June 2023

StayDry® Summary of Testing

Design Qualification Tests, Results, and Analysis

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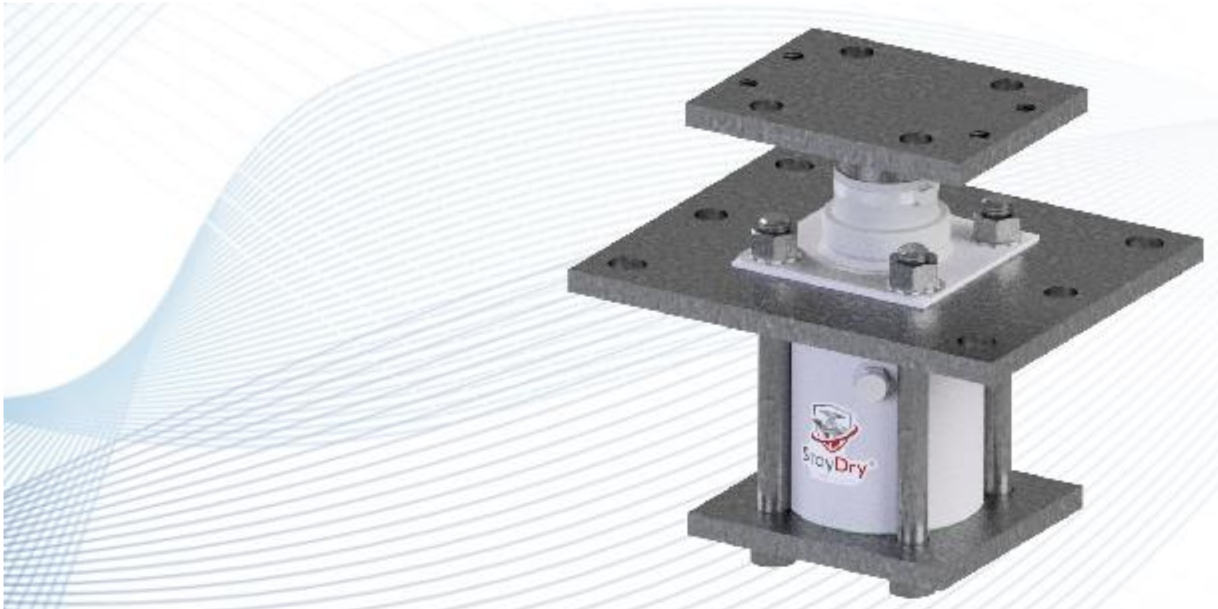


INTRODUCTION

This document provides a summary of the environmental testing that was performed to qualify the StayDry® rotating insulator bearing design. The tests were selected to represent a wide variety of typical and extreme environmental conditions that could be experienced by the bearing across the service life of the switch. The goal of this testing was to validate the design and show the benefits of using a hydrophobic vent in a disconnect switch rotating insulator bearing application.

The testing was performed across the span of three years in various locations across the United States, including an independent third-party laboratory and the Cleaveland/Price laboratory. Validation testing was performed to applicable national and military grade environmental test standards. Each test section lists the name of the test, the goal of the test, a description of the test and a typical in-service environmental condition related to the test. This test information is then followed by pictures showing the pre- and post-test conditions of the bearing for each test and a summary of the result of the testing.

