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APPLICATION OF PLASTICS IN THE BUILDING OF FLUID POWER ELEMENTS

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ПРИМЕНЕНИЕ ПЛАСТМАСС ДЛЯ ИЗГОТОВЛЕНИЯ ГИДРАВЛИЧЕСКИХ ЭЛЕМЕНТОВ

In the paper, a design concept and models of basic POM-type plastic hydraulic elements such as a gerotor pump, a pressure relief valve, an On – Off valve and a cylinder have been presented. The experimental research proved the elements work properly. A simple system made of the elements has been built. The system worked properly within the working pressure range up to 4MPa. Application of POM is advantageous for its simple and cheap method of production and silent operation.

Further research will be focused on higher strength plastics, development of new design solutions for the elements and better methods of their manufacture.

Keywords: POM-type plastic, hydraulic elements

Introduction

Similarly as in other areas of machine design, in the design of fluid power machines and appliances, plastics are getting more and more frequently used. They are, among others, applied in the:

- pump casings, valve blocks and filters [1],
- hydraulic cylinders [2],
- gears [3, 4, 5].

The application of plastics is advantageous for design reasons, as it leads to:

- mass reduction, higher damping capacity and noise reduction,
- improvement of the tribological properties of the collaborating elements,
- higher pollution resistance.

It is advantageous also for the technological and economic reasons as it enables:

- manufacturing of complex shapes by means of injection moulding,
- reducing of material and production costs.

The use of plastics, however, is connected with major problems such as:

- reduction of the elements' strength and load-carrying capacity,
- occurrence of size instability accompanying the temperature change and water content in the working fluid.

In spite of the problems, the tendency connected with the application of plastics in the design of fluid power machines seems obvious and is still developing.

In this situation, the Fluid Power Research Group (www.fprg.pwr.wroc.pl) from Wrocław University of Technology have taken up systematic design and experimental work aimed at the development of a complete hydraulic system made from elements, in which at least the key parts are made of plastics.

In the paper, a design concept of such a system including its fundamental elements, namely pumps, valves and hydraulic cylinders have been presented.

Plastic selection

The plastic selected for the project was pure polyoxymethylene (POM) and glass fibre polyoxymethylene POM-GF25. The basic properties of the selected plastics have been presented in Table 1.

POM features relatively high strength ($R_e=60\text{MPa}$) as well as relatively low strain ($E=3000\text{MPa}$). The material can work at temperature up to $100\text{ }^\circ\text{C}$. Although it absorbs water, the absorption is not considerable (0.7%), which is very important in the context of its possible application in water hydraulics systems. Selection of this material is advantageous for technological reasons because it can be processed by means of injection moulding. It also needs to be pointed out that POM is a cheap and accessible plastic.

Another plastic, namely POM-GF25 is also a material based on polyoxymethylene (POM). 25% of the material volume is fibre glass. The use of this additive results in an increase in the mechanical properties compared to the pure POM. The difference is particularly noticeable for Young's module E with a triple increase in the value which equals $E=9200\text{MPa}$.

Table 1

Properties of the selected plastics

		Plastic	
		polyoxymethylene POM	polyoxymethylene POM-GF25
No.	Parameter		
1.	Yield stress <i>Re</i>	60 MPa	120MPa
2.	Young's module <i>E</i>	3000 MPa	9200MPa
3.	Max working temperature <i>T</i>	100 ⁰ C	110 ⁰ C
4.	Friction coefficient <i>μ</i>	0,3	0.35
5.	Shrinkage	0.0285 cm/cm	0.0102 cm/cm
6.	Elongation factor	0.0001 cm/ ⁰ K	0.00004 cm/ ⁰ K
7.	Water absorption coefficient	0.7%	0.5%

The addition of glass fibre caused also a decrease in shrinkage of the elongation factor. In the case of the friction coefficient, a slight increase comparing to the pure polyoxymethylene POM was observed.

**Fluid power system elements
Gerotor pump**

It was assumed that a gerotor pump would be used in the hydraulic system.

In the question of the construction material, it was decided that plastics would be used for the making of the internal cycloidal gearing system, whereas metal would be used for the building of the shaft, bearings and the casing of the pump.

The theoretical basis presented in [3] was applied in the design, and next in the manufacture of the POM gerotor pump. The pump has been shown in figure 1.

