Seal design features for systems and units of aviation engines

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Abstract. Usually at seal designing the complex of problems is observed, which is restricted only by the friction pair. These problems are leakage, reliability, deformations of seal rings, heat generation in a gap etc. This method is the main, but for research of some problems it is not sufficient. Development of program complexes on the basis of numerical methods does possible an application of the second additional method. The second method consists in the research of seal as parts of system of the engine or its unit. In article the possibilities of seal research as element of air secondary system, oil system and engine supports are observed. In each case leakage and a seal design are defined through demanded parameters of systems. The combination of two research methods does possible improvement not only separate seal unit, but also to perfect the systems and efficiency of entire engine.

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Introduction

Creation of new samples of engineering is inseparably connected with a solution of a seal problem [1]. Aircraft engine and power plant seals are difficult specific designs that have no direct analogues in the nature. Process of seal designing is very difficult as a considerable quantity of various versions of operational conditions exists. This reason leads to high cost of seal units and high requirements to its reliability. Seal failures are on the third place among failures of aircraft engine elements.

Seal designing is based on the solution of the interconnected problem complex. It is necessary to consider simultaneously hydrodynamic (gas-dynamic), and thermal, and power problems. In some cases seal detail deformations on transitive modes are considered. Difficult computational models are especially necessary at designing aircraft, rocket engines and power plants that created on its basis. High technologies for the aircraft engine manufacturing can be successfully applied in other industries.

During seal design the main problems are containment and maintenance useful life. Realization of these requirements becomes complicated by modern engines reached parameters. In aircraft engine supports the seals work at temperatures up to 1000K, pressure difference up to 1 MPa, circumferential speed up to 250 m/s. In perspective the further increase of the overall pressure ratio, turbine rotor inlet temperature, bypass ratio, rotor rotation speed are expected. It increases loads at the seal units. It is necessary to consider that together with increase of engine parameters its useful life must be also increased. Demanded useful life for aircraft engine is 30 thousand hours, for power plants is 100 thousand hours. Introduction of new designs and converting of aviation engines limits by absence finished seal units with high useful life that can work in more severe maintenance conditions. [1, 2, 3]

Now as support seals of turbo machines rotors the labyrinth, face, radial face seals, graphite segment seals are widely applied. Recently the great attention is given to research the gas dynamic and gas static seals that work with the guaranteed gas lubrication in friction pair. Further in the article such seals will be mainly investigated. But the developed procedures and the may be used also for traditional seal types.

Main part

Question complex arising under a designing of face seals with gas lubrication and demanding of an extensive computational research is shown on fig. 1. [2] Within the limits of a considered first method it is possible to name these questions conditionally as "internal" (since for its solution only parameters inside of seal unit are used).

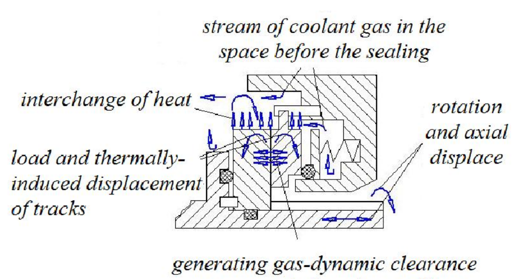

Figure 1 : Main problems solved at the seal designing as friction pair unit

Especially it is necessary to allocate following problems.

- Influence of flow structure of the sealing environment in a cavity before seal (cavity forms before seal) on a thermal seal condition.
- Influence of seal ring geometry on values of the thermal and power deformations arising in rings.
- Influence of ring deformations on the form and value of a sealing gap.
- Influence of the form and value of a sealing gap on pressure profile in a seal clearance.
- Influence of a pressure distribution in a seal clearance on a sealing ring deformation value.

Now at the engine designing the seal are considered as a separate unit. Flow parameters in a sealing gap and the sizes of leading-in and leading-out channels are set. However in a multimode power plant (aircraft engine) such method does not give enough exact results [4, 5]. Development of computational methods allows executing research of seal as a part of internal air system, oiling system, as a part of a support and research with changing of parameters on transitive modes [6, 7]. The similar method (second method) allows to integrate seal characteristics with efficiency parameters of all engine and to estimate additional factors which can exert influence on seal function ability. Fig. 2 shows the basic "external" problems demanding the solution at the seal designing.

