U.S. CONSUMER PRODUCT SAFETY COMMISSION
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January 8, 2018

Mr. Joe Musso
Chair for STP 507
Underwriters Laboratories, Inc.
333 Pfingsten Road
Northbrook, IL 60062

Dear Mr. Musso:

U.S. Consumer Product Safety Commission (CPSC) staff[1] analyzed exhaust fans in the December 2017 report, *CPSC Staff Assessment on Eutectic-Type Thermal-Cutoff Fuse Failures in Shaded-Pole Motors Used in Exhaust Fans* (attached). CPSC staff submits this proposal for review and comment by Underwriters Laboratories (UL) Standards Technical Panel (STP) 507 for electric fans.

Thermal protection devices, such as thermal cut-offs (TCOs), are a critical last line of defense for mitigating the risk of appliance component failures leading to overheating and fires. Thermal protection devices do not affect normal product operation, but if they are unreliable safety is reduced. Beginning in the early 1990s, CPSC recalled a series of automatic drip coffeemakers, due to thermal protection failures. The thermal cutoffs or thermal fuses in these coffeemakers malfunctioned, causing an overheating condition and a potential fire hazard. More than 1 million coffeemakers were recalled.[2]

From analysis of recalled coffeemakers and review of fire incidents, CPSC staff discovered that the one-shot thermal devices that were intended to prevent overheating under abnormal operation of the coffeemaker were not functioning as expected. Staff believed that long-term heating or thermal aging of the thermal devices was slowly altering the internal operating mechanisms and either increasing their activation temperature or shunting the

[1] The views expressed in this letter are those of CPSC staff, and they have not been reviewed or approved by, and may not necessarily reflect, the views of the Commission.

[2] https://cpsc.gov/Recalls/1990/Proctor-Silex-Voluntarily-Recalls-Certain-Automatic-Drip-Coffeemakers-Made-In-198586-That-May-Pose-Fire-Hazard; https://cpsc.gov/Recalls/1991/General-Electric-Voluntarily-Recalls-Certain-Drip-Coffeemakers-That-May-Pose-A-Fire-Hazard; https://cpsc.gov/Recalls/1994/750000-1984-To-1988-Black--Decker-And-General-Electric-Under-The-Cabinet-Coffeemakers-Recalled-Possible-Fire-Hazard

mechanism completely. The discovery of this thermal aging process resulted in UL incorporating construction and performance changes in the appropriate voluntary standards to address thermal devices used in coffeemakers. One of the new test methods was the "Conductive Heat Aging Test" (CHAT), which represented slow aging of the thermal device under load, while mounted directly to a heated surface. This and additional requirements in UL 1082, *Standard for Household Electric Coffee Makers and Brewing-Type Appliances*, became effective in 1993 and 1994.

CPSC staff believes an analogous situation may exist in exhaust fans that are typically installed in ceilings or walls in bathrooms and restrooms. CPSC staff evaluated fans that were listed to UL 507. Staff found that, under certain conditions, the tested motors during a locked rotor condition can thermally age components, such as TCOs and thus, present a higher risk of fire, which altered the melting properties of the thermal links in the TCO that caused a delay or prevented TCO activation.[3] These TCO delays or failures to activate led to overheated or ignited motors. The testing results support changes to UL 507 to incorporate a thermal aging test for the fans or motors in unattended areas.

CPSC staff recommends incorporating the performance tests given below into UL 507 to reduce the risk of exhaust fan incidents and the subsequent injuries and property damage potentially associated with exhaust fan fires. The CPSC report supports our recommendation and forms the basis for CPSC staff's belief that the performance conditions for fans used in unattended areas have the potential for causing deleterious thermal aging effects.

Based on the UL 507 proposal dated September 1, 2017, *1. Revision of Existing Requirements for Fan Motor Failure Mode Analysis for Fans in Unattended Areas*, and CPSC staff's December 2017 report, *CPSC Staff Assessment on Eutectic-Type Thermal-Cutoff Fuse Failures in Shaded-Pole Motors Used in Exhaust Fans*, staff proposes:

Revised Text (deleted text struck through; new text underlined):

22.8 Motors for use in unattended areas shall be tested in accordance with Section 178, General, ~~and~~ Section 179, Performance – Fan Motor Failure Mode Analysis, and Section 179a, Performance – Condition Thermal Aging.

FANS FOR USE IN UNATTENDED AREAS

178 General

178.1 In addition to any other motor requirements specified in UL 507, the requirements specified in Sections 178, ~~and~~ 179, and 179a apply to any motor used in fan products which are built into or within the building structure and which operate unattended or in situations in which the operator may not detect a locked rotor condition. ~~Examples include: wall-insert fans, through-wall fans, ceiling-insert fans, attic exhaust fans, whole house fans, and duct fans. Fans intended for use in cooking areas with integral blower assemblies and ceiling-suspended fans are not included.~~

[3] A contributing factor to this deviation from the original certification may be improper bending of the TCO wire leads, resulting in cracks in the epoxy seal around the wire leads.

Note: Examples include wall-insert fans, through-wall fans, ceiling-insert fans, attic exhaust fans, whole house fans, and duct fans.

Exception: These requirements do not apply to range hoods with integral blowers, downdraft fans with integral blowers, ceiling suspended fans, component fans, and recreational vehicle fans rated 24 V or less.

~~*Exception No. 1: These requirements do not apply to motors employing a single-operation device, a thermal cutoff, or a manual reset thermal protector when the device opens during the normal locked rotor testing in accordance with the Standard for Overheating Protection for Motors, UL 2111, or the Standard for Thermally Protected Motors, UL 1004-3.*~~

~~*Exception No. 2: These requirements do not apply to a motor in which there are no openings in the enclosure through which molten metal, burning insulation, flaming particles, or other ignited material could fall onto flammable material, or through which a flame could be projected*~~*.*

178.2 There shall be no increased risk of fire as evidenced by the burning of cotton. All cotton used for this test is to be sterile or surgical 100 percent cotton.

178.3 A motor shall be tested in accordance with this Section at each speed and rated voltage. A multispeed appliance utilizing a single speed motor shall be tested on high speed and low speed. ~~A motor with a single tapped winding is required to only be tested at high speed.~~

179 Performance – Fan Motor Failure Mode Analysis

179.1 Test preparation – fan motor failure mode analysis

179.1.1 The test procedure specified in this Section is to be conducted on either ten samples of a complete fan or ten samples of the motor.

Exception: For a motor employing a thermal cutoff or a manual reset thermal protector as a secondary or “back-up” protection, only three samples are to be tested. See 2.2.22.

179.1.2 For the purpose of this test, motor samples are to be provided without an automatic reset thermal protector. A “back-up” protector is to remain in the circuit.

179.1.3 A thermocouple is to be attached to the motor winding to verify constant temperature rise (motor heating) during the test. The rotor is to be locked.

179.1.4 Each sample of a complete fan is to be oriented as intended in the application. One layer of cotton is to be loosely draped around the area of the motor and any other area of the fan where flame could be projected or molten metal is emitted. When a barrier or guard is provided for the purpose of preventing flames or molten metal from escaping from the motor area, the cotton is to be loosely draped around the barrier or guard.

179.1.5 Each sample of a fan motor is to be placed on one layer of cotton on a wood surface. Each motor is then to be surrounded with one layer of loosely draped cotton.

179.2 Test procedure – fan motor failure mode analysis

179.2.1 The supply circuit is to be provided with a 20 amp slow blow fuse. If the fuse opens during the test procedure, it is to be replaced with the largest standard size fuse needed to continue the test, 179.2.2 The fan motor is to be energized in a room ambient temperature of 10 to 40°C (50 to 104°F) initially at the rated voltage of the fan until the winding temperature stabilizes.

179.2.3 Following stabilization, the voltage is to be gradually increased to achieve 10°C temperature rise per minute until ultimate results are observed (opening of motor windings and cool-down to a temperature of 90°C (194°F) or less, opening of a "back-up" or a current protector, or ignition of the cotton).

179a Performance – Condition Thermal Aging

179a.1 Test preparation – condition thermal aging

179a.1.1 The test procedure specified in this Section is to be conducted on either fifteen samples of a complete fan or fifteen samples of the motor with impeller.

179a.1.2 The motor samples shall be thermally conditioned at the arithmetic mean of the maximum measured temperatures from the Abnormal Operation Test and Normal Temperature Test for a period of ten weeks. The temperature shall be maintained constant within ±1 K.

179a.1.3 At the end of conditioning, the samples shall remain in the test chamber and be allowed to cool to less than normal temperature -35K.

179a.1.4 Each sample of a complete fan is to be oriented as intended in the application. One layer of cotton is to be loosely draped around the area of the motor and any other area of the fan where flame could be projected or molten metal is emitted. When a barrier or guard is provided for the purpose of preventing flames or molten metal from escaping from the motor area, the cotton is to be loosely draped around the barrier or guard.

179a.1.5 Each sample of a fan motor with impeller is to be placed on one layer of cotton on a wood surface. Each sample is then to be surrounded with one layer of loosely draped cotton.

179a.2 Test procedure – condition thermal aging

179a.2.1 All fifteen samples shall be tested in accordance with the Locked Rotor Test.

Rationale

According to the December 2017 report, *CPSC Staff Assessment on Eutectic-Type Thermal-Cutoff Fuse Failures in Shaded-Pole Motors Used in Exhaust Fans* (attachment), CPSC staff lab evaluation of field-recovered exhaust fans showed that under certain conditions, eutectic-type thermal fuses may fail to open due to thermal aging. Failure to open under locked rotor conditions could present a risk of fire due to overheating of the motor windings.

CPSC staff found that improper bending of the TCO's wire leads may have resulted in cracking of the epoxy seal, thus allowing oxygen to enter the TCO and alter the functioning temperature of the TCO and solder to flow out. UL 60691, Thermal-Links – Requirements and Application Guide, Section 11, Temperature test addresses aging for thermal links as a component, but not after the TCO has been installed in the motor. The motor assembly process may affect the properties of the TCO and thus alter its thermal response from what it exhibited during UL 60691 testing.

Periods of "on" time that are shorter than the activation time of a TCO during a locked-rotor condition can thermally age the TCO and possibly alter its functioning temperature. A fan entering into a locked-rotor condition may experience multiple events of thermal heating if the fan is not energized for sufficient time to cause the TCO to activate. These multiple heating events may have compounding effects on the TCO properties, thus causing the TCO to delay or fail to activate. CPSC staff's locked-rotor testing of the motors, in which the TCO failed to activate, showed that the winding can reach sufficiently high temperatures to eventually experience insulation breakdown and ignition.

We appreciate the opportunity to make recommendations to UL 507, *Electric Fans*. CPSC staff believes that these proposed requirements take into account foreseeable use of these products, and will increase the safety of electric exhaust fans for consumers. We look forward to participating in further discussions about this standard.

Sincerely,

Arthur Lee
Electrical Engineer
Division of Electrical Engineering

CPSC Staff Assessment on Eutectic-Type Thermal-Cutoff Fuse Failures in Shaded-Pole Motors Used in Exhaust Fans

December 2017

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Revision Changes

None

U.S. CONSUMER PRODUCT SAFETY COMMISSION
Directorate for Engineering Sciences

CPSC Staff Assessment on
Eutectic Type Thermal Cutoff Fuse Failures
in Shaded-Pole Motors used
in Exhaust Fans

December 2017

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EXECUTIVE SUMMARY

Staff searched the CPSC Injury or Potential Injury Incident (IPII) database for incidents involving exhaust fans for the 20-year period from January 1, 1997 to September 21, 2017. Staff identified 494 known incidents in that period related to permanently installed exhaust fans. The majority of these incidents occurred in residential bathrooms.

CPSC field staff collected 100 exhaust fan samples in 2017 from part of a larger inventory that had been collected and stored by a military base housing authority. The exhaust fans had been replaced base-wide due to a large number of failures. CPSC Engineering Sciences (ES) staff's testing of these motors showed that the winding temperatures can reach high temperatures sufficient to ignite the motor during a lock-rotor condition when the eutectic-type thermal cutoffs (TCO) fail to activate. ES staff conducted additional investigation to evaluate factors that may contribute to the TCO failing to activate. During locked-rotor operation, a TCO may reach elevated temperatures while remaining below its functioning temperature. These elevated temperatures may result in thermally aging the TCO, potentially altering its set functioning temperature. A fan that has entered into a lock-rotor condition may experience multiple events of thermal heating without causing the TCO to activate. These multiple heating events may have compounding effects on the TCO properties, thus causing either a delay in TCO activation or a failure to activate.

Even though the tested motors were listed to the appropriate voluntary UL standards, CPSC staff testing suggests that, in practice, thermal aging of the motors can cause the eutectic-type TCOs to fail. A contributing factor to this deviation from the original certification may be improper bending of the TCO wire leads, resulting in cracking the epoxy seal around the wire leads. During thermal heating, the melting properties of the thermal linkage in the TCO may be altered and cause either a delay in TCO-activation or failure to activate. If the TCOs in the motors fail to activate during a lock-rotor condition, the motor may overheat and ignite.

The results of this testing, and the fact that TCOs are used in many other consumer products, in addition to exhaust fans, support changes to the voluntary standards.

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1.0 INTRODUCTION

ES staff conducted an analysis of thermal cutoff fuse TCO failures in exhaust fan applications, specifically for fans that use eutectic-type thermal devices in shaded-pole motors. This report documents staff's analysis and assessment.

2.0 INCIDENTS

The CPSC's IPII database includes information on consumer product-related incidents that are collected through various reports and reporting systems.[1] The amount of information or detail can vary by the type of report. News reports typically contain minimal detail on the products and the events surrounding the incident. CPSC field investigators conduct In-Depth Investigations (IDIs) on specific incidents that may have originated from an IPII record. These investigations are conducted by CPSC field staff via phone or in-person interviews, and the investigations can include collection of police and injury reports. The investigation is documented in a report that typically contains detailed information on the products and events surrounding the incident, but the completeness of the reports depends on the information that the field investigator was able to collect.

2.1 Incidents

CPSC staff searched the IPII database for incidents involving exhaust fans, specifically the product code 380 (fans) that mentioned the word "exhaust" and indicated a fire or fire hazard. The search is not representative of any national statistics or estimates. The search produced 571incidents occurring between January 1, 1997 and September 21, 2017. Staff reviewed the search results; 77 of the incidents did not relate to structurally or permanently installed exhaust fans. The remaining 494 incidents contained sufficient information to determine that the incident involved a structurally or permanently installed exhaust fan. Of the 494 incidents 118 IDI reports resulted.

Of the 494 incidents with structurally or permanently installed fans, 71 incidents did not contain sufficient information to determine the exhaust fan's purpose. For example, staff could not determine in what room the fan was installed or for what purpose the fan was used. The remaining 423 incident reports contained sufficient information to determine the location of the exhaust fan and the likely use of the exhaust fan. The 423 incidents were categorized into five categories based on fan location (bathroom/restroom, kitchen, attic, laundry, and general). Incidents categorized as "general" involved locations that could not be assigned to one of the specific location categories. Table 1 lists the number of exhaust fan incidents by location.

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[1] The incidents are gathered from news reports, consumer self-reporting, Medical Examiners and Coroners Alert Program (MECAP), attorney reports, referals, and Section 15 reports.

Table 1. Dataset from January 1, 1997 to September 21, 2017

Incident Categories by Location	Count	Percent of Known
Bathroom/Restroom	318	75.18%
Kitchen	54	12.77%
Attic	27	6.38%
Laundry	8	1.89%
General	16	3.78%
Known incidents only	423	100%
Unknown	71	
Total Incidents related to exhaust fans	494	

More than 75 percent (318/423) of the known incidents occurred in a bathroom or restroom. The most likely origin of the incident in these cases was the exhaust fan. The incidents ranged in severity from minor smoke to fire spreading through the structure. Of the 318 incidents that occurred in a bathroom or restroom, almost 80 percent (254/318) occurred in a residence. "Residences" were defined as a single- or multi-family home, apartment, condominium, senior citizen living facility, and dormitory. Of the 318 incidents that occurred in a bathroom/restroom, almost 19 percent of incidents occurred in a commercial building. "Commercial facilities" were defined as a commercial store or workplace, public facility, restaurant, or hotel. There was insufficient information for four incidents, which were classified as Unknown. Table 2 lists the types of structures for incidents that occurred in a bathroom or restroom.

Table 2. Bathroom/Restroom incidents

Type of location	Count	Percent of Total
Residential	254	79.9%
Commercial	60	18.9%
Unknown	4	1.2%
Bathroom dataset total	318	100%

Almost 13 percent of the known incidents occurred in a kitchen. These incidents occurred in either a residential or commercial structure, such as a home or restaurant. The exhaust fans that were involved in these incidents appear to have been mostly used to exhaust the area above or near a cooking appliance. For residential incidents, the exhaust fan may have been integral to a microwave oven/hood or a range hood. For commercial locations, the exhaust fan incidents appear to be related to inadequate maintenance of the exhaust hood, such as excessive grease from cooking. For commercial locations, there were several incidents where the exhaust fans were used to exhaust the space above cooked food or the kitchen area.

There were 27 incidents involving attic fans. These incident reports specifically contained descriptions that the products were attic exhaust fans that were used to ventilate the air within the attic and not bathroom exhaust fans mounted in the ceiling where there was attic space above the ceiling. These incidents occurred in both residential and commercial structures.

There were eight incidents involving exhaust fans in laundry rooms. These incident reports specifically contained descriptions that the exhaust fans were in laundry-type rooms that were used to wash and dry clothes. These incidents occurred in both residential and commercial structures.

There were 16 incidents involving exhaust fans that were categorized as “general” because the rooms in which these incidents occurred did not fall into any of the other categories. These incidents occurred in rooms such as sheds, factory rooms, medication rooms, basements, or dining rooms.

There were 77 incidents that were not within scope of the report. Some of the “not-within-scope” incidents involved cooking fires that ignited exhaust fans, heater fans, window fans, portable product fans, such as leaf blowers, and HVAC fans.

2.2 Selected Incident Cases

The incidents below, which involved exhausts fan in a bathroom or restroom, were selected to illustrate some of the differences and similarities in the incidents.

<u>IDI 90611CCN0306</u>

This incident occurred in a 10-year-old duplex/multi-family home in May 1998. On the day of the incident, the consumer was home and turned on the bathroom exhaust fan located on the ceiling. The family left the home around 2:00 p.m. and left the bathroom exhaust fan running for about seven (7) hours until the family returned around 9:00 pm. Upon returning, the family heard the smoke alarm sounding and witnessed smoke in the home. The family called the fire department, which determined that the bathroom exhaust ceiling fan had overheated, causing the plastic cover to catch fire and fall onto the toilet. The toilet seat cover had ignited, which fell into the toilet.

<u>IDI 010402CCN474</u>

In March 2001, at about 6:50 a.m. the fire department responded to an apartment structure fire. Firefighters discovered fire in the walls and the attic above the bathroom where the incident exhaust fan was located. Fire had spread into the common bathroom wall between apartment units and in the adjacent bedroom walls. The fire department determined that the fire started from a 30-year-old exhaust fan located in the bathroom of the apartment.

IDI 031125CNE1123

The incident occurred in November 2003. The day before the incident, the bathroom exhaust fan was left "on." On the morning of the incident, the family dog began running in and out of the bathroom and barking. Shortly thereafter, a smoke alarm located in the hallway outside the bathroom began sounding. The family observed smoke and flames coming from the bathroom exhaust fan. The fire marshal concluded that the fan motor overheated and determined that the home insulating material in the attic was not a contributing factor in the fan overheating because there was adequate space between the insulation and the fan housing.

IDI 050506CNE2395

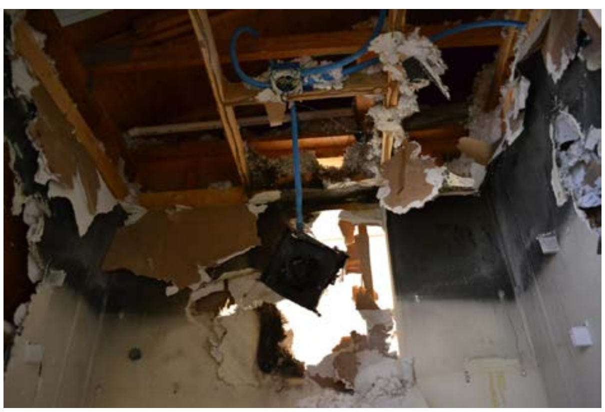
The fire occurred in a women's restroom of a closed nightclub section of a bar and restaurant business. An adjacent bar restaurant section was open for business and occupied by a bartender and several customers at the time of the incident. The owner indicated that even though the nightclub section had been closed, employees routinely used the bathrooms in that area. The men's and women's restrooms located in the nightclub were equipped with exhaust fans. The manager of the business reported that the fan in the women's restroom had been making a noise for about a week before the incident. At the time of the incident, the fire department extinguished the fire, which had traveled upward from the women's restroom into the second floor and attic, where it burned through parts of the roof.

IDI 050907CNE2758

On a morning in August 2008, the electricity in the residence and surrounding area had a power outage. After power had been restored in the afternoon, the occupants went throughout the home checking the light switches. This included the two switches in the second floor bathroom, which controlled the lights and incident exhaust fan. The occupants stated that the exhaust fan had "stopped" working about 3 years before the incident. Before the fan "stopped" working, the occupants reported that the exhaust fan had begun to make a noise. Before leaving the home, the occupant went around turning off the lights in the home, which they thought the second floor bathroom fan had been turned off. When they returned home in the evening, the homeowner found smoke coming from the roof vents of the structure. The fan had overheated and ignited and spread into the attic of the structure.

