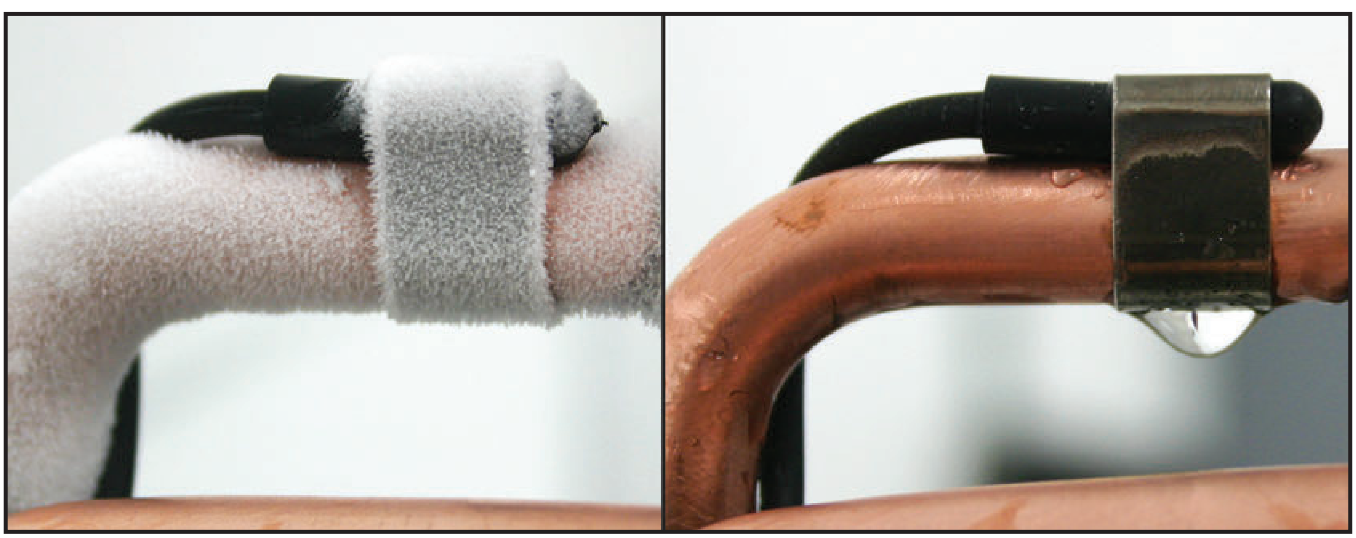
Sensing Solutions

WHITE PAPER

THERMISTOR PERFORMANCE AND RELIABILITY IN FREEZE/THAW APPLICATIONS

An Evaluation of Waterproofness and Response Time

QTI Engineering Department



ABSTRACT

Moisture is the main cause of failure for thermistor-based temperature sensors that are exposed to repeated freeze/thaw cycles (such as in refrigeration applications). The repeated thermal cycles result in weakened or broken bonds between components; moisture enters the probe causing thermistor failure. The purpose of this report is to fully test QTI's IP68 thermistor probe design in a refrigeration environment (consisting of repeated cool and defrost cycles) and document the performance characteristics over time. Additionally, QTI will test sensors from competitors that claim IP68 performance but rely on some form of mechanical seal or coating that is susceptible to failure. The report includes data from response time testing when the thermistor probes are mounted to copper tubing and will show how the response time is affected by utilizing various mounting and insulating options.

INTRODUCTION

Thermistors are ideal sensing devices for applications with operating temperatures ranging from -55˚C to +125˚C. Thermistor probes are abundantly used in refrigeration applications where temperatures range from -40˚C to +120˚C. The sensors are mounted to evaporator coils, discharge lines and inside cabinets among other locations. While thermistor probes are perfectly suited for these temperatures, the applications can be very harsh and can ultimately lead to premature failure. These failures not only require costly field repairs by certified technicians but can also mean the loss of hundreds of thousands of dollars in ruined product from groceries to pharmaceuticals.

The harsh operating environment comes from the effort to maximize cooling efficiency, automatically defrost and minimize energy usage. Evaporator coils within a refrigeration system are heated as needed in order to bring the temperature of the evaporator coils from ~-40˚C to +100˚C in order to remove the frost from the coils and fins to ensure efficient and effective cooling. While this temperature cycle is well within the previously stated operating temperature range for thermistor elements, it does present challenges for the various materials that are used in creating a fully assembled thermistor probe. Materials used (extension cables, housings, encapsulation compounds, etc.) must be suitable for the environment and a sealing method/material must be used in order to keep moisture from reaching the thermistor element. Should moisture enter the probe and reach the thermistor element, the sensor will fail prematurely.

This challenge led QTI Engineering to develop a sensor that is rated to IP68 (Ingress Protection – Dust tight and sealed against water when submerged to 15 meters). The IP68 sensor utilizes a Thermoplastic Elastomer (TPE) overmold that is chemically matched and bonded to the material used in the cable jacketing to ensure that moisture cannot reach the thermistor element. While there are other sensor assemblers that claim an IP68 rating for their thermistor probes, they rely on some sort of coating, epoxy bond, housing crimp, or other secondary feature to attempt to keep moisture away from the thermistor. QTI will test these thermistor probes alongside our IP68 probe and evaluate the performance and reliability of each. Performance measures will include response time, ease of mounting, etc., while reliability will be evaluated based on operation time before failure occurs.

