BIOSCIENCES BIOTECHNOLOGY RESEARCH ASIA, April 2015. Vol. **12**(1), 731-736

Designing of Low-flow Rate Sliding Bearings for Turbo Machinery Rotors

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DOI: http://dx.doi.org/10.13005/bbra/1718

(Received: 30 November 2014; accepted: 16 January 2015)

An effectiveness of support units of modern turbo machines, including sliding supports, largely depends on a design technology. Therefore, the aim of this paper is to develop a new design method of perspective hydrodynamic bearings with an elastic suspension of bushings. In this paper, constructions' peculiarities and an action mechanism are described as well as a design process of low demand sliding bearings. The efficiency of the proposed sliding bearing design was proved with liners counterbored to a radius of a shaft. A hydrodynamic model of a working bearing gap was described. By means of calculations it was found out that the nature of a pressure distribution in the case of the liners counterbored to a radius of a shaft is smoother (the implementation of the "filled" curve) than in the case of an axial bushings' counterboring that provides a higher working life of these bearings. A methodology for characteristics' calculating of an elastic suspension of liners is presented. Elastic deformation material MR properties exclude a "flutter phenomenon" of the bearing liner. The results of calculated researches of perspective bearings' characteristics are presented and the recommendations for the design optimization were given as well as the choice of materials. The mathematical model of the work system "working gap-liner-elastic suspension" was developed, which allows finding an optimal value of material parameters of "metal analogue of rubber" on the basis of calculations' results of lubricant flow characteristics in a work gap of as well as a size of a bearing, bearing. The combination of analytical methods and sophisticated software was used, such as ANSYS CFX, ANSYS APDL, ICEM CFD, and NX. A newly created SBDC design method, considers especially construction peculiarities and the mechanism of the work of these bearings. The bearing to be created is an effective solution for heavy-loaded rotors that require a dynamic stability and long life bearings. As part of a cast support a sliding bearing of a "dry crankcase" with liners counterbored to a radius of a shaft can serve as an effective substitute for rolling bearings and for sliding bearings of a traditional construction.

Key words: sliding bearing, a lubricant layer, elastic suspension, design methodology.

A creation of supports for high-speed gas turbines' units is a currently important (Zhdanov *et al*., 2013). The object of the research is segmented hydrodynamic bearings of a "dry crankcase" with liners countebored to a radius of a shaft and with a forced closure of working gap. These bearings with self-aligning bushings, which are made of an elastically deformed material MR (MR) on an elastic suspension, have a higher carrying capacity and working life, which is achieved by a liners counterbored to a radius of a shaft and forced closure of a working gap, which are the most effective solution allowing to reduce the demands on the oil supply system significantly (work under conditions of "dry crankcase"), including a decrease of its weight and a lubricant

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consumption, increasing the overall efficiency of the engine (Gordeev, 2008. Measures to eliminate a "flutter phenomenon" in a "dry crankcase" and liners counterbored to a radius of a shaft are forced loading of liners. A bearing can operate without forced oil feed to oil distribution grooves (a mode of "oil starvation").

The traditional method of sliding bearings calculation is based on the Reynolds equation (Bruce, 2012). The analytical methods for sliding bearings characteristics calculation (Voskresenskij *et al*., 1983; Chernavskij, 1963; Cameron, 1981) are imperfect (the need of two iterations, the use of tables and an approximation of their data, the influence of the chosen model of turbulence, etc.). In cases of a bearing complex geometry, this analytical method, based on the solution of the Reynolds equation, has its obvious limitations. This could be eliminated using the tools of computational hydrodynamics (CFD) (Huebner, 1974). An accuracy of the calculations carried out by means of CFD, is high (Uhkoette *et al*., 2012).

At the moment there is no SBDC design methodology, which considers the characteristics of their construction and use the modern computational tools (CFD) to the maximum. That is why the development of sufficient true methods of calculation is an important component in the design theory creation and development SBDC (Parovay *et al*., 2012).

METHODS

The offered bearings are designed to operate at high circumferential speeds of a shaft and possess a high carrying capacity. Dew to the liners, counterbored to a radius of a shaft a mode of liquid friction appeared immediately together with a shaft rotation. Elastically deformed material MR properties exclude a "flutter phenomenon". A material layer of an elastic suspension sags under the load, arising in the bearing liner, providing a liner rotation.

