GENERATOR PERFORMANCE PLUS™ HYDROGEN SEAL SYSTEM

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INTRODUCTION

The authors’ companies have collaborated to develop an advanced oil seal assembly for hydrogen-cooled generators. This new technology addresses our industry’s needs to reduce oil and hydrogen consumption, improve seal life, and upgrade existing seal technology.

Characteristics of this new shaft seal are:

- It replaces all existing generator shaft seals that function by flowing large amounts of seal oil.
- It is in active contact with the shaft and housing face under all conditions of generator operation. Hence, the required oil flow is reduced drastically.
- It results in lower hydrogen consumption and maintains high purity over entire range of gas pressures and bearing sizes.
- It operates with a small single flow seal oil system at maximum gas pressures, as compared with the larger double flow or vacuum treated single flow systems.

Generator life cycle gains can be realized by using the new technology to improve generator system performance. In addition, significant performance improvement can be achieved with higher maintained hydrogen purity and decreased hydrogen consumption. The new seal virtually eliminates oil ingress into the generator thus significantly reducing hydrogen consumption which saves operating and maintenance costs. Using the new seal technology, higher pressure can be achieved and maintained, which again increases the generator’s efficiency. It also eliminates potential seal rub damage since there is no metal-to-metal contact that can occur with conventional seals. Furthermore, the carbon seal is more tolerant to external vibration and oil temperature changes and even to coast down conditions with loss of oil. Finally, it is also possible to increase generator hydrogen operating pressures.

SEAL ASSEMBLY DESCRIPTION

The seal itself is provided pre-assembled in a stainless steel cartridge which allows retrofit into existing gland seal brackets on in-service units. The seal cartridge features a horizontally split housing with two segmented carbon seal rings; a Hydroload seal, and a Hydrovent® seal (Figure 1).

The hydrogen compartment is sealed by the Hydroload seal ring, and the bearing compartment is sealed by the Hydrovent® seal ring. High-pressure oil enters the seal housing cavity between the seal rings and breaks down the pressure to the bearing and hydrogen compartments. Each seal ring functions differently to provide controlled leakage to its respective compartment. The Performance Plus™ System seal design utilizes two segmented, spring-loaded carbon seal rings. The design results in significantly lower hydrogen-side and air-side oil flow rates. The seal can also act as a static seal upon loss of seal oil pressure, allowing for less hydrogen leakage and increased overall safety. The Performance Plus™ System package consists of the following:

- two segmented carbon seal cartridge assemblies
- modified or new gland seal brackets with allowance for regulated re-circulation oil flow control and monitoring, with associated instrumentation
- special bearing-side performance sensors and indicators, required flow balance valves, gauges and connecting flanges
- an option for a new seal oil skid customized for use with the new seal.

The new seal system is delivered in retrofit-ready condition. It can be installed during limited outages without the need for slope checks, thus significantly reducing outage time. The advanced seal can be applied to all hydrogen-cooled generators regardless of OEM.

HYDROVENT SEAL & HYDROLOAD SEAL OPERATION

The generator seal assembly separates the generator bearing sump from a high pressure hydrogen cooling compartment. High-pressure oil is supplied between the seal rings as shown Figure 2. The seal ring bores are configured with hydrodynamic pockets that produce a pressure gradient when the shaft is rotated. Each seal’s function is different and uni-directional.

Back-to-Back Seal Rings:

**Hydrovent® Seal:**
  - Operates in lift-off mode (Bearing side seal)
  - High pressure differential

**Hydroload Seal™:**
  - Operates in suction mode (H₂ side seal)
  - Low pressure differential

Figure 2 – Generator Seal Schematic

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HYDROLOAD SEAL

The Hydroload seal (US patent #4,082,296) is located adjacent to the hydrogen side of the generator and is intentionally designed to provide low leakage rates. The seal operates at a pressure of 5 to 8 psi and produces suction in the bore during shaft rotation, which tends to minimize leakage. Oil discharge from the seal passes into the hydrogen side of the generator where it is separated before oil recirculation is achieved.

The Hydroload seal force schematic is shown in Figure 3. The pressure forces acting on the seal are a function of the system oil pressure. With shaft rotation, shear-drag on the oil in the hydrodynamic pockets causes the oil to move through the open-ended pocket, which creates a suction force that draws the seal closer to the shaft.

