TESTS OF PTFE COMPOSITE MATERIALS FOR SLIDING RINGS

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The paper presents the conditions and the results of the research on the composite materials based on PTFE (polytetrafluorethylene) for sliding rings of the seal. The original tribological stand was applied in the experimental investigations. The test specimens in the form of rings were made of thirteen different PTFE composite materials which contained graphite, bronze and molybdenum disulfide. Frictional characteristics of changes in operating parameters of the tested sliding rings, i.e. friction moment and friction surface temperature - over time, unit pressures and liquid pressure - over time are presented.

Keywords: *PTFE composites, sliding rings, face seal, boundary condition*
DOI: https://doi.org/10.32845/msnau.2019.3.1

INTRODUCTION

Constructional elements of friction couples, for example, face seals, slide bearings, require usage of proper materials and proper selection of parameters of work, which assure appropriate lubrication condition between sliding rings. In the case of contact face seals, these conditions must ensure tightness contact between the mating surfaces and low frictional resistance at a given speed and pressure of the process liquid. These operating conditions of the seal in the papers [1, 2, 3, 4] are called the limit state or boundary state condition. Based on the well-known Stribeck curve, the state of friction between rotary and stationary rings in a face seal operating at the boundary state condition can be classified as boundary lubrication or mixed lubrication. Many researchers have investigated the frictional behaviour of face seals during previous decades, for example [3 - 10]. In experimental works [3, 5, 6, 7], the main parameter determining the working conditions of the face seal is the dimensionless duty parameter G, which is known in the theory of slide bearings. A very interesting approach to determining the operating conditions of the seal is described in papers [8, 9], where acoustic emission measurements were used to assess these conditions.

In this paper, the authors used the experimental procedure to determine the operating conditions of sealing rings described in previous works [10, 11]. Experiments are carried out with appropriate measurement equipment, which emulates working conditions of the face seal. The tests described in this paper has been carried out on the original stand [11], which is able to measure moments of friction, unit pressures between the rings, temperature of non-rotating sliding ring at the sealing surface, working pressure of the process liquid, and smoothly adjusted rotational speed of the shaft. Therefore, the stand allows to carry out research in the scope of selection of appropriate materials designed for sliding mechanical seals.

CONDITIONS OF THE TESTS

Experimental research was carried out on the testing stand that models real conditions of work of face seals. The testing enables:

– easy exchange of sealing rings (samples);
– fluent regulation of rings load and rotational speeds;
– measurement of temperature in crevice (at friction surface) and in sealed chamber;
– measurement of force (moment) of friction.

Furthermore, the stand has visible (accessible) working zone, which is essential to curry out tests and determine minimum unit pressures. The device for investigations of mechanical seals - SUM-1 is introduced on Fig. 1.

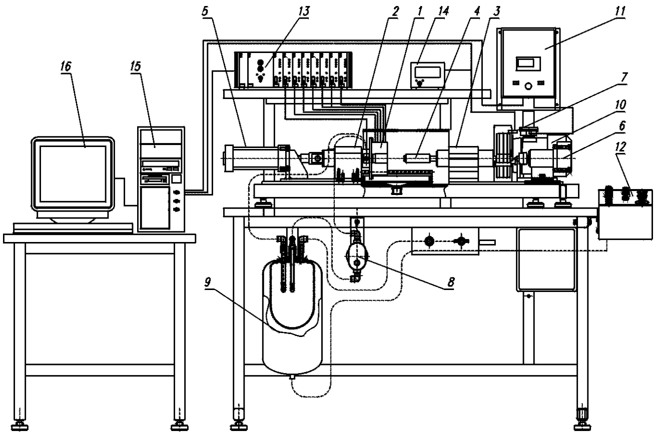

Fig. 1. The mechanical sealing device – SUM-1[11].
1 – measuring head, 2 – pressurizing head, 3 – driving spindle, 4 – shaft, 5 – hydraulic cylinder, 6 – buffer system , 7 – speed indicator, 8 – circulation pump, 9 – membrane wessel, 10 – electric motor, 11 – inverter, 12 – control desk, 13 – amplifier, 14 – tachometer, 15 – computer, 16 – monitor.

The device SUM-1 consists of the following main sub-assemblies and systems:

– testing head as sub-assembly that consist of pressurizing head and measuring head,
– spindle together with driving system,
– system of working liquid (system feeding seal in liquid),

– system loading the seal with axial force,

– block (system) of measuring,

– block (system) of regulation,

– pneumatic installation.

