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UTILIZATION OF MODERN ENGINEERING TOOLS FOR DESIGNING DIRECTIONAL CONTROL VALVE

WYKORZYSTANIE NOWOCZESNYCH NARZĘDZI INFORMATYCZNYCH DO PROJEKTOWANIA ROZDZIELACZA HYDRAULICZNEGO

A b s t r a c t

In the paper an example of application of the state-of-the-art engineering tools for designing of the body of a directional control valve is presented. For that purpose CAD and CAE tools were used. The work started with creation of solid models of the directional control valve. Next, these elements were used for virtual studies of fluid flow through the hydraulic channels as well as for stress simulation of the valve body. Finally a prototype of the valve was built and an experiment was conducted.

Keywords: *CFD analysis, FEM analysis, rapid prototyping, drop pressure measurements*

S t r e s z c z e n i e

W niniejszym artykule przedstawiono przykład zastosowania nowoczesnych narzędzi inżynierskich do zaprojektowania korpusu rozdzielacza hydraulicznego. Do tego celu użyto wielu programów z zakresu CAD i CAE. Prace rozpoczęto od przygotowania modeli bryłowych. Następnie modele wykorzystano do badań wirtualnych w celu wyznaczenia charakterystyk przepływu i wytrzymałości korpusu. W kolejnym kroku wykonano prototyp sekcji sterującej, który posłużył do badań doświadczalnych.

Słowa kluczowe: *analiza CFD, analiza MES, rapid prototyping, badania strat przepływu*

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1. Introduction

Development of computer systems caused in the late twentieth century an informatics revolution. Effects of these changes are also visible in case of engineering tools which are commonly called CAx. Nowadays, it is really hard to imagine development and introduction into production of a new product without the aid of computer. What in the past was made by means of a drawing board, pencil and sheet of paper is now done by means of the mouse, keyboard and appropriate software. The data of the designed products are saved in the form of digital numbers and kept on the server. The result of such an approach is that data are available not only to design-engineer but also to many other members of the team that are working in parallel on the same product. This allows parallel cooperation between individual engineers who are responsible for different tasks of designed component.

However, the tools are still not perfect. There is still a problem with exchange of the data between individual software. The most frequent models which are created in CAD systems can not be directly transferred to CAE program. Usually for such a data exchange special neutral formats, like IGES, are used. Unfortunately during such an operation, information about the parameters is lost. That means the parametric information about the solid model is not available any more. Integrated CAx packets such as Pro/Engineer, Unigraphics, Catia seem to be a solution to the problem of loss of data during exchange process. These kinds of programs have many modules that can be used for different types of development or virtual study. Obviously, a CAD 3D is the main design module.

Pro/Engineer includes both CAD 3D as well as simulation modules, respectively. This allows creation of a parametric model and next a virtual study by means of the finite elements method and others. However, in case of such an integrated system the range of the possible numerical analyses is smaller than in case of dedicated programs such as Ansys, Abaqus etc. Nevertheless, the ability of integrated systems is still enough for most of the applications, especially if the designed part works in an elastic range.

2. CAD modelling

Usually the design process of a new product starts with preparing solid elements of the designed part. For that purpose, CAD 3D systems are the most frequently used. Their undoubted advantage is the ability to extensive data exchange between other engineering tools. Exchange of the data between engineering software can be done in two ways.

Firstly, the file is transferred to the other module of the program. The big advantage is that the model is saved with all parameters used during designing. However, the disadvantage is a lesser capacity of such a program in comparison with dedicated one. Nevertheless, as mentioned before, for most cases the ability of integrated programs is wide enough for most applications.

Another way of data exchange between different engineering tools is utilization of neutral formats. This option is widely used if the range of the numerical simulation goes beyond the capabilities of the software included in the packet. Another possible reason can be a completely different type of analysis which is not available in the integrated engineering system. The disadvantage of such a solution is loss of the information about the parameters used during model creation.

In the paper an example of the design of a directional control valve is presented. First, the geometry has been built by means of Pro/Engineer software. Building of the geometry started with modelling of the body and the spool of the valve. Then, the rest of the parts was created. The solid models of the created hydraulic components are presented in Figure 1. Figure 1a), presents the solid model of the valve that is composed of two sections. Figure 1b), presents the cross-section of the body of the designed part.

