, even the smallest one sometimes is not required. RANS defines fluid velocity as:

$$u_i = \overline{u}_i + u_i' \tag{1}$$

where $\overline{u}_i$ - is the mean velocity value, u_i' - is the fluctuating velocity, i stands for velocity component.

RANS equations have the following form:

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho}{\partial x_i}(\rho u_i) = 0 \tag{2}$$

$$\frac{\partial \rho}{\partial t}(\rho u_i) + \frac{\partial \rho}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_i}{\partial x_i}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho\overline{u_\imath u_j}\right) \tag{3}$$

where: ρ – is the fluid density, u – is the fluid velocity, p – is pressure, μ – is the fluid dynamic viscosity, δ - is the Kronecker function.

Additional term which appears in Eq. (3) $-\rho\overline{u_\imath u_j}$ represents the effects of turbulence (called Reynolds stress) and makes that the set of Eq. (2) and Eq. (3) is not closed, therefore this term has to be modeled. There are few methods for closure RANS equations which are called turbulence models:

- zero equation turbulence models,
- one equation turbulence models,
- two equations turbulence models,

Above models use the Boussinesq hypothesis:

$$-\rho\overline{u_\imath u_j} = \mu_t\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{2}{3}\delta_{ij}\left(\rho k + \mu_t\frac{\partial u_k}{\partial x_k}\right) \tag{4}$$

There are also turbulence models which does not use the Boussinesq hypothesis like Reynolds stress models.

CFD tools allows to simulate fluid flow inside valves as well as simulations of phenomena which may cause valves failure or malfunction (Domagala et al., 2018a; Domagala et al., 2018b).

2 FLOW CONTROL VALVE

Flow control valve function is to maintain constant flow rate independently on pressure to inlet or outlet. Valve presented in Fig. 1. is a flow control valve controlled by proportional solenoid. The valve itself consists of two valve: throttle valve and compensation valve which means that the valve can be characterized as a structure with high scale of complexity. The value of flow rate which will be maintain in the system is set by the position of the spool on the left side. Constant flow rate is maintain by the position of the spool on the right side, which is determined by the flow conditions on inlet and outlet.

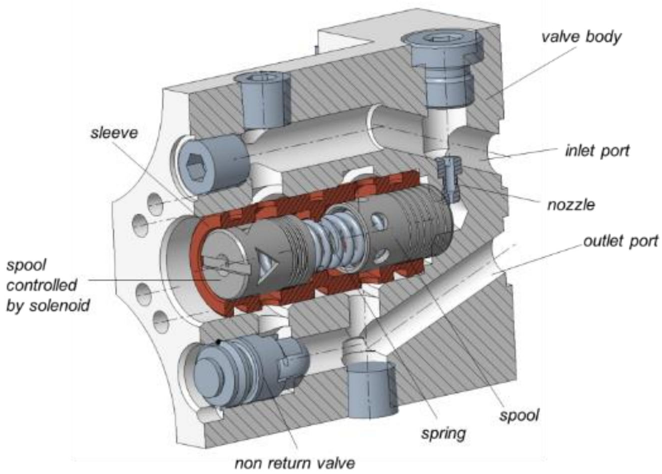

Fig. 1. Flow control valve.

3 NUMERICAL SIMULATION OF FLOW INSIDE FLOW CONTROL VALVE

Numerical simulations of fluid flow inside hydraulic valves are conducted for various goals, to investigate flow forces (Domagala, 2008; Lisowski et al., 2015; Lisowski et al., 2016; Lisowski et al., 2018) or to investigate dynamic behavior of valve components (Beune et al., 2012; Domagala, 2016).

Fluid flow inside the flow control valve is determined by position of spools, the left side spool position is set by solenoid while position of the second depends on flow conditions on inlet and outlet. Therefore, the flow simulation was conducted for two models as it is presented in Fig. 2. Results of numerical simulation of the part which includes spool set by solenoid are used as input data for the second model.

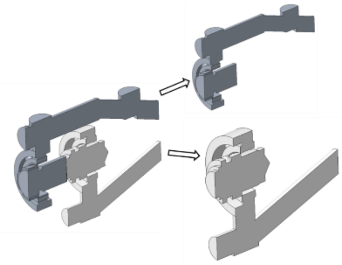

Fig. 2. Flow domains of flow control valve.

CFD simulation was performed in ANSYS CFX code for fixed component position for steady state conditions and for the following assumptions: (a) fluid (hydraulic oil) is homogeneous and has a constant properties: density 880 [kg/m3], viscosity υ =40 [mm^2/s]; (b) flow is turbulent: k-ϖ turbulence model was used; (c) model is in thermodynamics equilibrium, heat transfer is not included; (d) half of the geometrical model was used in simulations. An exemplary results of fluid flow inside flow control valve are shown in Fig.3 and Fig.4.

