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Feasibility Study of Labyrinth Seal in a High Pressure Ratio Fan Stage

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Abstract - Labyrinth seals are the most commonly used rotating seal in gas turbine engines. A straight teeth Labyrinth seal was designed for a High-Pressure Ratio (HPR) fan stage to seal the bearing from high pressure, warm air that enters through rotor-stator gap. A numerical simulation was carried out to accurately characterizing the leakage flow parameters like pressure, temperature and velocity to ascertain the design. Computational Fluid Dynamics(CFD) analysis of the seal was performed using commercial software ANSYS CFX. The Labyrinth seal was fixed on the stator wall against the rotor disc and the 2D model is subsequently used to determine flow velocity, temperature and pressure across the stationary seal. Four configurations of straight teeth labyrinth seals of various clearance like 0.1mm, 0.2mm, 0.3mm and 0.4mm were modeled using Solidworks and their effectiveness in safeguarding the front bearing of the Fan stage was studied at design speed of the fan stage.

Results showed that for a fixed seal pressure ratio, the leakage flow decreases with decreasing the seal clearance. The adiabatic temperature rise across the seal increases with decreasing clearance and obviously the pressure drop increased with decreasing the clearance. The observed temperature rise across the seal were 57K, 43K, 23K and -4K respectively at 0.1mm, 0.2 mm, 0.3mm and 0.4mm clearance respectively. From this feasibility study, it is found that the labyrinth seal up to 0.3 mm clearance can be comfortably use for this application.

Key Words: Pressure, Velocity, Leakage flow rate, Labyrinth seal, Pressure ratio.

1.INTRODUCTION

Labyrinth seals on rotating shafts perform non-contact sealing by regulating the flow of fluid via centrifugal motion as well as the formation of controlled fluid vortices via a series of chambers. Labyrinth seals don't make contact with them and aren't scratched out by them. Many gas turbine engines with high rotational speeds use labyrinth seals due to their lack of friction and longer lifetime.

The project aim remains to avoid internal bearing heating of High-Pressure Ratio Fan by minimizing the entry of hot air into it. In order to avoid internal bearing heating of HPR Fan the Labyrinth seal is proposed to install in between rotating part called rotor and stationary part called stator. By varying different seal clearances, the internal baring heating is studied in the other hand fluid characteristics like temperature, pressure and velocity etc., are studied.

1.1 HIGH PRESSURE RATIO (HPR) FAN STAGE

High Pressure Ratio (HPR) fan with Carbon Fiber Composite (CFC) blades were indigenously developed at CSIR-National Aerospace Laboratories. The mechanical integrity and aerodynamic performance of these blades were to be evaluated. For the performance evaluation of HPR fan with a suitable test section, An Axial Flow Compressor Research Rig (AFCR) is used which is available in propulsion division. where the fan stage is to be mounted in the rig. The test section essentially comprises of the fan stage to be tested, rotor-bearing system, bearing housing, seals, casing and the support structure was designed for the desired operational speed of 31240 RPM including 10% over speed.

1.2 INTRODUCTION ON LABYRINTH SEAL

A labyrinth seal is a form of mechanical seal which offers a tortuous path to help prevent leakage. This form of seal is commonly used within the bearing of an axle to help avoid the oil that lubricates the bearing from leaking out. A labyrinth seal is formed by several grooves pressing tightly inside another axle or into a hole, requiring the fluid to navigate a long and difficult path to exit. Screw threads on the outside and inside of the pieces are common. These interlocks establish the longer signature pathway that delays leakage. A very small clearance between the tips of the labyrinth threads and the running floor is needed for labyrinth seals on a rotating shaft.

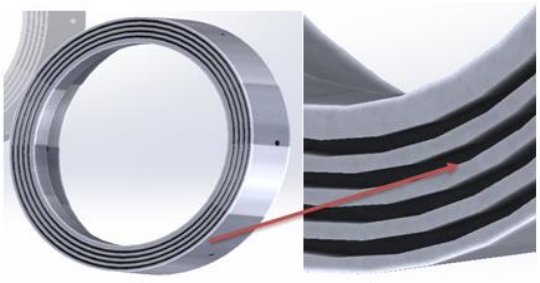


Fig.1.5.1 Labyrinth seal

1.3 OBJECTIVE AND SCOPE OF WORK

Objective of work is the performance study of a straight teeth labyrinth seal at various clearance using ANSYS CFX.

