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MARIUSZ DOMAGAŁA*

CFD ANALYSIS OF PILOT OPERATED RELIEF VALVE

ANALIZA CFD ZAWORU MAKSYMALNEGO POŚREDNIEGO DZIAŁANIA

Abstract

The paper presents a CFD analysis of a pilot operated relief valve. The motion equation for piston and poppet were applied to CFD code Ansys CFX for FSI analysis. The FSI analysis allowed obtaining flow phenomena that occur in the valve during valve operation. The results of FSI analysis have also been presented.

Keywords: *CFD, modeling, pilot operated relief valve*

Streszczenie

W niniejszym artykule przedstawiono modelowanie zaworu maksymalnego pośredniego działania z zastosowaniem metod CFD. Model matematyczny zaworu został użyty do analizy FSI, która umożliwiła badanie zjawisk występujących podczas pracy zaworu. Analizę FSI przeprowadzono w systemie Ansys CFX. W artykule przedstawiono wyniki analizy w postaci rozkładów prędkości przepływającej cieczy w zależności od położenia elementów roboczych.

Słowa kluczowe: *analiza CFD, modelowanie, zawór maksymalny pośredniego działania*

* Mariusz Domagała, MSc, supervisor: Edward Lisowski, PhD, DSc, prof. of CUT, Institute of Applied Informatics, Cracow University of Technology.

1. Introduction

CFD (Computational Fluid Dynamics), which is a relatively new method, is becoming more and more popular and very effective tool in modelling of flow phenomena. In recent years application this tool in modelling hydraulic components, particularly valves, has been observed. CFD is applied in modelling valves very often in order to obtain velocity or pressure distribution in flow domain or evaluate forces acting on valve elements. One of the problems that has to be solved during modelling hydraulic valves is determination of the position of valve components during valve operation. Although CFD analysis allows calculation of forces appearing on valve components, determination of valve component position depending on these forces is difficult and requires application of a new method which is called FSI (Fluid Solid Interaction). Recent releases of commercial CFD codes offer possibilities that allow analysing flow phenomena during valve operation. Calculation of valve elements position is a complex task, particularly for a pilot operated relief valve.

The task of modelling a pilot operated relief valve by the use of CFD was undertaken in the present work. The mathematical model of the valve was used in FSI simulation, which was aimed at analysing the phenomena that occur during valve operation. FSI analysis was conducted in Ansys CFX code.

2. Object of modelling

2.1. Description of a pilot operated relief valve

The object of modelling is pilot operated relief valve whose simplified structure is presented in Fig. 1. The valve is closed as long as the pressure at inlet is lower than the opening pressure set on valve. Poppet 1 on which spring with rate k_{sg} acts closing the flow through gap f_g. Pressures on both sides of piston 1, in chamber *A* and chamber *B* are equal. Flows from chamber *A* to chamber *Z* is closed by the spring with rate k_{st} acting on the piston. When the pressure in chamber *A* rises the poppet moves against the spring and fluid flows from chamber *B* to *Z*. Simultaneously, pressure in chamber *B* falls by the flow through gap f_t. This causes motion of the piston allowing fluid to flow directly to chamber *Z*.

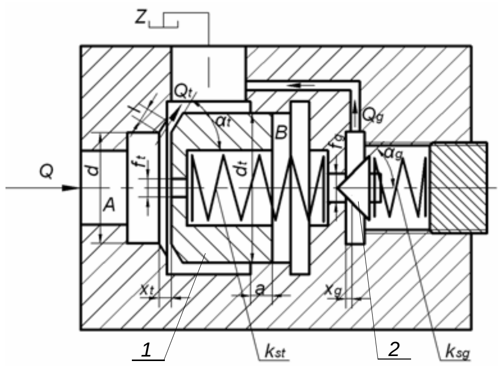

Fig. 1. Pilot operated relief valve

Rys. 1. Schemat budowy zaworu przelewowego pośredniego działania

2.2. Motion equation for a pilot operated relief valve

For modelling purposes it is necessary to describe the forces acting on piston and poppet as well.

Forces acting on piston:

– pressure force

$$F_{tp} = p_A \cdot (d - f_t) - p_B \cdot (d_t - f_t) \tag{1}$$

– pressure force in piston gap

$$F_{sz} = \pi \cdot p_A \left[\left(\frac{d}{2} + l \sin(\alpha_t) \right)^2 - \left(\frac{d}{2} \right)^2 \right] \tag{2}$$

– hydrodynamic force

$$F_{fd} = \frac{0{,}72 \cdot f_1}{\sqrt{\zeta_t}} p_A \tag{3}$$

– spring force

$$F_{ts} = k_{st} \cdot (x_t + x_{t0}) \tag{4}$$

– friction force

$$F_{tt} = \pi \cdot d_t \frac{a}{h} \cdot \mu \cdot \frac{dx_t}{dt} \tag{5}$$

where:

- f_t – gap inside the piston,
- d – diameter of inlet port,
- d_t – piston diameter,
- l – length of piston gap,
- p_A – pressure in *A* chamber,
- p_B – pressure in *B* chamber,
- α_t – angle of piston chamfering,
- f_1 – gap between piston and piston seat,
- ζ_t – coefficient of flow resistance,
- k_{st} – piston spring rate,
- x_t – piston displacement,
- x_{t0} – piston spring initial displacement,
- a – length of orifice between piston and its sleeve,
- h – thickness of gap between piston and sleeve,
- μ – dynamic viscosity.

