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Prognosing the durability of polymer sealings

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Materials

ABSTRACT

Purpose: The paper describes the phenomena connected with the sealing for water hydraulic systems.
Design/methodology/approach: For the durability tests two types of sealings, made of three polymeric materials recommended for use in water hydraulics systems have been used. In all investigation arrangements the same guide elements have been used. The tests have been performed maintaining water pressure on the sealing at a level of p = 8±1 MPa and the average speed of the piston rod of v ≈ 0.35 m/sec. Water temperature during investigations was regulated within the range of Tmin = 291 K and Tmax = 305 K. The leakage was distributed to the measurement hoses with the internal diameter of 5mm. For the investigations, the working piston rod with ø 45 f7 with the following parameters has been used: Material: chromium-nickel steel AISI 431 (Cr=16.7%, Ni=2.08%) covered with hard chromium plating of ≥ 20 µm, micro-cracks number ≤ 5 000/mm^2, Ra = 0.07 µm.
Findings: Weibull method, thanks to its multifunctionality, helps to select elements for certain applications (required long failure-free mileages → high characteristic durability – sealings series 30413). Equipment which works sporadically → low characteristic durability but e.g. lower weight and sizes of sealing element – sealing series 30412.
Practical implications: Within the confines of the given research concerning an optimal choice of piston rod sealing for water hydraulic systems, large dependence of the sealing durability on the properly chosen guide elements of the piston rod has been found. In extreme cases the durability changed even a few times.
Originality/value: The Weibull method has been applied for assessment of durability and reliability of mechanical parts. A computer program has been used to compare two types of piston rod seals used in water hydraulic power systems. Durability limits have been estimated even though discontinued measurement data were used.
Keywords: Engineering polymers; Properties; Mechanical properties; Statistic methods; Polymer sealings; PE-UHMW; Water hydraulic

1. Introduction

Within the confines of the research concerning an optimal choice of the piston rod sealings for water hydraulics systems the necessity appeared to perform the analysis of durability for individual elements. The tests were made in the symmetrical test cylinder which enabled simultaneous testing two piston rod sealings [1].

For the durability tests two types of sealings, made of three polymeric materials recommended for use in water hydraulics systems have been used. In all investigation arrangements the same guide elements have been used. The tests have been performed maintaining water pressure on the sealing at a level of p = 8±1 MPa and the average speed of the piston rod of v ≈ 0.35 m/sec. Water temperature during investigations was regulated within the range of Tmin = 291 K and Tmax = 305 K. The leakage was distributed to the measurement hoses with the internal diameter of 5mm.

For the investigations, the working piston rod with ø 45 f7 with the following parameters has been used: Material: chromium-nickel steel AISI 431 (Cr=16.7%, Ni=2.08%) covered with hard chromium plating of ≥ 20 µm, micro-cracks number ≤ 5 000/mm2, Ra = 0.07 µm

After initial tests it turned out that in the applied sealing system the expected durability is achieved for the sealings made of PE-UHMW, type 30412 – 0450 – 90 – S (Ø 45/51.2 x 4.8) and 30413 – 0450 – 90 – S (Ø 45/54.4 x 7.1) (Fig. 1).

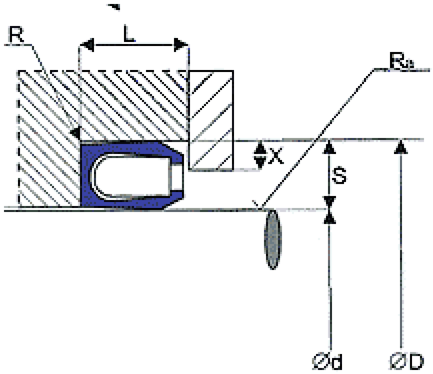


Fig.1. Sealing Mupuseal activated with the spring

2. Weibull method

During time-consuming hardness tests conducted in the symmetrical test cylinder, enabling simultaneous testing two piston rod sealings, the complete results were achieved, i.e. they were being conducted until a total damage (leakage) only for one sealing each pair. The second sealing could still work on. The replacement of the damaged sealing was connected with a significant risk of the damage of a good one. Due to the abovementioned fact the question arose if it is possible to make use of the results of the hardness tests achieved for the sealings which have not been damaged and have survived the friction distance. The results for these sealings are defined as so-called right-hand-discontinued ones i.e. stopped in the moment when the sealing element has not been damaged yet. To achieve this, the Weibull distribution is applied which is a probability distribution that finds its application in reliability testing [1,2,3,8,9,10]. The distribution derives its name from Swedish professor, Waloddi Weibull, who showed its usefulness for modelling different data sets in late 40s of the 20th century. Weibull distribution has found application for modelling the time of the utilization both the simplest electronic components (transistors, resistors) through small complex elements (transmitters, ball bearings) and the bigger equipment (dishwashers, bicycles, gear boxes) to the whole complexes which require highest reliability (nuclear power plants, satellites, heart pacemakers) [4,5,6]. For the analyses of the durability, reliability and failures by means of Weibull method, the data deriving from the leakages of the individual sealings have been used. As a measure of the durability the friction distance until the leakage (working distance of the sealing) has been assumed. Tests for the sealings have been found as complete (F) if the leakages exceeded the values, respectively: 100mm for the sealings series 30412 or 600 mm of water column (in a pipe of diameter 5 mm) series 30413. The tests for the sealings which leakages did not reach above mentioned values have been found as right-hand-discontinued (S). Determination of the parameters and each functions of the Weibull distribution was conducted by means of *Weibull++6* software by ReliaSoft Co. (USA) [7].

