27/28th International Conference
ENGINEERING MECHANICS 2022
Milovy, Czech Republic, May 9 –12, 2022
Paper **#108**, pp. 305–308, doi: 10.21495/51-2-305

INFLUENCE OF THERMO-MECHANICAL DEFORMATION ON THE LABYRINTH SEALS EFFICIENCY

Pařez J.[*], Čížek M.[**], Vampola T.[***]

Abstract: *This paper describes the influence of turbine engine operating conditions on the labyrinth seals and the related rotor and stator parts deformation. As the deformation due to centrifugal force and temperature field increases, the radial clearance between the stator and rotor decreases, and thus the operating conditions and efficiency of the entire turbine engine are changed. The paper presents a numerical calculation of the flow and a finite element calculation of the deformation in two operating modes, as well as the calculation model of labyrinth seals, which are often incorrectly used in research. Furthermore, the change of parameters depending on the number of labyrinth seal stages in the axial direction is studied. The result of the study is the dependence of efficiency on the size of the radial clearance and operating conditions.*

Keywords: Labyrinth seals, Thermo-mechanical deformation, Turbine engine, Efficiency.

1. Introduction

During turbine engine operation, a number of thermomechanical effects occur on engine components due to operating conditions. The components are stressed as a whole engine due to the operating conditions and interactions. These effects are classified according to the mechanism of their occurrence and studied according to the effects on the stress and deformation of the parts. It is clear that the influence of some mechanisms, such as centrifugal loading due to rotation or thermal deformation of high-temperature loaded parts, dominates. However, it is necessary to consider mechanisms that have a lesser influence on the overall deformation and stress. These mechanisms may not have a significant effect on the safe operation of the engine, but may have a positive or negative effect on the performance, efficiency, and maintenance of the engine.

This paper presents a numerical study of the effect of operating conditions on the assembly of labyrinth seals for aircraft turbine engines. These labyrinth seals are used to seal the high-pressure section of the engine secondary flow path from the ambient pressure section. The reason for using labyrinth seals as opposed to other sealing methods is the high speed of the rotor system, which in combination with the high temperature and pressure of the flowing gas can reach more than 50,000 RPM. Last but not least, the reason is that the equilibrium of the rotor system is not disturbed. The pressure efficiency of the labyrinth seals, which can be defined in Eq. 1 as the static pressure drop with respect to the ambient pressure, has a significant influence on the thermodynamic efficiency and losses of the entire turbine engine system.

$$\eta = \frac{p_{out} - p_{atm}}{p_{in} - p_{atm}} \tag{1}$$

The seal assembly consists of a stator part and a rotor part, with the seal teeth on the shaft shown in Fig. 1. The efficiency of labyrinth seals is determined by the flow rate of air through the seals and the related static pressure reduction on the seal's outlet. A current vortex is created between the tips of the rotating teeth and

[*] Ing. Jan Pařez.: Department of Mechanics, Biomechanics and Mechatronics, Faculty of Mechanical Engineering, Center of Advanced Aerospace Technology, Czech Technical University in Prague; Technicka 4; 160 00, Prague 6; Czech Republic, Jan.Parez@fs.cvut.cz

[**] Ing. Michal Čížek.: Center of Advanced Aerospace Technology, Faculty of Mechanical Engineering, Czech Technical University in Prague; Technicka 4; 160 00, Prague 6; Czech Republic, Michal.Cizek@fs.cvut.cz

[***] Dr. Ing. Tomáš Vampola.: Department of Mechanics, Biomechanics and Mechatronics, Faculty of Mechanical Engineering, Center of Advanced Aerospace Technology, Czech Technical University in Prague; Technicka 4; 160 00, Prague 6; Czech Republic, Tomas.Vampola@fs.cvut.cz

the stator part, resulting in a reduction in airflow. The dimension of the radial clearance is then influenced by this vortex and is therefore the most important design parameter of the seals.