The motion equation for piston is described by formula

$$m_{tz}\frac{d^2x_t}{dt^2}+\pi\cdot d_t\frac{a}{h}\cdot\mu\cdot\frac{dx_t}{dt}+\frac{0{,}72\cdot f_1}{\sqrt{\zeta_t}}p_A+k_{st}\cdot\left(x_t+x_{t0}\right)=p_A\cdot\left(d-f_t\right)-p_B\cdot\left(d_t-f_t\right) \tag{6}$$

Forces acting on poppet:

– pressure force

$$F_{gp}=p_B\cdot f_g \tag{7}$$

– hydrodynamic force

$$F_{gd}=\frac{0{,}72\cdot f_2}{\sqrt{\zeta_g}}p_B \tag{8}$$

– spring force

$$F_{gs}=k_{sg}\cdot\left(x_g+x_{g0}\right) \tag{9}$$

where:

f_2 – gap between poppet and poppet seat,
ζ_g – coefficient of flow resistance,
k_{sg} – poppet spring rate,
x_g – poppet displacement,
x_{g0} – poppet spring initial displacement.

The motion equation for poppet can be presented as

$$m_{gz}\frac{d^2x_g}{dt^2}+\frac{0{,}72\cdot f_2}{\sqrt{\zeta_g}}p_b+k_{sg}\cdot(x_g+x_{g0})=p_B\cdot f_g \tag{10}$$

3. FSI simulation

3.1. Motion equation for piston and poppet

FSI simulation allows an analysis of valve operation using the mathematical model presented above. It is realized by the transformation motion equation from a derivative form to a differential form using the following formulae for velocity derivative

$$\frac{dv}{dt}=\frac{v_{n+1}-v_n}{\Delta t} \tag{11}$$

and for velocity

$$v_{n+1}=\frac{x_{n+1}-x_n}{\Delta t} \tag{12}$$

where:

n – the iteration number,
Δt – time increment.

Transformation of the motion equation for piston and poppet is described below. The motion equation for piston can be presented in the following way

$$m_{tz}\frac{d^2 x_t}{dt^2} + \pi \cdot d_t \frac{a}{h} \cdot \mu \cdot \frac{dx_t}{dt} + F_{td} + k_{st} \cdot x_t + F_{\mathrm{ts}0} = F_{tp} \tag{13}$$

where:

F_{ts0} – initial spring force,
F_{td}, F_{tp} – forces that will be calculated during CFD analysis.

A differential form of piston motion equation

$$m_{tz}\left(\frac{x_{t_{n+1}} - x_{t_n}}{\Delta t^2} - \frac{v_{t_n}}{\Delta t}\right) + \pi \cdot d_t \frac{a}{h} \cdot \mu \cdot \left(\frac{x_{t_{n+1}} - x_{t_n}}{\Delta t}\right) + \mathrm{F}_{td} + k_{st} \cdot x_{t_{n+1}} + F_{ts0} = F_{tp} \tag{14}$$

The motion equation for poppet

$$m_{gz}\frac{d^2 x_g}{dt^2} + F_{gd} + k_{sg} \cdot x_g + F_{gs0} = F_{gp} \tag{15}$$

where:

F_{ts0} – initial spring force,
F_{gd}, F_{gp} – forces that will be calculated during CFD analysis.

A differential form of poppet motion equation

$$m_{gz}\left(\frac{x_{g_{n+1}} - x_{g_n}}{\Delta t^2} - \frac{v_{g_n}}{\Delta t}\right) + F_{gd} + k_{sg} \cdot x_{g_{n+1}} + F_{gs0} = F_{gp} \tag{16}$$

3.2. Valve grid

FSI simulation uses a deformable grid which has to be well prepared. Fig. 2 presents a grid for a closed valve, while Fig. 3 shows a grid for an opened valve. The main problem while preparing the grid is allowing simulation of valve operation in the whole range of piston and poppet position.

