Development tendencies of clearance compensation methods in internal gear pumps

Piotr Osiński[1] , *Michał* Stosiak[1] , *Paweł* Bury[1] , *Rafał* Cieślicki[1] , *Krzysztof* Towarnicki[1*], *Piotr* Antoniak[2]

[1]Wrocław University of Science and Technology, Faculty of Mechanical Engineering, Department of Technical Systems Operation and Maintenance, Poland
[2]Wrocław University of Science and Technology, Faculty of Mechanical Engineering, Department of Fundamentals of Machine Design and Mechatronic Systems, Poland

Abstract. Contemporary gear pumps, although their design has been under development for over four centuries, keep being modernized and improved. The work presents an analysis of design solutions, taking into account their operational features. The analysis included units with internal mesh. Emphasis was put on the problem of ensuring high values of volumetric efficiency by minimizing leakage in the widest possible range of loads while maintaining the highest possible hydraulic and mechanical efficiency of the displacement unit. Increasing the volumetric efficiency of positive displacement pumps is an important factor in the pursuit of increase in working pressures in hydrostatic systems. An important factor in production of pumps is cost of their production, which often leads to possibility of introducing additional modifications in the pump structure. Often changes made to the materials used in construction of pumps, allow reduction in their mass or sensitivity to the action of the transported liquid. The paper indicates the developed and proprietary solutions in this area and presents the results of experimental research.

1 Introduction

The main advantages of internal gear pumps in relation to external gear pumps is their lower noise emission, lower coefficient of non-uniformity of efficiency and more compact structure [1]. This is a consequence of a smooth interaction of the internal toothing wheel and the external toothing wheel. Sealing at the contact point of the mating wheels on the increased circumference of the wheels in contact with the suction and discharge spaces reduces loss of filling during liquid suction. Bearing in mind the abovementioned advantages, the aim focuses on achieving constantly higher pumping pressures by this type of pumps [2,3]. Obtaining higher pressures is associated with a need of high internal tightness. A measure of the pump's internal tightness is its volumetric efficiency. Increase of the volumetric efficiency in an internal gear pump can be achieved by introducing axial and radial compensation. The direction of a development began with the introduction of axial compensation, which is

* Corresponding author: krzysztof.towarnicki@pwr.edu.pl

already developed at a high level. An example of the applied axial compensation in a Bosch-Rexroth pump. [4] is presented below.

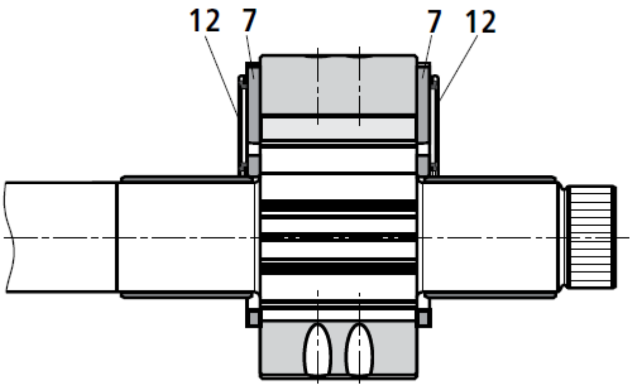

Fig. 1. Axial compensation in an internal gear pump. 7- axial discs, 12 - the surface of the discs affected by the discharge pressure. [4]

