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NUMERICAL ANALYSIS OF THE INFLUENCE OF INITIAL POSITION OF A PISTON ON FLUID EXCHANGE PROCESS IN A HYDRAULIC CYLINDER

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Abstract: *Research and implementation works carried out at the Mechanical Faculty of Wrocław University of Science and Technology, aimed at developing a hydraulic cylinder construction with increased possibility of heat dissipation and discharge of contaminants, were in part realized by means of a numerical flow model. The model, verified by the experiment during the implementation of the project enabled the detailed identification of phenomena occurring during the fluid exchange process in the cylinder chamber. The numerical simulations made it possible to identify the processes of mixing of two domains - the liquid supplied into the chamber and the liquid volume contained in it at the moment of starting the power supply process. The article presents examples of results of model tests, the analysis of which made it possible to determine the impact of the initial position of the piston on the nature of the process of liquid mixing in the cylinder chamber and the nature of flow occurring during the process of removing liquid mixture from the system. The results of the conducted simulations and the developed preliminary relationships describing the mixing process of two liquid domains are the basis for the construction works of the newly designed hydraulic cylinder, which is initially intended for commercialization.*

Keywords: Hydraulic cylinder, fluid exchange process, transient thermal analysis.

1. Introduction

The hydraulic cylinder, as one of a few elements of any hydraulic system, does not ensure a full flow of liquid. This fact is particularly important in the systems of machines operated in environments characterized by a significant amount of pollution and high temperature, such as occurring in underground mines of raw materials. As part of the work carried out by the authors, a new solution for the design of a hydraulic cylinder and its supply system was proposed (Siwulski and Warzyńska, 2017). The results of theoretical analyzes and preliminary numerical simulations were so promising that cooperation with the industrial side was established. The aim of the research and implementation project was to introduce a new solution to the market (Siwulski et al., 2018). At the same time, further work was carried out on the development of a useful model enabling the analysis of the phenomenon of mixing of two liquid domains in the cylinder chamber during its supplying and the phenomenon of liquid mixture removal during the chamber volume reduction. For the simulations, two independent liquid domains were set: the liquid supplying the system and liquid in the cylinder chamber at the initial time of operation. The liquid domains were assigned with different initial temperatures, which made it possible to directly determine the amount of thermal energy supplied and discharged from the cylinder chamber. The analysis of the state of knowledge has shown that in the international scientific papers there are no studies dealing directly with this subject, however, the phenomena occurring in the cylinder chamber seem to be analogous to the widely described processes of fuel injection into the combustion chamber of piston engines (Raj et al., 2013; Wu et al., 2014).

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2. Methods

Numerical simulations in a 3D domain in a transient state were performed with the use of Computational Fluid Dynamics (CFD) in the Ansys CFX application. The *immersed solid* algorithm was applied in order to enable the simulation of piston movement without the need to deform the finite volume mesh. The numerical model for simulation of liquid mixing and exchange process in a piston chamber of a hydraulic cylinder was positively verified on a dedicated test stand shown in Fig.1 (Siwulski et al., 2018). In the current simulations, the verified model was used to simulate various operating cases. The aim of the simulations was to determine the influence of initial piston position on fluid exchange process in a piston chamber. For that reason, the simulations consisted of seven cases which differed in the initial position of a piston from 0mm (the piston at its bottom dead end) to 720mm (the piston moved to a position of 80% of full stroke). In each simulation, the piston moved in one cycle of extension and retraction with a 20% of a full stroke, which was 180mm. The initial temperature of a fluid domain was set to 80°C and the temperature of fluid supplying the piston chamber was 40°C in each simulation. At the inlet the velocity boundary condition was set and at the outlet an atmospheric pressure. The adiabatic condition was set at the model walls. The properties of the working liquid have been assumed in accordance with the specifications of hydraulic oil HLP46, which was also used during the tests: kinematic viscosity 44.2 mm^2/s (for T=40°C), density 900 kg/m^3, specific heat 1880 J/kgK, heat conductivity 0.134 W/m·K. The finite volume mesh parameters were set identically for each simulation model (Fig.2).