<u>IDI 110322CCC2391</u>

The incident occurred at a daycare facility. The building was built in 1995, and has been used as a daycare facility since its construction. The fans were original when the building was constructed. The lights and fans were controlled by a single switch. Five days a week, the switch was turned on at approximately 6:30 a.m. and turned off at about 7:00 p.m. The incident occurred in March 2011. After the daycare lights and fans were switched on, the daycare heat was also turned on. Approximately 1 hour later, a teacher and her assistant smelled something burning and assumed it was related to the heating system. Even though after the heating system was turned off, the burning smell persisted. The director went to the infant room and localized the burning smell to the changing room/bathroom. The director notified the owner of the daycare and was advised to disconnect the exhaust fans because they were old. The director was unplugging the exhaust fan when a “large fireball shot out” of the exhaust fan. The daycare was evacuated and the fire department was summoned to extinguish the fire.



<u>IDI 130208CCC3391 and IDI 130326HWE0001</u>

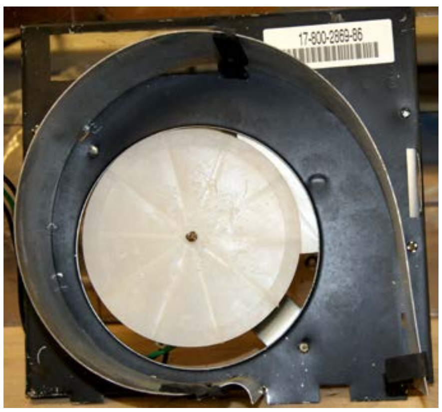
On two separate occasions, incidents involving bathroom exhaust fans occurred at Picerne Military Housing located on Ft. Riley Military Base, KS. The first incident occurred in June 2012, and was documented under IDI 130326HWE0001. The second occurred in February 2013, and was documented under IDI 130208CCC3391. The fans were installed sometime since 2007, when the housing construction was initiated. The housing authority stated that the same type of exhaust fans were installed in all the military homes constructed during that period. The housing authority reported that the fan motors had been seizing up. Because of this, the housing authority discontinued installing them in the homes in 2013, and removed all of the exhaust fans.

The June 12 incident occurred in a half bath in a single-family home. The Fort Riley Fire Department was dispatched to a structure fire at the residence. Upon arrival, the fire responders did not witness any signs of fire outside the home. Fire personnel entered the home to investigate and found water pouring from the first floor bathroom exhaust fan on the ceiling. The fire had been extinguished before fire fighters entered the home. The report identified that the plastic inside the fan had ignited, which then ignited the plastic vent hose. A plastic water line located above the fan had melted, which extinguished the fire. The cause of the incident was an overheated exhaust fan.

The February 5 incident occurred in a full bath on the second floor of a single-family home. There was extensive damage to the attic above the bathroom. The field investigator noted that the incident fan switch was in the "up" position, suggesting that the fan was on when the incident occurred. When the fire department arrived at the scene, fire personnel determined that the fire had spread into the attic area. An overheated exhaust fan caused the incident.

2.3 Incident Bathroom Exhaust Fans

The majority of the incidents (75 percent, 318/423) involved bathroom/restroom exhaust fans. Where photographs were available, the fans appear to have similar construction. The exhaust fans contain an external housing, a motor, an impeller, and a grill cover. The exhaust fans may incorporate a light option, but the incidents did not report the lighting assembly as the cause of the incident or fire. The "box" type exhaust fans contain a box housing that is mounted to the building structure. A fan assembly is mounted in the box housing. The fan assembly typically contains a mounting frame, fan motor, impeller, and power cord as shown in Figure 1. The box housing contains the electrical connections for the fan and light option and connection for the ducting.



Top of the exhaust fan assembly

Bottom of the exhaust fan assembly

Figure 1. Fan assembly for "box" type housing

A shaded-pole motor is an AC single-phase induction motor. The auxiliary winding, which is composed of a copper ring, is called a shading coil. The current in shading coil delays the phase of magnetic flux to provide a rotating magnetic field. The direction of rotation is from the unshaded side to the shaded ring. Typical components of a shaded pole-type motor are shown in Figure 2. Since these motors typically have low starting torque, low efficiency and a low power factor, these motors are typically suitable for low-power applications and are either thermally or impedance protected to prevent overheating. The type of protection can be identified by "T.P." or "Z.P." on the motor label, as shown in Figure 3. A Z.P. motor relies solely upon the impedance of the windings alone to prevent overheating; whereas, a T.P. motor relies upon a thermal protective device to prevent overheating.

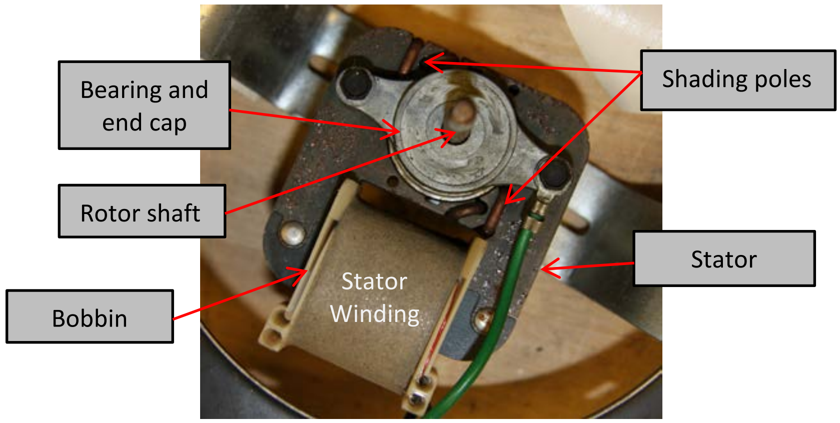


Figure 2. Shaded-pole motor

Figure 3. Identifying T.P. or Z.P.

Staff reviewed the IDIs to identify the types of fan motors used in the incidents. The dataset consisted of 118 IDIs. Of the 118 IDIs, 60 IDIs contained images of the incident exhaust fan. Of the 60 IDIs, 57 IDIs had sufficient information to identify the fan motor as a shaded pole-type motor. Three of the fans were not shaded pole-type motors; these were attic exhaust fans and appeared to be universal-type motors. Fifty-nine IDIs did not contain any identifiable information to determine the type of fan motor. Table 3 lists the number of identifiable shaded pole-type fan motors in the 118 IDIs.

Table 3. Shaded-pole motors

	Motor type count	Percentage of known
Shaded pole motor	57	95 %
Not shaded pole motor	3	5 %
Identified motor type	60	100 %
UniIdentified motor type	58	
Total IDIs	118	

3.0 RECALLS INVOLVING THERMAL PROTECTION

Consumer products with thermal protection have failed in the past. The most notable product recalls due to thermal protection failures in a consumer product occurred about 25 years ago involving drip coffeemakers. Beginning in the early 1990s, CPSC announced several recalls from different manufacturers of coffeemakers, where the thermostats and/or thermal fuses malfunctioned, thus, causing an overheating condition and a potential fire hazard.[2] The recalls involved more than 1 million coffeemakers.

Because of the recalls and coffeemaker fire incidents, CPSC staff discovered that the thermal devices used in these products can have the set point drift higher, or not function at all. Staff believed that thermal aging and/or heating of the thermal devices was causing the contact force to be reduced until the pressure between the contacts within the thermal device was nearly zero.[3] The episode resulted in Underwriters Laboratories (UL) incorporating construction and perfomance changes in the appropriate voluntary standards to addresss thermal devices used in coffeemakers. One of the new test methods was the "Conductive Heat Ageing Test" (CHAT), which represented slow aging of the thermal device under load, while mounted directly to a heated surface. This and other proposed requirements in UL 1082, *Standard for Household Electric Coffee Makers and Brewing-Type Appliances,* became effective in 1993 and 1994.

4.0 VOLUNTARY STANDARDS

Through collaboration with UL, a voluntary standard organization, safety standards are developed for a variety of consumer products, including exhaust fans. In many cases, these standards bring industry groups, government agencies, and consumer groups together to agree on the best consumer product safety practices. These standards have helped lead the way toward the development of safer consumer products.

Safety standards are constantly evolving and improving to adjust to the environmental changes, behavioral use, and technology. Below is a list of UL standards that may apply currently to exhaust fans or may have applied to exhaust fans in the past, but are no longer current:

UL 507, Standard for Electric Fans

UL 507 is intended to cover a large assortment of fan types, including exhaust fans. Exhaust fans are categorized as fans for use in unattended areas. These fan products are built into or within the building structure and may be operated unattended or in situations in which the operator may not detect a lock-rotor condition.

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[2] https://www.cpsc.gov/Recalls/1990/Proctor-Silex-Voluntarily-Recalls-Certain-Automatic-Drip-Coffeemakers-Made-In-198586-That-May-Pose-Fire-Hazard/; https://www.cpsc.gov/Recalls/1991/General-Electric-Voluntarily-Recalls-Certain-Drip-Coffeemakers-That-May-Pose-A-Fire-Hazard/; https://www.cpsc.gov/Recalls/1994/750000-1984-To-1988-Black--Decker-And-General-Electric-Under-The-Cabinet-Coffeemakers-Recalled-Possible-Fire-Hazard.

[3] *Temperature cutoffs (Thermal-links) for coffeemakers Extended Holding Temperature TH-100 rated TCOs*, InterControl. Hermann Köhler Elektrik GmbH & Co KG Schafhofstraße 30. 90411 Nuremberg. Germany.

ANSI/UL 2111, UL Standard for Overheating Protection for Motors

ANSI/UL 2111 was withdrawn and superseded by three dedicated standards, UL 1004-2, *Standard for Impedance Protected Motors*, UL 1004-3, *Standard for Thermally Protected Motors*, and UL 60730-2-2, *Standard for Automatic Electrical Controls for Household and Similar Use*; Part 2 *Particular Requirements for Thermal Motor Protectors*, beginning in 2013.

UL 1004-2, Standard for Impedance Protected Motors

UL 1004-2 is intended to be read with the *Standard for Rotating Electrical Machines – General Requirements*, UL 1004-1. The Standard applies to motors that rely solely upon the impedance of the motor windings to prevent overheating.

UL 1004-3, Standard for Thermally Protected Motors

UL 1004-3 is intended to be read with the *Standard for Rotating Electrical Machines – General Requirements*, UL 1004-1. The Standard applies to motors that rely upon a device (thermal motor protector) to prevent overheating.

ANSI/UL 1020, Standard for Thermal Cutoffs for Use in Electrical Appliances and Components

UL 1020 was withdrawn and superseded by UL 60691, *Thermal Links - Requirements and Application Guide* around 2003. The scope for ANSI/UL 1020 contained requirements that applied to thermal cutoffs intended to be embedded in windings or for freestanding use in end products.

UL 60691, Thermal Links - Requirements and Application Guide

The scope for UL 60691 is applicable to thermal links intended for incorporation into electrical appliances, electronic equipment, and component parts thereof, normally intended for use indoors to protect these products from excessive temperatures under abnormal conditions, including lock-rotor conditions.

5.0 FIELD SAMPLES[4]

The two incidents that occurred at Picerne Military Housing on Ft. Riley, KS military base in 2012 and 2013 provided an opportunity to collect a large number of samples for testing. CPSC field staff collected 100 exhaust fan samples in 2017. The fans were part of a larger inventory that had been collected and stored by the base housing authority when the exhaust fans had been replaced after a large number of exhaust fan failures. The fans were originally installed in the homes between June 2007 to February 2012. The fans were removed between April 15, 2013 and April 22, 2013. All the fans had similar manufacture dates from 2008 through 2010.[5] After the units were removed, the fans were placed into storage, initially office trailers, then into Conex units on post.

All of the fans collected were sold under the same brand name and contained the same motor manufacturer. The fan motors were shaded pole-type motors and had the same or similar construction. The main lot (96) of fan motors were constructed with a paper wrap around the winding core and had 25 stacked plates for the stator. Four fan motors had a slightly different construction, which included a plastic wrap around the winding core and had 35 stacked plates for the stator. All of the fans were thermally protected with a radial eutectic-type TCO.

5.1 Eutectic-Type Thermal Cutoff Fuses

A eutectic alloy is a homogeneous solid mixture of at least two metals or lattice components that is made up of the specific atomic/molecular ratio that yields the lowest possible complete melting point (eutectic temperature), which causes the solid mixture to change uniformly into a liquid mixture, as illustrated in Figure 4. In all other proportions, the mixture will not have a uniform melting point; some of the mixture will remain solid and some liquid. Eutectic TCO fuses contain a joint or linkage that is a eutectic alloy that will melt and open at the eutectic temperature.

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[4] The sections presented in this report were arranged for readability and understandability, not chronological order of the testing.

[5] The manufacturer date of the fan assembly does not necessarily represent the manufacture date of the fan motor. Staff believes that the fan motors were manufactured around 2000.

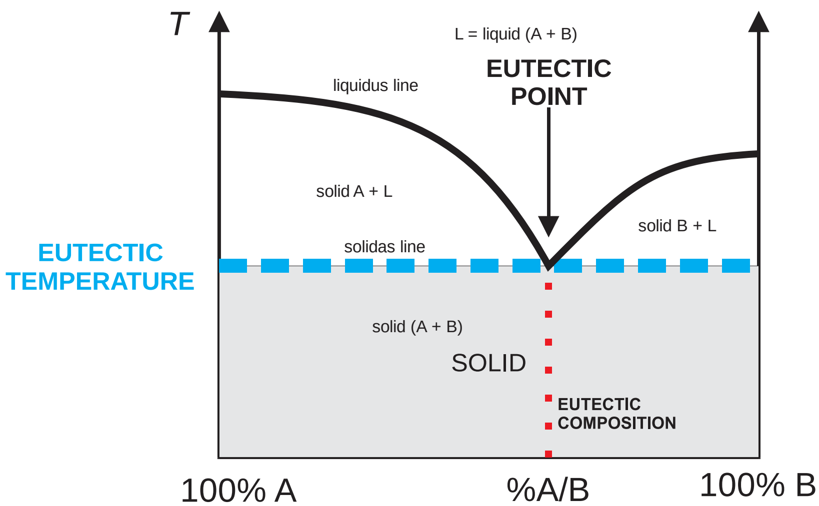


Figure 4. Eutectic system model

Eutectic TCOs are available with axial or radial lead wires, both having the same basic design as shown in Figure 5.[6] The fusible thermal linkage (thermal element) is a eutectic alloy that is welded across a pair of wire leads. The eutectic alloy is coated with a special compound to protect it from oxidation and allow wetting of the wire leads. Surface tension then separates the eutectic alloy, opening the circuit, thus activating the TCO. The fusible linkage is sealed in a special insulated housing.

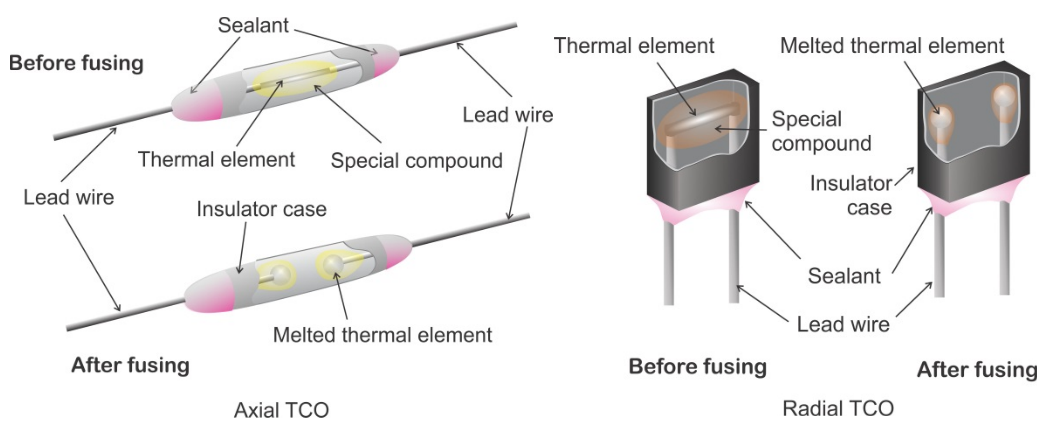


Figure 5. Eutectic-type thermal fuse

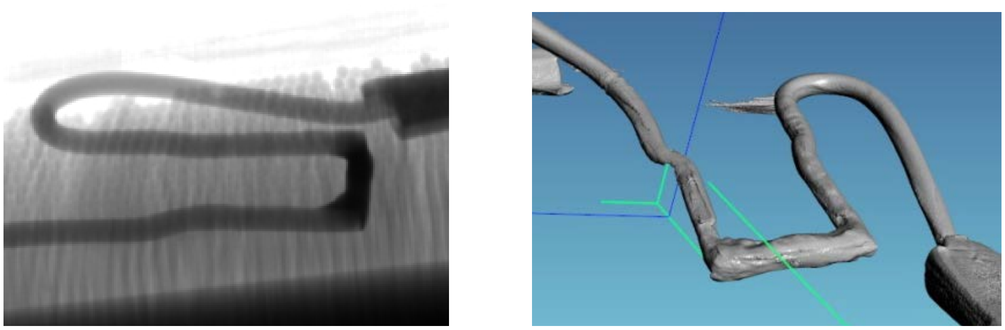
[6] Chatham Components Inc., Thermal Cutoffs, Elcut Brand Thermal Fuses, http://www.cci-tco.com/products/elcut-brand-thermal-fuse/.

5.2 Thermal Cutoff Fuses in the Fan Samples

All the fan samples contained radial eutectic-type thermal fuses. The fuses are marked with a functioning temperature of 136°C and rated for 250V 3A, as shown in Figure 6.

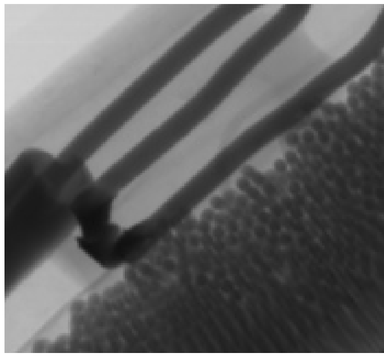
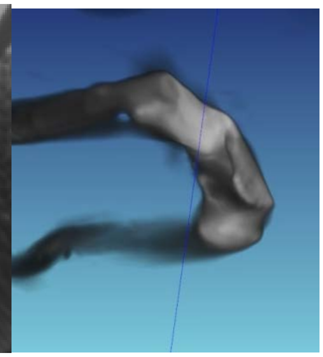
Figure 6. Radial eutectic-type thermal fuse in the sample fans

All 100 TCOs in the fans were x-rayed and 3-D imaged by computed tomography (CT). CT imaging can reveal detailed images of the internal TCO without destructive analysis. The CT scan allows cross-sectional details of the thermal linkage that cannot be seen in conventional radiographs by X-rays. The thermal linkage connects the two wire leads, as shown in the radiograph and CT images in Figure 7. In the examined thermal linkages in the fan samples, the thermal linkages varied with the shape of the linkage, such that some of the linkages were not uniform, as shown in Figure 8. It is unknown if the variations were caused from manufacturing or usage before collection.

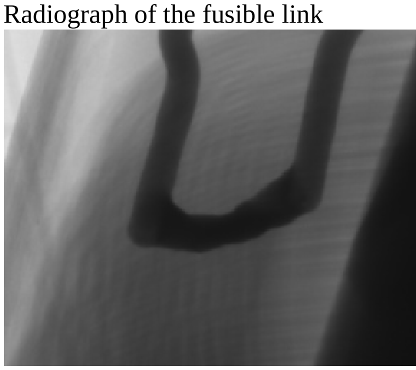
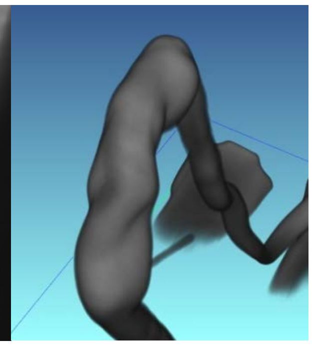


Radiograph of the fusible link — CT scan of the fusible link

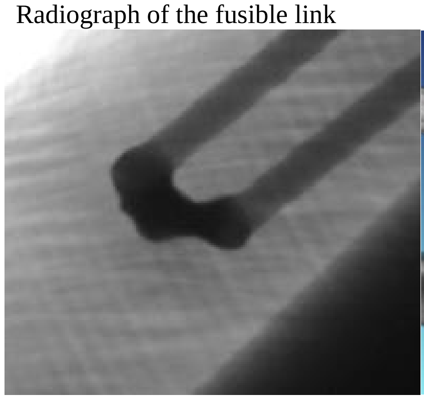
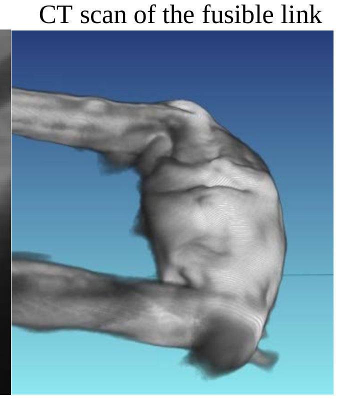
Figure 7. Smooth and uniform solder linkage (Sub 44)

Radiograph of the fusible link CT scan of the fusible link

Radiograph of the fusible link CT scan of the fusible link

Radiograph of the fusible link CT scan of the fusible link

Figure 8. Fusible link with irregular thermal linkages (Sub 91, 20 and 62)

5.3 Normal Fan Test

Staff measured and recorded the temperatures on the winding and within the TCO for one of the shaded-pole, motor-fan samples during normal fan operation. To record the temperatures, a fan (indexed as sub 60) was instrumented with three thermocouples on the paper wrap exterior of the winding, and within the TCO, as shown in Figure 9; the TCO was not in the circuit, *i.e.*, it was not carrying current. The top, side, and bottom thermocouples were secured against the winding wrap with thermal tape and a nylon plastic tie. To measure the temperature within a TCO, an activated or used TCO from another fan motor was removed and then modified with a thermocouple. The TCO was modified by drilling a small hole through the epoxy of the TCO and inserting a thermocouple, as shown in Figure 10. The hole was then resealed with an epoxy. The existing TCO within the motor was moved away from the winding and the thermocoupled TCO was located in its place. This allowed the modified TCO with the thermocouple to record the temperature as if the original TCO was installed. It would be expected that the thermocoupled TCO would measure a slightly lower temperature than an actual TCO because the lack of conductive heating from the winding and no current flow. The TCO plastic sleeve and winding wrap and tape were reinstalled and sealed before testing.

