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# Durability tests of prototype gear pumps with reduced flow ripple

**Piotr Osiński**

piotr.osinski@pwr.edu.pl | Orcid 0000-0001-9126-499X

**Paweł Bury**

pawel.bury@pwr.edu.pl | Orcid 0000-0002-1480-0653

**Rafał Cieślicki**

rafal.cieslicki@pwr.edu.pl | Orcid 0000-0003-3525-672X

**Janusz Rutański**

janusz.rutanski@pwr.edu.pl | Orcid 0000-0001-9272-9760

Faculty of Mechanical Engineering, Wroclaw University of Science and Technology

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## Abstract

This article presents the results of a durability test of a prototype low-pulsation pump. Hydraulic measurements conducted during the test enabled visualisation of the behaviour of the unit in working conditions. The test was conducted according to a strict factory standard, which states that pump performance parameters cannot decrease by more than 8% during durability testing. The material presented in this publication is the result of a study within the project entitled *The development of innovative gear pumps with a reduced level of acoustic emission*. The solution developed as part of the project has been successfully implemented for a series of gear pumps consisting of twenty-two units. Among other awards, the product won the Gold Medal at the 10$^{th}$ International Fair of Pneumatics, Hydraulics, Drives and Controls, Kielce 2017.

**Keywords:** gear pump, helical gear pump, silent pump, low pulsation pump

## 1. Introduction

The most commonly used displacement pumps in hydrostatic drive systems include gear pumps with external gearing. Despite the significant disadvantage of high noise, gear pumps are distinguished by having the ability to suck in liquids, they have a high power to weight ratio, and they have lower sensitivity to hydraulic fluid contamination than other types of displacement pump (Osiecki, 2004; Szablowski, 1997).

Currently, two trends are apparent in the development of gear pumps:

- increasing the power to weight ratio (Zardin, Natali, Borghi, 2019),
- reducing the flow ripple, and at the same time the level of generated noise (Pavić, Chevillotte, 2010; Miccoli, Pedrielli, Parise, 2016).

The first of these trends is usually accomplished in one of two ways: by optimising the geometry of the pump elements in terms of weight reduction or by increasing working pressures. The second of these trends is based on modification of the tooth profile. There are known and applied solutions involving the use of helical involute gears, the transition to no-backlash meshing or the use of non-involute tooth profiles (Osiński, 2013; Kollek, Osiński, 2009; Zhao, Vacca, 2018).

The main source of noise in non-cavitation systems is pressure ripple (Battarra, Mucchi, 2018). All elements subjected to the pulsation of pressure vibrate causing the emission of noise (Liu, Ba, Ren, 2019; Zhao, Vacca, 2018). The pressure ripple directly results from the flow ripple; therefore, the reduction of the flow ripple results in a reduction of the noise generated (Antoniak, Stryczek, 2018; Rodionov, Rekadze, 2017).

Based on our own research, it can be observed that pump modifications aimed at reducing noise usually have negative effects in the form of loss of the high efficiency that conventional units have. The loss of efficiency mainly results from volumetric losses. In gear pumps, the main volumetric losses are located in two areas: between the tooth tips and the pump body; on the face surfaces of the gears (Bury, Osiński, Rutański, Zakrzewski, 2016).

In the first stage, prototype gear pumps with helical gears with backlash were made, for which a number of research investigations and tests were conducted. The obtained results enabled making the final design without backlash, which was implemented and appreciated on the domestic market, winning the Gold Medal at the 10th International Fair of Pneumatics, Hydraulics, Drives and Controls, Kielce 2017.

