14th World Congress in Computational Mechanics (WCCM)
ECCOMAS Congress 2020
Virtual Congress: 11 – 15 January 2021
F. Chinesta, R. Abgrall, O. Allix and M. Kaliske (Eds)

ADVANCED NUMERICAL MODELS FOR DESIGN AND OPTIMIZATION OF THRUST BEARING HYDRODYNAMIC CHARACTERISTICS

OLGA V. ANTONOVA[1], YURI YA. BOLDYREV[2], ALEXEY I. BOROVKOV[1] AND IGOR V. VOYNOV[3]

[1]Higher School of Mechanics and Control, Peter the Great St.Petersburg Polytechnic University
Polytechnicheskaya, 29, 195251, St.Petersburg, Russia
antonova@compmechlab.com, https://www.spbstu.ru/

[2] Higher School of Applied Mathematics and Computational Physics, Peter the Great St.Petersburg Polytechnic University
Polytechnicheskaya, 29, 195251, St.Petersburg, Russia
yyb150546@mail.ru @compmechlab.com, https://www.spbstu.ru/

[3] Institute of advanced manufacturing technologies, Peter the Great St.Petersburg Polytechnic University
Polytechnicheskaya, 29, 195251, St.Petersburg, Russia
voynov@compmechlab.com, https://www.spbstu.ru/

Key words: Optimum design, Thrust bearing, Load Capacity, Microgeometry Profiling.

Summary. Efficiency of hydrodynamic thrust bearings used in a wide range of power machines is characterized by including the load capacity of an oil wedge, which has nonlinear dependence on gap size. In this study we consider the different types of lubricant layer microgeometry profiling with the aim of optimal design of the hydrodynamic bearing characteristics for ensuring the maximum load capacity using advanced numerical models and methods. We enlarge the results of significant research works of J.W. Rayleigh and S. Y. Maday in relation to the hydrodynamic sector self-aligning acting thrust bearings based on advanced numerical methods. Different geometrical parameters which define profile curvature were used as optimization variables. The maximum of pressure integral over the lubricant layer surface as objective function was used. Hydrodynamic problems using Navier-Stocks equations were solved based on numerical approach and commercial CFD code ANSYS/CFX using the St.Petersburg Polytechnic Supercomputer Center.

1 INTRODUCTION

Nowadays, in the field of mathematical modelling thrust bearing characteristics and in face of growing demand of effective thrust bearings with optimal characteristics, advanced numerical procedures and methods are widely applied for bearing design. For different type of bearings one of the important problems is the load capacity maximization, which determines the efficiency of the bearings. The load capacity maximization problem generally is equivalent to the problem of profiling the microgeometry of the thrust bearing lubricating layer.

In this study, the problem of optimal design is considered in relation to the design of a thrust bearing with self-aligning segments using numerical models of working fluid domain.

Typical design of thrust bearing with self-aligning segments produced by Kingsbury Inc. [1,2] are shown in Figure 1. For this type of bearing hydrodynamic characteristics were considered in detail in previous works [3,4].

Figure 1: Typical thrust bearing design

2 MATHEMATICAL MODELS

In this study, to determine the pressure fields in the lubricating layer computational fluid dynamics methods are used, based both on the models of the Navier-Stokes equations and their development – models turbulent flows based on the Reynolds equations and on the basis of the equations hydrodynamic theory of lubrication.

