Functional Verification and Performance Studies of the Gerotor Pump Made of Plastics

Justyna Krawczyk(✉)

Department of Fundamentals of Machine Design and Mechatronic Systems, Wroclaw University of Science and Technology, Wroclaw, Poland
justyna.krawczyk@pwr.wroc.pl

Abstract. Paper presents the prototype of the gerotor pump with body and gear set made of plastics, its functional tests (checking measurements, run-in process) and experimental research of the efficiency characteristics. The positive results of previous researches of plastics gear sets allowed for the next step in the design of the entire plastic body of the gerotor pump. Experimental research was aimed at checking the proper functioning of the pump with a plastic body and verification of operational factors, impact of speed and pressure on the pump characteristics. Functional tests and experimental studies confirmed the correctness of the structural solution of the pump body. The pump with a plastic body was working correctly as a low pressure unit at low range of rotational speed. Experimental research of the plastic gerotor pump confirm that plastics as a construction material can be used in hydraulics.

Keywords: Gerotor pump · Cycloidal gears · Plastics

1 Introduction

The basic energy generator in hydraulic systems are gear pumps. Three types of gear pumps can be distinguished: external gear pumps, internal gear pumps and gerotor pumps.

Gear set is an essential element influencing the operation of the gear pump. Thanks to this element, gerotor pumps gain an advantage over external and internal gear pumps. They have a very compact design, smaller dimensions and lower weight. With low and light units they can obtain high efficiency thanks to the intertooth displacement chambers which have a large volume. This types of pumps are reliable and durable. In order to take the next step in the development of gerotor pumps, current market trends should be followed.

In the construction of hydraulic machines and components, as well as in other areas, the reduction of the weight and dimensions of manufactured elements, as well as reduction of the cost of their manufacture is increasingly being sought. However, to make this possible, it is necessary to search for new construction materials and new manufacturing methods. A new direction in the field of construction of hydraulic components and systems is the use of plastics as a construction material [1–4]. The use of plastics is advantageous for structural, technological, operating [5] and economic reasons. Due to current trends, the Fluid Power Research Group (FPRG) from the

J. Stryczek and U. Warzyńska (Eds.): NSHP 2020, LNME, pp. 386–395, 2021.
https://doi.org/10.1007/978-3-030-59509-8_35

Department of Fundamentals of Machine Design and Mechatronic Systems from the Wroclaw University of Science and Technology, began work to create a complete hydraulic system, in which basic elements such as a pump, cylinder [6] or valves [7, 8], or at least their main parts will be made of plastic [9, 10].

Work on the hydraulic system with plastic elements started with the design and production of a gerotor pump. Initially, only the epicycloidal gear set, was made of plastic and the rest of the pump: body, shaft and bearings, were made of metal. The papers [9, 12] presents the research of a gerotor gear set made of plastics and it was proved that gerotor sets made of various materials can work in gerotor pumps with an aluminum body. Theoretical and experimental research of the gerotor pump with gears made of plastic confirm the possibility of using plastics as a construction material in hydraulics.

These positive results allowed for the next step in the design of the entire plastic body of the gerotor pump. The work [17] presents a design solution of a gerotor pump with a plastic body, while [14] presents the design principles of a gerotor pump with plastic gears and body. Therefore, the goal of the paper was established to presents the prototype of the complete plastic gerotor pump and its functional tests (checking measurements, run-in process) and experimental research of the efficiency characteristics.

2 Plastics as a Construction Material

The analysis and selection of plastic is the first and key stage in the design of hydraulic components. From a wide set of parameters characterizing the plastic, a narrower set of parameters is chosen, which are important from the point of view of the pump body design. Those are:

- yield strength *Re* and Young's modulus *E* - characterizing the strength of the material,
- shrinkage *S* and coefficient of linear expansion *W* - characterizing the dimensional stability of the material during body manufacture,
- working temperature *T* and coefficient of water absorption *A* - characterizing the dimensional stability of the material during operation,
- price and availability of plastic on the market.