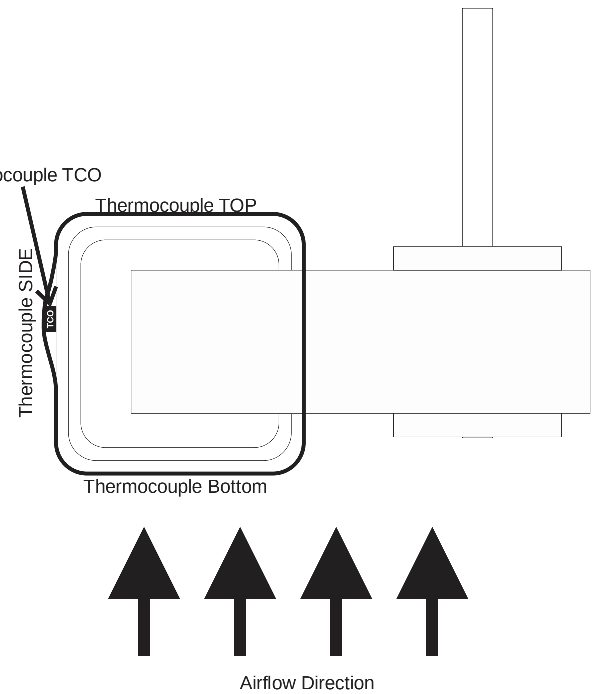
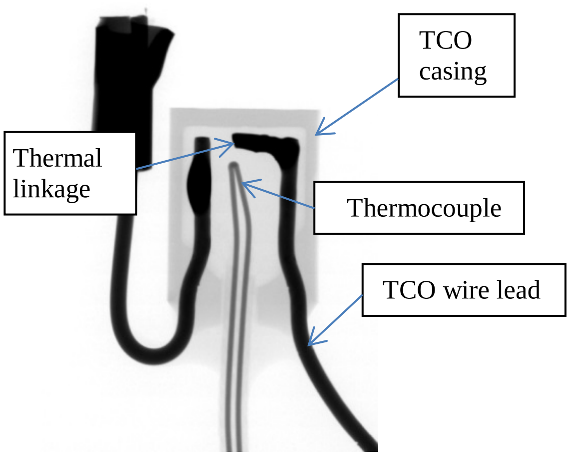
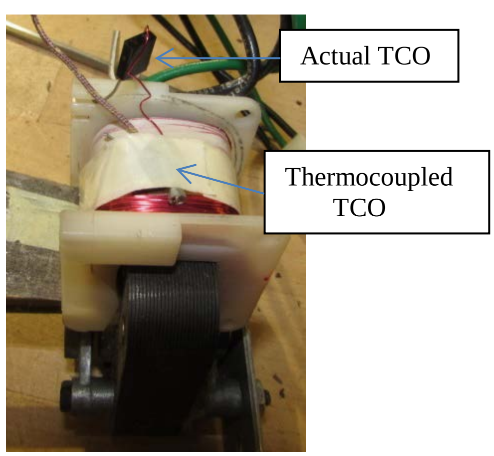


Figure 9. Thermocouple locations on the motor (side view)





Modified TCO with thermocouple   Actual TCO moved aside and TCO (thermocouple) installed

Figure 10. TCO with thermocouple

The testing showed that the TCO's internal temperature for this freely spinning motor with impeller is about 73°C. The thermocouple at the top of the winding measured slightly higher, at 76°C, than the TCO temperature as shown in Figure 11. When the fan was de-energized, the thermocouples located on the winding wrap measured an increase in the winding temperature because of the lack of airflow over the thermocouples when the impeller stopped spinning. The temperature within the TCO did not measure the same increase in temperature when the fan was de-energized. This is most likely caused by the TCO being located below the wrap, which caused the TCO not to be affected by the airflow.

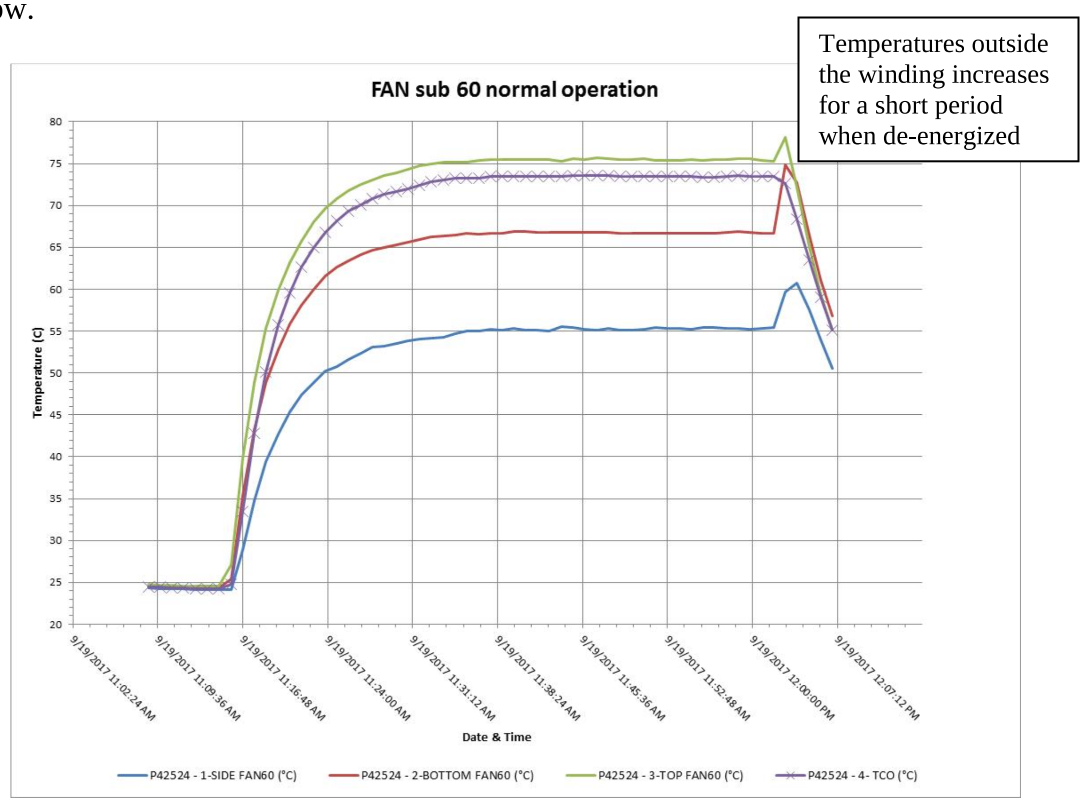


Figure 11. Temperature measurements on the winding and within the TCO (Fan 60)

5.4 Abnormal Fan Test

Fan sub 45 rotor did not turn freely in the condition in which it was received because of what appears to be dust and grime build-up at the bearings. When the sample was energized, the impeller/rotor did not spin; thus, it was in “locked-rotor” condition. Figure 12 shows sub 45 before any testing.

The fan was tested in its as-received condition, *i.e.*, locked-rotor condition. A single thermocouple was placed on the side of the winding, on the outside of the wrap, adjacent to the TCO location. After being energized, the TCO activated after 22 minutes, as shown by the temperature traces in Figure 13. For the location of this thermocouple, the temperature shows a maximum of 120ºC, but this location is about 20ºC cooler than the actual TCO or at the top of the winding. The actual TCO functioning temperature (T_f) was calculated to be about 140ºC (120ºC + 20ºC), which corresponds closely to the T_f of 136ºC. This testing in lock-rotor condition also verified that the side thermocouple measurements on the paper wrap were about 20ºC lower than the actual TCO or the top of the windings. Figure 14 shows the radiographs of the TCO’s fusible link after lock-rotor testing, which shows the thermal linkage melted or open.

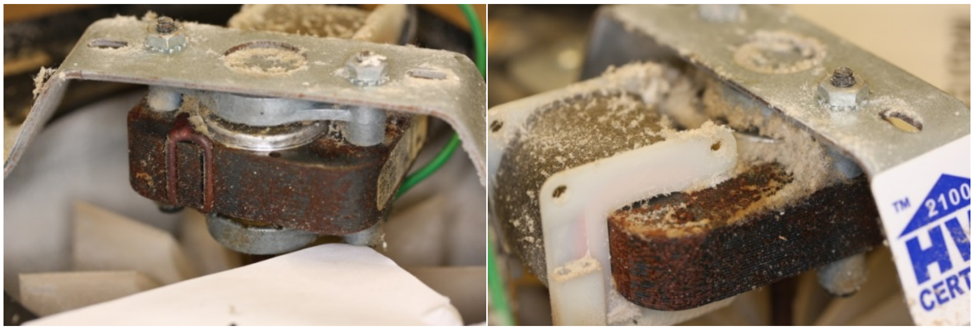


Figure 12. Sub 45 with dust and surface rust on core

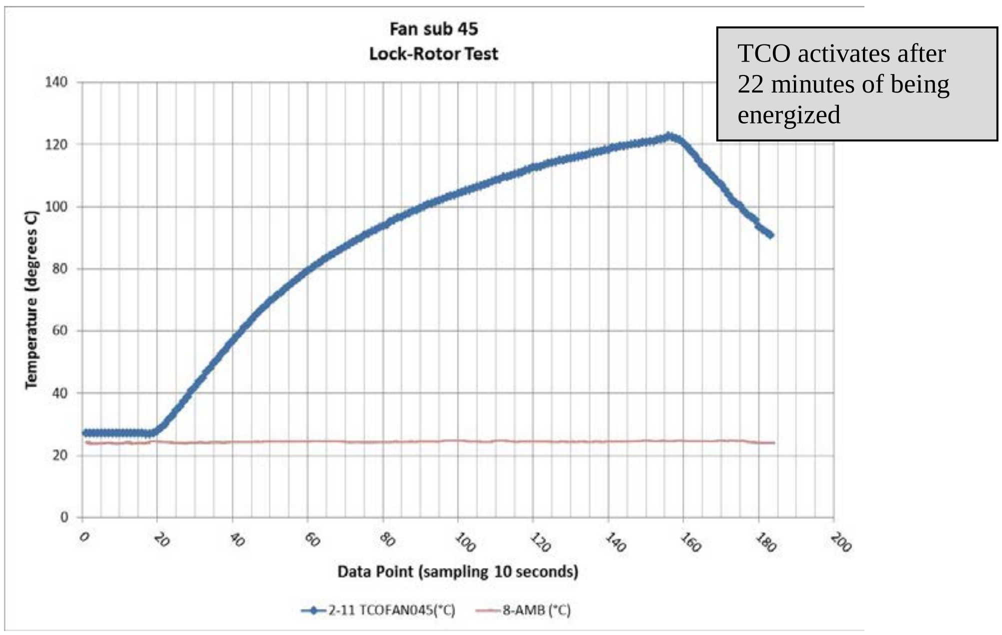
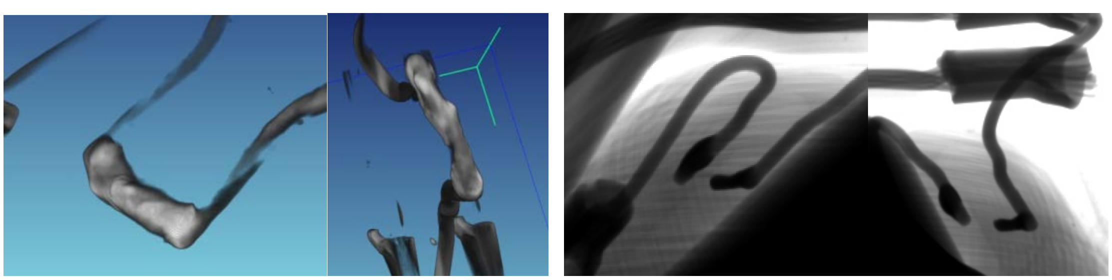


Figure 13. Sub 45 temperature measurement outside the winding



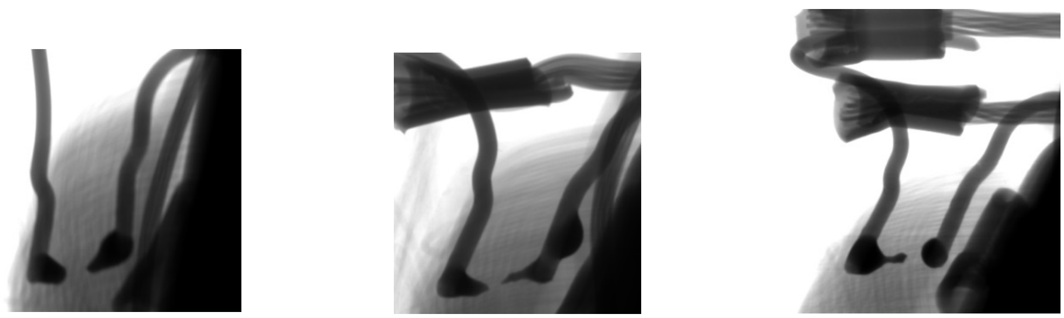
Before lock-rotor test After lock-rotor test

Figure 14. Radiograph and CT scans of the TCO before and after lock-rotor testing (Sub 45)

In other testing, where the TCO opened during lock-rotor conditions around the same elapsed time of 20 minutes, the thermal linkage had the same characteristic of only one end of the thermal linkage melting, as shown in Figure 15. This appeared to be caused by the TCO wire lead that is connected to the winding having a higher temperature than the wire lead connected to the power conductor. The wire lead would conduct the thermal energy from the winding during locked-rotor operation, thus causing one TCO wire lead to heat faster than the other TCO wire lead. Staff observed that for cases when the elapsed time was longer during the lock-rotor condition for the TCO to trip, and the temperature was higher than average, the thermal linkage would have inconsistent melting patterns, as shown in Figure 16. Staff expected that the delayed opening would result in a uniform temperature gradient within the TCO, thus causing the fusible linkage to melt completely or uniformly. But this was not the case, because the thermal linkage had irregularities, which suggests that other factors may be affecting the melting characteristics of the linkage.

Sub 04 Sub 40 Sub 36

Figure 15. Radiographs of TCOs after lock-rotor testing with consistent shape



Sub 69 Sub 10 Sub 58

Figure 16. Radiographs of TCOs after lock-rotor testing with unusual shapes

The same fan sub 60 that was instrumented with a thermocouple inside a TCO was used to measure the temperatures during lock-rotor conditions. Similar to the normal operation test, fan sub 60 had the three thermocouples on the paper wrap exterior of the winding and thermocoupled TCO. The lock-rotor condition was operated for 20 minutes to simulate the TCO tripping after 20 minutes in lock-rotor testing, as seen in Sub 45. After 9 minutes 12 seconds, the TCO temperature reached 105°C, as shown in Figure 17. At 15 minutes, the TCO temperatures reached 130°C. Shortly before 20 minutes, the TCO temperature reached 140°C. The TCO temperature measured approximately 142°C at 20 minutes or the manual trip time. The measurements in this test closely correspond to the sub 45 locked-rotor test. As mentioned previously, the TCO in sub 45 tripped at a measured temperature on the side of the winding around 120°C, and the temperature measured on the side of the winding in the test after 20 minutes of operation was about 123°C.

Figure 17. Temperature on the winding and within the TCO during a lock-rotor test

5.5 Lock-Rotor Test with TCO Bypassed

To evaluate worst-case scenario, fan sub 42, which had been previously tested in the lock-rotor test and the TCO tripped, was modified with the TCO bypassed. The tripped TCO was left intact in the motor, and a short piece of wire was soldered across the TCO wire leads to create a permanent linkage, thus bypassing the TCO. The test was to evaluate this motor if the TCO were to fail or not activate during a lock-rotor condition.

The fan was instrumented with a thermocouple located at the bottom of the winding, as viewed with the fan installed (see Figure 9 - Thermcouple BOTTOM). A second thermocouple was located exterior to the motor winding and on the same side as the TCO (see Figure 9 - Thermcouple SIDE). The lock-rotor test was conducted by blocking the impeller and energizing the fan. The thermocouple temperature measurements were recorded every 5 seconds.

The testing was conducted in three separate test periods. The first test period lasted 2 hours. The winding reached a steady-state temperature of 160ºC. After an elapsed time of 2 hours, the test was manually terminated. The fan was allowed to cool to room temperature before re-testing. The second test period was 2 hours. The winding reached a steady-state temperature of 200ºC. The test was manually terminated after 2 hours. The fan was allowed to cool to room temperature before re-testing.

For the third test period, the fan was energized in the lock-rotor condition, and after about 30 minutes, the temperature increased rapidly, which resulted in smoke and flames. The thermocouple temperature traces are shown in Figure 18. The motor winding ignited, which then ignited the plastic impeller, as shown in Figure 19. The plastic impeller resulted in dripping, flaming plastic. The total lock-rotor test time was about 4.5 hours (period 1 + period 2 + period 3).

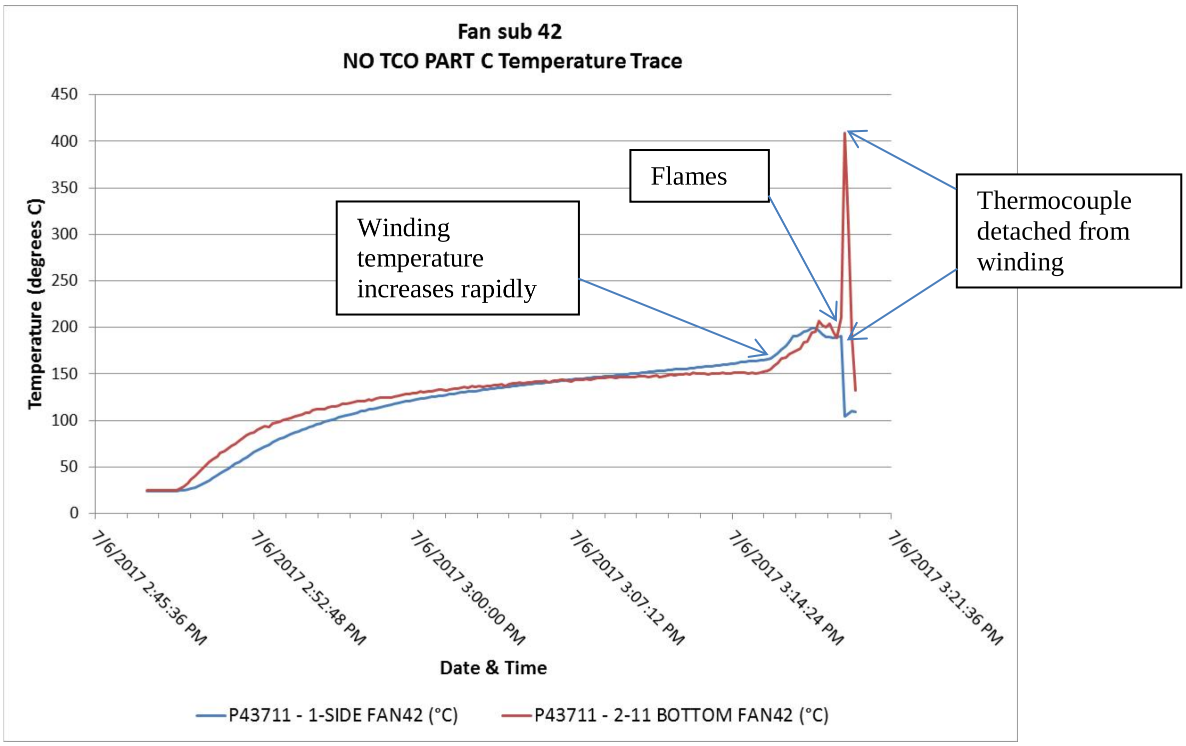


Figure 18. Sub 42 third test period Lock-Rotor Test with no TCO

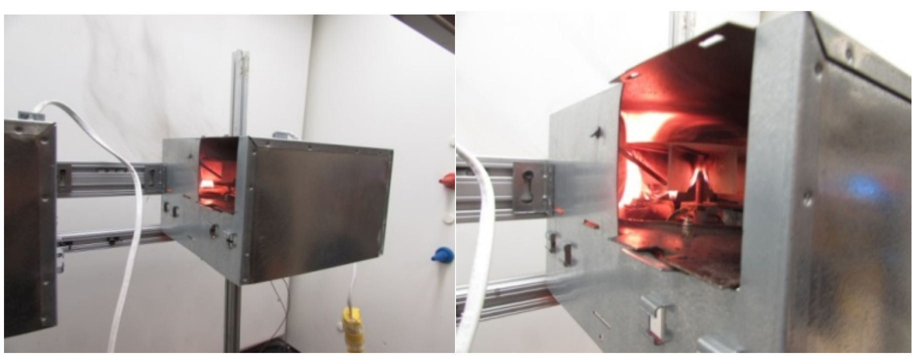


Figure 19. Bypassed TCO lock-rotor test

5.6 TCO Trip-Time Testing

The 100 samples that were collected from Picerne Military Housing on Ft. Riley, KS military base were randomly assigned to seven different test groups. Table 4 lists the fan motor subs as assigned to the seven test groups. Test groups 1, 2, 4, 5, and 6 had 15 fan samples. Test group 3 had 14 fan samples, and test group 7 had 11 fan samples.

