Protecting Nuclear Reactor Cooling Pump Face Seals from Electrostatic Erosion and Electrochemical Corrosion

Overview

Mechanical end face seals for nuclear reactor recirculation pumps (RRPs) and reactor coolant pumps (RCPs) are critical components in preventing the escape of radiation from reactor primary cooling systems.

But stray voltages can build up on RRP/RCP motor shafts and lead to currents which electrically erode face seals. The result is radial canals along which an uncontrolled release of radioactive cooling water can occur, necessitating an unplanned shutdown.

By providing a highly reliable electrical path from shaft to seal housing, specially designed AEGIS® Reactor Pump Protection Rings (RPPRs) safely neutralize the electrical potential difference between the pump shaft and the seal housing, preventing harmful shaft voltages from causing electrical damage to face seals.

ÆGIS®

Introduction

Mechanical end face seals are key components in the reactor coolant system pressure boundaries of nuclear power plants. These seals limit the leakage of reactor cooling water along the shafts of pumps.

Mechanical face seals are designed to be lubricated by the source media (in this case reactor cooling water), and maintaining the integrity of this fluid film is essential for their proper operation. But stray voltages on an RRP/RCP shaft can create stray currents that can both exacerbate electrochemical corrosion and cause electrostatic erosion on the faces of these seals.

As nuclear power plants age (the average age of U.S. commercial reactors is about 37 years), addressing the reliability of critical systems and components (such as cooling systems) is proof of the nuclear industry's promise and commitment to the safety of its plant and customers.

To ensure the integrity of RRP/RCP mechanical face seals, they are constantly monitored for flow, temperature, and pressure while in operation, and any readings outside preset ranges trigger automatic alarms. But once the seal face suffers electrical damage, mechanical erosion (due to the flow of cooling water through a "channel"), or mechanical abrasion (when the seal faces touch) can magnify the damage. And unless plant personnel disassemble the seal, it will be difficult for them to determine if any early-stage electrostatic erosion and electrochemical corrosion has occurred. Often, the first indication of seal erosion damage is a loss of sealing pressure due to coolant leakage. And while certain seals (such as the Flowserve N-Seal) are capable of restaging the pressure, seals without this capability may need to be replaced, necessitating an unplanned shutdown.

To maximize efficiency and minimize worker exposure to radiation, such work must be carefully planned and efficiently executed. And while the necessary costs of scheduled maintenance shutdowns are very high (as high as $3 million for the first day and $500,000 or more for each subsequent day), they pale in comparison to the costs of unplanned shutdowns due to preventable RRP/RCP seal failures, and resulting lost revenues.

Reactor Recirculation/ Coolant Pump Face Seal Damage Compromises Reactor Coolant System

To prevent the escape of radioactive water from nuclear reactor primary cooling systems, reactor recirculation pumps are equipped with seals that limit and safely redirect reactor coolant leakage from the pump shaft.

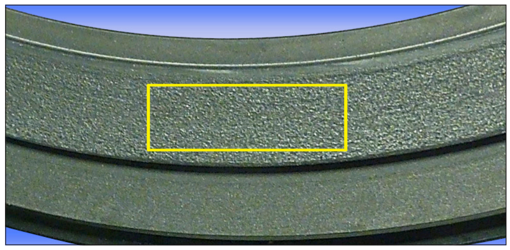
According to Gerard van Loenhout and Jürg Hurni in their article, *Implementation of multiple measures to improve reactor recirculation pump sealing performance in nuclear boiling water reactor service,* "sealing a RRP using a mechanical end face shaft seal is considered one of the most challenging applications found in the industry [1]."

Hydrodynamic face seals are designed with opposing faces that are in physical contact when the pump shaft is at rest, but which separate when the shaft is spinning to trap a thin layer of liquid which provides sealing and lubrication.

[1] *van Loenhout, Gerard, Ing., and Jürg Hurni, Ing., "Implementation of multiple measures to improve reactor recirculation pump sealing performance in nuclear boiling water reactor service." Editorial. VGB PowerTech Nov. 2014: 72. Print.*

For improved seal face lubrication, seals are often designed with features that promote fluid penetration into the sealing gap. For example, many of these seals employ thermo-hydrodynamic circulation slots around the circumference of the harder (often tungsten carbide) rotating face seal.

RRP/RCP seals are susceptible to stray currents, which left unchecked, can damage the seal faces, creating channels through which cooling water can leak. So, when sealing pressure begins to decay prematurely, forensic inspection of the seals often reveals radial canals on seal faces due to water flowing across them at high speed. Rapid mechanical erosion damage (Figure 3) often obscures a root cause — electrical damage to the seal.



