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Determination of a face seal's operational parameters on test bench

Abstract

The paper presents a method for determination of static characteristics of a gas lubricated face seal on the basis of experiment performed on the test bench. It has been developed a mathematical model $Q_N=f(t_g, p_g, n)$ depicting effect of temperature of the gas t_g, pressure of the gas p_g and rotational speed of the shaft n on flow rate value of the gas Q_N. This dependency was used to determine pressure of the gas required for a selected operational parameters of the machine. To asses correctness of functioning of the seal it has been performed measurements of a selected 3D roughness parameters of the sealing rings. Slight changes in values of the 3D surface roughness of stationary and rotating rings before and after 25 working hours allow for conclusion about nearly contactless character of operation of the seal.

Keywords: face seals, testing of the seals.

1. Introduction

Mechanical face seals belong to devices serving to eliminate a leakage in area where the shaft passes through opening in casing of a machine (e.g. impeller pump). Principle of operation consists in throttling of leakage in a slot created by end faces of being in contact mating rings, from which one ring is mounted in the casing, while the second ring rotates together with the shaft [1]. The rings of the seal are characterized by very small flatness deviation of working end faces (of about 0.3÷0.6 μm) obtained through lapping operation, the most often using a single disc lapping machines [2].

The face seals are counted among critical components of many fluid-flow machines, because the seals determine operational life and reliability. For this reason, the manufacturers perform tests of the seals, simulating real operational conditions of the seal. Determination of allowable operational parameters of a given type of the seal belongs to key factors for correct application of the seal in a particular machine.

Special type face seals, implemented in case of very high rotational speeds, are so called gas lubricated mechanical seals. As lubricating film, which prevents friction, serves gas cushion formed during rotational movement of the seal, through hydrodynamic compression of the gas in shallow, spiral grooves machined on surface of one from the rings [3]. Seals of such type are characterized by predetermined flow rate of the gas through the gap created by the cushion of the gas. On value of the flow rate (except features of the design structure) the biggest effect have: rotational speed of the shaft, pressure and temperature of the gas. Experimental tests of prototype enable verification of conceptual design, capability to generation of the gas cushion and determination of static and stepwise characteristics [4]. The experimental tests also enable determination of mathematical relations between parameters having effect on operation of the device.

2. Methodology and techniques of the tests

The tests were aimed at determination of the characteristics and definition of optimal operational parameters of prototype gas lubricated seal of the 30GSL/A5-I.439 type (Fig. 1) manufactured by the ANGA Uszczelnienia Mechaniczne Sp. z o.o. Company having its premises in Kozy.

Throttling of leaking process gas in the seal of the 30GSL/A5-I.439 type takes place in the gap created by faces of the rings 1 and 3. On sealing surface of the ring 1 are machined spiral unidirectional grooves, where occurs hydrodynamic compression of the gas, resulting in formation of gas cushion and acting as lubricating film.

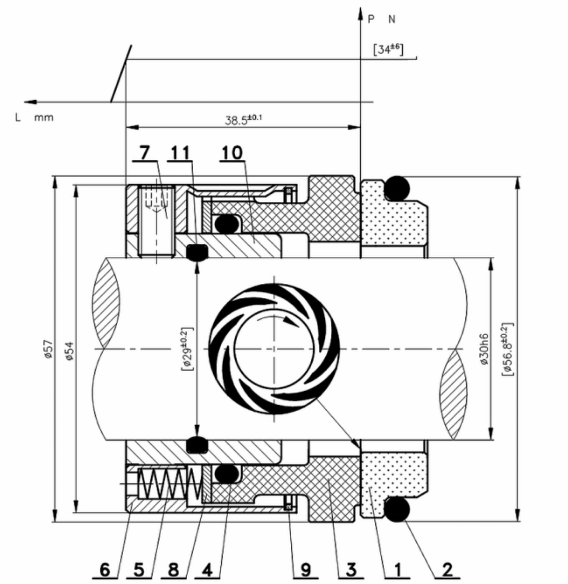

Fig. 1. The essential parts of the tested face seal [5]: 1 – stationary ring, 2 – static O-ring, 3 – rotating ring, 4 – dynamic O-ring, 5 – springs, 6 – seal housing, 7 – set screws, 8 – thrust plate, 9 – snap spring ring, 10 – protective sleeve, 11 – static O-ring

The input values x_i connected with operational parameters of the seal are:
- temperature of the process gas t_g, °C,
- pressure of the process gas p_g, MPa,
- rotational speed of the shaft n, rpm.