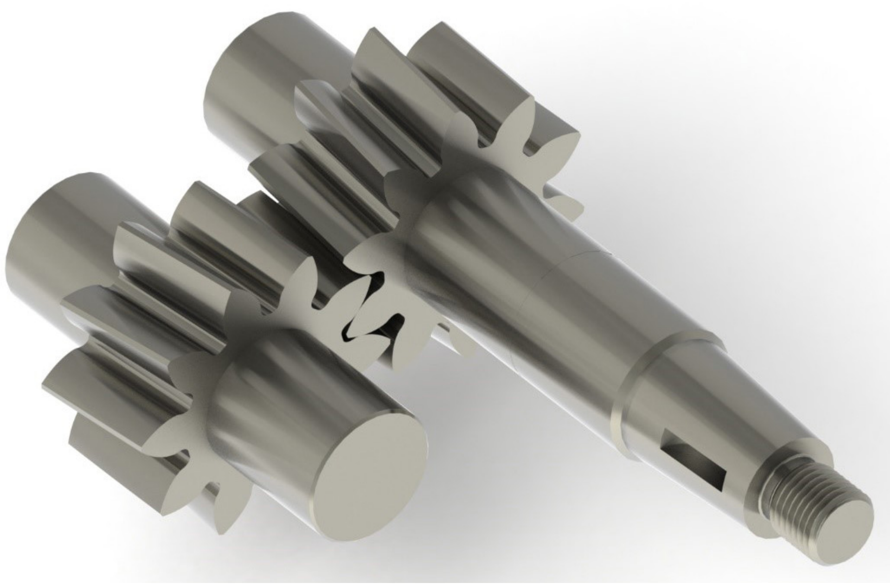

**Fig. 1.** The helical gears used in the tested pump (source: Bury, Osiński, Rutański, Zakrzewski, 2016)


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## 2. Subject of research

The research object was a pre-prototype pump which was created as part of a project entitled *The development of innovative gear pumps with a reduced level of acoustic emission*. The unit was optimised using multi-valued logical trees. The optimisation process was conducted taking into account five basic criteria: tool performance, obtaining a minimum compression ratio, the occurrence of small changes in dynamic forces in meshing, obtaining a minimum rate of flow ripple and ensuring high energy efficiency (Osiński, 2017). Taking into account the adopted criterion conditions among the selected alternative combinations of the three-involute profile, a profile characterised by the occurrence of two regular involute and one extended involute was indicated. The pump developed by Wrocław University of Science and Technology was manufactured by Hydrotor S.A. The tested unit is denoted as 3PW-SE-32/28-2-776 with serial number A150 20008. The displacement of the pump is q = 32 $cm^3$/rev, the nominal pressure $p_{t\,nom}$ = 28 MPa, while the maximum pressure is $p_{t\,max}$ = 32 MPa. The pump uses helical gears (shown in Fig. 1) to reduce the flow ripple and the generated level of noise.

The tested pump has helical gears with backlash, but the next generation of the pump has gears without backlash. The differences between the theoretical flow non-uniformity coefficient for different types of gears are shown on Table 1.

**Table 1.** Theoretical flow non-uniformity coefficient for different types of gears (Bury, Osiński, Różański, 2017)

| Types of gears | Straight gears | Helical gears |
|---|---|---|
| with backlash | 26.5% | 19.7% |
| without backlash | 5.9% | 4.2% |

## 3. Description of the test and measuring equipment

The durability test is part of the obligatory set of tests before the pump is put into production. The test according to the accepted standard requires a million load cycles. The period of one cycle is 2 s, in which the pump is loaded with nominal pressure for half of the cycle, after which it is relieved. The test is conducted at the nominal speed. Figure 2 presents a single load cycle during durability testing.

The test was divided into several stages. After each stage, hydraulic tests were conducted in the Laboratory of Hydraulic Drives and Vibroacoustics of Wroclaw University of Science and Technology. The tests were performed for the selected rotational speeds of n = 800; 1000; 1500; 2000 rpm. The disqualifying

