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Evaluation of pressure losses reduction possibility for WEH22 directional control valve by internal geometry correction

Ocena możliwości obniżenia strat ciśnienia rozdzielacza WEH22 przez korekcję geometrii wewnętrznej

Abstract

The article presents the evaluation of possibility of pressure losses reduction at the flow through a WEH22 hydraulic directional control valve. For this purpose, 3D models of flow paths were built using the Creo Parametric software. Then the models were used in the ANSYS/Fluent software to calculate pressure losses. The results of the analysis have allowed for determination of possibilities of pressure losses reduction without changing overall dimensions of the valve body.

Keywords: hydraulic directional valve, computational fluid dynamics

Streszczenie

W artykule przedstawiono ocenę możliwości obniżenia strat ciśnienia przy przepływie przez rozdzielacz hydrauliczny WEH22. W tym celu zbudowano modele 3D dróg przepływowych, które wygenerowano za pomocą programu CREO Parametric, a następnie te modele wykorzystano w programie ANSYS/Fluent do obliczenia strat ciśnienia. Uzyskane wyniki analiz pozwoliły na określenie możliwości obniżenia strat ciśnienia bez zmian wymiarów gabarytowych korpusu rozdzielacza.

Słowa kluczowe: rozdzielacz hydrauliczny, obliczeniowa mechanika płynów

1. Introduction

Hydraulic drives are used in many machines and devices. Especially electromagnetically controlled elements are suitable for automation, as they can be easily controlled by a computer or digital controllers. Compared to other systems, lower efficiency is a disadvantage of a hydraulic system. However, due to the advantages of a hydraulic drive, it is still being developed and improved. The article aims at minimizing pressure losses for the hydraulic directional control valve WEH22 type without changing its overall dimensions. These directional control valves are widely used in the industry and offered by many companies manufacturing hydraulic elements, e.g. Bosch-Rexroth [1], and Ponar Wadowice in Poland [2]. Their advantage is a simple structure consisting of a cast body containing a spool in various shapes corresponding to different flow path configurations. This valve can be operated at pressure up to 35 MPa and flow rate up to 450 dm^3/ min. It means that the valve can be applicable to systems with a capacity up to 260 kW. It is produced with a connecting pattern according to the ISO 4401-08 standard [3] so it can be used interchangeably by many manufacturers. The article focuses on a particular solution manufactured by Ponar Wadowice [2]. The solution currently has similar characteristics to Rexroth [1]. Conducting calculations of this type of object is difficult due to the complex geometrical shape of flow paths, which are usually made by means of the casting technology. In order to automatically generate series of objects to investigate them, Creo Parametric software was applied. The flow analysis was carried out using the CFD method in the ANSYS / Fluent software [4]. This approach was also used in other papers, e.g. [5] and [6].

2. Modeling of flow path geometry

Schematic view of the directional control valve WEH22 type is shown in Fig.1. It consists of a body 1, a spool 2 and a pilot valve 3. Body 1 is made in the casting process in which adequate channels are initially performed. Then, the excess of material is machined in the holes where higher accuracy is required. To conduct the analysis, a 3D geometric model of the individual components, as well as a 3D model of liquid in the inner space is required. CAD techniques are used for this purpose. 3D models of the PA (Fig. 2.) and BT (Fig. 3.) flow paths are separable so that their analyses can be carried out independently. The presented model is parametric and can generate many variants of directional control valve design solutions and 3D geometric models of the fluid in the valve at the same time.