The output value z_w is:
- flow rate of the gas Q_N, normal l/min.

To the most important disturbances h_z belong: vibrations of the test bench during its operation, pressure fluctuation of the process gas, temperature fluctuations of the process gas, fluctuation of the rotational speed.

In turn, as a constant values c_s can be assumed: test bench, ambient temperature, ambient pressure, chemical composition of the process gas.

General scheme of the tested object is shown in the Fig. 2.

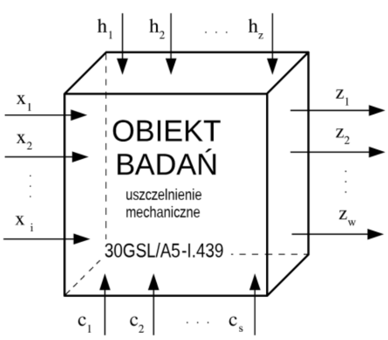

Fig. 1. The general scheme of a qualitative model of the tested object

The tests comprised determination of an effect of selected operational parameters, i.e. temperature of the process gas t_g, pressure of the process gas p_g and rotational speed n on value of the flow rate of the gas through the seal Q_N. Volumetric flow rate of the gas is expressed in normal liters per minute, describing volume of the gas in normal conditions, i.e. absolute pressure 1013.25 hPa and temperature 0°C, flowing through gap of the seal during 1 minute. Adopted unit of measure corresponds to mass flow rate of the gas, what eliminates uncertainty of the measurement, resulted from variability of parameters of condition of the gas.

Tests of the prototype seal were performed on a special purpose test bench (Fig. 3).