The scheme of the bearing work is shown in Fig.1, where a – starting position; b – working position, c – scheme for the formation of reactions in the "gap-liner-metal analogue of rubber". In the picture 1: [omega] – shaft speed frequency; [delta] – nominal gap; $[\text{delta}]_1$, $[\text{delta}]_2$ – input and output working gaps; $!_{pad}$, $!_{MR}$, C_{MR} – the centers of mass of the liners of the MR material in nominal and compressed states respectively; N-bearing load; $W_{[sigma]}$ – total force of pressure on the liner; P_{MR} – the force of the material reaction "metal analogue of rubber"; O, O_1, O_2 O' – centers of the calculating coordinate systems: the nominal of the shaft, liner, working gap; O' – the offset center of the shaft in the operating position [9].

A force, appearing in a gap presses the bearing. The material of the elastic suspension is deformed, causing the rotation of the liner. There is a movement of a shaft ("ascending") as well, by means of which the geometry of a narrowed gap is achieved. When the mode of fluid friction is achieved, the characteristic form of the pressure distribution is realized in the bearing gap (Fig. 1, b, c).

However, bearings are very sensitive to rotor misalignments, that is why it is necessary to ensure a high accuracy of a supports coaxially (Uhkoetter *et al*, 2013). One of the ways to ensure this, is the use a cast construction instead of a welded one (Chaadaev and Novikov, 2009). That is why, the bearings will be subjected to less dynamic forces; that increases a lifetime of support units (Belousov and Novikov, 1986). In order to control an oil supply in the unit construction, consumables chokes (jets) can be used for each liner. Fixed value of a lubricant consumption and multiple oil usage increases the engine efficiency.The possibility to change the bearing characteristics by means of changing of jets, increases the versatility of bearings (Parovay and Falaleev, 2013).

In the modeling of bearings and in a construction of grid models capabilities of a grid generator were used ICEM CFD as well as the CAE media of ANSYS APDL modeling. Such an approach for the creation of the finite element models was stipulated by small values of a bearing working gap (Belousov *et al*., 2009), the strict requirements of computational hydrodynamics for a form and aspect ratio of finite elements, a compulsory presence of the near wall layer of elements, by which are the vortex phenomena is considered as well as fluid taking off from the walls of a model (Guo *et al*. 2005). During the work process, the technique of finite element grid overlay on the hydrodynamic model of ultra-narrow gaps has also been established (Parovay *et al*., 2012).

In some calculations the function of the introduction of a movable rigid body was used (an imitation of a "floating" of a shaft in a bearing) and following usage of a deformable mesh of finite elements of variable stiffness. In the calculation the model of grid deformation was applied, in which the increased stiffness of the deformable grid near surfaces (near wall layer) was determined. The selected turbulence models and the heat transfer models influence to a large extent the nature of the convergence of the calculations and the final result (Tucker and Keogh, 1996). As a result there were obtained a distribution of a pressure in the bearing gap with an axial counterboring of liners (traditional construction) and the counterboring of liners to a radius of a shaft (Fig. 2).

In the calculating process, the effect of a "grease self-feeding", (the presence of the area of the negative pressure in the front part of the liner and as a result it "sucks" a grease to a working gap) was confirmed.

In the designing of perspective segment sliding bearings, one of the stages of the calculation is determination and optimization of characteristics of elastically deformed liners' suspension. The results of hydrodynamic characteristics calculation of a lubricant flow in a working bearing gap, namely with a distribution of a pressure in a working gap (Parovay and Falaleev, 2013), are used as the input data for the determining material parameters of an elastic suspension (Jiang *et al*., 2005). Optimization of these characteristics is the necessary condition of the mechanism for liner turning in an elastic suspension. The developed technique is built on the model of Buzickiy V.N. and Troynikov A.A. for the MR material (Buzickiy and Trojnikov, 1976). The initial parameters include: κ_1 N κ_2-matching constants; $[sigma]_{Tu}$, $\overline{[sigma]}_{Tu}$ – yield point and the relative yield point of the material of the wire H_C -height of the sample in a free state; *S*-the cross section square area of the sample; $\overline{[delta]}_0$ – relative axial preload of the sample $\overline{[rho]}_c$ – relative density; $\overline{[rho]}_Z$ – relative density of the sample; $\bar{d}_u$ – relative diameter of the wire.

