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Numerical Simulation of Flows through Labyrinth Seals

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Abstract. A numerical code for calculation of leakage flow and rotordynamic coefficients of labyrinth seals has been developed. The code is based on the solution of Reynolds-averaged Navier--Stokes equations combined with a two-equation turbulence model. The numerical solution is achieved with finite volume method and the rotordynamic coefficients are evaluated from several simulations with different rotor precessions. The solution is compared to single control volume based bulk flow method [2].

Introduction

Labyrinth seals are commonly used in turbines and compressors to dissipate energy and reduce the amount of leakage flow. Unfortunately the rotor vibrations cause a non-uniformity in the circumferential pressure distribution which in turn produces forces acting on the rotor and can cause the rotor to become unstable. The prediction of rotordynamic coefficients and leakage flow for a straight-through teeth on stator labyrinth seal is the main subject of this work.

Flow field and rotordynamic coefficients calculation

The code is based on the implicit 3D finite volume scheme with AUSM type flux splitting for convective terms and central approximation for viscous terms. The system of Navier-Stokes equations is combined with standard two-equations SST $k - \omega$ model. The steady state solution is sought for precessing rotor in the rotating frame of reference whose angular speed corresponds to the precession. The forces acting on the rotor are evaluated for each precession speed and finally the rotordynamic coefficients (i.e. stiffness coefficients K, k, and damping coefficients D, d) are calculated using least-squares method from (see [1])

$$F_r/\epsilon = -(K + d\Omega), \quad (1)$$
$$F_t/\epsilon = k - D\Omega. \quad (2)$$

Here F_r and F_t are the radial and tangential components of the force, ϵ is the rotor displacement, and Ω is the precession angular speed.

Results

The simulation has been run for straight-through type of seal with parameters given in the table 1. The predicted leakage flow rate 0.222 kg/s corresponds well to the reference solution obtained with OpenFOAM package (0.223 kg/s) as well as with simple bulk-flow (0.208 kg/s) and with experimental data [1] (0.205 kg/s). The table 2 shows calculated force components for different precession speeds relative to rotor angular speed.

Table 1: Geometrical and operationg parameters of the labyrinth seal with 8 teeth on stator.

Shaft radius	75.578	mm	Tooth clearance	0.229	mm
Tooth width	0.152	mm	Tooth height	3.175	mm
Tooth pitch	3.175	mm			
Inlet total pressure	18.3	bar	Inlet temperature	300	K
Inlet swirl	12	m/s	Outlet pressure	10.248	bar

Table 2: Force components for various precession speeds

	PFR=0	PFR=1/4	PFR=1/2	PFR=3/4	PFR=1
F_{rad} [N]	-0.57	0.09	0.75	1.40	2.06
F_{tan} [N]	2.50	2.59	2.74	2.95	3.22

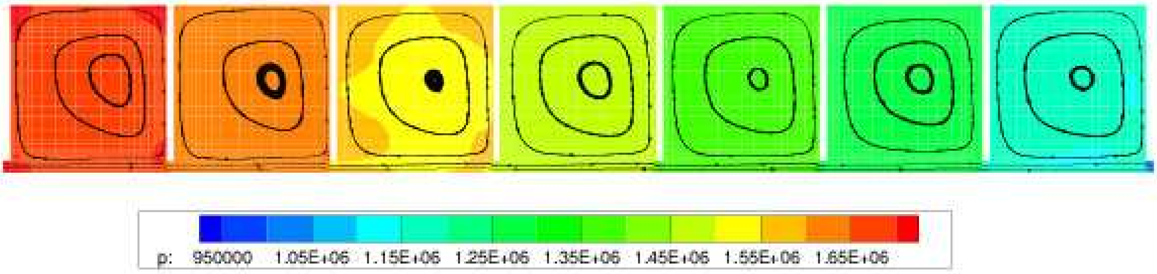

Fig. 1: Pressure distribution and streamlines in 2D cut through labyrinth seal.

Summary

The code for calculating leakage flow and rotordynamic coefficients has been developed. The predicted leakage flow rate corresponds very well experimental data as well as with correlation based bulk-flow and with fine mesh solution using OpenFOAM package. The calculated force components agree for PFR=0 with OpenFOAM solution.

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References

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