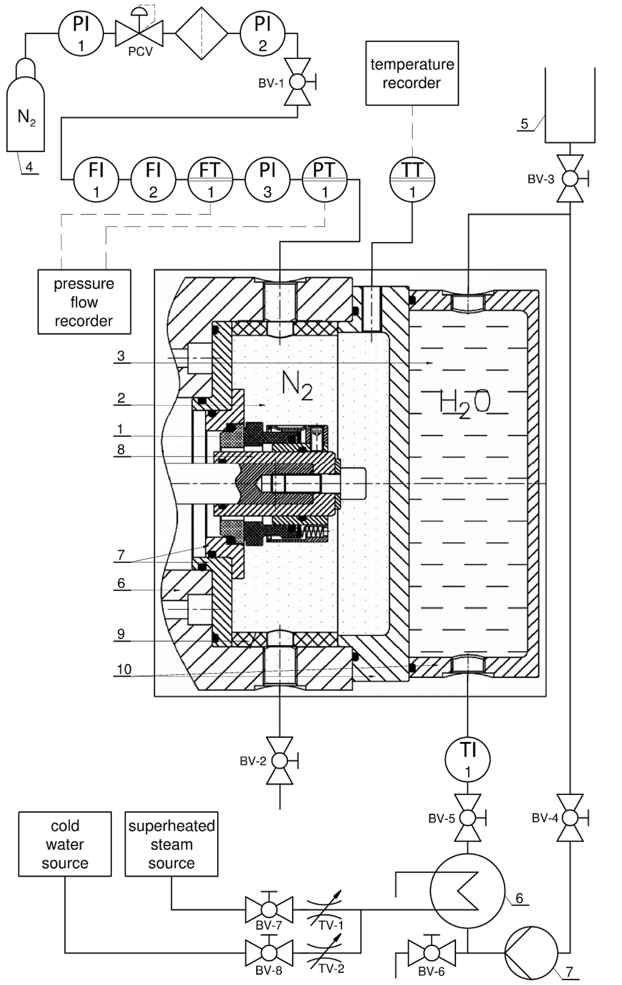

Fig. 3. Scheme of the housing and a pneumatic and hydraulic system for the 30GSL/A5-I.439 seal testing: 1 – tested seal; 2 – process gas chamber; 3 – heat exchange chamber; 4 – gas cylinder with nitrogen; 5 – surge tank; 6 – heat exchanger: tank with coil; (6) – test rig housing; 7 – reducing covers; 8 – mounting bushing; 9 – pressure bushing; 10 – covers; PI-1 – gas cylinder pressure indicator, measuring range 300 bar; PI-2 – reduced pressure indicator, measuring range 25 bar; PI-3 – process gas pressure indicator; FI-1 – rotameter, measuring range 0.1-0.5 l/min; FI-2 – rotameter, measuring range 0.5-1.0 l/min; TI-1 – water temperature indicator, measuring range 120°C; FT-1 – nitrogen flow rate mass flow meter, measuring range 0.001-4,300 Nl/min; PT-1 – pressure transducer, measuring range 0.00-1.60 MPa; TT-1 – temperature transducer, measuring range 40-260°C; PCV – pressure regulator, range 0-100 bar; BV-1 – nitrogen shut-off valve; BV-2 – nitrogen drain valve; BV-3 – shut-off valve of surge tank; BV-4, BV-5 – shut-off valves of heat exchange circuit; BV-6 – water drain valve; TV-1 – superheated steam throttle valve; TV-2 – cold water throttle valve

Construction of power transmission system was based on components of asynchronous motor having bearings lubricated with oil mist. The transmission system was equipped with infinitely variable rotational speed control within range of 0÷18 000 rpm, accomplished by frequency converter of the OMRON RX A4110 type with feedback readout.

The test bench was equipped with pneumatic system having incorporated instruments to monitor parameters of the working gas, which flows through the seal during the tests. To the most important from them belong: pressure transducer of the PT016R (Turck) type and transducer of mass flow rate of the EL-FLOW F-111B (Bronkhorst) type connected with the Metronic MPI-G recorder, and thermo-resistant sensor of the TOP-PKGKbm-21 type (ALF-SENSOR) with the A/D converter and the Simex SRD-99 recorder. Additionally, there were used standard rotameters and manometers to controlling changes of the measured quantities.

Changes of temperature of the gas in the measuring chamber of the seal were performed by swilling of its front wall with water of specified temperature. The water was heated/cooled in the heat exchanger, feeding its heating/cooling coil with hot steam or cold water.

3. Results of the tests and analysis

According to general scheme of the model of the tested object (Fig. 2), it has been assumed [8]:
$z = Q_N$, in normal l/min],
$x_1 = t_g$ – variability range: 22÷80°C,
$x_2 = p_g$ – variability range: 0.5÷1.2 MPa,
$x_3 = n$ – variability range: 3000÷12000 rpm,

It has been elaborated mathematic model of flow rate of the gas in form of second-order polynomial with dual interaction [7]:

$$z = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{11} x_1^2 + b_{22} x_2^2 + b_{33} x_3^2 + \\ + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 \quad (1)$$

where: b_0, b_1, b_2, b_3, b_{11}, b_{22}, b_{33}, b_{12}, b_{13}, b_{23} – regression coefficients.

In course of the tests it has been implemented the PS/DS-P: α[1.2154/3×5] plan (static-determined-orthogonal-selective-multifactorial plan), in which every quantity takes five values. In the calculations for i=3 was taken value of α=1.2154 [6]. Levels and values of the independent variables for accomplishment of the PS/DS-P: α[1.2154/3×5] plan are compiled in the Table 1.

Tab. 1. Levels and values of the independent variables for implementation of the plan PS / DS-P: α [1.2154/3×5]

Input values			Values for the codes (α = 1.2154)				
x_i		Δx_i	$-\alpha$	– 1	0	+ 1	+ α
$x_1 = t_g$	°C	24	22	27	50	75	80
$x_2 = p_g$	MPa	0.29	0.50	0.56	0.85	1.14	1.20
$x_3 = n$	rpm	3700	3000	3800	7500	11200	12000

Succession of individual tests, implemented parameters and values of the flow rate Q_N are specified in the Table 2.