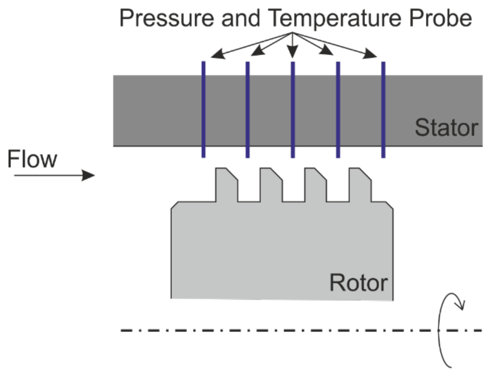

Fig. 1: Labyrinth Seal Scheme

2. Methods

As mentioned above, when labyrinth seals are operated, the entire system is loaded with a combination of mechanical and thermal loads. Radial clearance is chosen as the variable because its size has the greatest influence on the pressure efficiency of labyrinth seals. The goal of the sealant teeth design is to minimize this radial clearance while maintaining the safety and functionality of the entire system. The mechanisms that cause the deformation of the blade disk and, consequently, the reduction of radial clearance are listed in the following points.

- Due to centrifugal force
- Due to the disc temperature
- Force from inlet/outlet pressure difference
- On the teeth due to the temperature from the flowing gas in the rotating rotor
- From contact surfaces.

The centrifugal force of a rotating disk, which can rotate more than 50,000 RPM, has the greatest effect on the deformation of the disk and thus reduces the radial clearance. Another mechanism that causes the deformation is the thermal deformation, which corresponds to the heating of the disk by the flowing air to a temperature higher than 300 [°C]. Last but not least, the deformation of the labyrinth seal teeth is influenced by the temperature increase between the individual stages due to thermodynamic friction, as published in (Čížek et al., 2021). The result is a decrease in radial clearance with the number of labyrinth seal stages. The following table Tab. 1 shows the deformations depending on the operating conditions, which are the inlet pressure of 200 [kPa], the inlet temperature, the rotation of the rotor system over 50,000 RPM, and the increase of the thermodynamic temperature due to the friction of the rotating surfaces.

Tab. 1: Deformation under operation conditions.

	Inlet Temperature 15 [°C]		**Inlet Temperature 300 [°C]**	
	Therm. Heating [°C]	**Max. Deformation [µm]**	**Therm. Heating [°C]**	**Max. Deformation [µm]**
Inlet	0	-	0	-
Stage 1	0,9	14,9	1,2	178,8
Stage 2	2,6	15,9	3,7	180,0
Stage 3	3,8	16,7	5,1	181,1
Outlet	5,9	17,3	7,5	182,1

2.1. Computational Labyrinth Seal Model

The default computational model does not consider the disk operating conditions listed in the previous chapter. A similar geometry for all stages is given and does not consider the thermal and mechanical deformation that changes the dimensions for all stages and teeth. This model is very often presented in scientific publications (Kim et al., 2009) and does not correspond to the real behaviour of the assembly.

2.2. Deformed Labyrinth Seal

Under operating conditions, the computational model is deformed and thus its functional properties change significantly. Due to the centrifugal force and thermal load, the disk is deformed and stretched in the radial direction, reducing the radial clearance between the stator and the rotor. Due to the temperature rise caused by the friction, there is non-uniform heating in the axial direction, so the deformation caused by the thermodynamic temperature increases with the number of sealant teeth. In the following Fig. 1 and Fig. 2, the temperature field and the disk deformation for inlet temperatures of 15 and 300 [°C] are shown.

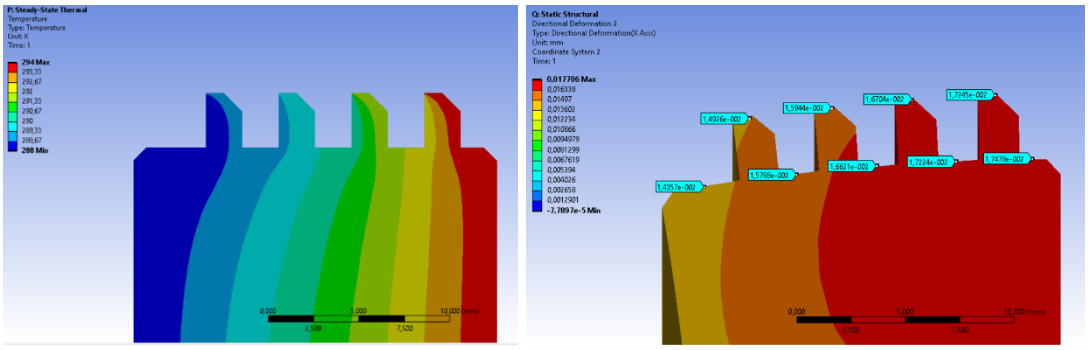

Fig. 1: Deformed Labyrinth Seal – 15[°C].