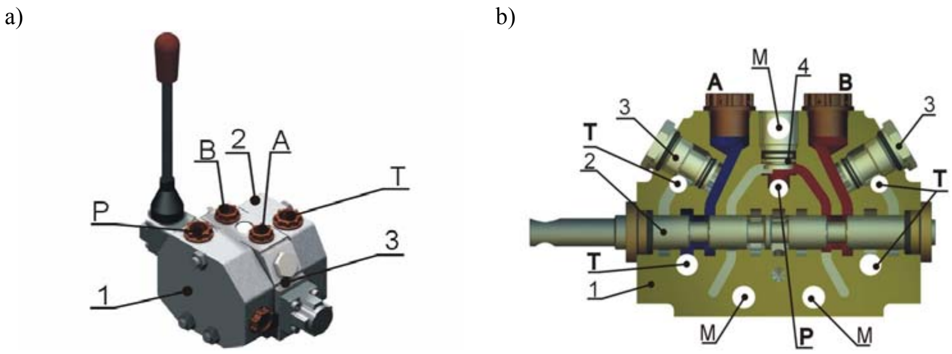

Fig. 1. Solid models: a) 1, 2 – output covers, 3 – steering section, b) section 1 – body, 2 – spool, 3 – valve, 4 – check valve

Rys. 1. Modele bryłowe: a) 1, 2 – pokrywy zamykające, 3 – sekcja sterująca, A, B – odbiorniki, P – pompa, T – zbiornik, b) 1 – korpus, 2 – suwak, 3 – zawór przelewowy, 4 – zawór zwrotny

3. Numerical analysis

3.1. CFD analysis

The pressure drop during fluid flow through a directional control valve can be calculated by means of Bernoulie's principle (eq. (1))

$$\Delta P_{1-2} = P_1 - P_2 = (p_1 - p_2) + \rho n g (h_1 - h_2) + \frac{\rho}{2}(v_1^2 - v_2^2) \tag{1}$$

where:

- ρ – density of fluid,
- g – gravitational acceleration,
- n – coefficient,
- p_1, p_2 – static pressure in cross-sections 1 and 2,
- v_1, v_2 – flow velocity in cross-sections 1 and 2,
- h_1 i h_2 – the height of cross-sections 1 and 2 above the horizontal reference plane.

The disadvantage of such a method is lack of the possibility of getting characteristics of the flow inside the valve. Much better results can be obtained by means of a numerical method such as CFD. The example can be utilization of the FLUID program.

The mentioned software allows 3D modelling of the flow phenomena through hydraulic components. Most frequently the CFD codes for analysis use a transformation of the Navier-Stokes equation to averaged Reynold's equation (eq. (2))

$$\rho \frac{Du_i}{Dt} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho\overline{u_i' u_j'}\right) \tag{2}$$

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{3}$$

By means of computer simulation it is possible to carry out the analysis of the disadvantageous phenomena that occur during fluid flow through the channels of the directional control valve. It is also possible to compare different designs and check the implemented changes on the behaviour of the fluid. Observation of such phenomena inside the hydraulic elements is very hard to realize in real models. In case of the directional control valve it is practically impossible. Application of the CFD code seems to be the only solution.

In the presented design task numerical analysis of the flow has been carried out. Simulation has been conducted for different values of volumetric fluid flow in the range of 0 to 100 dm^3/min. 2D axisymmetric as well as 3D model of flow have been considered. At first, simulation was carried out using a k–ε turbulence model. Next, the simulations were repeated for a k–ε*RNG* model. Studies were conducted for a few solutions of the check valve as well as flowing channels. The discrete model was prepared using Gambit program, and next the model was transferred to FLUENT code in which a numerical simulation was carried out. During the simulation a mesh was adopted. In Figure 2 the map of the static pressure for two examples of solutions of the check valve is presented. Those examples correspond to an axisymmetric model.

a) b)