Tab. 2. Levels and values of the independent variables for implementation of the plan PS / DS-P: α [1.2154/3×5]

No	Code values			Set values			Value measured in successive repetitions	Average value
	$\hat{x}_i$			x_i				
	$\hat{x}_1$	$\hat{x}_2$	$\hat{x}_3$	$x_1 = t_g$	$x_2 = p_g$	$x_3 = n$	$z = Q_N$	$\bar{z} = \overline{Q}_N$
1	– 1	– 1	– 1	27	0.56	3798	0.032; 0.031; 0.035; 0.032; 0.031;	0.032
2	+ 1	– 1	– 1	75	0.56	3798	0.006; 0.007; 0.008; 0.009; 0.007;	0.007
3	– 1	+ 1	– 1	27	1.14	3798	1.298; 1.301; 1.294; 1.289; 1.293;	1.295

Tab. 2. cont. The implementation scheme of the experiments and measurement results

No	Code values $\hat{x}_i$			Set values x_i			Value measured in successive repetitions	Average value
	$\hat{x}_1$	$\hat{x}_2$	$\hat{x}_3$	$x_1 = t_g$	$x_2 = p_g$	$x_3 = n$	$z = Q_N$	$\bar{z} = \overline{Q_N}$
4	+ 1	+ 1	− 1	75	1.14	3798	0.667; 0.671; 0.678; 0.675; 0.679;	0.674
5	− 1	− 1	+ 1	27	0.56	11202	0.683; 0.702; 0.691; 0.697; 0.694;	0.693
6	+ 1	− 1	+ 1	75	0.56	11202	0.542; 0.540; 0.547; 0.549; 0.551;	0.546
7	− 1	+ 1	+ 1	27	1.14	11202	2.898; 2.903; 2.917; 2.922; 2.911;	2.910
8	+ 1	+ 1	+ 1	75	1.14	11202	2.147; 2.151; 2.156; 2.149; 2.157;	2.152
9	0	0	0	51	0.85	7500	0.920; 0.917; 0.922; 0.915; 0.924;	0.920
10	− α	0	0	22	0.85	7500	0.832; 0.837; 0.845; 0.841; 0.835;	0.838
11	+ α	0	0	80	0.85	7500	0.686; 0.695; 0.679; 0.682; 0.685;	0.685
12	0	− α	0	51	0.50	7500	0.224; 0.229; 0.224; 0.231; 0.218;	0.225
13	0	+ α	0	51	1.20	7500	1.911; 1.914; 1.907; 1.921; 1.908;	1.912
14	0	0	− α	51	0.85	3000	0.203; 0.194; 0.197; 0.201; 0.196;	0.198
15	0	0	+ α	51	0.85	12000	1.498; 1.501; 1.498; 1.497; 1.504;	1.500

For each from 15 systems of the plan it has been performed 5 repetitions of the flow rate Q_N measurement (thought switching-off and repeated start-up of the drive). Readout of the flow rate values was carried out after 20 minutes from time of obtainment of the set point speed. Assumed time was selected during initial tests and was sufficient to assure steady operational parameters of the seal.

All obtained measurement results were tested with the Grubbs test to eliminate coarse errors. Critical value of the Grubbs test was assumed as T_{kr}=1.869 for the significance level of 0.05 and five repetitions.

Coefficients of the regression function of the tested object were determined with use of the STATISTICA computer program [7]. In result, it was obtained complete model of the tested object in form of:

$$Q_N = -0{,}0243238899 + 0{,}0185383002 t_g - 1{,}891486669 p_g - 0{,}0000638132 n + 0{,}0000391754 t_g^2 + 2{,}2377695769 p_g^2 + 0{,}0000000027 n^2 - 0{,}0216738506 t_g p_g - 0{,}0000003658 t_g n + 0{,}0002204733 p_g n \quad , (2)$$

Values of the regression coefficients were calculated with accuracy to 10 decimal places due to big differences in numerical values (even up to 6 orders of magnitude).

Statistical analysis of the regression equation (2) was performed using the STATISTICA computer software (Tab. 3).

Tab. 3. Statistical analysis of multiple regression of the complete model

N=75	Summary of linear regression of the dependent variable Q_N in normal l/min, R=0.99728520; corrected R^2=0.99382699 $F_{0,05;9;65}$=1324.7; p=1.2·10^{-71}; Std error of estimation: 0.06405			
	b	standard error	t(65)	level p
free term	−0.0243238899	0.165130	−0.1473	0.883350
t_g	**0.0185383002**	**0.002891**	**6.4124**	**0.000000**
p_g	**−1.8914866694**	**0.298894**	**−6.3283**	**0.000000**
n	**−0.0000638132**	**0.000018**	**−3.5194**	**0.000795**
t_g^2	−0.0000391754	0.000024	−1.6359	0.106699
p_g^2	**2.2377695769**	**0.164211**	**13.6274**	**0.000000**
n^2	**0.0000000027**	**0.000000**	**2.6600**	**0.009831**
$t_g p_g$	**−0.0216738506**	**0.001455**	**−14.8945**	**0.000000**
$t_g n$	**−0.0000003658**	**0.000000**	**-3.2090**	**0.002070**
$p_g n$	**0.0002204773**	**0.000009**	**23.3710**	**0.000000**