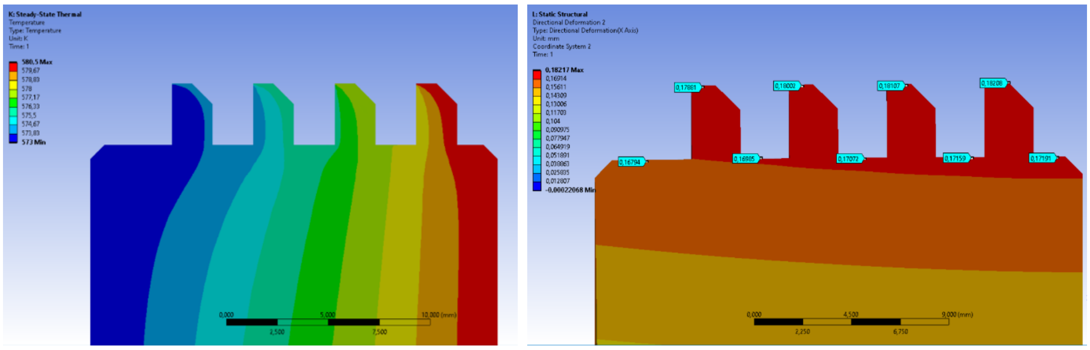

Fig. 2: Deformed Labyrinth Seal – 300[°C].

Numerical Efficiency Results

The aim of the numerical analysis is to determine the partial static pressures and the associated efficiency according to Eq. 1. In the following Fig. 3, the Mach numbers for the computational model and the deformed model are shown.

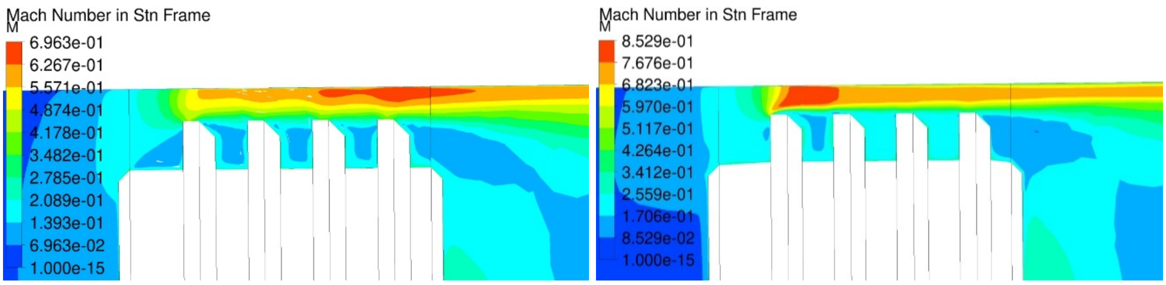

Fig. 3: Mach num. of Comp. Model (left) Compared with Def. Model under 300[°C] (right).

The results in Fig. 3 shown a change in the distribution of the Mach number due to the reduction in radial clearance and a related change in pressure and temperature field. The maximal value of Mach number shifts to the inlet region, causing aerodynamic clogging at the first teeth of the seal. The resulting inlet – outlet values of the static pressure, mass flow and efficiency parameters drop are obtained for the deformed and computational models described above is shown in Tab. 2.

The first, results for 2 undeformed models and 2 deformed models under operating conditions and inlet air temperature of 15 and 300 [°C] is listed. The graphs of the temperature and efficiency parameters on the flow direction are shown in the following Fig. 4 and Fig. 5.

Tab. 2: Results of Labyrinth Seal.

