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EXPERIMENTAL INVESTIGATIONS OF GUIDE RINGS MADE OF UHMWPE AND PTFE COMPOSITE IN WATER HYDRAULIC SYSTEMS

In the present work two materials of guiding elements were tested in water hydraulic. The guide elements used for the test station were made of UHMWPE and PTFE filled with 23% of carbon powder and 2% of graphite powder (Kefloy-22). During investigations of hardness conducted for stuffing box packings in water hydraulic systems an analysis of proper selection of piston rod guiding elements has also been carried out ø 45 f7 (R_a = 0.07÷0.20 μm, R_m ≤ 2.5 μm). Working piston rod made of chromium-nickel steel AISI 431 (Cr = 16.7%, Ni = 2.08%) has been used for investigations. Some of the guiding elements, after proper selection of the material, could be still used, despite damaged seal. The tests have been performed maintaining water pressure on the sealing at a level of p = 8±1 MPa and the average velocity of the piston rod of v ≈ 0.35 m/s. Water temperature during investigations was regulated within the range of T_{min} = 291 K and T_{max} = 305 K. Variable value of friction coefficient has been obtained for the guide rings made of PTFE composite with the change in piston rod velocity and friction force as a function of the velocity of single guide element made of Kefloy-22 after the distance of 15 000, 60 000 and 90 000 m. For the lifetime reaching friction distance of 200 km the guide rings can be used several times. Similar measurement has been performed for guide elements made of UHMWPE. The seals were disassembled during tests from the stuffing boxes. During assessment of the elements made of polyethylene with very high molecular mass (UHMWPE) it was found that friction force (and the friction coefficient, respectively) after 108 000 cycles (i.e. 108 000 m), decreased only by 30%. It was also found that friction coefficent for UHMWPE μ_{UHMWPE} has a continuous value within the range of applied velocity of v = 0.05 to 0.40 m/s. In order to determine friction coefficient μ_{UHMWPE} the weight of the piston rod was calculated, whose mass m = 15.5 kg, thus pressing force N = 152 N. At the friction force for single guide element, after the distance of 3500 m, with F_{pr} = 20 N value of μ_{UHMWPE} = 0.26. However after 108 000 m of friction distance the friction coefficient μ_{UHMWPE} = 0.20. It should be highlighted that these coefficients concern dry friction. Kefloy-22 can be successfully used for guide rings in water hydraulic systems. Application of guide rings made of UHMWPE has been estimated negatively. It has been revealed that there was not beneficial to produce the guide elements from this material despite the fact that UHMWPE has the lowest abrasive wear from all polymers. Problem occurred due to wear particles disturbing the work of the cylinder.

Keywords: **engineering polymers, polymer seals, UHMWPE, PTFE composite, water hydraulic**

BADANIA EKSPERYMENTALNE PIERŚCIENI PROWADZĄCYCH WYKONANYCH Z PE-UHMW I KOMPOZYTU PTFE PRACUJĄCYCH W HYDRAULICE WODNEJ

Podczas wykonywania badań trwałościowych, uszczelnień dławnicowych w układzie hydrauliki wodnej dobrano skojarzenie, w którym uszczelnienie tłoczyskowe wykonano z PE-UHMW, natomiast pierścienie prowadzące z kompozytu PTFE (Kefloy-22). Do badań zastosowano tłoczysko robocze ø 45 f7 o poniższych parametrach: materiał: stal chromowo-niklowa gat. AISI 431 (Cr = 16,7%, Ni = 2,08%) chromowana technicznie o gr. powłoki ≥ 20 µm, elipsoidalność ≤ ¼ f7, liczba mikropęknięć ≥ 5000/mm^2, R_a = 0,07÷0,20 µm, R_m ≤ 2,5 µm. Niektóre z elementów prowadzących, dzięki prawidłowemu doborowi materiału, mogły być używane nadal, mimo zniszczenia uszczelek. Badania prowadzono, utrzymując ciśnienie wody obciążające uszczelki na poziomie p = 8±1 MPa oraz prędkość średnią tłoczyska v ≈ 0,35 m/s. Temperatura wody podczas badań, a tym samym temperatura tłoczyska, była regulowana w zakresie T_{min} = 291 K, T_{max} = 305 K. Otrzymano zależność wartości współczynnika tarcia pierścieni prowadzących wykonanych z kompozytu PTFE od prędkości ruchu tłoczyska. Przy trwałości uszczelnień dochodzącej do 200 km drogi tarcia pierścienie prowadzące mogły być stosowane kilkakrotnie. Pozytywnie oceniono Kefloy-22 jako materiał do zastosowania na pierścienie prowadzące w hydraulice wodnej. Oceniono negatywnie stosowanie pierścieni prowadzących wykonanych z PE-UHMW. Zaproponowano właściwy dobór materiałowy zestawów uszczelniająco--prowadzących.