Note: **with boldface** are marked values of significant coefficients of the regression

Significance of complete equation was verified with use of the Snedecor F-test, computing values of the $p=P(F \geq F_{obl})$. If $p<\alpha$=0.05 than the equation is significant at significance level of alfa. However, significance of individual terms of the regression equation was calculated with use of the Student's t-test, computing value of the $p=P(|t| \geq t_{obl})$. If $p<\alpha$=0.05 then term of the regression equation is significant at significance level of α. Negative results were obtained for 2 components: free term (which doesn't undergo elimination) and the term t_g^2. After elimination of the t_g^2, values of the regression coefficients of remaining terms have been corrected.

The result is incomplete model of the tested object in form of:

$$Q_N = 0{,}0584578101 + 0{,}0145424069 t_g - 1{,}8856649749 p_g - 0{,}0000636765 n + 2{,}2343450507 p_g^2 + 0{,}0000000027 n^2 - 0{,}0216738506 t_g p_g - 0{,}0000003658 t_g n + 0{,}0002204733 p_g n \quad , (3)$$

Analysis of the regression equation (3) was performed with use of the STATISTICA computer program (Tab. 4).

Tab. 4. Statistical analysis of multiple regression of the incomplete model

N=75	Summary of linear regression of the dependent variable Q_N in normal l/min, R=0.99717327; corrected R^2=0.99367023 $F_{0,05;8;66}$=1453.1; p=1.0·10^{-72}; Std error of estimation: 0.06486			
	b	standard error	t(66)	level p
free term	0.0584578101	0.159168	0.3673	0.714592
t_g	**0.0145424069**	**0.001566**	**9.2870**	**0.000000**
p_g	**-1.8856649749**	**0.302644**	**-6.2306**	**0.000000**
n	**-0.0000636765**	**0.000018**	**-3.4681**	**0.000927**
p_g^2	**2.2343450507**	**0.166270**	**13.4381**	**0.000000**
n^2	**0.0000000027**	**0.000000**	**2.6179**	**0.010961**
$t_g p_g$	**-0.0216738506**	**0.001474**	**-14.7089**	**0.000000**
$t_g n$	**-0.0000003658**	**0.000000**	**-3.1690**	**0.002319**
$p_g n$	**0.0002204773**	**0.000010**	**23.0798**	**0.000000**

Note: **with boldface** are marked values of significant coefficients of the regression

Developed form of the incomplete model of the tested object is significant, and all terms of the equation (except the free term which doesn't undergo elimination) are significant.

Correct operation of the tested seal is connected with maintenance of the gas flow rate Q_N within a certain interval. Lower limiting value of this interval denotes minimal value of the flow rate occurring when contactless operation of the seal is maintained. On the basis of preliminary tests of the 30GSL/A5-I.439 type seal, minimal value of the flow rate Q_N was estimated as about 0.2 normal l/min. In turn, upper limiting value of the interval (called as allowable leak of the gas) results from necessity of limitation of excessive consumption of the gas, depending on individual application. In case of the tested seal, value of allowable leak was assumed at the level 1.6 normal l/min.

Effect of temperature t_g, pressure p_g of the gas, and rotational speed of the shaft n on flow of the gas Q_N through prototype seal of the 30GSL/A5-I.439 type is presented in form of diagrams in Figs. 4÷6. Due to the fact that the model comprises independent variables, the spatial diagrams depict dependency of the gas flow Q_N in function of two parameters (temperature t_g, and pressure p_g of the gas), at constant value of the third parameter (rotational speed n). The diagrams were developed with consideration of limitation of the parameters which comply with condition of maintaining flow rate value within allowable interval of 0.2÷1.6 normal l/min.

