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Numerical Investigation of a Labyrinth Seal with number of teeth in an Axial Compressor of a Gas Turbine

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Abstract—
Increase of Aero-engine performance with the improvement of core flow processes has become more and more complicated. So improvement in efficiency of sub systems can improve the overall engine efficiency. Use of labyrinth seal for improvement of secondary flow system performance is popular and common. Labyrinth seal is widely used in sealing solutions of gas turbine due to its low price, low maintenance, high temperature capability and minimal rub particle contamination. Labyrinth seals are normally used to control the leakage flow in the compressor stator well. The upstream and downstream rotor-stator cavities of the labyrinth seal can cause complex reverse leakage flows which affect the compressor efficiency and the overall engine performace. In the present paper numerical study was made to understand the effects of number of teeth over the leakage flow rate.
Keywords*-Labyrinth, rotating cavity, working tip clearance, gas turbine, CFD*

I. INTRODUCTION

Sealing is an important factor in almost every aspect of our daily lives within our homes and vehicles. Varieties of seals are used in the vehicles and the turbochargers with varied designs, materials and purposes. Among them there will be at least one seal whose purpose is to separate engine air flow from lubricating oil, i.e., to avoid mixing them. Our present study is interested in such seals. In the oil and gas industry, or in a petrochemical processing plant, many pumps and compressors are used with similar seals and these seals closely resemble to those used in gas turbine engines on aircraft [4].

The rotors in an aero engine gas turbine run at very high RPM and have high surface velocities. So, the seal need to operate at high clearances or should be lubricated to cool the heated surfaces. The types of seals that are used in a gas turbine are: 1) labyrinth seals, 2) circumferential segmented seals and 3) radial face seals or carbon face seals. In the present work we focus on numerical investigation of smooth land labyrinth seal by changing the number of teeth [4].

As the name imply, a labyrinth seal works by accommodating a contorted path to reduce the flow through that path or simply to inhibit the leakage. A series of restrictions followed by a clear volume creates expansion of a gas and, hence, reduces the pressure. A series of
labyrinth teeth are like series of restrictions arranged to inhibit leakage also the teeth have a close clearance gap between the rotor and stator components. And then a pressure drop occurs across each tooth [4].

II. LITERATURE REVIEW

[1] Relatively simple considerations of a fluid-mechanics nature allow the extension of the validity of Martinis formula for ideal seals to seal configurations in industrial use and give results within 5 per cent of those obtained from measurements using air. The formulas describe the off-design performance of the seals mostly within 8 per cent but at least within 15 per cent of the test results.

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Martin’s well-known formula gives the mass flow for an ideal gland as follows.

$$= 5.68 \frac{1-(\quad)^{-}}{(\quad)^{-} - \ln} \qquad 1$$

[2] Rig testing was conducted by stocker et. al, to determine labyrinth air seal static and dynamic leakage performance for smooth land, abradable land, and honeycomb lands. They used a conventional four knife straight-through seal and an advanced seal design (inclined teeth). The effects of land surface roughness, abradable land porosity, rub grooves, honeycomb cell size and depth, and rotation on seal performance were determined using the conventional straight-through seal.

The major results obtained in this program include the following.

- An advanced labyrinth seal design was developed that reduced leakage 26.9% compared to a conventional stepped seal.
- Using a honeycomb land with the advanced seal increased leakage 68.6% compared to the solid-smooth land.
- Honey comb lands were found to reduce leakage up to 24% for conventional straight-through labyrinth seals.
- Some abradable lands were found to leak substantially more than a solid-smooth land.
- Grooving a porous abradable seal land significantly reduced leakage through the material.
- Rotation reduced straight-through seal leakage up to 10% for smooth and abradable lands, but it had negligible effect with the honeycomb land.
- Rotation decreased the advanced seal leakage approximately 6% for the solid-smooth and abradable lands. However, the honeycomb and experienced a 6.4% leakage increase with rotation compared to the static performance.
- The advanced seal rotational power absorption for the solid-smooth land is approximately the same as the four knife straight-through seal.
- Rotational effects do not influence the selection of the seal knife optimum pitch for a straight-through seal.

III. DESCRIPTION OF GEOMETRY

A. Selecting of seal and system conditions

The seal is selected from the existing turbofan engine. The seal is located at the second stage HP compressor. The geometrical characteristics of the cavity and diameter of the seal are optimized or finalized based on efficiency of other components of the system. And the study on this seal can help in understanding the other seals by extending the results.