2 Radial compensation for internal gear pump

For over 50 years, the main emphasis has been put on the development of radial compensation. The Otto Eckerle company was a precursor and a leading manufacturer implementing the idea of radial clearance compensation. During one decade, it has patented nearly ten different concepts that have been used in internal gear pumps [5]. Patent No. US3525581 [6] from 1968 (Fig. 2) describes a pump with internal mesh, including an additional compensating piston (4), which is acted on by a pressurized liquid. A slight pressure force causes the piston to rotate around the locking pin. The piston presses against the toothed ring and presses it against the sickle insert (1). This will bring the pinion (3) into contact with the crescent insert which allows the circumferential gap to be minimized. The invention according to a patent no. USRE27901 [7] is also based on use of a piston exerting pressure on a toothed ring. The difference from the previous solution focuses on use of spring elements that introduce preload and generate thrust force at start-up when the pressure is too low to ensure an appropriate level of circumferential gap compensation. Additionally, the pump housing is turned off-center in relation to the gear shaft. This design of the body allowed simplification of the design of the compensating piston (the guide channels and additional seals of the space affected by pressure were removed). Inventions described in patents no. USRE27904 [8] from 1968 and US3779674 [9] from 1971 are based on the same concept. The circumferential gap compensation described in the 1974 patent no. US3912427 [10] is distinguished by a considerably simplified structure. The compensating piston was ruled out, and the compensation itself was implemented around the circumference of the gear. Each tooth tip in a rim has a corresponding compensation field located on its circumference. A pressurized liquid is brought to it, which ensures that the rim is pressed against the sickle insert. In the patent no. US4132515 [11] from 1977, circumferential compensation is achieved by pressing the sickle insert against the wheel and toothed rim.

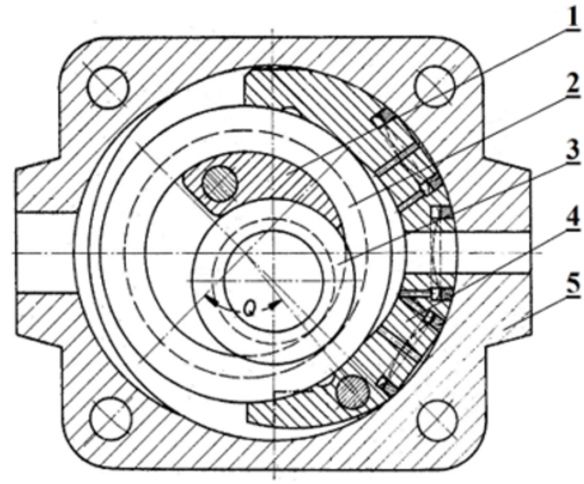

Fig. 2. Gear pump with internal meshing with compensation of radial clearances according to the patent no. US3525581 [6] by Otto Eckerle from 1968: 1 - sickle insert, 2 - toothed rim, 3 - toothed wheel, 4- piston mechanically compensating radial clearances 5- pump housing.

Following the idea of radial compensation in the Otto Eckerle pumps, also in external gear pumps, compensating elements appeared, pressed against the tips of the teeth. Examples include solutions from companies such as Bosch (patent no. US3995975 [12] from 1975), Tyrone Hydraulics (patent no. US4266915 [13] and WO8101315 [14] from 1979, US4336005 [15] from 1980) and others.

In the 1980s, in German patent publications, radial compensation appeared in a gear pump with internal meshing, in which a modification of the sickle insert was used. The patent solution DE2533646 [16] is presented below.

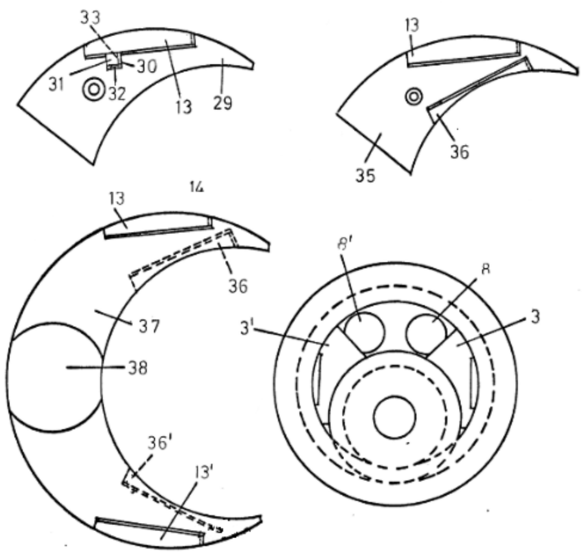

Fig. 3. Modifications of the sickle insert based on the patent development DE2533646. [16]

In the following years, modifications to the sickle inserted were refined. In 1990, another patent application no. DE2760463 was issued [17]. The concept of the solution is presented below in Fig. 4.