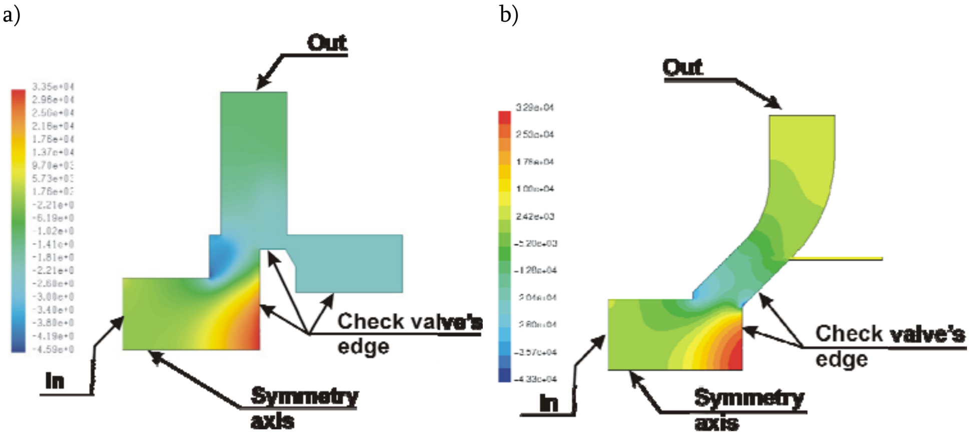

Fig. 2. Pressure distribution for a design of a check valve chamber

Rys. 2. Rozkład ciśnienia dla przykładowego rozwiązania komory zaworu zwrotnego

Determination of stream lines is important meaning for the analysis of the phenomenon that occurs in the hydraulic components during fluid flow. Thanks to that it is possible to design new flow ways in such a way that the flow of the fluid is less turbulent. In Fig. 3 streamlines between tank port P and receiver port A is presented. Based on the results of numerical simulation it can be said that the large number of disadvantageous phenomena occurs in the area of spool chamber as well as check valve. Re-design of these elements can significantly decrease the pressure drop during the fluid flow through the directional control valve.

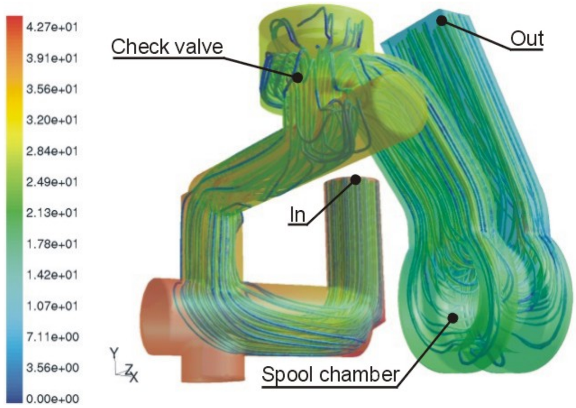

Fig. 3. Streamlines for the flow channel between pump (P) and receiver (A)

Rys. 3. Linie prądu dla drogi przepływowej między pompą (P) a odbiornikiem (A)

3.2. FEM analysis

Stress analysis was conducted in Pro/Mechanica software, which is a part of the Pro/Engineer packet. It was possible to transfer the geometry from CAD module to FEM module in exactly the same form without losing any information. Thanks to that it was possible to use all advantages of parameterization, because the model did not lose any information about parameters. In case of transferring the files through neutral files such an operation would not be possible.

For an FEM analysis only half of the model of the control valve body was used. It was possible to use such simplification because of the symmetrical building of the analysed part. Also in order to decrease the simulation time some of the details such as rounds were omitted. Usually these details do not affect the strength of the designed component, however, the mesh in such a region is finer and this causes an increase of the simulation time.

In Fig. 4 a map of radial displacements of the control valve body is presented. The max. peak displacements occur in the lower part of the spool chamber. However, the values of displacements were considerably smaller than the required clearance and came to 2,5 μm for compression and 5,0 μm for tension.

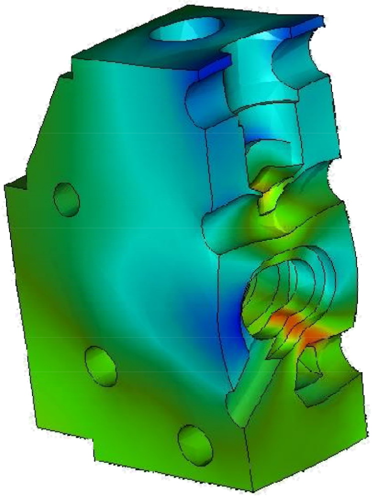

Fig. 4. Stress distribution of the control valve body

Rys. 4. Rozkład naprężeń promieniowych dla modelu korpusu rozdzielacza

4. Building a prototype

In case of hydraulic components, one of the tests is measurements of the pressure drop that occurs during fluid flow through the channels of the system in question. Usually it is done on a specially prepared test stand. The cost of the preparation of the prototype is one of the major problems in case of experiment. In most cases the hydraulic directional control valve is made of cast iron using cast and machine cutting processes. All of this makes the prepared prototype relatively expensive. Because of that, it pursues to minimize the number of prototypes. Very often the prepared valve is not optimal from the point of view of energy losses, and this leads to higher utility cost of the designed product. Also, the construction of the component is not optimal, which increases both the cost of production and cost of the final product.

It seems that the Rapid Prototyping method can be a promising solution for the companies that produce hydraulic components. With the aid of a computer method and numerical simulation the number of required prototypes can be reduced to one which indicates improvement of flow characteristics. Next, model can be relatively easily prepared for experimental study by transferring the hydraulic components saved in the form of digital file to the real part. The last step is conducting of the experiment itself.