In gerotor pumps so far designed and tested by the FPRG, plastics POM, PPS and PEEK were used to make gear sets [11–13]. Experimental research on plastic gears began with the basic POM material [15, 16]. This material is easily available on the market, cheap and easy to machine processing. It also has good strength properties (E = 3000 MPa, Re = 60 MPa), good dimensional stability during manufacture (S = 0,0285 cm/cm, W = 0,0001 cm/°K) and good dimensional stability during operation (A = 0,7%, T = 100 °C). In subsequent phases of experimental research, materials with better properties were used, i.e. PPS [11, 12] and finally PEEK [9]. It was decided to use the same material selection cycle to make the entire pump body. Therefore, POM was used to make the first prototype of the pump body [14, 17]. Experimental research is aimed at checking the proper functioning of the pump with a plastic body, therefore, to eliminate the effect of deformation of the gear set on the pump characteristics, it was decided to choose a better, more stable PEEK material for the gerotor gear set. PEEK has higher than POM strength properties (E = 12700 MPa, Re = 230 MPa), higher dimensional stability during manufacture (S = 0,005 cm/cm, W = 0,00004 cm/°K) and higher dimensional stability during operation (A = 0,4%, T = 240 °C).

3 The Plastic Pump Prototype

Using the modification rules presented in [17, 18] a new modified shape of the gerotor pump body was developed. Figure 1 shows parts of a gerotor pump with a plastic body. The front (Fig. 1a), middle (Fig. 1b) and back (Fig. 1c) bodies are made of POM plastic, while the gear set (Fig. 1d) was made of PEEK plastic. The driving shaft is made of steel and the slide bearing (Fig. 1b) in which the gear set rotates is made of bronze. Due to the fact that we are dealing with a unit - prototype product, in order to eliminate the costs associated with the implementation of the injection mold, the pump prototype was made by machining processing.

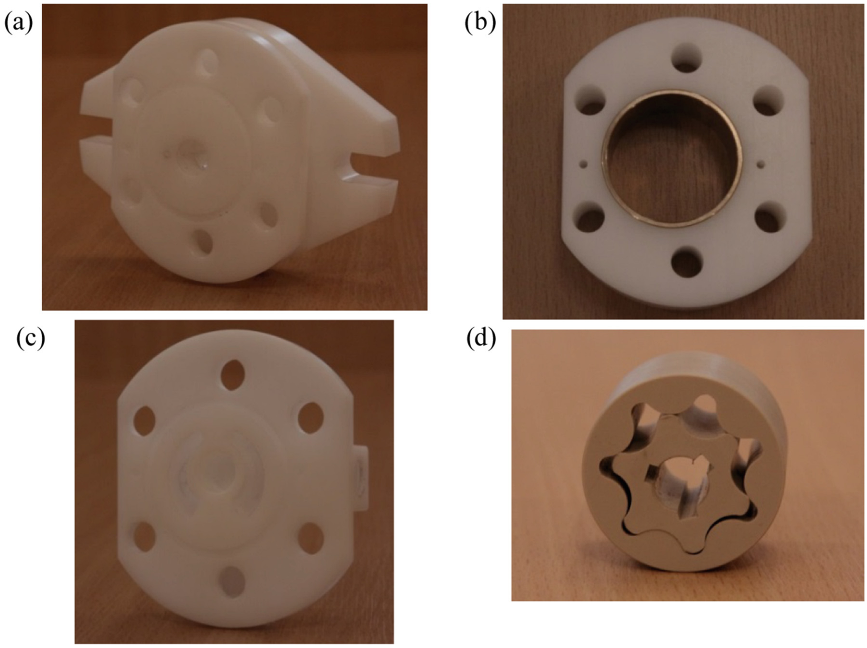

Fig. 1. Gerotor pump body parts made of plastics: a) front body; b) middle body with slide bearing; c) back body; d) epicycloidal gear set

The produced elements were subjected to checking measurements. The surfaces that have a significant impact on the assembly and proper functioning of the pump have been measured, i.e. the diameters of the bearings, driving shaft and gear set, as well as the width of the wheel assembly and central body. Real, measured dimensions were consistent with drawing dimensions, the accuracy of the elements was within the dimensional tolerances adopted in the technical documentation. All surfaces were smooth and clean.