Dimensionless form of Navier-Stokes equations was used (1), where V is the velocity vector, p is the pressure, P and L=R c pressure and size scales, ρ and ν are the density and kinematic viscosity. For the velocity scale ωR, is chosen, and for the pressure scale, the pressure of the external medium is p_a:

$$
\begin{gathered}
(V \cdot \nabla)V = -Eu\,grad\,p + \frac{1}{Re}\nabla^2 V \\
div V = 0 \\
W = -\int_{\Omega} p\,d\Omega \\
p|_{\partial\Omega} = 0
\end{gathered}
\tag{1}
$$

Euler and Reynolds numbers:

$$
\begin{gathered}
Eu = P/\rho V^2 \\
Re = |V|\,L/\nu
\end{gathered}
\tag{2}
$$

The working fluid domain is represented in Figure 2. The left part of this figure illustrates area Ω. For equations (1), (2) $r \in \Omega$. The right part shows the working domain investigated using

ANSYS CFX software

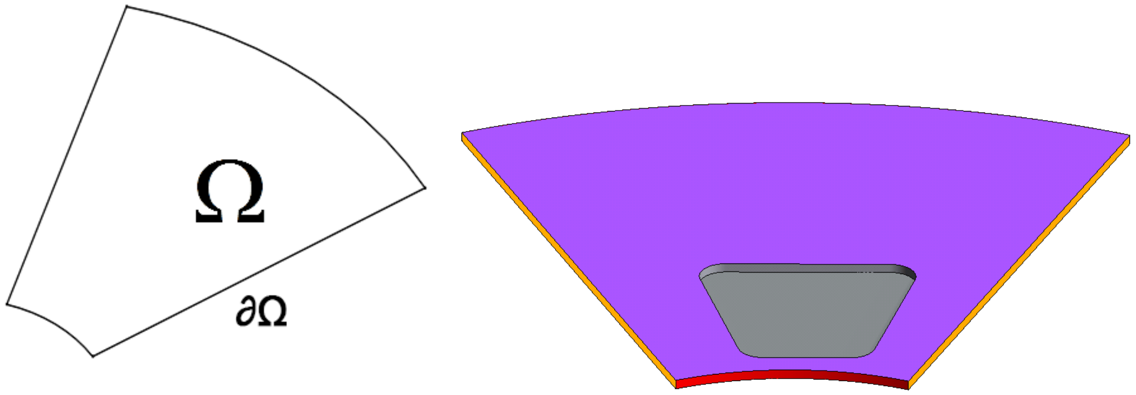

Figure 2: Single segment assembly and working fluid domain

Dimensionless form of Reynolds equation (3) for compressible fluid in Ω

$$div(h^3 p \nabla p - \Lambda phV) = 0 \quad (3)$$

Here, dimensionless pressure p and coordinates r and φ are normalized by ambient pressure pa, and by Lr и Lφ values. Profile function h is normalized by h_{min} Velocity vector V=(1,0) normalized by value |V|.

The typical mesh of fluid domain is represented in Figure 3. It is important that the lubricant layer zone has not less than 40 elements and also has mesh thickening toward the rotating surface.