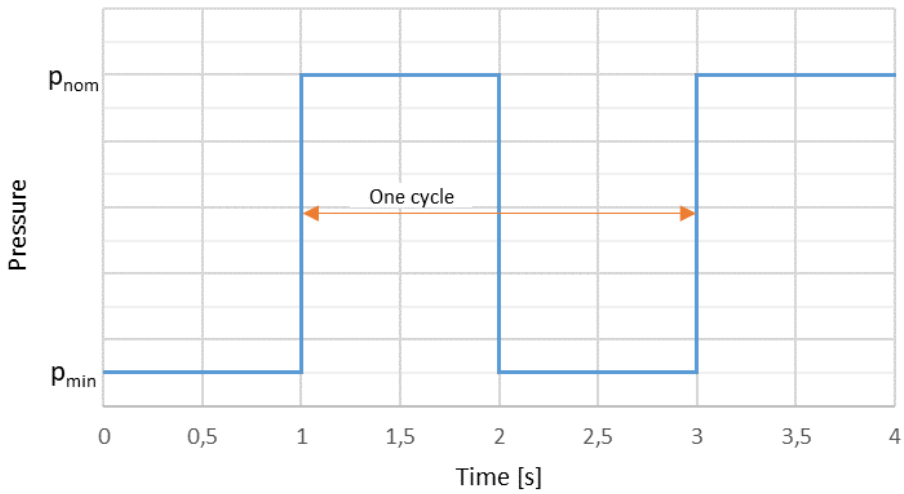


**Fig. 2.** Load cycle graph (source: own compilation)

condition of the pump in accordance with the standard is a drop in efficiency for any working pressure by more than 8% in relation to the characteristics obtained after the factory delivery of the pump.

Figure 3 presents a schematic of the hydraulic system that enabled continuous pressure level on the suction side and the discharge side. The pressure level on the suction side was made possible by a system consisting of a feed pump (3) and needle valves (9 and 11). The load of the tested pump was obtained through a needle valve (10) and the pump was secured with a safety valve (7). Pressure gauges on the suction side of the pump were operated by vacuum/pressure gauges (13, 14), while the manometer (15) was on the pressure side. The flow rate was set using sequentially switched flow meters (16). The temperature of the working liquid was controlled by means of a cooler installed in the tank in accordance with feedback from a thermistor sensor placed in the tank (18).

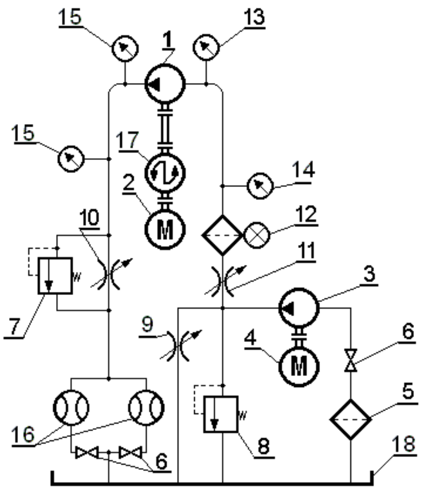


**Fig. 3.** Scheme of the measurement stand: 1 – tested gear pump; 2 – DC drive motor; 3 – feed pump; 4 – AC motor; 5 – suction filter; 6 – shut-off valve; 7, 8 – safety valves, 9, 10, 11; – needle valves; 12 – flood filter; 13, 14 – vacuum/pressure gauges; 15 – manometer; 16 – flow meter; 17 – torque gauge; 18 – tank (source: own compilation)

## 4. Tests and results

The following graphs (Figs. 4–7) present volumetric efficiency determined successively after run-in (0 cycles), after the execution of around 250 thousand, 500 thousand and 750 thousand cycles, and after completion of the test (1 million cycles).

## 5. Conclusions

The presented characteristics perfectly show the behaviour of the pumps during the simulated conditions occurring during operation.

The conducted durability test of the prototype pump did not show premature wear of the unit. The examined unit did not lose the initial volumetric efficiency across almost the entire range of rotational speeds and pressures, what is more,