		Deformed Labyrinth Seal Model			Computational Labyrinth Seal Model		
Pin [kPa]	**Tin [°C]**	**Δp [kPa]**	**ΔT [°C]**	**ΔQ [kg*s^{-1}]**	**Δp [kPa]**	**ΔT [°C]**	**ΔQ [kg*s^{-1}]**
200	15	-44,9	5,9	5,14E-06	-59,8	5,8	1,50E-05
200	300	-52,4	7,5	3,46E-06	-58,6	7,2	1,08E-05

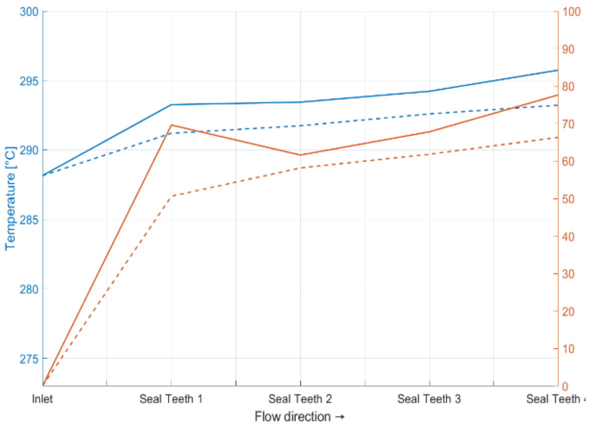

Fig. 4: Num. results with inlet temp. T15deg

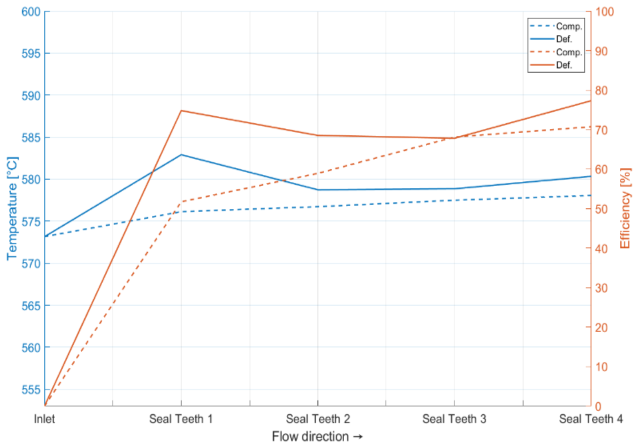

Fig. 5: Num. results with inlet temp. T300deg

3. Conclusions

The influence of operating conditions on the efficiency and parameters of the labyrinth seal in the turbine engine was presented. The computational model and the deformed model under operating conditions with intake air temperature of 15 and 300 [°C] were compared. First, based on the numerical analysis, the thermodynamic heating due to the friction of the vortices of the airflow in each stage of the labyrinth seals was determined. Then, it was determined on the basis of the FEM model of radial deformation, which reduces the radial clearance between the stator and rotor surfaces. Then, the pressure drop was numerically calculated and the pressure efficiency of the labyrinth seal was determined. The results show that the calculation of labyrinth seals must consider operating and thermodynamic conditions, which have a significant impact on the size of the radial clearance and, in this case, have a positive effect on the efficiency of the entire system. Moreover, an increase in temperature with the number of stages and a decrease in radial clearance with the number of teeth in the axial direction are demonstrated. The results presented are then experimentally investigated in a test setup under operating conditions.

Acknowledgement

Authors acknowledge support from the ESIF, EU Operational Programme Research, Development and Education, and from the Center of Advanced Aerospace Technology (CZ.02.1.01/0.0/0.0/16_019/0000826), Faculty of Mechanical Engineering, Czech Technical University in Prague.

References

Čížek, M. and Pátek, Z. (2020) On CFD Investigation of Radial Clearance of Labyrinth Seal of a Turbine Engine. *Acta Polytechnica*, vol. 60, no. 1, pp. 38-48

Čížek, M., Popelka, L. and Vampola, T. (2021) Labyrinth seal total temperature investigation. In *Proceedings Topical Problems of Fluid Mechanics*, ISSN 2336-5781, DOI: 10.14311/TPFM.2021.003, pp. 16-23

Kim, T. S. and Cha, K. S. (2009) Comparative analysis of the influence of labyrinth seal configuration on leakage behavior. *Journal of Mechanical Science and Technology*, vol. 23, no. 10, pp. 2830-2838