Figures 1 & 2

(Courtesy of van Loenhout and Hurni [1])

Used to prevent leakage of cooling water along the shafts of reactor recirculation pumps, hydrodynamic face seals have mating faces that make contact when the pump shaft is at rest, but which separate when the shaft spins. This separation traps a thin film of liquid between the faces, which provides both sealing and lubrication. Stray voltages can damage both the soft graphite face (Figure 1) and the hard tungsten carbide face (Figure 2) of these seals through the processes of electrochemical corrosion and electrostatic erosion.

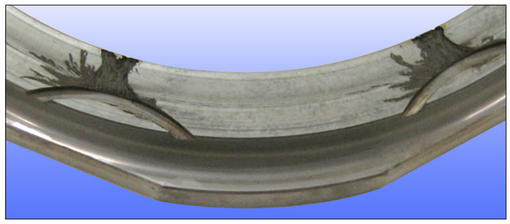


Figure 3

(Courtesy of van Loenhout and Hurni [1])

To promote fluid penetration into the sealing gap between them, face seals are often designed with thermo-hydrodynamic circulation slots, which increase liquid flow between the seals and reject particulates. The irregular canals radiating from these slots are the result of electrical damage caused by stray voltage discharges.

[1] *van Loenhout, Gerard, Ing., and Jürg Hurni, Ing., "Implementation of multiple measures to improve reactor recirculation pump sealing performance in nuclear boiling water reactor service." Editorial. VGB PowerTech Nov. 2014: 72. Print.*

Reactor Pump Protection Rings — A Solution Based on Shaft Grounding Technology Proven in Industry

A solution to seal damage and failure caused by stray currents in pressurized water reactor (PWR) and boiling water reactor (BWR) plants came in the form of a robust shaft grounding ring. Designed to mitigate voltage potential differences between the rotating shafts and the stationary mechanical face seals, AEGIS® conductive microfiber rings protect RRP and RCP face seals against electrical erosion and electrochemical corrosion by minimizing current flow between pump shafts and seal housings.

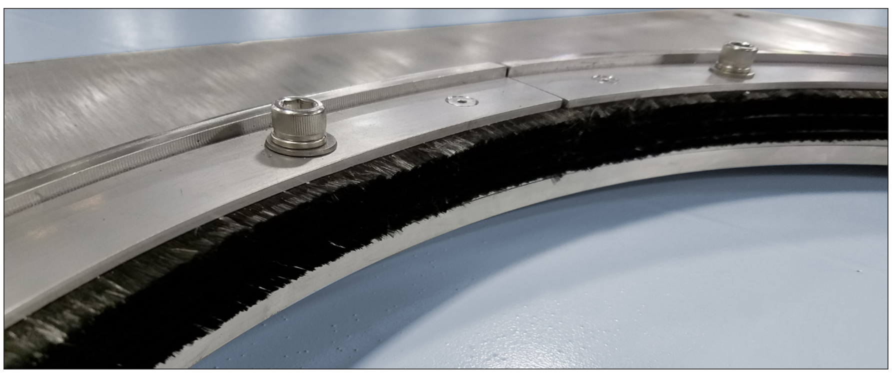


Figure 4

With 6 rows of specially designed microfiber brushes, the AEGIS® RPPR Ring provides more than 10 million discharge points for stray shaft voltages, reducing the potential across pump face seals and protecting them from electrochemical corrosion and electrostatic erosion.

The AEGIS® RPPR Ring is a circular ring with an inner circumference of which is lined with more than 10 million specially engineered conductive microfibers, a full 360° around, and arranged in 6 parallel rows. These highly reliable proprietary microfibers drastically reduce any potential voltage differences by creating a very-low-impedance path between the rotating pump shaft and the mechanical seal housing.

Advanced AEGIS® Technology Protects RRP/RCP Systems

The AEGIS® RPPR's design and its proprietary microfiber brushes combine to provide unmatched shaft grounding performance for significantly longer than normal nuclear plant maintenance intervals. By contacting the rotating RRP/RCP shaft surface with ultra-low friction, they provide the most reliable operation of any shaft grounding technology. For nuclear plants, this means proven protection against damage from stray currents between scheduled shutdowns, as well as fewer unplanned shutdowns and the staggering costs associated with them.

Key to the AEGIS® Ring's performance is its proprietary conductive microfibers. They are specially engineered with specific mechanical and electrical characteristics that maximize conductivity and minimize wear. And AEGIS® microfibers can withstand prolonged temperatures to over 410°F (210°C), making them well-suited to nuclear power applications.

AEGIS's patented FiberLock™ channel locks the conductive microfibers securely in place, allowing them to flex without breaking.

Success at a Swiss Nuclear Station...