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The boundary conditions for the present work are tabulated below. And all the conditions are taken from the physical measurement values during operating conditions of the engine. The seal should be studied and optimized under these boundary conditions.

Table III-1: Boundary conditions

S.NO	PARAMETER/CONDITION	VALUE
1	Rotational speed	20400 rpm
2	Total Pressure at Inlet (rotor exit)	886 kPa
3	Static Pressure at Inlet (rotor exit)	570 kPa
4	Total Temperature	820 K
5	Static Pressure at Outlet (stator exit)	634 kPa
6	Mass flow rate	29 kg/s

B. Seal geometry and analysis

The Figure 3-1 shown below depicts the HP compressor of a gas turbine engine. The stages marked from 1 to 5 are rotors. The stages marked from A to E are stators. There will be axial clearance between rotor and stator. The air flows from rotor 1 to rotor 5 shown in the Figure 3-1. The rotors impart velocity to the air and increase the total pressure of the air while the stator converts part of total pressure to static pressure. So the static pressure will be higher at exit of stator compared to the exit of rotor. The air after stator enters cavity and tries to mix with the air at entry of stator due to the pressure difference. This is not desirable and causes the loss of compressor efficiency. The seal we choose to study is on stator B as shown in Figure 3-1 below. And the cavity is marked in purple.

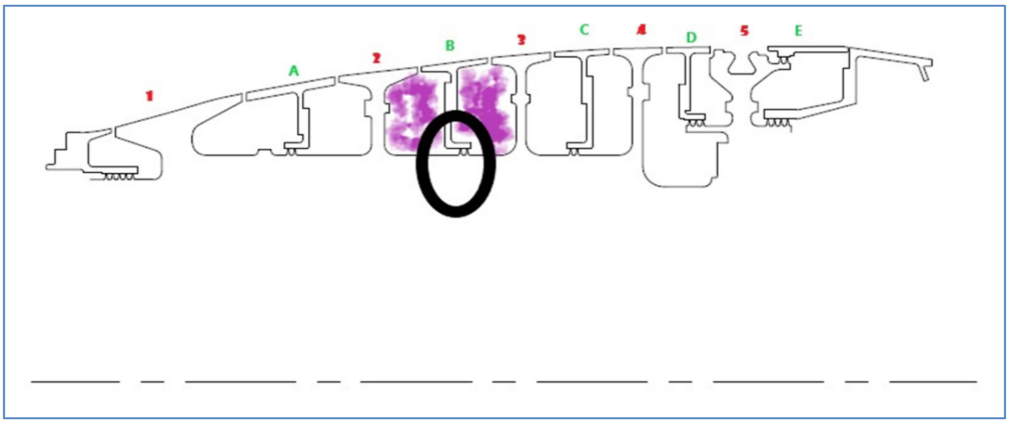

Figure 3-1: Location of seal in a gas turbine engine.

IV. NUMERICAL MODELLING

A. Seal Geometry

The seal cavity is modeled in Ansys design modeler. Figure 4-1 below shows the geometry of the labyrinth seal and seal cavity. Figure 4-1 below shows the boundaries of the geometry.

The Complexity of the model is reduced by ignoring the rotor and stator blades. But the mass flow is matched with the engine mass flow. The percentage of the mass flow entering the cavity and leaking across the seal is measured for seal efficiency.

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The model will be too big to mesh if taken 360^0. So the model is taken only as a 2^0 sector model so that meshing elements will be less. And periodicity condition may be applied during setting up the model. Because we have taken a very small sector which is very thin around 5mm, the analysis is similar to 2D analysis.

The tooth shape is selected with small tip width and the flat bottom based on the results provided at [6]. And the teeth are positioned upstream of the channel. The position of teeth at either upstream or downstream will have better performance of the seal [7].