The part of testing device SUM-1 presented testing head is introduced on Fig. 2.

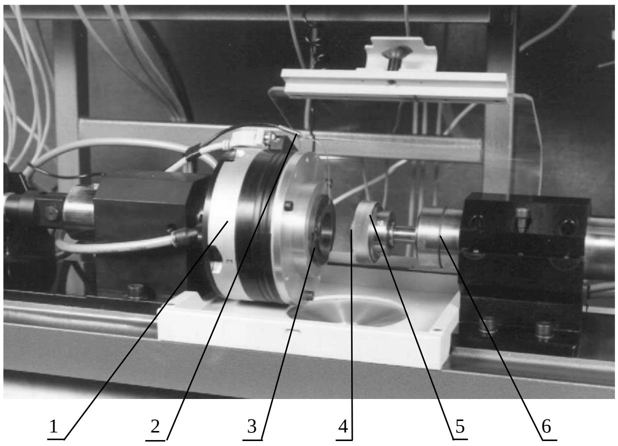

Fig.2. Side-head zone of testing device SUM-1:
1 – measure side-head, 2 – temperature-sensitive element,
3 – seat seal ring, 4 – rotational seal ring, 5 – casing rotational ring,
6 – spindle.

The testing head assures:

– clamping the sealing face model,

– presetting work parameters (unit pressures – *pj*, medium pressure –*pc*),

– measurement of work conditions: values of sliding rings load – *F*, moment of friction – *Mt*, temperatures at surface of friction of solid ring –*T*.

Scheme of the face sealing and the parameters operating condition were presented in the Fig. 3.

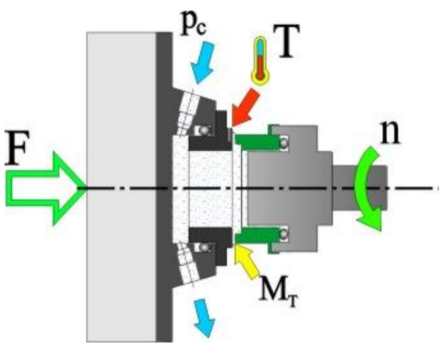

Fig. 3. Scheme of the measuring head and the model of the face seal.

Input parameters of work (input – factors) are preset through the pressurizing head. Pressurizing head can move along axis, so that one can install and uninstall sealing rings, and assure maintenance of given values of load during the work. In the vicinity of disk of the pressurizing head - meaning in the vicinity of non-rotational ring there is installed a sensor of medium pressure. The measuring head is attached to the disc of pressurizing head. The non-rotational ring of the tested face seal is installed in the seat of the measuring head. The head enables measurements of the output factors. Moment of friction and the rings load are measured by the means of extensometer sensors. The rings load is a preset value and it is a variable in formulas for calculation of unit pressures. Measurement of the temperatures in the vicinity of sealed surfaced is done with a thermocouple sensor introduced in the hole in non-rotational ring.

MATCHING THE RANGE OF ADMISSIBLE UNIT PRESSURES

One of the basic characterizations of a given set of materials for sealing rings is the dependence of the admissible unit pressures (or sealing rings load) on sealed medium pressure and rotational speed of shaft (or relative sliding speed) pj = f (p, v). Values of the admissible unit pressures correspond to so-called boundary state condition of the face seal [1, 4]:

- the minimum unit pressure pj_{min} corresponds to a zero leakage condition i.e. condition in which intensity of leaking is equal to rate of medium evaporation from the friction zone - so-called lower border-state;

- the maximum unit pressure pj_{max} corresponds to the condition of maximum (critical) temperature for given set of materials, which exceeding ends up with “catastrophic” waste of sealing rings (in general the ring made of smaller hardness material) – so-called. upper border-state.

Exploitation of the sealing with minimum unit pressures may cause a sudden “opening” of the crevice and loss of tightness, while maximum pressures may cause quick waste and shortening the period of work i.e. lowering the persistence sealing. The minimum unit pressure, corresponding to maximum tightness is a state of equilibrium of powers, which one can to call a state of “temporary” equilibrium. Even little external disturbances appearing during exploitation of the sealing may cause “knock:” the system out of that state and lead to leakage. Protection from this unprofitable (undesirable) state can be applying unit pressures that imperceptibly exceed the minimum values. Protection from the maximum (upper) values of the unit pressures is maintenance of work parameters at temperature smaller then the critical.