Słowa kluczowe: **polimery konstrukcyjne, uszczelnienia polimerowe, PE-UHMW, kompozyt PTFE, hydraulika wodna**

INTRODUCTION

The purpose of the investigations was to determine optimal combination of piston rod seal-guide ring. They concerned the type of the seal and materials of both seal and guide ring. The results of the investigations of seal selection on the basis of lifetime and friction forces have been described before [1]. The purpose of this paper was to indicate the polymer suitable for water hydraulic systems.

DESCRIPTION OF TEST STAND

Figure 1 presents the test cylinder. The cylinder (2) is placed on the base (1) and fixed with two clamping rings (14). The piston rod (3), made of stainless steel, moves inside the cylinder forced by the movement of force sensor (4). Filling up of the cylinder (2) with water takes place after unscrewing upper head of hand pump (6) and loosening air vent (5). After water appears in the air vent and the water surface is found at the half of height of the hand pump cylinder (6) the air vent is tightened and the upper head of the pump is assembled. The pressure inside the cylinder is produced by the pressurised nitrogen from the gas cylinder (12). Pressure from the gas cylinder is reduced several times by means of pressure reducer (10) and then it is transferred through the hose (11) to the gas/water intensifier (13) with 10:1 ratio. Reading of the water pressure transferred through the hose (9) from the cylinder (2) is made by means of the gauge (7). The possible leakage from the seal that can appear is drained through leakage pipes (15) into the measuring containers. Temperature measurements are read by sensors (8). Both cylinders are placed on one base and their piston rods are connected by means of force sensor working at the compression/tension conditions which enables the measurements of friction forces in sealing. The stroke was 0.5 m and the minimal cycle time amounts to ca. 3 s.

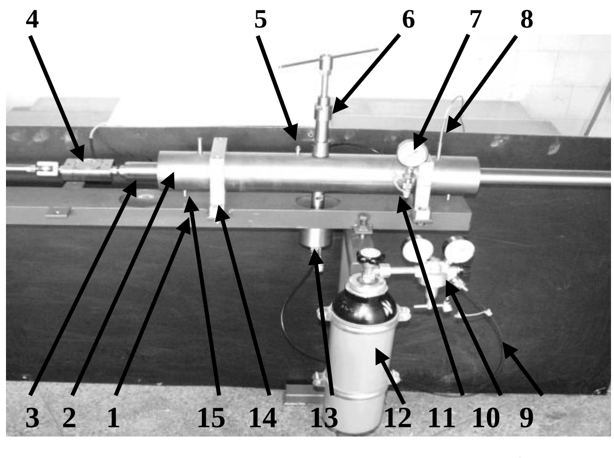

Fig. 1. Test stand: 1 - base, 2 - cylinder, 3 - piston rod, 4 - force sensor, 5 - air vent, 6 - hand pump, 7 gauge, 8 - temperature sensors, 9 - hose, 10 - pressure reducer, 11 - hose, 12 - gas cylinder, 13 - gas/water intensifier , 14 -clamping ring, 15 - leakage pipes

Rys. 1. Widok stanowiska badawczego: 1 - podstawa, 2 - cylinder napełniany wodą, 3 - tłoczysko badawcze, 4 - czujnik siły, 5 - odpowietrznik, 6 - pompka ręczna, 7 - czujnik ciśnienia wody, 8 - czujnik temperatury, 9 - wężyk ciśnieniowy wody, 10 - reduktor ciśnienia, 11 - wężyk ciśnieniowy azotu, 12 - butla ze sprężonym azotem, 13 - gazowo-wodny multiplikator ciśnienia, 14 - uchwyt mocujący, 15 - rurka wylewowa do pomiaru przecieków