As it has been shown in figure 1a, the body of the pump was made of an aluminum alloy, and the shaft was made of steel. The shaft revolves in the bimetallic bearings (figure 1c). Figure 1b illustrates a POM gear system made mounted in a bronze bearing of the central body of the pump. In the back body (figure 1c), kidney-like chambers for the supplying and receiving the working fluid from the intertooth displacement chambers made between the rotating gears are located. The gear system was made by means of the injection moulding in the laboratory of the Machines and Automation Institute of Wroclaw University of Technology, using a dedicated injection mould.

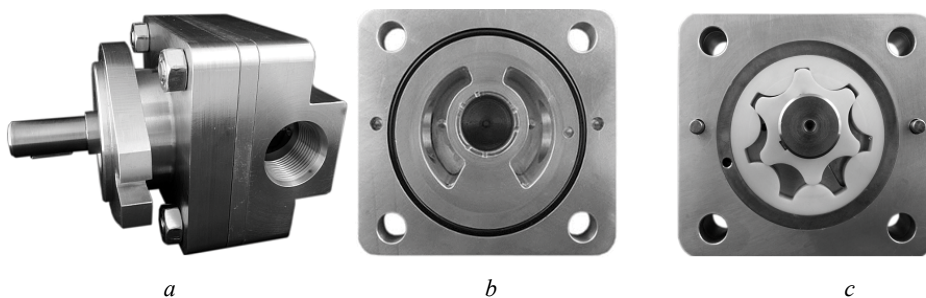


Fig. 1. The experimental gerotor pump with POM gears:
a– the pump, b – gears in the background of the pump's front body, c – the back body

The experimental research on the pump was carried out on a test stand at the Wroclaw University of Technology. The pump's efficiency characteristics have been shown in [6]. Figure 2. Figure 2 shows that the pump was working at pressure $p=6\text{MPa}$ and rotational speed $n=1500\text{ rev/min}$ with $\eta_v=70\%$ volumetric efficiency. The oil temperature change from $T=25^{\circ}\text{C}$ to $T=50^{\circ}\text{C}$ caused an increase in the volumetric efficiency to $\eta_v=80\%$, which, on its part, was caused by the gears' size increase generated by the working fluid temperature which internally sealed the pump. The research showed that the collaboration of the POM gear system and the aluminum alloy with the bronze bearing slot was correct. The final conclusion of the research was that the POM gear system can be loaded with pressure $p=6\text{MPa}$, which corresponded with the prognosis given in [5, 6].

The fluid power cylinder

Based on [7, 8], a design concept for the fluid power cylinder shown in figure 3 was developed. It was assumed that the cylinder pipe (1), the head (2) (3) and the piston rod (4) would be made of POM. The piston (5), however, would be made of stainless steel.