TESTING PERFORMED

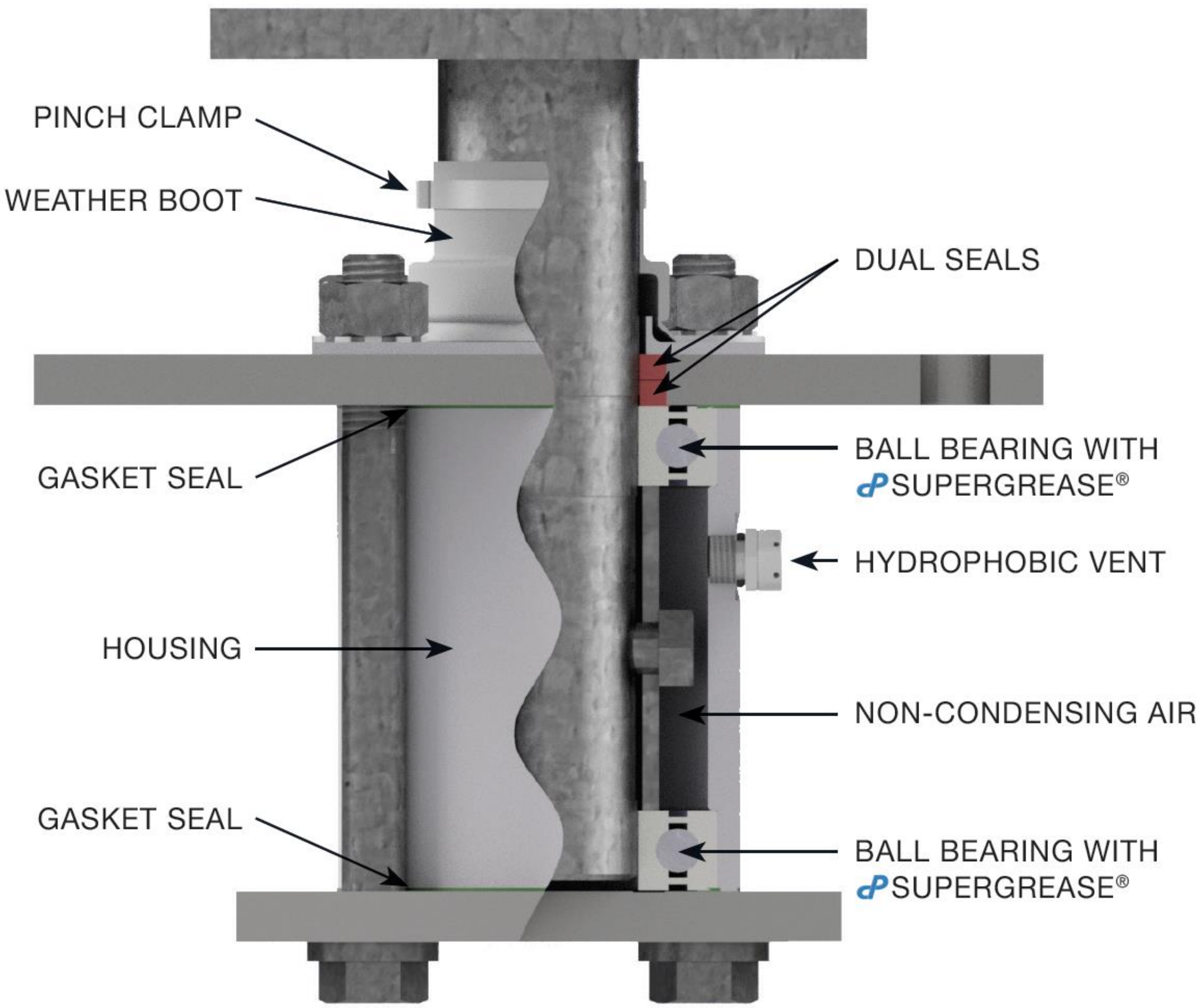


Figure 1: StayDry® Bearing Cutaway

Test 1: Dust Ingress

Table 1: Dust Ingress Test Information

Name	Dust Ingress
Goal	Prove resistance to dust or dirt entry into bearing.
Description	Each bearing assembly was placed in a dust chamber and subjected to an IP5X dust ingress test in accordance with IEC 60529. A vacuum was applied to each unit per Category 1, and 30-second vertical burst cycles were applied using a total of 6.3 kg of talcum powder.
In-Service Condition	Windblown dust, dirt, and contamination in the air
Standard	IEC 60529
Duration	8 hours
Lab	Clark Dynamic Test Laboratory
Location	Large, PA

Tests 1–4: Test Object Identification

Table 2: Tests 1-4 Configurations

Name	Description	Configuration
UUT1	2″ Shaft Bearing Assembly with Vent	No grease on bearings
UUT2	2″ Shaft Bearing Assembly with Vent	With grease on bearings
UUT3	3.5″ Shaft Bearing Assembly with Vent	With grease on bearings

Note: Tests 1-4 were performed on the same bearing assemblies in succession.

Figure 2: Dust Ingress Pre-Test Condition

Figure 3: Dust Ingress Post-Test Condition

Test 1 Results

Post-test inspection showed no ingress of dust into the bearing assembly. Refer to “Post-Tests 1–4 Teardown” pictures on page 13.

Test 2: Water Ingress

Table 3: Water Ingress Test Information

Name	Water Ingress
Goal	Prove resistance to water entry into bearing.
Description	Each bearing assembly was subjected to a 1 min/m^2 (3-minute minimum) IPX5 water ingress test in accordance with IEC 60529. An IPX5 nozzle with the appropriate flow and test distance was used. Testing was performed on every side of each bearing that would be exposed to ingress when mounted in the field. Following the test, each bearing was allowed to drip dry for 10 minutes.
In-Service Condition	Heavy rain
Standard	IEC 60529
Duration	1-minute exposure (4 sides)
Lab	Clark Dynamic Test Laboratory
Location	Large, PA

Figure 4: Water Ingress Pre-Test Condition

Figure 5: Water Ingress In-Process Testing

Figure 6: Water Ingress Post-Test Condition

Test 2 Results

Post-test inspection showed no ingress of water into the bearing assembly. Refer to “Post-Tests 1–4 Teardown” pictures on page 13.

Test 3: Humidity

Table 4: Humidity Test Information

Name	Humidity
Goal	Prove resistance to internal condensation and corrosion in bearing due to changes in humidity.
Description	Each bearing was subjected to humidity testing in accordance with MIL-STD-810G Method 507.5 “Aggravated Cycle”. Each bearing was subjected to a 240 hour profile in accordance with Section 2.6.3 Figure 507.5-7 and Table 507.5-IX. Initial Soak Condition: 23 °C @ 50 % RH Cycle Condition: 30 °C @ 95 % RH to 60 °C @ 95 % RH
In-Service Condition	High humidity
Standard	MIL-STD-810G Method 507.5
Duration	240 hours
Lab	Clark Dynamic Test Laboratory
Location	Large, PA