Table 4. Sample Test Group

Test Group 1		Test Group 2		Test Group 3		Test Group 4		Test Group 5		Test Group 6		Test Group 7	
No.	Sub No.	No.	Sub No.	No.	Sub No.	No.	Sub No.	No.	Sub No.	No.	Sub No.	No	Sub No.
1	60	1	53	1	39	1	81	1	46	1	72	1	91
2	80	2	83	2	71	2	45	2	22	2	38	2	8
3	98	3	4	3	64	3	11	3	57	3	61	3	74
4	13	4	95	4	75	4	28	4	37	4	97	4	86
5	70	5	40	5	3	5	67	5	48	5	96	5	31
6	78	6	12	6	30	6	58	6	23	6	25	6	65
7	52	7	88	7	55	7	66	7	50	7	24	7	18
8	27	8	16	8	42	8	9	8	33	8	34	8	85
9	36	9	26	9	99	9	17	9	14	9	32	9	21
10	69	10	20	10	19	10	84	10	59	10	44	10	56
11	2	11	7	11	10	11	1	11	94	11	29	11	62
12	76	12	90	12	63	12	51	12	68	12	77		
13	92	13	87	13	41	13	6	13	54	13	47		
14	89	14	79	14	5	14	93	14	73	14	15		
15	35	15	100			15	43	15	49	15	82		

Two test frames were constructed for the testing. One test setup included a large test frame that allowed up to 15 fans to be tested at the same time, as shown in Figure 20. A second smaller test setup was constructed using a test frame that can accommodate up to two fans to be tested, as shown in Figure 21. Since the testing was lock-rotor condition, no vent hose was connected to the fan exhaust box housing.

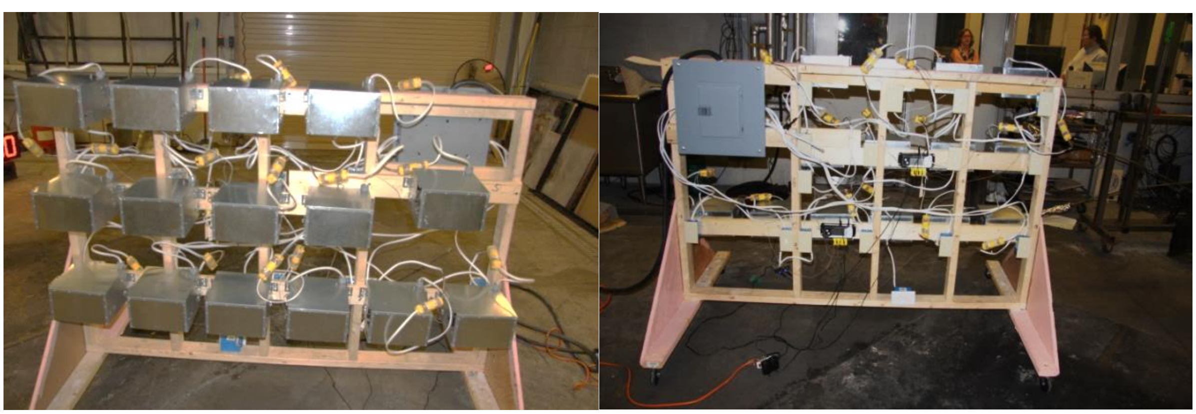


Figure 20. Large test frame and setup for up to 15 fans

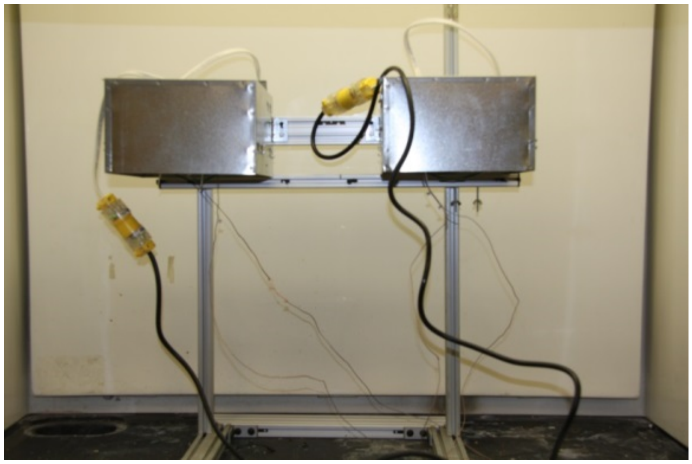


Figure 21 Smaller test frame and setup for up to 2 fans

5.6.1 Test Groups 1 and 2 - Lock-Rotor Test (15 fans per group)

Test Groups 1 and 2 each had 15 fans. Both groups of fans were tested on June 22, 2017. Each fan was instrumented with a thermocouple located on the exterior of the motor winding wrap on the side. Staff conducted a locked-rotor test by blocking the impeller with a nail through the side of the housing and energizing the fan with 120 VAC. The average ambient temperature at the start of the test was 26.8°C. Staff recorded the thermocouple measurements every 30 seconds.

All the TCOs activated (except Sub 60 due to the power connector coming loose early in the test). The measured temperature at the side of the winding when the TCO activated was between 110°C and 151°C (average 123°C). Sub 60 was later used for testing under the Section 5.3 Normal Fan Test to record temeprature traces during normal operation. Based on the sub 60 temperature traces under Normal Fan Test, we assume that the TCO temperatures should be about 20°C higher than the temperature on the side of the windings. This would translate to between 130°C and 171°C at the TCO and an average of 143°C . The activation times varied between 20 to 50 minutes for both test groups.

5.6.2 Test Group 3 - 105°C Variable Duration Conditioning and Lock-Rotor Test

Test Group 3 had 14 fans. All 14 fans were placed in a conditioning oven at 4 p.m. on June 23, 2017. The conditioning oven temperature was set at 105°C. The 105°C conditioning temperature corresponds to approximately 50 percent of the temperature difference (mean) between the TCO temperatures at trip and normal operation, as shown in equation [1] below. The fans were conditioned continuously at 105°C for a minimum duration of 64.3 hours to a maximum of 305 hours. The fans were removed from the conditioning oven at different times. After a fan sample was removed from the conditioning oven for testing, the fan motor was allowed to cool to room temperature before conducting the lock-rotor test.

$$\left(TCO\ temp_{at\ trip} - TCO\ temp_{normal}\right) \times 50\% + TCO\ temp_{normal} = Conditioning\ Temp \quad [1]$$

$$(143℃ - 73℃) \times 73℃ = 107.5℃ \approx 105℃$$

During lock-rotor testing, each fan was instrumented with two thermocouples. One thermocouple was located on the exterior of the motor winding wrap on the side of the winding. The second thermocouple was located on the bottom of the winding as viewed when the fan is installed. The lock-rotor test was conducted by blocking the impeller and energizing the fan. The thermocouple temperature measurements were recorded every 10 seconds.

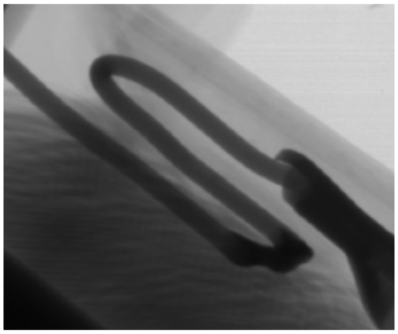
The smaller test setup was used during this testing series. Two fans were randomly removed from the conditioning oven at different conditioning periods to be tested. Table 5 lists the test frame location, thermocouple number, and conditioning period associated with each fan sub number.

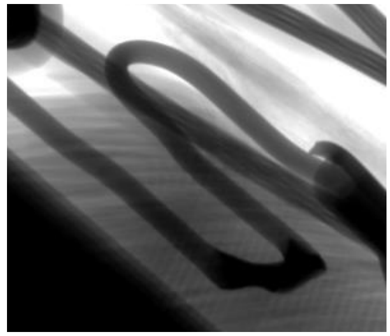
Table 5. Conditioning periods for Test group 3 subs

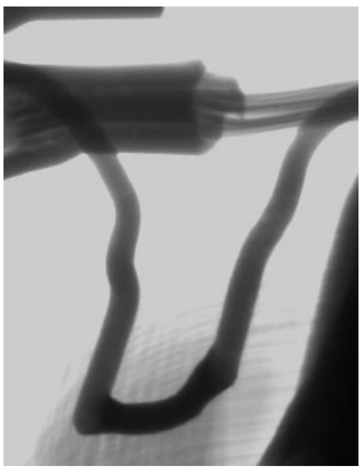
Sub	Start Conditioning	End Conditioning	Conditioning Period (hh:mm)
42	6/23/17 4:00 PM	6/26/17 8:30 AM	64:30
10	6/23/17 4:00 PM	6/26/17 8:30 AM	64:30
63	6/23/17 4:00 PM	6/28/17 9:00 AM	113:00
5	6/23/17 4:00 PM	6/28/17 9:00 AM	113:00
19	6/23/17 4:00 PM	7/3/17 8:30 AM	232:30
41	6/23/17 4:00 PM	7/3/17 8:30 AM	232:30
64	6/23/17 4:00 PM	7/5/17 8:00 AM	280:00
75	6/23/17 4:00 PM	7/5/17 10:00 AM	282:00
99	6/23/17 4:00 PM	7/5/17 4:00 PM	288:00
71	6/23/17 4:00 PM	7/5/17 4:00 PM	288:00
39	6/23/17 4:00 PM	7/6/17 9:00 AM	305:00
3	6/23/17 4:00 PM	7/6/17 9:00 AM	305:00
30	6/23/17 4:00 PM	7/6/17 9:00 AM	305:00
55	6/23/17 4:00 PM	7/6/17 9:00 AM	305:00

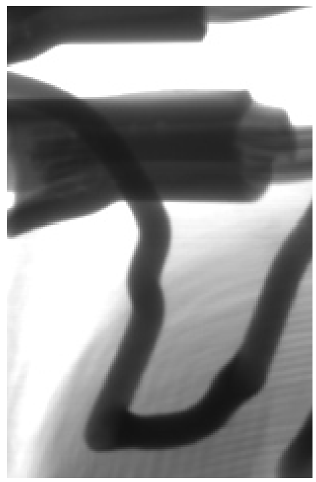
Effects of Conditioning to the Thermal Linkages

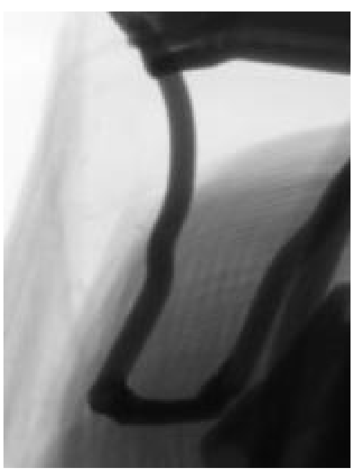
For test group 3, all of the TCOs were x-rayed before and after conditioning. The thermal linkages did not appear visually to have changed after conditioning at 105ºC for up to 305 hours. Figure 22 shows radiographs of the thermal linkages before and after conditioning for various lengths of time.

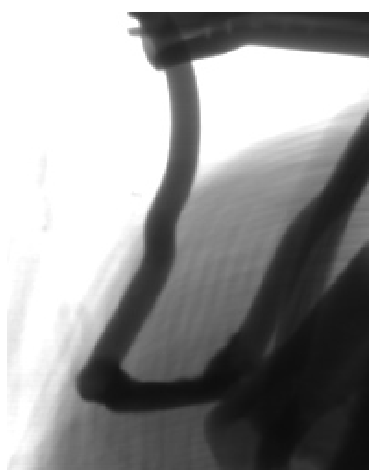

Sub 10 - Before conditioning


Sub 10 - After conditioning@105°C 64.5 hours


Sub 19 - Before conditioning


Sub 19 - After conditioning@105°C 232.5 hours


Sub 41 - Before conditioning


Sub 41 - After conditioning@105°C 232.5 hours

Sub 39 - Before conditioning

Sub 39 - After conditioning@105°C 305 hours

Figure 22 Thermal linkages before and after conditioning

Results

Of the 14 units tested, one unit failed to open, allowing the winding to overheat and smoke. The unit's bobbin melted from overheating and arcing within the winding. Eight of the 14 units' TCOs opened within 24 minutes. Two of the 14 units' TCOs opened around 50 minutes, reaching temperatures above the rated T_f for the TCO. Eight of the 14 units had elevated temperatures that exceeded the TCOs' rated opening temperature of 136°C. Table 6 lists data for Test Group 3.

Table 6. Test Group 3 - 105°C Conditioning and Lock-rotor Test Data

Sub	Condition Period (hh:mm)	Max. Temp. at side (°C)	Calculated Functioning Temperature (°C)	Max. Temp. at bottom (°C)	Elapsed Time to Trip (hh:mm:ss)	TCO Open or Activated	Smoke or Fire	Failed to Trip at 136°C
42	64:30	111.9	~132	Loose thermocouple	0:19:30	Yes	No	No
10	64:30	127.5	~148	181.6	0:52:00	Yes	No	Yes
63	113:00	109.0	~129	Loose thermocouple	0:22:00	Yes	No	No
5	113:00	131.0	~151	141.9	0:18:00	Yes	No	Yes
19	232:30	138.6	~159	127.2	0:54:00	Yes	No	Yes
41	232:30	209.8	N/A	302.0	2:40:00	No	Yes	Yes
64	280:00	155.8	~176	203.8	3:26:00	Yes	No	Yes
75	282:00	128.8	~149	157.5	0:24:00	Yes	No	Yes
99	288:00	151.6	~172	183.2	4:00:00	Yes	No	Yes
71	288:00	116.4	~136	146.4	0:19:00	Yes	No	No
39	305:00	111.9	~132	153.4	0:18:00	Yes	No	No
3	305:00	109.4	~121	140.2	0:22:00	Yes	No	No
30	305:00	158.5	~179	213.4	1:37:00	Yes	No	Yes

Sub	Condition Period (hh:mm)	Max. Temp. at side (°C)	Calculated Functioning Temperature (°C)	Max. Temp. at bottom (°C)	Elapsed Time to Trip (hh:mm:ss)	TCO Open or Activated	Smoke or Fire	Failed to Trip at 136°C
55	305:00	105.4	~125	154.3	0:22:00	Yes	No	No

Sub 10 - Lock-Rotor Test

Staff conditioned the fan (sub 10) for 64 hours 30 minutes. During the locked-rotor testing, the TCO activated. The TCO activated approximately 52 minutes after the rotor was locked. The activation time was about 30 miutes longer than seen during typical lock-rotor testing, which activated around 20 minutes within the testing. Figure 23 shows the temperature traces for the thermocouples during the lock-rotor test.

Figure 24 shows the CT scan of the fusible link after the lock-rotor test. As seen in prior testing when the trip time is longer than average, the fusible link melts at the center of the link. The figure does show a partial wetting of the electrodes occurred, which allowed the solder link to bead.

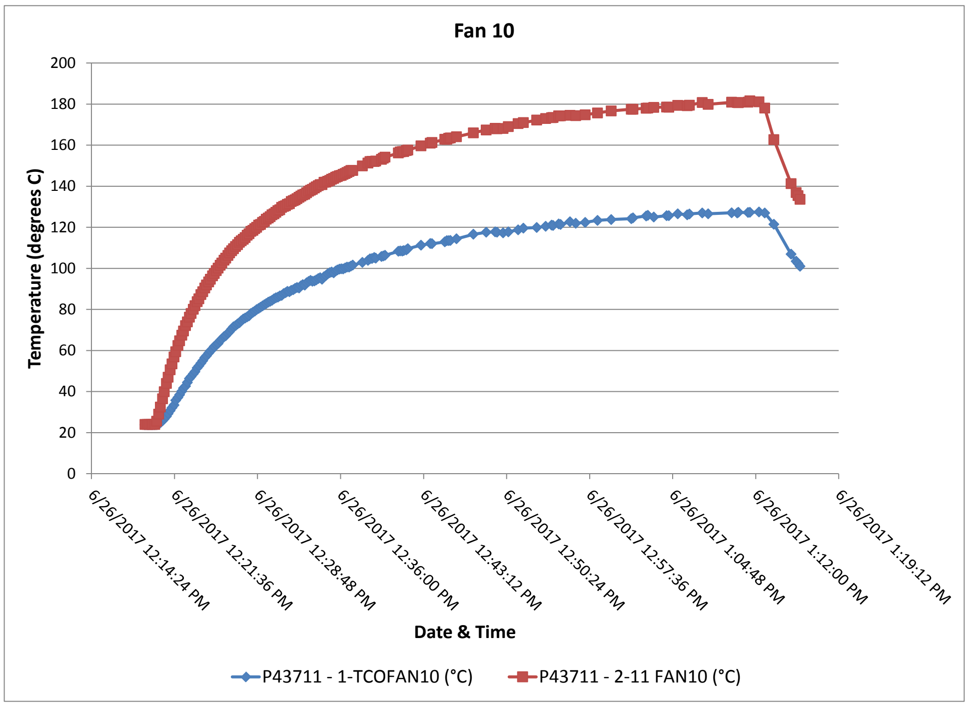


Figure 23. Temperature traces for Sub 10 Test Group 3 - Lock-Rotor Test

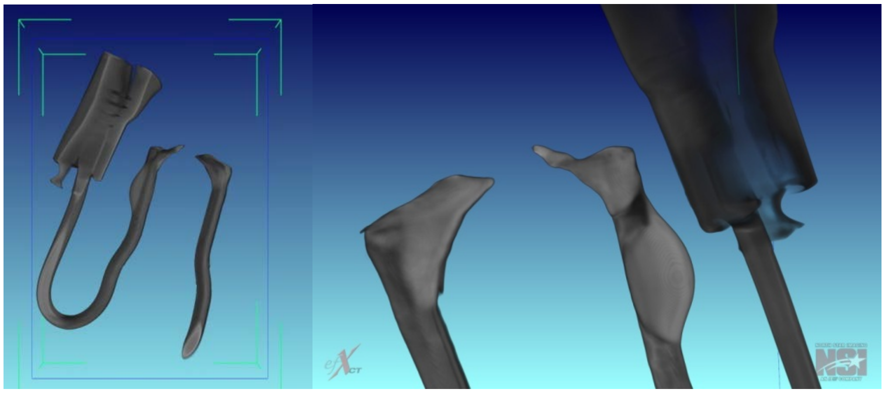


Figure 24. CT scan of the fusible link after lock-rotor testing (sub 10)

Sub 41- Lock-Rotor Test

Staff conditioned the fan (sub 41) for 232 hours 30 minutes. During the lock-rotor testing, the TCO did not activate. After about an hour, the temperature appeared to have leveled to a constant temperature or steady state. Staff terminated the lock-rotor testing after approximately 2 hours 30 minutes. Figure 25 shows the temperature traces for the thermocouples during the lock-rotor test on July 3, 2017.

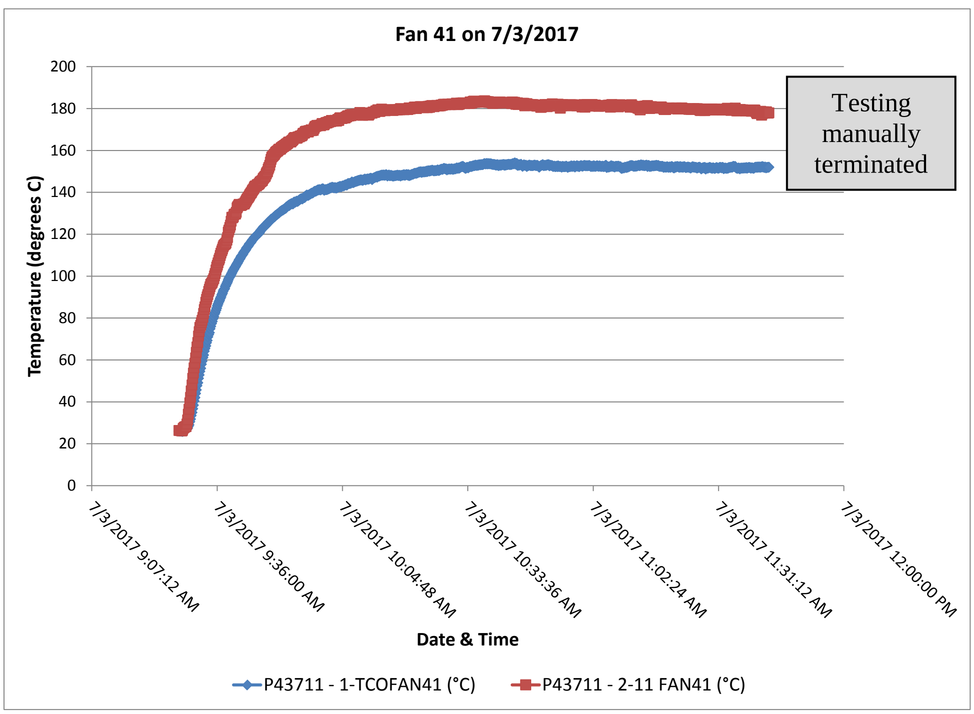


Figure 25. Temperature traces for Sub 41 Test Group 3 - Lock-rotor Test

Staff allowed the fan to cool to room temperature before retesting. During the second lock-rotor test, the temperatures increased rapidly, and the unit began to smoke. The temperature suddenly increased and arcing could be heard. Suddenly the arcing ceased, and the temperature began to decrease. Figure 26 shows the temperature traces for the thermocouples during the lock-rotor test on July 5, 2017. The thermocouple located at the

TCO (blue trace) detached from the surface of the winding when the unit began to smoke, which resulted in a sudden drop in temperature. The elapsed time to maximum temperature was about 9 minutes, 50 seconds.

Figure 27 shows the fan producing significant smoke during the second lock-rotor testing. There were no visible flames during the testing. Examination of the motor shows localized overheating and arcing in the winding. The full elapsed time for the first and second lock-rotor tests was about 2 hours 40 minutes.