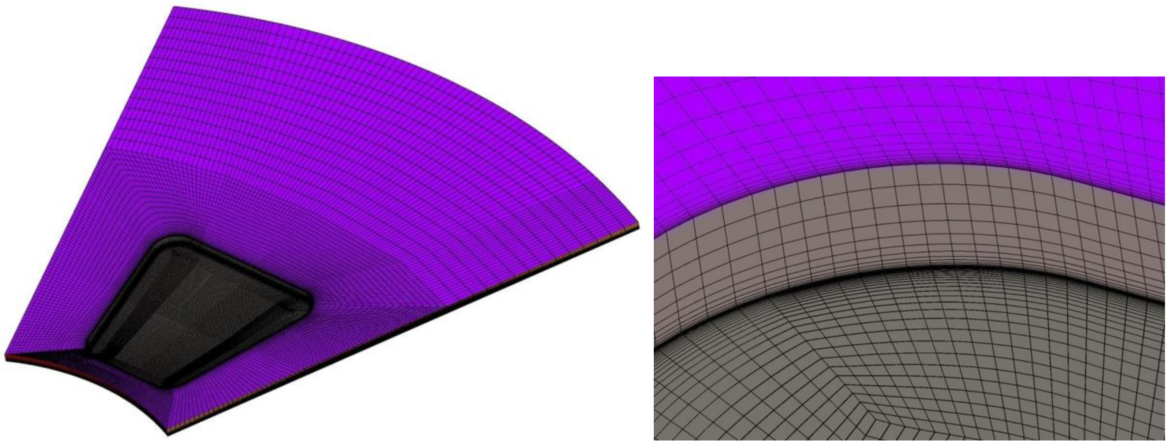

Figure 3: Fluid domain mesh

3 OPTIMIZATION PROBLEM STATEMENT

Consider the formulation of the optimization problem for a bearing segment in a liquid with the criterion of the maximal bearing capacity based on the Reynolds model of the lubricating layer [4,5].

The optimization problem formulation is represented below (4):

$$\begin{gathered} div(h^3 p \nabla p - \Lambda p h V) = 0 \; in \; \Omega \\ p|_{\partial\Omega} \\ h \geq 1 \\ W = -\int_{\Omega} p d\Omega \end{gathered} \tag{4}$$

where, p and the coordinates r and φ are normalized by the ambient pressure p_a, and the corresponding dimensional values L_r and L_φ, characterizing segment dimensions. The profile function h is normalized by h_{min}. The velocity vector Vφ=(1,0) normalized by the maximum value of |Vφ|.

The optimization problem for sector region was solved. Thrust bearing profile was approximated by curve consisted of two parts: straight line and generalized ellipse. Sector region was received by transformation from rectangular region and four geometrical parameters defined the generalized ellipse.

4 NUMERICAL RESULTS

To solve the optimization problem, the CFD mesh for investigated fluid domain was generated and the hydrodynamics problem, using Navier–Stokes equations, was solved using ANSYS CFD software in combination with commercial optimization code IOSO. As an objective function, the maximum of pressure integral over the lubricant layer surface was used.

The IOSO software uses its own algorithm. The main step is to divide each iteration of the Pareto frontier search into two stages: the construction of functions approximating the objective functions in a certain area and the extremes search of these approximation functions. Below are the results obtained using the IOSO software.

The numerical simulation of the problem was carried out using St. Petersburg Polytechnic Supercomputer Center. In Figure 4 the typical pressure distribution received for single segment is shown.

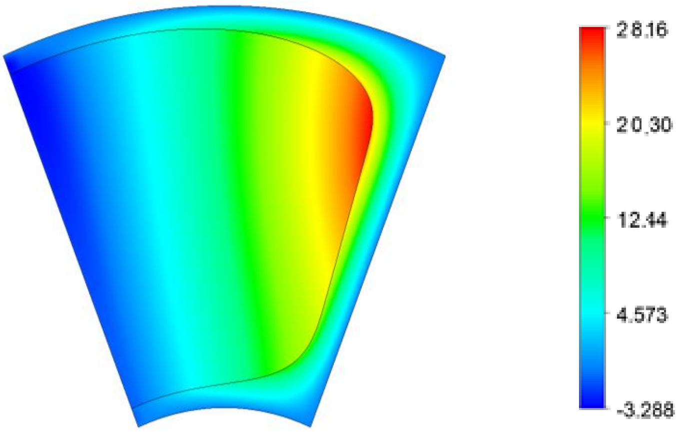

Figure 4: Pressure distribution

4.2 Optimization results

Initially dependences of pressure are received separately for each of the optimization variables. Based on these preliminary results variable's ranges were defined.

As a result of numerical solution, the optimal parameters and thrust bearing design were found. In Figure 5.the dependence of lifting force on generalized ellipse parameters is represented.

