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TOTAL PRESSURE DISTRIBUTION OF LABYRINTH SEAL INVESTIGATION

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Abstract: *This article would like to introduce the total pressure investigation in a labyrinth seal test device. Labyrinth seals are commonly used in gas turbines. The labyrinth seal incorporates typical setting and control which is using in the turbopropeller gas turbine in aviation. Based on the previous research at Center of Aviation and Space Research, the new labyrinth seal test device was designed. The research is focusing to evaluate the pressure and total temperature sensitivity study which can be evaluate in real measurement in the future. The description of the test device is included.*

Keywords: Labyrinth seal, Turbopropeller gas turbine, Labyrinth seal test device.

1. Introduction

Labyrinth seals are an integral part of the general turbomachinery. The seals are using for contactless sealing in the secondary air flow path (Sultanian, 2018). In this article, the main point is to investigate the air flow in labyrinth seal in a turbopropeller gas turbine. The turbopropeller gas turbine is using for propulsion turbopropeller aircrafts (Kurzke et al., 2018).

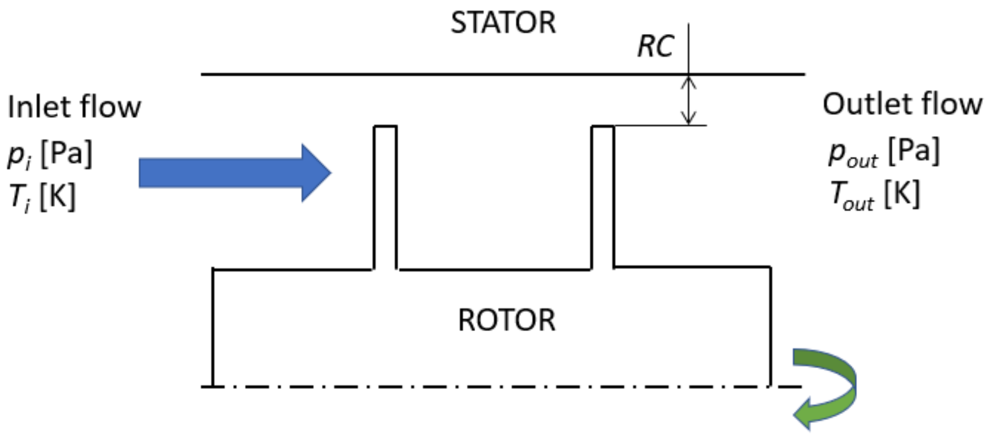

Fig. 1: Labyrinth seal design description

The labyrinth seal air flow is demonstrated in Fig. 1. The air flow is coming from left to right side with the inlet boundary conditions – total inlet pressure p_i [Pa] and total inlet temperature T_i [K]. The outlet boundary conditions are described by outlet pressure p_{out} [Pa] and total outlet temperature T_{out} [K]. There are teeth between the inlet and outlet cross-sections. The distance between the tip of the teeth and the stator wall is radial clearance *RC* [mm]. Earlier research published by Čížek et al. (2020) shows that the total temperature in the labyrinth seal increases. In a subsequent article Čížek et al. (2021) published a comparison of total temperature measurements and Computational Fluid Dynamics (CFD) calculations. The main goal of this paper is to extend the computational matrix, which was published in Čížek et al. (2022), by cases of other boundary conditions of total pressure.

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2. Test device description

In the Center of Aviation and Space Research, the new labyrinth testing device was designed and manufactured. The cross section of the device is in Fig. 2.

