Tests of New Methods of Manufacturing Elements for Water Hydraulics

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Keywords: Water Hydraulics, Hydraulic Cylinders, Hydraulic Pumps, Directional Control Valve, Coating, Plastic

Abstract. The article presents a review of modern methods of producing hydraulic components that can work with water as a working medium. The presented technology of coating and production of plastic elements is an alternative to the currently used stainless steel construction. Large-scale testing of cylinders and valves made in coating technology has been carried out. Innovative methods for designing pumps made of plastic have been developed, and were confirmed by laboratory tests.

Introduction

Research conducted on the use of water as a working medium not only in power hydraulics, but also in other branches of industry (fire extinguishing, refrigeration, etc.) confirm the existence of problems with its use [1, 2, 3]. However, the advantages far outweigh its disadvantages. That is why it is so important to use water hydraulics in natural environment friendly applications [4]. Especially if their price will not be a big obstacle. Currently, the cost of components made of stainless steel 3 ÷ 4 times exceeds the price of standard oil hydraulic elements [5, 6]. The first solution to its reduction is the technology of chemical-physical coatings integrating the Diamond Like Carbon coating technology (DLC) Coating with innovative technology with self-lubricating properties of the Columnar Nanostructured Coating (CNC). The research of these coatings was one of the topics of the EU project called "Novel high-pressure water hydraulic equipment for application in the mining and mining sector" with the working name “Hydrocoat”. Tests were carried out in the fluid power laboratory which currently is a part of the Laboratory of Techno-Climatic Research and Heavy-Duty Machines at the Cracow University of Technology. The second method is the use of plastics. The research of hydraulic pumps and other elements made of plastic bodies is carried out by the Fluid Power Research Group at the Wrocław University of Science and Technology.

Materials

The parts produced for oil hydraulics were specially treated. The metal-contacting parts were covered with special patented protective layers. This technology is treated as a solution enabling an adaptation of the already existing valves and cylinders to work in a water hydraulic system. These layers are the following: the Diamond Like Carbon (DLC) and Columnar Nanostructured Coating (CNC) with self-lubricating properties. Their use contributes to the lowering of the friction force and also provides a layer protecting steel from corrosion [2, 7]. In addition, using the experience gained

Materials Research Proceedings **5** (2018) 200-205 doi: http://dx.doi.org/10.21741/9781945291814-35

in the research of water hydraulic systems, the seals were replaced in the tested cylinders. The new seals were made of materials that could cooperate with water, such as: ULTRALEN 90 and KEFLOY 22 [1].

In turn, the use of plastics in the construction of pumps brings design, technological, operational and economic benefits such as reduction of mass, simplification of construction, self-sealing ability, improvement of tribological properties between cooperating elements, increase of resistance to contaminants in the working fluid, increase of the ability to damp vibrations and reduce noise [8]. And above all, pumps made of plastics can work with various working fluids, such as hydraulic oils, water, emulsions, nanofluids and chemical fluids [2, 9]. As a plastics easily available on the market, cheap and easy to process polyoxymethylene POM was chosen [10].

Cylinder tests

The aim of the research was to confirm the effectiveness of the developed cover technologies. The Polish Standard PN - 72 / M - 73202 concerning tests of oil hydraulic cylinders was used during the tests of a water hydraulic cylinder. No standards have yet been developed for testing elements using water as a working fluid. According to it, external leak tests and internal leak tests were conducted, the friction force, volumetric efficiency, hydraulic - mechanical efficiency and total efficiency were determined [11].

Tests with a static pressure load did not show measurable external or internal leaks. Therefore, the determination of hydraulic - mechanical efficiency was reduced to determine the equivalent, total efficiency of the cylinder as a function of piston velocity and working pressure. A special stand was designed for the tests, where in the welded frame of C - profiles, cylinders connected with a trolley were mounted. The wheels of a trolley were run along the inner surface of the frame. One of the cylinders was used for the drive, while the other was used to generate the load. The displacement of the piston L, the pressure on the piston side p_{a1} and the pressure on the rod side p_{a2} of the cylinder were measured. During efficiency tests, the temperature of the water in the hydraulic system was T = + 40 °C. They were repeated, for comparison, for other values of temperature. To determine the impact of pressure on the total efficiency, tests were carried out at the piston velocity of v = 0,2 m/s and the working pressure p_Z changing from the minimum to the nominal value. To determine the influence of velocity on the total efficiency of the cylinder, tests were carried out at the nominal load pressure and the speed changing from 0,05 to 0,2 m/s.

Figure 1 shows three - dimensional characteristics of the determined total cylinder η efficiency for the extension and retraction depending on the velocity of the v piston and the theoretical F force. The force was calculated as a product of pressure and surface area on the piston side of the cylinder during extension and on the rod side of the cylinder during retraction.