TEST SETUP AND DETAILS

RELIABILITY TEST SETUP

A refrigeration unit was purchased from a major manufacturer (see Fig. 1). This unit has a programmable controller that will be set for specific freeze/thaw cycles. Thermistor probes will be mounted to the evaporator; directly in contact with frost and condensation present throughout the process.

Figure 1. Refrigeration Test Unit.

RELIABILITY TEST PROCEDURE

1. Mount five QTI IP68 sensors to 3/8" copper evaporator line using Ni plated steel clip (see Fig. 2).
2. Mount one standard QTI sensor (non-IP68 but assembled using best practices) to evaporator line.
3. Mount one competitor's probe to 3/8" copper evaporator line.
4. Mount one standard "CPC" probe to 3/8" copper evaporator line.
5. Wire all sensors into data acquisition system and start unit. Allow unit to cycle continuously between approximately -20˚C to +50˚C.
6. Sensors will be monitored to determine the point at which failure has occurred as a result of the testing.

RESPONSE TIME TEST SETUP

Thermistor probes will be mounted to evaporator coil and monitored by a data acquisition system. Response time will be evaluated when attached in various methods (zip-tie, clip, tape), with and without insulation covering sensor, and compared to a thermocouple "standard".

Figure 2. IP68 sensor mounted to 3/8" tube with QTI clip.

RESPONSE TIME TEST PROCEDURE

Test One:

1. Test QTI's IP68 response time when mounted to evaporator line with zip-tie.
2. Test QTI's IP68 response time when mounted to evaporator line with Ni plated steel clip.
3. Test QTI's IP68 response time when mounted as in #2 but with insulation tape covering sensor (see Fig. 3)

Test Two:

1. Test competitor's IP68 response time when mounted to evaporator line with zip-tie.
2. Test competitor's IP68 response time when mounted to evaporator line with clip.
3. Test competitor's IP68 response time when mounted as in #2 but with insulation tape covering sensor.

Figure 3. Evaporator line with insulating tape over sensor.

TEST RESULTS

RESPONSE TIME TEST RESULTS

(Completed 1/18/13)

Test One:
Five probes of each type were tested per the response time test procedure previously described. The probes used were:
1. QTI standard construction thermistor probe (1/4" OD nickel plated brass tube)
2. QTIP68
3. QTI standard construction thermistor probe (3/16" OD stainless steel tube)

Probe Type 1 (seconds)	Probe Type 2 (seconds)	Probe Type 3 (seconds)
8.80	17.15	7.06
7.85	17.81	6.41
9.06	17.44	6.54
8.65	17.53	7.00
8.07	17.15	6.13

Table 1: Response Time Test Results

Test Two:
Figure 4 below shows the response time results when the thermistor probes are mounted to copper tubing with the appropriate size clips.

