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OPTIMUM DESIGN OF HYDRODYNAMIC THRUST BEARINGS WITH RAYLEIGH'S POCKET PROFILES

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Abstract. Optimum design problem for hydrodynamic self-aligning acting thrust bearings was considered. Based on results for rectangular region the problem for sector region was solved. As an objective function, the maximum of pressure integral over the lubricant layer surface was used and five geometrical parameters described Rayleigh's pocket shape were used as optimization variables during optimization procedure. The bearing pressure distribution was determined on the basis of the Navier-Stokes equations using the ANSYS / CFX software. Numerically the optimization problem was solved using three different methods: IOSO, SIMPLEX and pilOPT+AFilter SQP realized in two commercial optimization software IOSO and modeFRONTIER.

The aim of this investigation was designing the technologically advanced profiles of thrust bearing sector microgeometry ensuring the maximum load capacity.

1 INTRODUCTION

In face of growing demand of effective thrust bearings with optimal performance characteristics, has prompted engineers to apply advanced numerical procedures and optimization methods in bearing design. In this field one of the important problems is the load capacity maximization, which generally determines the efficiency of the bearings. Otherwise, load capacity maximization problem is equivalent to the problem of profiling the microgeometry of the lubricating layer on the basis of the maximum lift force.

In this investigation, the problem of optimal design is considered in relation to the design of a thrust bearing with self-aligning segments. Typical thrust bearings with self-aligning segments are shown in Figure 1. Mostly, for this type of bearings, the shape of the profile is determined by the segment geometry (lining of the segment) and the segment installation angles in the lubricant flow. In work [1], for thrust bearing with self-aligning segments hydrodynamic characteristics were considered in detail.

Figure 1: Typical thrust bearings [2,3]

Here we consider the problem of designing an optimal thrust bearing sector profile based on Rayleigh's pockets. Notable that the first formulations of the considered problem goes back to the work by J.W. Rayleigh published in 1918 [4] and the work by S. Y. Maday published in 1967 [5]. In 1918, Rayleigh established that the optimal profile in one-dimensional case problem is piecewise-step, and indicated that in the spatial case it has the shape of a pocket.

In later works [6, 7] the Rayleigh's results were confirmed already for two-dimensional case in framework of variational problem solution

In our study, the previous results are enlarged in relation to the sector thrust bearings with profiles based on Rayleigh's pocket shape using advanced computing technologies.

2 THEORETICAL BACKGROUND

In our current investigation we formulate the optimization problem in such a way: find among continuous in Ω functions p that satisfy the boundary value problem for Reynolds equation (1, 2) and among piecewise continuous functions h satisfying the condition (3) those that provide minimum to functional (4).

$$div(h^3\nabla p - hV) = 0 \; in \; \Omega \tag{1}$$

Here the dimensionless pressure p and the equation (1) is an equation for the excess pressure in the lubricant layer in region Ω.

The boundary conditions for equation (1) correspond to zero pressure on the boundary $\partial\Omega$ of region Ω:

$$p|_{\partial\Omega} = 0 \tag{2}$$

Restriction for the lubricant layer profile function h:

$$h \geq 1 \tag{3}$$

And (4) is the lifting force of the lubricant layer. Note that the negative sign is chosen only according to traditional rules of the variational calculus for searching a functional minimum.

$$W = -\int_{\Omega} p d\Omega \tag{4}$$

This problem statement was described in details in author's previous work [8]

3 OPTIMIZATION PROBLEM STATEMENT AND RESULTS FOR SECTOR REGION

It is quite obvious that solving a full-scale variational problem it is a very time-consuming task. Therefore, for industrial engineering it is important to apply advanced computational technologies based on widely available software resources such different software for optimization [8,] and solving computational fluid dynamics problems. It makes possible to reduce the laboriousness in solving an optimal problem, but requires its specific reformulation.

In our case, this new formulation assumes, firstly, the replacement of the boundary value problem (1, 2) by the boundary value problem for the Navier – Stokes equation in order to determine the pressure distribution, secondly, the parametric specification of the flow region (bearing profile). Note that the functional of our problem remains the same.