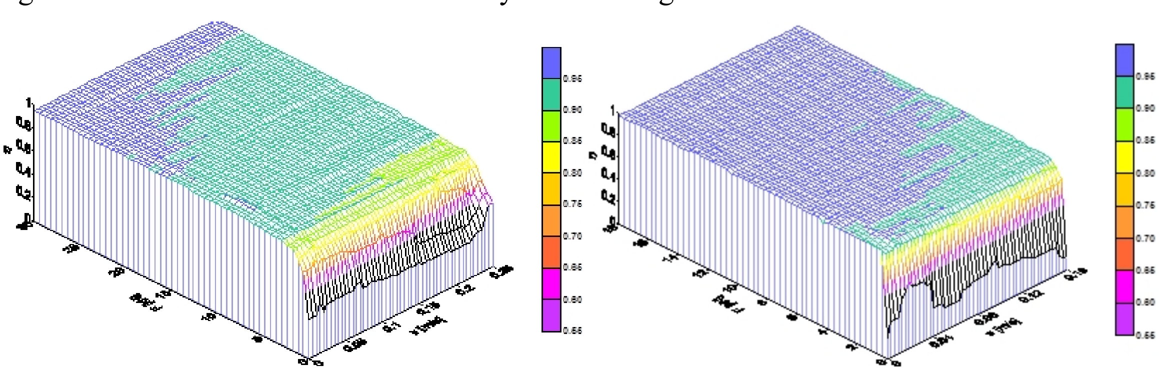

Fig. 1. Characteristics of the total cylinder efficiency during extension and retracting [7]

Materials Research Proceedings **5** (2018) 200-205 doi: http://dx.doi.org/10.21741/9781945291814-35

Valves tests

The problem of a proper design of the gap between the movable elements of the spool directional control valve is particularly difficult when water is used as a working medium [12]. The low value of its viscosity coefficient causes the increase of leakages and a friction force. For these reasons, a directional control valve was constructed of four two-way ON/OFF valves. They were chosen because they are durable and relatively uncomplicated. Four separate ON/OFF valves were covered with a CNC coating and mounted in a specially designed aluminium block (Fig. 2). To control the coils of these valves, a programmable electronic module was designed and made. It enabled an independent activation and deactivation of each ON/OFF valve. That is why the distributor could work in any configuration of ways. Tests of the directional control valve consisted of functional tests in a hydraulic system with a cylinder and determination of flow characteristics for individual way of valve (Fig. 3) [13].

Fig. 2. View of a four - way, three - position manifold body with four ON/OFF valves [13].

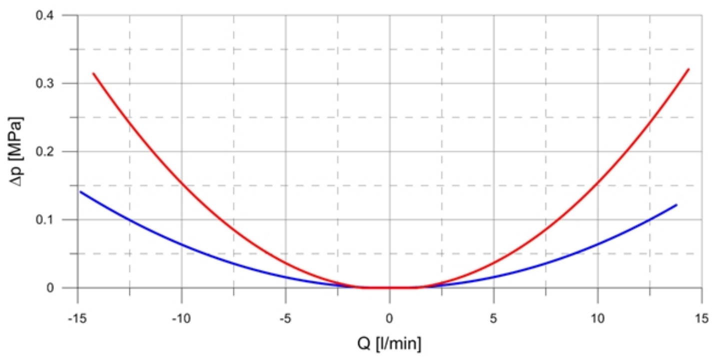

Fig. 3. Flow characteristics for roads P - A (red graph, negative values Q), P - B (red graph, positive values Q), A - T (blue graph, positive values Q), B - T (blue graph, negative values Q)

Pump tests

The tests of pumps and rotary motors with the use of covers did not bring the expected results. The exact analysis of the problem revealed that the use of coatings presents difficulties in keeping the strength and clearances between the elements. Therefore, it was considered reasonable to make such an element from scratch, ideally, from an easily accessible and easily machinable material such as plastics [14, 15]. It was assumed that the general shape of a pump body should be formed as a prism with a square base. By removing the material from this general shape and applying the principles of global and local modification, the final shape of the pump body was obtained (Fig. 4). In addition, using the generally known methods of designing hydraulic machines and systems and the Finite Element Method (FEM), the author's methodology for shaping the bodies of hydraulic machines from plastics was developed [14].

Fig. 4. View of a gerotor pump with a body made of plastics

The assembled gerotor pump with a plastic body has been subjected to experimental research on a test stand in order to determine its basic hydraulic characteristics. The test stand enabled the measurement of hydraulic parameters, such as flow and pressure at the inlet and outlet of the pump, and measurements of mechanical parameters, such as torque and rotational speed. Signals from measuring instruments were sent to the computer using a laboratory signal amplifier. The CatmanEasy computer program was used to archive and analyze the measurements on the computer. The tested pump was driven by a DC electric motor with the power of 30 kW and the maximum speed of n = 3000 rpm. A throttle valve was used to load the pump. To protect the pump and electric motor from overload, an overflow valve was used.