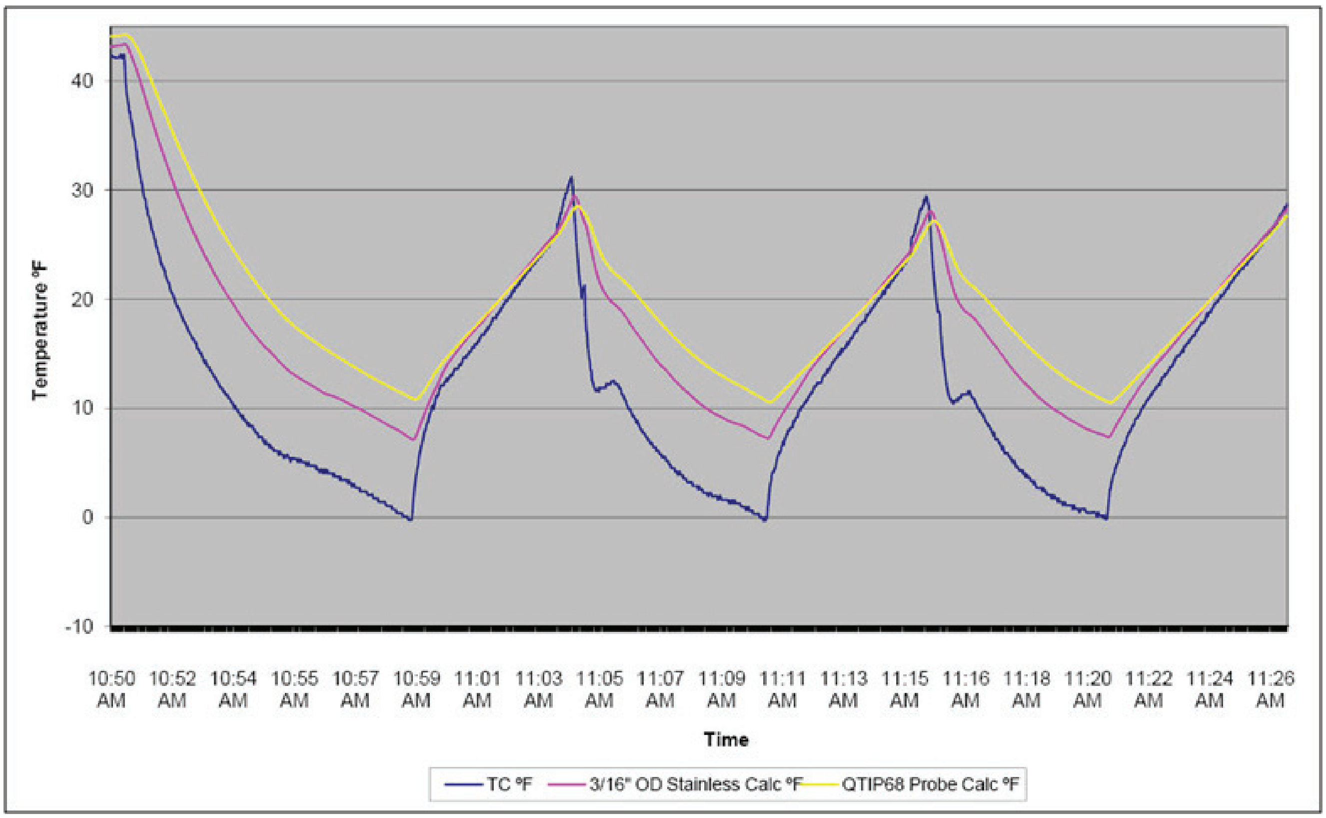


Figure 4. Response time chart with sensors mounted to copper line with spring clips

RELIABILITY TEST RESULTS - INITIAL

The system was started on 7/8/11 and has been allowed to run continuously (24 hours per day). Data was logged continuously and one full day of operation using both a QTI IP68 probe and a competitor's "IP68" probe was captured. The QTI data can be seen in Figure 5. As you can see, the system remains in refrigeration mode for almost 2 hours (builds up considerable frost and ice) then goes to defrost mode.

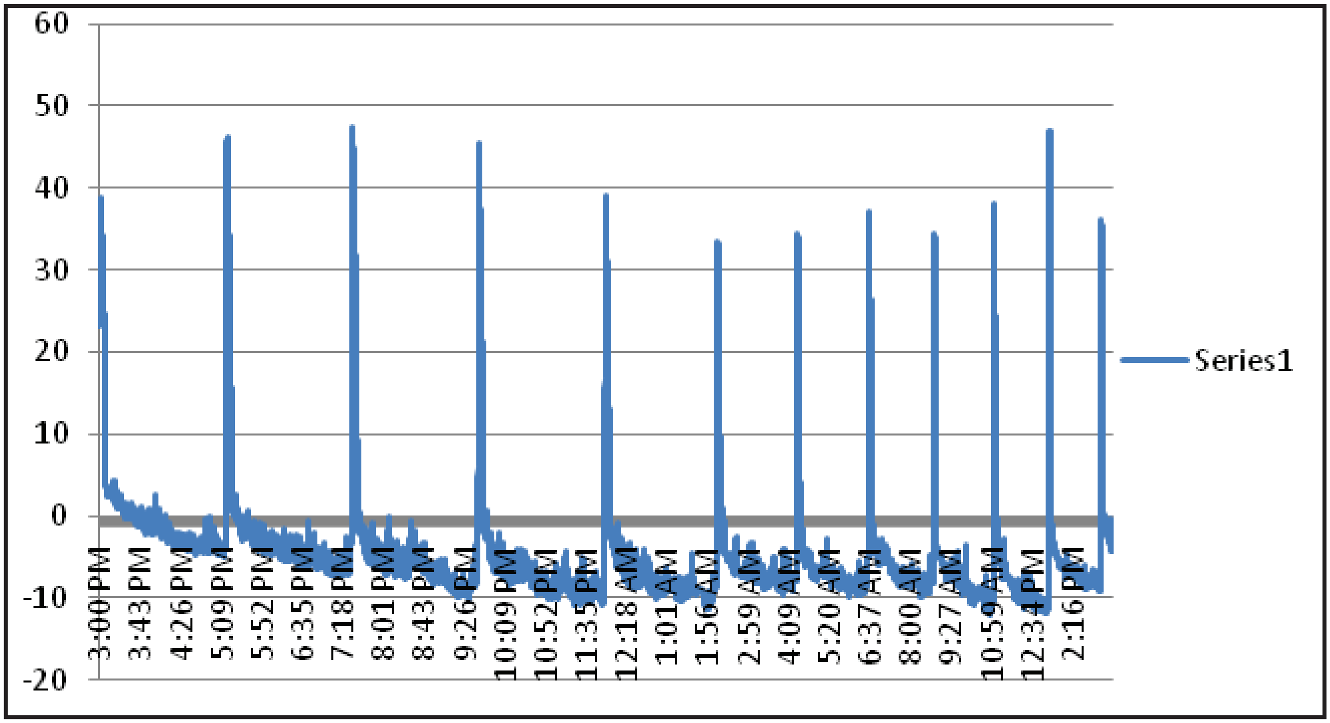


Figure 5. QTI IP68 #4 temperature graph for day one of testing

The data from the Competitor's probe can be seen in Figure 6. This probe is mounted ~1" away from the location of the QTI IP68 sensor (just far enough to allow room for the clips to sit side-by-side). As you can see, the Competitor's probe does have a slightly reduced offset from the actual temperature of the evaporator – this is attributed to the stainless housing on that part as opposed to the overmolded plastic housing on QTI's part.