After completing the measurements, checking and verifying surfaces, pump was assembled. The assembly proceeded without any disturbances, which was favored by the precise production of the body parts. All necessary elements, i.e. bearings, dowels, seals, gear set and driving shaft were embedded in the body, then the complete pump was tightened with six bolts and a torque $M_s = 30$ Nm. After tightening, it was possible to rotate the driving shaft, and thus a gear set, without jamming and the need to apply a lot of force, which indicates the correct assembly of the pump.

The assembled pump was placed on the test stand. The pump was attached to the console by means of a specially formed mounting flange in the pump's front body and two fastening screws tightened with a torque $M_s = 30$ Nm. Appropriate dimensions and fits made it possible to maintain concentricity between the pump shaft and the drive shaft of the electric motor. The connection of both shafts was ensured by two bellows couplings between which a torque meter was mounted. After attaching the pump to the console at the stand, supply lines were tightened to it. Figure 2 shows the view of the pump on the test stand.

Fig. 2. Pump mounted on the test stand

4 Experimental Research of the Pump Model

Figure 3a shows a diagram of a test stand for conducting basic hydraulic research of a gerotor pump with a plastic body. The test stand enables measurements of hydraulic parameters, i.e. flow (*Q [l/min]*) and the pressure at the inlet and outlet of the pump

(a)

(b)