On the stand SUM-1 (Fig. 1) where carried out tests in boundary state condition of sliding rings of face sealing model made of the following materials: non-rotational ring (contra-specimen) – steel NC10 heat treated to hardness 60 HRC and rotational ring – PTFE composite materials. Water was used as the process liquid.

The tests were run on thirteen samples made of composite materials PTFE which contained bronze, graphite and molybdenum disulfide. The compositions of each composite is presented in table 1.

Table 1. Composition of the composite materials PTFE.

Sample number	Bronze %	Graphite %	MoS_2 %	PTFE %
PTFE1	4,5	2,7	0,8	92
PTFE2	36,5	2,7	0,8	60
PTFE3	4,5	18	0,8	76,7
PTFE4	36,5	18	0,8	44,7
PTFE5	4,5	2,7	3,7	89,1
PTFE6	36,5	2,7	3,7	57,1
PTFE7	4,5	18	3,7	73,8
PTFE8	36,5	18	3,7	41,8
PTFE9	21	10,5	2,2	66,3
PTFE10	40	10,5	2,2	47,3
PTFE11	21	1	2,2	75,8
PTFE12	21	10,5	0,5	68
PTFE13	21	10,5	4	64,5

The sliding rings applied in the experiment were 43 mm in outer diameter and 37 mm in inner diameter. The stationary sliding ring was mounted in a clamping head. The surface of the stationary ring was polished in several stages - the last polish was finished with 1200 grain sanding paper to obtain a smooth (mirror) surface. The surfaces of the rotational sliding rings were polished in several stages as well. Additionally, after the last polish finished with 1200 grain sanding paper, the rings were grinded on a special cast-iron shield.

After fastening the rings in the measuring head and spindle, one gradually enlarged the load, rotational speed and pressure of the working liquid up to the values assumed in the experiment. The value of the load was regulated so that there was no leakage (too little load) so that there was no temperature increment at surface of friction and moment of friction (too large load). This way of regulation allowed to hold the conditions of bottom border-state of work of the sealing rings. After a certain time - from several to tens of minutes (depending on kind of preset parameters) conditions of work were becoming stable. A computer program registered whole process.

The tests were curried out for the following values of preset parameters:

- for rotational speed n = 3000 r.p.m. pressure of working liquid (sealed) was equal to pc = 1,5 — 2 —2,5 —3 —3,5 —4 bar;

- for pressure of the working liquid pc = 3 bar the rotational speed was equal to n = 2000 —3000 —4000 —5000 —6000 r.p.m.

Measured output parameters are: temperature at surface of friction T, moment of friction Mt, and rings load Fg (program after processing the data converts load into unit pressures p_j).

Each of tests lasted about one hour.

Exemplary results were introduced on graphs 4, 5, in coordinates - measured output parameter – time. The temperature of work at surface of friction was stable during the process attaining values of –at the beginning of test about 26°C, and at the latter part of test about 33°C. The biggest values of temperature of work – up to 39°C were recorded for rotational speeds 5000 and 6000 r.p.m.. On the basic of data from the experiment in a stable state (it was assumed, that final 15 minutes of test sufficiently characterizes stable parameters of work) average values of measured quantities were calculated.

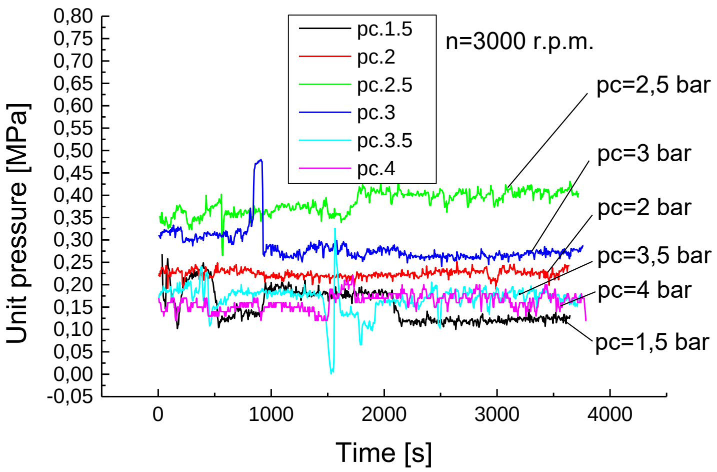

Fig. 4. Change of unit pressure at time for rotational speed n=3000 r.p.m. and different values of medium pressure (sealing rings: steel NC10 – composite PTFE3).