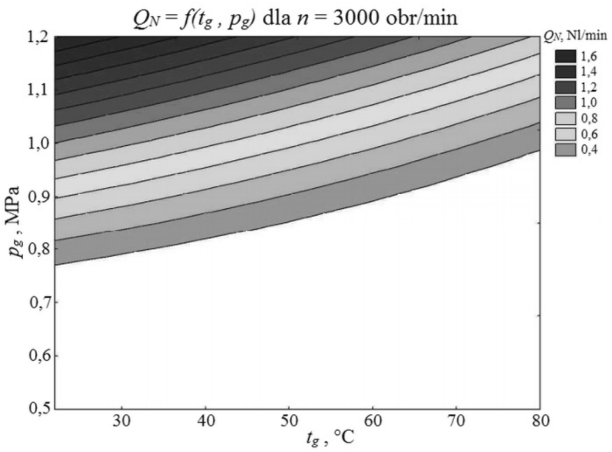

Fig. 4. The effect of temperature t_g and pressure p_g on value of gas flow rate Q_N through the tested seal in the permissible range 0.2÷1.6 normal l/min (seal rotational speed n=3000 rpm)

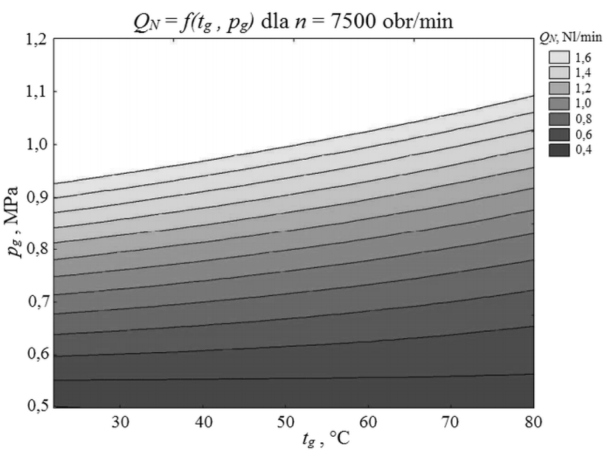

Fig. 5. The effect of temperature t_g and pressure p_g on value of gas flow rate Q_N through the tested seal in the permissible range 0.2÷1.6 normal l/min (seal rotational speed n=7500 rpm)

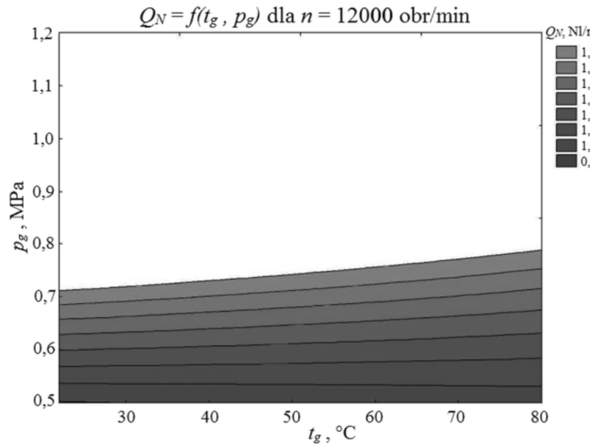

Fig. 6. The effect of temperature t_g and pressure p_g on value of gas flow rate Q_N through the tested seal in the permissible range 0.2÷1.6 normal l/min (seal rotational speed n=12000 rpm)

On the basis of the developed mathematical model it is possible to determine if the seal can operate correctly with a given values of the parameters t_g, p_g, n, by substitution of these values to the equation 3. Simultaneously, knowing rotational speed of the device and the temperature, it is possible to select pressure of the gas which would assure correct operation of the seal. For example, wanting to install the seal in a machine operated with rotational speed 3000 rpm at temperature not exceeding 50°C, the pressure not lower than 0.85 MPa should be assured.

4. Assessment of wear on end faces of the rings of the seal

Except allowable range of the gas flow rate values Q_N it is also important to maintain contactless character of the gaso-dynamic seal operation during its rotational motion. Presence of contact of the faces results in friction forces between the stationary ring and the rotating ring of the seal, what can cause wear of the rings.

Wear of the end faces of the tested gas lubricated seal was assessed by comparison of selected 3D surface roughness parameters of the rings before and after dynamic operation. The following parameters of the 3D roughness have been selected: amplitude parameters of the surface – arithmetic mean height of the surface *Sa*, root mean square height of the surface *Sq*, maximum peak height of the surface *Sp*, maximum pit height of the surface *Sv*, maximum height *St*, and parameters of the areal material ratio curve – core height *Sk*, reduced peak height *Spk*, reduced dale height [9, 10].