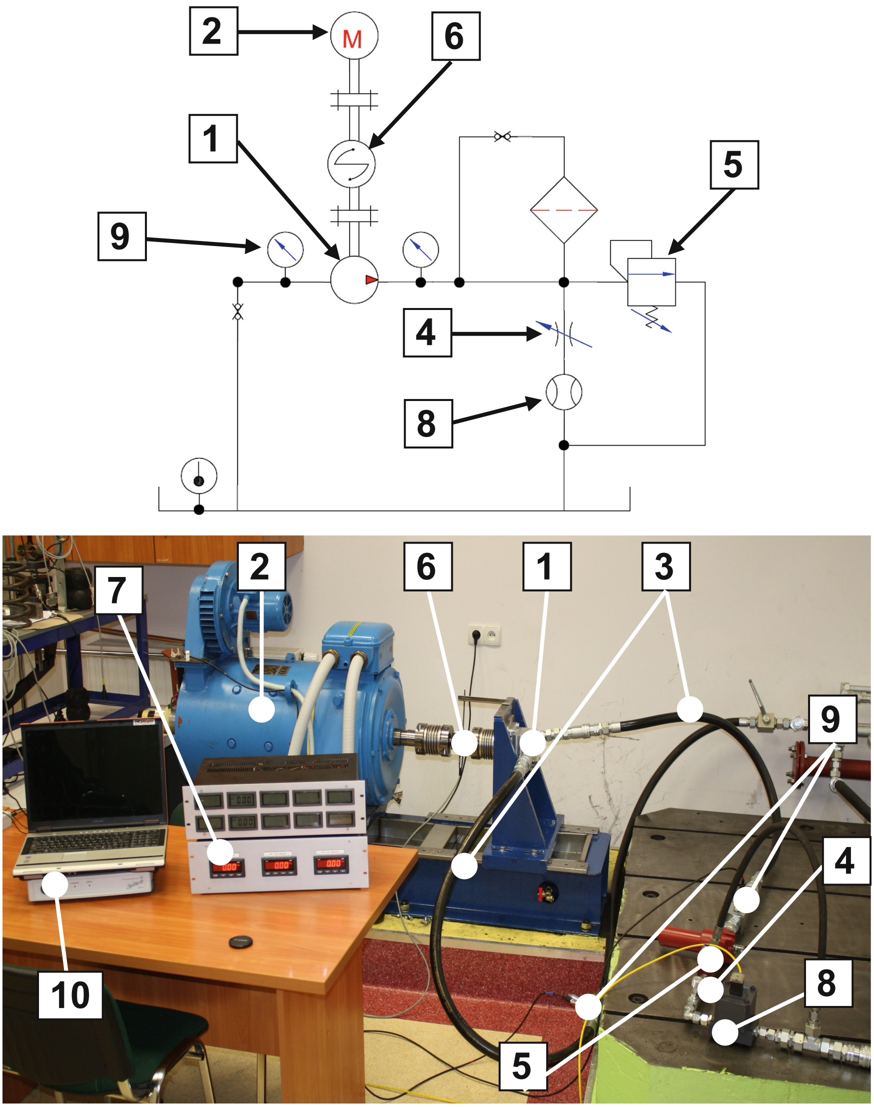

Fig. 3. Test stand: a) diagram of a test stand; b) view of the stand at the FPRG Laboratory: 1 – tested pump, 2 – electric motor, 3 – input and output lines, 4 – throttle valve, 5 – overflow valve, 6 – torque meter, 7 – tachometer, 8 – flow meter, 9 – pressure sensors, 10 - signal amplifier

(*p [bar]*), and measurements of mechanical parameters, i.e. torque (*M [Nm]*) and rotational speed (*n [rpm]*).

The view of the actual stand is shown in Fig. 3b. The tested pump (1) is driven by an electric motor (2). Connection of the pump with the hydraulic system is ensured by supply lines (3). A throttle valve (4) is used to load the pump. The overflow valve (5) was used to protect the pump and electric motor against overload. The drive torque of the pump was measured with a torque meter (6), and the rotational speed with a tachometer (7). The flow rate was measured with a flow meter (8) and the pressure in the input and output lines with pressure sensors (9). Signals from measuring instruments will be sent to a computer using a laboratory signal amplifier (10). The CatmanEasy program was used to archive and analyze measurements on a computer.

The basic hydraulic research program of the gerotor pump included:

- checking the correct operation of the pump with a plastic body,
- determination of volumetric η_v and total η efficiency of the pump depending on various values of rotational speed,
- determination of volumetric η_v and total η efficiency of the pump depending on various values of working pressure.

5 Results and Analysis of Basic Hydraulic Research

5.1 Run-in Process

Before commencing the detailed hydraulic characteristic tests, the pump was started and run-in was performed. It has been found that the pump works correctly, performs its function continuously and without interference. There was no unsealing of the body and no external leaks.

After run-in, the pump was dismantled and its parts checked in order to determine the effects of parts' collaboration and their possible wear. During the inspection of the pump parts, the effects of lapping plastic were noticed. The lapping effects are shown in Fig. 4. Figure 4a shows the material overflow in the form of a circle. It was caused by friction of the rotating gear set on the faces of front and back body. As a result, the material was "stuffed" into the free space between the gear set and the bearing in which the gears were rotating. Figure 4b shows a blocked leakage channel that drains hydraulic oil from under the shaft sealing ring. This is the effect of lapping, excess material has been "pushed" into the channel hole, which caused it to clog. The lapping effects have been removed, and no such effects appeared on subsequent tests.