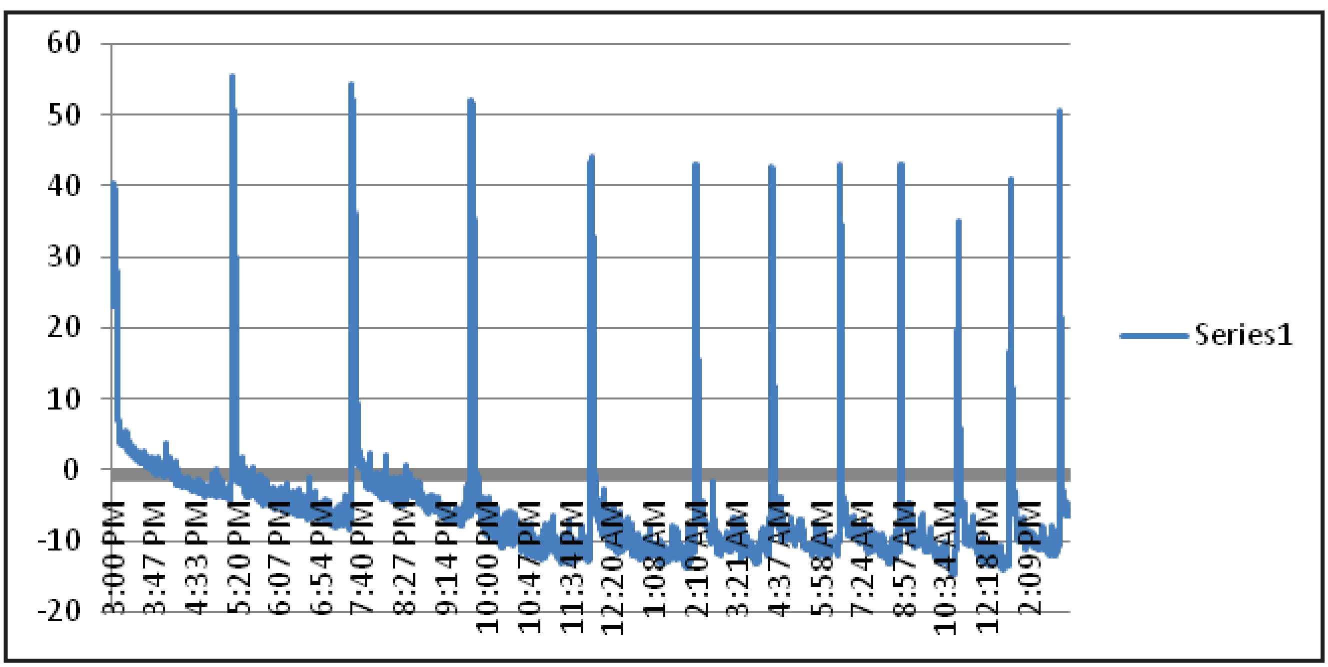


Figure 6. Competitor's probe temperature graph for one day of testing

In order to show how these various probes compare to one another on a single chart, the data was combined and can be seen in Figure 7 below. The comparison shows a QTI IP68 probe, Competitor's probe and a standard CPC probe. As you can see, the CPC appears to track the temperature more closely than the other two probes. Given the construction methods involved in the 3 probes, this is likely due to the fact that the thermistor inside the CPC probe could easily be in direct contact with the wall of the stainless probe. The QTI IP68 probe and the Competitor's probes both keep the thermistor element relatively centered within the housing.

