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NUMERICAL ANALYSIS OF HYDRAULIC OIL FLOW THROUGH CHANNELS AND CHAMBERS OF THE CYLINDRICAL PISTON VALVE

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ABSTRACT
Recent developments in Computational fluid dynamics (CFD) have enabled accurate and reliable calculations of pressure, velocity and temperature field, during the fluid flow through different technical parts and systems. This paper presents the application of numerical analysis based on the Finite Volume Method (FVM) for the analysis of hydraulic oil stationary flow through the channels and chambers of the cylindrical piston valve. By means of software COMET and numerical simulation, Δp - Q characteristics for 3D model of the distributing valve with cylindrical piston were defined and compared to experimentally obtained characteristics. The applied mathematical model is established on the basic fluid mechanics equations given in integral form. The equations of the mass, momentum, energy and space conservation that define mathematical model were closed with appropriate constitutive relations. Basic equations were discretized and transformed into the subsystems of nonlinear algebraic relations with unknown variables as components of velocity, pressure, temperature, kinetic energy of turbulence and its dissipation rate. Due to nonlinearity, these subsystems were solved by iterative method based on the algorithm with segregated solution strategy. Verification of the application of numerical analysis, based on FVM for the analysis of hydraulic oil stationary flow through 3D model of channels and chambers of distributing cylindrical piston valve, was performed by comparing the numerical and experimental results.

Keywords: numerical analysis, numerical simulation, finite volume elements, distributing cylindrical piston valve, hydraulic oil

1. INTRODUCTION
Distributing valve with cylindrical piston is one of the most important regulative components of the hydraulic system. The principal function of the distributing valve in classical hydraulics is fluid direction through channels and chambers. In the frame of proportional and servo hydraulic systems, besides the above mentioned main function, distributing valve impacts the kinematic and dynamic characteristics as well as the pressure characteristics of fluid. Nowdays, classical, proportional and servo distributing valves are inevitable parts in hydraulic systems used in industrial processes. Due to that fact, distributing valves are the topic of numerous scientific-research papers, [1]. Based on R. von Mises research, S.-Y. Lee and J. F. Blackburn gave the basics of fluid flow research through the

channels and chambers. The numerical analysis for description of fluid flow through channels and chambers of distributing piston valves and it's behaviour during the process was applied in limited number of cases. Almost all previous numerical analyses were done on simple 2D models, using specially developed software for simulations. In his research A. Kilchmann used finite difference method. M.Y. Guo and K. Nakano after R. N. Clark 's research analyzed the compensation of fluid acting force on the piston of distributing valve by the boundary elements method. T. Tsukiji conducted his research using the numerical analysis and simulation of fluid flow by method of discrete vortices. Recently some investigations of fluid flow analysis of distributing valves with cylindrical piston have done by the FEM (Finite Element Method) and FVM (Finite Volume method). M. Kipping, Th. Grauer, H. Nguyen, C. Jansson, K. Engelsdorf, K. Klarecki, E. Tomasiak and J. Kosmol based their investigations on the finite element method, while X. Baudry, J. Mare and M. Ristic used the finite volume method.

2. NUMERICAL ANALYSIS

2.1. Introduction

The simulation and analysis of hydraulic oil stationary flow through chambers and channels of the model of distributing valves with cylindrical piston was performed using the *Comet* software based on finite volume method. The *Comet* software, version 1.51, works under the SuSe Linux operating system, version 8.0. All simulations and calculations during the numerical analysis were done on personal computer with Intel Celeron-S processor, 1200 MHz (12x100) and 247 MB RAM memory (PC 133 SDRAM).

All analyses were done on the model of distributing valve with cylindrical piston shown on Figure 1. Also the most important geometrical characteristics of the piston and the valve body are presented on Figure 1, [1].