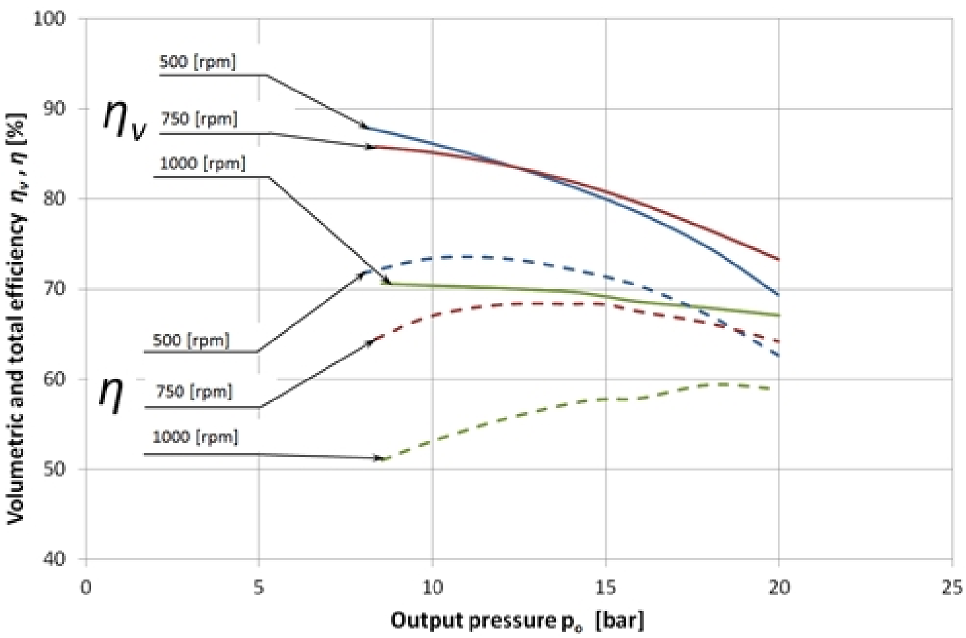

Fig. 5. The characteristics of volumetric and total efficiency, depending on the output pressure η_v, $\eta = f\,(p_{out})$, for different rotational speeds n = 500 ÷ 1000 rpm

Figure 5 shows that the pump was working in the range of working pressure of p = 0 - 20 bar and rotational speed of n = 500 - 1000 rpm. The η_v volumetric efficiency varied in the range of η_v = 89 - 70%, and the total η efficiency varied in the range of η = 73 - 50%. The relatively low efficiency prevented further loading of the pump, which could lead to its seizure. Figure 4 shows that the volumetric η_v and total η efficiency decreases with the increase of the *p* output pressure and the *n* rotational speed. This is explained by the fact that as the *p* pressure and *n* rotational speed increase, the deformation of the plastics pump body increases, which causes internal leakages in the pump, which in turn decreases the efficiency of the pump.

Summary

The results of tests of cylinders, directional control valves and pumps presented in this paper confirmed the possibility of using water in hydraulic systems. Working parameters of the tested hydraulic components are at satisfactory levels [16]. High efficiency and no leakages in the cylinders and low resistance of flow in the directional control valve decrease hydraulic, mechanical and volumetric losses in the entire system. Energy consumption is reduced. The whole system becomes more efficient and more economical. Covering the inner surface of the cylinder and the surface of the piston and piston rod confirms the protective properties of the coatings. They protect steel elements against corrosion. The lack of observable internal and external leakages during the static pressure test, testify proper cooperation between the sealing material, cylinder surface and piston rod, despite extremely low viscosity of water in relation to viscosity of hydraulic oil.

Two main objectives have been achieved in relation to hydraulic pumps: the methodology of designing bodies of hydraulic machines made of plastics was developed and verified by designing, making and experimental testing of a gerotor pump with a plastic body. The pump with the POM body works properly in the pressure range of $p = 0 \div 20$ bar and the speed of $n \leq 1000$ rpm. At the same time in future, plastics with higher strength and greater dimensional stability should be chosen, so it can be used for medium pressure pump bodies ($p = 60$ bar).

Using the developed methodology of designing bodies of hydraulic machines made of plastics, the construction solution can be improved from the point of view of various criteria, including material, strength, geometrics and technology. The principles of global and local modifications of the pump body are open and in the future can be expanded and improved. By using the modification process, the structural solution of pump, valves and motor bodies can be corrected at the design stage.

Promising results were obtained, giving a basis for further work on a new generation of relatively cheap components for water hydraulics. Currently, the Fluid Power Research Group from Wrocław University of Science and Technology is working on adapting the plastic pump to work on water as a working medium. The tests will be carried out at a stand prepared by the Water Hydraulics Laboratory at the Cracow University of Technology. Considering extensive experience of scientists from both universities, the success of the project is expected.

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