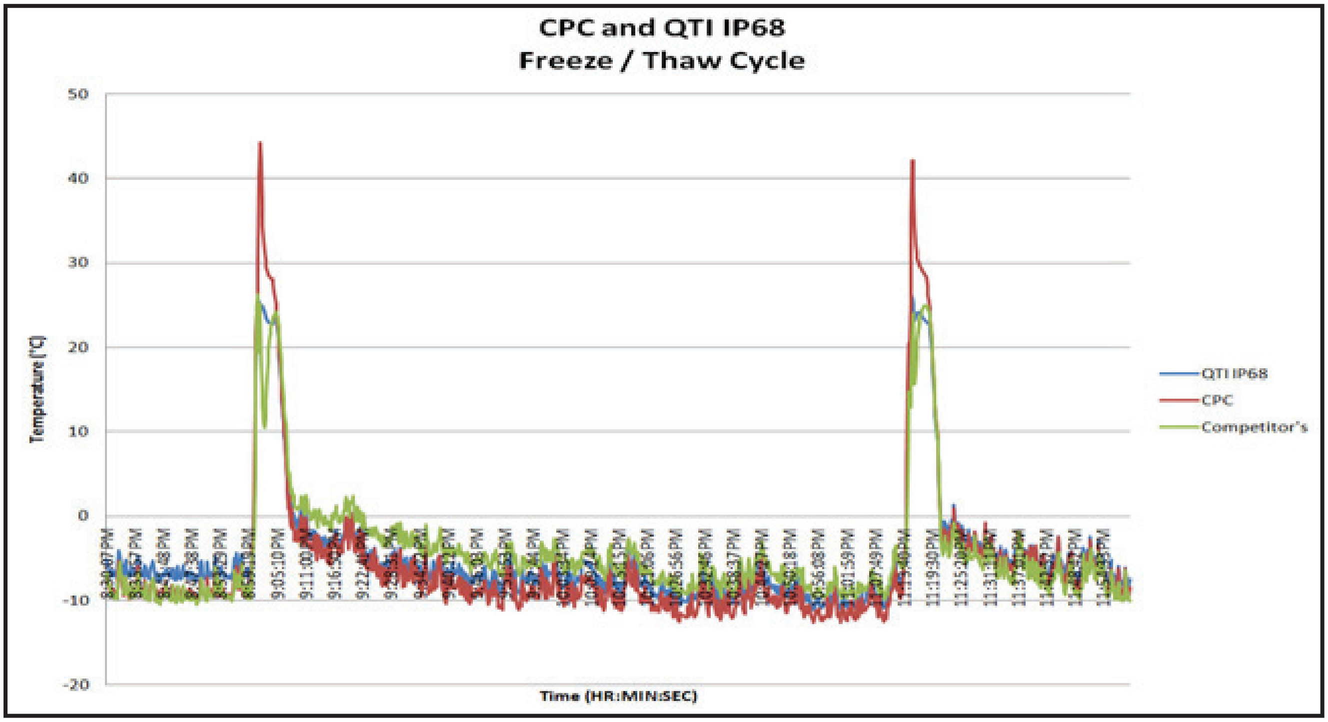


Figure 7. One thermal cycle for QTI IP68 probe with CPC probe and Competitor's probe

RELIABILITY TEST RESULTS – ONGOING

After 5 months of continuous operation (~1800 cycles), the "Generic" probe failed. This is a standard probe constructed using industry standard best-practices for non-waterproof probes (much like the CPC probes). The repeated thermal cycles caused the thermistor to fail (open).

The system continued to operate and on 2/20/12 (~2700 cycles), the Competitor's probe showed an apparent failure. This probe is marketed as IP68 and is supposed to be designed and manufactured to withstand the harsh environment of refrigeration systems. This sensor has an apparent crack that propagated within the ceramic sensing element after being subjected to the thermal cycles. Instead of reading 10K ohms at 25˚C, the thermistor reads 20K ohms (when measured in an oil bath controlled to 25C +/-0.005˚C). In the field, this type of failure would be seen when a refrigeration unit failed to continue cooling because the 'believed' temperature of the room was already sufficiently cold when in actuality the material was warming past the acceptable limit.

The system continued to operate and on 6/8/12 (~4000 cycles), the CPC probe has fully failed. It was starting to fail about a month ago but we allowed it to continue to run. Failure mode appears to be moisture induced silver dendrite growth across the face of the thermistor chip. The thermistor should have been reading a temperature of 4˚C and instead was reading 59˚C. We are documenting the failure to have happened at 4008 thermal cycles (although the actual 'start' of the failure was at about the 3600 cycle mark). After removing the probe from the evaporator line, a quick visual inspection shows a large gap between the lead wires and the epoxy, the epoxy is very soft, and with slight pressure applied to the epoxy, moisture can be pressed out of the sensor housing.

The system continues to operate. As of 3/4/2013 (~7200 cycles), after more than a year and a half of continuous freeze/thaw cycling, the QTI IP68 sensor continues to accurately read the temperature.

IMAGES FOR REFERENCE

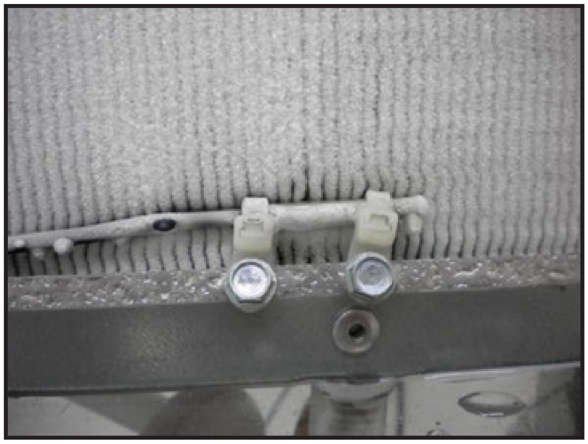


Figure 8. Iced thermistor probe on evaporator.