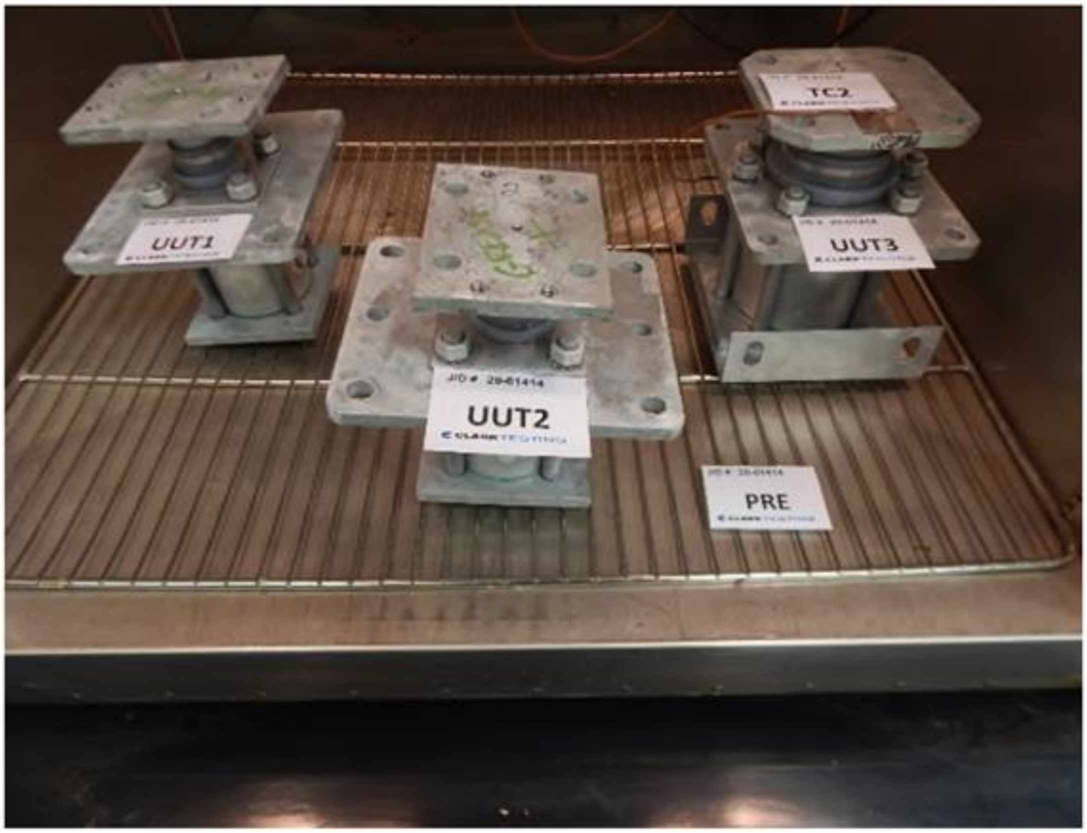


Figure 7: Humidity Pre-Test Condition

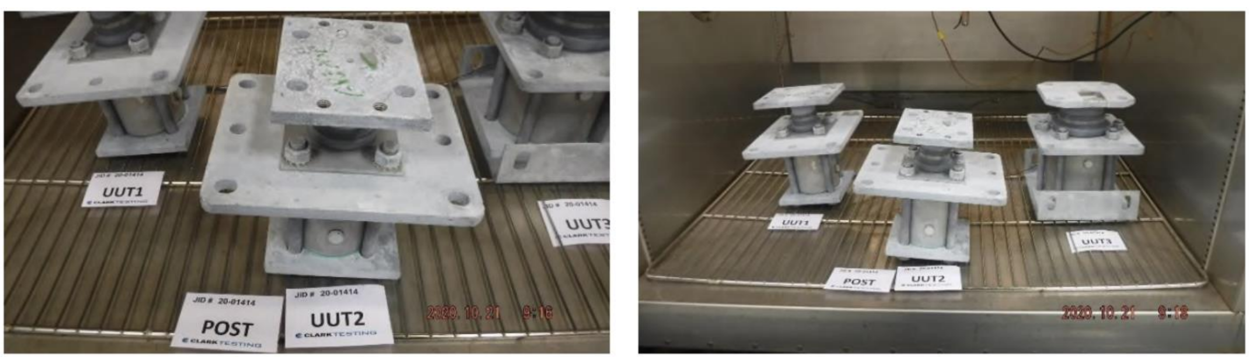


Figure 8: Humidity Post-Test Condition

Test 3 Results

Post-test inspection showed no internal condensation or corrosion due to high humidity. Refer to "Post-Tests 1–4 Teardown" pictures on page 13.

Test 4: Salt Spray

Table 5: Salt Spray Test Information

Name	Salt Spray
Goal	Prove resistance to salt and water ingress into bearing.
Description	Each bearing was subjected to a salt spray test in accordance with MIL-STD-810G Method 509.5. Each bearing was placed in a salt fog chamber that was prepared with a salt solution of 5 % and a pH between 6.5 and 7.2. The delivery rate was 1–3 mL per hour with a cabinet temperature of 35 °C ± 2 °C. The chamber exposed each bearing to 24 hours of salt spray. Each bearing was then removed and allowed to air dry for 24 hours. This was repeated for two cycles resulting in a total test time of 96 hours. Following the completion of the test, each unit was rinsed with tap water and allowed to dry for 24 hours.
In-Service Condition	Coastal environment with airborne salt spray
Standard	MIL-STD-810G Method 509.5
Duration	96 hours
Lab	Clark Dynamic Test Laboratory
Location	Large, PA

Figure 9: Salt Spray Pre-Test Condition

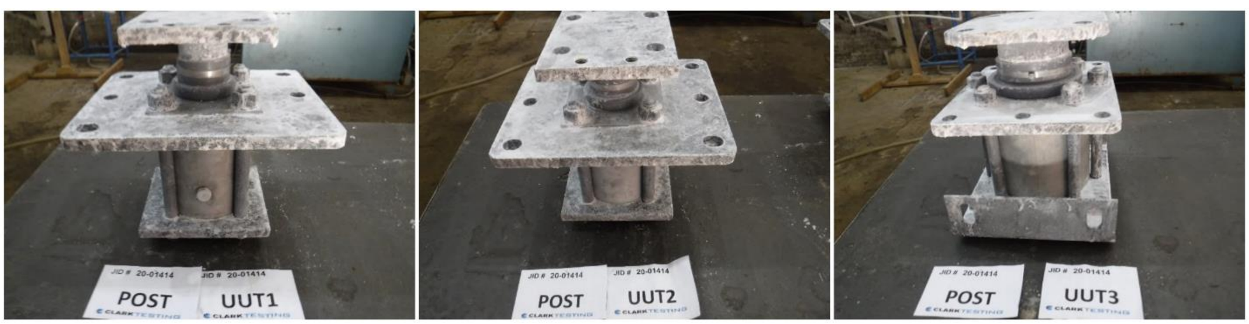


Figure 10: Salt Spray Post-Test Condition

Test 4 Results

Post-test inspection showed no ingress of salt or water into the bearing and no corrosion. Refer to "Post-Tests 1–4 Teardown" pictures on page 13.

Post-Tests 1–4 Teardown

Following tests 1–4, the bearing assemblies were completely disassembled to inspect the inside surfaces for signs of dust, water, condensation, salt, or other contaminants. There were no signs of entry for any of these substances, and all bearings looked the same as when they were newly assembled. See Figures 11–13.