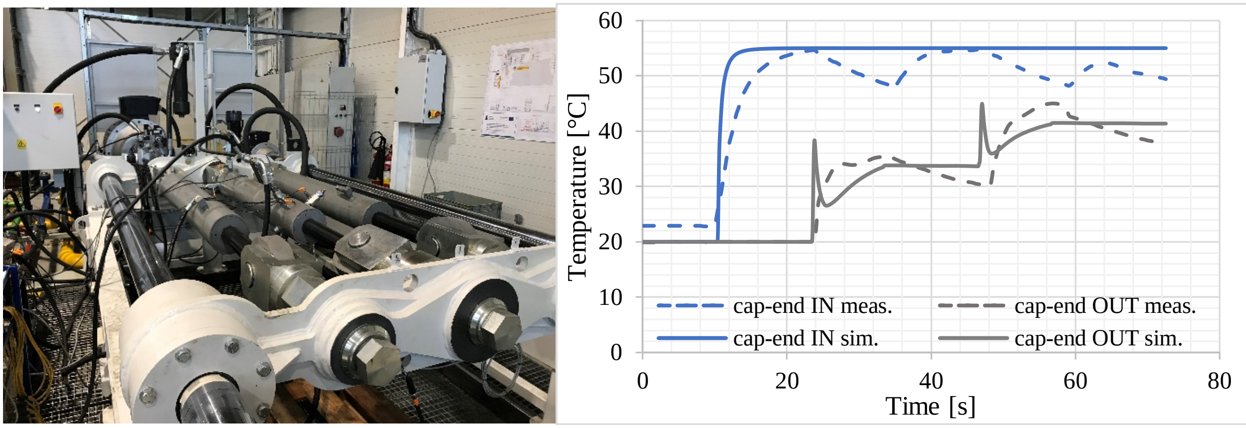

Fig. 1: Test stand for experimental tests and the results of numerical model verification (Siwulski et al., 2018).

3. Analysis of numerical simulations results

The results of numerical simulations are presented in Fig. 3 in a form of a plot of an average fluid temperature flowing out directly from the cylinder chamber. The location of a measurement plane is shown in Fig. 2.

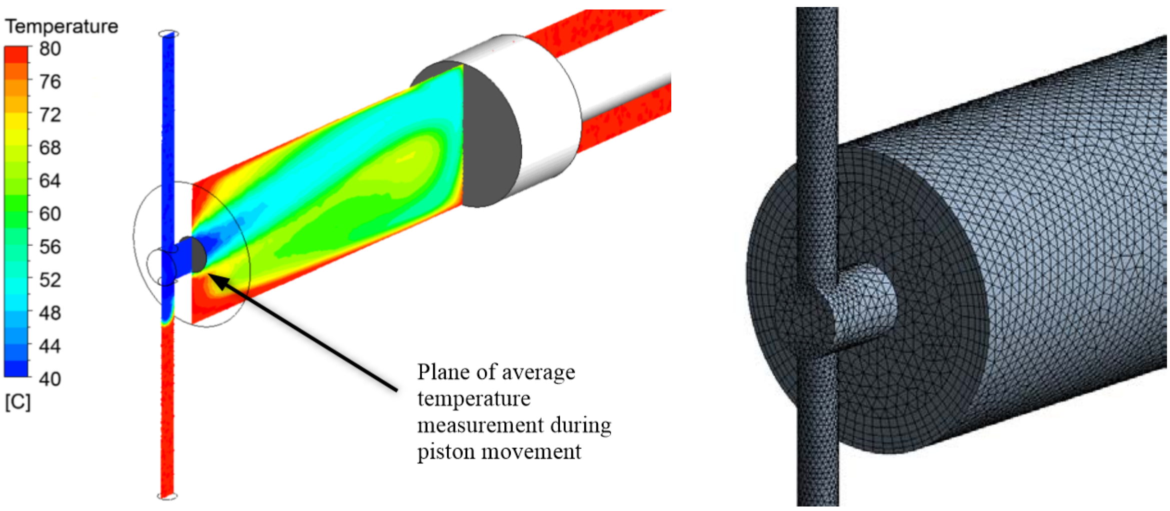

Fig. 2: Sample temperature contour plot of simulation results with indication of a measurement plane of average temperature and the finite volume mesh.