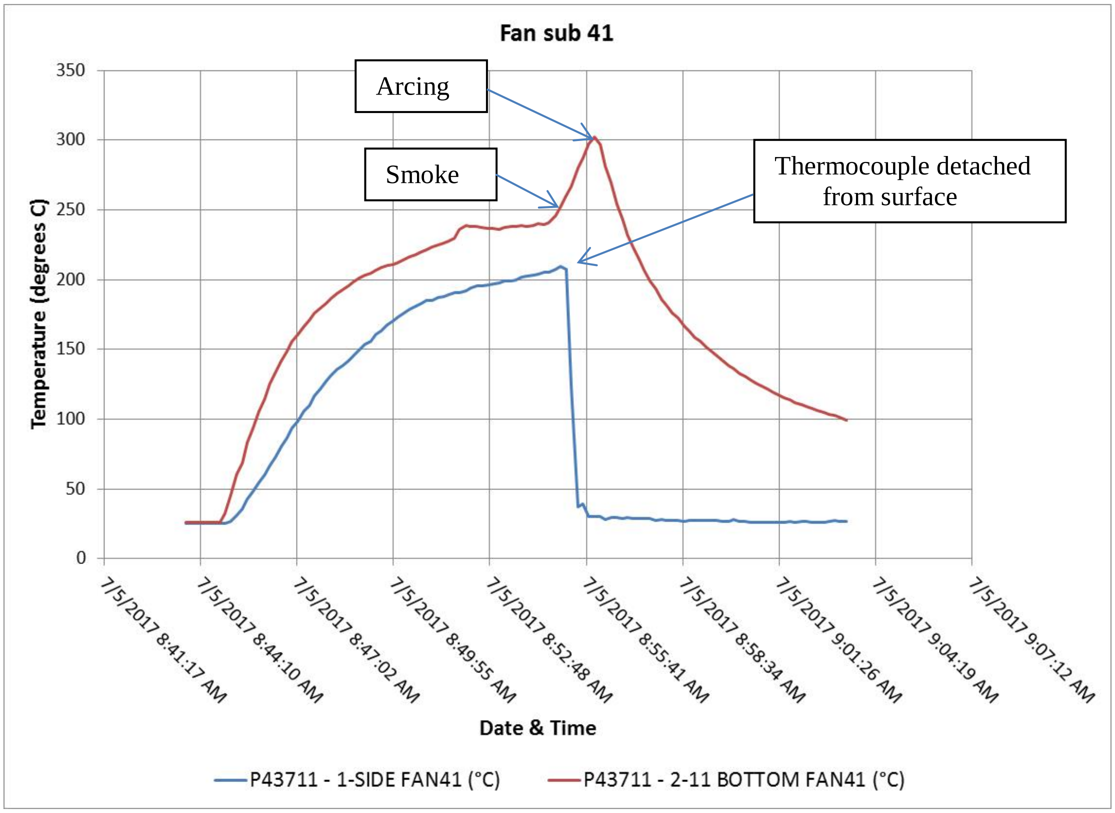


Figure 26. Temperature traces for Sub 41 Test Group 3 - Lock-Rotor Test on July 5, 2017

Figure 27. Sub 41 Test Group 3 - Lock-Rotor Test producing smoke and post examination

Post examination shows the TCO’s fusible link to be intact, as shown by CT scans in Figure 28. During lock-rotor testing, the TCO failed to activate, but the event ended because the motor winding opened, thus de-energizing the motor.

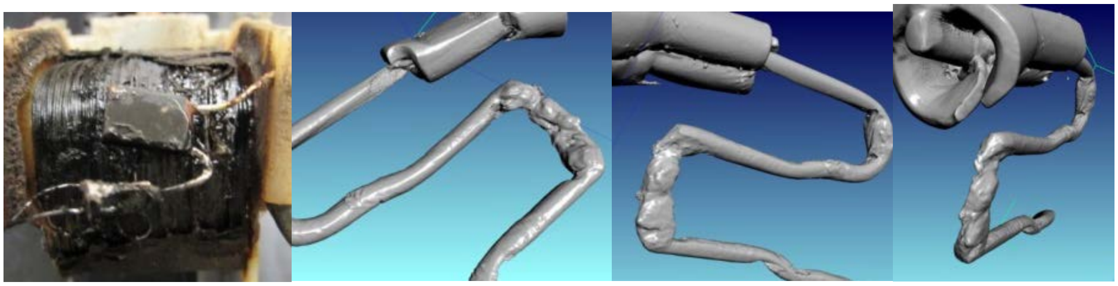


Figure 28. TCO from Sub 41 after Lock-Rotor Test

<u>Sub 64 - Lock-Rotor Test</u>

Staff conditioned the fan (sub 64) for 280 hours. During the initial lock-rotor testing on July 5, 2017, the TCO did not activate. The temperature appeared to have leveled to a constant temperature or steady state. Staff manually terminated the testing at noon, after approximately 3 hours 15 minutes.

Staff allowed the fan to cool for 45 minutes (to approximately room temperature) before retesting. During the second lock-rotor test, the TCO activated. Figure 29 shows the temperature traces for the thermocouples during the second lock-rotor test. The TCO tripped after approximately 11 minutes during the second lock-rotor test.

Post examination revealed a solder bead external to the TCO casing, as highlighted by the yellow circle shown in Figure 30. Microscopic images of the TCO show that the solder bead originated from inside the TCO because solder was located in cracks between the epoxy seal and the lead wire, as shown in Figure 31. Figure 32 shows the CT scans with the partially melted fusible link after the testing, thus, indicating the TCO did activate, but abnormally. Visible in the CT scan is the solder bead, highlighted by the yellow circles.

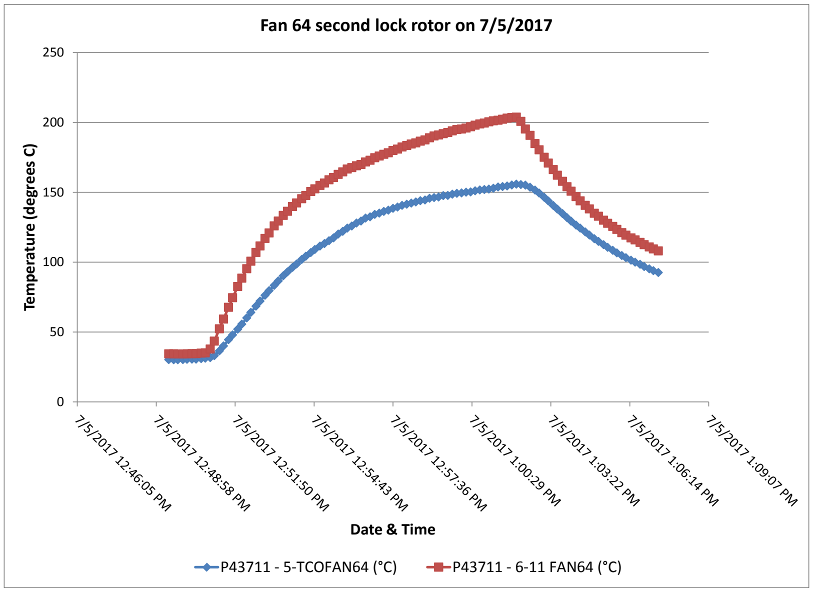


Figure 29. Temperature for Sub 64 Test Group 3 during Second Lock-Rotor Test

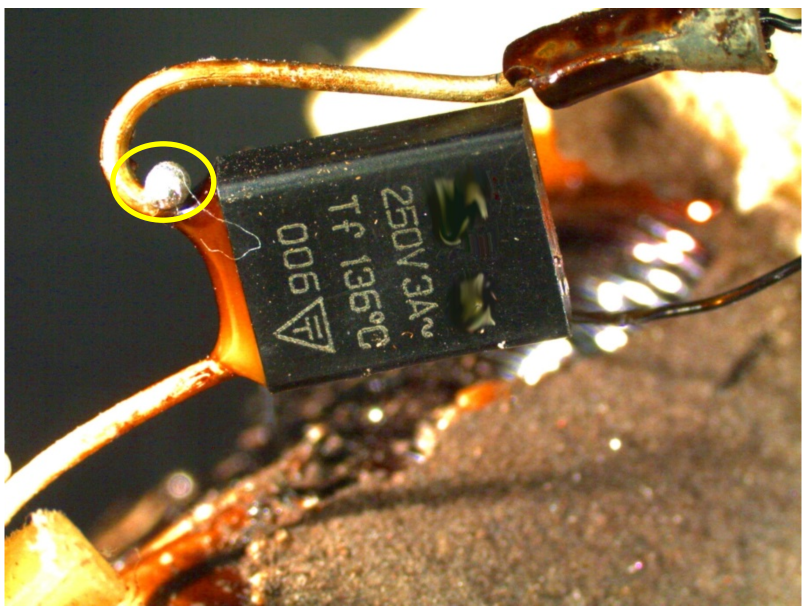
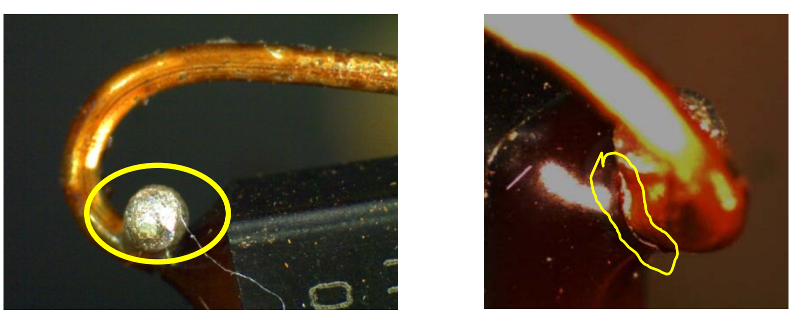


Figure 30. Solder bead on TCO lead from Sub 64 after second Lock-Rotor Test


Solder bead Solder in the cracks of the epoxy/electrode
Figure 31. Microscopic images of the solder bead and solder in the cracks (Sub 64)

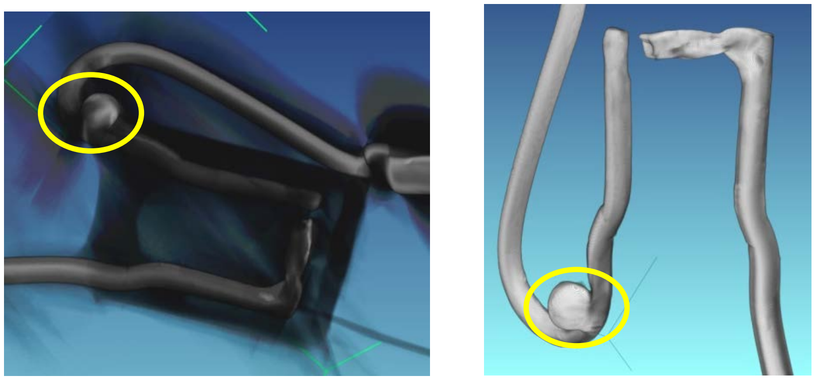


Figure 32. CT scans of the TCO showing the solder bead (Sub 64)

<u>Sub 99 - Lock-rotor Test</u>

Staff conditioned the fan (sub 99) for 288 hours before being subjected to three lock-rotor test periods as summarized in Table 7. During the initial lock-rotor test (segment A), the TCO did not activate. During the second lock-rotor test (segment B), the TCO did not activate. The TCO activated during the third lock-rotor test (segment C). Figures 33 and 34 show the temperature traces for the thermocouples during the three segments of lock-rotor test. The TCO tripped after approximately 30 minutes during the third lock-rotor test, but after almost 5 hours of combined lock-rotor testing (sum of the test duration for all of the segments up to the activation).

Table 7. Segment lock-rotor testing (Sub 99)

Testing Segment	Test Duration (hh:mm:ss)	Maximum temperature at Side Windings (C)	Calculated TCO Temperature (C)	Maximum temperature at Bottom Windings (C)	Notes
PART A	3:09:36	150	~170	182.6	Manually terminated
PART B	1:12:06	151.6	~172	183.2	Manually terminated
PART C	0:29:42	140.9	~161	173.3	TCO tripped

Post examination revealed the TCO had a solder bead external to the TCO casing. Figure 35 shows the CT scans with the partially melted fusible link after the testing, thus, indicating the TCO did activate, but abnormally. Microscopic images show that the solder originated from inside the TCO because of solder located within the cracks between the epoxy seal and the lead wires. Figure 36 shows the microscope images of the solder bead and solder in the cracks.

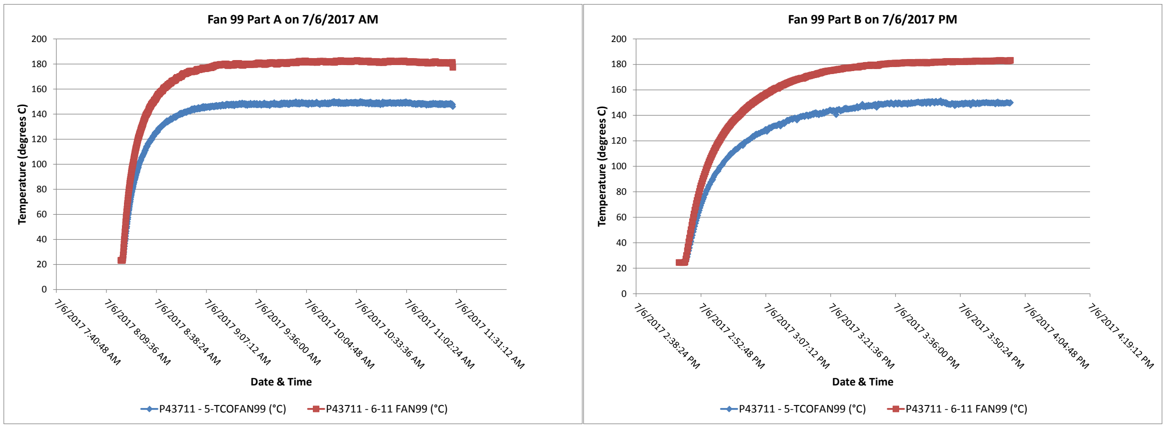


Figure 33. Segment Part A and B temperatures for Sub 99 Test Group 3 - Lock-Rotor Test

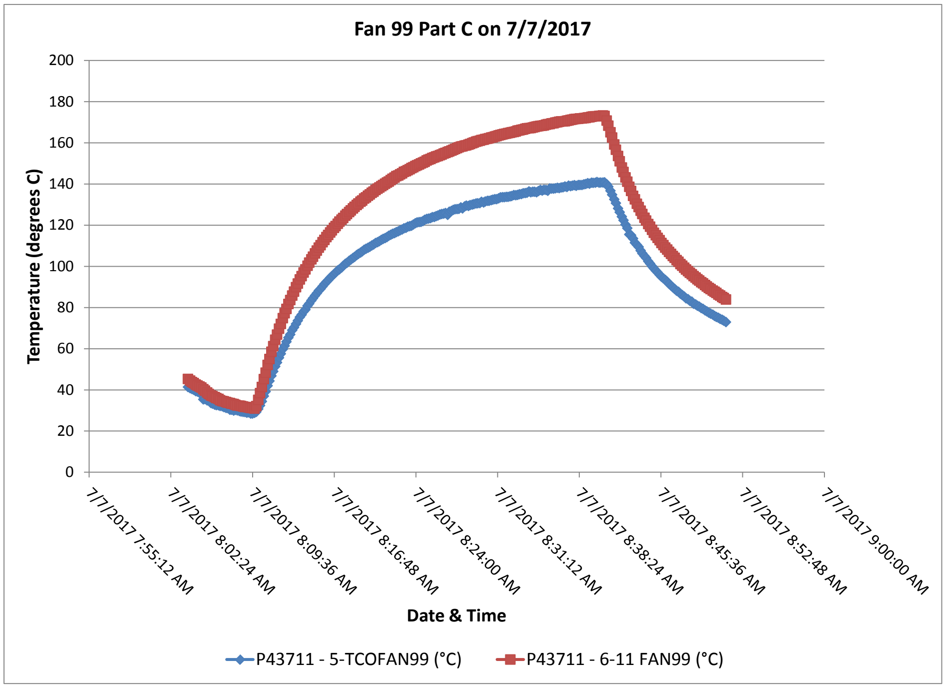


Figure 34. Segment part C temperature traces for Sub 99 Test Group 3 - Lock-Rotor Test

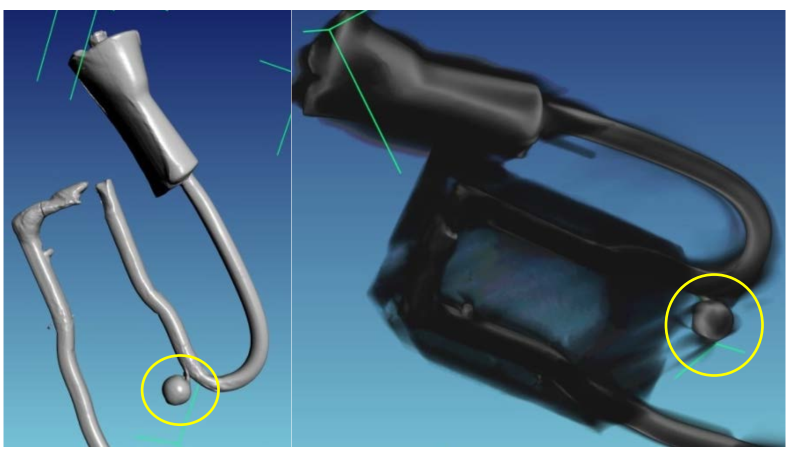
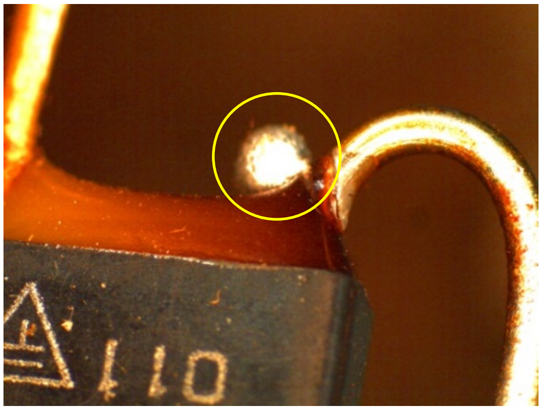
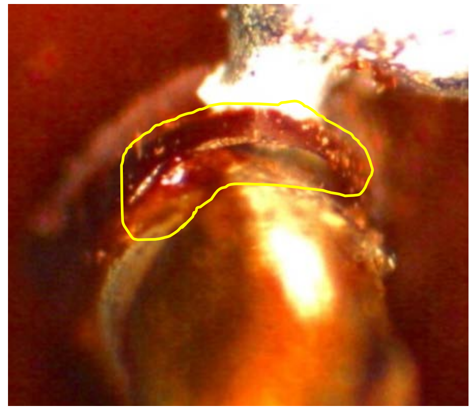


Figure 35. CT scans of the TCO showing the solder bead (Sub 99)



Solder bead



Solder in the cracks of the epoxy/electrode

Figure 36. Microscopic images of the solder bead and solder in the cracks (Sub 99)

5.6.3 Test Group 4 - 105°C 165 Hours Conditioning and Lock-Rotor Tests

Test Group 4 had 15 fans. Staff placed the 15 fans in the conditioning oven at 2:30 p.m. on July 6, 2017. Staff set the conditioning oven at 105°C. After 165 hours (July 13, 2017 at 11:30 am), all 15 units were removed from the conditioning oven and installed in the large test frame. The fans were allowed to cool to room temperature before testing. A single thermocouple was placed on the side of the winding for each fan sample. The fans were tested in a lock-rotor condition on July 14, 2017. Figure 37 shows the temperature traces for Test Group 4 – Lock-Rotor Test.

Eleven of the 15 fans had the TCO activate in less than 45 minutes during the lock-rotor testing. One fan's TCO opened shortly after 2 hours (sub 58). Three of the 15 fans' TCOs (sub 6, 51 and 66) failed to activate or open after 4 hours of lock-rotor, and staff manually terminated the test. Table 8 lists the test results from Test Group 4 lock-rotor testing.