**Figure 3 - Hydroload Seal Force Schematic**

HYDROVENT® SEAL

The Hydrovent® seal (US patent #5,558,341) is located adjacent to the bearing side of the generator and operates in a lift-off mode at 83 psid. Controlled leakage results since this seal lifts off the shaft during operation. Oil is returned to the bearing sump and then onto the main oil supply system. The Hydrovent® seal force schematic is shown in Figure 4. The hydrodynamic pockets are configured differently from the Hydroload seal. With shaft rotation, a pressure rise develops when oil is pumped into the dead-ended hydrodynamic pockets, which causes the seal to lift off the shaft.

The hydrodynamic pressure rise is shown in the schematic below as a rise in the force diagram located in the bore. The hydrodynamic pocket features that contribute to the pressure rise are: pocket depth, length, and width. The Hydrovent® seal also contains a small orifice at the terminus of each hydrodynamic pocket that can regulate the pressure rise should it be necessary. The orifices can be seen in the photograph of the seal ring bore configuration in Figure 5 below.

**Figure 4 - Hydrovent Seal Force Schematic**

**Figure 5 – Seal Ring Photographs**

SEAL PERFORMANCE

Leakage rates improve drastically with the new generator seal technology. Rig tests with the full-size seal demonstrate the reduced leakage as shown in Figure 6 and Figure 7 below. Tests were conducted with Teresstic® 32 oil delivered at generator conditions and shaft rotation at the same pitch-line velocity as a 16” generator shaft operation at 3600 RPM. Oil temperature rise is roughly 60°F at maximum speed and pressure conditions.
Several successful customer applications were installed last year. These installations follow several years of development testing that was conducted using a sub-scale seal assembly that operated at generator conditions. Additionally a full-size 16” seal test rig, permitted the simulation of customer specific generator service applications.

The first application of the new seal system to a central station turbine generator took place in the Spring of 2003 at TVA, Shawnee Unit #2 and subsequently at Unit #6. Both systems are performing well. Additional units are currently being installed at several other TVA sites (Allen, Gallatin) and for two FPL units. Additionally, PPL, Colstrip’s 930MVA Unit 3 is currently being upgraded with a seal and auxiliaries system. Engineering studies are underway for several nuclear units.

Currently there are seal applications in operation covering applications to journals with diameters of 16, 17, 18, 21 and 22 inches. 14 inch applications are currently being installed at several sites. 20,000 hours of combined running experience and data has been accumulated. On average, maintained hydrogen purity improves to 99.985%, thus significantly reducing windage loss as shown in Figure 8.

SUMMARY AND CONCLUSIONS

The authors’ companies have collaborated to develop an advanced oil seal assembly for hydrogen-cooled generators and turbomachinery. This new technology addresses our industry’s desires to reduce oil and hydrogen consumption, improve seal life, and upgrade existing seal technology for hydrogen-cooled turbine generators.

Its superior features enable it to significantly outperform conventional sealing technology. Due to the advanced seal technology, hydrogen purity can be improved, which has a positive impact on overall generator performance. The estimate is that 1% increase in H₂-purity translates to up to 250kW additional power output per year.

The new generator seal provides generator users with the following benefits:

- Eliminates seal rub damage to shaft
- Long Seal life (>100,000 hrs) or ten years
- Controlled oil flow at various pressures
- Seals can be easily retrofitted
- Split housing construction for ease of generator assembly
- Gland seal bracket slope machining is not required
- Segmented contact riding seal design is not susceptible to binding on shaft
- Tolerant to shaft vibration
- New seal is tolerant to varied oil inlet temperatures
• New seal prevents shaft rubs due to thermal mismanagement
• Tolerant to water in oil (within certain specifications)
• Tolerant to dirty oil
• Carbon seals are tolerant to coast down conditions with loss of oil
• With loss of oil carbon seal functions as a static gas seal to prevent H₂ ingress into the bearing compartment
• Oil ingress into the generator is minimized or eliminated

SEAL OIL AUXILIARY EQUIPMENT:

Two Options:
• Install new seal oil skid
• Retrofit existing equipment to satisfy Performance Plus™ System reduced flow requirements

OIL SKID - PERFORMANCE PLUS™ SYSTEM:
• AC and DC pumps
• Shell in tube cooler
• Differential pressure regulating valve
• Single smaller duplex filter
• Reduced number of gauges, valves, etc.

These seals have performed well in extensive laboratory testing with full-sized test rigs, and a broad range of field applications to in-service turbine generators which have all been successful.

The new seal technology (marketed as The Performance Plus™ System) is targeted principally to replace hydrogen cooled generator turbine and collector end bushing seals that exhibit high oil and hydrogen loss. To cope with existing high leakage rates, large capacity pumps and oil/H₂ separators have been required. Performance Plus™ can eliminate the high leakage rates, thus eliminating the need for the large pumps and oil/hydrogen separators.