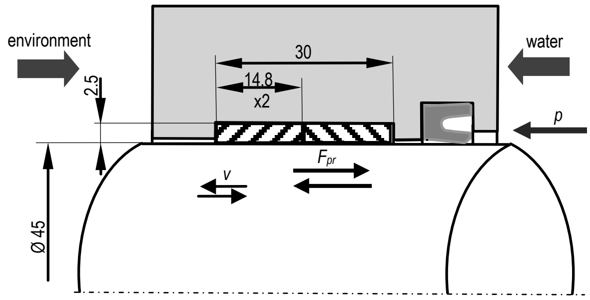

Fig. 2. Seal and guide rings in stuffing-box

Rys. 2. Uszczelka i pierścienie prowadzące w zabudowie dławnicy

For typical hydraulic cylinder the guide elements are located before seal i.e. at the pressure side, which ensures their proper lubrication. The guide rings were placed under the seal rings (Fig. 2) in order to achieve maximal concentricity. The external distance of test cylinder guide elements gives opportunity for the guide rings wear products to get into the interior of the cylinder only during the cycle of in-movement of the piston rod into the seal. Due to the leakages of lubricant, the self-lubricating elements had to be used, proper for the material of piston rod. This arrangement also enabled better damping of vibration of piston rod free ends.

The guide elements used for the test station were made of UHMWPE and PTFE filled with 23% of carbon and 2% of graphite (Kefloy-22) [2] (Tab. 1).

TABLE 1. **Materials of guide elements**

TABELA 1. **Materiał pierścieni prowadzących**

UHMWPE	UHMWPE virgin
PTFE composite	PTFE + 23% carbon + 2% graphite (Kefloy-22)

RESEARCH

Due to significantly high coefficient of linear thermal expansion of the polymers, the guide elements in pneumatic and hydraulic cylinders are produced from the cut tape, and a gap with a certain width is left between the ends [2]. Length of the tape is calculated as below:

$$L = 3.114\,(d + g) - 1,\ \text{mm} \tag{1}$$

where: d - piston rod diameter, 45 mm; g - thickness of the tape, assumed value: 2.5 mm.

Width of the rings was accepted as 14.8 mm; in both stuffing-boxes 2 rings were located (Figs. 2 and 3).

Fig. 3. Packing nut (left), stuffing-box with guide rings made of PTFE composite in closed groove (central), stuffing-box with opened groove of seal and leakage holes (right) [2]

Rys. 3. Nakrętka dławnicy (po lewej), dławnica z pierścieniami prowadzącymi w zamkniętych rowkach (pośrodku), dławnica z otwartym rowkiem na uszczelkę i otworami do przecieków (po prawej) [2]

Parameters of working piston rod as well as the parameters of the investigations are shown in Tables 2 and 3.

TABLE 2. **Parameters of piston rod [3]**
TABELA 2. **Parametry tłoczyska**

Diameter	45 f7
Ellipsoidality	≤ ¼ f7 (for ø 45)
Material	chromium-nickel steel AISI 431 (Cr = 16.7%, Ni = 2.08%)
Covered chromium plating	≥ 20 μm
Roughness	R_a = 0.07÷0.20 μm, R_m ≤ 2.5 μm

TABLE 3. **Parameters of the investigations**
TABELA 3. **Parametry badań**

Objects	Pressure *p* MPa	Velocity *v* m/s	Temperature K	Investigation
Seals+guide elements	8±1	0.35	291÷305	Durability, total friction force
Only guide elements	0	0.05-0.40	291±5	Friction force F_{cpr}

Initially, the guide rings made of UHMWPE (polyethylene ultra high molecular weight) were used for the investigations [4-9], however, it was found that during sealing tests conducted also on UHMWPE, there is still a water drops streaking effect at the piston rod ends protruding from the cylinder, which leads to clogging of the seal by wear products - lifetime only 20 000 m (Fig. 4). Wear products caused damage of the seals and investigations of guide rings made of UHMWPE. Only friction force after 108 000 m was determined. In order to determine the friction force for the guide set (two guide rings in stuffing-box (see Fig. 2) F_{pr}, a friction force was first determined for the two guide sets (in both stuffing-boxes) F_{cpr}

$$F_{pr} = F_{cpr}/2, \text{ N} \quad (2)$$

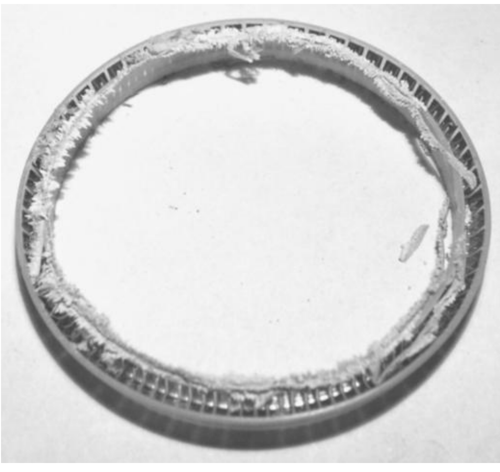

Fig. 4. Mupuseal 30412 - 0450 - 90 - S seal after 20 000 m of friction distance. Visible wear products on the seal from the guide elements made of UHMWPE [1]

