EXPERIMENTAL RESEARCHES OF THE PULSE GAS BARRIER FACE SEAL

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DOI: 10.17973/MMSJ.2019_12_2019033

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The article presents a promising non-contact face seal of the rotor of a dynamic machine. The principle of pulse balancing of the movable sealing ring is applied in the seal design. The design of the test equipment and seal samples, which were used to conduct comprehensive investigations of the seal in the operating range of speeds and pressures, are considered. The analysis of the experimentally obtained data of the barrier gas flow rate parameters and pressure changes in the working gap of the seal is carried out. A comparison of the traditional physical model of the working process of leaking pulse seals with the results of the research is performed. Identified and analyzed the fundamental differences of working processes of the traditional leaking and considered non-leaking pulse seals. A model of the physical process is developed and recommendations for the creation of a mathematical model of the gas barrier pulse seal are formulated.

KEYWORDS

impulse seal, barrier gas, sealing rings, pressure distribution, flow rate characteristics

1 INTRODUCTION

Pumping and compressor equipment is widely used in almost all industries for pumping various chemical properties of mediums and products, which are often characterized by high corrosion activity and toxicity. In practice, to cut off the leakage of the pumped medium along the shaft of the centrifugal machine, double seals with a barrier liquid are widely used, and this liquid enters in the chamber of the centrifugal machine and partially spoils the main product.

As a result of the search for the seal design, in which there is no ingress of process fluids into the pumped product, a design of the mechanical impulse face seal was created, in which the product leaks are locked with a neutral gas film of high pressure in the operation gap (Fig. 1) [Kuznetsov 2002, Kuznetsov 2005].

The use of the proposed seal design will improve the economic and environmental efficiency of individual units and production processes [Martsynkovskyy 2011, Pustan 2013].

For the introduction of this seal into production and reliable use in the responsible units, it is necessary to conduct its comprehensive experimental and theoretical researches. Theoretical research consists in the development of a mathematical model of the process in seal, as well as analysis and comparison of the calculated characteristics with the characteristics obtained in the course of experimental researches [Zahorulko 2015, Zahorulko 2016, Tarel'nik 2017].

To develop a mathematical model of the seal, it is necessary to have an accurate understanding of the processes occurring in its operation gap. As a basis for the development of a physical model of the working process of a impulse gas barrier seal in the first approximation, a physical model of the long-known design of a leaky impulse seal with deliberately created leakage of sealing liquids through the operation gap to maintain a contactless mode of operation is adopted.

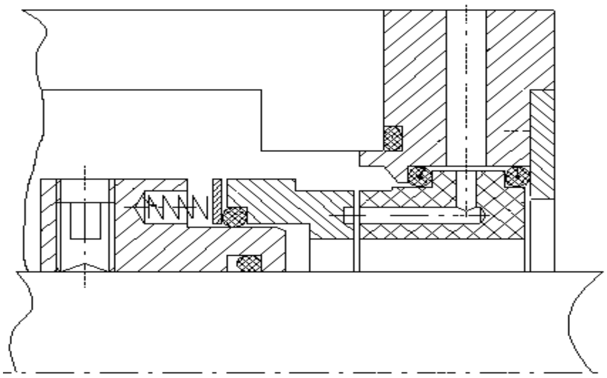

Figure 1. Impulse face seal

2 PHYSICAL MODEL OF THE WORKING PROCESS IN THE SEAL

The seal functions as follows – in the absence of rotation of the shaft, the pressure of the gate gas is not enough to open the end joint between the sealing rings. Due to the very low viscosity the gas evenly fills the operation gap and prevents the flow sealing medium through the gap. When the shaft rotates, the closed chambers on the working surface of the rotating sealing ring are briefly aligned with the outlet of the special feed channels on the surface of the stationary sealing ring and the barrier gas from the channels enters the chambers. Due to the compressibility of the gas, the pressure in the chamber increases to the pressure of the barrier gas supply, and after the chamber leaves the feed outlet, the pressure in it gradually decreases due to the expiration of the gas into the gap. The rate of pressure drop in the chamber depends on the size of the gap formed between the sealing rings during the rotation of the shaft. Thus, the value of the minimum gas pressure in the chamber depends on the speed of rotation of the rotor and the radial length of the gap in the direction from the chamber to sealing region of the machine and in the direction direction from the chamber to the area behind the seal. In a certain way chosen configuration of the surfaces of the sealing rings, the value of the hydraulic load and the combination of the values of the sealing and barrier pressures the minimum gas pressure in the chambers remains higher than the pressure of pumped sealing medium. Taking into account that the distance between the chambers in the circumferential direction is small, the pressure on the annular section of the gap between the chambers can be considered equal to the average pressure in the chambers. Therefore, inside the gap on the radius of the arrangement of the cells and the outlets of the feed channels creates a continuous zone in which the gas pressure exceeds the pressure of the pumping medium in front of the seal. Thus, the barrier gas in the seal performs two functions – creates a continuous layer of lubricant and provides locking of the pumped medium, preventing its flow behind the seal [Kuznetsov 2005, Balara 2018, Janekova 2014, Lesso 2010, 2014, Prislupcak 2014, 2016, Rimar 2016, Sebo 2012, Straka 2013, Vojtko 2014, Zaborowski 2007, Panda 2016].