To simplify the transformation process, the notation of the values A and B were introduced, which include only known parameters for an objective:

$$A = K_1 \bar{\sigma}_{Tu} H_C \left(1.1 + 0.2\bar{\Delta}_0 - 0.9\bar{\Delta}_0^{\,2}\right)\left(0.2 - \bar{\rho}_Z\right)\left(20 + \bar{d}_u\right);$$

$$B = K_2 \sigma_{Tu} S \left(0.8 - 2.3\bar{\Delta}_0 + 3.4\bar{\Delta}_0^{\,2}\right)\left(\bar{\rho}_Z + 0.02\right)\left(23 - \bar{d}_u\right).$$

The solution of the equations' system, which describes the relationship between the stress and the deformation of material, are the expressions for $\overline{[rho]}_c$, T_n and a_n, where $\alpha_П$ – the value of the deformation of the elastic liner made of "metal analogue of rubber " material; $T_П$ – the load on the liner:

$$\bar{\rho}_c = \frac{0.64AC + 0.03B}{B + AC};$$

$$a_n = A\left(0.64 - \frac{0.64AC + 0.03B}{B + AC}\right)$$

$$T_n = AC\left(0.64 - \frac{0.64AC + 0.03B}{B + AC}\right)$$

Through the initial data: relative axial preload of the sample $\overline{[delta]}_0$; $\overline{[rho]}_Z$; known coefficients κ_1 and κ_2; characteristics of the wire material $[rho]_u$, $[sigma]_{Tu}$, E_u (modulus of the material elasticity) relative wire diameter $\bar{d}_u$ determined values $\overline{[rho]}_c$, T_n and a_n required material characteristics of a "metal analogue of rubber", including a wire diameter $[delta]_P$ are found.

Investigation of the characteristics of the described model allows optimizing the parameters of an elastic suspension by the following values: axial preload, relative wire diameter, diameter of the helix, characteristics of the material.

RESULTS

As a result of the computational research the new type of the generalized method of bearings' designing was created, including the steps of the geometry selection, 3D-modeling design, the creation of the finitely element models of the narrow gaps, the calculation of the lubricant layer characteristics, the calculation of the characteristics of the elastic suspension liners, semi parametric design optimization. As a result, the Fluid Structure Interaction (FSI) system calculation of the "elastic suspension-liner-working gap-the shaft" is conducted.

The results of the research of the effect of the angle of the bearing liner rotation on the grease flow characteristics in the working gap are shown in Fig. 3. The relation of the force versus angle is the maximum that indicates the presence of the optimal values of the working angle of the loaded liner [delta]$_{opt}$. The chart of the maximum pressure is infinitely close to the maximum value of the pressure, which is impossible to exceed with the given working gap construction and with operational characteristics.

The obtained results, answering the questions about the lubricant action in extremely narrow gaps (5-15 microns), confirm high lifetime characteristics of the bearing.

Established design methodology allows designing and calculating any segment hydrodynamic bearing. The proposed method for parameters calculation of an elastic suspension allows determining the diameter of a wire material and the desired density at a stage of designing.