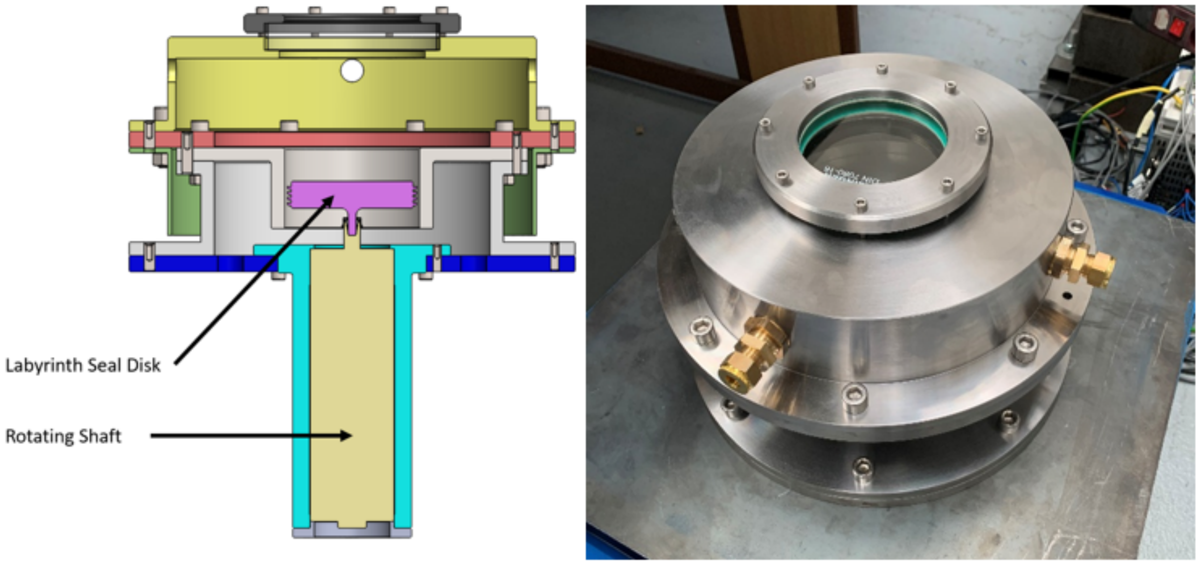

Fig. 2: Description of the testing device

3. CFD analysis

Numerical analysis was calculated using the CFD computing software CFX, which is one of the two CFD solvers available in ANSYS. Four teeth were used in the test equipment and in the calculation, as this configuration is common in an aviation gas turbine. The boundary conditions for the analysis were:

- $RC = 2$ mm
- $p_i = [200, 300, 400]$ [kPa]
- $p_{out} = 101.325$ [kPa]
- $T_i = [288, 423]$ [K]
- $T_{out} = 288$ [K]
- Rotational speed $n = [5, 10, 15, 20, 25, 30, 35, 40, 45, 50] * 10^3$ [min^{-1}]

Based on previous research in Čížek et al. (2022), the turbulent model k-ε was used in all calculations. Air Ideal Gas is used as the flow medium.

The temperature T_{out} represents the opening outlet temperature for 1st iteration (ANSYS Help). The aim of these calculations was to perform an analysis of the inlet total pressure and the inlet total temperature of the labyrinth seal.

A total of 60 calculations were performed. Two parameters were examined in the calculations:

- Pressure difference between the inlet and outlet of the labyrinth seal Δp
- Total temperature difference between the inlet and outlet of the labyrinth seal ΔT

Figures 3 and 4 show the overall temperature and pressure differences. In both graphs, it is possible to see pressure and total temperature differences in 10 constant values of steady state rotational speed, when the total temperature increases and the pressure keeps an approximately constant value. It can be seen that when the inlet pressure is higher, the overall temperature difference is smaller in both settings (i.e., T_{in}).

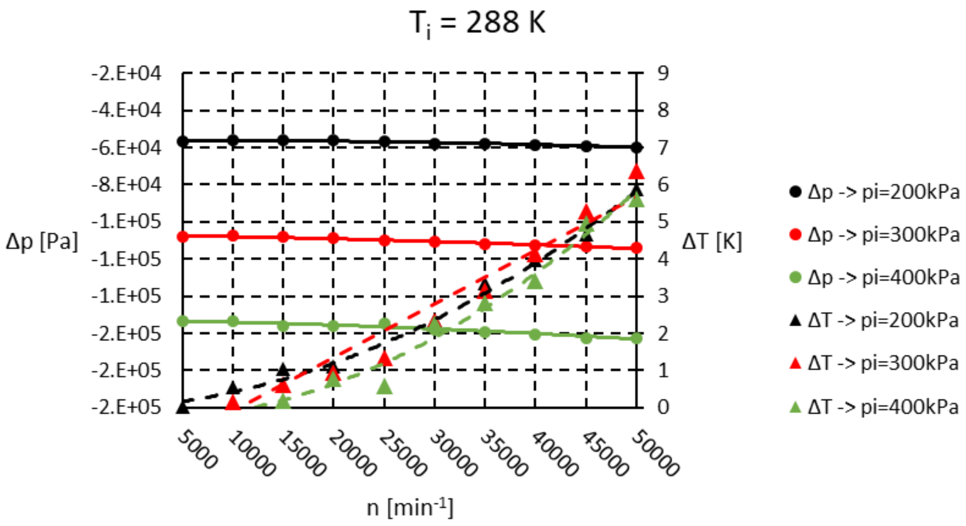

Fig. 3: Total temperature and pressure differences distributions with 288 K inlet temperature