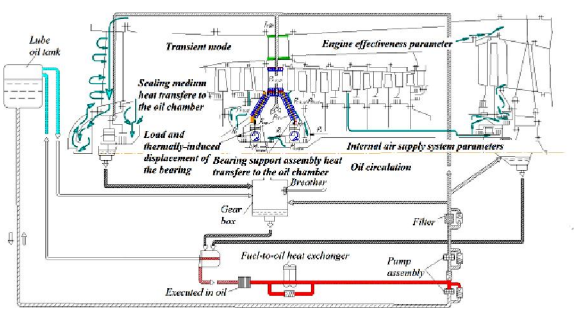

Figure 2 : Some problems at the seal designing as a part entire engine

The basic "external" problems are [8]:

- Influence of seal containment on parameters of air internal system (value of air bleedings on pressurization and breathing, cooling of hot elements, balance system etc.);
- Influence of power and thermal deformations of support walls on value of a seal gap on all engine working modes;
- Influence of seal containment on heat emission in oil and the value of consumption;
- Communication of seal characteristics with seal ring deformations on transitive modes;
- Influence of seal containment on parameters of engine efficiency;
- Reliability prediction of sealing unit and its influence on parameters of engine reliability.

For more detailed modeling of processes that take place in the engine, it is necessary to investigate of seal working as a part of engine air internal system.

During this research following problems are solve. There are definition of seal efficiency in engine air internal system, calculation of interaction interference of air internal system parameters and seal characteristics, selection of the refined seal design.

Process of seal designing as a part of air internal system can be realized in the next three stages. The first stage consists in complex definition of flow parameters in a engine flowpath and convection coefficients in all channels. The given method is described in classical works [9] and widely applied at the engine designing.

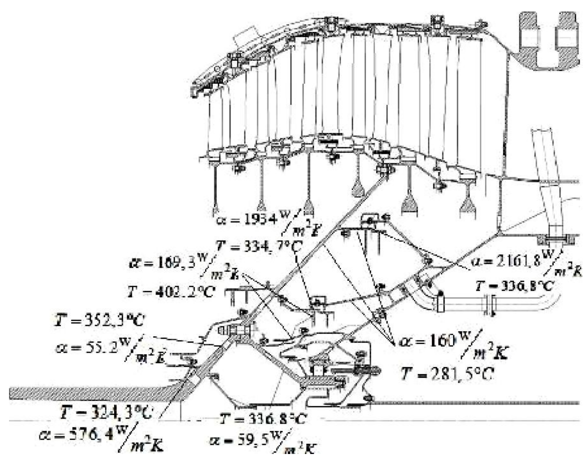

Figure 3 : Accounted results of an air internal system parameters for the turbine model

It does necessary the solution of a inverse problem: by means of known channels geometry and values gas dynamic parameters in flowpath it is necessary to determine flow parameters flows on all network. This calculation should consider influence of a flow heating. The problem should solve by step-by-step approximation method. This solution was realized for the turbine cooling system for the NK-93 engine (Joint Stock Company “SSTC named after N.D. Kuznetsov”), turbine model for GE-90 prototype and 370-14-1 pump compressor. Example for convection coefficient definition in turbine model for GE-90 prototype is shown at the fig. 3.

The second stage consists in definition of deformation mode for channels details and especially investigated seal unit details (fig. 3). The third stage is an estimation of influence of seal unit containment on parameters of engine efficiency. The given estimation essentially depends from a seal position in an engine design (support seals in the compressor and the turbine, seal of cooling system or balance system, flowpath seal). Methods of a refined efficiency estimation for engine units and the for specific fuel consumption have been developed.

Application of the given design method for seal allows not only to correct seal parameters on all modes, but also makes possible applications of perspective non-contact seals not only in support, but also in a engine flowpath [2, 10-12].