Based on results for rectangular region [9, 10] the problem for sector region was solved. In this case profile was approximated by curve consisted of two parts: straight line and generalized ellipse. Figure 2 shows sector region received by transformation from rectangular region and four geometrical parameters defined the generalized ellipse.(5)

$$(\frac{x}{a})^n + (\frac{y-c}{b-c})^n = 1 \tag{5}$$

These four parameters a, b, c and n together with Rayleigh's pocket depth h were used as optimization variables during optimization procedure (n is generalized ellipse exponent).

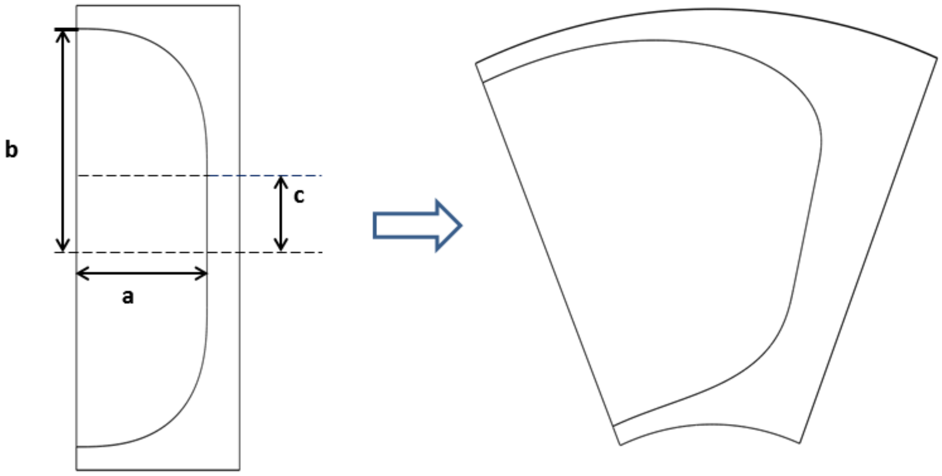

Figure 2: Sector region

The optimization problem was solved using three different numerical methods: IOSO, SIMPLEX and pilOPT+AFilter SQP. First one is realized in commercial optimization code IOSO and two others are integrated in code modeFRONTIER.

pilOPT is a multi-strategy self-adapting algorithm that combines the advantages of local and global search, and balances in an intelligent way the real and RSM-based [11] optimization in the search for the Pareto front. pilOPT gives remarkable performance even when handling complex output functions and highly-constrained problems. It can be used for both single and multi-objective optimization problems, even though it performs better with the latter.

Adaptive Filter SQP (AFSQP) [12] is a Sequential Quadratic Programming algorithm which obtains global convergence through an adaptive filter technique. AFSQP is developed by Esteco scientific team [13] with the purpose of reducing the number of evaluations required and of handling constraints characterized by possibly different numerical scales.

Finally, SIMPLEX is the «Nelder & Mead Simplex» [14] updated to take into account discrete variables and constraints. SIMPLEX is an algorithm for non-linear optimization problems, not the simplex method for linear programming. It does not require derivatives evaluations, so it is more robust than algorithm based on local gradients.

The IOSO software uses an algorithm whose key 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 and modeFRONTIER software.

Let's proceed directly to the optimization procedure. To solve the optimization problem, the CFD mesh for investigated domain was generated and the hydrodynamics problem, using Navier–Stokes equations, was solved. As an objective function, the maximum of pressure integral over the lubricant layer surface was used.

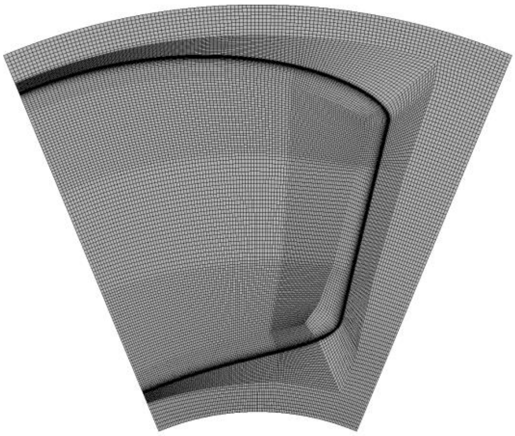

Figure 3: CFD mesh for investigated domain

Initially dependences of pressure are received separately for each of the optimization variables. Figure 3 shows the typical dependence for generalized ellipse exponent and also demonstrates the greatest impact on the load capacity value. Based on these preliminary results variables ranges were defined. Figure 4 illustrates selected ranges.