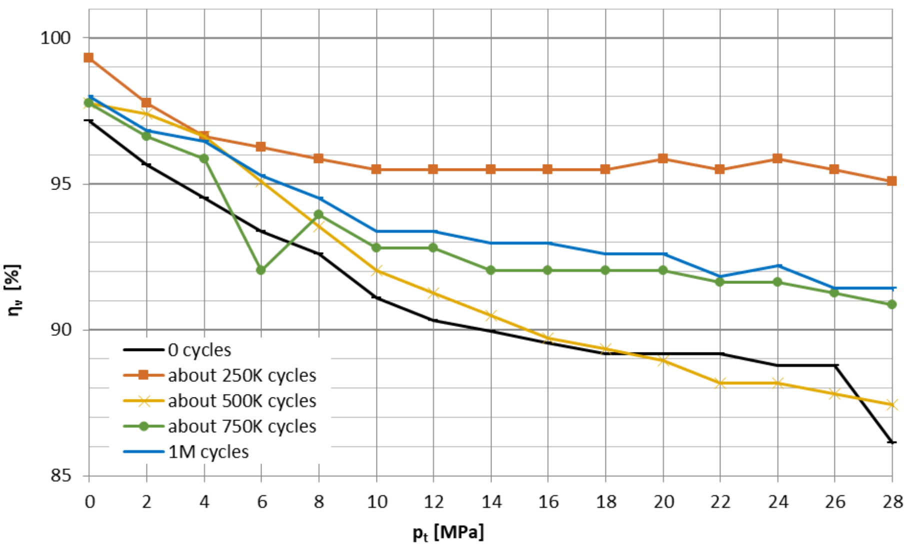


**Fig. 4.** Comparison of volumetric efficiency during the durability test for rotational speed of 800 rpm (source: own compilation)


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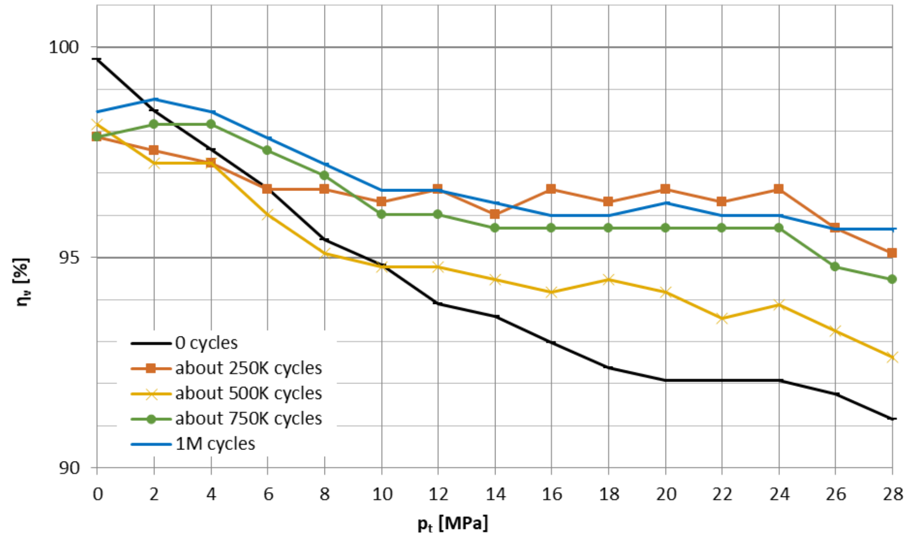


**Fig. 5.** Comparison of the volumetric efficiency during the durability test for the speed of 1000 rpm (source: own compilation)

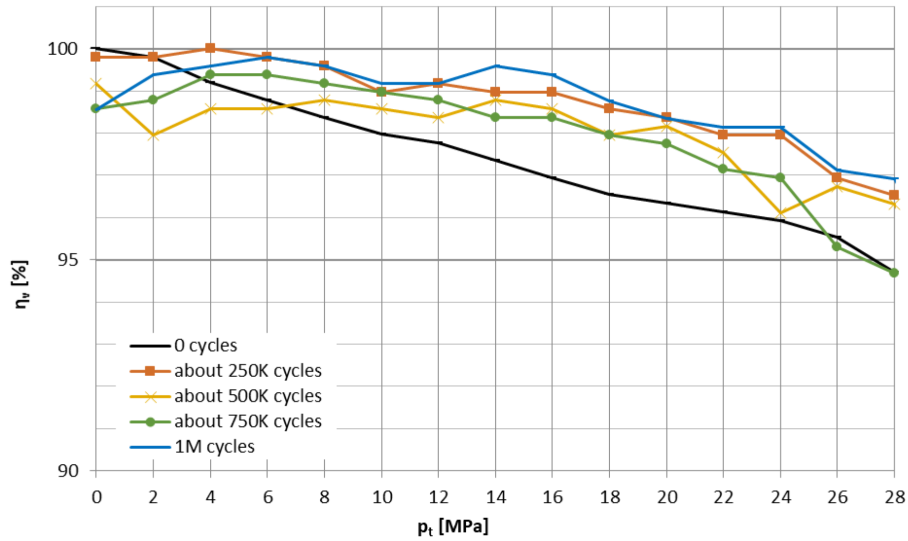


**Fig. 6.** Comparison of volumetric efficiency during the duration test for the speed of 1500 rpm (source: own compilation)