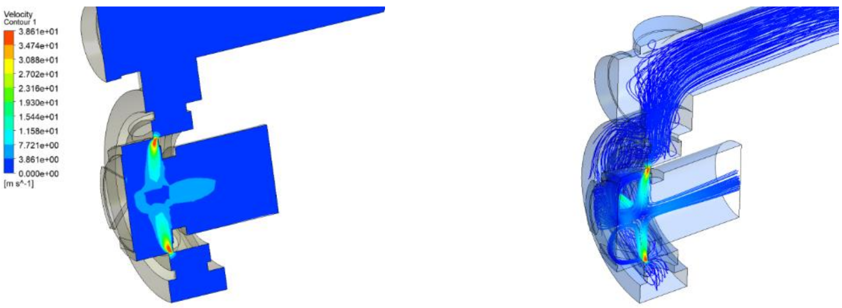

Fig. 3. Velocity distribution (left side, in m/s) and pathlines (right side) for the part with spool controlled by solenoid

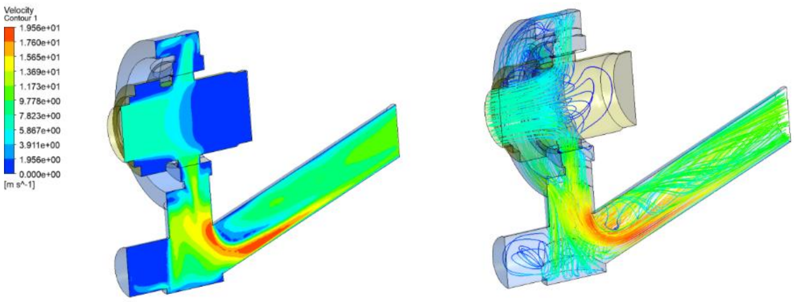

Fig. 4. Velocity distribution (left side, in m/s) and pathlines (right side) for the part with second spool.

Numerical simulations of flow inside the valve allowed also to obtain pressure drop at the first spool (controlled by solenoid) which is presented in Fig.5. Spool position is normalized value, where 0 is initial position (valve is closed) while 1 is fully open valve.

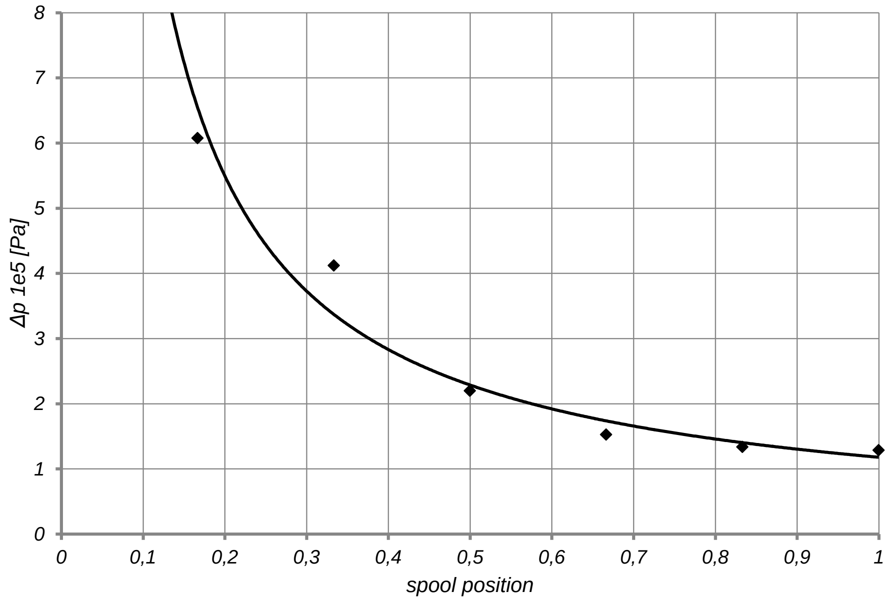

Fig. 5. Pressure drop during flow at the spool controlled by solenoid.

4 CONCLUSIONS

Numerical simulations of flow inside valves bring new quality in modelling such components. Information which are obtained during CFD simulation allows to investigate phenomena which appears during fluid flow which might be used during design process. Due to the problems with experimental tests of fluid flow inside valves numerical tools seems to be very efficient design tool which might be used as a virtual test stand for verification of assumptions and requirements. Results of CFD simulations might be also used for adjusting electronic control systems.
Obtained results may be used in construction of heavy-duty machines hydraulic systems (Pobedza and Sobczyk, 2013; Krawczyk and Sobczyk, 2018) or in a precision control of a flow in biotechnology reactors (Skrzypczak-Pietraszek et al., 2018). A methodology presented may be also useful in materials science, in modeling of structure modifications (Lipinski and Wach, 2014) or surface modifications (Gadek-Moszczak et al., 2014; Bara et al.,2016; Opydo et al., 2016; Radek et al., 2018). It may be also used in an uncertainty quantification (Pietraszek et al., 2016; Kozien and Kozien, 2017) and related risk management (Kielbus and Karpisz, 2019) as a tool for construction of a surrogate model (Ferdek and Kozien, 2013). Finally, the results should be widely disseminated in academia and industry by scientific and industrial databases (Gawlik et al., 2015; Karpisz and Kielbus, 2018).

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