(a)
(b)

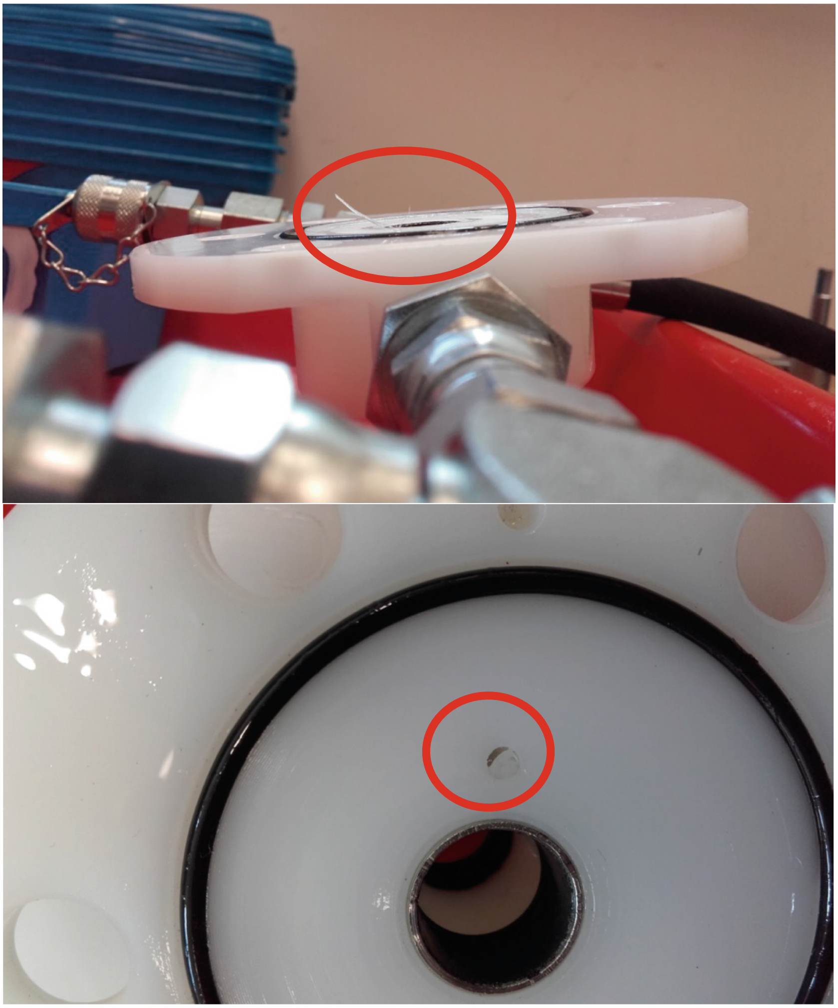

Fig. 4. Plastic lapping products: a) overflow of material in the form of a circle; b) blocked leakage channel that drains hydraulic oil from under the shaft sealing ring

5.2 Basic Hydraulic Characteristics

After checking the parts and removing the lapping effects, the pump was reassembled on the test stand and basic hydraulic characteristics were tested. Figure 5 shows the characteristics of volumetric η_v and total η efficiency depending on the output pressure, for different shaft rotational speeds. The drawing shows that the pump was operating in the working pressure range p = *0–20* bar and rotational speed n = *500–1000* rpm. The volumetric efficiency η_v varied in the range η_v = *89–70%* while the total efficiency η in the range η = *73–50%*. Relatively low efficiency prevented further loading of the pump, which could lead to seizing. The figure shows that the volumetric η_v and total

η efficiency decrease with increasing output pressure p and increasing rotational speed n of pump shaft.

This is explained by the fact that as the pressure and speed increase, the body deformations increase [19], which cause the formation of uncontrolled internal gaps, which in turn cause the formation of increased leaks in the pump which causes a decrease in volumetric η_v and total η efficiency.