Table 8. Test Group 4 - 105°C Conditioning and Lock-Rotor Test Result

Test Group 4			TCO		
Test Frame Location Number	Fan Sub No.	Thermocouple id	Tripped	Elapsed Time	TCO Failed to Activate Normally
1	81	P43711-1-11FAN01	Yes	32 m 35 s	No
2	45	P43711-2-11FAN02	Yes	32 m 35 s	No
3	11	P43711-3-11FAN03	Yes	33 m 34 s	No
4	28	P43711-4-11FAN04	Yes	37 m 24 s	No
5	67	P43711-1-11FAN05	Yes	40 m 15 s	No
6	58	P43711-6-11FAN06	Yes	2 h 3 m 43 s	Yes
7	66	P43711-7-11FAN07	No	Over 4 hours	Yes
8	9	P43711-8-11FAN08	Yes	34 m 54 s	No
9	17	P42524-1-11FAN09	Yes	35 m 53 s	No
10	84	P42524-2-24FAN10	Yes	40 m 52 s	No
11	1	P42524-3-24FAN11	Yes	44 m 12 s	No

12	51	P42524-4-24FAN12	No	Over 4 hours	Yes
13	6	P42524-5-24FAN13	No	Over 4 hours	Yes
14	93	P42524-6-24FAN14	Yes	38 m 1 s	No
15	43	P42524-7-24FAN15	Yes	30 m 11 s	No
Ambient		P42524-8-24Amb			

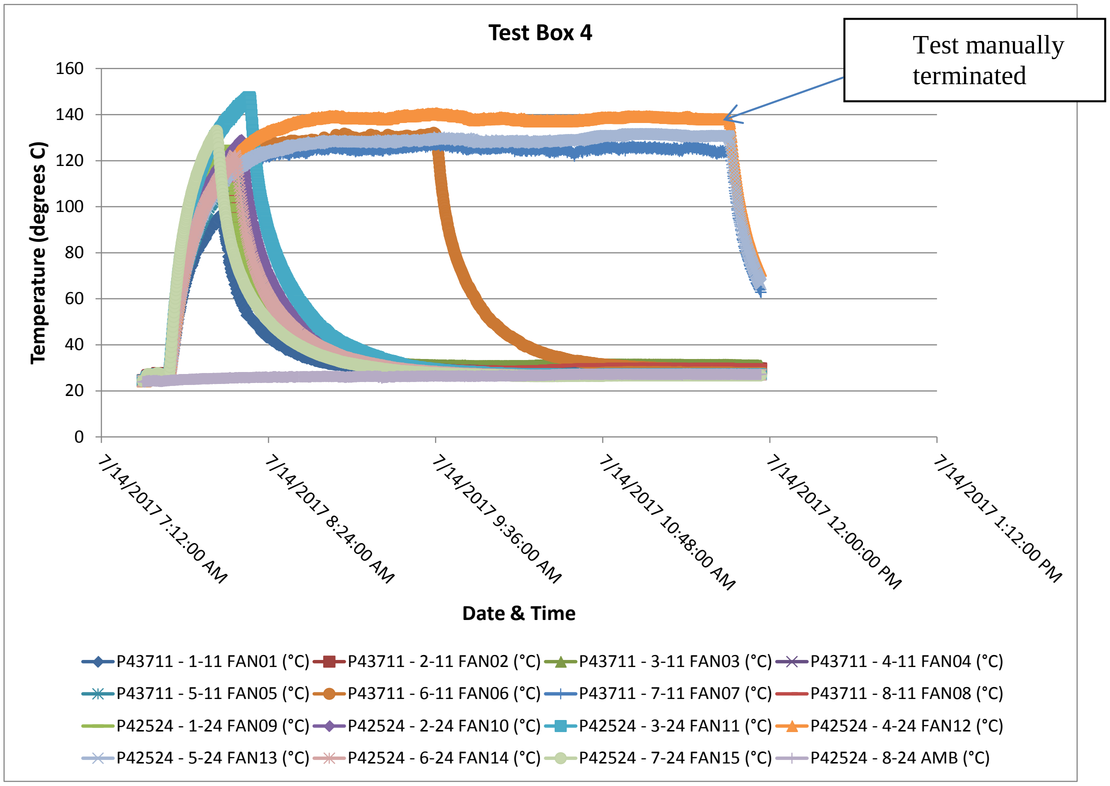


Figure 37. Temperature traces for Test Group 4 - Lock-Rotor Test

Figure 38 shows fan subs 6, 51, 58 and 66 temperature traces for Test Group 4 – Lock-rotor Test. These subs had a TCO that had activation trip times that were long or never tripped. The TCOs were x-rayed and CT scanned.

Figure 39 shows the TCO from sub 58, which tripped but took more than 2 hours. As seen in previous TCOs that had a long trip time, the melted linkage would bead to both wire leads; but in this case, the radiograph shows a thin portion of the fusible link still present.

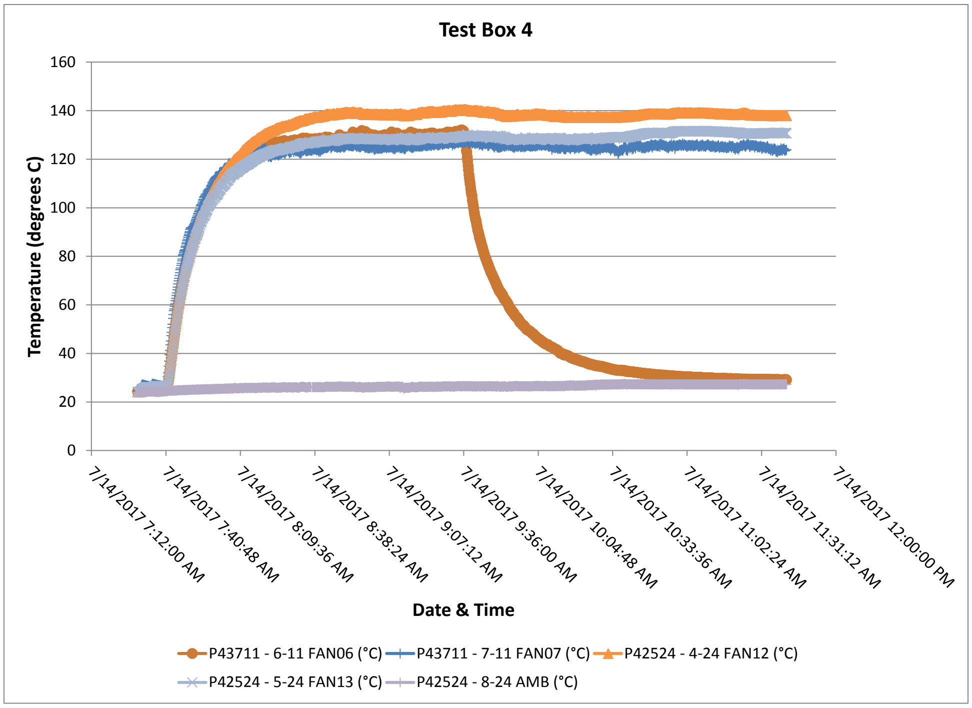
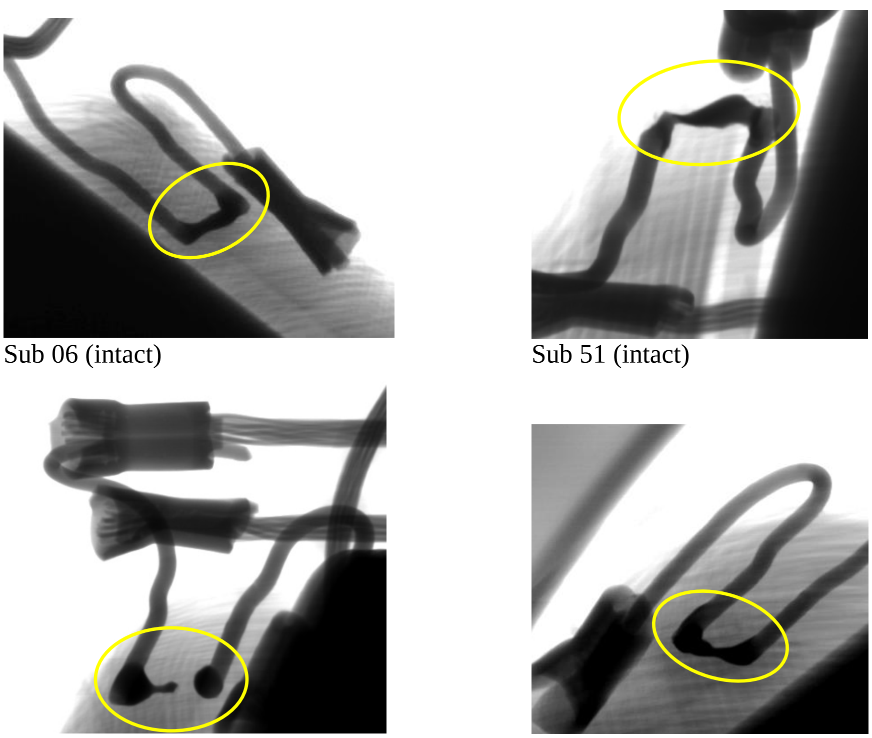


Figure 38. Temperature traces for Subs 6, 7, 12 and 13 (Test Group 4 - Lock-Rotor Test)



Sub 06 (intact) Sub 51 (intact)

Sub 58 (open) Sub 66 (intact)

Figure 39. Radiograph of subs 6, 51, 58 and 66 after Lock-Rotor test

5.6.4 Test Group 5 - 105°C 330 Hours Conditioning and Lock-Rotor Tests

Test Group 5 had 15 fans, but only 13 fans were subjected to the lock-rotor test. All 15 fans were in the conditioning oven continuously for 330 hours at 105°C. After 330 hours, all 15 units were removed from the conditioning oven and allowed to cool to room temperature (approximately 23°C) before testing.

Each fan was instrumented with three thermocouples. Channel 1 thermocouple (T) was located at the top of the winding wrap, as viewed with the fan installed. Channel 2 thermocouple (M) was located on the exterior of the winding wrap and on the side of the motor winding on the same side as the TCO. The third thermocouple (B) was located at the bottom or on the lowest side of the winding wrap when the fan is installed. The lock-rotor test was conducted by blocking the impeller and energizing the fan. The thermocouple temperature measurements were recorded every 10 seconds.

<u>Results</u>

Seven of the 13 fans had the TCO activate in less than 34 minutes during the lock-rotor testing. The average maximum winding temperature measured was 160°C before the TCO tripped. On average for the seven fans, the TCO tripped about 20 minutes into the lock-rotor testing. Two (Fan subs 46 and 68) of the 13 fans ran in lock-rotor condition for at least 1 hour before the TCO tripped. One (Fan sub 94) of the 13 fans ran in a lock-rotor condition for almost 37 minutes on the first day before the test was manually terminated (end of the day). When the same unit (Fan sub 94) was lock-rotor tested on the second day, the TCO tripped after about 32 minutes. One (Fan sub 54) of the 13 fans was tested in the lock-rotor condition for a continuous 22 hours, which did not result in the TCO to open or a fire. Staff manually terminted the testing (the fan was de-energized). Two (Fan subs 73 and 23) of the 13 fans ignited during the lock-rotor testing. The TCOs failed to activate in both of these units. Table 9 lists the test results from Test Group 5 lock-rotor testing.

Table 9. Test Group 5 – Conditioning 330 hours at 105°C and Lock-Rotor Test Results

Test Group 5		TCO				
Test date	Sub No.	Tripped	Elapsed time	Maximum temperature	TCO failed to activate normally	Results
7/31/2017	46	Yes	1 h 1 m 55 s	163°C	Abnormal	Steady state before tripping, Late TCO trip
8/1/2017 – 8/2/2017	94	Yes	36 m 57 s (Day 1) 31 m 57 s (Day 2)	202°C	Abnormal	Late TCO trip
8/2/2017	57	Yes	33 m 42 s	202°C	Normal	
8/3/2017 -8/4/2017	37	Yes	15 m 12 s	159.6°C	Normal	
	54	No	Steady state for 22 hours continuous	224.8°C	Failed to open	Manually terminated testing

8/2/2017	73	No	steady state (~189°C) 1 h 55 m 40 s	507.4°C	Failed to open	Fire
	33	Yes	18 m 52 s	145.7°C	Normal	
8/2/2017	14	Yes	20 m 52 s	137.4°C	Normal	
	49	Yes	17 m 01 s	163.9°C	Normal	
8/4/2017	48	Yes	18 m 21 s	147.7°C	Normal	
	23	No	steady state (~186°C) 2 h 03 m 41 s	547.3°C	Failed to open	Fire
8/4/2017	50	Yes	15 m 02 s	165.2°C	Normal	
	68	Yes	2 h 6 m 12 s	206.2°C	Abnormal	Steady state before tripping

Sub 73 – Conditioning and Lock-Rotor Test

Fan sub 73 was in lock-rotor condition for about 1 hour and 56 minutes before the unit ignited, as shown in Figure 40. The fan's winding temperature was at a steady-state temperature (~188°C) above the TCO function temperature for about 1 hour, until the winding temperature began to increase rapidly. This rapid increase in temperature is an indication of shorting in the winding, which reduces the winding resistance and increases the current. Before ignition, with the winding temperature at about 233ºC, the unit was producing visible white smoke. When the unit ignited around 289°C, there was a large flash and flames for a brief moment. It appears that the gaseous vapors driven off the winding coating ignited. The flames subsided slightly until the wrap around the winding and the coating on the windings started to burn, growing in intensity. The flames impinged on and ignited the plastic impeller. The burning impeller and bobbin resulted in dripping flaming plastic. Four layers of cheesecloth were placed under the fan to be used as an ignition indicator to verify that the dripping plastic continued to burn as it landed on the surface below. The dripping flaming plastic caused the cheesecloth to ignite, which indicates that the fan's plastic grill could also ignite in this type of situation. Figure 41 shows a sequence of photographs demonstrating the progression during lock-rotor testing on sub 73.

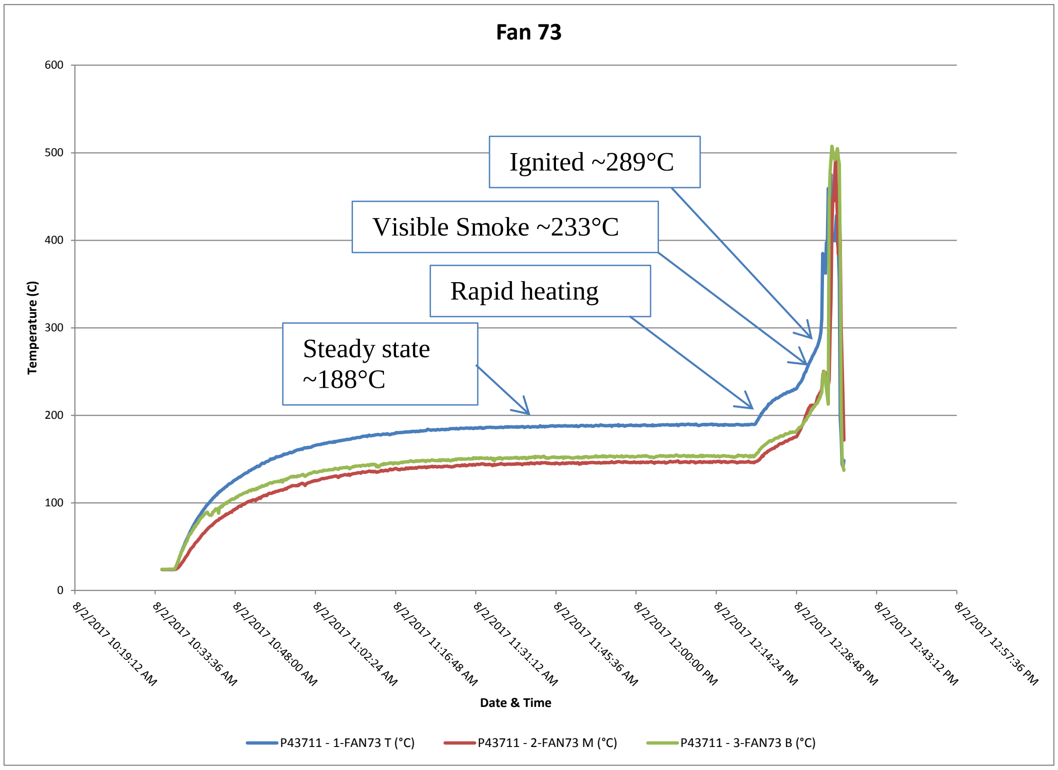


Figure 40. Winding temperatures during lock-rotor test for Fan sub 73

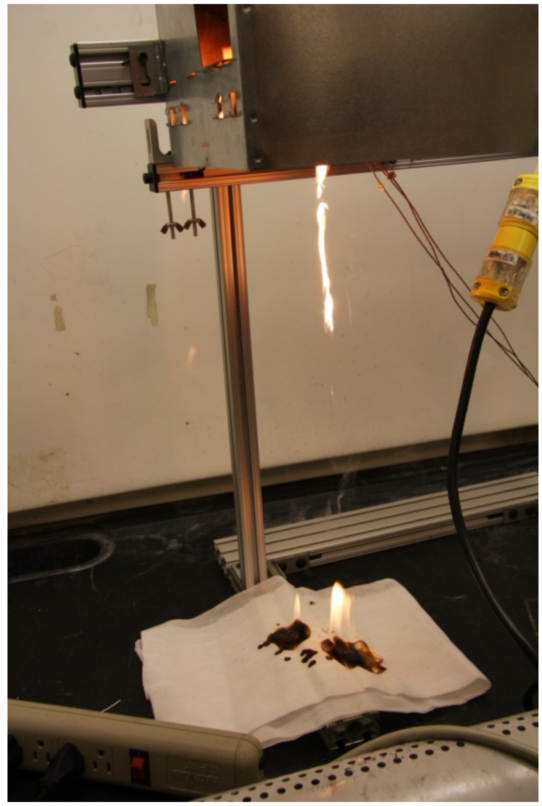

At around 233ºC, the fan begins producing white smoke


At sufficient temperatures, there appears to be an ignition of gases around the motor around 288°C


The large flames subside and the winding wrap and/or the winding coating appears to be burning


More of the winding wrap and the coating on the winding burns, thus creating a larger flame

The impeller has ignited and begins to sag onto the motor



Dripping flaming plastic ignites the cheesecloth ignition indicator

Figure 41. Fan sub 73 during lock-rotor test

Figure 42 shows a radiograph of the TCO after the test. Post-test radiographs of the TCO show the TCO is open, which was caused by the intense heat from the flames. This would suggest that any analysis of a TCO after a fire incident does not necessarily indicate the status of the TCO during the incident.

Figure 42. Radiograph of the TCO after the test (sub 73)

CPSC staff reviewed the CT scans of the thermal linkage for fan sub 73. The thermal linkage shows abonormalities as shown in Figure 43. The CT scans appear to show the linkage to take partial form of the TCO case, such that a flat section had formed. In theory, temperatures below T_f may be causing the thermal linkage to soften. This may cause changes in the eutectic materials, where it may alter the eutectic temperature or $T_{f.}$

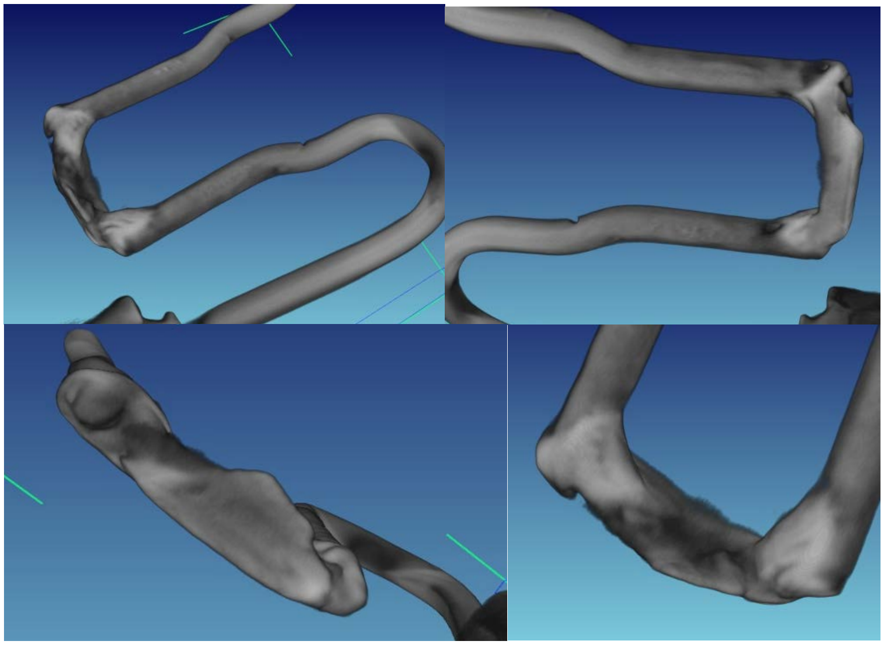


Figure 43. CT scans of the TCO before conditioning (sub 73)

Sub 23 – Conditioning and Locked-Rotor Test

Fan sub 23 was in lock-rotor for about 2 hours and 40 minutes before the unit ignited, as shown in Figure 44. The fan's winding temperature, ~186°C, was at steady state, above the TCO specified activation temperature, until the winding temperature began to increase rapidly. This rapid increase in temperature indicates shorting in the winding, which reduces the winding resistance. Before ignition, at about ~292ºC, the unit was producing visible white smoke. Similar to Fan sub 73, when the unit ignited at ~340°C, it produced a large flash and flames for a brief moment. The large flames subsided slightly, until the flames ignited more of the wrap around the winding and/or the coating of the winding. The flames impinged on and ignited the plastic impeller. The burning impeller and bobbin resulted in dripping flaming plastic. Four layers of cheesecloth were placed under the fan to be used as an ignition indicator. The dripping flaming plastic ignited the cheesecloth, which indicates that the fan's plastic grill could also ignite in this type of situation. Figure 45 is a sequence of photographs during lock-rotor testing for sub 23.