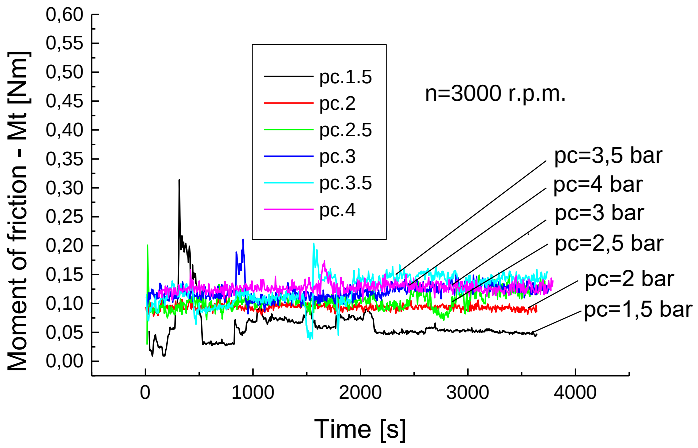

Fig. 5 Change of moment of friction at time for rotational speed n=3000 r.p.m. and different values of medium pressure (sealing rings: steel NC10 – composite PTFE3).

After observing the runs (Fig. 4, 5) it was found that stabilization of majority of running parameters follows after about half an hour i.e. more-less at half of assumed cycle. It was assumed that bottom border-state would be characterized by parameters obtained in steady-state conditions. For statistical analysis the experimental data was taken from the last 15 minutes of run.

FINDINGS OF THE RESEARCH ON COMPOSITE MATERIALS

This paper presents results of the tests of the sliding rings made of composites PTFE in the conditions of the lower border state. It was assumed:

- constant rotational speed of the shaft n = 3000 r/min
- constant liquid pressure pc = 1,5 bar.
- values measured involved the load – Fg, moment of friction Mt, and the temperature at the surface of friction of the stationary ring.

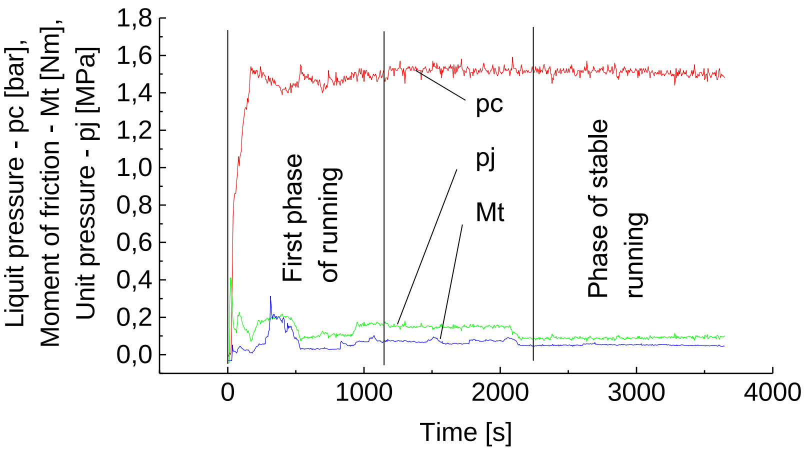

Fig. 6. Change of the operating parameters – pc, Mt, pj for sliding rings NC10-PTFE 3 (B4,5G18SMS0,8)

Figure 6 presents exemplary charts of changes of the moment of friction – Mt, unit pressures – pi, and pressure of the process liquid – pc, for sliding rings NC10 – PTFE 3 (composition according to the table 1.) It is possible to notice the initial phase of the process where there are fluctuations of the moment of friction and unit pressures. The fluctuations result from adjustment of the load – Fg, and the pressure of the process liquid, carried out to arrive at lower border state. After a certain time – usually a few or few dozens of minutes (in the figure about 2200 s) – the parameters of work stabilize. The parameters measured in this phase of the process are used in further analysis.

The similar tests were run on thirteen samples made of PTFE composite materials presented in table 1. From the charts obtained for each composite material, values of the operating parameters (in the state of stable running) were read, and presented in the table 2.

Table 2. Operating parameters - working load Fg, moment of friction M_t, operating temperature T - of the sliding rings for stabilization low border condition for different composite materials PTFE.