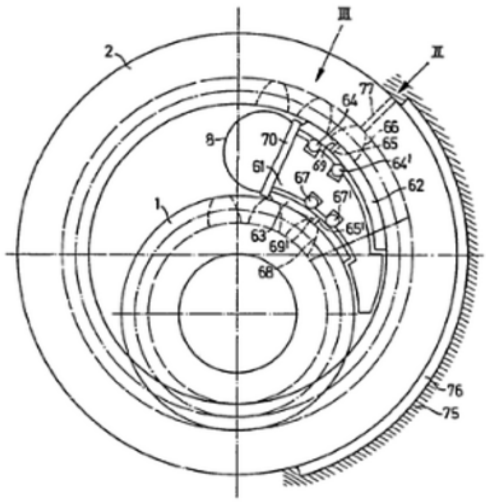

Fig. 4. Modifications of the sickle insert based on the patent development DE2760463. [17]

Further work in this direction led to the construction of a pump prototype and later on, its mass production. The maximum instantaneous pressure achieved by such a pump reaches the value of 40 MPa. The view of the ECKERLE pump produced in series is presented below.

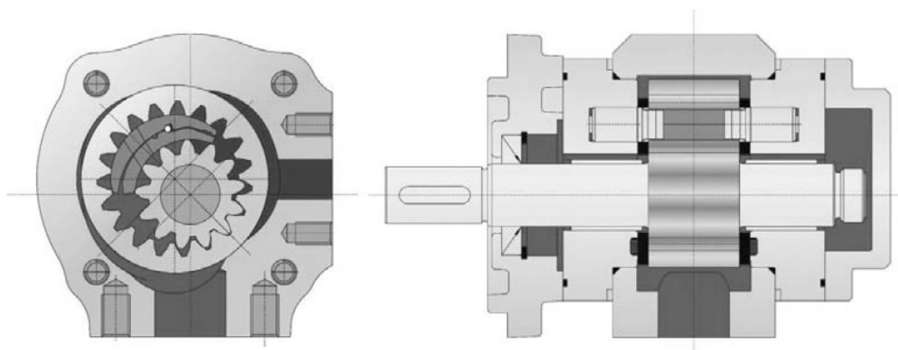

Fig. 5. Cross-sectional view of a pump with internal gearing with radial compensation. [18]

The presented solution is based on making a sickle insert of two elements, based on a pin. The pivoting mounting of the insert elements allows reducing the play between the raceway and the tips of the gear teeth depending on the discharge pressure. An important feature of the solution is the design of the chambers, appropriately connected to the suction and discharge space. Due to this solution, the forces acting on the toothed ring are balanced, the value of which changes with the change of discharge pressure.

A similar solution was submitted in 2003, also to the German patent office by the VOITH company. According to the claims of the patent no. DE10334954 [19], the developed sickle insert consists of two parts arranged radially next to each other. A space is created between the elements of the insert, which is connected with the discharge chamber of the pump. The principle of operation is the same as in the ECKERLE solution, i.e. the resulting pressure difference between the inner and outer part of the insert causes the insert raceway to press against the tops of the gears, reducing the radial clearance. The cited solution is presented in Figure 6.

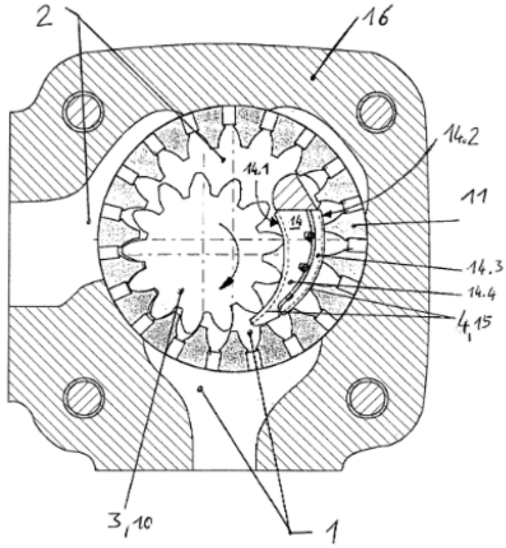

Fig. 6. Cross-section of a pump with a modified sickle insert based on the patent document DE10334954. [19]

The above solution allowed VOITH to introduce several series of pumps to the market, one of which can reach momentary pressures up to 34.5 MPa. Figure 7 shows a cross section through a VOITH pump