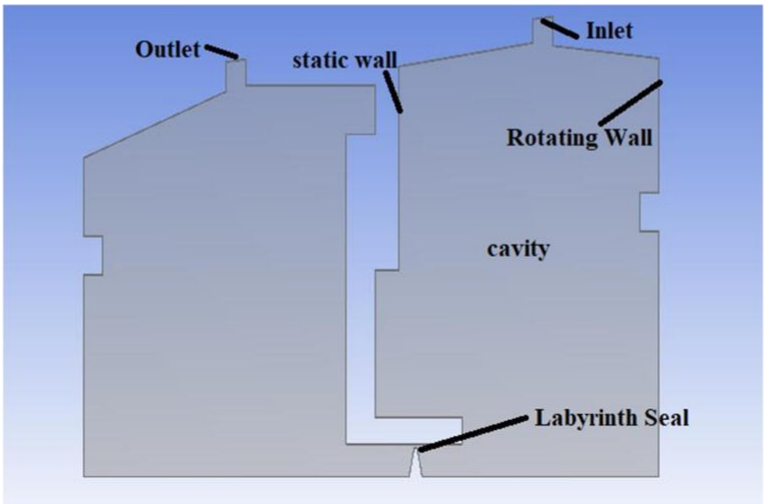

Figure 4-1: Geometry of the Model.

Here the analysis of seal is carried out to compare the results by changing the number of teeth at different clearance values. Figure 4-1 shows only geometry of 1 teeth model. The model will be similar by number of teeth are increased to 2 and 3 and analysis is done.

B. Meshing the model

Structured meshing is adopted to mesh the cavity. Ansys meshing tool is used to mesh the model. The model is a revolved body so sweep method is used to mesh the body. Figure 4-2 below have the sweep method meshing. The meshing near the seal is very fine for better results near that zone. 5 layers are taken around the boundaries for more defined results at the boundary especially at the seal.

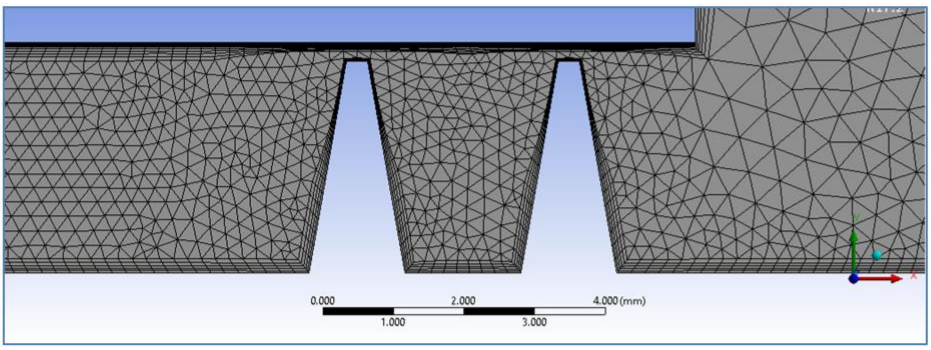

Figure 4-2: Meshing of the model in full cavity

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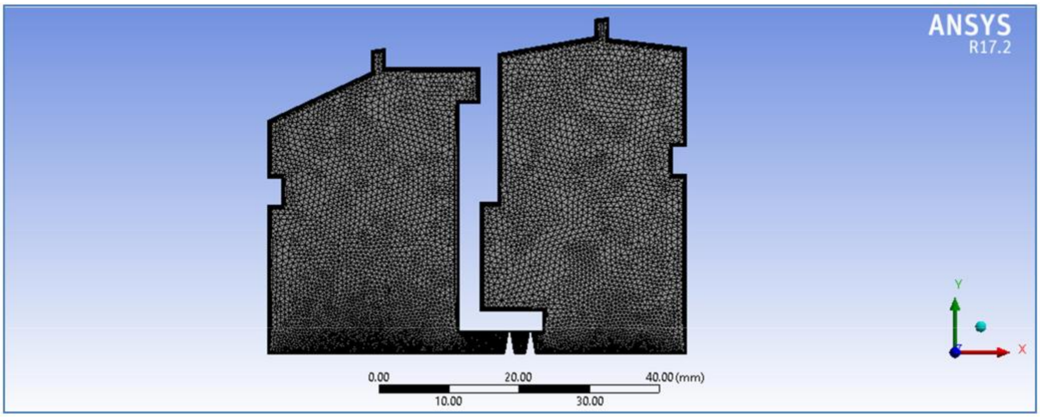