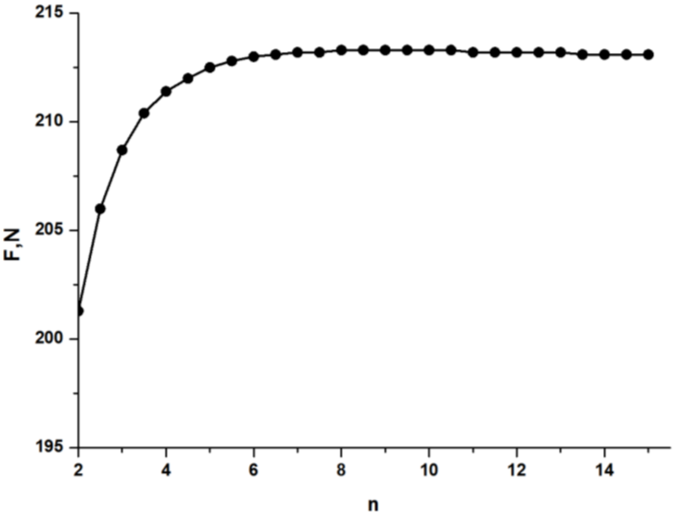

Figure 4: Dependence of lifting force on generalized ellipse exponent

The numerical simulation of the problem was carried out using St. Petersburg Polytechnic Supercomputer Center. As a result, using three different methods, the optimal parameters were found.

Table 1 presents four of them. In Figure 5 the pressure distribution for the optimum profile is shown and in Figure 6 the dependence of the maximum pressure on a coordinate for section y=0 is demonstrated.

Table 1: Optimization results

Method/parameter	a,m	b,m	c,m	n
IOSO	0.089	0.090	0.035	3.7
SIMPLEX	0.090	0.089	0.030	3.5
pilOPT+AFilter SQP	0.090	0.089	0.030	4.5

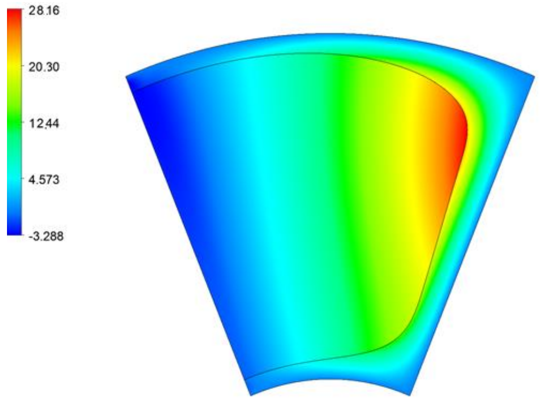

Figure 5: Pressure distribution for the optimum profile, kPa

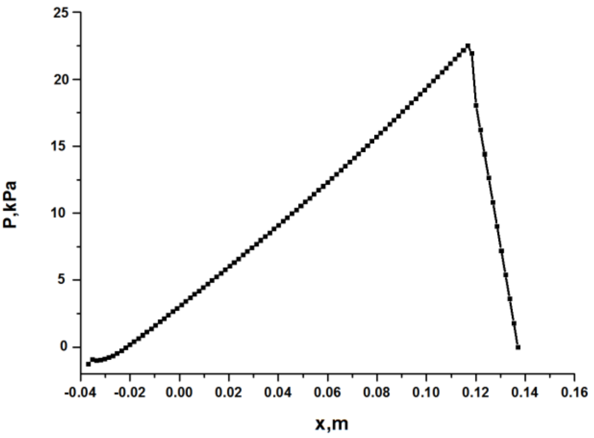

Figure 6: Dependence of pressure on a central coordinate

4 CONCLUSION

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.

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