Table 1.
The results of reliability tests for Mupuseal sealings

Mupuseal sealings 30412-0450-90-S		Mupuseal sealings 30413-0450-90-S	
Symbol for the test: F – finished (complete) S – stopped (discontinued)	Friction distance [m]	Symbol for the test: F – finished (complete) S – stopped (discontinued)	Friction distance [m]
F	20000	S	60000
S	20000	S	60000
F	50000	F	79000
S	50000	S	79000
F	72000	F	101300
S	72000	S	101300
S	90000	F	152000
S	90000	S	152000

Table 2.
The values for parameters, the equations of the function of Weibull distribution and the durability characteristic of the Mupuseal 30412 – 0450 – 90 –S sealings

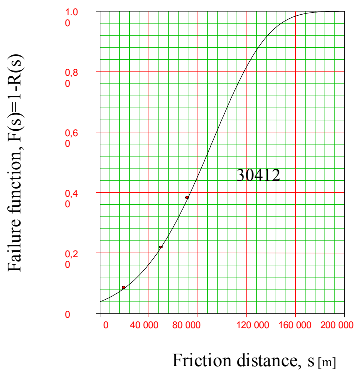
Mupuseal 30412-0450-90-S, with the level of confidence ±95%	
Failure function $F(s) = 1 - e^{-\left(\frac{s+151000}{6,4583}\right)^{249730}}$	
Survival function $R(s) = e^{-\left(\frac{s+151000}{6,4583}\right)^{249730}}$	
Probability density function $f(s) = \frac{6,4583}{249730} \cdot \left(\frac{s+151000}{249730}\right)^{5,4583} \cdot e^{-\left(\frac{s+151000}{249730}\right)^{6,4583}}$	
$\hat{T}$ - characteristic durability (usability) $\hat{T}_{30412}$ = 98 730 m	$\hat{T}_{down}$ = 55 582 m $\hat{T}_{up}$ = 150 870 m

The values for characteristic durabilities given in the tables 2-3, i.e. up to the mileage with which 63.2% of sealing population undergone failure show 80% higher durability of the sealings series 30413 as compared with the durability of sealings series 30412. The graphs of individual functions of Weibull distribution functions have been presented below, according to the equations of the Tables 2-3, intentionally plotted parallel for both sealing types. It enables quick readings and comparison of probabilities of reliable sealings work. For example: on the basis of failure charts (Fig. 2) it can be assumed that 4% of sealings series 30412 may already undergo damage at the starting point of utilization while up to 60 000 m no sealing series 30413 undergoes damage.

Table 3.
Values of parameters for the equation of function of Weibull distribution and characteristic durability for Mupuseal 30413 – 0450 – 90 –S sealings

Mupuseals 30413-0450-90-S, with the level of confidence ±95%	
Failure function $F(s) = 1 - e^{-\left(\frac{s-70608}{0,8159}\right)^{108630}}$	
Survival function $R(s) = e^{-\left(\frac{s-70608}{0,8159}\right)^{108630}}$	
Probability density function $f(s) = \frac{0,8159}{108630} \cdot \left(\frac{t-70608}{108630}\right)^{0,1841} \cdot e^{-\left(\frac{t-70608}{108630}\right)^{0,8159}}$	
$\hat{T}$ - characteristic durability (usability) $\hat{T}_{30413} = 179\ 238$ m	$\hat{T}_{down} = 81\ 566$ m
	$\hat{T}_{up} = 1\ 146\ 500$ m

a)



b)