Figure 4-3: Meshing of the model near seal location

C. Setting up the model

The setup for solving the model numerically was done in Ansys FLUENT. A pressure based solver under steady state conditions is used. Turbulent flow model with standard K-ε model [3, 5] and standard wall friction conditions are used. Energy equation is included. Periodicity boundary condition applied to two side walls to make it a 3600 model. All the boundary conditions are as per the Table III-1. SIMPLE scheme as a solution method with least squares cell based with second order upwind for momentum, energy and first order upwind for turbulent KE and dissipation rate. Solutions won't converge above 10-5 for the given geometry. After the grid convergence study the number of elements are chosen to be 2 lakhs beyond which the change in result is not beyond 0.2%

V. RESULTS

The final results are presented in a graphical format below. It clearly shows that as the clearance increases the leakage mass flow increases. And the graph is almost linear with the numerical results. And the leakage mass flow is studied for 1 tooth, 2 teeth and 3 teeth. With increase in number of teeth the constriction increases and net mass flow reduces. The same is found in numerical analysis of the seal. The Figure 5-1 shows that the mass flow across seal reduces as the number of teeth increases. The mass flow with three teeth is almost half of the mass flow with 1 tooth.

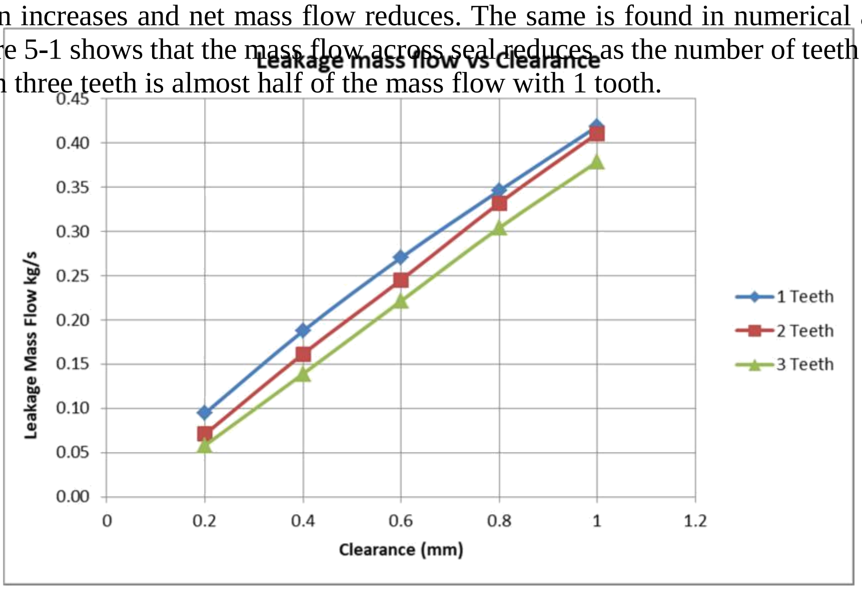

Figure 5-1: Graph showing the variation of leakage flow with change in clearance for different teeth

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The Pressure difference across 1 tooth is higher as compared with pressure difference across 2 teeth. And thus the mass flow across 1 tooth is higher than mass flow across 2 teeth and 3 teeth. The velocity decreases with increase in number of teeth such that the pressure increases and thus reduces the pressure difference. The contour plots of pressure and velocity are given below.