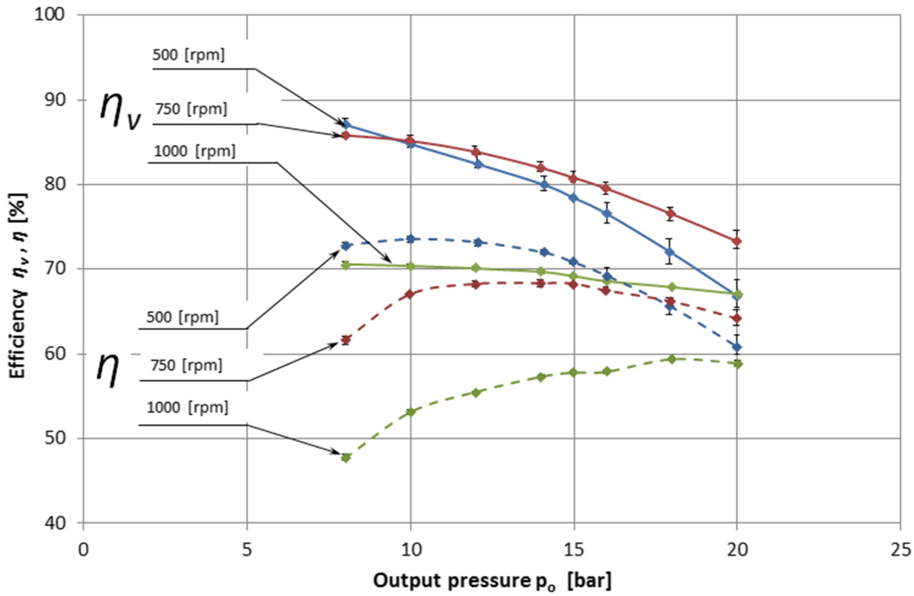

Fig. 5. Characteristics of volumetric and total efficiency depending on the output pressure η_v, $\eta = f(p_o)$, for different pump shaft rotational speeds n = 500 ÷ 1000 obr/min

6 Summary and Conclusions

Experimental research of the plastic gerotor pump confirm that plastics as a construction material can be used in hydraulics.

Experimental studies confirmed the correctness of the structural solution of the pump body. The pump with a plastic body was working correctly as a low pressure unit, in the pressure range $p = 0 \div 20$ bar and rotational speed in the range $n = 500 \div 1000$ rpm, obtaining volumetric efficiency $\eta_v = 89\text{–}70\%$ and total efficiency $\eta = 73\text{–}50\%$. However, the selection of POM material for the pump body proved to be not completely accurate. This material is not suitable for working with higher technical parameters $p > 20$ bar and $n > 1000$ rpm. Materials with better parameters should be looked.

At the same time, the need to test the deformation of the pump body is visible, to check the influence of operational factors such as pressure, rotational speed and time of their operation on the values of axial and radial deformations of the gerotor pump body.

The pump body made of plastic should work in the elastic range so that the body deformations in critical places take values lower than the permissible deformations [20], so that there are no internal leaks that reduce the technical parameters of the pump.

It is anticipated that as a result of further improvement of the entire construction and technological process it will be possible to obtain a pump with higher technical parameters, working at higher working pressures of the range $p = 6$ MPa, with volumetric efficiency $\eta_v = 70\%$ and total efficiency $\eta = 60\%$.