Rys. 4. Uszczelka Mupuseal 30412 - 0450 - 90 - S po 20 000 m drogi tarcia. Na uszczelce widoczne produkty zużycia pierścieni prowadzących wykonanych z PE-UHMW [1]

In order to obtain the measurements of friction force for F_{cpr} possibly close to the real state, the piston rod and the guide elements were several times washed by the technical acetone, which was then left to free evaporation. The layer of the material produced during operation and pushed into the piston rod structure was deliberately not removed. The seals were disassembled during tests from the stuffing boxes. During assessment of the elements made of polyethylene with very high molecular mass (UHMWPE) it was found that friction force (and the friction coefficient, respectively) after 108 000 cycles (i.e. 108 000 m), decreased only by 30%. It was also found that friction coefficent for UHMWPE μ_{UHMWPE} has a continuous value within the range of applied velocity of v = 0.05 to 0.40 m/s. In order to determine friction coefficient μ_{UHMWPE} the weight of the piston rod was calculated, whose mass m = 15.5 kg, thus pressing force N = 152 N. At the friction force for single guide element, after the distance of 3 500 m, with F_{pr} = 20 N value of μ_{UHMWPE} = 0.26. However after 108 000 m of friction distance the friction coefficient μ_{UHMWPE} = 0.20. It should be highlighted that these coefficients concern dry friction. Similar measurement have been performed for guide elements made of Kefloy-22, after 15 000, 60 000 and 90 000 m of friction distance *s*. The guide elements used in the test station were made of PTFE filled with 23% of carbon and 2% of graphite (Kefloy-22) [10-12]. Wear products from guide rings made of Kefloy-22 did not cause damage of the seals (Fig. 5).

Fig. 5. Mupuseal 30413 - 0450 - 90 - S seal after 90 000 m of friction distance. Visible wear products on the seal from the guide elements made of Kefloy-22

Rys. 5. Uszczelka Mupuseal 30413 - 0450 - 90 - S po 90 000 m drogi tarcia. Na uszczelce widoczne produkty zużycia pierścieni prowadzących wykonanych z Kefloy-22

Figure 6 presents the example of the friction forces only for the guide elements made of Kefloy-22. The chart shows ”soft” vibration damping and fluctuation of friction force. Vibration damping is a quality characteristic for polymers and PTFE has one of the best damping coefficient, if construction polymers are considered. Due to this properties the polymers have thoroughly superseded bronze from hydraulic systems. The vibrations with short wavelength are caused by the graphite on the piston rod [13]. This causes variable friction force (ca. 3.5÷7.5 N). The charts for the dependence of friction force on the velocity, for single guide element made of Kefloy-22 are presented in Figures 7-9. Very broad range of friction coefficient $\mu_{Kefloy\text{-}22}$ was found, e.g. for the range of applied velocity, after the friction distance of 15 000 m, together with the increase of the velocity its value changes from 0.20 to 0.065.

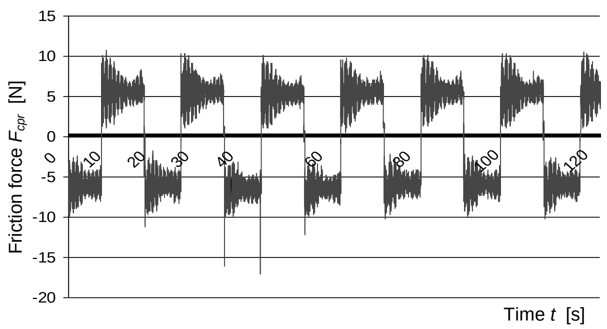

Fig. 6. Friction force diagram of guide elements made of Kefloy-22. Distance 99 000 m, sampling frequency 100 Hz, time of measurement 120 s, average velocity v = 0.09 m/s, average friction force value F_{cPr} = 6 N

Rys. 6. Wykres siły tarcia pierścieni prowadzących wykonanych z Kefloy-22. Droga tarcia 99 000 m, częstotliwość próbkowania 100 Hz, czas pomiaru 120 s, prędkość ruchu v = 0,09 m/s, średnia wartość siły tarcia F_{cPr} = 6 N

After friction distance of 90 000 m the opposite situation takes place - while increasing the velocity the friction coefficient increases from 0.039 to even 0.37.