The measurements were carried out using the Form Talysurf 120 contour measurement system produced by the Taylor Hobson Company. Conical gauging point of the K501/1685 type with fillet radius 2 µm and angle 60° was used. Measurements of the surface roughness and topography were performed in four uniformly spaced locations on sealing surfaces of the both rings. Measurements of the topography have been performed on the surfaces with dimension 2 mm × 2 mm, performing 401 linear runs distant from each other with 5 µm. In course of the measurements the following parameters have been used: sampling length l_r=0.25 mm, evaluation length l_t=2.8 mm, number of sampling lengths i=5. It has been adopted sampling step Δ_x=0.35 µm, number of recorded points N_x=8000, feed rate of the gauging point v_{os}=0.5 mm/s, and Gauss filter.

In the Table 5 are written the following parameters of the 3D surface roughness 3D: *Sa*, *Sq*, *Sp*, *Sv*, *St*, *Sk*, *Spk*, before and after 25 operational hours of the seal. During this time there were performed in total 75 cycles of start and stop of drive system of the bench.

Tab. 5. The results of measurements of selected parameters of 3D surface roughness of the sealing rings (before and after 25 h of operation)

Stationary ring				
Parameter, μm	before operation		after 25 h of operation	
	measured values	average	measured values	average
Sa	0.0343; 0.0361; 0.0339; 0.0361;	0.0351	0.0385; 0.0401; 0.0429; 0.0420;	0.0409
Sq	0.0559; 0.0589; 0.0578; 0.0568;	0.0574	0.0605; 0.0623; 0.0617; 0.0600;	0.0611
Sp	0.2831; 0.2294; 0.2975; 0.2631;	0.2683	0.2239; 0.2745; 0.2508; 0.2473;	0.2491
Sv	0.6219; 0.6685; 0.6501; 0.6759;	0.6541	0.7592; 0.6985; 0.7218; 0.7563;	0.7340
St	0.9738; 0.9314; 0.3195; 0.9625;	0.9468	0.9846; 0.9546; 0.9771; 0.9602;	0.9691
Sk	0.0495; 0.0464; 0.0460; 0.0500;	0.0480	0.0467; 0.0481; 0.0473; 0.0470;	0.0473
Spk	0.0368; 0.0372; 0.0394; 0.0368;	0.0376	0.0360; 0.0372; 0.0370; 0.0362;	0.0366
Svk	0.0750; 0.0749; 0.0764; 0.0750;	0.0753	0.0750; 0.0753; 0.0762; 0.0725;	0.0748
Rotating ring				
Parameter, μm	before operation		after 25 h of operation	
	measured values	average	measured values	average
Sa	0.0559; 0.0548; 0.0578; 0.0551;	0.0559	0.0604; 0.0599; 0.0572; 0.0589;	0.0591
Sq	0.1036; 0.0988; 0.0973; 0.0996;	0.0998	0.0948; 0.0913; 0.0923; 0.0910;	0.0923
Sp	1.1936; 1.2463; 1.3197; 1.2280;	1.2469	1.2713; 1.2006; 1.2471; 1.2293;	1.2371
Sv	5.3457; 4.6733; 5.0482; 5.1188;	5.0465	2.5672; 2.9693; 2.1292; 2.8386;	2.6261
St	7.2428; 6.9853; 7.0061; 7.1105;	7.0862	3.6596; 4.1658; 3.9625; 3.8853;	3.9183
Sk	0.0759; 0.0774; 0.0800; 0.0782;	0.0779	0.0793; 0.0812; 0.0780; 0.0782;	0.0792
Spk	0.0564; 0.0562; 0.0580; 0.0560;	0.0567	0.0570; 0.0572; 0.0565; 0.0562;	0.0567
Svk	0.1140; 0.1104; 0.1198; 0.1119;	0.1140	0.1124; 0.1196; 0.1154; 0.1103;	0.1144

Obtained results in case of the stationary ring are pointing at a slight increase of such 3D surface roughness parameter values like: *Sa*, *Sq*, *Sv* and *St*. However, values of such roughness parameters like: *Sp*, *Sk*, *Spk* and *Srk* undergo a slight decrease in result of operation of the seal.