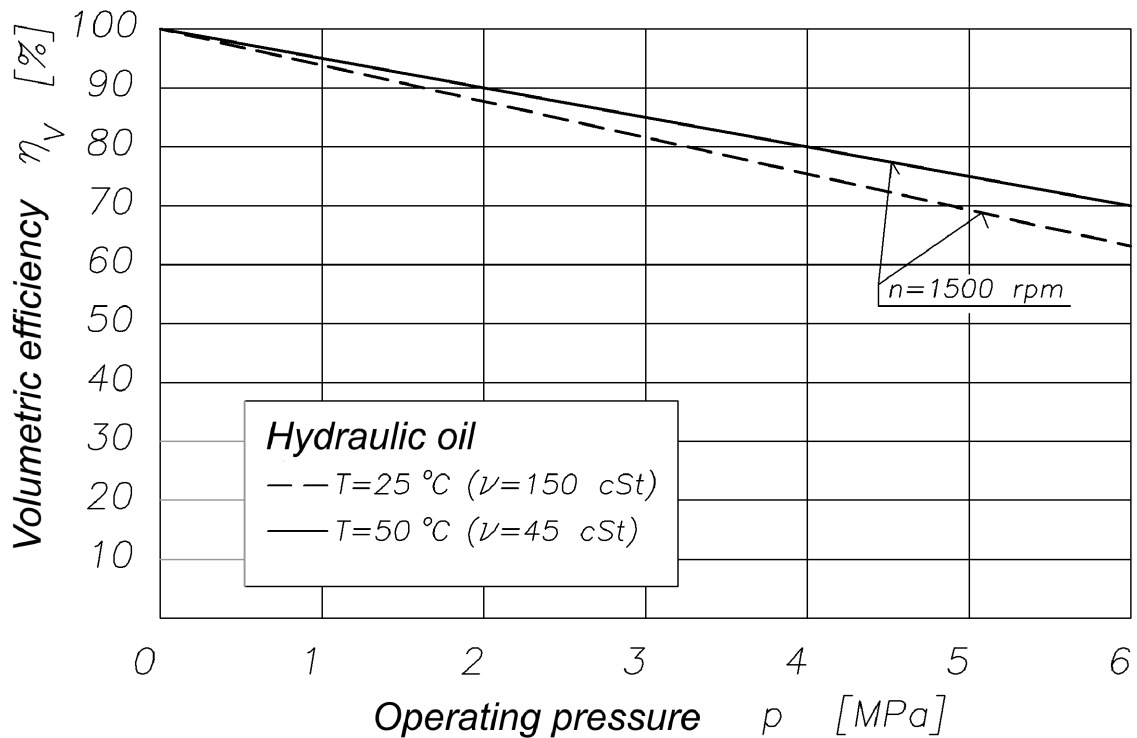


Fig. 2. Efficiency characteristics of the gerotor pump with POM gears [6]

The initial research made by means of MES showed that the cylinder pipe (1) was subject to transverse strain. In the range of the assumed working pressures (6MPa), however, the strain was small enough to be compensated by the deformability of the sealing unit (6) of the piston rod.

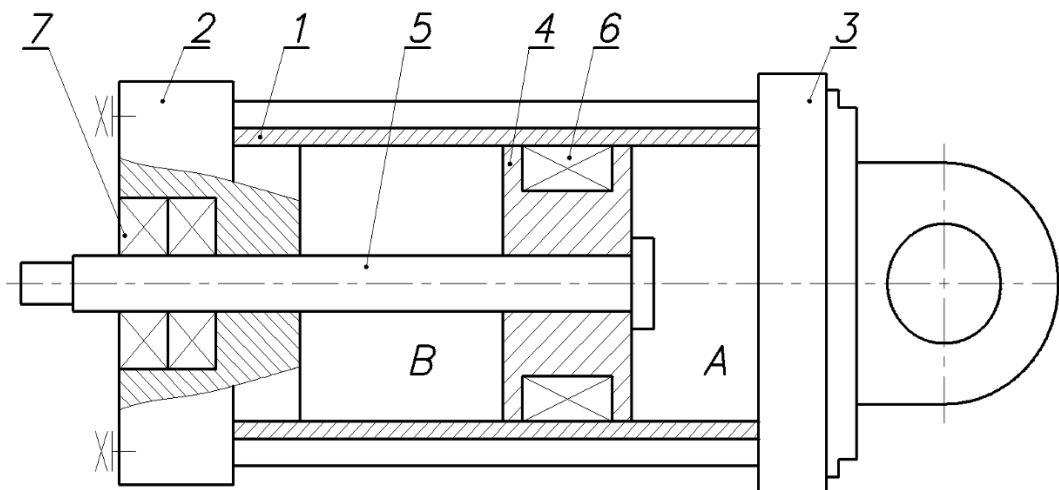


Fig. 3. Conceptual diagram of the hydraulic cylinder

Thus, the tightening of the under-the-piston rod chamber (A) and over-the-piston rod chamber (B) was maintained. A special attention ought to be paid to the sealing unit of the piston rod (6) and the piston (7), which should provide not only the tightening but also good collaboration with the plastic. A view of the hydraulic cylinder made according to that concept has been presented in figure 4.

Figure 4 depicts the cylinder with two heads, in white, made of plastic. In the heads, black threaded ends for the connection of the fluid lines are fixed.

Elements of the hydraulic cylinder are connected by means of four long screws. Three of the screws are presented in figure 4c.