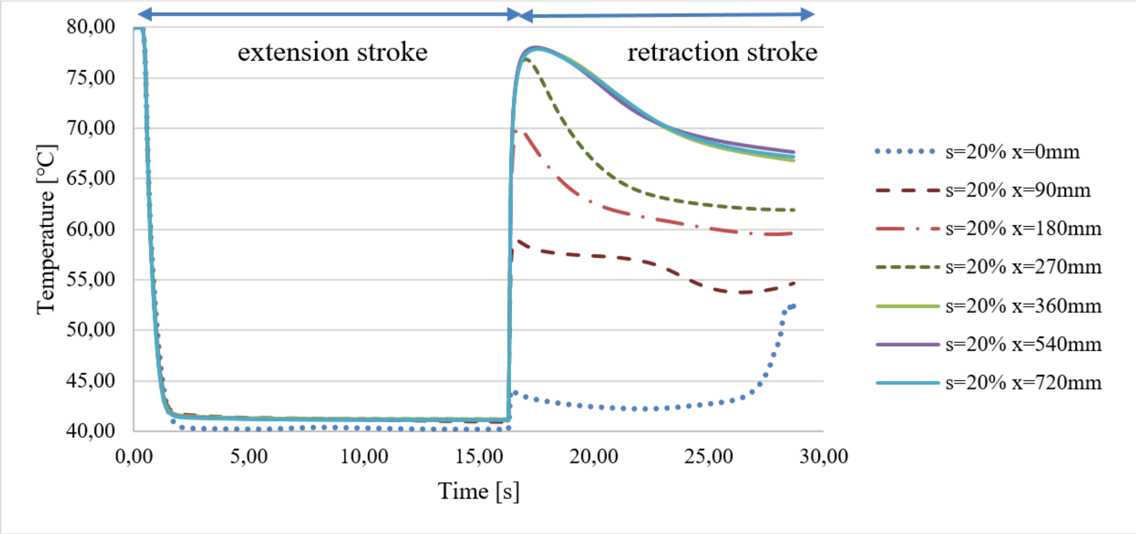

Fig. 3: Average temperature measured directly at the outlet of a piston chamber versus time of extension and retraction stroke of a piston.

The simulation results directly indicate that it is possible to divide the nature of liquid exchange in the cylinder chamber with respect to the initial position of the piston into three types, described as type I, II and III.

The type I of exchange occurs when in the initial position the piston is located a short distance from the bottom surface of the cylinder or is adjacent to it and the initial volume of liquid is not significant. In this case, the stream of liquid flows at the surface of the moving piston, however, some part of the volume of liquid in the channel supplying the chamber in the initial stage of movement is introduced into the volume located at the bottom of the chamber from which partially or completely (in the case of returning the piston into a position adjacent to the bottom of the chamber) is discharged outside the chamber (Fig.4a). In the presented simulation results, this type of exchange can be identified after a characteristic increase in the temperature of the liquid discharged from the system in the final stage of the piston movement. In the analyzed example, such results were obtained in the range of initial positions of the piston equal to 0 and 90 mm (Fig.3.).

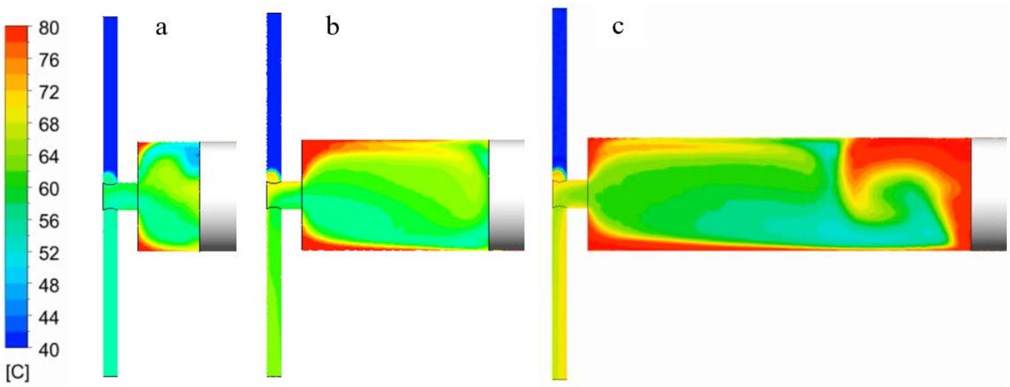

Fig. 4: Visualisation of temperature of oil in a piston chamber of a hydraulic cylinder after one full cycle: a – simulation case with stroke s=20% and initial position of a piston x=90mm, b - simulation case with stroke s=20% and initial position of a piston x=270mm, c - simulation case with stroke s=20% and initial position of a piston x=720mm.