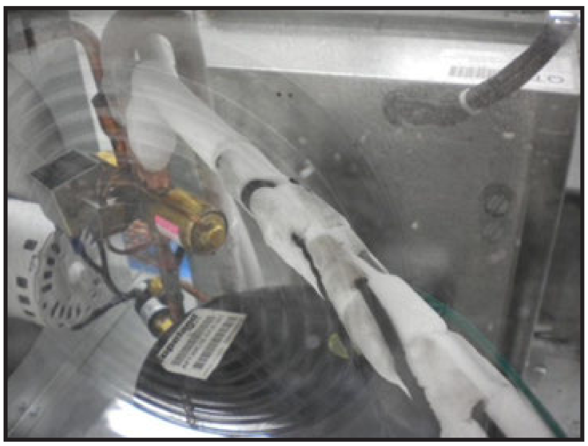


Figure 9. Iced sensors mounted to copper tubing.

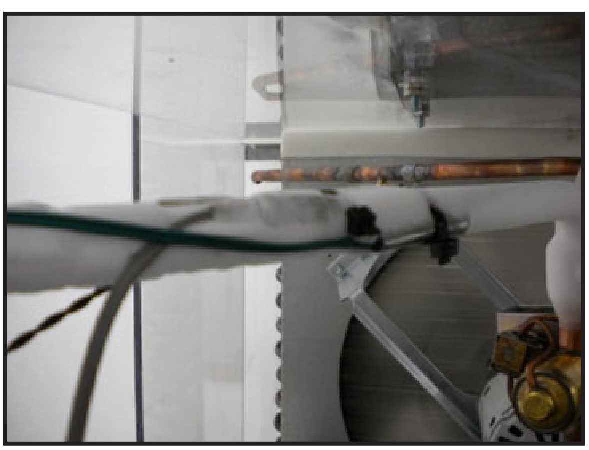


Figure 10. Iced sensors mounted to copper tubing.

ABOUT QTI SENSING SOLUTIONS

QTI Sensing Solutions was founded in 1977 to meet the increasing demand for high quality electronic components for the aerospace industry. Since then, QTI has exceeded the requirements of some of the most stringent high cost of failure applications, changing the landscape of the supply chain for the entire industry.

Today, QTI continues to maintain its leadership position for mission-critical applications as well as for medical and industrial applications by supplying the world's top companies with innovative products and services. In fact, QTI developed the highest standard for surface mount thermistors with the introduction of qualified surface mount parts to MIL-PRF-32192; supplying design engineers with fully qualified Defense Logistics Agency options for two PTC and three NTC surface mount package styles. Additionally, QTI has partnered with the NASA Goddard Space Flight Center for surface mount thermistors qualified to S311-P827, an industry first!

In addition to QTI's accomplishments, our ISO:09001:2000 and AS9100 certified manufacturing and testing facilities in Idaho enhances our ability to meet the needs of today's challenging temperature measurement and control applications.

LEARN MORE

If you would like to learn more about how QTI can help you, please contact us today. We would be happy to discuss your project with you and help with the product selection process. Additionally, if you are unable to find the item you need, our engineers may be able to produce a custom component for your individual application.

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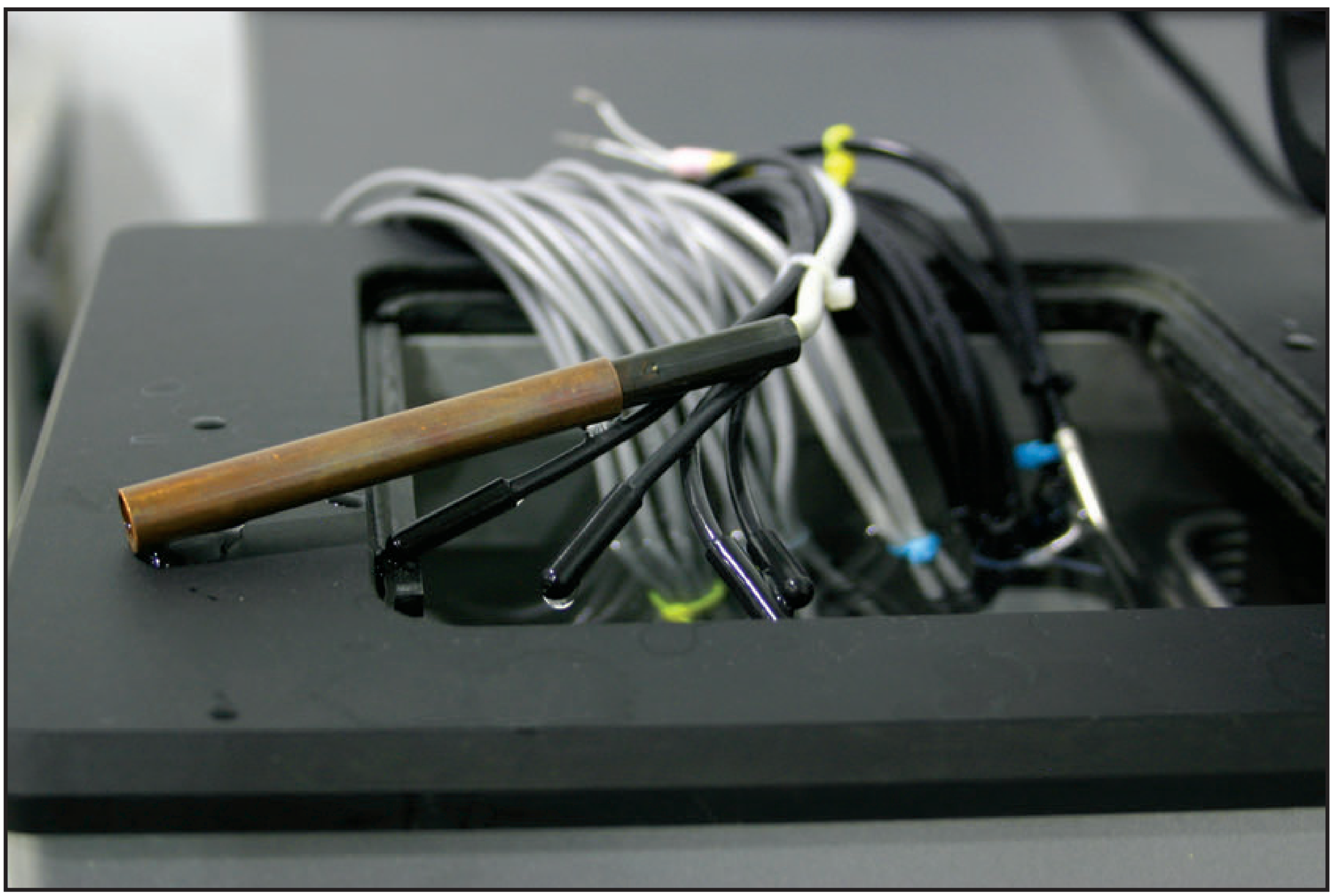
ADDITIONAL INFORMATION: THERMISTOR PERFORMANCE AND RELIABILITY IN HARSH ENVIRONMENTS