The developed physical model needs to be verified by experimental research of the functioning of the experimental design of the seal.

3 EXPERIMENTAL EQUIPMENT

For a detailed investigation of the processes occurring in the operation gap of the working seal, the bench equipment was designed and assembled, which allows to measure the pressure in a separate chamber and in the space between the chambers in the gap, and also to measure the flow rate of barrier gas through the gap of the seal. A computer was used to display, process and record signals from pressure sensors [Kuznetsov 2005].

The block diagram of the experimental stand is shown in Fig. 2. The test bench consists of a test chamber, a gas treatment system and a drive. The asynchronous motor, whose rotation speed is set by a thyristor frequency converter, rotates the test seal, which is placed in the test chamber of the stand 3. The required sealing conditions are provided by the gas treatment system. The source of the pressure of the sealing and barrier mediums during the operation of the seal is the pressure accumulator 19, consisting of several gas cylinders with a total volume of 150 l, which are filled by the barier medium (atmospheric air is used as the barrier medium) by the compressor. The settled gas through the valve 17 goes to two gas reducers (pressure regulators) 13 and 15. The gas pressure in front of the reducers is controlled by a pressure gauge 16. Reducers 13 and 15 set the pressure, simulating the barier and sealing pressures of the centrifugal machine, respectively. After the reducer 13, the gas with the required pressure, which is controlled by the pressure gauge 11, through the valve 10, the cylinder 9, the fine filter 6, and the rotameter 4 enters the tested seal. From the reducer 15, gas with pressure controlled by the pressure gauge 8 enters the cylinder 5 through the valve 7. If experiments are to be carried out using a liquid sealing medium, the container shall be pre-filled with the appropriate liquid. The sealing medium with pressure from the cylinder enters the body of the test chamber. Both barrier and sealing mediums supply lines contain valves 12 and 14, which are used to relieve pressure in chamber 3 after the end of the test. The flow rate of the input buffer medium is measured by a rotameter 4. The total flow rate of leaks of the sealing and buffer media in the case of the same physical properties is measured by rotameter 1. The pressure in the test chamber 3 is determined by a pressure gauge 20 [Kuznetsov 2002].

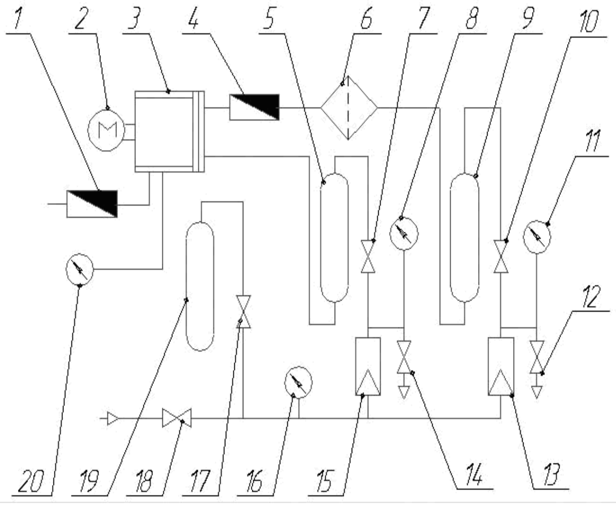

Figure 2. Block diagram of experimental bench equipment

During the experimental researches we used two impulse gas barrier face seal design. The first design is a copy of the seal, which is now installed as an experiment on the actual operating unit of the chemical plant. The second design has a special design that allows to measure the pressure in the sealing ring's chamber and in the space of the gap between the two adjacent chambers.