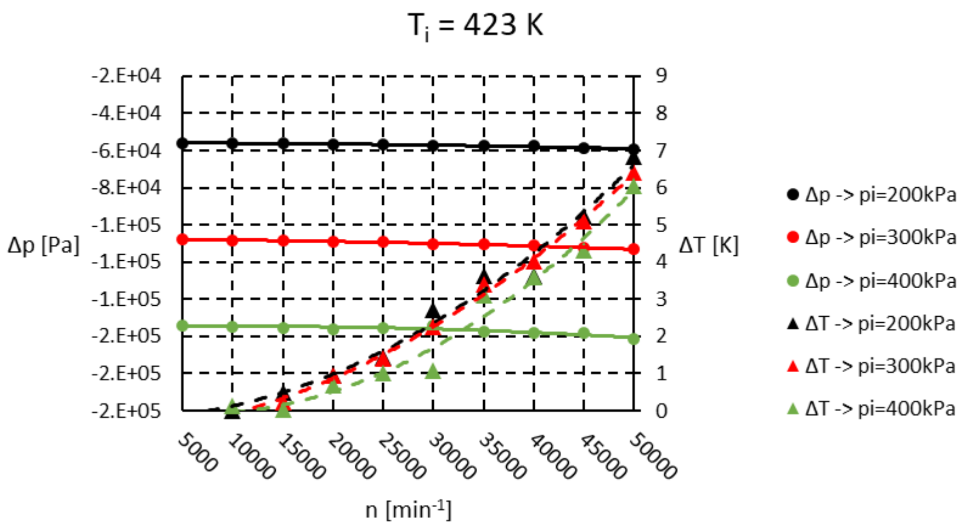

Fig. 5: Total temperature and pressure differences distributions with 423 K inlet temperature

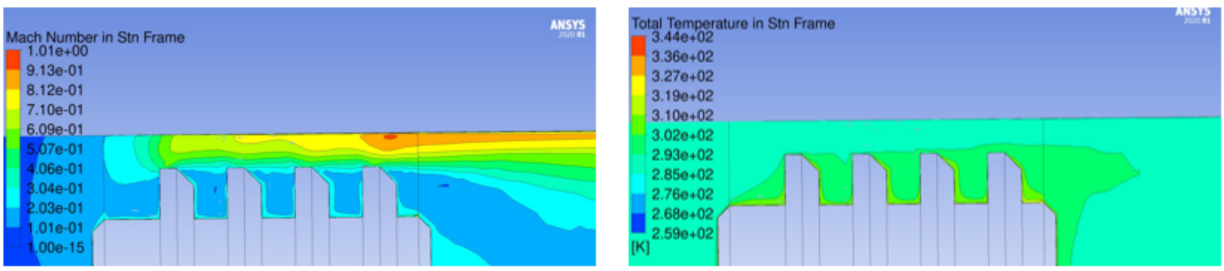

Fig. 4: Mach number and total temperature distributions

Figure 5 shows the Mach number and the total temperature distribution in the cross section of the seal. The Mach number is maximal in the last teeth, because in the last teeth the air flow expands to the surroundings of the seal.

4. Results

From the plots it is possible to see how the labyrinth seal is working. In general, for good sealing in the secondary air flow path it is necessary to have *RC* as small as possible. In this test device, the clearance is set to 2 mm. In (Čížek et al., 2020) it is possible to see the sensitivity of the radial clearance size. Despite the fact that the clearance is relatively large, the total temperature difference is higher than 5K. This corresponds to previous research. The Mach number and total temperature distributions are shown in Fig. 5.

Tab. 1: Constant rotating speed pressure and temperature differences comparison

p_i [kPa]	T_i [K]	n [min-1]	Δp [kPa]	ΔT [K]
200	288	20000	-56.2	1.12
		50000	-60	5.87
	423	20000	-56.4	0.96
		50000	-59	6.84
300	288	20000	-108.9	0.94
		50000	-114.2	6.37
	423	20000	-108.9	0.95
		50000	-113.3	6.4
400	288	20000	-156.3	0.78
		50000	-162.4	5.63
	423	20000	-155.8	0.7
		50000	-161.3	6.07

Table 1 shows the pressure and total temperature differences for the two constant speed values. It is possible to see that the inlet pressure has no significant effect on the total temperature. A higher impact than the inlet pressure has the inlet temperature. Under conditions of a constant speed of 50,000 rpm, it can be seen that the difference is greater than 1.1 K. It is not a negligible value, because when the RC should me smaller, the total temperature difference should be higher. For the future, it is necessary to 1. verify the obtained values within a correct measurement campaign and 2. update the calculation and the test device for more variants of the radial clearance, because in aviation gas turbines is possible to see smaller values.

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