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A NEW DESIGN OF A HYDRAULIC CYLINDER WITH AN IMPROVED FLUID MIXING IN THE CHAMBERS

The article presents a new concept of a hydraulic cylinder with an improved fluid mixing in the chambers, which may highly contribute to a better heat exchange and therefore improve the reliability of operation. In the paper, the preliminary comparative results of computational fluid dynamics (CFD) analyses are shown. The two constructions were analyzed: the standard one and the new design of hydraulic cylinder. The results of the calculations indicate, that the new cylinder design is characterized by a better thermal energy dissipation.

Introduction

Hydraulic cylinders for application in industrial automation, and in particular in heavy industry such as mining, often work in demanding conditions in systems with higher temperatures and under high workload. Increasing the concentration of mining and operating at deposits at increasing depths and at the more difficult climatic conditions influence the level of reliability of mining machines. The analysis of failure [2], in self-propelled drilling and anchoring machines, reveals that the mean time between failures is at a level of proximately 90 hours, and above 30% of all recorded failures concern hydraulic cylinders. The other study regarding loaders and other machines, shows that above 35 failures of cylinders were reported in a four-month time period, and almost a half of that was due to oil leakage. The main reason of the described failures is probably a thermal degradation of the seal elements in hydraulic cylinders (as shown in Figure 1), due to strict operating conditions and excessive heat, which lead to decrease in the efficiency and considerable damage [1, 4]. Therefore, one of the major issues for reliable operation of hydraulic cylinders according to authors is effective dissipation of heat from the working chambers.

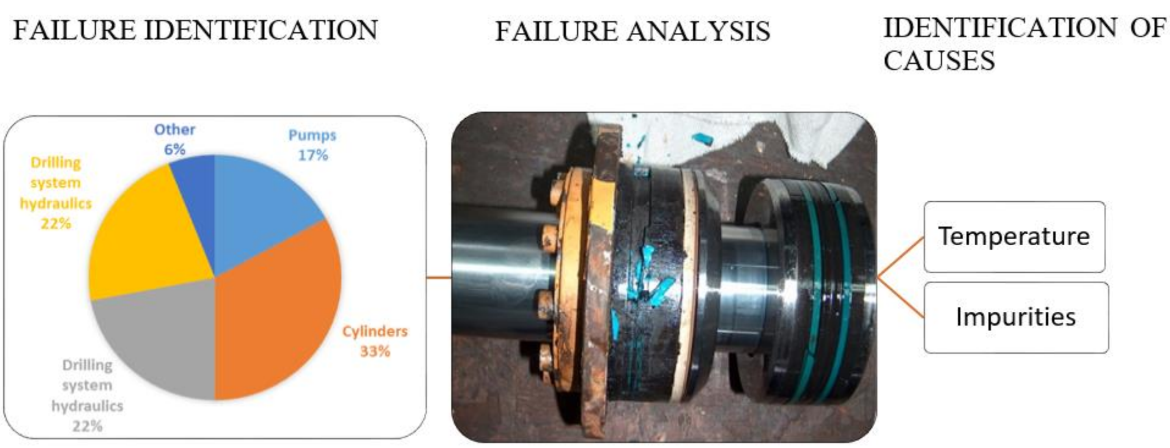

Figure 1 – A diagram illustrating the process of failure identification leading to causes identification

A new design of a hydraulic cylinder

The new concept of the hydraulic cylinder (Patent Application No. P415174, [3]) assumes that each of the working chamber of the hydraulic cylinder is supplied by two hydraulic lines with clearly defined functions. The fluid is supplied by the power supply line, and discharged by the relief line through appropriate valves or the directional valve. In addition, the control valves are located as close as possible to the hydraulic cylinder, preferably in a valve block located on the cylinder. The new solution allows a full circulation of the hydraulic fluid in the chambers of the cylinder, and thus effectively remove thermal energy. In Figure 2 the new concept of a hydraulic cylinder with a control system is shown schematically. The following example illustrates one of the possible solutions that may differ in a type of cylinder, number of control valves or include additional hydraulic elements, e.g. a hydraulic lock.