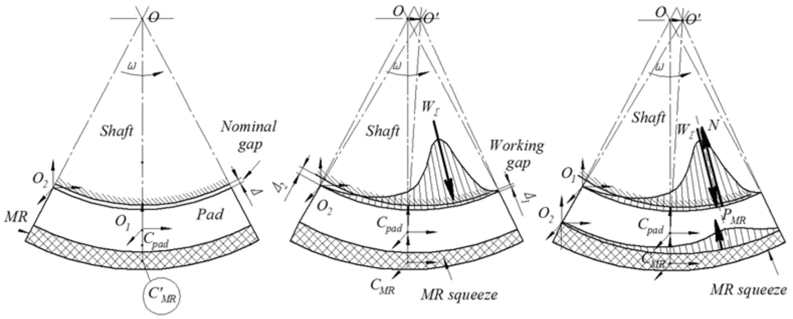

Fig.1. The bearing design scheme

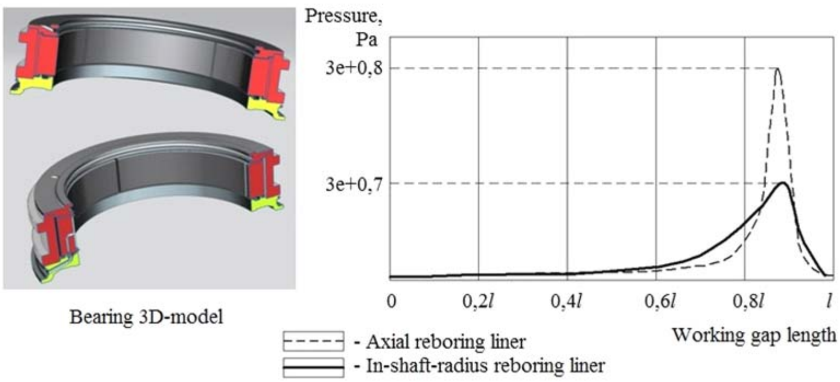

Fig. 2. Lubricant pressure distribution along the length of a bearing liner

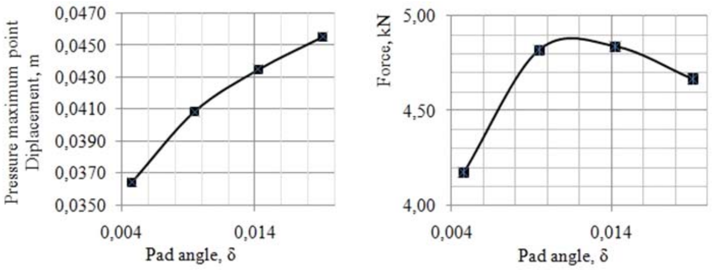

Fig. 3. Dependence of the maximum pressure and force on a size of a gap

DISCUSSION

The installation of sliding bearings instead of roller bearing in a stationary gas turbine unit, allows increasing the dynamic stability of a rotor and a turbine lifetime without serious design changes (Chaadaev and Novikov, 2009). The test results (Gordeev, 2008) have shown that SBDC with four liners is an optimal design, moreover, the measurement results, and the calculations of bearings of similar construction provide the material for further research (Tschoepe and Childs, 2014).

Existing methods of calculation cannot be applied due to differences in a design of bearing. The created SBDC design methodology considers the structure peculiarities and mechanism action of the given bearings. The technique allows removing the inaccuracies arising from the use of the known analytical methods (Bruce, 2012).

The analysis of a pressure distribution in a gap bearing with an axial liners' counterboring (traditional design) and the liners counterbored to a radius of a shaft (Fig. 2) showed the following. The type of dependences coincided with the theoretical one, for segment bearings with self-aligning liners (Voskresenskij *et al*., 1983). The nature of a pressure distribution in the case the liners counterbored to a radius of a shaft is smoother (the implementation of the "filled" curves), in the case of the axial counterboring – "peak", the maximum pressure is almost two times as greater than the counterboring to the radius of the shaft. The similar data for a traditional bearing were obtained in the works of (Chernavskij, 1963; Cameron, 1981). A smoother pressures' distribution in the lubrication layer of the bearing points at the increased lifetime of these bearings (Bruce, 2012; Voskresenskij *et al*., 1983). This was confirmed by the experimental researches of bearings with liners counterbored to a radius of a shaft (Gordeev, 2008).

The article presents the mathematical model of the material "metal analogue of rubber". This material allows solving the problem of a vibration protection effectively (Ulanov and Lazutkin, 1997). A material model allows determining the required characteristics of an elastic suspension material for a bearing design. But for an efficient calculation of the system, the finite element model material "metal analogue of rubber" is necessary. You can use the work of (Yan *et al*., 2011; Ulanov and Ponomarev, 2009). In this case, a complex finite model of "working gap-line-elastic suspension" will be created, which will allow solving the conjugated problems of hydrodynamics, thermal analysis and deformation.

CONCLUSION

During the study, a mathematical model of the system "working gap-liner-elastic suspension" was developed as well as the designing method of the hydrodynamic bearing with an elastic suspension of liners, allowing finding the optimal characteristics of a material of an elastic suspension on the basis of the results of hydrodynamic calculations. The proposed bearing is an effective solution for heavy loaded rotors that require a dynamic stability and a long lifetime of a bearing. As a part of a cast support, a sliding bearing of a "dry crankcase" with liners counerbored to the radius of a shaft can serve as an effective substitute for rolling bearings and sliding bearings of a traditional construction. However, the article does not solve the following problems: hydrodynamic, thermal and deformational, which is a limitation of this work. Solving these problems will allow simulating a real loading of bearing elements and increase sufficient a validity of design calculations. It is also necessary to conduct a model interaction in an "elastic suspension liner gap" with the use of FSI technology. This requires the use of a finite element model of a material of an elastic suspension.

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