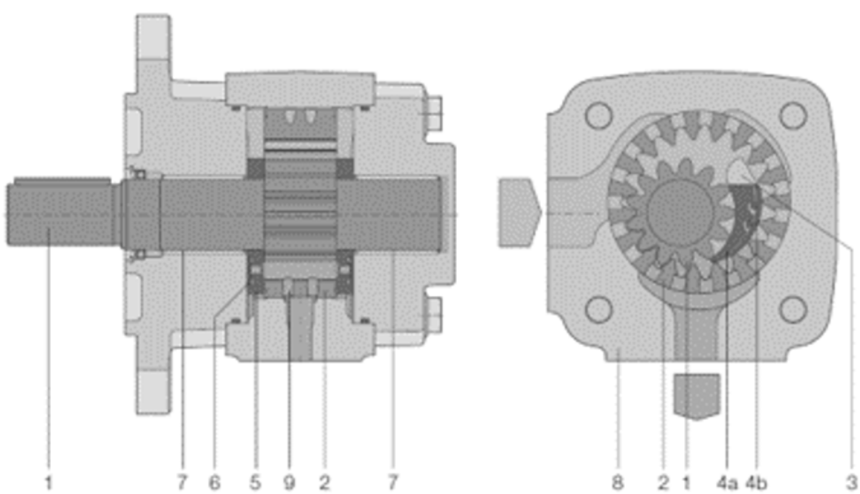

Fig. 7. A cross-sectional view of a VOITH internal gear pump with radial compensation. [20]

3 Preliminary test results for an internal gear pump with modification of the sickle insert

Another solution for radial compensation, instead of building the sickle insert from several elements, is to introduce a partial incision in the classic sickle insert. As a result, two flexible tongues are obtained, which under the influence of pressure are deformed, reducing the play between the track of the insert and the tips of the gear wheel. The described solution was developed in two versions and then submitted to the Polish Patent Office. The applications were received with the number P.431145 [21] displacement pump with internal gearing with compensation of radial clearances and P.431146 [22] gear pump with internal gearing with compensation of radial clearances. The introduced solutions allow an increase in the volumetric efficiency of the hydraulic machine. This is an important element considering the increased interest in use of internal gear pumps [23]. Due to the growing share of plastics in the production of hydraulic elements of drive systems [24, 25] and the use of new light and high-strength composite materials [26], a modification of the sickle insert was performed by use of plastic with low processing costs. The diagram of the hydraulic system used during the measurements is presented below [27, 28] - Fig. 8.

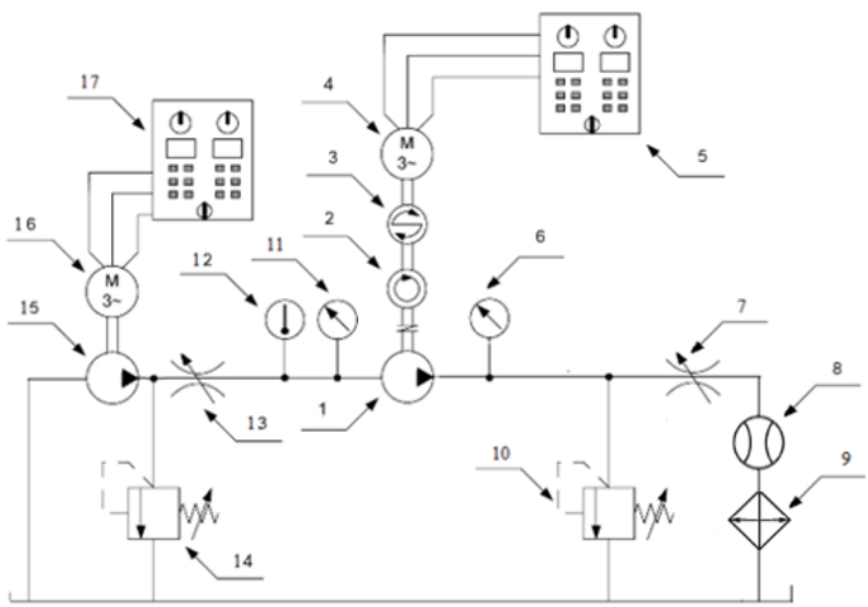

Fig. 8. Hydraulic diagram of the test system. 1 – tested gear pump, 2 – tachometer, 3 – torque meter, 4 – electric motor, 5 – control cabinet, 6 – pressure transducer, 7 – throttle valve, 8 – , 9 – cooler, 10 – safety valve, 11- pressure transducer, 12 - thermometer, 13 – throttle valve on the discharge line of the feed pump, 14 – safety valve on the discharge line of the feed pump, 15 – feed pump, 16 – electric motor driving the feed pump, 17 – control cabinet of the electric motor driving the feed pump. [27,28]