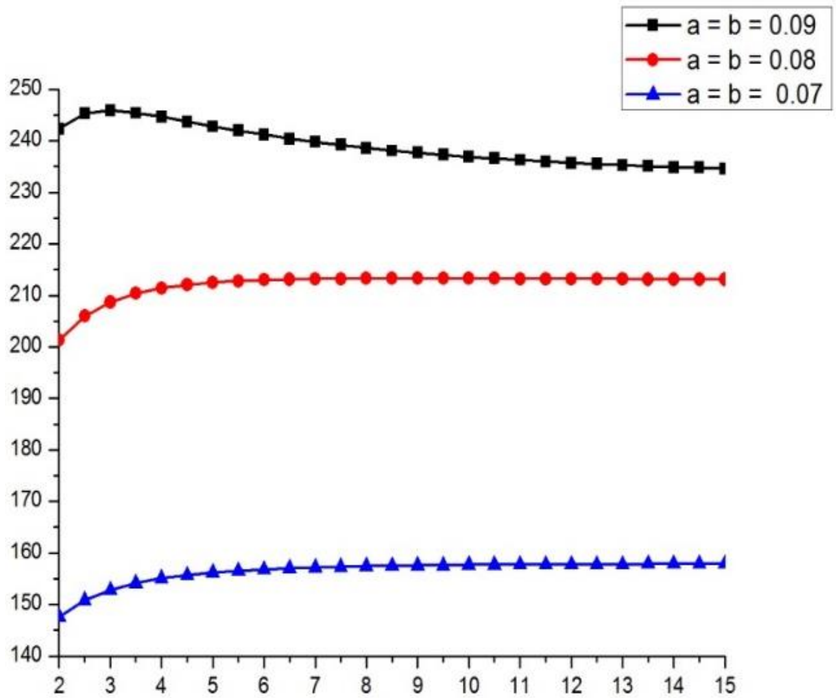

Figure 5: Dependence of lifting force on generalized ellipse parameters

Obtained results demonstrate the greatest impact on the load capacity value and are discussed in detail in previous works of authors [3,4] with more results with different optimization algorithms using [6-8].

5 CONCLUSIONS

We considered the solution to the optimal design problem for thrust bearings with respect to the lifting force maximum. As a mathematical model the Reynolds model for an incompressible lubricant was used. To obtain the results, it is important to use modern software tools efficiently both for solving the problem of the pressure field determination and for the optimization. The results obtained are well correlated with results obtained earlier in the framework of full scale variational problem and can be used in design process of wide range of thrust bearings.

REFERENCES

[1] The Mechanical Engineering reprint of December 1950 by Albert Kingsbury titled «Development of the Kingsbury Thrust Bearing»

[2] Kingsbury A. Experiments wits an air lubricated bearing // Journal American Society of Naval Engineers. v.9. 1897. - pp.267-292.

[3] Antonova, O.V., Boldyrev, Y.Y., Borovkov, A.I., Voinov, I.B. On the Development of a Design Procedure of the Hydrodynamic Characteristics of Hydrogenerator Thrust Bearings Taking into Account the Heat Exchange. Journal of Machinery Manufacture and Reliability Volume 46, Issue 6, 2017, pp 572-578.

[4] Antonova, O.V., Boldyrev, Y.Y., Borovkov, A.I., Voinov The Problem of Constructing Optimal Processable Profiles of Plain Bearings. Journal of Machinery Manufacture and Reliability Volume 49, Issue 9, 2020, pp 757-762.

[5] Yu. Ya. Boldyrev Variational Rayleigh Problem of Gas Lubrication Theory. Low Compressibility Numbers. Fluid Dynamics Volume 53, Issue 4, 2018, pp 471-478.

[6] Turco A. (2010) Adaptive Filter SQP. In: Blum C., Battiti R. (eds) Learning and Intelligent Optimization. LION 2010. Lecture Notes in Computer Science, vol 6073. Springer, Berlin, Heidelberg

[7] Turco A. Adaptive Filter SQP – Description /Alessandro Turco – Techical Report 2009-002, Esteco modeFrontier UserGuide, June 22, 2009, p.11

[8] Nelder J.A. A Simplex method for function minimization/ J.A. Nelder, R. Mead// Computer Journal, vol. 7, p. 308 1965