The longitudinal section of the test chamber assembled with the experimental unit of the first design is shown in Fig. 3. Stationary in the circumferential and axial directions the ring 16 with outlets of feed channels 4 is placed in the lid 1. Sealing of the barrier gas supply to the channels is carried out by the o-rings 2 and a compression ring 3. Fastening of the rotating part of the seal to the shaft 9 is carried out by a hollow bushing 11, which is fixed from the displacement by the key 10 and the nut 12. The support bushing 14, containing the holes for the springs 13 and the pins 7, transmits the torque to the sealing ring 6, which containing the chambers 5. In order to evenly load the ring with springs and fix the secondary seal, an auxiliary ring 15 is inserted between the ring 6 and the springs 13. The sealing pressure is applied to the body 8 of the test chamber. The barrier gas is supplied to the ring 16 through a special channel made in the cover 1.

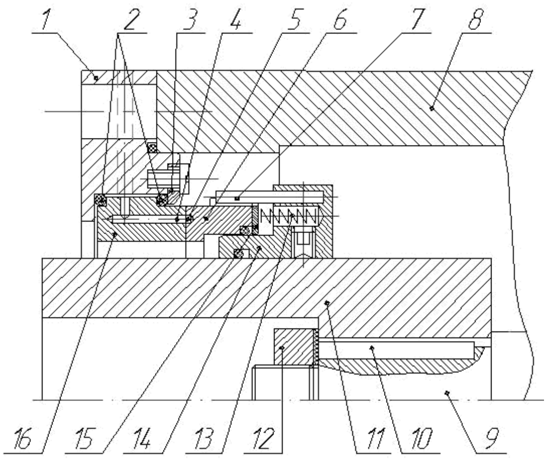

Figure 3. Longitudinal section of the test chamber of the stand with seal of the first design

To measure the pressure of the barrier medium in the operation gap, a seal has been developed, manufactured and assembled (Fig. 4), in which the sealing ring with the chambers is fixed, mounted in the housing, and the ring with the feed channels – rotating, movable in the axial direction.

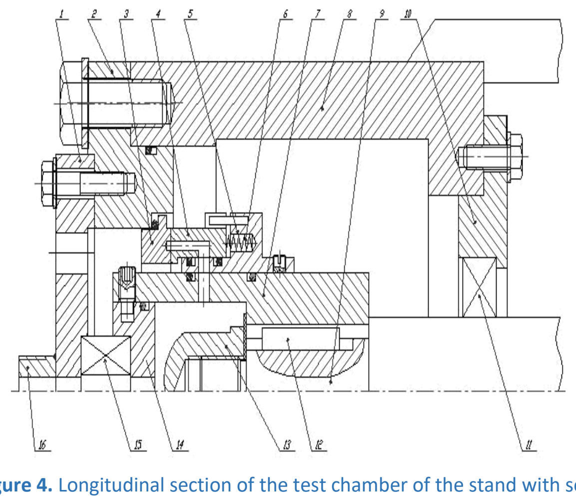

Figure 4. Longitudinal section of the test chamber of the stand with seal

This is made in order to be able to place electronic pressure sensors in the ring with chambers and not to clutter the stand with a system of sliding contacts. Fixation of the ring with sensors from the rotation made it possible to provide free output of electrical wires from the sensors to the measuring and recording equipment. For leakproof inlet of the sealing pressure along the shaft into a rotating ring used mechanical seal with the gas lubrication.

The test chamber 8 of the test bench is closed at the front by a cover 2 with a flange 1 attached to it, and at the rear (from the input side of the drive shaft 9) by a rear cover 10. On the back side of the test chamber an auxiliary seal 11 with gas lubrication is supplied. On the shaft 9, a special bushing 7 is planted, fixed from the displacements with a key 12 and a nut 13. On the bushing 7 are: the bearing bushing 5, a ring with a supply channels 4, the springs 6. The fixed ring with shambers 3 is placed in the cover 2. On the bushing 5 is one of the rings 14 of the auxiliary seal on the gas lubricant is installed. For the supply of the barrier medium in the flange 1, a fitting 16 is provided, and special holes are drilled for the removal of the total leakage and the output of the pressure sensor wires. As for leashes rotating seal rings are used pins.

During operation, the dfhhier gas through the fitting 16 and the auxiliary seal 15 enters the bushing 7. Further, through the radial holes, the gas enters the feed channels of the rotating ring 4. After leaving the channels, the barrier gas flows through the gap into the atmosphere and into the case of the test chamber 8. The buffer gas leakage through the auxiliary seal 15 for the required operating conditions shall be determined before the main tests [Kuznetsov 2005].

