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LEAKAGE FOR AN ALL-METAL COMPLIANT GAS SEAL OPERATING AT HIGH TEMPERATURE

TRACK OR CATEGORY: Seals

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ABSTRACT

Parasitic secondary flows in turbomachinery represent a substantial loss in system efficiency and power delivery. Labyrinth seals are a common seal type, albeit they wear out and penalize performance, even affecting rotordynamic stability. Better sealing types are sought to improve overall system efficiency and to save energy. The paper describes a high temperature test rig (max. 300ºC) to quantify the leakage of various seal types and reports measurements with a labyrinth seal and a novel all-metal seal [1], both of the same size. The comparison of leakages shows the novel seal, due to its self-controlled clearance, leaks 50% or less than the labyrinth seal over a range of pressures and temperatures.

INTRODUCTION

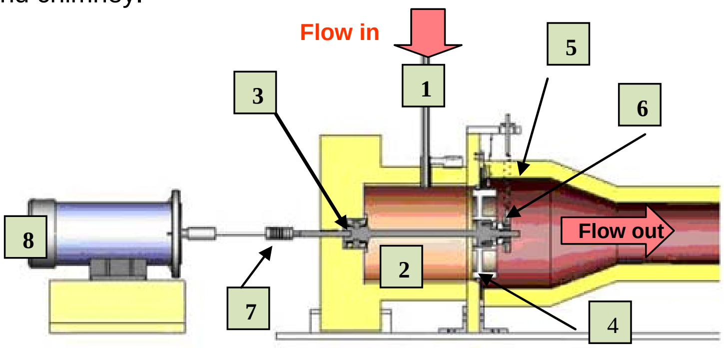
Turbomachinery seals are designed to maintain efficiency by minimizing leakage; therefore, seal design is the most cost-effective measure to increase performance by restricting secondary leakage. Operation at high gas temperatures, pressures, and rotor speeds aims to increase efficiency, hence seals must be able to limit flow while enduring rigorous operating conditions [2]. Refer to Chupp et al. [3] for a comprehensive review of the purpose and significance of sealing in turbomachinery, particularly in gas and steam turbines. In these applications, mechanical elements sealing secondary flows; i.e., seals to reduce leakage, operate at temperatures up to 600°C, differential pressures up to 21 bar, and withstanding surface speeds up to 400 m/s [3]. These extreme operating conditions demand of seals with specialized materials and engineered configurations, and also create particular challenges to guarantee reliable sealing performance with an extended life.

HIGH TEMPERATURE GAS SEAL TEST RIG

Fig. 1 shows a cross section view of the high temperature seal test rig surrounded by thick thermal insulation [4]. Two tapered rolling element bearings support a long and thin shaft and disc inside a pressurization vessel supplied with hot air. The overhung rotor is connected to a direct current (DC) motor (90 V, 9.4 A) through a quill shaft and flexible coupling. A test seal fits in a circumferential groove machined at one end of the vessel and secured in place by a metal ring and bolts. The cantilever rotor arrangement permits a quick exchange of test seal without affecting the installation of major components in the system. The rotor support bearings are rolling element tapered bearings that withstand high temperatures when packed with special grease. The bearings' outer races fit into a cylindrical casing in the pressure vessel while the inner races are press fitted onto the shaft end. An aluminum silicate plate faces the closed end of the pressure vessel and acts as an insulation element that reduces excessive heat flowing into the bearings section.

The air inlet temperature and pressure upstream of a test seal, the rotor speed, and the disc centering are independently controlled throughout the experimental procedure. The test rig is ready for testing upon installation of a seal facing the outer diameter of the disc. Two fiber optic sensors, orthogonally positioned, measure the radial displacements of the disc. A careful centering of the disc with respect to the seal ensures a uniform radial gap.

Pressurized cold air flows through a particle and coalescing filter to remove impurities. The air stream proceeds through a turbine flow meter recording its volumetric flow rate (maximum range ~ 21 ACFM). The mass flow rate is determined from the volumetric flow rate for a specific pressure and air temperature at standard air conditions. The cold air then flows through an electromechanical control valve and into the electric heater. The electromechanical control valve controls the air flow and upstream pressure. The valve opens gradually, through 14 distinct set positions, until fully opened. An electric heater (12 kW, 240 V) warms oil-free incoming air to a set temperature (max. 300 °C) with delivery at a maximum pressure of 8 bar. The hot air flows into the pressurization vessel where the air inlet temperature and absolute pressure are recorded. Finally, the hot air flows through the test seal and vents into the atmosphere through an exhaust pipe and chimney.