QTI Engineering Department



THERMAL SHOCK TESTING

THERMAL SHOCK TEST SETUP

QTI IP68 sensors were submitted to an extensive thermal shock test. The sensors were submerged in a series of hot and cold baths and tested to determine if a sensor failure occurred.

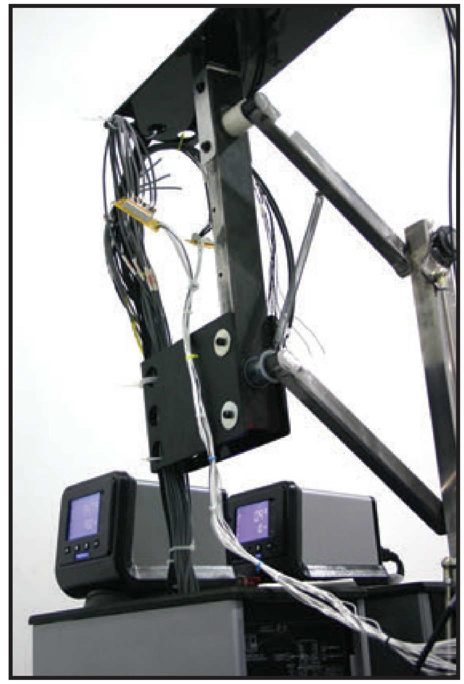


Figure 11. Probes immersed in the 95˚C bath. The probes are attached to a robotic arm that moves them from bath to bath.

THERMAL SHOCK TEST PROCEDURE

1. Test parts are attached to a mechanical arm and immersed 4" into a 1˚C bath.
2. After 2.5 minutes the parts are transferred to a 95C bath and immersed 4".
3. The parts are moved back to the first bath after 2.5 minutes.
4. Steps two and three are repeated continuously.
5. Probe temperature data is fed to a computer where it is plotted in real time, allowing electrically failed probes to be identified.
6. Probes are visually inspected for damage due to the thermal stress.

THERMAL SHOCK TEST RESULTS

This semi-automated process is able to test probes at the rate of about 100 thermal cycles per day. This method of testing has been used on a number of probes from QTI and competitors:

Two of a competitor's probes, consisting of a thermistor potted in a 3" long copper tube, were tested. Within 250 cycles one of the copper tubes started sliding off the epoxy. One failed electrically at 585 cycles, and the other was removed from the test at 1000 cycles due to the copper tube coming off and water pushing out of the cable jacket, a sign that failure was imminent.

Figure 12. A competitor's probes potted in copper tubes and QTI's unpotted IP68 probes.

Several QTI IP68 probes were potted in open-ended 1" long brass tubes. At 25 to 50 cycles the housings started coming off the IP68 probes. As of 1030 cycles the IP68 parts are still electrically good.

Several QTI IP68 probes were potted with epoxy into 1/4" and 3/8" OD stainless closed end tubes. The housings started slipping off the IP68 probes around 250 cycles. While these parts still tested OK electrically, the forces present in the heat/cold cycles cause the IP68 overmold to plastically deform and completely pull out of the epoxy around it.

QTI's IP68 probes without housings perform well in this test. They have undergone 2175 cycles during testing at QTI and withstood 20,000 cycles at a customer's facility with no electrical problems.

While QTI's IP68 probes are resilient, the extreme temperature cycles make it hard to maintain epoxy/housing or epoxy/wire bonds. The potted samples shed their housings relatively quickly while still maintaining good electrical properties and water tightness.