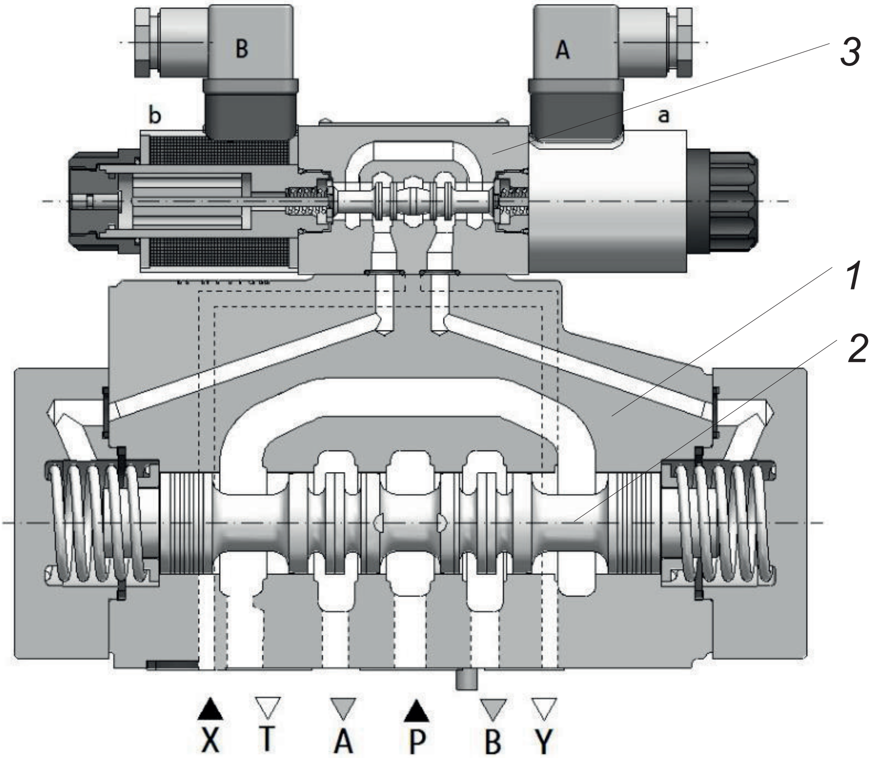

Fig. 1. View of directional control valve WEH22: 1 – body, 2 – spool, 3 – pilot valve