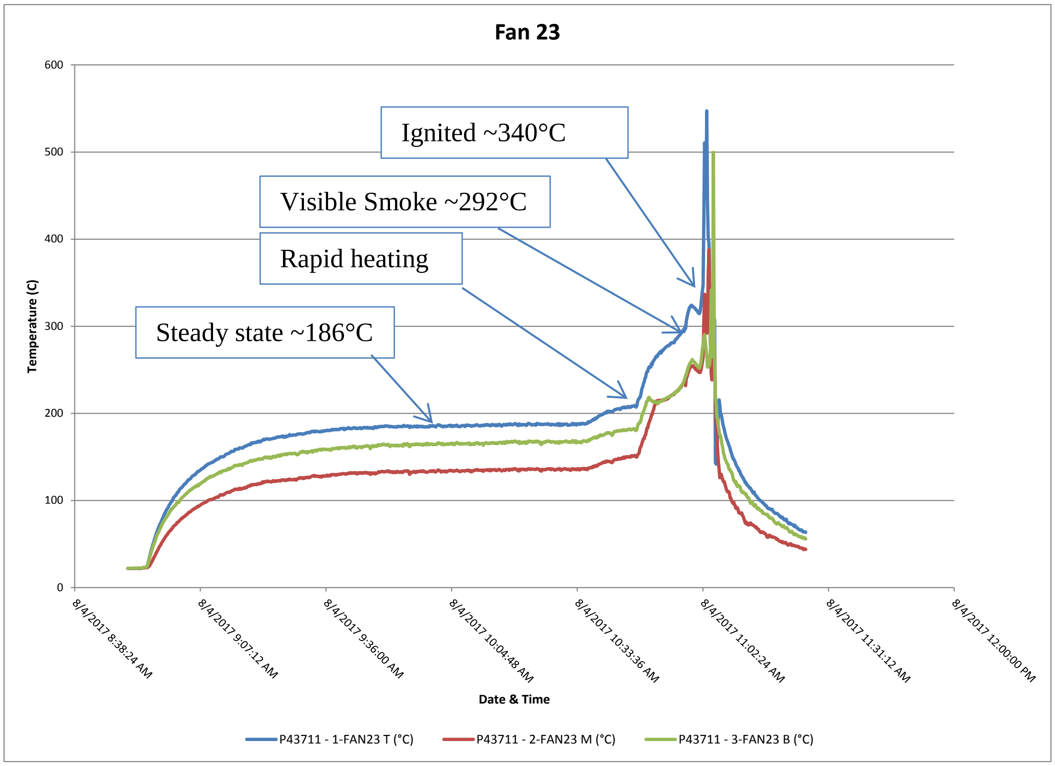


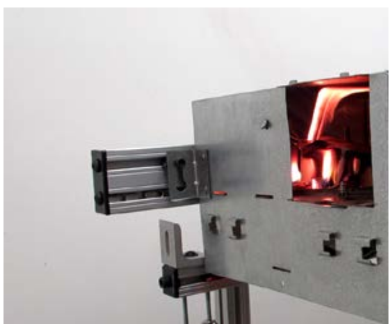
Figure 44. Winding temperatures during lock-rotor test for Fan sub 23

At around 292ºC, the fan begins producing white smoke

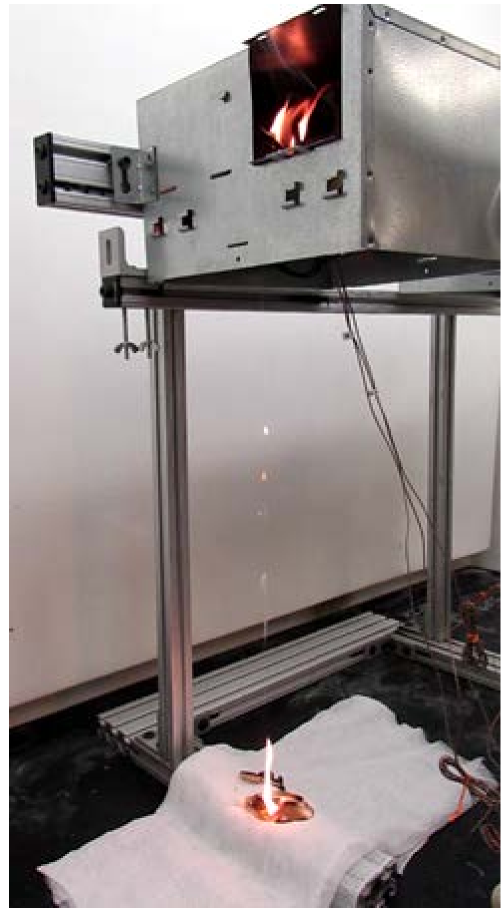
At approximately 340°C, there appears to be an ignition of gases around the motor

The large flames subside and the winding wrap and/or the winding coating appears to be burning

More of the winding wrap and the coating on the winding burns, thus creating a larger flame



The impeller has ignited and begins to sag onto the motor



Dripping flaming plastic ignites the cheesecloth ignition indicator

Figure 45. Fan sub 23 during lock-rotor test

Figure 46 shows a radiograph of the TCO after the test. Post-test radiographs of the TCO show the TCO is open, which was caused by the intense heat from the flames. This would suggest that any analysis of a TCO after a fire incident does not necessarily indicate the status of the TCO during the incident. The radiograph shows a thin portion of the thermal linkage intact. It would appear even at the high temperatures when the motor ignited, portions of the eutectic material in the thermal linkage could not melt.

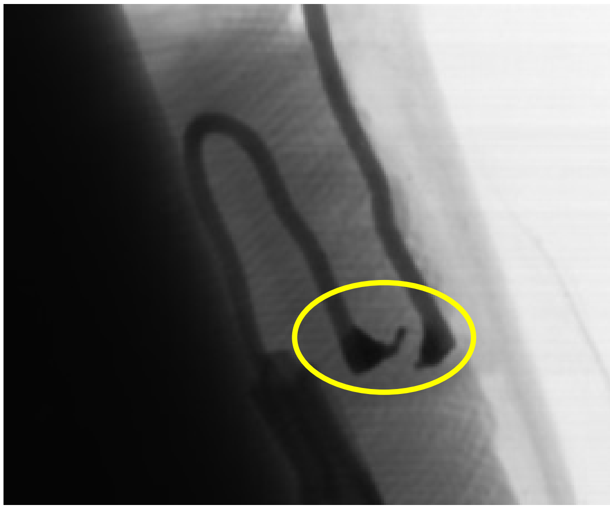


Figure 46. Radiograph of the TCO after the test (sub 23)

The CT scans of the thermal linkage for fan sub 23 were reviewed. The thermal linkage shows some abonormalities, as shown in Figure 47. The CT scans appear to show the linkage uneven and bulging in some areas.

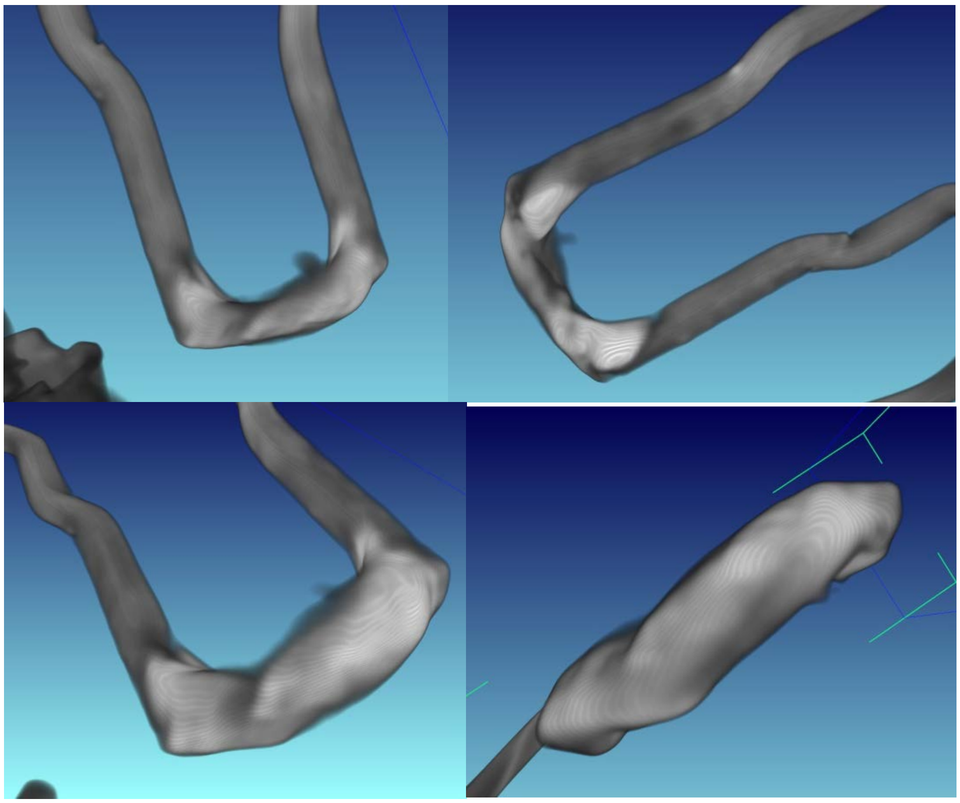


Figure 47. CT scans of the TCO before conditioning (sub 23)

<u>Sub 54 – Fails to Open After 22 Hours of Lock-Rotor Testing</u>

As previously indicated, fan sub 54 was tested in lock-rotor condition for 22 hours. After the initial 3 hours, the temperature increased and then leveled off. The fan maintained a steady temperature that was well above the TCO activation temperature for the majority of the testing, as shown in Figure 48. The TCO did not activate, and staff manually terminated the test after 22 hours. Figure 49 shows radiographs of the TCO after the test. The linkage appears to have thinned out, but is still intact. The figure shows a bead had formed outside the TCO casing.

Figure 50 shows radiographs of the TCO before and after the test. From these angles, the thermal linkage appears not to have changed shape significantly, but depending on the viewing angle, the thermal linkage is thicker or thinner.

Figure 51 shows CT scans of the TCO after the test. CT scans of the TCO confirm the solder link within the TCO is intact. The radiographs and CT scans show a solder bead has formed outside the TCO casing. This would suggest that the TCO is no longer hermetically sealed when thermally aged or placed under thermal stress. The reason that the windings were operating at such an elevated temperature for so long without eventually breaking down is not known, but it can be surmised that the winding coating would eventually deteriorate and cause shorts within the winding because the eurectic temperature has changed from T_f.

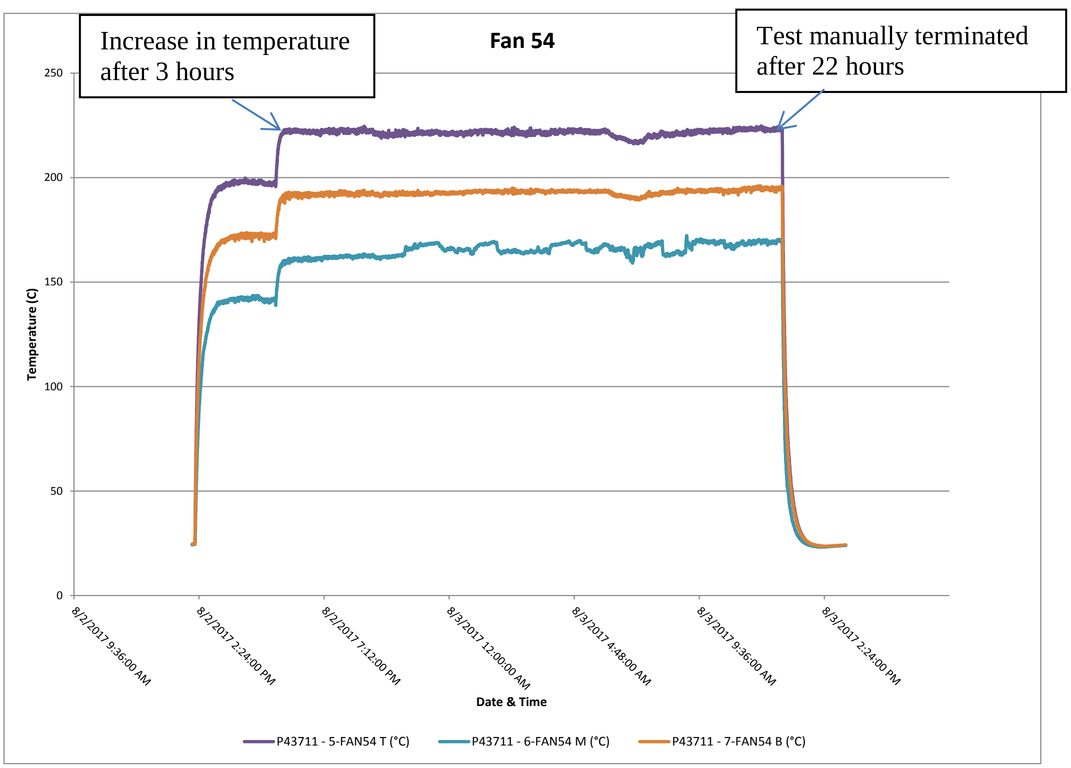


Figure 48. Winding temperatures during lock-rotor test for Fan sub 54

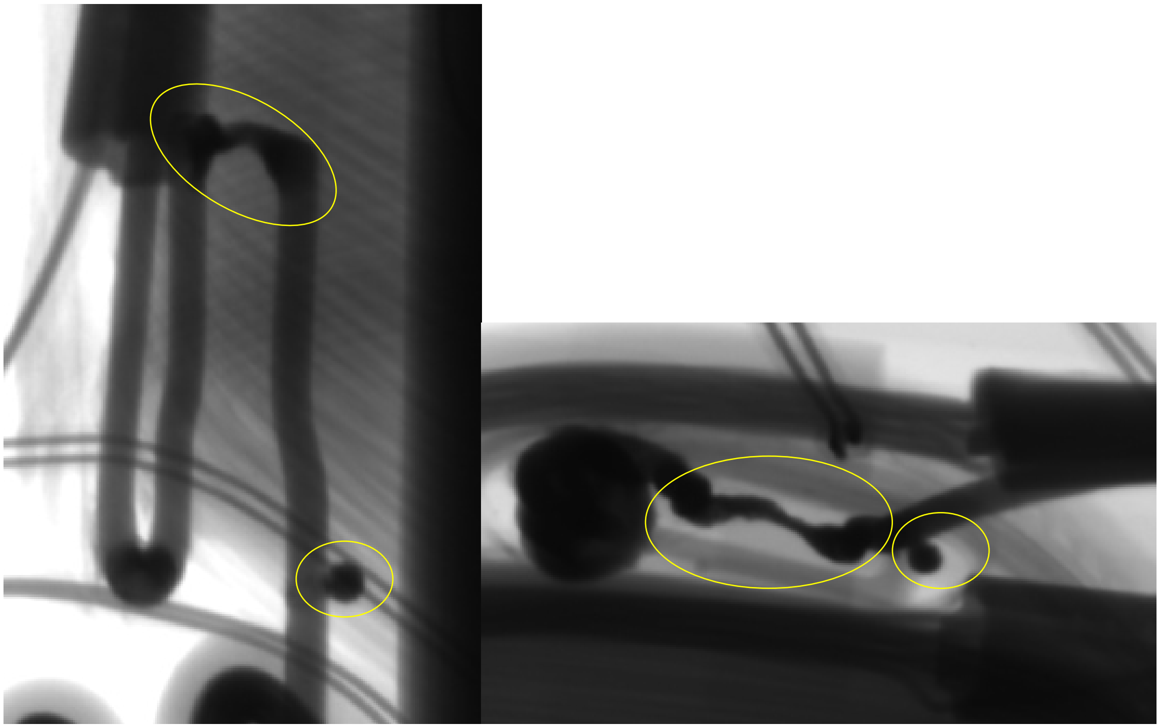
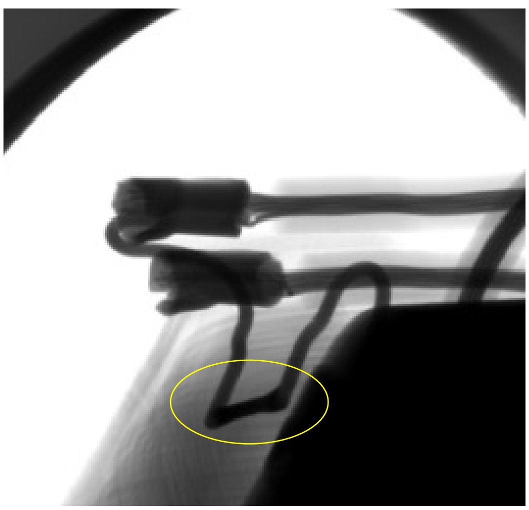


Figure 49. Radiograph of the TCO after the test (sub 54)



Before lock-rotor test

After lock-rotor test

Figure 50. Radiograph of the TCO before and after the test (sub 54)

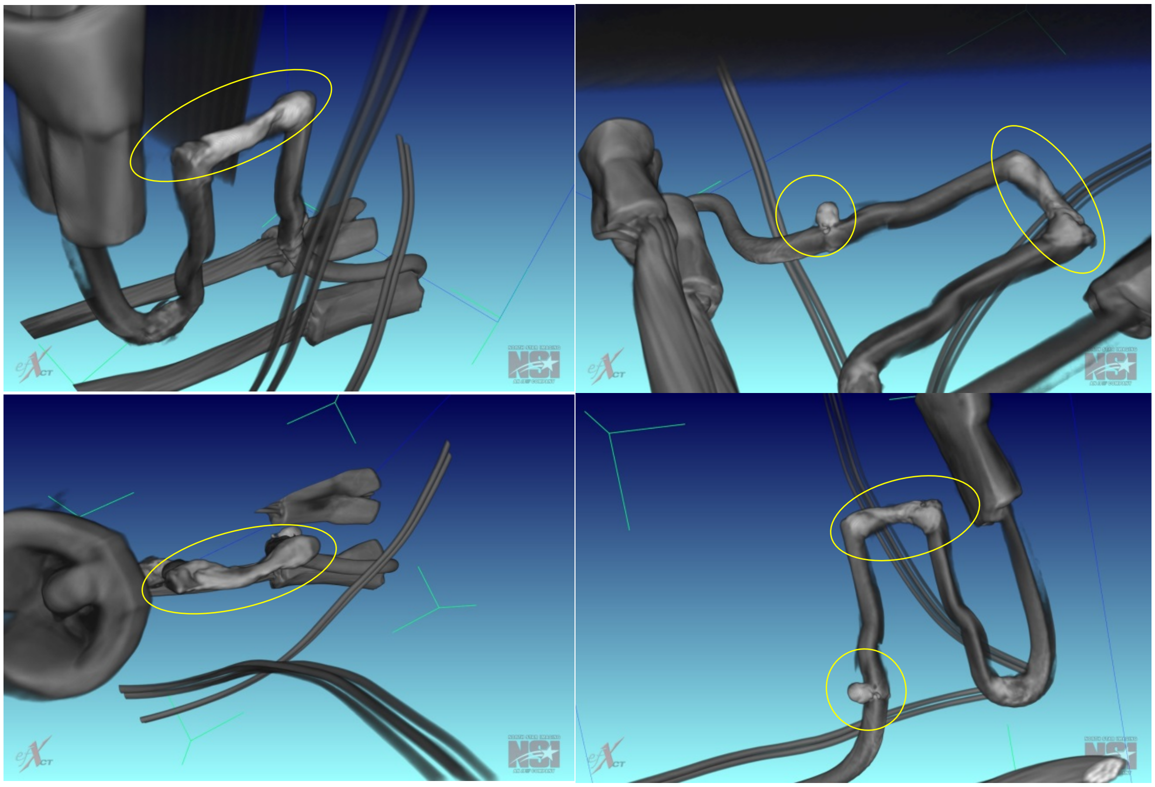
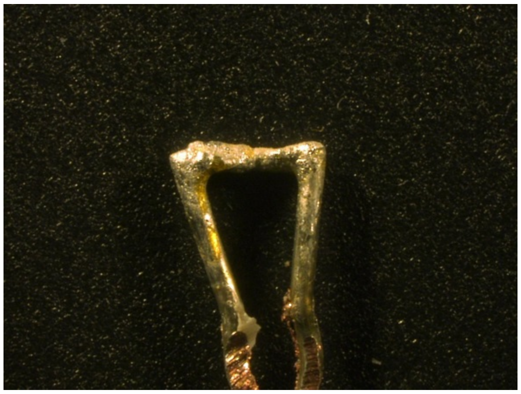
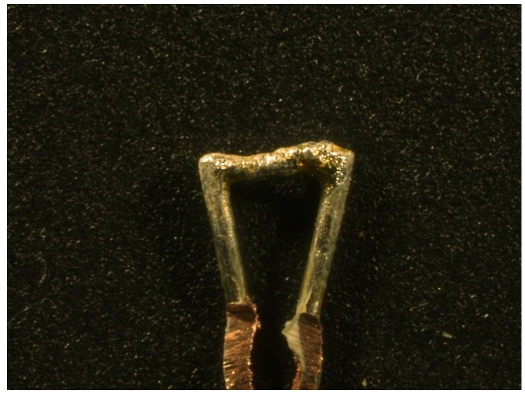


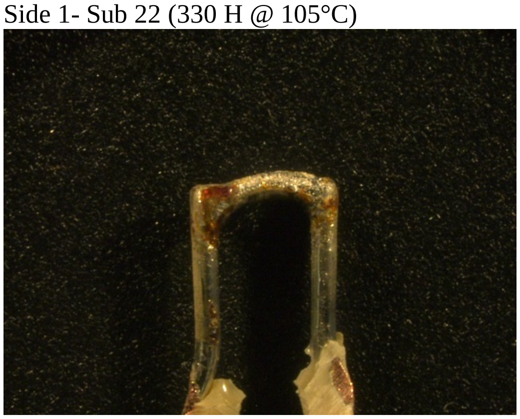
Figure 51. CT scans of the TCO after the test (sub 54)

6.0 Analysis of the Special Compound (Flux) and Solder Link

Subs 22 and 59 (conditioned for 330 hours at 105°C) from Test Group 5 were reserved for analysis of the solder link within the TCO. The TCO casing was opened and the internal components were removed. For comparison, two TCOs, sub 74 and 85 (no conditioning), from Test Group 7 were also reserved for TCO analysis where the TCO casing was opened and the internal components removed. Figure 52 shows the solder links from Fan subs 22 and 59, which have been conditioned 330 hours at 105°C. Figure 53 shows the solder links from Fan subs 74 and 85, which have not been conditioned. Sub 85 shows some deformation in the solder link, where part of the solder link has flattened and formed to the interior of the TCO casing, but this was already present before any conditioning of the TCO. The mechanical structure of the solder linkage appeared unchanged as a result of the conditioning, when the before and after radiographs were compared.