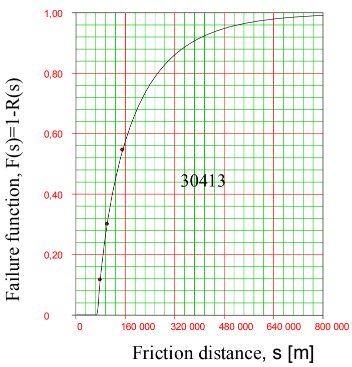
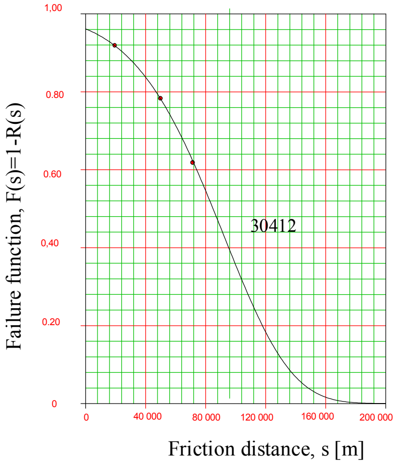


Fig. 2. Failure function *F(s)* chart as a function of friction distance for sealings Mupuseal 30412 – 0450 – 90 – S (a) and 30413 – 0450 – 90 – S (b)

a)



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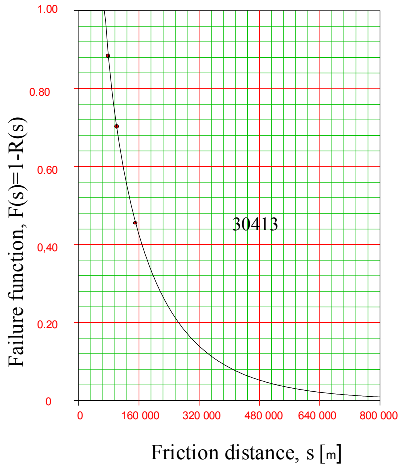
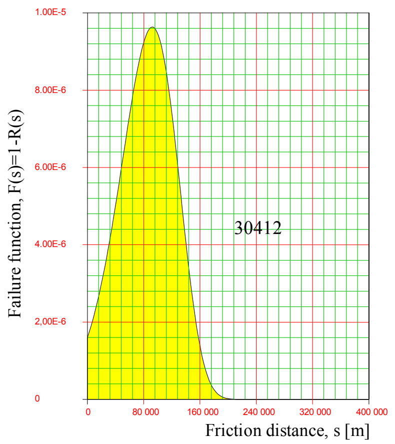


Fig. 3. The chart for probability density function *f(s)* as a function of friction distance for sealings type Mupuseal 30412 – 0450 – 90 – S (a) and 30413 – 0450 – 90 – S (b)

According to the results shown in the Fig. 3 the value of the failure function for friction distance up to 240000 m changes to a large extent. The probability of the failure being 58% of sealings population is reached only at the 160 000 m. However, for the sealings series 30412 the probability of failure after 160 000 m reaches 98% of parts! Because the survival function is a completion for the failure function to 1, it can be assumed that the reliability of the sealings series 30413 at the mileage of 60 000 equals 100% (Fig 3) i.e. no sealing of this type will be damaged. After such a mileage only 70% of sealings series 30412 will be usable. Function of probability density (Fig. 4) enables to define the most critical moments for sealing work. The highest probability of failure for sealings series 30412 appears at the moment of mileage of ca. 95 000 m and it reaches the value of 0.00001. For the sealings series 30413 the highest probability of failure is eight times higher already at the moment of mileage of 70 000 m.

However, it should be pointed that up to that mileage the probability of the failure equals 0, while for sealings series 30412 at the moment of start-up each element is already endangered to the failure with the probability of 0.000016 and the probability of failure increases five times along with the mileage.

a)



b)

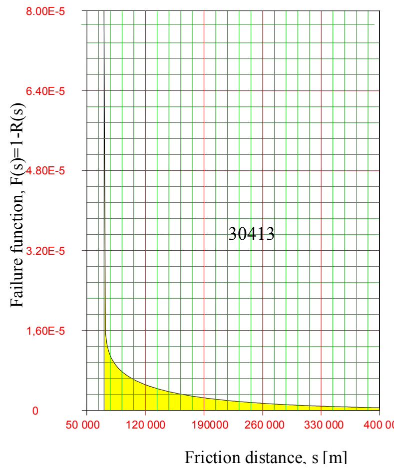


Fig. 4. The chart for probability density function *f(s)* as a function of friction distance for sealings type Mupuseal 30412 – 0450 – 90 – S (a) and 30413 – 0450 – 90 – S (b)

3. Conclusions

The method applied during the investigations enables using "discontinued" (stopped) measurements as well in predicting durability which enables shortening the time of the investigations. Determination of failure function *F(s)* facilitates planning of necessary repair works or the replacement of a sealing element.The chart for probability density function *f(s)* presents "critical" mileages for sealing elements – it shows the necessity of inspections after certain mileages. Weibull method, thanks to its multifunctionality, helps to select elements for certain applications (required long failure-free mileages → high characteristic durability – sealings series 30413). Equipment which works sporadically → low characteristic durability but e.g. lower weight and sizes of sealing element – sealing series 30412.

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