Scope of the work is the design of a straight teeth labyrinth seal by considering the various teeth clearance for the existing test section of a high-pressure ratio fan stage. To carry out the performance study of the seal at various clearance like 0.1mm, 0.2mm, 0.3mm and 0.4mm using ansys cfx cfd tool to find out the flow parameters like temperature, pressure velocity of fluid passing through the labyrinth seal and hence the suitability of it to the HPR fan stage

2. HPR FAN SPECIFICATION AND ITS TEST SECTION

The HPR Fan stage test section includes the rotor, stator, the rotor-bearing system and the casing.The fan stage test section consists of the inner components and the outer components. The inner components are rotor, stator, seals, rotor shaft, fan disk, spinner, nose cone, bearing adaptors, bearing spacers, bearing adaptor support with struts, balancing collar and the stiffener plate. The outer components are bell mouth, inlet casing, middle casing, spacer rings, volute collector and the collector chamber.

The compressor drive shaft was configured as an overhung rotor. The fan is axially located against the shaft shoulder. SKF make lock nut, KMK6 is used to secure the spinner and the compressor. A rotary shaft seal is used to seal the bearing from high pressure, warm air that enters through rotor–stator gap. The nose cone is mounted to the shaft ahead of the spinner to provide smooth flow of air to the fan blades. The mounting arrangement consists of bearing adaptors, adaptor support with strut, spacers, locknuts, seals and the outer casing. A PTFE seal reinforced with glass fibre is chosen. PTFE seals are characterised by low friction and their stick-slip–free running, reducing the temperature generation and permitting higher peripheral speeds. The cross-sectional view of HPR fan test section is shown in Fig.2.1

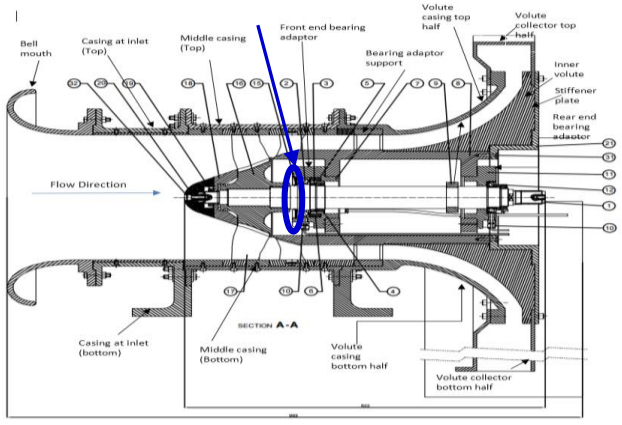


Figure 2.1 High Pressure Ratio Fan Test Section

In the existing design of the test section, the mechanical assembly is not flexible to use the PTFE seals for the multiple times. Hence, alternatively it is proposed to use the labyrinth seal in between the rotor disk and the bearing housing support.

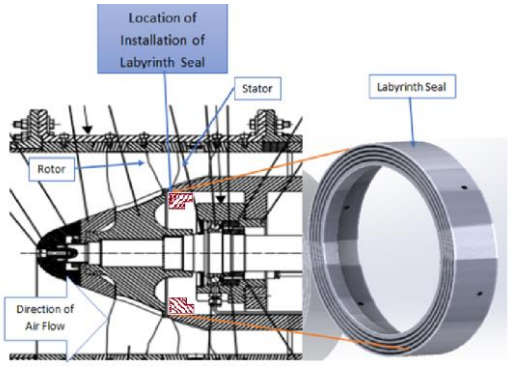
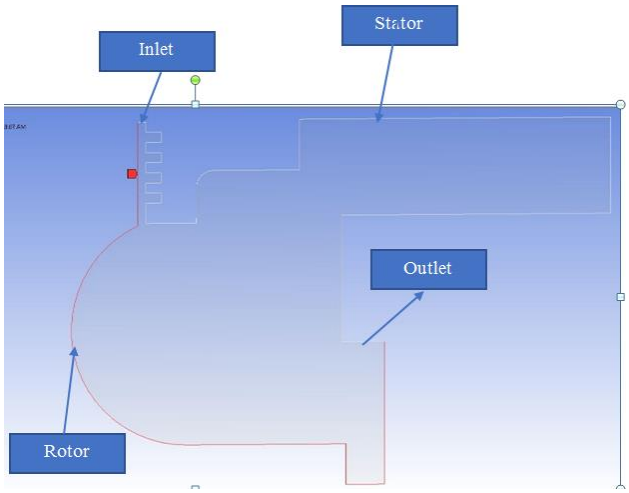


