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Radial Lip Seals for Aerospace Applications – An Overview

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Extended Abstract

A seal is a component that impedes the flow of fluid through a given system. The word 'impede' holds emphasis as there is no such thing as a zero leakage seal. All dynamic seals must leak, even if it is as low as 1 mm^3 per year and referred to as 'emission' (Flitney 2014).

Since the 1700's, seals have continued to evolve and develop in their design, geometries and materials. The design of the radial lip seal has evolved from oil resistant leather to synthetic rubber and eventually, replaced by high temperature elastomers. The 1980's saw the revolution of the radial lip seal from a single commodity seal to a 'sealing system', which included the housing bore, shaft, lubricant along with several operational factors.

Radial lip oil seals are rotary shaft seals placed on a shaft, usually with an interference fit and are used in both static and dynamic sealing applications. They aim to prevent unintended leakage of oil past the seal and prevent debris from entering the system. Their design usually includes a sealing lip and a dust lip to achieve these goals. The sealing lip slides on the surface of the shaft and achieves sealing with the help of a garter spring with a pre-load. Such seals usually rely on a thin film of lubricant, around 2-5 microns in thickness, in between the seal and shaft surface to operate. The sealing system, thus, consists of three components: seal, lubricant film and shaft. The interface between the seal and shaft is one that is most interesting as it is where the actual sealing takes place.

There is no such thing as a perfect sealing system – the requirements for each application will dictate the design and selection of a seal used. Seals are subject to harsh environmental conditions including high temperatures, high pressures, system vibration, shaft-run out and misalignment. These conditions will influence the fatigue, wear, friction, lip temperature, surface polish and leakage at the sealing interface. Often, not all these conditions can be avoided and it is up to the engineer to make selections for the elastomer material, filler content, shaft coating, and other factors based on the needs of that system. Reducing wear and friction in a system for longer seal life can result in accepting some leakage in the system. In contrast, to reduce leakage of oil in a system, we must often accept that the seal can experience pre-mature wear if it runs dry.

The standards DIN 3760, DIN 3761-1 and ISO 6194-1 specify the state-of-the-art design of radial lip seals, the housing bore, shaft, lubricant and operating conditions. In addition to specific requirements for the seal itself, the standards also specify several factors to consider for all the remaining elements of the system. The use of a sleeve

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fitted on the shaft is common as surface treating large shafts is expensive and cumbersome. They fit onto the shaft and rotate along with it. In instances of significant wear or damage, simple replacement of the sleeve is only required.

Radial lip oil sealing systems show a high complexity. Important are the specifications and standards for lip oil seals. Even so, storage and installation of these seals can also affect their performance as they are easily damaged. The significance of seals is high, because their failure can pose a potential threat to the over-all safety of the aircraft. Safety is the common denominator for all stakeholders in the aerospace industry. This shows the general importance of sealing elements in aerospace applications and the potential detrimental consequence of their failure.

Three examples of aircraft seal failure demonstrate the significance of general sealing components by showing how varying degrees and types of seal failure has threatened their safety. While different seals are failing in varying incidents, the point is to draw attention to the significance of these inexpensive components that are critical in nature. The three cases should be pointed out: 1.) Airbus A320neo P&W: 2017-2018, 2.) Airbus A330-323 P&W turbofan engines: 2016 and 3.) Airbus A320 IAE/P&W: 2014.

1.) This problem came about in early 2018 with P&W's new GTF engine (geared turbofan engine) for the Airbus A320neo. A design flaw discovered in January 2018 on approximately 100 of these engines, some of which were in the Airbus assembly plant and others in service, resulted in recalling these engines. This was because four aircraft engines experienced sudden shutdowns during take-off or during flight. The root cause of the engine shut down was the knife-edge seal (similar design to the labyrinth seal, patented by P&W). It was said by the Chief Executive that fixing this faulty seal would cost the company $50 billion and increase the company's losses on geared turbofan engine deliveries closer to $1.2 billion (Trimble 2018, Bogaisky 2018a, Bogaisky 2018b).

2.) During boarding of a flight from London Heathrow Airport, the aircraft cabin filled up with smoke, resulting in immediate evacuation of all passengers. The source of this smoke traced back to a failure of the Auxiliary Power Unit (APU) compressor carbon seal (carbon seals are also known as mechanical seals). This resulted in oil leakage and contamination of the bleed air supply. Metallic debris found in the shared oil system compromised the load compressor bearing, resulting in failure of the compressor carbon seal. The report also mentions that the APU manufacturer had experienced similar events prior to this one where failure caused oil entering the bleed air system through the load compressor carbon seal (AAIB 2017).

3.) This flight from Cochin to Delhi by Air India experienced uncontained engine failure in flight and a fire confined to engine 2 only. Cause of this incident led back to inadequate overhaul practices of the oil seal during maintenance procedures. During overhaul, the #4 bearing seal underwent a lapping process (superfinishing process of the surface). The anti-weep grooves, present to prevent the oil from escaping the compartment during sub idle conditions, were not cleaned and inspected properly. This resulted in blockage of the grooves with lapping debris. As a result, the oil escaped the #4 bearing compartment and went into the high-pressure turbine (HPT). Eventually, this compromised the air seal placed at the turbine, causing low cycle fatigue fracture of the second stage air seal at high temperatures and damaging the turbine blades. Two of the seals in two different places in the engine experiencing failure resulted in the engine fire (AAIB 2014).

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