The most important condition of containment maintenance and reliability for the seal is maintenance of the demanded sealing gap form and a comprehensible stress level in details of sealing unit. The formed increasing deformations can lead to destruction of rings or to a full gap opening. Both cases are inadmissible for aircraft engines and power plants [1, 2].

An engine supports are possible to divide on a compressor and turbine supports. For compressor support most often used variants are the forward support position, an between cascades position and a back position that are integrated either with outside, or with an inside combustor chamber housing. Similar classification can be made for turbine supports. The support rule strongly influences on the thermal and deformation mode of its elements. It is necessary to consider and influence of the general support design as a engine part. For example, application of the common support for triple spoon shaft turbine does difficult maintenance of its element cooling.

In this article it is necessary to allocate principal load types that acting on a support and to estimate its influence on deformations of seal unit details. Also both separate influence of separate components of loading, and result of its common effect are investigated. About influence of deformations on characteristics of seals (contact and non-contact, gas static and gas dynamic) the great number of publications is available [1, 2 etc.]. But conventionally only that ring deformation of friction pair that arises from action of sealing and sealed environments, and also deformations of close details in a design is considered. However all kinds of the loads that are acting on a support can exert influence on ring deformations. And this influence can be very significant.

Generally following internal loads act on compressor and turbine supports (fig. 4): thermal, pressure difference, radial and axial loads from a rotor, torques. External loads are an inertial loads, including gyroscopic torques of rotors at a changes of aircraft attitude, aerodynamic loads from external contours of an engine nacelle and loads connected with not axial input flow in the fan, thrust, weight, etc. [12, 13].

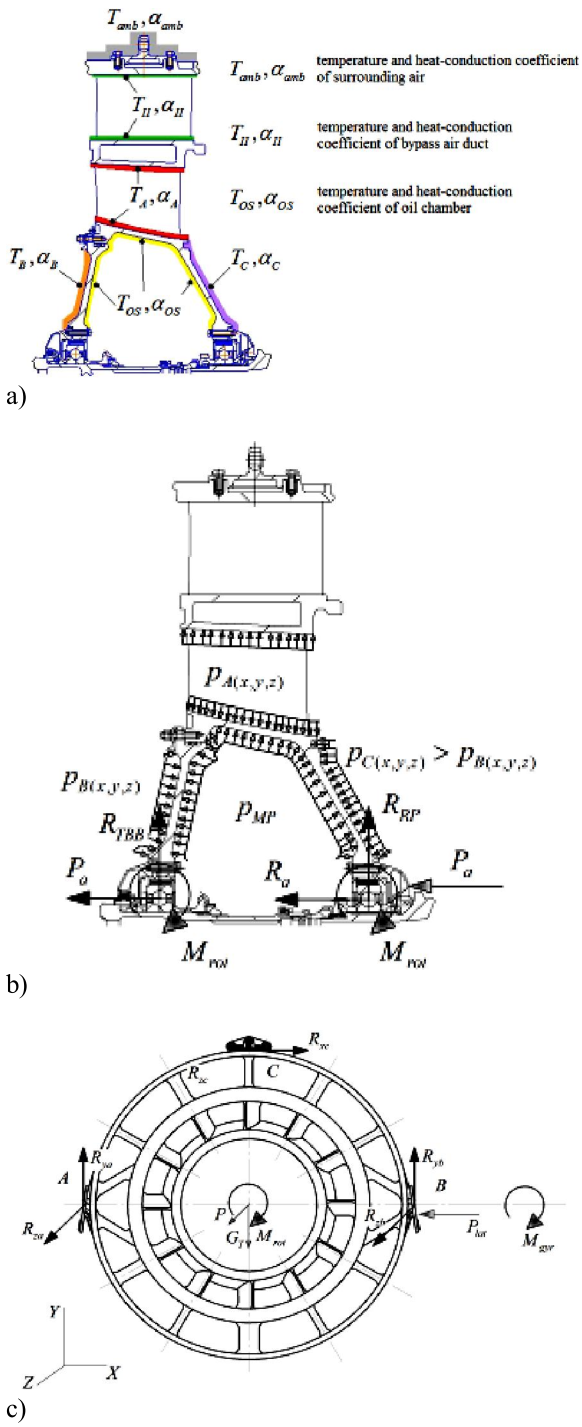

Figure 4: Internal temperature loads (a), internal power loads (b), external power loads (c) affected on the bearing assembly

Importance of seal studying as support element has been confirmed by computational research of maintenance defect. On NK-144 engines during flight time defect of a support was. Pressure difference in a support was above admissible up to 100 kPa (admissible value is 50 kPa) (fig. 5).