4 RESULTS OF EXPERIMENTAL INVESTIGATIONS

With the help of the described equipment, a large number of researches were conducted, during which a combination of the values of the pressure of the pumped medium (from 0.05 to 0.45 MPa), the pressure of the barrier gas (from 0.1 to 0.5 MPa) and the speed of the drive shaft (from 1000 to 3000 rpm) were varied. Water and air were used as the pumped medium.

The first stage of research is to investigate the characteristics of the flow rate of barrier gas through the operation gap of the seal (Fig. 5).

As a result of the analysis of the obtained experimental data, it is noted that with an increase in the frequency of rotation of the shaft, an increase in the flow of barrier gas is observed, which indicates an increase in the gap between seal surfaces. This operation of the barrier seal is fully consistent with traditional ideas about the impulse seal – with increasing speed reduces the period of time between the filling chambers with the barrier gas, so the average pressure on this annular section of the gap increases. The balance of axial forces acting on the axial-moving ring is violated, for its restoration, the gap automatically increases, thereby reducing the resistance of the end throttles above and below the chambers, therefore, the initial value of the average pressure in the chambers is restored, but with a larger value of the operation gap.

It is also revealed that with increasing pressure of the pumped medium the flow rate of the barrier gas (with the same difference between the pressure of the pumped medium and the barrier medium ΔP) significantly decreases. And this is clearly manifested with a small number of chambers (with an increase in the number of chambers, this dependence ceases to be pronounced).

It is found that the number of chambers significantly affects the flow of barrier gas through the seal: with the increase in the number of chambers, the flow characteristic of the seal is steeper. In other words, with a large number of chambers, the impulse seal works like a gas-static one, since the circumferential length of the gaps between the chambers tends to a minimum, and the entire annular area of the gap on which the chambers are located tends to a gas-static annular groove, which is reflected in the kind of the flow characteristics. Small changes in the pressure of the barrier gas lead to significant changes in its flow rate, that is, to a noticeable change in the value of the working gap.

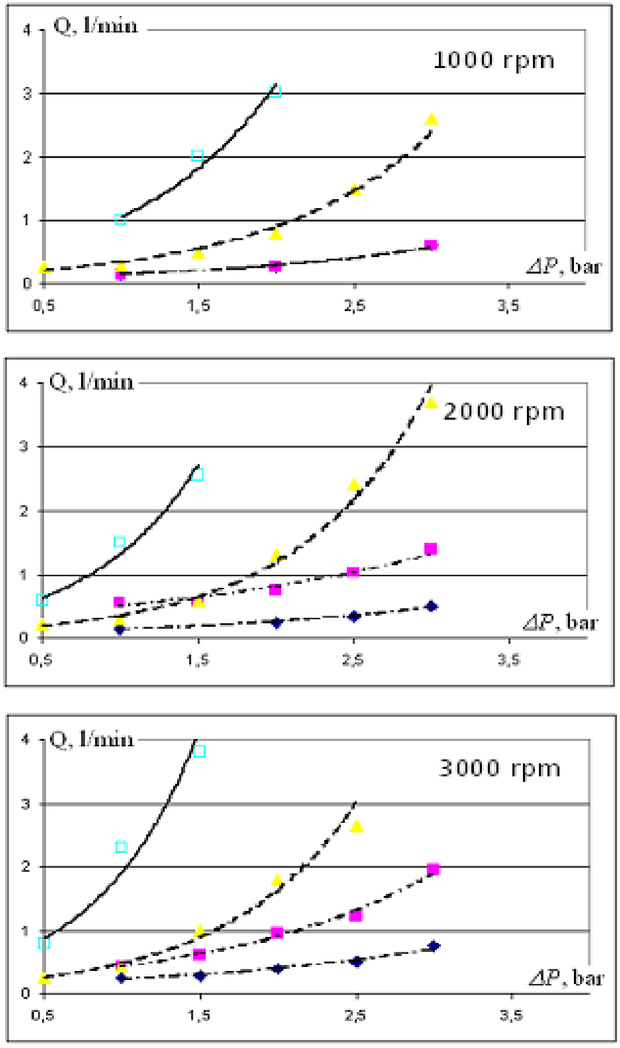

Figure 5. The flow rateof barrier gas through the working gap seal:
◆ – 6 chambers and 4 outlets of supply channels,
■ – 12 chambers and 3 outlets of supply channels;
▲ – 12 chambers and 4 outlets of supply channels;
□ – 24 chambers and 4 outlets of supply channels

With a small number of chambers, the barrier seal operates steadily in non-contact mode, the flow characteristics are more flat. A significant increase in the difference of pressures leads to a slight increase in the flow rate of the barrier gas, therefore, the gas layer in the gap becomes more rigid and less responsive to changes in external factors.