To ensure a constant value of the suction pressure of the main pump, a feed pump was installed. The measurements were taken after the test run of the hydraulic system and correctness check of the measurement devices' indications. The first insert was made of POM plastic without modification, the second one was also made of POM plastic, but with a modification, while the third one was also made of PA plastic, also with a modification. During each replacement of the sickle insert, the bolts holding the body parts were tightened with the same value equal to 20 Nm. The results of the performed measurements are presented below.

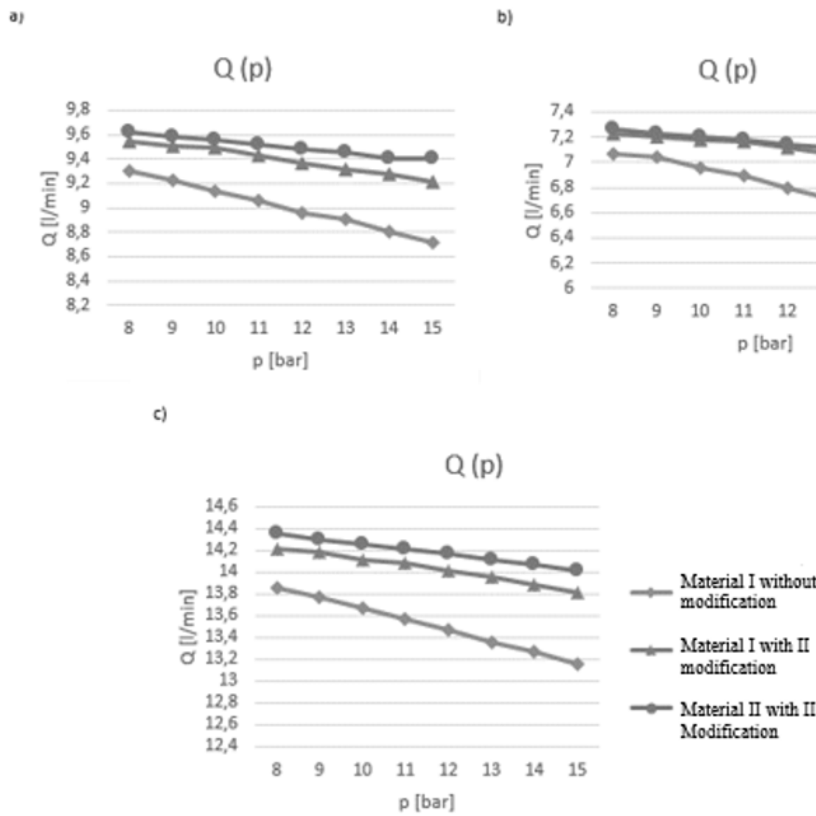

Fig. 9. Characteristics of the gear pump with internal gearing with I modification sickle insert at different rotational speeds of the pump shaft: a) n = 750 [rpm], b) n = 1000 [rpm], c) n = 1500 [rpm]. [27,28]

Summarizing the carried out measurements, it can be stated that the introduced modification allows maintaining the pump efficiency with increasing pressure. In an unmodified insert, the performance decreases significantly with increasing discharge pressure. The first modification of the insert consisted in cutting a channel inside the insert of a size corresponding to ¼ of the insert's length. After an analysis of the measurements with the incision made, next step was to make a longer channel corresponding to half the length of the insert. The results of measurements after the second modification of the insert made of both previously used materials are presented below.