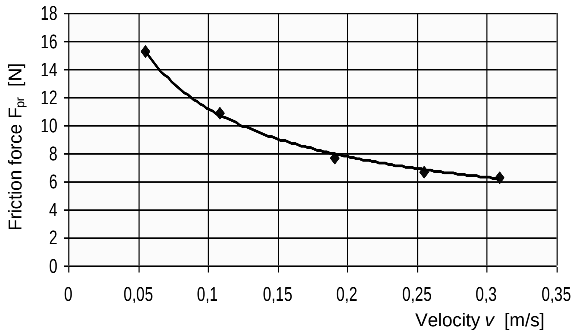

Fig. 7. Friction force as a function of the velocity of single guide element made of Kefloy-22 after the distance of 15 000 m

Rys.7. Siła tarcia w funkcji prędkości pojedynczego pierścienia prowadzącego wykonanego z Kefloy-22 po drodze tarcia 15 000 m

On the basis of Figure 7 it can be assumed that during initial period of mating of guide elements made of Kefloy-22 (PTFE + 23% of carbon + 2% of graphite) with the piston rod surface, an adhesion wear mainly occurred [14]. Friction node was also subject to running-in during this period. During first period the phenomena according to the theory of mechanical locking, typical for the polymer-metal contact, occurred. Next stage of running-in is an increase in friction force as a result of adhesion, visible especially at the lower velocity values. Separation of the surface by the products of abrasive wear, being also the lubricant, leads to the fluid friction - both surfaces, at this moment, do not contact with the point of highest irregularities of the surface. However, due to the increased thickness of the graphite on the piston rod a phenomenon of polymer material deformation of elastic nature occurs, especially visible on the charts of friction elements (Fig. 6).

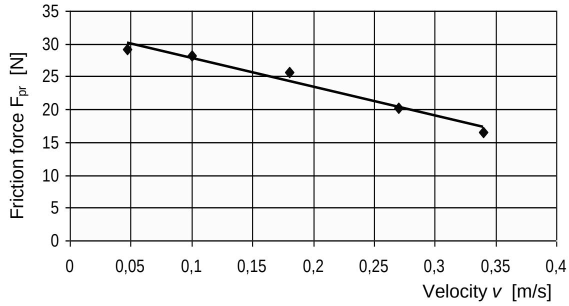

Fig. 8. Friction force as a function of the velocity of single guide element made of Kefloy-22 after the distance of 60 000 m

Rys. 8. Siła tarcia w funkcji prędkości pojedynczego pierścienia prowadzącego wykonanego z Kefloy-22 po drodze tarcia 60 000 m

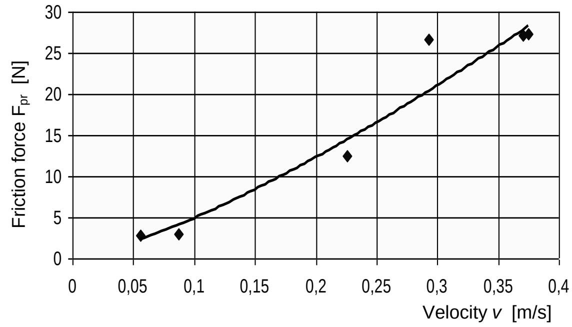

Fig. 9. Friction force as a function of the velocity of single guide element made of Kefloy-22 after the distance of 90 000 m

Rys. 9. Siła tarcia w funkcji prędkości pojedynczego pierścienia prowadzącego wykonanego z Kefloy-22 po drodze tarcia 90 000 m

The friction coefficient, from this moment increases with the increase of velocity (Fig. 9). Friction begins to be of a mixed nature.

CONCLUSIONS

The assumed purpose of the investigations has been achieved. The combinations have been selected for piston rod sealing made of UHMWPE and guide rings made of PTFE composite (Kefloy-22). For the lifetime reaching friction distance of 200 km [1] the guide rings can be used several times. Kefloy-22 can be successfully used for guide rings in water hydraulic systems.

Application of the guide elements made from Kefloy-22 enable using wear products as a lubricant. In this paper the application of UHMWPE as a material for guide elements work in water hydraulic were investigated. Our studies revealed that there was not beneficial to produce the guide elements from this material despite the fact that UHMWPE has the lowest abrasive wear from all polymers. Problem occurred due to wear particles disturbing the work of the cylinder.

Further investigations are recommended in order to reduce the amount of graphite and carbon from guide ring material. This should improve the lifetime of piston rod sealing, which seem to depend on the thickness of the lubricant film on the push rod.

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