In case of the rotating ring, in result of operation of the seal, it is seen a distinct decrease of the following parameters *Sv* and *St*, while the following parameters undergo a slight decrease only: *Sq* and *Sp*; the parameters of the areal material ratio curve: *Sk*, *Spk* and *Srk* remain practically at the same level.

Differences in changes of the 3D surface roughness parameter values, for the stationary and rotating rings, in result of operation of the seal, should probably be explained by different types of materials of the both rings.

This can be confirmed by images of surface topography shown in the Figs. 7÷10.

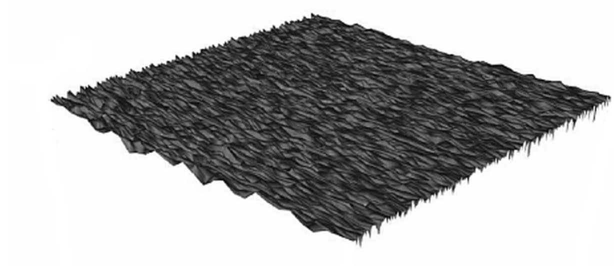

Fig. 7. Topography of the rotating ring sealing surface (prior the dynamic operation)

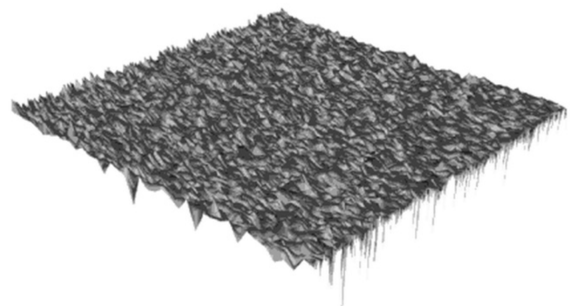

Fig. 8. Topography of the rotating ring sealing surface (after 25 h of the dynamic operation)

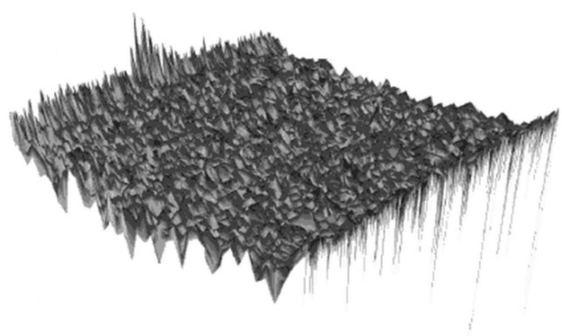

Fig. 9. Topography of the stationary ring sealing surface (prior the dynamic operation)

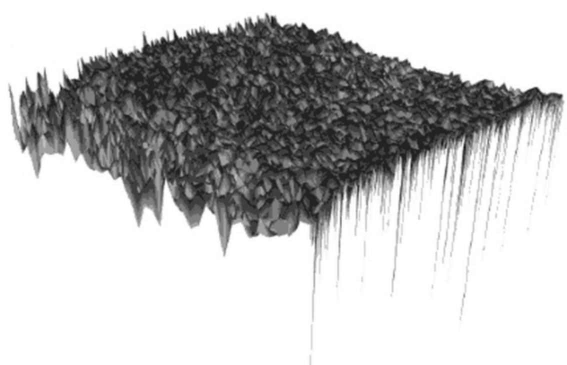

Fig. 10. Topography of the stationary ring sealing surface (after 25 h of the dynamic operation)

5. Summary

Experimental tests of the prototype gas lubricated face seal have allowed elaboration of mathematical model, which describes selected static characteristics. The model enables determination of recommended and allowable operational parameters of the tested gas lubricated face seal for a specific industrial application.

In addition to allowable flow rate of the gas QN flowing through the seal, it was also necessary to maintain contactless character of the operation during rotational motion. Changes in values of most 3D surface roughness parameters of the sealing rings resulted from operation of the seals are pointing at a slight (infinitesimal) wear. In connection with aggregate time of the tests and changing values of the input parameters (rotational speed n of the shaft, temperature t_g and pressure p_g of the gas) it can be concluded that in the whole analyzed range of variability of these parameters, during rotational movement of the seal, it was formed the gas cushion to prevent friction. A slight wear mentioned above is probably connected with presence of a contact during start and stop of the seal only.

Adopted methodology of the research can be implemented to determination of static characteristics, also in case of other type gas-lubricated seals, inclusive of a duplex seals in face-to-face and tandem systems.

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