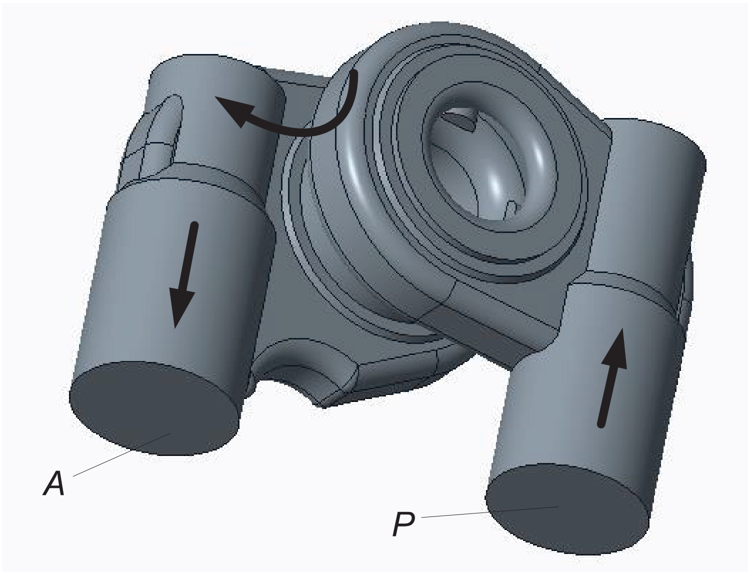

Fig. 2. Automatically generated 3D model of PA flow path

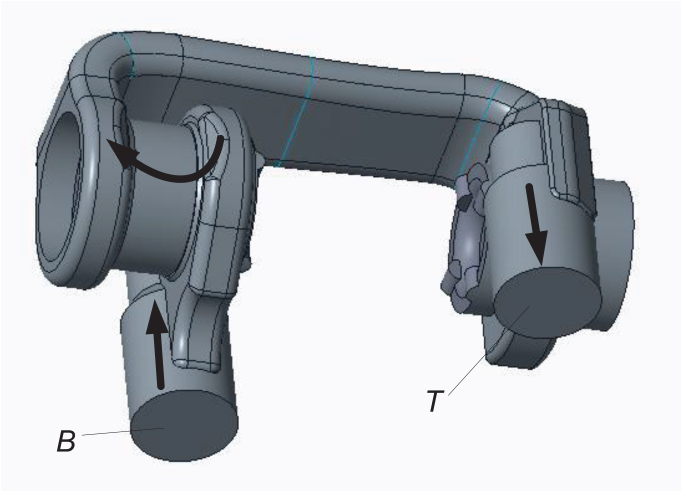

Fig. 3. Automatically generated 3D model of BT flow path

3. CFD analysis

In order to perform the analysis, flow kind must be determined. The ANSYS/Fluent software allows researchers to choose from a variety of models available including: *k*-ε, *k*-ω, Reynolds etc. In the case of flow through the directional control valve, *k*-ε model works well enough due to the fact that in the valve there are no conditions for the formation of laminar flow [5, 8]. Thus, the *k*-ε turbulence model was chosen for the simulation study. The application of this turbulence model in similar cases gave good results also in other authors' works [6, 7]. The kinetic energy of the turbulence and the dissipation factor are computed from the following equations:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left(\left(\alpha+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right)+G_k+G_b-\rho\varepsilon-Y_M+S_k \tag{1}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_i}(\rho\varepsilon u_i)=\frac{\partial}{\partial x_j}\left(\left(\alpha+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right)+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon \tag{2}$$

where:

- G_k – represents the increase in the kinetic energy of turbulence caused by the gradient of average velocities,
- G_b – energy generated by the phenomenon of buoyancy,
- Y_M – energy associated with the compressibility of liquids,
- $C1\varepsilon$, $C2\varepsilon$, $C3\varepsilon$ – model constants,
- S_k, S_ε – Prandtl's numbers, respectively,
- μ_t – turbulent viscosity.

Turbulent viscosity, μ_t, is calculated as follows:

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon\ k} \tag{3}$$

Model constants: $C_{1\varepsilon}$ = 1,44, $C_{2\varepsilon}$ = 1,92, C_m = 0,09, s_k =1.0, s_ε = 1.3.

The boundary conditions are set as follows:

1. On the input of flow paths the velocity average magnitude of working liquid is assumed. Considering the flow range of the WEH22 directional valve, five values of flow rate are selected, respectively 100, 200, 300, 400 and 450 dm^3/min.
2. On the flow path output the constant pressure value of 0,1 MPa is assumed.
3. Furthermore, it is assumed that the channel walls are smooth, and that the working fluid is hydraulic oil with the following characteristics:
   - density ρ_0 = 870 kg/m^3,
   - dynamic viscosity μ = 0,013 Pa/s.

The series of calculations were programmed in ANSYS/Workbench using the previously created geometry, mesh of one flow path and the assumed boundary conditions.

Mesh of the flow path PA is showed in Fig. 4. It includes 1 085 725 cells and 303 687 nodes. The obtained results of flow simulations for flow rate Q = 450 dm^3/min. are showed in Fig. 5 and Fig. 6. Fig. 5 shows the distribution of pressure on the walls for flow path PA and Fig. 6. shows the distribution of velocity vectors along the streamlines. The pressure on the walls varies and reaches higher values in the areas of stream direction change, while the velocity reaches the highest values within the spool.

Calculation process was carried out for the BT flow path in a similar way as for the PA flow path. In this case, the mesh model (Fig. 7) contains 2 278 375 cells and 631 977 nodes and also 5 boundary layers. Fig. 8 shows the distribution of pressure on the walls of the BT flow path, while Fig. 9 shows the velocity distribution of velocity vectors along the streamlines. The pressure on the walls of the flow path reaches higher values in the areas of stream direction change, while the velocity reaches the highest values in the gap formed between the spool and the edge of the chamber connecting it with B port.