The type II of liquid exchange is characterized in that the flow of the supplied liquid also cleans the surface of the moving piston, however, during the return movement the liquid originally located in the volume adjacent to the bottom of the chamber is not discharged from the system during the return movement (Fig.4b). In the described case, the measured temperature at the outlet of the system during the liquid discharge processes is a function decreasing over time, however its values are directly related to the value of the initial position of the piston. In the analyzed example, such results were obtained in the range of initial positions of the piston equal to 180 and 270 mm (Fig.3).

The type III nature of the exchange of fluid is characterized by practically constancy of the characteristic of the course of the temperature measured at the outlet of the system as a function of the initial position of the piston (Fig. 3). In this case, the mixing process of the liquid occurs without contact with the surface of the piston (Fig. 4c). It is also possible to isolate the volumes of liquid originally located in the area adjacent to the bottom of the chamber and in direct contact with the surface of the piston, which do not mix with the liquid and remain in the chamber during the return movement of the piston. In the analyzed example, such results were obtained in the initial piston positions of 360, 540 and 720 mm (Fig. 3).

The three areas of fluid exchange process may be determined by an average value of temperature during the retraction stroke depending on the initial position of a piston at the start of a cycle as shown in Fig.5. The conducted analysis is the basis for deriving mathematical models describing the process of liquid mixing in the cylinder chamber, and then for proper and intentional introduction of changes in the cylinder design.

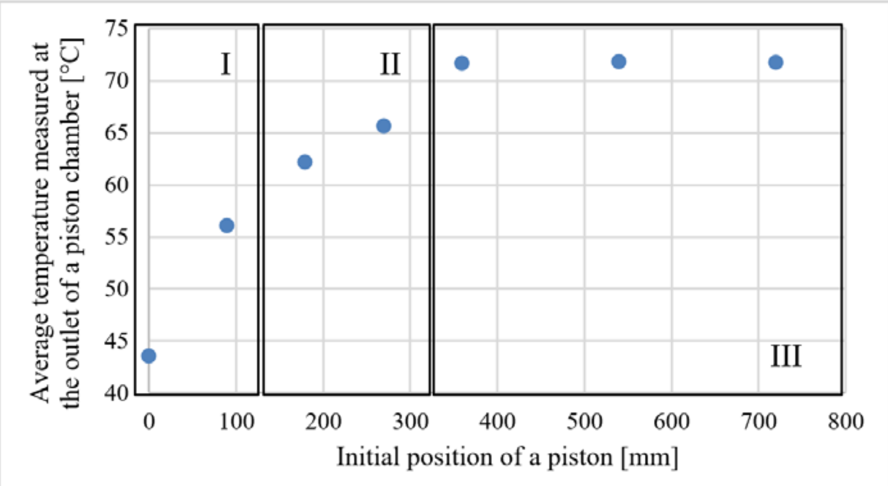

Fig. 5: Areas of type I, II and III of fluid exchange process determined by an average value of temperature during the retraction stroke depending on the initial position of a piston at the start of a cycle.

4. Conclusions

The numerical analyzes made it possible to initially identify the character of the liquid mixing phenomenon in the cylinder chamber and to propose its first description. The obtained results clearly indicate that the commonly used assumption of temperature constancy of the whole liquid volume in the system is a great simplification. At the same time, the hypothesis was confirmed that a certain volume of liquid in the cylinder chamber may not be exchanged with the supply system during operation, which is a disadvantage both from the point of view of thermal energy dissipation and discharge of contaminants from the hydraulic cylinder. The presented results are only a part of the work carried out on the development of the basis of a new approach to the design process of hydraulic cylinders characterized by increased resistance to external conditions and higher reliability.

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