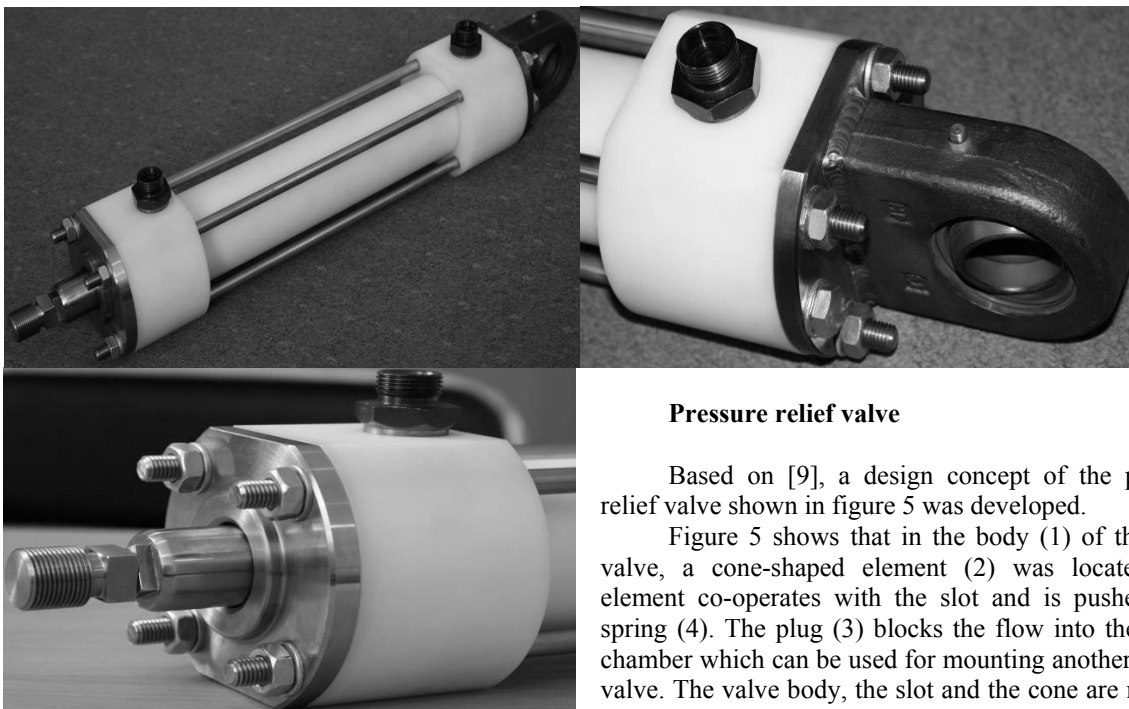


Fig. 4. Hydraulic cylinder made of POM. a – overview, b – head 3 with the joint, c – head 2 with the piston end

Pressure relief valve

Based on [9], a design concept of the pressure relief valve shown in figure 5 was developed.

Figure 5 shows that in the body (1) of the relief valve, a cone-shaped element (2) was located. The element co-operates with the slot and is pushed by a spring (4). The plug (3) blocks the flow into the empty chamber which can be used for mounting another type of valve. The valve body, the slot and the cone are made of POM-GF25. The spring is made of stainless steel. The valve works so that the working fluid flowing at high pressure into the inlet (W_e) pushes the cone (2) up and flows through the outlet (W_y).

A view of the relief valve made according to the concept has been presented in figure 7. Figure 5a illustrates a general view of the valve. It includes: the body (1), the base (2), the cover (3) and spring clamp control (4). Figure 5b shows the cover (3) and figure 6c depicts the base (2), which are connected with screws.

Initial experimental research on the valve proved its proper operation in the hydraulic system.

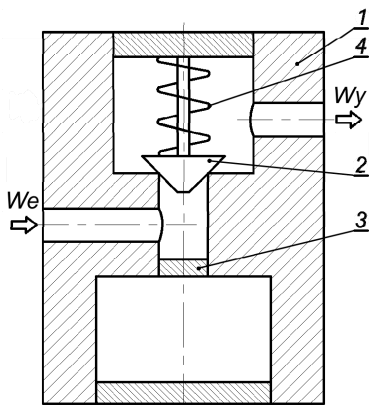


Fig. 5. Conceptual diagram of the controlled check valve

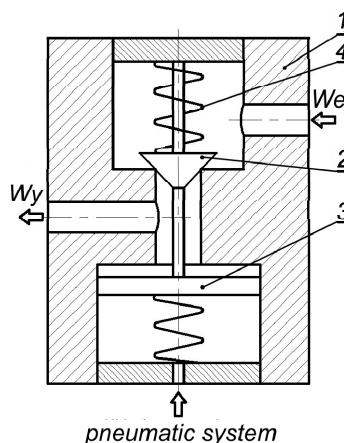


Fig. 6. Conceptual diagram of the On – Off valve

On – Off valve

Based on [9] a design concept of a controlled check valve was developed (figure 6). In the body of the valve (1), a cone-shaped closing element (2) collaborating with the slot was fixed. The cone is pushed by the spring (4) and connected with the control piston (3). The under-the-piston rod chamber is connected with a pneumatic system.