References

1. Bonanno, A.: Matarialli plastici, caratte ristiche a limitti. Oleodynamica Pneum 68–73 (2008)
2. Bełzowski, A., Stróżyk, P.: Assessment of repair reinforcement of polyester-glass fibre pipe. KOMPOZYTY **2**, 179–184 (2008)
3. Gamez-Montero, P.J., Antoniak, P., Castilla, R., Freire, J., Krawczyk, J., Stryczek, J., Codina, E.: Magnet-sleeve-sealed mini trochoidal-gear pump prototype with polymer composite gear. Energies **10**, 1–18 (2017). https://doi.org/10.3390/en10101458
4. Rokala, M., Kaskinen, K.T.: The effect of PV-RAE on PEEK-MADE slipper behavior in water hydraulic axial piston unit. In: The Twelfth Scandinavian International Conference on Fluid Power SICFP 2011, Tampere, Finland, vol. 1, no. 4, pp. 89–101, 18–20 May 2011
5. Rodionov, L., Rekadze, P.: Experimental vibroacoustic research of a gear pump made of different materials. Proc. Eng. **176**, 636–644 (2017)
6. Stryczek, P., Przystupa, F., Banas, M.: Research on series of hydraulic cylinders made of plastics. In: 2018 Global Fluid Power Society Ph.D. Symposium (GFPS), 18–20 July 2018, Samara, Russia. Institute of Electrical and Electronics Engineers Inc. (2018)
7. Marciniak, L., Banaś, M., Stryczek, J.: The design and theoretical and experimental study of the plastic hydraulic valves. In: 9th FPNI Ph.D. Symposium on Fluid Power, Florianópolis, SC, Brazil, 26–28 October 2016 (2016)
8. Banaś, M., Antoniak, P., Marciniak, L., Stryczek, J.: Visualization of flow phenomena in hydraulic throttle valves of plastics. MATEC Web Conf. **211**, 19001 (2018). https://doi.org/10.1051/matecconf/201821119001
9. Stryczek, J., Banaś, M., Krawczyk, J., Marciniak, L., Stryczek, P.: The fluid power elements and systems made of plastics. Proc. Eng. **176**, 600–609 (2017)
10. Krawczyk, J., Stryczek, J.: Układ hydrauliczny z elementami wykonanymi z tworzyw sztucznych; Hydraulic system with parts made of plastics. Górnictwo Odkryw **54**(3), 52–57 (2013)
11. Krawczyk, J., Stryczek, J.: Badania pompy gerotorowej z kołami zębatymi wykonanymi z PPS. Hydraul. i Pneumatyka **34**, 15–18 (2014)
12. Krawczyk, J., Stryczek, J.: Construction and experimental research on plastic cycloidal gears used in gerotor pumps. In: 8th FPNI Ph.D. Symposium on Fluid Power, FPNI 2014, Lappeenranta, Finland, 11–13 June (2014)
13. Krawczyk, J., Stryczek, J.: Pompa gerotorowa z tworzyw sztucznych. In: Napędy i sterowania hydrauliczne i pneumatyczne 2015, Szklarska Poręba-Jakuszyce, 18–20 marca 2015. Wrocław : Ośrodek Doskonalenia Kadr SIMP, pp. 164–170 (2015)
14. Krawczyk, J., Stryczek, J.: Design and experimental research of a plastic gerotor pump. In: 2018 Glob. Fluid Power Soc. Ph.D. Symp. (GFPS), 18–20 July 2018, Samara, Russ. 1–8 (2018). https://doi.org/10.1109/GFPS.2018.8472370

15. Stryczek, J., Bednarczyk, S., Biernacki, K.: Gerotor pump with POM gears: design, production technology, research. Arch. Civil Mech. Eng. **14**(3), 391–397 (2013). https://doi.org/10.1016/j.acme.2013.12.008
16. Biernacki, K., Stryczek, J.: Analysis of stress and deformation in plastic gears used in gerotor pumps. J. Strain Anal. Eng. Des. **45**, 465–479 (2010). https://doi.org/10.1243/03093247JSA630
17. Krawczyk, J., Stryczek, J.: Designing of the gerotor pump body made of plastics. In: 9th FPNI Ph.D. Symposium on Fluid Power, Proceedings of ASME, Florianópolis, SC, Brazil, 26–28 October 2016, pp. 1–6 (2016)
18. Krawczyk, J.: Metodyka kształtowania korpusów maszyn hydraulicznych z tworzyw sztucznych na przykładzie pompy gerotorowej. Wroclaw University of Science and Technology, doctorate thesis (2017)
19. Kujawa, M., Kowalewski, P., Wieleba, W.: The influence of deformation under tension on some mechanical and tribological properties of high-density polyethylene. Polymers (Basel) **11**, 1429 (2019). https://doi.org/10.3390/polym11091429
20. Stefan, S.: Napęd hydrostatyczny: Podręcznik. Wrocław, WNT (1984)