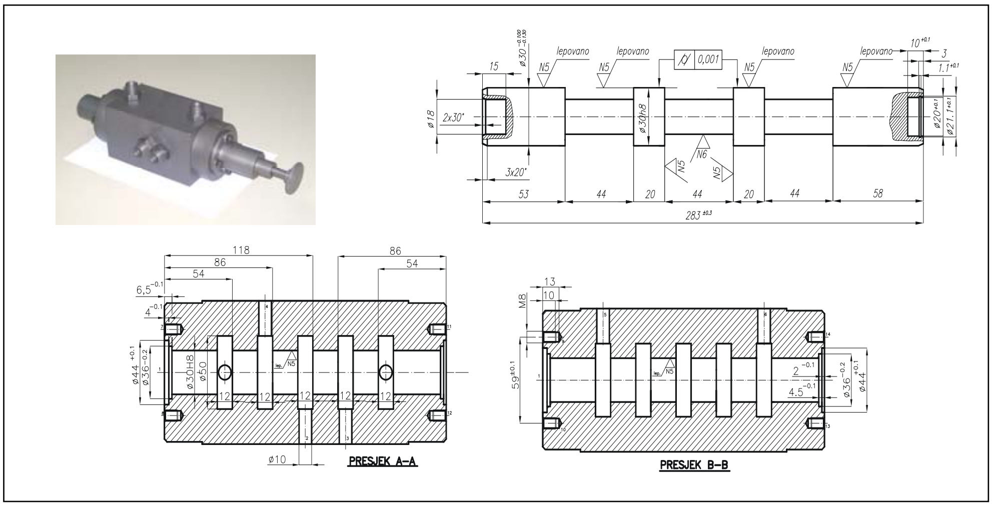


Figure 1. Distributing valve model with cylindrical piston

2.2. Mathematical model

The equations that completely describe the flow of Newton's incompressible and viscous hydraulic oil through chambers and channels of distributing valve with cylindrical piston are:

- Equation of conservation of mass or continuity equation,
- Conservation of momentum (Euler's first law, Newton's second law),
- Conservation of energy (First law of thermodynamics) or equation of energy balance.

The continuity equation is derived from the mass conservation law and may be expressed as:

$$\frac{d}{dt}\int_V \rho\, dV + \int_S \rho\,(\mathbf{v}-\mathbf{v}_s)\, d\mathbf{s} = 0\,, \qquad \ldots(1)$$

where ρ is the fluid density , **v** is the vector of fluid velocity, $\mathbf{v}_s$ is the velocity vector of surface S and **s** is the outer vector of the surface S which bounds the control volume (CV) defined in any given point.

The equation of momentum conservation, known as the Cauchy's first law in fluid mechanics, applied to the control volume (CV) can be defined as:

$$\frac{d}{dt}\int_V \rho\,\mathbf{v}\, dV + \int_S \rho\,\mathbf{v}\,(\mathbf{v}-\mathbf{v}_s)\cdot d\mathbf{s} = \int_S \mathbf{T}\cdot d\mathbf{s} + \int_V \mathbf{f}_b\, dV\,, \qquad \ldots(2)$$

where **T** is the Cauchy's stress tensor and $\mathbf{f}_b$ is the vector of resulting mass force.

Applying the first law of thermodynamics on the control volume, the law of energy conservation can be expressed as:

$$\frac{d}{dt}\int_V \rho\, E\, dV + \int_S \rho\, E\,(\mathbf{v}-\mathbf{v}_s)\cdot d\mathbf{s} =$$

$$= \int_S \mathbf{q}_h\cdot d\mathbf{s} + \int_V s_h\, dV + \int_S (\mathbf{T}\cdot\mathbf{v})\cdot d\mathbf{s} + \int_V \mathbf{f}_b\cdot\mathbf{v}\, dV\,, \qquad \ldots(3)$$

where E is the total energy, $\mathbf{q}_h$ is the vector of thermal flux and s_h is a thermal source. The total energy is defined as a sum of thermal, mechanical, chemical and other types of energy per unit mass.

Taking into account that the fluid flow through channels and chambers of distributing valves with cylindrical pistons is dominantly turbulent, Reynolds averaged Navier-Stocks equations (RANS) are used for mathematical description of the flow. These equations enable the simplification of description and analysis of turbulent flow and fluid characteristics using the averaged and fluctuated values. The time interval used in averaging has to be long enough in comparison to the period of pulsation of the characteristic physical value, as well as small enough comparing to the time of noticable change of the averaged value. This process enables to get the averaged basic equations which describes the averaged fluid flow.

The use of averaged basic equations raises the problem of closing the system of equations (continuity equations, Reynolds equations, energy (thermal) equations). In other words this is the problem of defining the relations for turbulent flux of momentum and energy and turbulent dissipation. These additional relations together with basic equations comprise the closed system of equations, well known as turbulence flow model. In this research the numerical calculation of hydraulic oil fluid flow through channels and chambers of distributing valve with cylindrical piston was performed by use of standard k-ε turbulence model, which is the most used model in engineering practice during the last thirty five years, [2,3].