The body of the valve and the slot are made of POM-GF25, and the spring is made of stainless steel.

The valve can be used as a two-way directional valve.

The body (1) with the slot and the closing element (2) are planned to be made of plastic.

Figure 7 shows also element (3), namely a control piston collaborating with a pneumatic system. The piston will be made of POM-GF25 .

The valve can be used as a pneumatically controlled 2-way two-position directional valve (2/2).

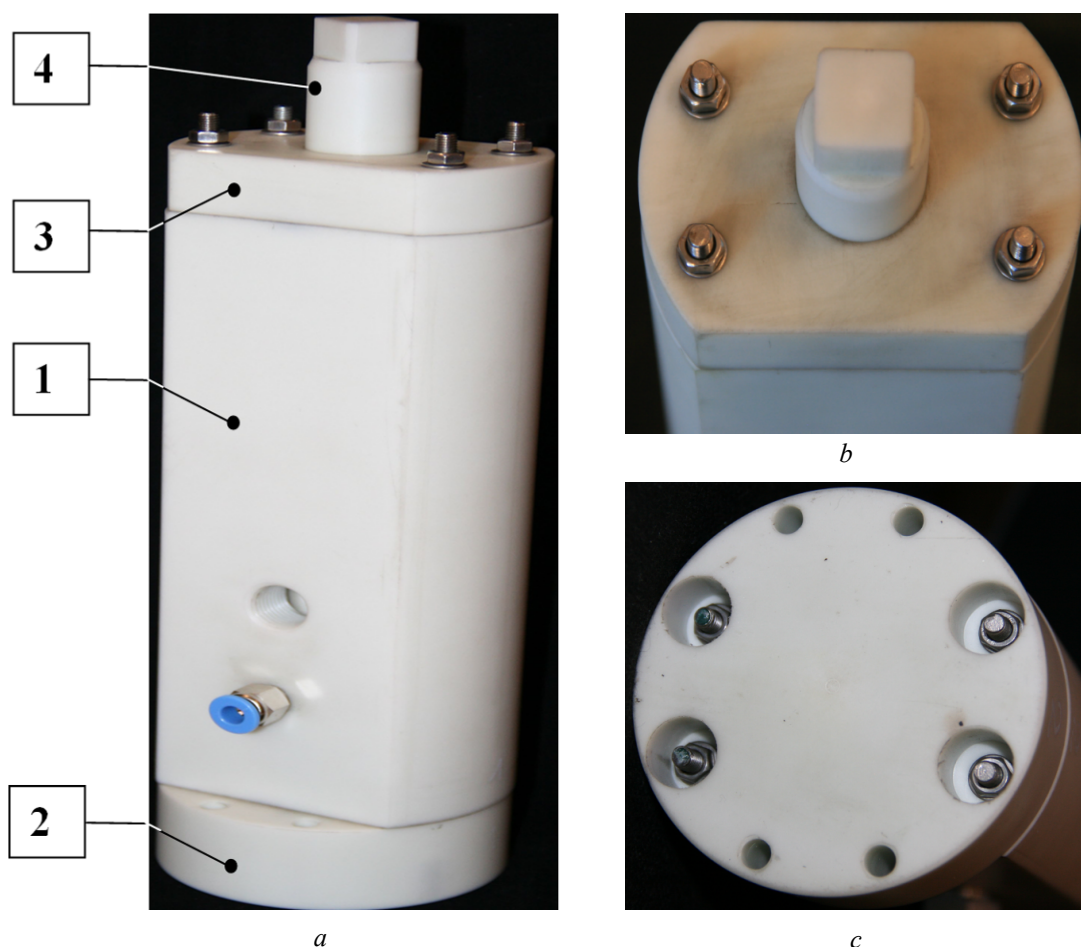


Fig. 7. View of the relief valve, a – general view, b – view from the side of the cover, c – view from the side of the base

The inlet channel (W_e) is connected to the chamber before the cone (2), whereas the outlet channel (W_y) to the chamber under the cone. Starting up the pneumatic system causes pushing the control piston (3) and the cone (2) connected with it. The cone goes up and the fluid starts flowing through (W_e/W_y).