Fig 2.2 : The Location of Installation of Labyrinth Seal in HPR Fan test section

Above figure shows the Location of Installation of Labyrinth Seal in HPR Fan test section

3. TWO DIMENTIONAL FLUID MODEL AND BOUNDARY CONDITIONS FOR NUMERICAL SIMULATION



Boundary Conditions at inlet

Considered Zone: inlet., Type: Pressure inlet. Total Gauge Pressure: 200000 Pa., Initial Gauge Pressure: 184000 Pa., Total Temperature: 367 Kelvin.. Specification Method: K and Omega SST

Outlet Boundary Conditions

Zone Considered: Outlet, Type: Pressure Outlet, Gauge Pressure: 100000 Pa, Specification Method: K and Omega SST

Rotor Boundary Conditions

Zone Considered: Rotor, Type: Wall, Wall Motion: Moving wall, Type of Motion: Rotational, Speed of Rotation: 2974.041 (rad/sec)

Stator Boundary Conditions

Zone Considered: Stator, Type: Wall, Wall Motion: Stationary Wall

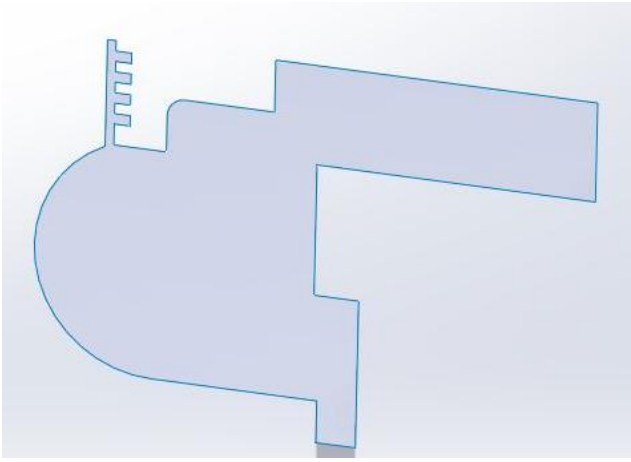


Figure 4.1.1 Two-D Drafting of Fluid Domain

Above figure represents the two - dimentional fluid domain available after installing labyrinth in between rotating part called rotor and stationary part called stator. By varying different seal clearances (0.1mm, 0.2mm, 0.3mm and 0.4mm) at inlet and the internal baring heating is studied in the other hand fluid characteristics like temperature, pressure and velocity etc., are studied.

4. CONCLUSIONS

A numerical simulation model was established for this feasibility study of a Labyrinth seal using the CFD analysis method and the effects of the labyrinth seal clearance were checked.
From the numerical study the following conclusions are drawn

- For a fixed seal pressure ratio, the leakage flow decreases with decreasing the seal clearance.
- The pressure drop increased with decreasing the clearance.
- The adiabatic temperature rise across the seal increases with decreasing clearance. The observed temperature rise across the seal were 57K, 43K, 23K and -4K respectively at 0.1mm, 0.2mm, 0.3mm and 0.4mm clearance respectively. From this feasibility study it is found that lesser the labyrinth seal clearance, lesser the leakage rate.

To safeguard the high speed ball bearing used in the fan stage, the maximum temperature raise at the bearing location was kept 349 K. Hence the seal teeth clearance ranging from 0.1mm to 0.3mm is in safer range. 0.3 mm clearance is the maximum clearance can be maintained where temperature reaches is 332 K.

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