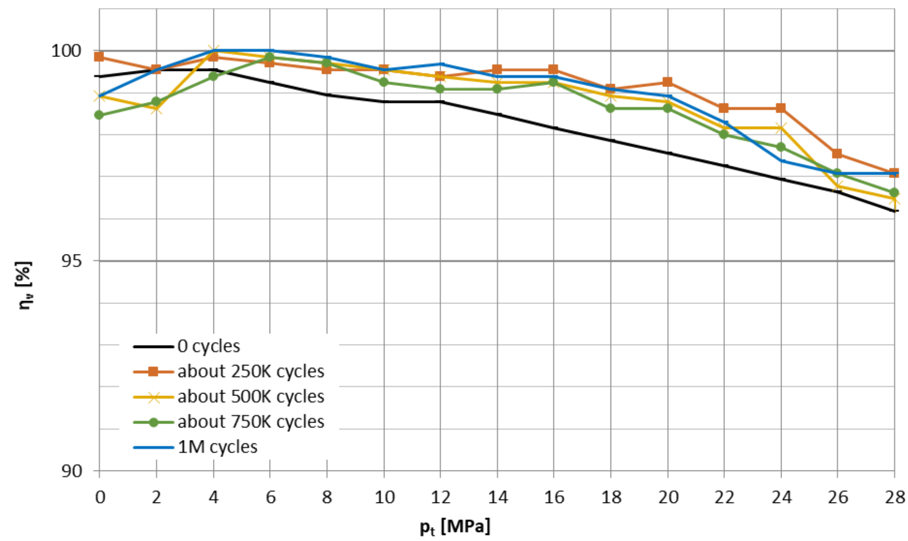


**Fig. 7.** Comparison of volumetric efficiency during the durability test for the speed of 2000 rpm (source: own compilation)

in some working pressure it increased significantly after the first part of the test (after around 250 thousand cycles). The volumetric efficiency $h_v$ with the maximum delivery pressure $p_t$ = 28 MPa and the speed n = 1500 rpm for all stages assumed values under 8% of the permissible reduction (Table 2). The pump is characterised by high durability. The efficiency at the nominal pressure after 1 million cycles is 9.8% higher than the permissible reduction.

**Table 2.** Volumetric efficiency measured during the test of the prototype pump for nominal speed (source: own compilation)

| **Durability test** | **Pump 3PWR-SE-32-28-2-776 no A150 20008** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Working pressure [MPa]** | | | | | | | | | | | | | | |
| | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 |
| | Volumetric efficiency [%] | | | | | | | | | | | | | | |
| before test | 100 | 99.8 | 99.2 | 98.8 | 98.4 | 98.0 | 97.8 | 97.4 | 97.0 | 96.5 | 96.3 | 96.1 | 95.9 | 95.5 | 94.7 |
| minimum permissible efficiency | 92.0 | 91.8 | 91.3 | 90.9 | 90.5 | 90.2 | 90.0 | 89.6 | 89.2 | 88.8 | 88.6 | 88.4 | 88.2 | 87.9 | 87.1 |
| after 1 million cycles | 98.6 | 99.4 | 99.6 | 99.8 | 99.6 | 99.2 | 99.2 | 99.6 | 99.4 | 98.8 | 98.4 | 98.1 | 98.1 | 97.1 | 96.9 |

In addition to the increase in volumetric efficiency, an increase in the value of total and hydraulic-mechanical efficiency was also observed. This fact indicates the occurrence insufficient initial (factory) run-in. Slight roughness or waviness of the tooth's profile causes greater friction loss of the cooperating tooth pairs. After some time, when the surfaces are smoothed out due to running-in, these wheels function with less play. This can only occur if the surface roughness is negligible. When the roughness and waviness is larger, the surface can be damaged, which causes larger profile and pitch errors. Thus, after proper run--in, an increase in hydraulic and mechanical efficiency was observed, as was an accompanying increase in the total efficiency. The test results can certainly be considered positive.