As numerical method Finite Volume Method is based on transformation of mathematical model into the system of algebraic equations, generally nonlinear. The transformation of basic equations given in integral form (equations of conservation, constitutive relations, initial and boundary conditions) into the system of algebraic equations were performed using the discretization of space, time and equations. Basic equations are partitioned and transformed into the subsystems of nonlinear algebraic equations. The unknown variables are velocity, pressure, temperature, kinetic energy of turbulence and its dissipation rate. Due to nonlinearity these subsystems were solved by iterative method based on the algorithm with segregated solution strategy.

2.3. Numerical simulation results

Numerical simulation of hydraulic oil turbulent flow through channels and chambers of the distributing valve with cylindrical piston, Figure 1, was performed using 3D mesh shown on Figure 2. The analysis was done for the following values of clearance *z*: 0,6mm; 0,8 mm; 1,0 mm, [1]. The 3D mesh was created by 235200 finite volumes for z = 0,6 mm, 99168 for z = 0,8 mm and 81024 finite volumes for z =1,0 mm.

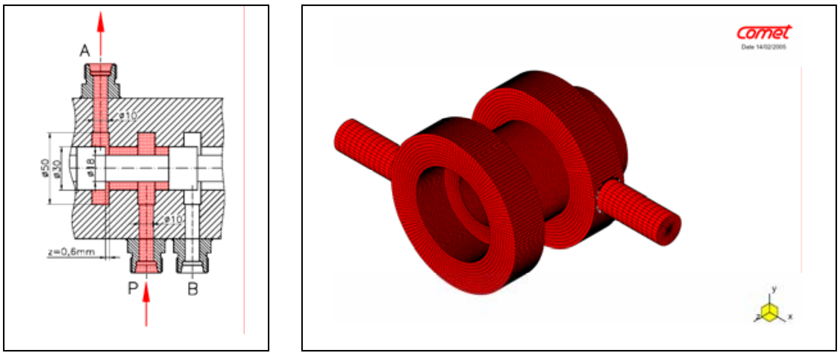
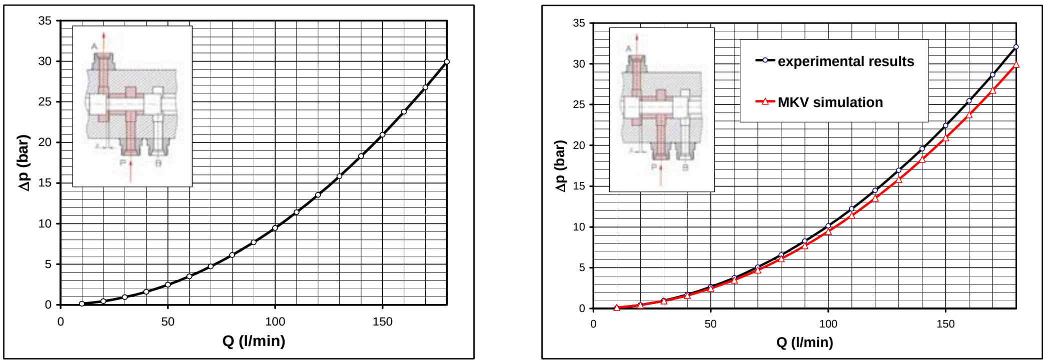


Figure 2. 3D mesh model of channels and chambers of the distributing valve with cylindrical piston for hydraulic oil flow from the opening P to A and clearance z = 0,6 mm

The numerically obtained Δp-Q diagram for distributing valve with clearance z = 0,6 mm is shown on Figure 3a. Similar diagrams for clearances of z = 0,8 mm and z = 1,0 mm can be found in [1]. Also, the experimentally obtained Δp-Q diagram is shown on Figure 3b to enable comparison between experimental and numerical results. The difference between the numerical and experimental results is approximatelly ± 6 %.



a) Numerical results *b) Numerical and experimental results*

Figure 3. Δp-Q diagrams for the case of oil flow from the opening P to A and z = 0,6 mm

3. CONCLUSION

Comparing the results of Δp-Q relation obtained by numerical simulation and experimental testing of turbulent stationary hydraulic oil flow through chambers and channels of the distributing valve model with cylindrical piston, it was confirmed that FVM can be successfully used for the analysis of hydraulic oil flow in 3D model of distributing valve with cylindrical piston. The differences between the numerical and experimental results were about ±6%, which is quite acceptable for this kind of fluid flow.

4. REFERENCES

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