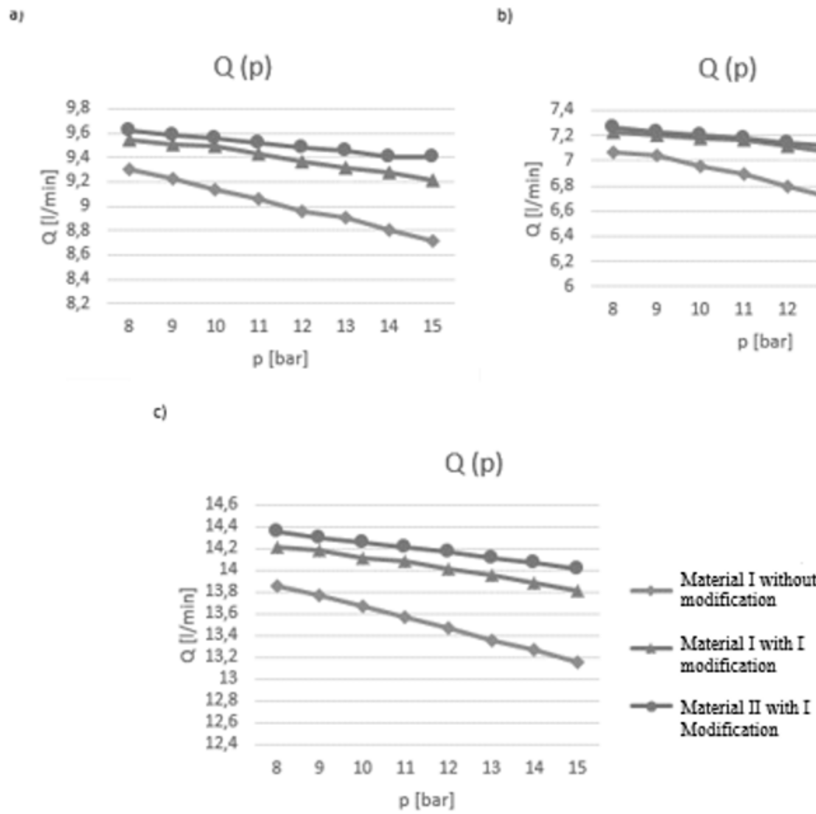

Fig. 10. Characteristics of a gear pump with internal meshing with various sickle inserts tested at different rotational speeds of the pump shaft: a) n = 750 [rpm], b) n = 1000 [rpm], c) n = 1500 [rpm]. [28]

Basing on a comparison of the measurements applied for the two different modifications, it can be concluded that even a small incision in the channel inside the insert increases the volumetric efficiency compared to the conventional solution. For both modifications, a higher performance is achieved by the pump with a modified PA plastic insert.

4 Summary

The current trend in the construction of hydraulic drive systems focuses on achieving high delivery pressures by positive displacement of pumps. It reduces the area of kinematic elements of hydraulic receivers, especially the diameters in hydraulic cylinders. As a result, a significant increase in the ratio of power transmitted to weight is achieved. Therefore, it becomes necessary to build pumps that allow them to generate higher discharge pressures while maintaining high efficiency. The use of internal gear pumps is becoming more and more popular due to the lower noise, high degree of tooth coverage and lower filling losses. Undoubtedly, an important parameter that allows increase in the pumping pressure by the pump is volumetric efficiency. In the case of a gear pump with internal gearing, it is important to equip it with axial and radial compensation. Axial compensation was introduced as first, and then improved for many years, achieving high tightness and durability parameters. However, the radial compensation is still modified to achieve high volumetric efficiency while maintaining hydraulic-mechanical efficiency. Durability and cost of implementing of this solution are also important. This paper presents various examples of radial offsets in approved patent solutions as well as commercially available pumps from well-known manufacturers. Moreover, the preliminary results of the pump efficiency measurements depending on the discharge pressure were also presented, according to the proprietary solution submitted to the patent office under the number P.431145 [21]. The main factor of the structural modification is execution of the channel inside the sickle insert, allowing for radial compensation. Further work will be focused on optimizing both shape and size of the channel made to maintain the highest possible hydraulic and mechanical efficiency with an increase in volumetric efficiency.