Figure 11: UUT1 Post-Tests 1–4 Interior and Bearing Condition

Figure 12: UUT2 Post-Tests 1–4 Interior and Bearing Condition

Figure 13: UUT3 Post-Tests 1–4 Interior and Bearing Condition

Test 5: Temperature Shock

Table 6: Temperature Shock Test Information

Name	Temperature Shock
Goal	Prove there is no increase in operation torque with extreme temperature and relative humidity changes.
Description	Each bearing was subjected to a temperature and humidity profile that cycled from +140 °F at 90 % RH to -40 °F at 30 % RH. Each temperature was held for two hours, and then repeated.
In-Service Condition	Hot weather followed by a fast-moving cold front or cold rain
Standard	None
Duration	48 hours
Lab	Cleaveland/Price Laboratory
Location	Trafford, PA

Test 5: Test Object Identification

Table 7: Temperature Shock Test Configuration

Name	Description	Configuration
UUT4	2” Shaft Bearing Assembly with Vent	With grease on bearings

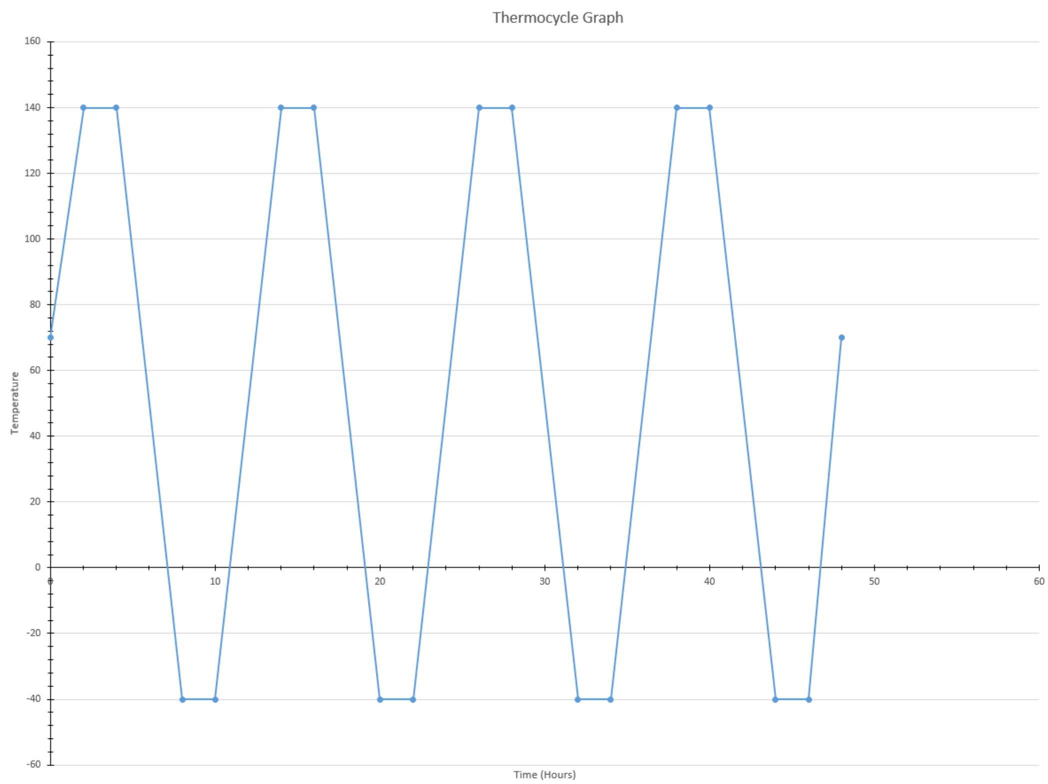


Figure 14: Thermocycle Temperature Profile Graph

Table 8: Thermocycle Torque to Turn Bearing

Chamber Temperature (°F)	Torque to Operate After First Cycle (in-lb)	Torque to Operate After Last Cycle (in-lb)	Percent Change (%)
-40	65	41	-37
-15	41	31	-24
70	37	20	-46
140	37	22	-41

Figure 15: UUT4 Thermocycle Test Object

Test 5 Results

After four thermocycles, the bearing showed a decrease in operation torque at each of the four temperature check points. In addition, the increase in torque at low temperatures compared to room temperature was very acceptable with an increase of only 28 in-lb.

Test 6: Forced Humidity

Table 9: Forced Humidity Test Information

Name	Forced Humidity
Goal	Prove corrosion resistance to humid air entry and exchange.
Description	Each bearing was subjected to large flows of humid air into and out of the chamber to replicate, at a larger scale, the airflow that naturally occurs during atmospheric temperature and pressure changes. A small air pump pushed humidified air through both bearing housings for 120 seconds. A solenoid closed, and the chamber was pressurized to 0.5 psig for 30 seconds. The pump was deactivated, and the solenoid valve was opened for 30 seconds to vent the bearing housings. While this occurred, the environmental chamber temperature was increased to 120 °F over a two-hour period and held for four hours. The temperature was then decreased to -40 °F over a two-hour period and held for four hours. The environmental chamber and pump were cycled continuously for 28 days.
In-Service Condition	Accelerated temperature and pressure changes in a humid environment
Standard	None
Duration	28 days
Lab	Cleaveland/Price Laboratory
Location	Trafford, PA

Test 6: Test Object Identification

Table 10: Forced Humidity Test Configurations

Name	Description	Configuration
UUT5	2” Shaft Bearing Assembly with Vent	No grease on bearings
UUT6	2” Shaft Bearing Assembly with No Vent	No grease on bearings