## References

Antoniak, P., Stryczek, J. (2018). Visualization study of the flow processes and phenomena in the external gear pump. *Archives of Civil and Mechanical Engineering*, 18(4), 1103–1115.

Battarra, M., Mucchi, E. (2018). Incipient cavitation detection in external gear pumps by means of vibro-acoustic measurements. *Measurement*, *129*, 51–61.

Bury, P., Osiński, P., Różański, R. (2017). Pulsacja wydajności w pompach zębatych o obniżonej emisji akustycznej. In *XXX konferencja PRMR. Zakopane 24-27.01.2017* (pp. 1–13). Zakopane: Instytut Mechanizacji Budownictwa i Górnictwa Skalnego.

Bury, P., Osiński, P., Rutański, J., Zakrzewski, I. B. (2016). Badania porównawcze właściwości akustycznych i hydraulicznych niskopulsacyjnych pomp zębatych serii 2PW-SES. In *Napędy i sterowania hydrauliczne i pneumatyczne 2016: międzynarodowa konferencja naukowo-techniczna*. Katowice.

Kollek, W., Osiński P. (2009). *Modelling and design of gear pumps*. Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej.

Liu, D., Ba, Y., Ren, T. (2019). Flow fluctuation abatement of high-order elliptical gear pump by external noncircular gear drive. *Mechanism and Machine Theory*, *134*, 338–348.

Miccoli, G., Pedrielli, F., Parise, G. (2016). Simplified methodology for pump acoustic field analysis: the effect of different excitation boundary conditions. In *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*. Hamburg.

Osiecki, A. (2004). *Hydrostatyczny napęd maszyn*. Warszawa: Wydawnictwa Naukowo-Techniczne.

Osiński, P. (2013). *Wysokociśnieniowe i niskopulsacyjne pompy zębate o zazębieniu zewnętrznym*. Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej.

Osiński, P. (2017). *Pompy zębate o obniżonym poziomie emisji hałasu*. Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej.

Pavić, G., Chevillotte, F. (2010). Noise characterization of pulsating hydraulic sources. In *Proceedings of ISMA 2010: International Conference on Noise and Vibration Engineering including USD2010*. Leuven.

Rodionov, L., Rekadze, P. (2017). Experimental Vibroacoustic Research of a Gear Pump Made of different Materials. *Procedia Engineering*, *176*, 636–644.

Szablowski, K. (1997). *Pompy wyporowe*. Warszawa–Kraków: PWN.

Zardin, B., Natali, E., Borghi, M. (2019). Evaluation of the Hydro-Mechanical Efficiency of External Gear Pumps. *Energies*, *12*(13), 2468.

Zhao, X., Vacca, A. (2018). Analysis of continuous-contact helical gear pumps through numerical modeling and experimental validation. *Mechanical Systems and Signal Processing*, *109*, 352–378.

# Badania trwałościowe prototypowych pomp zębatych o obniżonej pulsacji wydajności

**Streszczenie**

W artykule przedstawiono wyniki testu trwałościowego, prototypowej pompy niskopulsacyjnej. Pomiary hydrauliczne przeprowadzone podczas testu pozwalają na wizualizację zachowania jednostki w trakcie pracy. Test przeprowadzono zgodnie ze ścisłymi normami fabrycznymi, które określają, że parametry wydajności pompy nie mogą się zmniejszyć o więcej niż 8% podczas testu trwałości. Materiał przedstawiony w publikacji jest wynikiem badań w ramach projektu *Rozwój innowacyjnych pomp zębatych o obniżonym poziomie emisji akustycznej.* Rozwiązanie opracowane w ramach projektu zostało z powodzeniem wdrożone jako seria pomp zębatych składająca się z 22 jednostek. Produkt zdobył m.in. Złoty Medal na 10. Międzynarodowych Targach Pneumatyki, Hydrauliki, Napędów i Sterowań, Kielce 2017.

**Słowa kluczowe:** pompa zębata, cicha pompa, pompa o obniżonej pulsacji