Development of the unified range of friction couples of gas-dynamic face seals

Dmitry Konstantinovich Novikov

Samara State Aerospace University, Moskovskoe Shosse, 34, Samara, 443086, Russia

Abstract. Sealing systems of turbomachinery define possibilities of intensification of work process in them. Gas-dynamic face seals are standard technical solution for compressors. The research objective in this article is building the unified range of friction couples of gas-dynamic face seals of compressors for gas industry. Scientifically proven suggestions on selection of seal ring dimensions are described in the article. Geometric, gas-dynamic and strength criteria defining selection of carbon ring diametric sizes have been suggested. The unified range of friction couples has been selected. It is applied to all compressors for natural gas pumping.

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Introduction

Gas-dynamic face seals (Fig. 1) represent the standard type of compressor rotor support seals [1]. A set of questions arising when designing face seals that require a comprehensive calculation research [2-9]: generation of the hydrodynamic pressure in a clearance, friction in a clearance, power and thermal deformations of a friction couple, friction couple cooling, shaft rotation and its axial movements. All the above issues are interrelated. Methodical bases for their comprehensive solution are described in work [10]. Designing of gas-dynamic face seals is a highly technological and labor-intensive process [11-14]. To increase labor productivity and reduce design efforts of high-tech products the manufactures use unification and standardization of parts and mounts. Unification is an effective and cost-effective method of designing a range of derived mounts and parts of the same purpose but with different parameters of geometry, performance, capacity etc. based on the initial model. In some cases it is possible to design a range of various capacities or performance as well as their mounts and parts that differ in geometry only.

Gas pumping units used today are of different capacity and, thus, different compressor discharge. As compressor capacity depends on its dimensions (as a rule in increase in compressor capacity the shaft diameter increases) we can theoretically obtain a set of mounting seats for gas-dynamic face seals. Methods of designing derived mounts and their ranges based on unification are not universal and comprehensive. Each of them can be applied to a limited category of products.

Today compressors for natural gas pumping are equipped with gas-dynamic face seals systems of different manufacturers, at that, gas-dynamic face seals have different friction couple sizes. The friction couple is the most important component of the gas-dynamic face seal. Designing the unified range of friction couples will allow to significantly reduce periods and costs of seal designing as friction couple designing is the most labour intensive stage in designing. Therefore, the purpose of researches described in this article is developing the unified range of friction couples of gas-dynamic face seals.

Selection of diametric sizes of a sealing ring of gas-dynamic face seals

When designing gas-dynamic face seals it is necessary to set initial dimensions of a friction couple for their further optimization. At that, it is necessary to consider the following basic requirements to seals: required sealing capacity; high reliability; acceptable dynamic properties; small sizes and weight [10].

These requirements are rather contradictory. The analysis of the developed methods of analysis and design of gas-dynamic face seals [10] allowed to specify the requirements for selection of seal dimensions:

1. Providing balance of axial forces applied to the friction couple;
2. Providing balance of the deflection moment applied to the friction couple;
3. Providing the required size and form of a seal clearance;
4. Providing high stiffness of a gas layer;
5. Providing performance of a secondary seal;
6. Providing small sizes of a friction couple;
7. Reducing the impact of process tolerances on dimensions.

To select diametric sizes of a carbon ring (Fig. 1) at the preliminary stage the following criteria have been developed:

1. The geometric criterion which is the friction couple discharge coefficient $k=(D_2^2-D_y^2)/(D_2^2-D_1^2)$. Where: D_1 – internal diameter of the friction couple seal band; D_2 – external diameter of the friction couple seal band; D_y – diameter of secondary seal location. The recommended parameter value is $k=0.83…0.835$. With these values high axial stiffness of a gas layer

and multiple operating conditions of gas-dynamic face seals are provided.

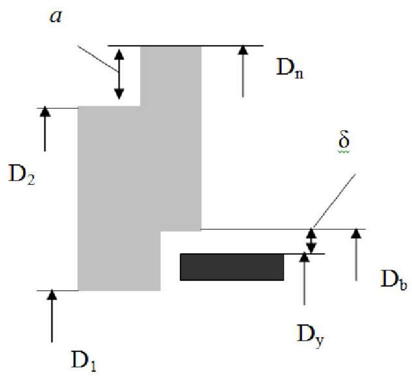

Fig. 1. Carbon ring diagram

2. The strength criterion which is carbon ring radial shrinking in the area of secondary seal location $\Delta r=\Delta pD_bD_n^2/(E(D_n^2-D_b^2))$. Where: Δr – radial shrinking value; Δp – gas pressure drop; D_b – internal diameter of the friction couple ring in the area of secondary seal location; D_n – external diameter of the friction couple; E – material elasticity module. The recommended acceptable parameter value is $\Delta r=0{,}75\delta$, where δ – mounting radial clearance between carbon and bearing. In this case performance of the secondary seal and carbon ring mobility is provided. It is necessary to take into account that $D_b=D_y+2\delta$, $D_n=D_2+2a$. Size a is required for pin location from rotation and it is structurally defined.

3. Gas-dynamic criterion which is gas layer bending stiffness is $C_\theta=-\Delta M_\Theta/\Delta\theta$. Where: ΔM_Θ – change in the lubricant film deflection moment in case of change in clearance tapering angle $\Delta\theta$. The recommended value of this criterion is not less than 10^4 *Nm/rad*. In this case balance of deflection moments on the carbon ring which is the weakest friction couple element will be provided in minimum clearance deformation. Acceptable dynamic characteristics of gas-dynamic face seals will also be provided. With this parameter value the impact of process tolerances on friction couple geometric parameters will be minimized.