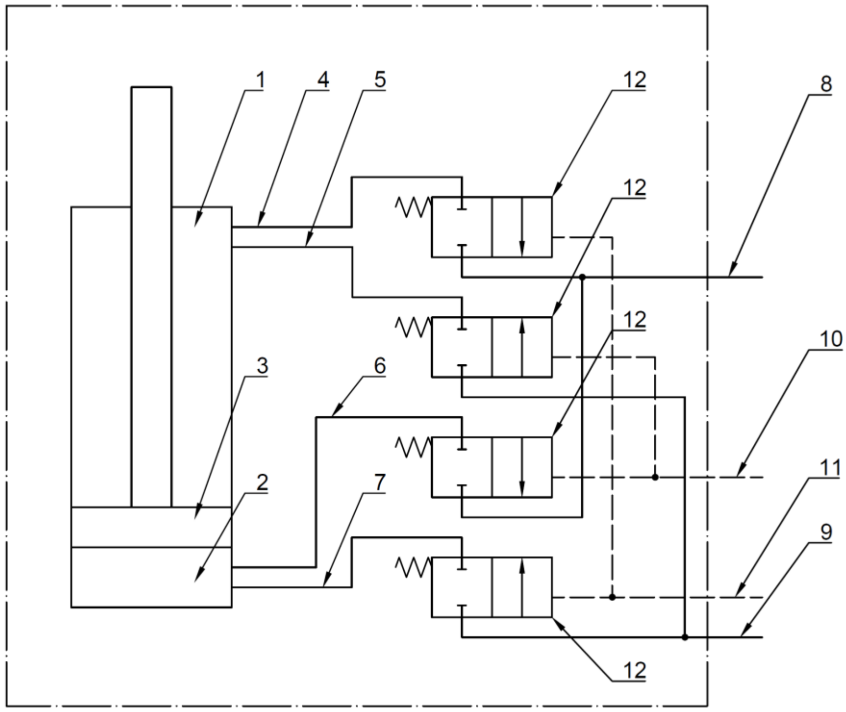

Figure 2 – The schematic of a new design of hydraulic cylinder with a control circuit: 1, 2 – cylinder chambers, 3 – piston; 4, 6, 8 – relief lines; 5, 7, 9 – power supply lines; 10,11 – control lines; 12 – directional control valves [3]

Results of numerical calculations

For the analysis of fluid flow, a geometrical model of the cylinder of a self-propelled mining machine was used. The comparative analyses of fluid flow were performed for the standard design and the new design of a cylinder. The standard model of a cylinder has a single line adjusted to each of the chambers and it was assumed that the control valves are located at a distance of 500mm from the cylinder. A new model of the cylinder includes a total of four lines, each of the chambers has a separate supply and relief line, which are shortened to 100mm because of the valves mounted in a block on a cylinder. Numerical simulations in the field of computational fluid dynamics (CFD) were done in Ansys CFX. In the calculation, the algorithm of immersed solid was used in order to enable simulation of the piston movement without deformation of a finite volume mesh. The parameters of the fluid were similar to hydraulic oil Hydrol 68, without the change of parameters depending on the temperature and pressure. The boundary condition at the inlet was mass flow rate Q=1.5 kg/s, while at the outlet a free outflow at atmospheric pressure. The difference in temperature between the fluid in a chamber and fluid in a supply line was set at 40°C. Pre-start temperature in the entire fluid domain was set at 80°C while the temperature of the fluid at inlet equal to 40°C. In both presented in this study simulations piston movement function was set in the range of 50% of the full stroke. As a result of numerical analyses, temperature distributions in the domain of fluid in the individual time steps in transient simulation were obtained. Total analysis time was equal to two cycles of the cylinder, which was 2.8s. In Figure 3 the distribution of temperature in fluid domain after the second advancing movement is shown for both cylinder constructions.