In Fig. 5 the process of building prototype by means of Rapid Prototyping method is presented. It shows the process of "printing" the subsequent layers of thermoplastic material.

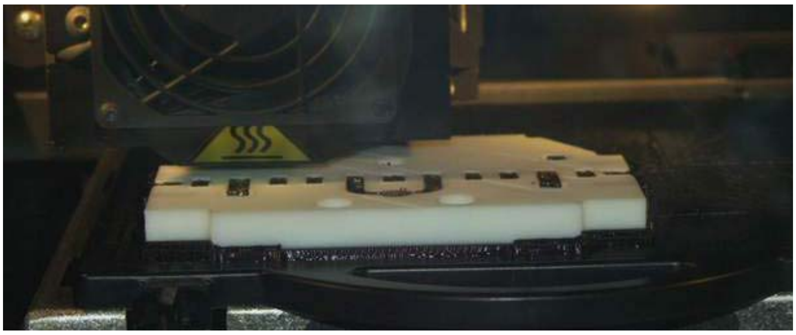

Fig. 5. Generation of control valve body by means of Rapid Prototyping method

Rys. 5. Proces tworzenia korpusu rozdzielacza za pomocą metody Rapid Prototyping

5. Experimental study

In order to conduct the experiment of the pressure drop a specially designed test stand was built. The studies were conducted for a defined range of volumetric flow. The flow was steered in an automatic way by means of a computer program. During the experiment the pressure was measured by means of pressure sensors that were placed on the input and output ports of the control valve. Additionally, the value of volumetric flow was recorded.

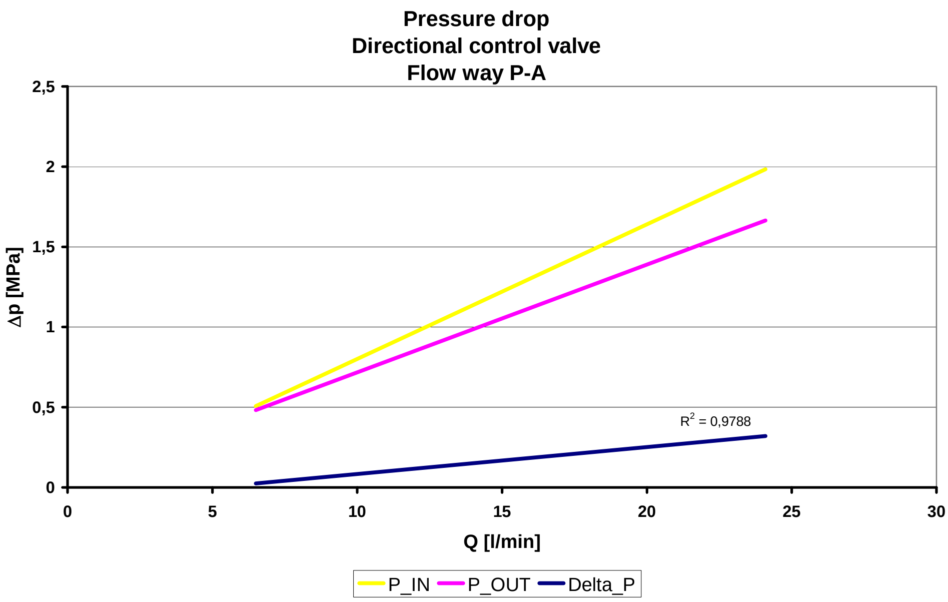

Fig. 6. Pressure drops for the flow channel P-A

Rys. 6. Straty ciśnienia dla drogi przepływowej P-A

In Fig. 6 pressure drops are presented. The flow ways between the input to the hydraulic valve and the receiver output were measured. In the graph the yellow curve represents the pressure measured by sensor at input (p_in), whilst the purple curve represents the pressure measured at output one (p_out). The blue line is finally a pressure drop that is a difference between the output and input. Measurements were done for a volumetric flow in the range between 5–20 [l/min].

6. Summary

The subject presented in the paper was the application of the state-of-the-art engineering tools for studying the phenomena that occur during flow of fluid through a directional control valve. The stress analysis of the control valve body was presented. Also the results of simulation of fluid flow through channels of the hydraulic components were shown. For verification of the numerical studies an experimental study was carried out. The prototype was built using Rapid Prototyping method.

The conducted studies show that by the application of the modern engineering tools it is possible to study the hydraulic components in a virtual way without the necessity of building many prototypes. Finally, only a limited number of prototypes has to be built for final verification of the numerical study. It seems that such a method can be successfully used in everyday work.

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