The influence of the number of supply channels outlets on the flow rate of the barrier medium through the seal is qualitatively similar, i.e. with an increase in the number of supply channels outlets, the flow through the seal increases significantly.

As a result of the conducted investigations, the influence of the operation parameters on the change of the barrier gas pressure distribution diagram directly in the chambers and on the annular portion of the working gap between adjacent chambers was also researches.

These results of researches show that at a constant value of the difference between the barrier and the sealing operating pressures with increasing rotor speed or the value of the sealing pressure, the amplitude of the barrier gas pressure fluctuations in the chamber and in the space between the chambers decreases.

An increase of the differential between operating pressures leads to an increase the amplitude of the pressure fluctuations in the chambers and between the chambers, which can cause a breakthrough of the sealing medium through the face gap (Fig. 6). The use of sealing rings with a reduced number of chambers allows to reduce the amplitude of pressure fluctuations in these places with the same operating parameters.

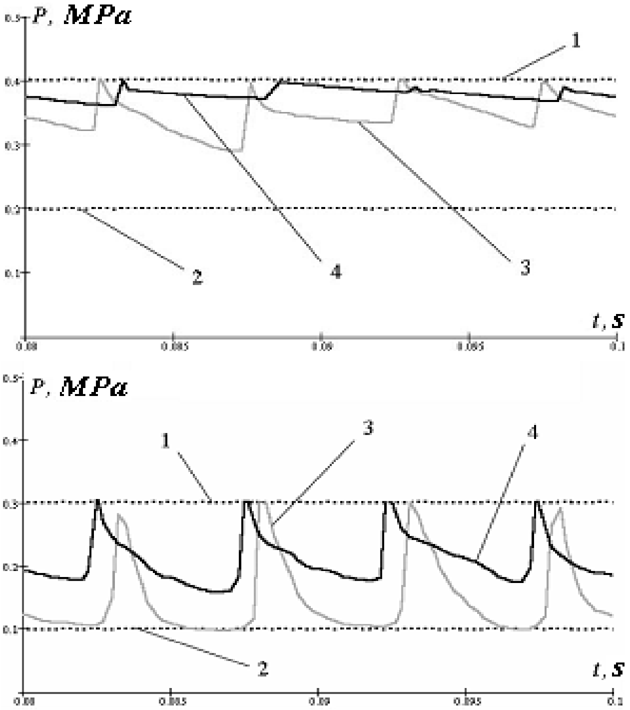

Figure 6. Change of pressure in locations of the sensors:
1 – pressure buffer gas;
2 – the pressure of the sealing medium;
3-pressure in the space between the chambers;
4 - pressure in the chamber

As shown by the investigations, the seal has the property of self-regulation: the pressure values in the specific areas of the gap and the flow rate of the barrier gas, and hence the value of the gap, correspond to certain operating conditions and chenges in accordance with the conditions. The possibility of fine-tuning the value of the operation gap of the seal by changing the pressure of the berrier gas is revealed. Having established obviously big difference between pressures of the sealing and barrier mediums (especially at low speeds of rotation of a shaft) it is possible to cause intentionally opening of a operation gap and flow through it of the sealing product in area behind a seal without violation of a steady contactless mode of operation.

5 CONCLUSIONS

The obtained experimental data show that with a sufficiently large number of chambers (when the circumferential distance between adjacent chambers is less than the circumferential length of the chamber itself), the operation of the seal can be described by a traditional mathematical model for leaky impulse seal with deliberately created leakage of sealing liquids through the operation gap to maintain a contactless mode of operation is adopted, but only after its adaptation for use in gas medium. When used in sealing rings with a reduced number of chambers (when the distance between individual chambers is much greater than the circumferential length of the chambers themselves) in the traditional mathematical model, it is necessary to enter the account of the influence of the number of chambers and outlets of feed channels, as well as circular gas flows in the operation gap. To do this, it is advisable to obtain a solution of the problem of pressure distribution in the gap of the seal.

ACKNOWLEDGMENTS

The authors would like to thank the KEGA grant agency for supporting research work and co-financing the project KEGA: 004TUKE-4/2017.

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