The following algorithm for defining friction couple diametric sizes is suggested.

1. The carbon ring internal diameter D_1 is selected by the known shaft diameter for design considerations.
2. A number of gas-dynamic calculations for a friction couple are performed and the sealing surface width is defined (D_2-D_1) based on the conditions providing the recommended value of the gas-dynamic value C_θ.
3. Having selected the geometric criterion value k we define (taking into account equation $D_b=D_y+2\delta$) the internal diameter of the carbon ring $D_b=2\delta+\sqrt{(D_2^2-k(D_2^2-D_1^2))}$.
4. Having selected the strength criterion value Δr we can calculate the minimum value $D_n=\sqrt{(\Delta rED_b^2/(\Delta rE-\Delta pD_b)}$. Then we check the condition $D_n=D_2+2a$.

Diametric sizes of a carbon ring uniquely determine diametric sizes of the mount of gas-dynamic face seals. Thus, maximum possible shaft bushing internal diameter is $D_{shaft}=D_1-10mm$. The minimum possible case external diameter is $D_{case}=D_н+7mm$.

Thus, the scientifically proven method to define dimensions of gas-dynamic face seals has been developed at the preliminary design stage. Then, when performing check calculations geometrical dimensions will be further specified.

Selection of standard series of mounting seats for gas-dynamic face seals

In using gas-dynamic face seals it is necessary to note that standard shaft diameter series are used only for mounting seats for bearings and are defined by the value of the transmitted torque. Diameters of shafts for seal installation can be different in the value from diameters for bearings due to design requirements, for example, ease of installation or need in thrust shoulders.

To accurately define the size range of seal mounting seats it was necessary to examine support node designs of all the advanced Russian compressors for natural gas pumping.

All the seal mounting sizes for the shaft and case are classified into groups. Diameters of the shaft under the seal are taken as characteristic dimensions. The mounting diameter of the seal case is taken as a dimension limiting the group which is defined by design and technological capabilities for friction couple designing.

The internal diameter of the carbon ring is limited by the shaft diameter, size of cross section of the rubber sealing ring of the shaft and rotor bushing thickness and should be guaranteed 10 mm larger than the shaft diameter.

The carbon ring on the external diameter is fixed by the pin connection against rotation. The pin diameter is selected from carbon strength conditions for breaking and wear. Taking into account the required clearances and case bushing thickness for pin installation we obtain that the required mounting diameter of the seal case should be 7 mm less than the external diameter of the carbon ring.

The conducted analysis of mounting surfaces for the seal case in existing natural gas compressors (Fig. 2) showed that all of them can be divided into four groups with the following diameter of mounting seats for shaft seals: from 115 to 130 mm; from 130 to160 mm; from 160 to 185 mm; from 185 mm and more.

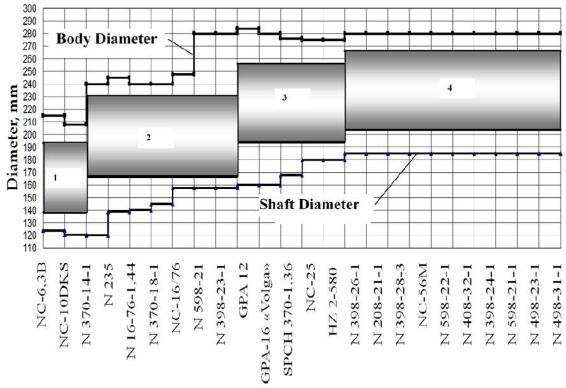

Fig. 2. Flow chart of selection of the unified range of seal friction couples for natural gas compressors

Table. Seal design characteristics

Parameter	Friction couple 1	Friction couple 2	Friction couple 3	Friction couple 4
Pressure drop 5.2 MPa; rotor speed 550 rad/sec				
Clearance size, μm	2.7	2.6	2.5	2.4
Gas leakage, g/sec	0.61	0.6	0.62	0.7
Clearance change amplitude, μm	0.39	0.4	0.44	0.41
Pressure drop 5.2 MPa; rotor speed 830 rad/sec				
Clearance size, μm	2.8	2.8	2.9	2.8
Gas leakage, g/sec	0.7	0.8	0.9	1.1
Clearance change amplitude, μm	0.4	0.42	0.47	0.45

Taking into account this data using the proven design technology [10] the unified range of seal friction couples prepared and successfully tested has been designed. Design characteristics of seals are given in the table. Tests have been performed on the dynamic test stand the design of which is described in work [3].

During the experimental researches the measured gas leakage values differed from the design values by not more than 10%. This proves high design quality and reliability of calculation methods used.

Conclusions

Gas-dynamic face seals represent the basic type of compressor rotor support seals. A set of calculation and experimental researches conducted allowed to develop a unified range of friction couples for such seals when used in compressors for natural gas pumping. Seals designed have acceptable leakage and good dynamic characteristics. Due to this time and resource expenditures for development of new compressor seals dramatically decrease. The results obtained are useful for both research workers and engineers involved in designing gas-dynamic face seals.

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Corresponding Author:
Dr.Novikov Dmitry Konstantinovich
Samara State Aerospace University
Moskovskoe Shosse, 34, Samara, 443086, Russia

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