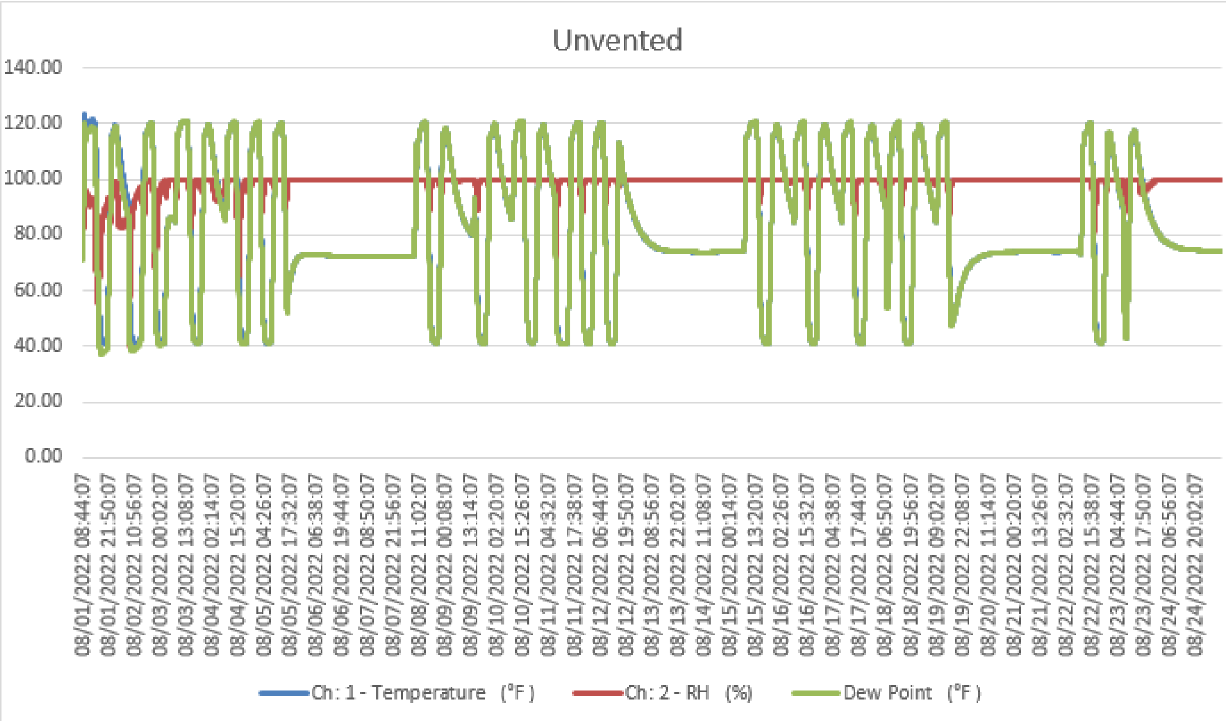


Figure 16: Unvented Bearing Temperature vs. Relative Humidity vs. Dew Point

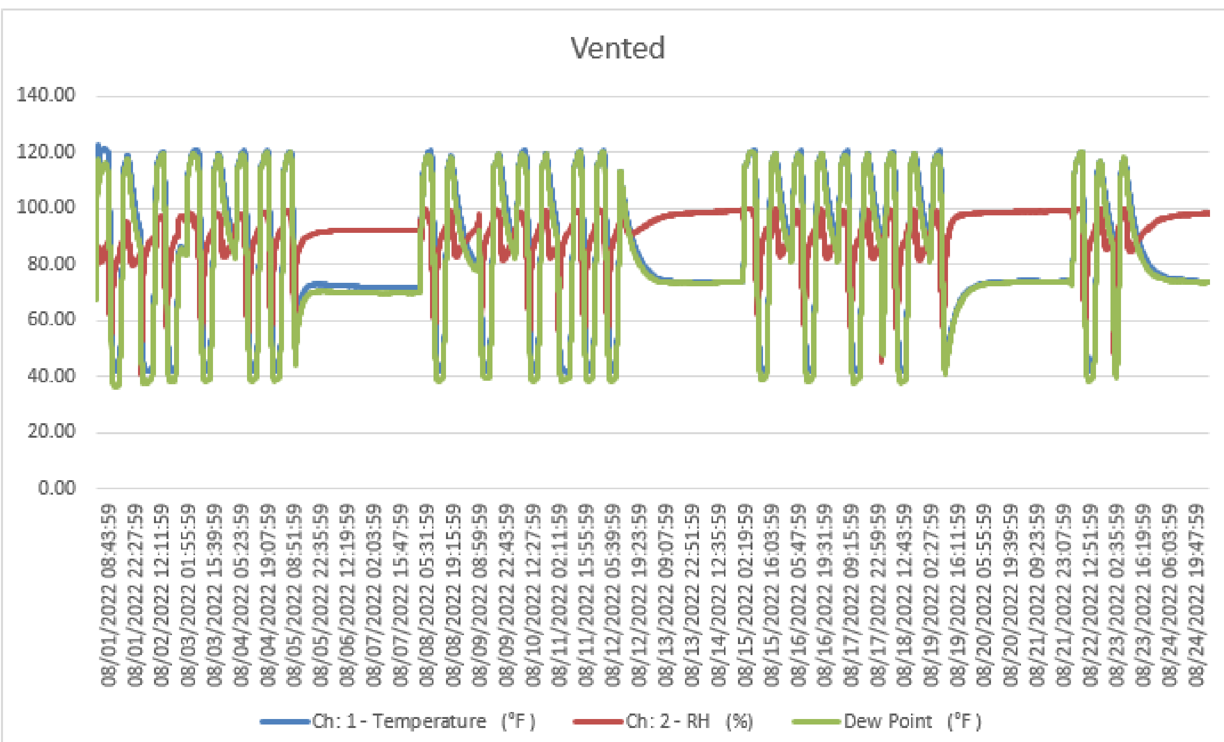


Figure 17: Vented Bearing Temperature vs. Relative Humidity vs. Dew Point

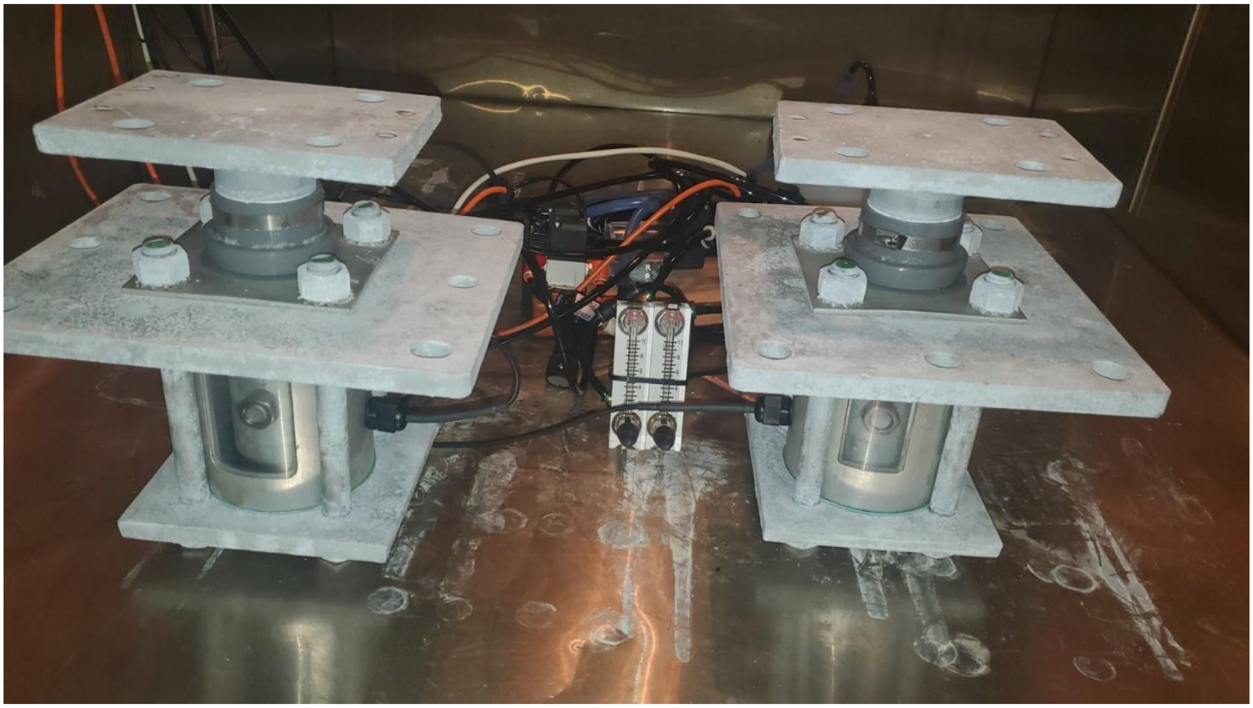


Figure 18: UUT5 and UUT6 Forced Humidity Test Setup

Figure 19: UUT5 Vented Bearing, Forced Humidity Post-Test Condition

Figure 20: UUT6 Unvented Bearing, Forced Humidity Post-Test Condition

Test 6 Results

Post-test inspection showed no rust on the bearings in the vented assembly and a considerable amount of rust on the bearings in the unvented assembly. The rotation of the bearing shaft on the unvented assembly was very rough due to corrosion of the metal surfaces of the bearing.

Test 7: Field Test 1

Table 11: Field Test 1 Information

Name	Field Test #1
Goal	Prove hydrophobic vent function with no grease on bearings.
Description	Each bearing assembly was placed in an outdoor environment in an upright position. One bearing assembly utilized a hydrophobic vent and the other bearing assembly had a small 1/8" diameter hole drilled in the housing with no hydrophobic membrane. Both designs had no grease on the bearings.
In-Service Condition	Typical Eastern United States weather
Standard	None
Duration	1 year (UUT7) / 4 months (UUT8)
Lab	Cleaveland/Price Outdoor Test Yard
Location	Trafford, PA

Test 7: Test Object Identification

Table 12: Field Test 1 Configurations

Name	Description	Configuration
UUT7	2" Shaft Bearing Assembly with Vent	No grease on bearings
UUT8	2" Shaft Bearing Assembly with 1/8" Hole	No grease on bearings