References

1. J. Stryczek, *Gears for hydraulic machines*, Publishing house PWR, Wrocław, (2000).
2. M.Rundo, Simulation Modelling Practice and Theory, Volume **71**, s.1-14, (2017).
3. R. P. Lambeck, Marcel Dekker INC, Hydraulic pumps and motors, New York (1983).
4. Product catalog of the PGH 3X internal gear pumps by Bosch-Rexroth.
5. P. Osinski, *High-efficiency gear pumps*, Publishing house PWR, Wrocław, (2019).
6. O. Eckerle, Patent US nr 3525581,Wear and tear-compensating high-pressure gear pump, (1967), https://patents.google.com/patent/US3525581A.
7. O. Eckerle, Patent US nr RE27901, Wear (and tear) compensating high-pressure gear pump, (1974), https://patents.google.com/patent/USRE27901E.
8. O. Eckerle, Patent US nr RE27904, Wear (and tear) compensating high-pressure gear pump, (1974), https://patents.google.com/patent/USRE27904E.
9. O. Eckerle, R. Jung, Patent US nr 3779674, High-pressure gear pump, (1973), https://patents.google.com/patent/US3779674A.
10. O. Eckerle, R. Jung, Patent US nr 3912427, (1975), https://patents.google.com/patent/US3912427A.
11. O. Eckerle, Patent US nr 4132514, High pressure hydraulic pump and motor,, (1976), https://patents.google.com/patent/US4132514A.
12. P. Bosch, Patent US nr 3995975, Gear pump, (1974), https://patents.google.com/patent/US3995975A.
13. J. R. McBurnett, J.M. Eley, Patent US nr 4266915, Gear pumps and motors, (1978), https://patents.google.com/patent/US4266915A.
14. J. M. Eley, A. Joyce, Patent WO nr 8101315, Contaminant resistant gear pumps and motors, (1979) https://patents.google.com/patent/WO1981001315A1.
15. J. McBurnett, J. M. Eley, Patent US nr 4336005, Gear pumps and motors, (1979), https://patents.google.com/patent/US4336005A.
16. O. Eckerle, R. Jung, Patent DE nr 2533646, High pressure gera pump or motor – has crescent shaped component for sealing and compensating high radial forces, (1975), https://patents.google.com/DE2533646A1.
17. O. S. W. Eckerle, Patent DE nr 2760463C2, (1977), https://patents.google.com/patent/DE2760463C2.
18. Product catalog of ECKERLE HYDRAULIC DIVISION internal gear pumps EIPH2.

19. F. Arbogast, P. Peiz, Patent DE nr 10334954, Hydropumpe (2003), https://patents.google.com/patent/DE10334954A1.
20. VOITH GROUP IPVA internal gear pump product catalog.
21. K. Towarnicki, M. Stosiak, P. Antoniak, Positive displacement pump with internal gearing with compensation of radial clearances. Patent application no. P 431145 z 16.09.2019. 17 p.
22. K. Towarnicki, M. Stosiak, Gear pump with internal gearing with compensation of radial clearances. Patent application no. P 431146 z 16.09.2019. 17 p.
23. E.B. Lewis, H. Cyndi, World Pumps, Volume **2005,** issue 462, s.26-27, (2005).
24. J. Stryczek, S. Bednarczyk, K. Biernacki, Archives of Civil and Mechanical Engineering, vol. **14**, nr 3, s.391-397, (2014).
25. J. Stryczek, M. Banaś, J. Krawczyk, L. Marciniak, P. Stryczek, vol. **176**, s.600-609, (2017).
26. W. Błażejewski, M. Lubecki, P. Mayer, M. Stosiak, K. Towarnicki, *The use of new materials in elements and hydraulic systems,*. In: The International Scientific and Technical Conference Hydraulic and Pneumatic Drives and Controls 2018 Condition, Need, Expectations and Possibilities. Work, Mining, Construction and Technology Machines, Kliczków Castle, 7-9 November 2018, Wrocław, Poland (2018).
27. P. Antoniak, M. Stosiak, K. Towarnicki, *Preliminary testing of the gear pump with internal gearing with modification of the sickle insert*. W: Engineering Mechanics 2019 : 25th international conference : book of full text, 13-16 May 2019, Svratka, Czech Republic (2019).
28. P. Antoniak, M. Stosiak, K. Towarnicki, Acta Innovations **32**, pp. 84-90, (2019).