PTFE	Fg [N]	M_t [Nm]	T [^oC]
1	354	0,08	28
2	320	0,09	32
3	240	0,05	28
4	257	0,04	28
5	354	0,08	32
6	271	0,06	33
7	249	0,05	33
8	369	0,1	30
9	286	0,07	31
10	274	0,07	31
11	245	0,06	33
12	251	0,05	29
13	308	0,06	30

The chart of moments of friction in stable conditions for each composite was presented in the Fig. 7.

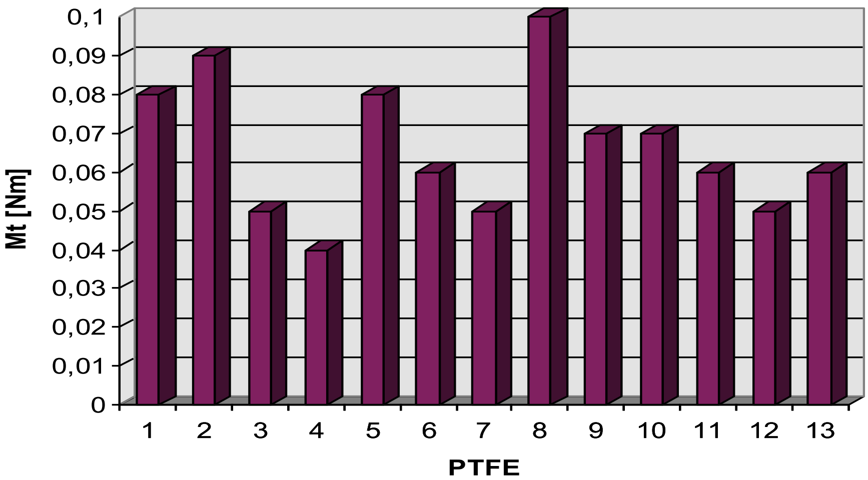

Fig. 7. Values of the moment of friction Mt of the sliding rings for stabilization low border condition for different composite materials PTFE.

Within the spec of the tests there are no great differences of the temperature, which varies in the range from 28 C to 33 C and is stable. The greatest loads no the sliding rings occurred with composites PTFE1, PTFE5 and PTFE8. The first two contain the smallest amount of components and obviously the greatest amount of clear PTFE i.e. 92% and 89,1%, and PTFE8 contain the greatest amount of components – thus the smallest amount of clear PTFE from the thirteen tested samples. This fact confirms the validity of the assumed border amounts of components. Greeted amounts of components may negatively influence the operating parameters – particularly the load. The best effects were obtained with the materials containing 18% of graphite excluding previously mentioned PTFE8. Generally presence of graphite positively influenced on operating parameters of the sliding rings, particularly PTFE3, PTFE4 and PTFE7. Graphite particles, which are the products of wear, create a frictional film, which stabilizes the work of the sealing.

CONCLUSION

Introduced in this paper way of testing sliding rings along with testing stand can be useful to estimate materials for sliding elements of mechanical seals, and qualification of their running parameters, especially in bottom border-state.

From the curried out tests it turns out, that changing such parameters as pressure of sealed liquid or rotational speed demands – in order to assure tightness – suitable change of rings load, and what follows, also change of unit pressures

Tests of models of the face seals carried out on the stand SUM-1 allowed to identify operational parameters of respective sliding couplings in the conditions of the lower border state. From the findings presented above, it results that non-active components significantly influence on operating parameters of the sliding rings – particularly the load. This piece of information allows for selection of the materials accordingly to assumed criteria – for example unit pressures or minimal moment of friction.

It was found that non-active components applied for modification of the PTFE improve its properties in respect of usefulness in application for sliding rings. However, the composition of the composite should be properly matched for the given operational parameters.

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Випробування композитних матеріалів з ПТФЕ для запірних кілець

У статті представлені умови та результати досліджень композиційних матеріалів на основі ПТФЕ (політетрафторетилен) для запірних кілець ущільнення. В експериментальних дослідженнях було застосовано оригінальний трибологічних стенд. Зразки для випробувань у формі кілець були виготовлені з тринадцяти різних композиційних матеріалів з ПТФЕ, які містили графіт, бронзу і дисульфід молібдену. Представлені фрикційні характеристики змін робочих параметрів випробовуваних запірних кілець, тобто моменту тертя і температури поверхні тертя - в часі, питомих тисків і тиску рідини - в часі.

Ключові слова*: композити ПТФЕ, запірні кільця, торцеве ущільнення, гранична умова.*

Дата надходження до редакції: 19.06.2019