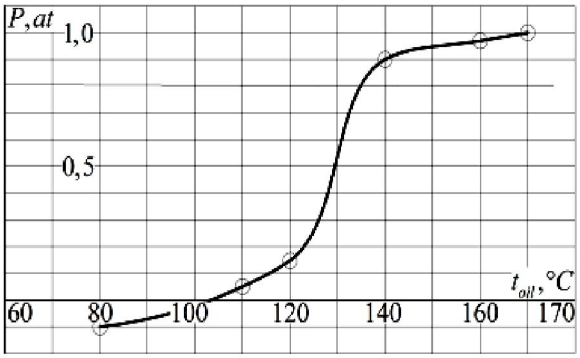

Figure 5 : Pressure difference in the oil cavity of bearing support

Defect occurred during of the moment when plane approached to destination place. The plane flied with a speed 2,2M and then it reduced altitude and changed speed to 0,8M. One of the possible reasons of defect it is deformation of a wall support. As walls were deformed and opened a sealing gap.

The developed models and design methods allow to analyze each of load kinds of the support on seal characteristics and to choose, for each separate case, most important from it.

Bearings and other friction units up state in the engine supports during define useful life strongly depends from oil cavity containment and from heat quantity entering in this cavity. Main heat part enters not only with sealing gas through seals, but also through support walls. Its value can achieve up to 80 % from entire heat quantity. It is especially important to study seal work as a part of engine oil system, and an influence of the processes that occurring in seal, on work of oil system [14]. Generally it is connected with fact that the oil heating in an engine support should be in borders from 40 to 70 degrees. At modern levels of temperature make realization of this requirement very difficult.

In article of oil consumption values through aviation turbojet bypass engines (including afterburning) (fig. 6a) and turbo-prop engines (fig. 6б) have been analyzed.

From the analysis of drawings it is probably to conclude that the volume of oil consumption directly depends from engine thrust (or powers). For turbo-prop engines it is on 40 - 50 % more. Also an oil consumption volume for civil and military engines differs. Other factor influences the oil consumption is the total heat flow getting into a support.

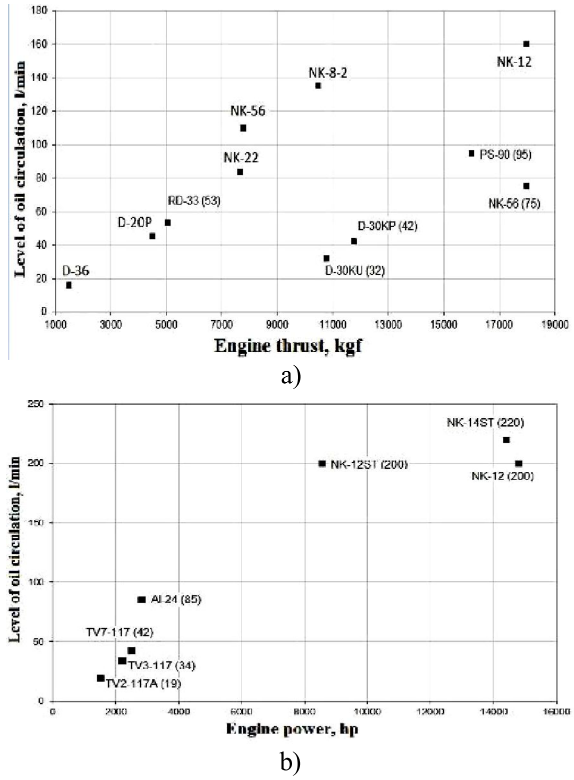

Figure 6 : Oil consumption in turbojet engines (a) and turboshaft engines (b)

On fig. 7 experimental relations for the oil consumption through three engine supports NK-144 are shown.