The view of the On – Off valve was made according to the concept and is very similar to the view of the relief valve presented in figure 5. The basic difference is the connection hole of the pneumatic system, which is made in the valve's base.

The initial experimental research on the valve proved its proper operation as a 2/2 directional valve in the hydraulic system.

Hydraulic system with plastic elements

The presented plastic elements were made for the building of the hydraulic system shown in figure 8.

A gerotor pump (1) driven by an electric motor (6) is supplied with hydraulic oil from the tank (7) and passes it on to the On – Off valve (3), and then further on to the cylinder (4). In the charging line, the relief valve (2) protects the system. The channel and the connection elements are made of stainless steel.

The initial research shows that both elements, as well as the entire system, ought to work within the pressure range not exceeding 4MPa .

Conclusion and further research

The theoretical and design analysis, as well as the experimental research carried out on the models prove the assumed applications of plastics for the making of hydraulic elements possible. The elements can be used for the assembly of simple fluid power systems which can work with mineral oil.

So far, for strength reasons, plastic systems work at the working pressure not exceeding 4MPa. Their advantages are simple design, silent performance, low weight, and a simple and low-cost production method. It is possible to use plastic elements and systems in food industry, automotive industry, medicine or chemical industry.

The authors dare say that in the nearest future, the research and development in this field ought to be aimed at the

- application of new high-strength plastics,

- improvement on the new design solutions concerning complex shapes of the hydraulic elements,
- improvement of the production technology ensuring high precision and stability of the hydraulic elements at low costs.

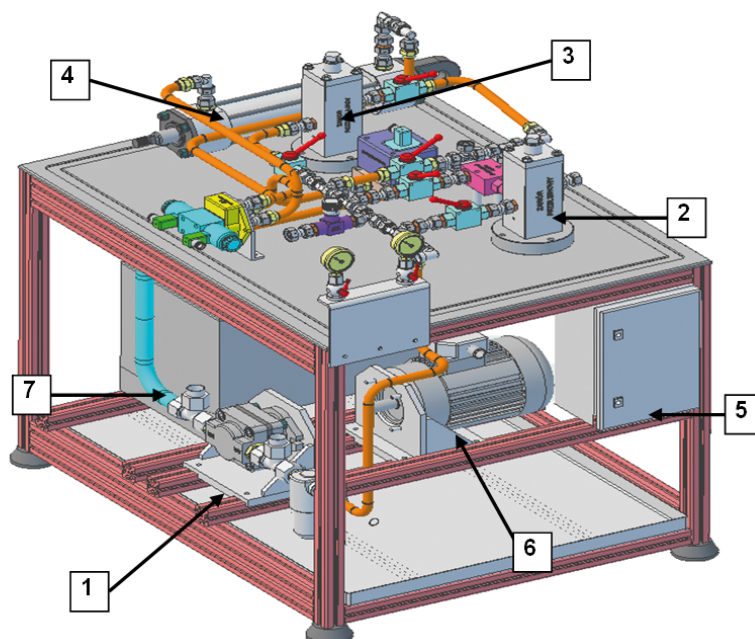


Fig. 8. A view of the hydraulic system; 1 - pump, 2 - pressure relief valve, 3 – On – Off valve, 4 – hydraulic cylinder, 5 - electric box, 6 - motor, 7 - tank

Аннотація. В роботі представлені, концепції дизайну і моделі гідравлічних елементів, виконаних з пластмаси, таких як героторний насос, предохранительный клапан, кран і циліндр. Експериментальне дослідження показало, що елементи працюють належним чином. Представлена проста гідравлічна система, зібрана з виготовлених елементів. Система працювала належним чином в робочому діапазоні тисків до 4 МПа. Застосування POM має такі переваги, як простота і низька вартість виробництва, а також безшумна робота. Дальніші дослідження будуть направлені на пластмаси, що мають більш високу міцність, розробку нових конструктивних рішень для елементів і більш досконалих методів їх виробництва.