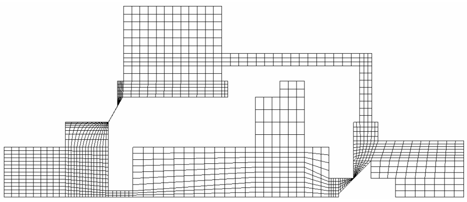

Fig. 2. Grid for closed valve

Rys. 2. Siatka dla zaworu zamkniętego

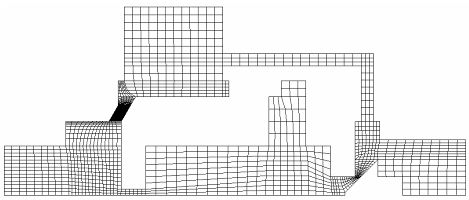

Fig. 3. Grid for opened valve

Rys. 3. Siatka dla zaworu otwartego

4. CFD results

The results of FSI analysis are presented in a graphic form in Figs 4–7 as a fluid velocity distribution for various positions of piston and poppet.

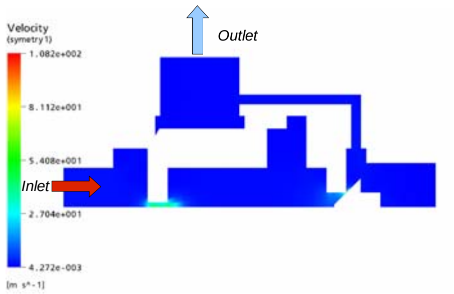

Fig. 4. Fluid velocity, $x_t = 0$ mm, $x_g = 0{,}05$ mm

Rys. 4. Rozkład prędkości cieczy

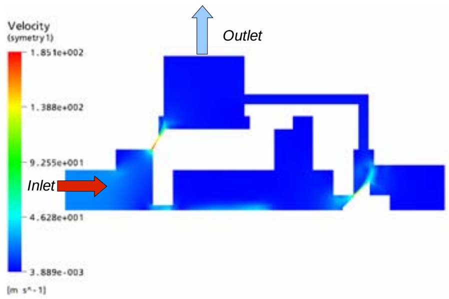

Fig. 5. Fluid velocity, $x_t = 0{,}01$ mm, $x_g = 0{,}1$ mm

Rys. 5. Rozkład prędkości cieczy

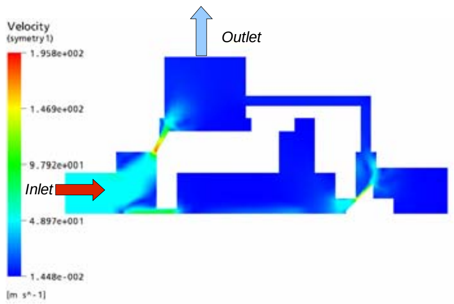

Fig. 6. Fluid velocity, $x_t = 0{,}4$ mm, $x_g = 0{,}27$ mm

Rys. 6. Rozkład prędkości cieczy

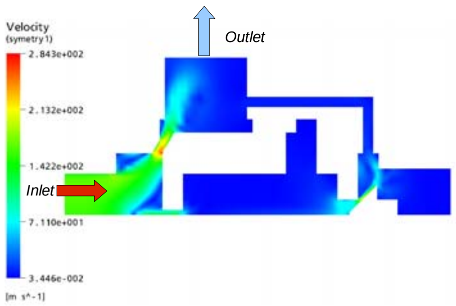

Fig. 7. Fluid velocity, $x_t = 1$ mm, $x_g = 0{,}44$ mm

Rys. 7. Rozkład prędkości cieczy

Figure 8 presents the position of piston and poppet in the function of flow rate. As can be noticed, at the first stage of valve operation only the poppet is in motion, after the pressure in chamber *B* falls, the piston moves opening flow from chamber *A* to chamber *Z*.

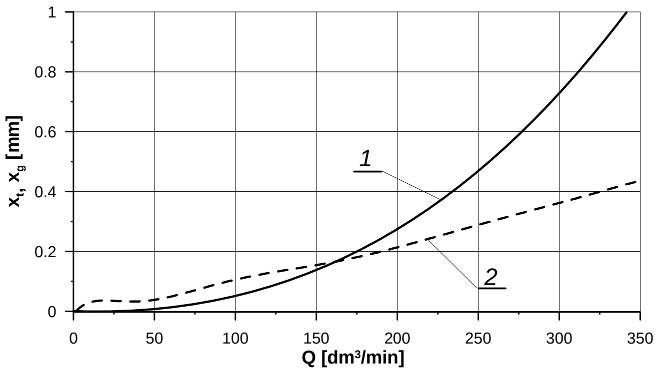

Fig. 8. Position of piston and poppet in function of flow rate: 1 – piston, 2 – poppet

Rys. 8. Położenie elementów roboczych: 1 – tłoczek, 2 – grzybek

5. Conclusions

The application of FSI simulation allowed obtaining interaction between the flowing fluid and piston and poppet. The prepared CFD model of a pilot operated relief valve allowed an analysis of flow phenomena that appear in the valve during operation. FSI simulation seems to be an effective tool in modelling a pilot operated relief valve.

CFD analysis was carried out in Ansys CFX code at the Academic Computer Center CYFRONET.

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