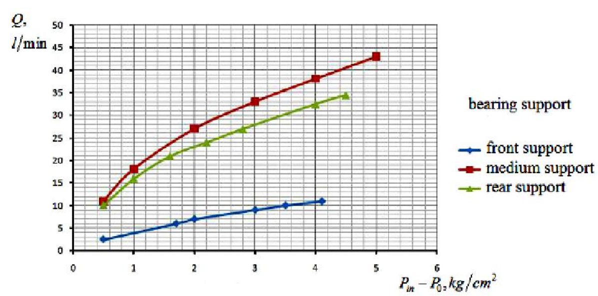

Figure 7: Oil consumption through three supports of aviation engine

The further application of this method is possible for research of the most perspective design of thermal protection for a support. This design is the buffer cavity that is applied on many modern engines [14]. Also it can be used for designing of separate elements of an oil feed and drain in a support [15].

The significant part of seal damages has from occurrence of dangerous vibration. On fig. 8 a seal ring is shown that was collapsed at compressor mode changing from one to another.

Therefore creation of design methods of dynamics of a face contact and non-contact seals taking into account a feature of its operation in a structure entire engine is necessary. This method should allow to estimate deformation mode of pair friction rings at various rotation speed taking into account also dynamic excitation and to make the recommendations for choice seal designs.

Figure 8: Vibration damage of seal ring

External disturbances, shaft vibration, whipping of rotating details do possible occurrence of non-stationary processes destroy the equilibrium and stability of a seal ring that is moving in an axial direction. Also it excites oscillations in seals [16]. Dynamics questions are important for seals that work at high rotation speed and in compressed gases [17, 18].

For the solution of the delivered problem the following sequence of calculation is offered.

- Selection of a flight cycle (or a cycle of power plant working) and definition of temperature loads and pressure forces.
- Carrying out of the complex thermal and structural calculations of a support and seal (for example, in program complex ANSYS) for definition of detail deformation influences on seal geometrical parameters.
- Carrying out of dynamic calculation taking into account nonlinearity (it consists in the account of seal ring deformations that induce non-linear change of parameters of an layer air together with a change of the seal gap form).

In a result of calculation the change of gap value and form depending from time, change of lubricating layer rigidity, damping coefficient, and also the amplitude-frequency characteristic are determined. The created model of seal allows to analyze linear and angular oscillations. During dynamic calculation the change of gap value between moving and motionless seal rings, and also change of its form are determined. In a result following relations of amplitude and sealing gap change from oscillations frequency are received. These relations have characteristic changes of the curve form from the non-linear change of rigidity (fig. 9).

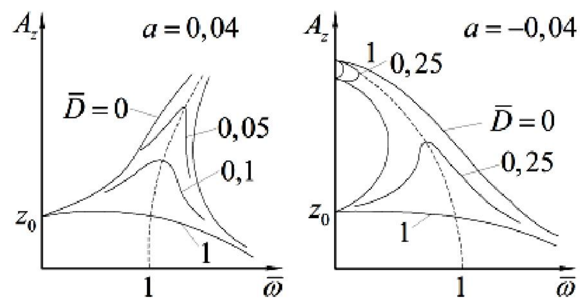

Figure 9: Relations of amplitude and sealing gap change from oscillations frequency

Non-linear change of rigidity of layer air from seal ring deformation leads to a bending of an amplitude-frequency characteristic. Usually seal is made so that it worked on the right branch of characteristic.

Received amplitude-frequency characteristic allows to make a necessary constructive changes for maintenance of stable work of investigated seal (for example, to increase of damping coefficient of air layer with changing of the groove forms on contacting surfaces).

Conclusions

The limited volume of the article does not allow to research all details of the considered problems and to give the organized computational substantiation of all results. Moreover at a design stage it is possible to estimate only influence of seal containment on engine efficiency parameters. The estimation of influence on parameters of reliability isn't in frames of the given analysis. But in this case the seal designing as an element of engine or its systems has large perceptivities for the solution of the above described problems.

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