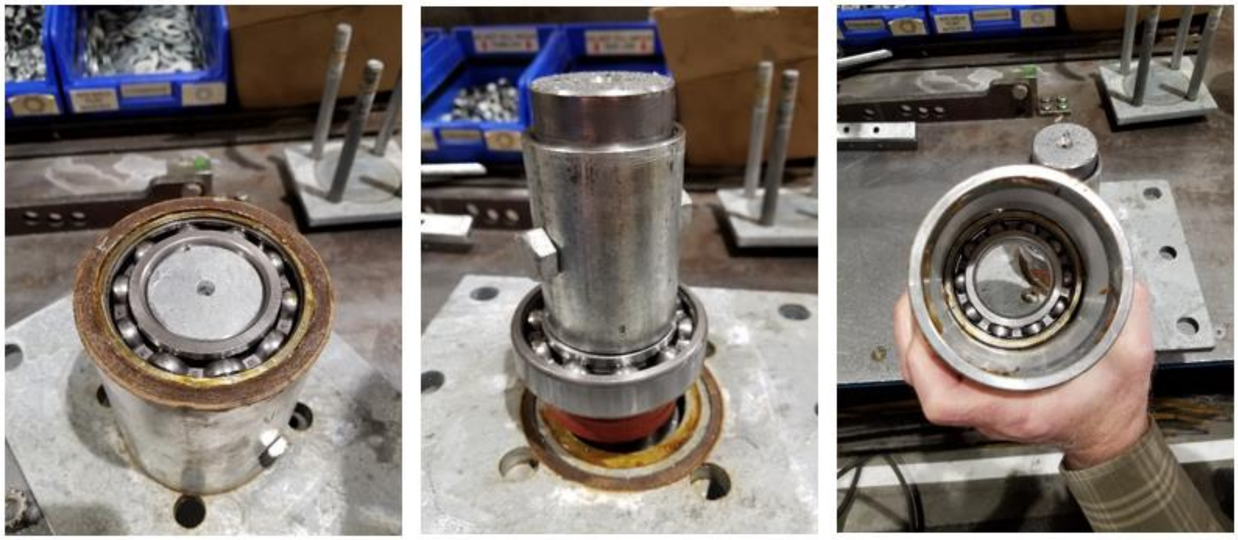


Figure 21: Field Test 1—UUT7 One-Year Inspection

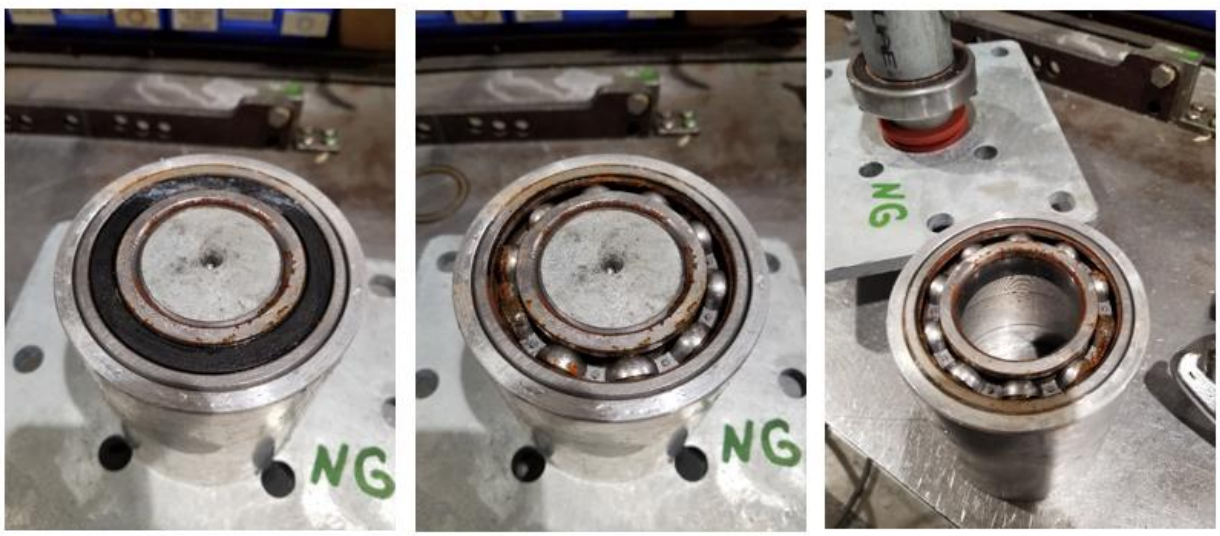


Figure 22: Field Test 1—UUT8 Four-Month Inspection

Test 7 Results

Post-test inspection showed no rust on the bearings in the vented assembly and a considerable amount of rust on the bearings in the unvented assembly. The bearings from the vented assembly had smooth rotation while the bearings from the unvented assembly were frozen after four months. Note that both bearings had no pressure across the seals because both had an opening into the bearing housing, one with a hydrophobic vent and one with a 1/8" diameter hole. Only the bearing with the hydrophobic vent had no corrosion, which demonstrates the value of the hydrophobic vent in this application.

Test 8: Field Test 2

Table 13: Field Test 2 Information

Name	Field Test #2
Goal	Prove hydrophobic vent function with grease on bearings.
Description	Each bearing assembly was placed in an outdoor environment in an upright position. One bearing assembly utilized a hydrophobic vent and the other bearing assembly had a small 1/8" diameter hole drilled in the housing with no hydrophobic membrane. Both designs had grease on the bearings.
In-Service Condition	Typical Eastern United States weather
Standard	None
Duration	1 year
Lab	Cleaveland/Price Outdoor Test Yard
Location	Trafford, PA

Test 8: Test Object Identification

Table 14: Field Test 2 Configurations

Name	Description	Configuration
UUT9	2" Shaft Bearing Assembly with Vent	With grease on bearings
UUT10	2" Shaft Bearing Assembly with 1/8" Hole	With grease on bearings

Figure 23: Field Test 2—UUT9 One-Year Inspection

Figure 24: Field Test 2—UUT10 One-Year Inspection

Test 8 Results

A one year, post-test inspection showed no rust on the bearings in the vented assembly and a considerable amount of rust on the bearings in the unvented assembly even though there was grease to help prevent corrosion. The bearings from the vented assembly had smooth rotation while the bearings from the unvented assembly were completely frozen and unable to be rotated due to corrosion of the metal surfaces of the bearing.

Test 9: Field Test 3

Table 15: Field Test 3 Information

Name	Field Test 3
Goal	Observe visual change in two different bearing configurations through clear, polycarbonate bearing housings.
Description	Two bearing assemblies were built with clear, polycarbonate housings to be able to see changes inside the bearing. One bearing assembly utilized a hydrophobic vent and the other bearing assembly did not.
In-Service Condition	Moderate temperature, low humidity weather
Standard	None
Duration	6 months
Lab	Cleaveland/Price Laboratory
Location	Trafford, PA

Test 9: Test Object Identification

Table 16: Field Test 3 Configurations

Name	Description	Configuration
UUT11	2" Shaft Bearing Assembly with Vent, Clear Housing	No grease on bearings
UUT12	2" Shaft Bearing Assembly with No Vent, Clear Housing	No grease on bearings

Figure 25: Field Test 3—UUT11 and UUT12 Six-Month Inspection

Test 9 Results

A six-month visual inspection showed that the unvented bearing assembly had white oxidation on the interior galvanized surfaces along with rust on the bearings. The vented bearing assembly showed no oxidation on the interior surfaces or corrosion of the bearings. Even after four years the bearing with the hydrophobic vent rotates smoothly but the unvented bearing shaft is not able to be rotated.