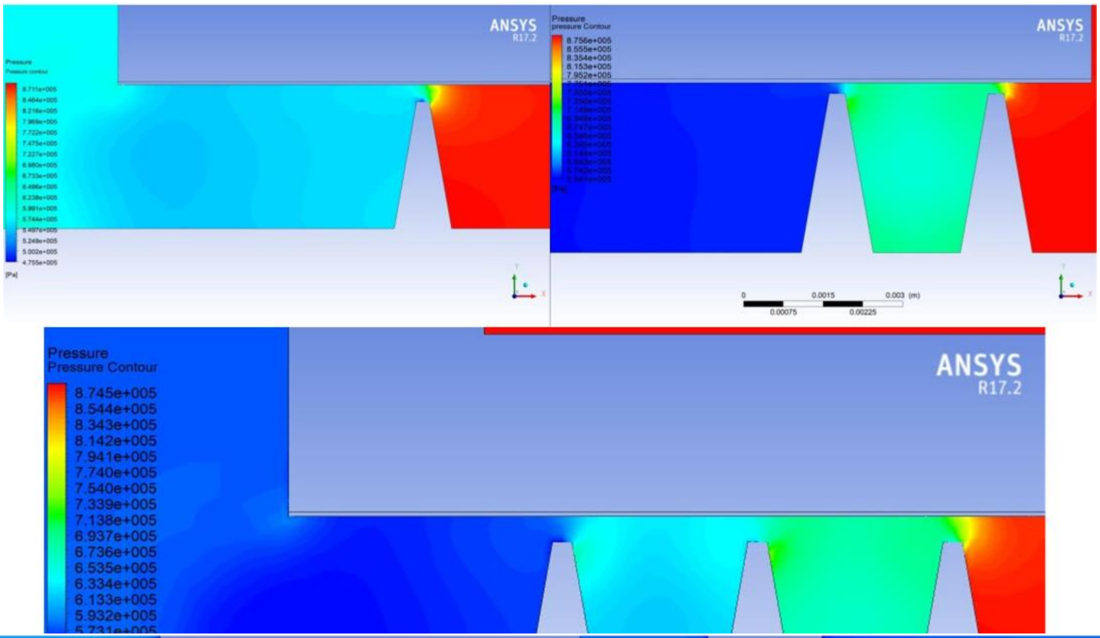

Figure 5-2: Pressure contours showing the pressure difference

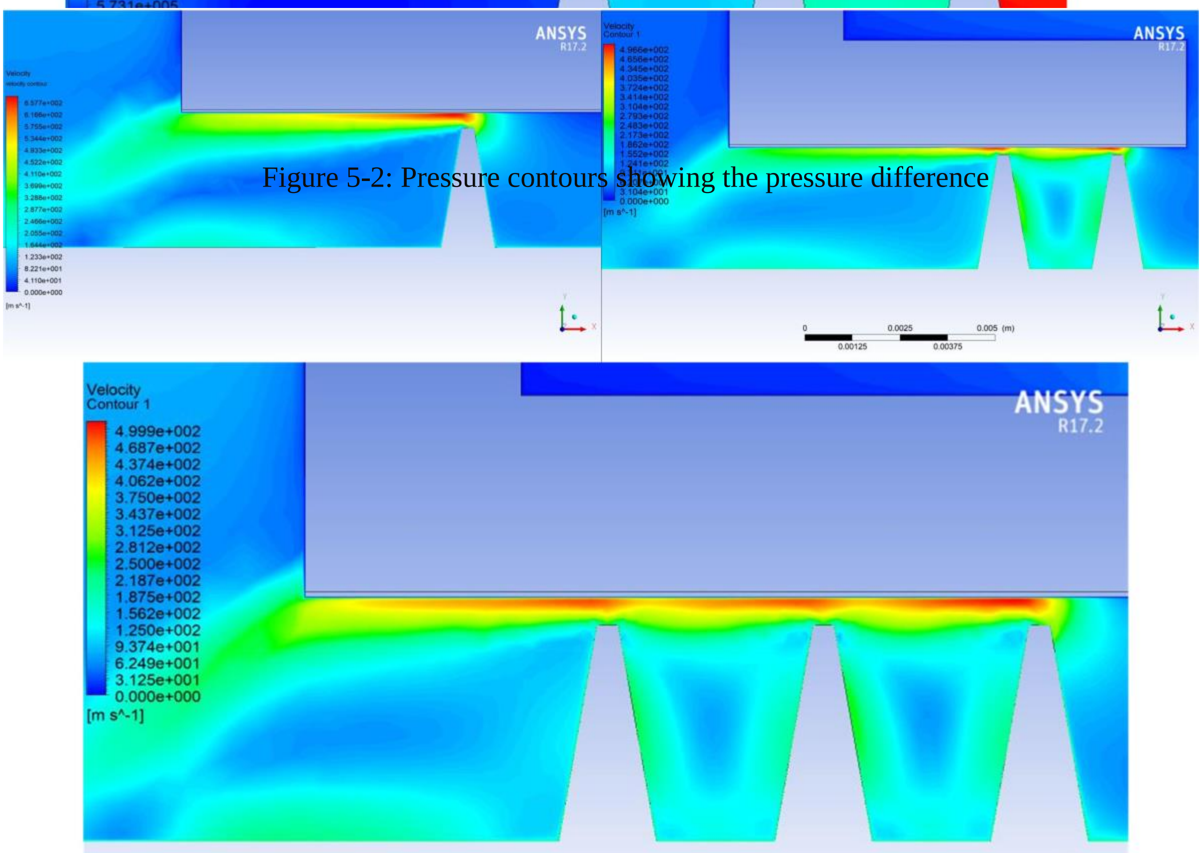

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Figure 5-3: Velocity contour plots showing the velocity patterns