Fig. 4. Mesh of PA flow path

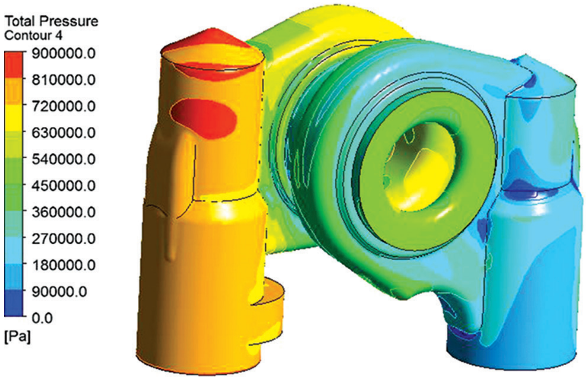

Fig. 5. Pressure distribution on the channel walls of PA flow path

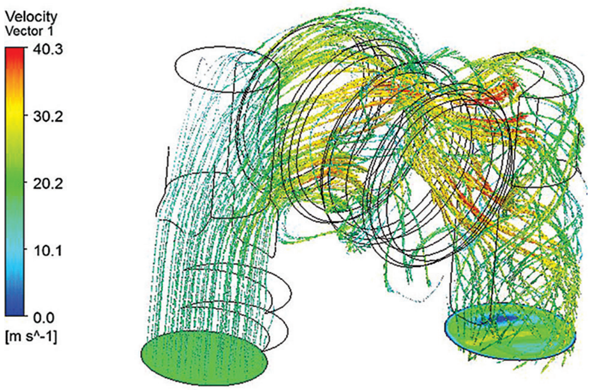

Fig. 6. Fluid velocity vectors along the stream lines for PA flow path

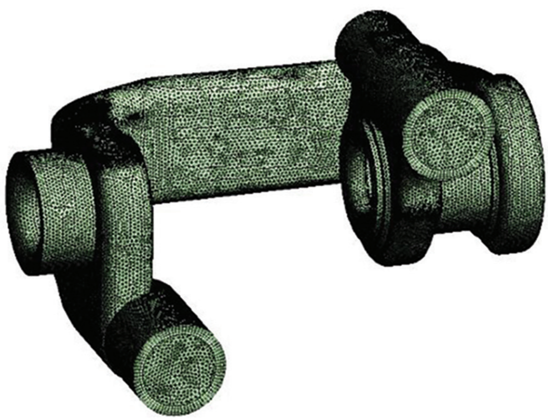

Fig. 7. Mesh of BT flow path

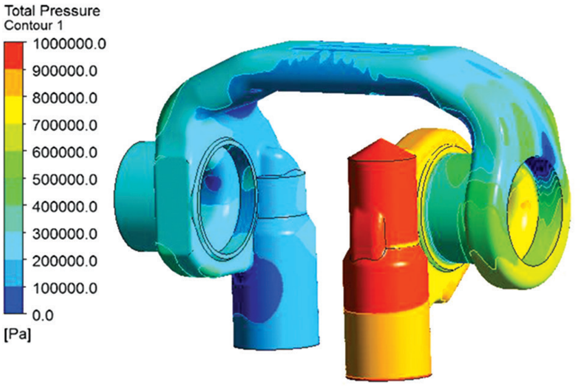

Fig. 8. Pressure distribution on the channel walls of BT flow path

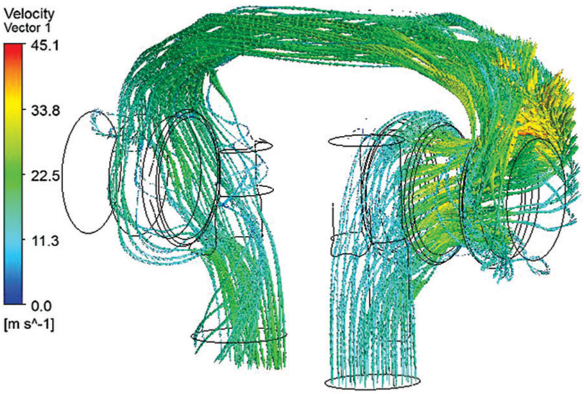

Fig. 9. Fluid velocity vectors along the stream lines for BT flow path

4. Summary

The article proposes the use of parametric modeling capabilities in Creo Parametric software and the possibility of operations on solids using Boole's algebra. As a result, a set of flow paths was generated automatically. Consequently, the paths were examined using ANSYS/Fluent under identical conditions. As a result of the analysis, some possibilities of pressure losses reduction were found. Pressure losses reduction requires an increase of flow path across sections, especially in the surroundings of the control edges. A small effect can also be achieved by the increase of inlet cross sections.

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