1	Hot air inlet	5	Optical displacement sensor
2	Pressurization vessel and shaft	6	Centering mechanism
3	Radial Support bearings	7	Flexible coupling
4	Disc and test seal location	8	Electric drive motor

Fig. 1: Cutaway view of high temperature seal test rig [4].

DESCRIPTION OF THE TEST SEALS

Figure 2 shows pictures of the test labyrinth seal and the all-metal HALO® seal [1], and Table 1 lists the seals' dimensions and materials. The all-metal seal comprises of nine (~40º) arcuate pads cantilevered from an outer rim. The compliance of the thin beams (flexures) facilitates radial displacement of the pads. A downstream plate blocks any flow through the gaps behind the pads. The pads are not flat, but have a machined converging-divergent profile that promotes the development of hydrodynamic pressure to lift-off the pads with rotor speed thus ensuring non-contact operation with the disc. Note that the seal pads can displace a maximum of 0.25 mm within the gap behind the cantilever spring elements. The all-metal seal is a clearance controlled seal; with external pressurization the flexures displace the pads towards the disc thus closing the annular gap [1].

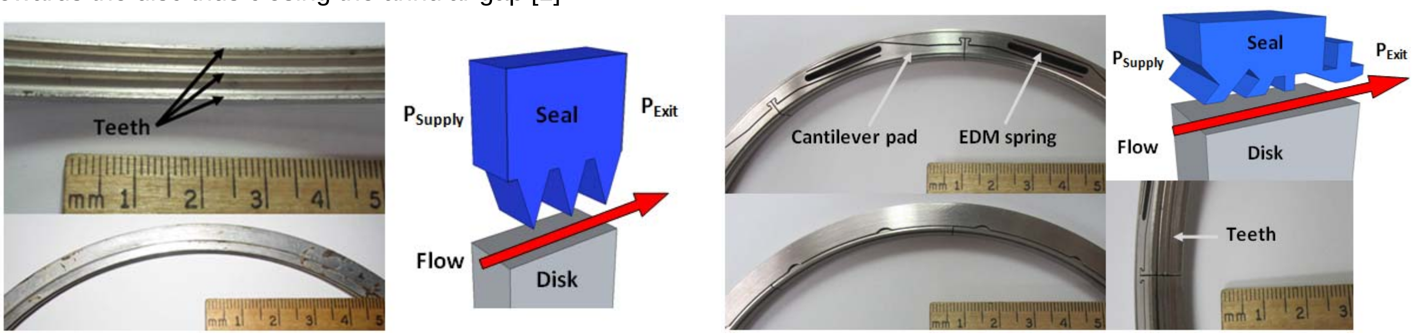


Fig. 2: Test labyrinth seal (left**) and all-metal seal (**right**) and schematic views of gas flow.**

Table 1: Dimensions and material properties of labyrinth seal and disc and all-metal seal and disc.

Labyrinth seal material	Aluminum
Outer diameter	183.20 mm
Inner diameter	167.85 mm
Length axial, *l*	8.40 mm
Tip width	0.17 mm
Cavity depth	3 mm
Disc Material	4140 Steel
Disc OD	166.81 mm
OD – ID_s = diametral clearance	1.04 ±0.026 mm

All –metal seal material	**Steel**
Outer diameter	183.0 mm
Inner diameter (upstream)	167.3 mm
Inner diameter (downstream)	167.2 mm
Seal axial length, *l*	8.5 mm
Pad allowable radial movement	0.25 mm
Pad axial length	8.0 mm
Pad arc length	57.4 mm
OD – ID_s = diametral clearance	0.40 ±0.025 mm

LEAKAGE MEASUREMENTS WITH A LABYRINTH SEAL AND AN ALL-METAL SEAL

In the tests hereby reported, the rotor was stationary (no spinning). Measurements of seal leakage were conducted at increasing air inlet temperatures (*T*) from 298^o-573^{o}K (300^{o}C). The air supply pressure (P_s) varied from 101-808 kPa and the exhaust pressure (P_a) is ambient at 101 kPa. Recall that the air gas constant is R_g=287 J/kg-^{o}K.

Figure 3 depicts the recorded seals' leakage (gram/s) versus the inlet to exhaust pressure ratio, P_s/P_a, for increasing air inlet temperatures (30^o, 100^o, 200^o and 300^{o}C). For all pressures ratios, the all-metal seal leaks 50% or less than the labyrinth seal. For P_s/P_a > 3.0, the novel seal leaks ~¼ the flow rate of the labyrinth seal, hence it demonstrates excellent sealing characteristics. Moreover, tests with the all-metal seal continued to higher pressure ratios (max. P_s/P_a=8); a feature that could not be achieved with the labyrinth seal. The maximum uncertainties for the leakage measurements are 4.4% in pressure ratio and 4.5% in mass flow rate for a 95% confidence interval.