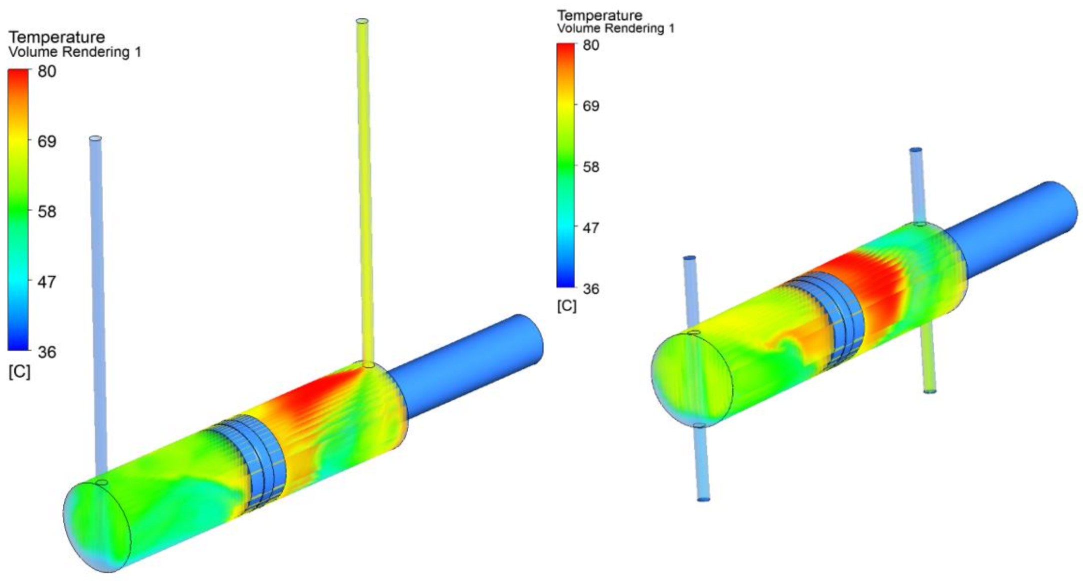

Figure 3 – Comparison of the CFD results – temperature distribution in oil domain after one cycle:
1 – standard cylinder design, 2 – new cylinder design

In order to quantitatively compare the two designs of cylinders, the following parameters were introduced:

–Average temperature t_a – average temperature of fluid flowing out of the system measured at the outlet during retracting of the first and second cycle, measured on the basis of temperature at the outlet plot versus time of simulation (Figure 4),

–Temperature increase Δt – the temperature difference between the average temperature and the temperature of inflowing fluid into the chamber,

–Relative difference RD – a parameter showing the improvement of heat dissipation, the ratio of temperature increase difference between new and standard cylinder to the temperature increase of the standard cylinder (Eq.1):

$$RD = \frac{\Delta t_{new} - \Delta t_{std}}{\Delta t_{std}} \cdot 100\% . \quad (1)$$

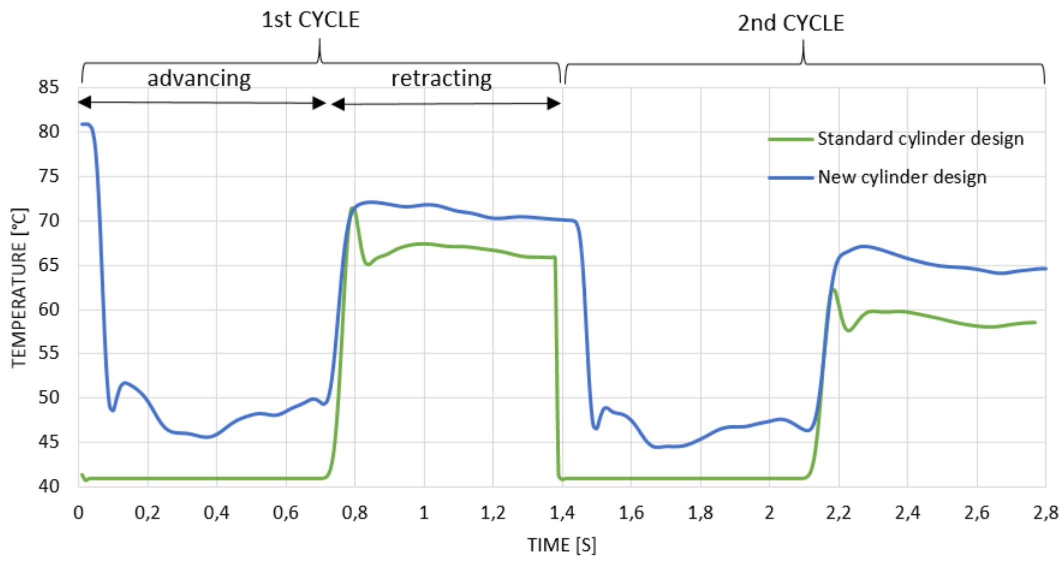

Figure 4 – A comparison of the temperature at the outlet during the double cycle of the hydraulic cylinders

The results of the comparison are shown in Table 1.

Table 1 – Comparison of the cylinder designs on the basis of thermal energy dissipation

	1st cycle		**2nd cycle**	
Cylinder type	standard	new	standard	new
Average temperature [°C]	64.57	69.34	57.92	63.87
Temperature increase [°C]	24.57	29.34	17.92	23.87
Relative difference [%]	19.41		33.18	

Conclusions

The results of the numerical simulations showed that after a first cycle, in the new design of a cylinder, about 19% more of thermal energy was removed than in a standard cylinder design. An increased efficiency of heat exchange is even more noticeable after a second cycle, where the relative difference was 33% in favor of a new cylinder design. The results of numerical simulations at this stage of the study have not yet been verified on the test rig, but on the basis of comparative analysis, with the same parameters set, appear to be promising. In the next stages of work, carried out together with an industrial partner PONAR Engineering company, it is planned to test prototypes of a new cylinder design and to conduct more sophisticated numerical analysis taking into account the actual parameters of the system. The next step will be to determine favorable location of cylinder ports to ensure optimal heat exchange by flow and mixing of fluid.

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