At a nuclear station in Switzerland, electrochemical corrosion and electrostatic erosion of RRP face seals were identified as possible sources of premature failures — failures in which an uncontrolled amount of contaminated water could leak past the seals[1]. The suspected cause was stray currents on RRP motor shafts that were discharging through the face seals, eroding them and increasing the risk of radiation leaks. The plant was able to effectively mitigate the problem through measures that reduced these stray currents to levels low enough to avoid unplanned shutdowns – measures that included the installation of AEGIS® conductive microfiber rings on RRP shafts.

Leads to the Installation of an AEGIS® RPPR at a US Nuclear Plant

When engineers at an east coast US nuclear plant learned about the success of AEGIS® Rings at the Swiss nuclear station from the van Loenhout and Hurni article, they were intrigued and anxious to test the efficacy of the rings in protecting RCP face seals at their plant.

The plant engineers initially selected one RCP to test the effectiveness of the AEGIS® RPPR Ring. The hope was that the ring would protect the RCP seals from electrical

[1] *van Loenhout, Gerard, Ing., and Jürg Hurni, Ing., "Implementation of multiple measures to improve reactor recirculation pump sealing performance in nuclear boiling water reactor service." Editorial. VGB PowerTech Nov. 2014: 72. Print.*

damage. The stainless steel ring was designed specifically for this application by Electro Static Technology to minimize the potential of the stray currents between the pump shaft and the pump housing across the mechanical face seals. The ring was installed on the 24" diameter smooth surface of the coupling which connects the pump motor to the pump shaft.

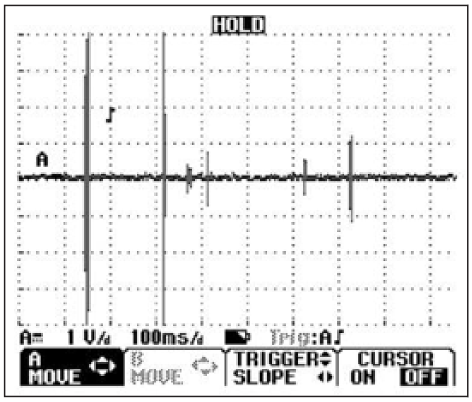


Figure 5

(Courtesy of Giglio Freeman Associates, LLC)

Shaft voltage readings taken from a reactor coolant pump (that was experiencing premature face seal failure) at a US east coast nuclear plant — before installation of an AEGIS® RPPR Ring:

This ungrounded measurement at 1V per division shows an 8V peak-to-peak voltage. The voltage is random in nature and not relatable to unit speed or line frequency.

Before installing the ring, the plant contracted Giglio Freeman Associates, LLC, an independent firm specializing in shaft voltage measurement in nuclear facilities, to take shaft voltage readings on the pump both before and after installation of the AEGIS® Ring. The initial reading was taken with the pump running at normal speed and load conditions before the AEGIS® RPPR was installed. It showed shaft voltage of 8V peak-to-peak.

A Challenging Installation

The ring was installed during a scheduled shutdown in 2016. The installation was performed by plant personnel using detailed plans developed with the support of the AEGIS® engineering staff.

Figure 6

Installed on a reactor coolant pump at a US nuclear power plant, the AEGIS® RPPR dramatically reduced shaft voltages to non-damaging levels.

Verifying That the Ring Had Solved the Problem

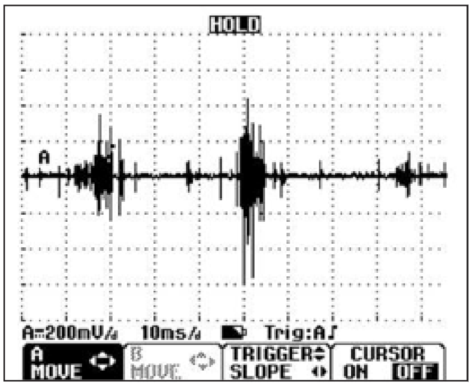


Figure 7

(Courtesy of Giglio Freeman Associates, LLC)

This measurement taken at 200 mV per division — after installation of the AEGIS® RPPR Ring — shows 600 mV peak as the maximum voltage measured. The time and voltage scales were adjusted due to the substantial decrease in electrical activity.

Readings taken after the AEGIS® RPPR's installation showed dramatically lower pump shaft voltage levels than those prior to its installation. The ring had reduced shaft voltage levels to a maximum of 600 mV peak-to-peak.

Once convinced of the effectiveness of the AEGIS® RPPR in preventing face seal damage, plant engineers were excited to share the results with colleagues in the nuclear power industry. In fact, they were so impressed that they suggested the AEGIS® team make a presentation on it to the Pressurized Water Reactor Owners Group.