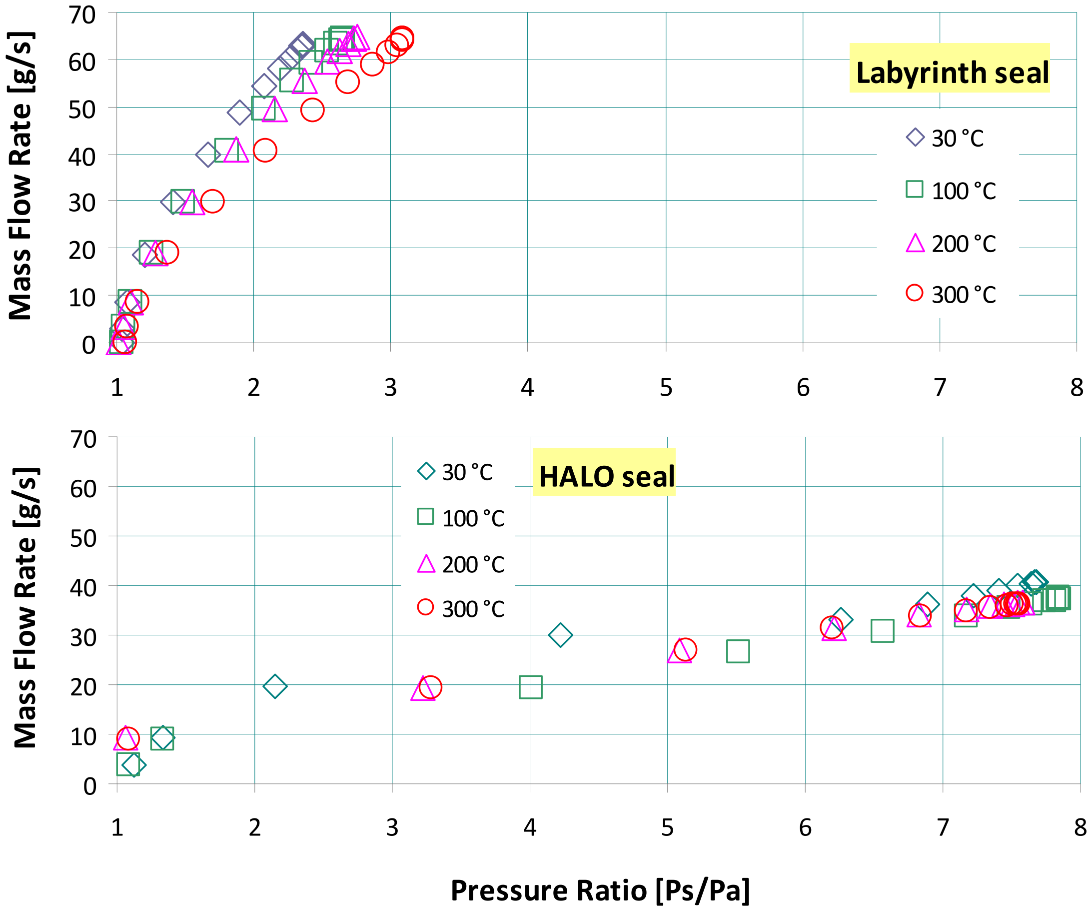


Fig. 3: Leakage for labyrinth and all-metal (HALO®) seals vs. pressure ratio (P_s/P_a) at increasing air temperatures.

CONCLUSIONS

Parasitic secondary flow losses (seal leakage) reduce efficiency and power delivery in turbomachinery. Seal flow rate measurements with increasing inlet air temperatures (to 300°C) show an all-metal seal leaks 50% or less than a labyrinth seal of the same dimension. For pressure ratios (P_s/P_a) > 3.0, the novel seal leaks ~¼ the flow in a labyrinth seal, thus demonstrating its excellent sealing characteristics. Moreover, tests with the novel seal proceeded to higher pressure ratios (max. P_s/P_a=8), an operating feature that could not be achieved with the labyrinth seal. The leakage tests demonstrate the novel seal gives a remarkable improvement to restrict secondary flows and the ability to operate with large pressure differentials.

ACKNOWLEDGMENTS

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KEYWORDS: Seals