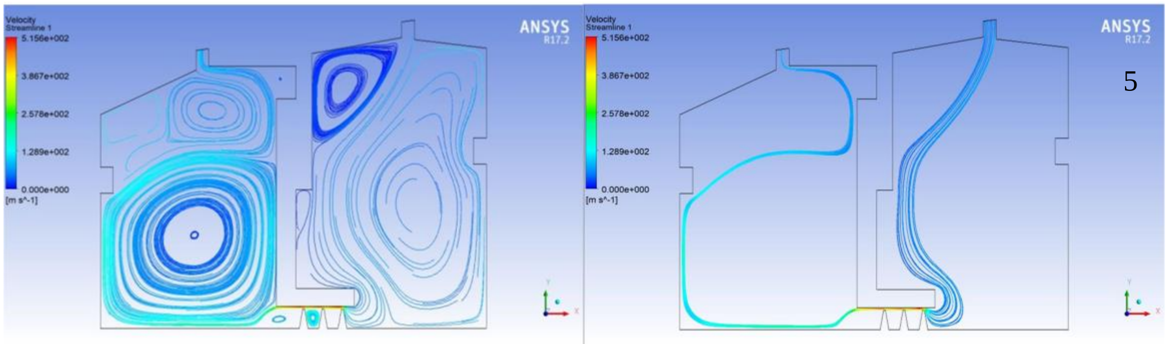

Figure 5-4: Streamlines in the cavity shown for 3 teeth model.

Streamlines from the inlet (right side) can be seen shifting towards the left due to the rotation of the rotor portion.

VI. CONCLUSIONS

As the number of tooth increases the leakage mass flow decreases. So it’s pretty obvious that more the teeth lesser the leakage. Since weight is the primary constraint in aerospace industry the optimum teeth have to be chosen based on the working conditions of the engine. Lesser the clearance more chances of rubbing with the land. The optimum clearance for any engine should be worked out based on the tolerance stack up and the bearing clearances. However, lesser clearances are always advantageous for engine performance.

REFERENCES

[1] Geza Vermes in Fluid mechanics approach to labyrinth seal leakage problem in An ASME publication, paper number 60-GTP-12

[2] H.L Stocker, D.M. Cox and G.F. Holle on Aerodynamic performance of conventional and advanced design labyrinth seals with solid smooth, abradable and honey comb lands in NASA CR-135307 EDR9339

[3] Jun Li, Shengru Kong Xin Yan, Shinnosuke Obi and Zhengping Feng on Numerical investigations on leakage performance of the rotating labyrinth honeycomb seal in J. Eng. Gas Turbines Power. Jun 2010, 132(6): 062501

[4] Robert K. Flitney in A Description of the types of high speed rotary shaft seals in gas turbine engines and the implications for cabin air quality in Journal of Biological physics and chemistry,14, 85-89, Published 2018.

[5] Da Soghe, R., Andreini,A., and Facchini, B., 2009, “Turbine Stator Well CFD Studies: Effects of Coolant Supply Geometry on Cavity Sealing Performance,” ASME Paper No. GT2009-59186.

[6] Romulo B. Freitas, Leandro M. Fernandes and Marcio T. Mendonca “Computational Evaluation of Labyrinth Seal configurations” 50th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition January 2012, Nashville, Tennessee.

[7] Kong, X., Liu, G., Liu, Y., and Zheng, L., 2018, “Performance Evaluation of the Inter Stage Labyrinth Seal for Different Tooth Positions in an Axial Compressor,” Proc. Inst. Mech. Eng., Part A, 232(6), pp. 579–592

[8] Ba, Peng, et al. “3D Numerical Analysis about Effect of Seal Clearance on Labyrinth Seal Performance.” Advanced Materials Research, vol. 852, Trans Tech Publications, Ltd., Jan. 2014, pp. 583–587. Crossref,

ISSN: 2233-7857 IJFGCN

Szymański, Artur & Dykas, Sławomir & Wróblewski, Włodzimierz & Rulik, Sebastian. (2014). Numerical Analysis of a Tip Labyrinth Seal of High Rotating Rotor. Cieplne Maszyny Przepływowe Turbomachinery 0137-2661.

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