A common question the engineers encountered when discussing their results with engineers from other plants was whether AEGIS® RPPR Rings would provide the same magnitude of voltage reduction – in absolute or percentage terms – in all cases. The simple answer is no. Each system will experience different voltage readings, and these readings may vary over time. Shaft voltages are not static, and different conditions yield different shaft voltage readings. The need to neutralize shaft-to-housing voltage

Figure 8

An AEGIS® RPPR made of 304 stainless steel was installed around the 24" diameter pump motor shaft using a custom mounting fixture (see Figure 9) also fashioned out of stainless steel.

by providing a reliable path for currents away from face seals and safely to ground, however, remains constant regardless of the system.

Other Custom-Engineered Solutions and Successful Installations

Soon after that presentation, Electro Static Technology received design requests from several other US nuclear power plants. Engineers at Electro Static Technology (the manufacturer of AEGIS® Rings) worked closely with the engineers at these plants to develop custom shaft grounding rings and mounting fixtures to secure the rings in the correct position around the RRP shafts.

In one case, the end result was an AEGIS® RPPR designed to fit the 24" diameter coupling surface between the motor and the pump. To ensure the ring did not increase the volume of flammable material, it was constructed of 304 stainless steel. As with other AEGIS® RPPRs, the stainless steel mounting bracket design was customized to the application, with features to simplify installation during the plant shutdown and to reduce maintenance personnel badge time for the installation.

Now, after successful installations at seven nuclear power plants, including the remaining RCPs at the initial power plant, the AEGIS® RPPRs are quickly becoming the "go-to" solution for protecting RRP and RCP face seals from electrostatic erosion and electrochemical corrosion.

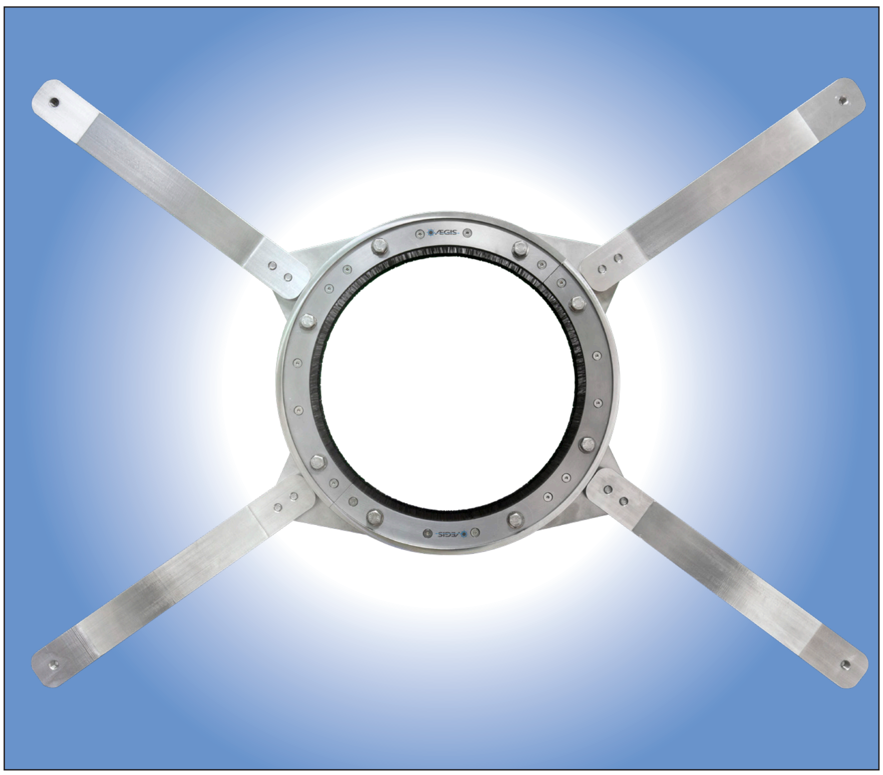


Figure 9

In addition to tailoring each AEGIS® RPPR to the specific pump and application, AEGIS® engineers also design custom mounting brackets that simplify and speed the ring's installation.

Conclusion

Electrostatic erosion and electrochemical corrosion of pump face seals at nuclear power plants jeopardize the safe operation of the reactor and can result in costly unscheduled shutdowns and repairs. By installing mitigation to prevent face seal erosion, plants can avoid these unscheduled shutdowns, saving millions of dollars.

Originating from a proven shaft grounding technology designed for large electric motors, AEGIS® Reactor Pump Protection Rings (RPPRs) are now being used in nuclear plants both in the United States and Europe, and have proven highly effective in mitigating stray currents that can compromise the integrity of these pump face seals.

Based on an initial success at a Swiss nuclear plant, Electro Static Technology has since supplied AEGIS® RPPRs customized to the specific installation needs of several major nuclear plants in the United States.

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