HIGH PRESSURE WATER WASH TESTING

HIGH PRESSURE WATER WASH TEST SETUP

Two QTI IP68 sensors were individually mounted and tested under a high pressure water washer to simulate cleaning conditions in industrial applications. The sensors were tested with different distances between the sensor and the end of the pressure washer, as well as with and without reinforcement.

HIGH PRESSURE WATER WASH TEST PROCEDURE

1. Mount a QTI IP68 sensor and submit the sensor to a 2500 psi water wash for one minute, with a distance of 25 cm between the sensor and the pressure washer nozzle.
2. Visually inspect the sensor for signs of damage.
3. Mount a reinforced QTI IP68 sensor and submit the sensor to a 2500 psi water wash for one minute, with a distance of 10 cm between the sensor and the pressure washer nozzle.
4. Visually inspect the sensor for signs of damage

Figure 13. Pressure washing a QTI IP68 sensor at a distance of 25 cm.

HIGH PRESSURE WATER WASH TEST RESULTS

At 25 cm and 10 cm with reinforcement the sensors looked undamaged. It is not recommended, however, to pressure wash the QTI IP68 sensor at 10 cm without reinforcement.

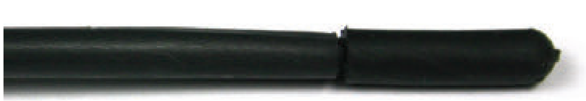


Figure 14. A reinforced QTI IP68 sensor.

Figure 15. The IP68 sensor after pressure washing at 25 cm.

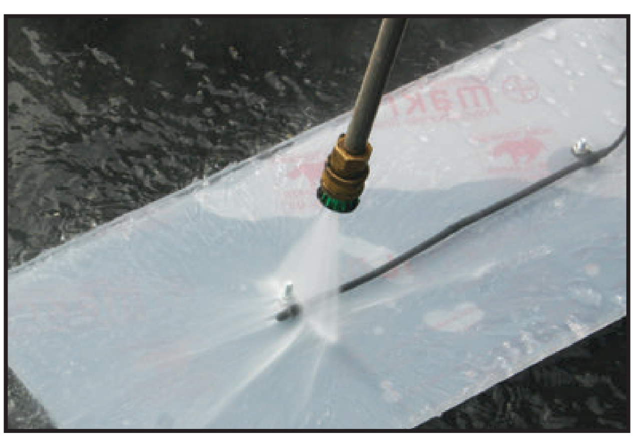


Figure 16. Pressure washing at reinforced QTI IP68 sensor at a distance of 10 cm.

Figure 17. The reinforced sensor after pressure washing at a distance of 10 cm.

TPE DATA SHEET

QTIP68 SERIES MATERIALS COMPATIBILITY INFORMATION

The QTI IP68 series sensors are manufactured using a TPE/TPV jacketed cable and fully overmolded, integrated sensor. The TPE thermoplastic vulcanizate is a fully crosslinked, EPDM/PP compound with excellent oil and chemical resistance with a maximum service temperature of 275°F. The following information relates to the wetted or exposed surface of both the cable jacket and overmolded sensor end.

Physical Properties	Value	Units	Method
Hardness			
Injection Molded, 5 sec	81		
Extrusion, 5 sec	77	Shore A	ASTM D2240
Specific Gravity			
23°C	.97		ASTM D792
Compression Set [125°C, 70H]			
22 hr @70°C	43	%	ASTM D395
Ozone Resistance			
500 hr, 100 pphm 0_3 conc.	Good		ASTM D1149
Tensile Strength			
23°C, 500 mm/min	20.1	Mpa	ASTM D412
Tensile Modulus @ 100%			
23°C, 500 mm/min	8.9	Mpa	ASTM D412
Ultimate Elongation			
23°C, 500 mm/min	570	%	ASTM D412
Tear Strength			
23°C, 500 mm/min	74.5	kN/m	ASTM D624
Flammability			(Die C)
	Pass		UL94-HB

Maximum recommended operating temperature: 275°F

Chemical Resistance	Rating	Chemical Resistance	Rating
IRM 903 Oil (70 hrs @ 125°C)	C	Methylethylketone (MEK)	B
ASTM # 1 Oil (168 hrs @ 100°C)	A	Acetic Acid	A
Diesel Oil	C	Hydrochloric Acid 10%	A
Automatic Transmission Fluid (168 hrs @ 121°C)	C	Potassium Hydroxide 50%	A
Hydraulic Brake Fluid @ 100°C	A	Sodium Hydroxide 50%	A
Antifreeze (Ethylene glycol/water 50/50) @ 121°C	A	Glycerol	A
Sea Water (168 hrs @ 100°C)	A	Methanol	A
Water @ 100°C	A	Lithium Grease (168 hrs @ 100°C)	B
Zinc Chloride 10%	A	Ethanol	A
Sodium Chloride 15% (168 hrs @ 23°C)	A	Sulfuric Acid 98% (168 hrs @ 23°C)	A

Volume Swell Rating: % volume swell as per ASTM D471
A=20% or below (highly recommended), B=20-40, C=40-60%, D=60-80%, E=80-100%

Note: All information supplied by QTI is believed to be correct. It is supplied upon the express condition that the customer shall make its own assessment to determine the product suitability for a particular use.