Test 10: Field Test 4

Table 17: Field Test #4 Information

Name	Field Test 4
Goal	Prove ability of a sealed volume with a hydrophobic vent to allow liquid water to evaporate from inside.
Description	An open chamber was constructed with a clear, polycarbonate housing sealed with gaskets and two steel plates on each side, similar to the construction of a typical bearing. The assembly was held together with four bolts. A hydrophobic vent was mounted to the clear housing, and one teaspoon of liquid water was placed in the housing. The assembly was placed in a temperature-controlled, indoor office environment.
In-Service Condition	Water bypasses seals and enters bearing housing
Standard	None
Duration	118 days
Lab	Cleaveland/Price Laboratory
Location	Trafford, PA

Test 10: Test Object Identification

Table 18: Field Test 4 Configurations

Name	Description	Configuration
UUT13	Clear Housing with Vent Sealed by Two Steel Plates	Empty cavity

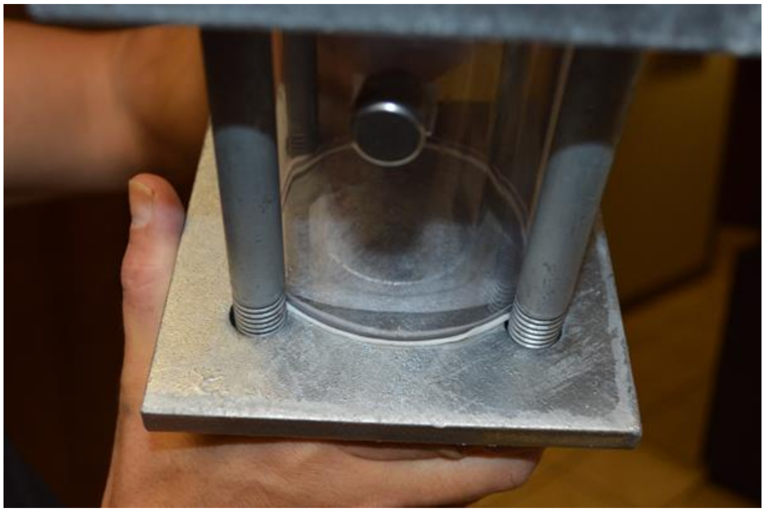


Figure 26: Field Test 4—Sealed, Vented Volume with One Teaspoon of Liquid Water

Figure 27: Field Test 4—118-Day Visual Inspection

Test 10 Results

After 118 days, the teaspoon of water was completely evaporated from the inside of the housing. The hydrophobic vent allowed the water vapor to flow from high water vapor concentration (inside) to low water vapor concentration (outside).

Test 11: Field Test 5

Table 19: Field Test 5 Information

Name	Field Test 5
Goal	Prove ability of a bearing assembly with a hydrophobic vent to perform after years of service in a hot, humid, outdoor environment.
Description	A StayDry® bearing was built and placed in an upright position in an outdoor location in the Southeastern United States. Operation was checked each year. The bearings were completely degreased and the dust covers on the bearings were removed.
In Service Environmental Condition	Hot, humid, Southeastern United States weather
Standard	None
Duration	4 years
Lab	N/A
Location	Naples, FL

Test 11: Test Object Identification

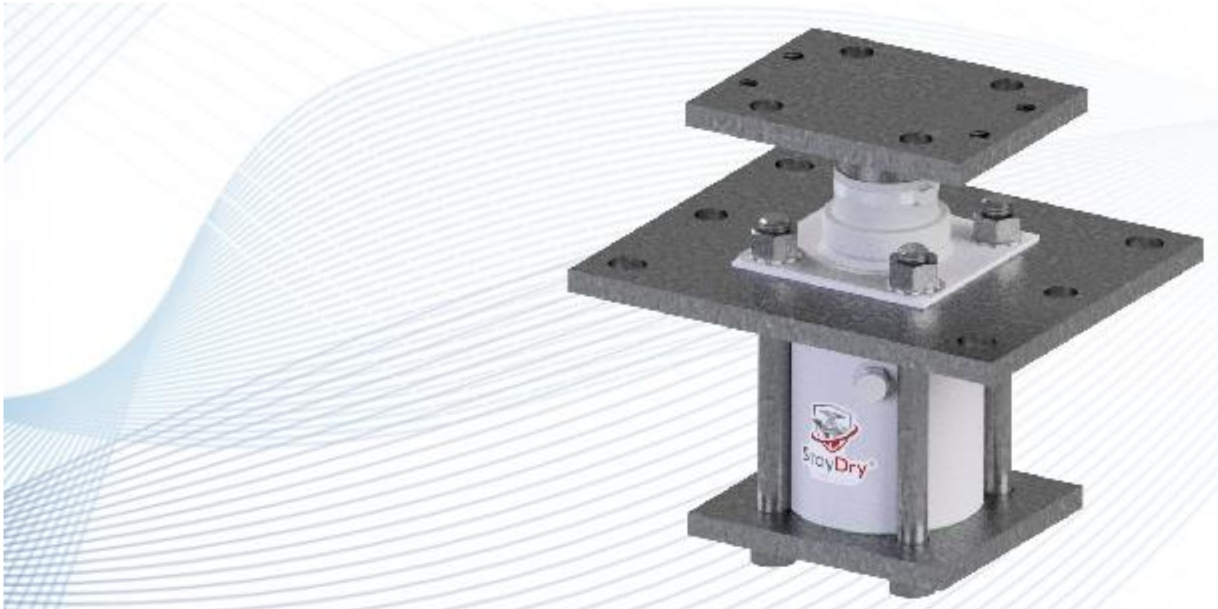
Table 20: Field Test 5 Configurations

Name	Description	Configuration
UUT14	2" Shaft Bearing Assembly with Vent	With no grease on ball bearings

Figure 28: Field Test 5—UUT 14 Test Location

Test 11 Results

After four years outdoors in a hot, humid environment, the bearing continues to rotate smoothly and there is no indication that there is any corrosion present. This is particularly impressive as the ball bearings are completely free from the protection of any grease.



CONCLUSION

In conclusion, this testing showed that the StayDry® rotating insulator bearing assembly had excellent performance across a wide variety of challenging environmental tests. An independent third-party laboratory verified the performance of the design against established national and military grade standards. Hydrophobic membrane technology has been utilized for several decades across a wide variety of industries to protect enclosed volumes from the effects of temperature and pressure fluctuations, moisture and contaminants. The use of a hydrophobic membrane in a disconnect switch rotating insulator bearing application allows a switch to have unparalleled reliability across even the most extreme environmental conditions.