Ключевые слова: POM-типу пластикове, гідравлічні елементи

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References

1. Bonanno A. Materiali plastici, caratte ristiche a limitti. Oleodinamica Pneumatica, article 2008, p-p 68-73.
2. Belzowski, A. ; Strózyk, P. Assessment of repair reinforcement of polyester-glass fibre pipe. KOMPOZYTY Nr 2/2008, pages. 179-184.
3. Biernacki K., Stryczek J. Analysis of stress and deformation in plastic gears used in gerotor pumps. The Journal of Strain Analysis for Engineering Design, October 2010, vol. 45, Issue 7, pages 465-479.
4. J. Stryczek, S. Bednarczyk, K. Biernacki. Strength analysis of the polyoxymethylene cycloidal gears of the gerotor pump. Archives of Civil and Mechanical Engineering 2014. <http://dx.doi.org/10.1016/j.acme.2013.12.005>. ARTICLE IN PRESS.
5. J. Stryczek, S. Bednarczyk, K. Biernacki. Gerotor pump with POM gears: Design, production, technology, research. Archives of Civil and Mechanical Engineering 2014. <http://dx.doi.org/10.1016/j.acme.2013.12.008>. ARTICLE IN PRESS.

6. *Bednarczyk S., Biernacki K., Stryczek, J.* Application of plastics in manufacture of the gerotor pump .The Twelfth Scandinavian International Conference on Fluid Power SICFP'11. May 18- 20, 2011, Tampere Finland. Vol. 3(4), pages 369-383.
7. *Stryczek J., Wołodźko J.* Projektowanie węzłów uszczelniających cylindrów hydraulicznych. Opracowanie wewnętrzne Politechniki Wrocławskiej, Wrocław 2009.
8. *Stryczek J., Wołodźko J.* Projekt wstępny cylindra hydraulicznego z tworzyw sztucznych. Opracowanie wewnętrzne Politechniki Wrocławskiej, Wrocław 2011.
9. *Stryczek J., Wołodźko J.* Projekt wstępny zaworu zwrotnego i maksymalnego z tworzyw sztucznych. Opracowanie wewnętrzne Politechniki Wrocławskiej, Wrocław 2012.

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1. *Bonanno A.* Matariali plastici, caratte ristiche a limitti. *Oleodinamica Pneumatica*, article 2008, p-p 68-73.
 2. [Belzowski, A.](#) ; [Stróżyk, P.](#) Assessment of repair reinforcement of polyester-glass fibre pipe. *KOMPOZYTY* Nr 2/2008, pages. 179-184.
 3. *Biernacki K., Stryczek J.* Analysis of stress and deformation in plastic gears used in gerotor pumps. *The Journal of Strain Analysis for Engineering Design*, October 2010, vol. 45, Issue 7, pages 465-479.
 4. *J. Stryczek, S. Bednarczyk, K. Biernacki.* Strength analysis of the polyoxymethylene cycloidal gears of the gerotor pump. *Archives of Civil and Mechanical Engineering* 2014. <http://dx.doi.org/10.1016/j.acme.2013.12.005>. ARTICLE IN PRESS.
 5. *J. Stryczek, S. Bednarczyk, K. Biernacki.* Gerotor pump with POM gears: Design, production, technology, research. *Archives of Civil and Mechanical Engineering* 2014. <http://dx.doi.org/10.1016/j.acme.2013.12.008>. ARTICLE IN PRESS.
 6. *Bednarczyk S., Biernacki K., Stryczek, J.* Application of plastics in manufacture of the gerotor pump .The Twelfth Scandinavian International Conference on Fluid Power SICFP'11. May 18- 20, 2011, Tampere Finland. Vol. 3(4), pages 369-383.
 7. *Stryczek J., Wołodźko J.* Projektowanie węzłów uszczelniających cylindrów hydraulicznych. Opracowanie wewnętrzne Politechniki Wrocławskiej (Design of joints sealing hydraulic cylinders. Develop internal Wrocław University of Technology). Wrocław 2009.
 8. *Stryczek J., Wołodźko J.* Projekt wstępny cylindra hydraulicznego z tworzyw sztucznych. Opracowanie wewnętrzne Politechniki Wrocławskiej.(Preliminary design of the hydraulic cylinder of plastic. Develop internal Wrocław University of Technology) Wrocław 2011.
 9. *Stryczek J., Wołodźko J.* Projekt wstępny zaworu zwrotnego i maksymalnego z tworzyw sztucznych. Opracowanie wewnętrzne Politechniki Wrocławskiej (Preliminary design of the check valve and a maximum of plastics. Develop internal Wrocław University of Technology). Wrocław 2012.

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