Side 1- Sub 22 (330 H @ 105°C)


Side 2 – Sub 22 (330 H @ 105°C)


Side 1 – Sub 59 (330 H @ 105°C)

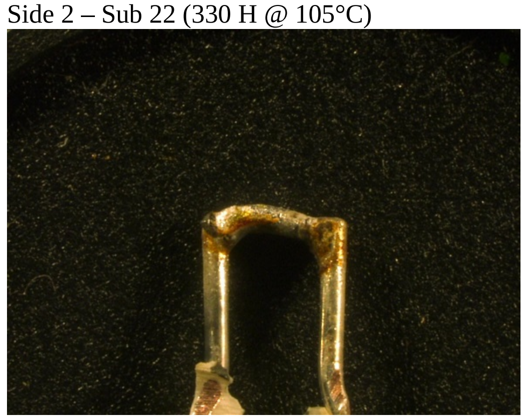
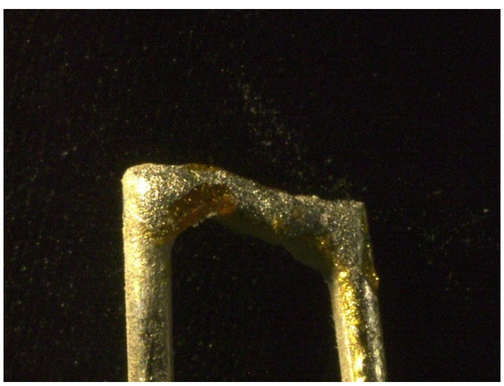
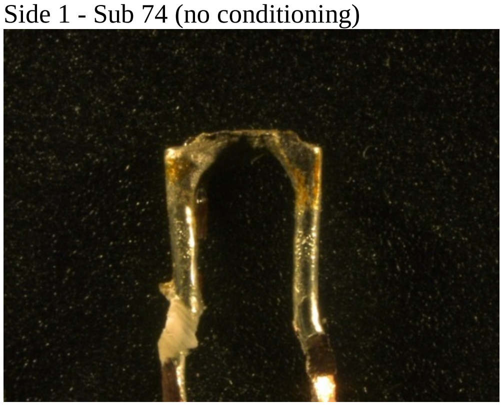

Side 2 – Sub 59 (330 H @ 105°C)

Figure 52. TCO solder link from Fan subs 22 and 59 (conditioned 330 hours @ 105°C)


Side 1 - Sub 74 (no conditioning)

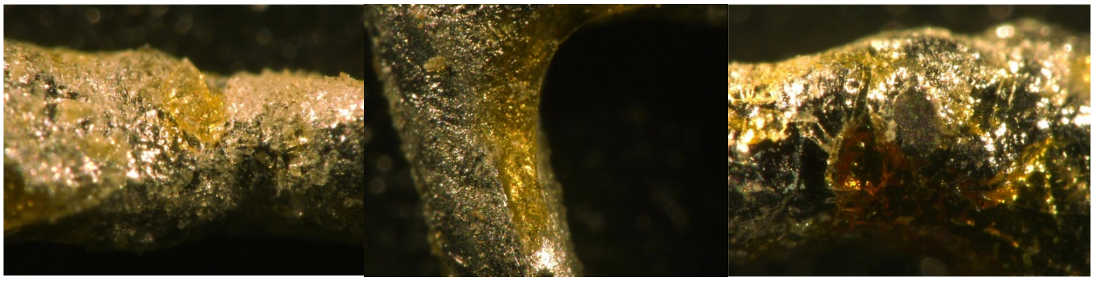

Side 2 - Sub 74 (no conditioning)


Side 1 - Sub 85 (no conditioning)


Side 2 - Sub 85 (no conditioning)

Figure 53. TCO solder link from Fan subs 74 and 85 (no conditioning)

Staff observed under a microscope that a yellowish substance was on the solder link, as shown in Figures 54 and 55. This was thought to be the special coating or flux material. Staff also observed that the conditioned TCOs appeared to have less of the yellowish substance than the TCOs that were unconditioned, but staff did not measure an actual mass content or volume of the substance for each sample.

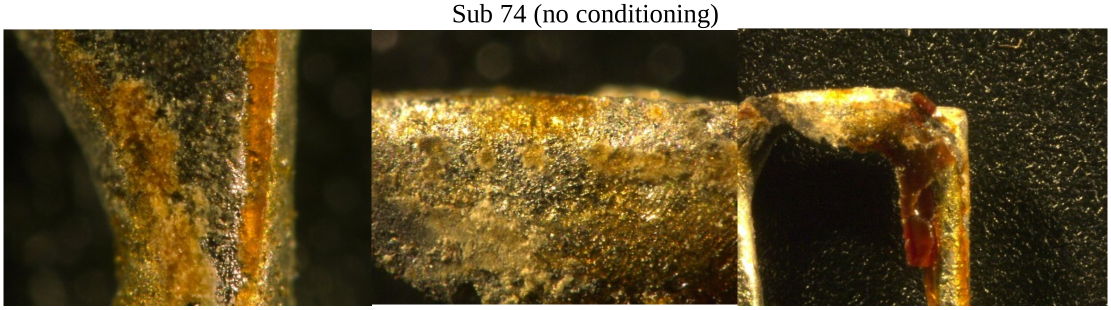


Sub 22 (330 H @ 105°C)

Sub 59 (330 H @ 105°C)

Figure 54. Close-up images of the TCO solder link (conditioned 330 hours @ 105°C)

Sub 74 (no conditioning)



Sub 85 (no conditioning)

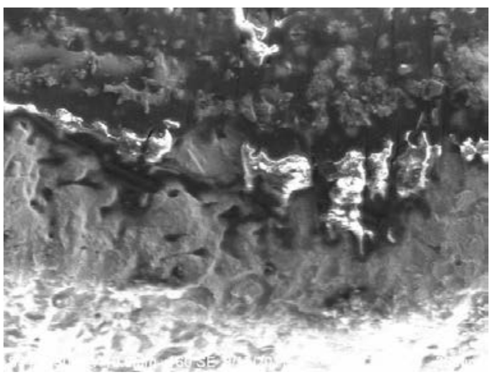
Figure 55. Close-up images of the TCO solder link (no conditioning)

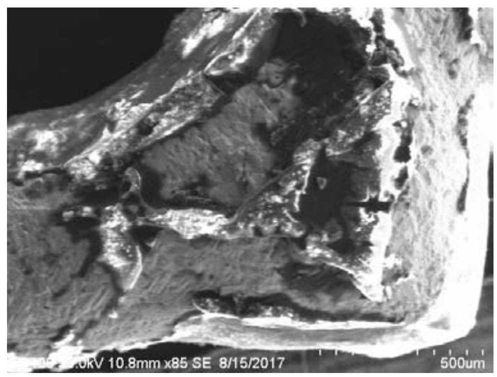
The TCOs were further explored using a scanning electronic microscope (SEM) and x-ray diffraction (XRD). SEM is used for topographical, compositional and morphological characterization. XRD is used to study nature of phases/microstructure and their crystal structure. Figure 56 shows SEM scans of the solder link and terminals. SEM and XRD analysis for sub 59, which was conditioned at 105ºC, show that the wire leads are copper and the thermal linkage is comprised of mainly tin, indium, and lead.

Area of interest 1 is the solder link. This is mainly comprised of carbon (C), oxygen (O), indium (In), tin (Sn), and lead (Pb). There is a trace amount of Silicon (Si). The indium, tin, and lead are most likely the elements that make up the solder link. Carbon and oxygen are most likely the elements that make up the special compound coating.

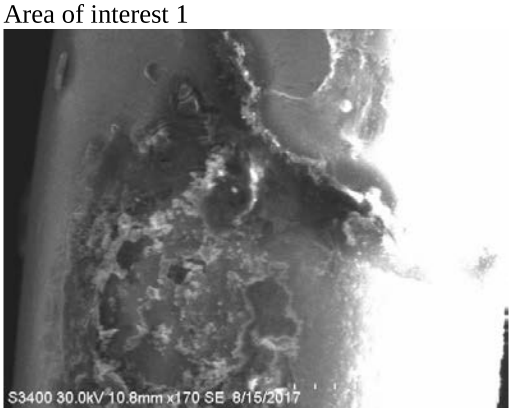
Area of interest 2 is the solder link connection to the copper terminal. This is mainly comprised of C, O, In, Sn and Pb. There is a trace amount of silicon (Si) and copper (Cu). Copper shows up because it is the bulk material of the terminal.

Areas of interest 3 and 4 are the copper terminals. This is mainly comprised of Cu and Sn. There are lower amounts of C and O.

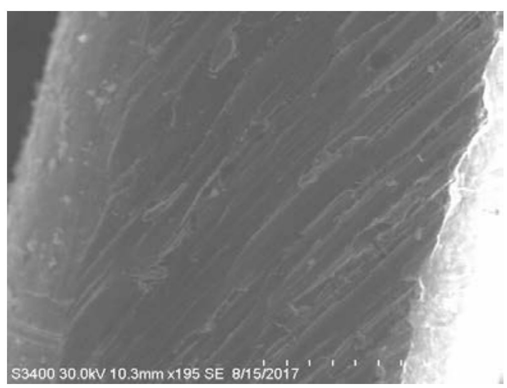

Area of interest 1



Area of interest 2



Area of interest 3

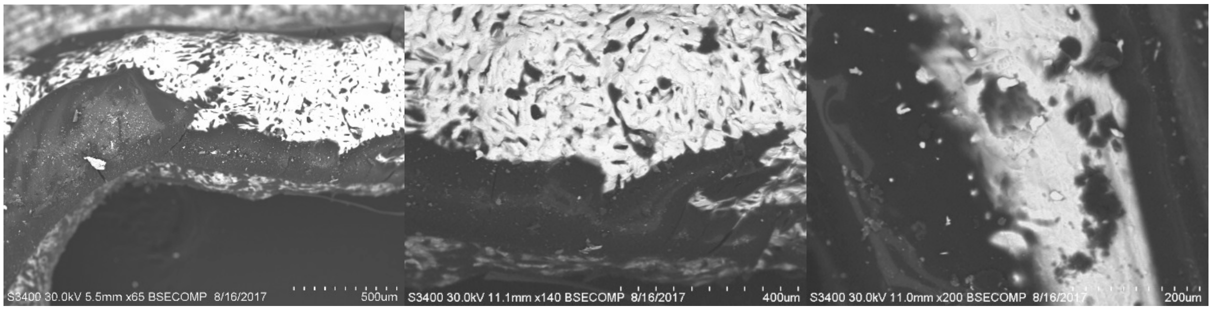


Area of interest 4

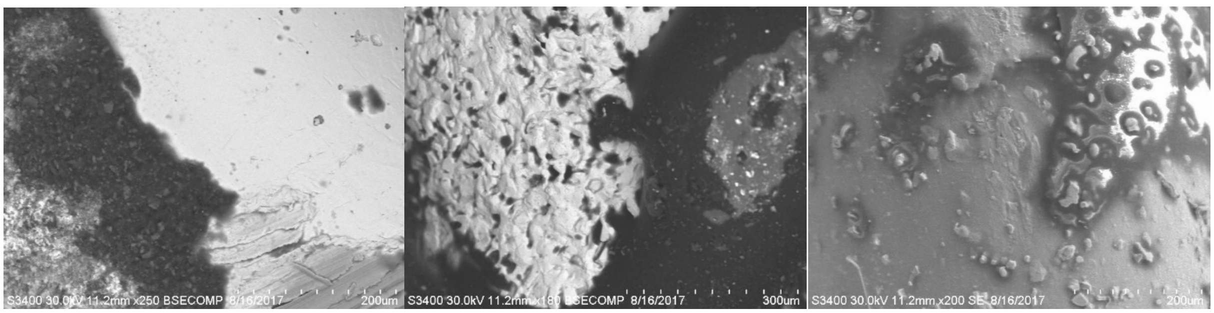
Figure 56. SEM scans for Sub 59

SEM analysis for sub 74, which was not conditioned, is shown in Figure 57.
Area of interest 1 is the solder link. This is mainly comprised of C, In, Sn, and Pb. The Indium, Tin, and Lead are most likely the elements that make up the solder linkage. Carbon and Oxygen are most likely the elements that make up the special coating.
Area of interest 2 is a close-up of an area from area interest 1. This is mainly comprised of C, O, In, Sn, and Pb. There is a trace amount of Si.

Areas of interest 3, 4, 5, and 6 are areas that had coating on the terminals or solder link.



Area of interest 1 | Area of interest 2 | Area of interest 3



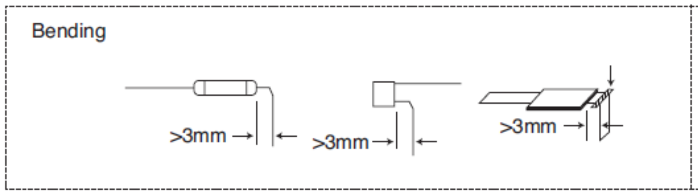
Area of interest 4 | Area of interest 5 | Area of interest 6

Figure 57. SEM scans for Sub 74

7.0 Bending and Forming TCO Leads (Design Applications - Forming and Cutting)

Staff conducted research to determine whether there is standard practice for bending the lead wires on TCOs. Below is a list of precautious in bending the wire leads. The general practice appears that the bend should occur 3 to 4 mm from the seal. It is also recommended that the wire lead is held during the bending to prevent stress on the seal, which may cause the seal to leak. Lock-rotor testing has shown that solder from the thermal linkage can seep out of the seal, forming a solder bead on the wire lead outside the casing. This would suggest that a crack has formed between the seal on the wire lead.

- Lead wires (terminals) are to be bent or cut at least 3mm away from the TCO seals to avoid damaging the TCO (axial/radial type) or body (thin type). The TCO seals (axial/radial type) shall not be grasped with any tools or holders. Terminals of thin type TCO are to be grasped before they are bent. (See Fig. 1) (Reference - XICON PASSIVE COMPONENTS, Thermal Cutoffs (TCO)/Thermal-Links 447-XYP 1BF145-RC).



- Lead wires (terminals) are to be bent or cut at least 3 mm away from the TCO seals to avoid damaging the TCO (axial/radial type) or body (thin type). The TCO seals (axial/radial type) shall not be grasped with any tools or holders. Terminals of thin type TCO are to be grasped before they are bent. (See Fig.1) (Reference - PANASONIC, Thermal Cutoffs (TCO))

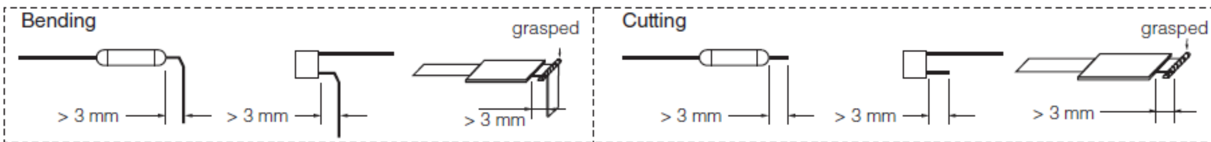
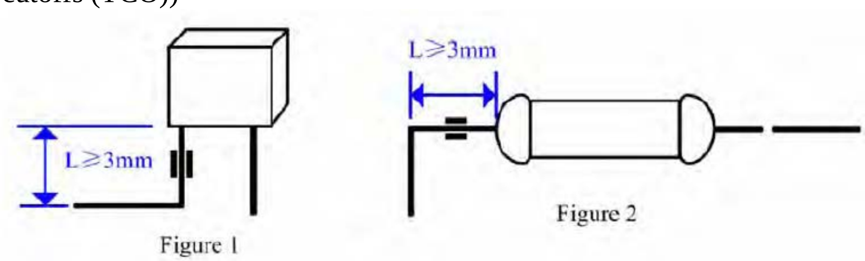


Fig-1

- When bending a lead wire for installation, fix the part of the lead between the body and the lead section to be bent using a tool, and gently bend the lead section that is at least 3 mm from the body. Never hold the body with a tool. (Reference - Bending Lead Wires – Cautions (http://www.cci-tco.com/bending-lead-wires-cautions/)
- When bending a lead, bend at a location 3mm minimum from the body of the thermal cutoff. See below. (Reference - Thermtrol, Mechanical Thermal Cutoffs (0.5 to 7 amp))
- Bend the lead wire at least 4 mm away from the molding. Otherwise, the damage of the molding worsens the airtightness and impedes the normal operation of the thermal fuse. Use a nipper or other tool to prevent damage. (Reference - SUNGWOO INDUSTRIAL, No.1 Thermal Cutoff Fuse Manufacturer in Korea | Sung Woo Industrial Co. – Precautions)
- When bending the lead wire, to avoid applying excessive pressure to the root of the lead wire, secure the lead wire close to the case, and bend the part beyond the secured section. The lead wire should be bent at a distance of 3 mm or more from the body of the fuse, and should not be twisted. (Reference - NEC/SCHOTT, Thermal Fuse)
- If the lead has to be used by bending it, bend it at approx. 3mm in minimum away from the molded section. Use radio pinchers to bend the wire, as shown in Fig.1 and not to damage the molded section of the case and the lead wire. (Reference - Xiamen SET Electronics Co.,Ltd, Thermal cutoffs (TCO))



- Bend the lead wire at least 4 mm away from the seal. The damage of the sealant worsens the air tightness. Note that bending is conducted with care, since the worst air tightness impedes the normal operation of TCO. Holders or tools used during lead forming must not grasp the body, but lead wire. Doing so can protect from damage to the body of TCO. (Reference - US ELECTRONICS, INC, Thermal Cutoff Fuses)

UL 60691, *Thermal-Links – Requirements and Application Guide,* contains construction requirements under Section 9 – Mechanical Requirements. The section specifies that "Leads and terminal parts shall be secured so that stress on them during installation and normal use does not impair operation of the THERMAL-LINK. THERMAL-LINKS using seals with formed leads for use in appliances or components shall not be bent less than 3 mm from the THERMAL-LINK seal." The section states that the leads are to be bent at least 3 mm from the seal, unless the following two exceptions are met:

Exception: Leads may be bent less than 3 mm from the seal, if

a) the THERMAL-LINK manufacturer's bending fixture and procedure does not transmit stress to the THERMAL-LINK operating mechanism, and

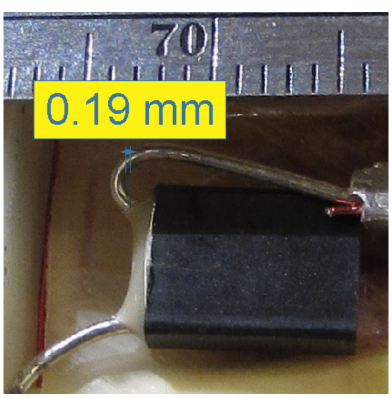
b) formed test samples shall be subjected to the bending/twist lead secureness test of 9.4 and the RATED FUNCTIONING TEMPERATURE test of 11.2.

To determine the installation construction of the wire leads on the TCOs for the motor fan samples in this testing, 15 units were randomly selected from Test groups 1 and 2. These units all functioned when previously tested in the lock-rotor testing, and the testing should not have altered the TCO position and the wire lead positions and configuration. Table 10 lists the fan samples selected and the measured distances between the seal and the bend in the wire leads. Two of the 15 samples measured had wire lead lengths greater than 3 mm between the seal and the inside bend. The average length between the seal and inside bend in the wire lead was 1.28 mm. This suggests that the TCOs' seal can be damaged during the bending of the wire leads, which can allow oxygen to enter into the TCO case. From the literature, damaged seals may alter TCOs' functioning temperature.

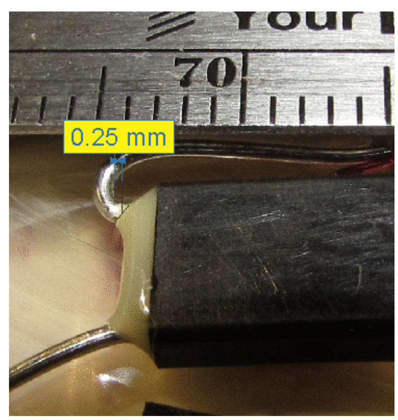
Table 10. Distance between the seal and the wire lead bend

	Sub #	Distance (mm)
Test 1	60	4.14
	98	0.19
	52	1.10
	27	4.52
	36	0.56
	89	0.52
	35	0.55
Test 2	Sub #	Distance (mm)
	53	0.83
	4	1.00
	88	1.43
	16	1.13
	26	0.25
	20	1.86
	79	0.38
	100	0.80
	Average (mm)	1.28

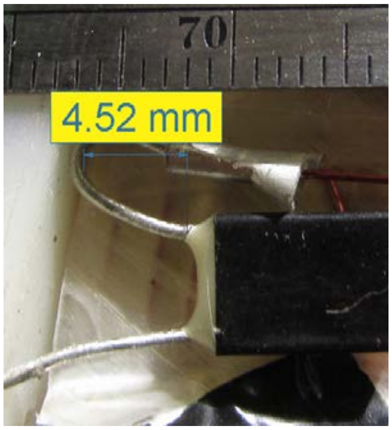
Figure 58 shows the TCO wire lead bends can vary between fan motors. Even though sub 27 shows the wire lead bend greater than 3 mm, it appears that the base of the wire lead near the seal was not secured when the wire lead was bent, which is evident by the outward angle of the wire lead.



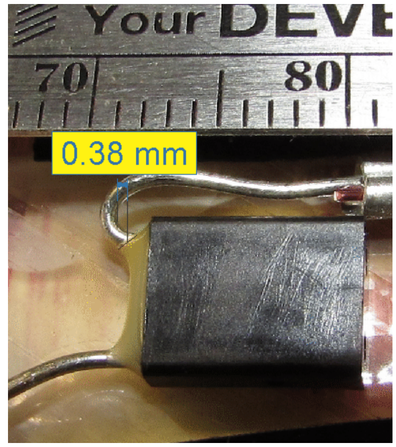
Wire lead with 0.19 mm length between the seal and bend (Sub 98)



Wire lead with 0.25 mm length between the seal and bend (Sub 26)



Wire lead with 4.52 mm length between the seal and bend (Sub 27)



Wire lead with 0.38 mm length between the seal and bend (Sub 79)

Figure 58. Wire bend lengths vary between TCOs in the Fan samples

8.0 Discussion

The CPSC lab testing of field samples supports that during the life of the fan motor, the eutectic thermal fuses may fail due to thermal aging, thus presenting a fire hazard. The observations indicate that exposure of the TCO to heat and oxygen over time may delay the opening, and in some cases, result in failure to open. Because the conditioning at 105ºC over a period time did not change the thermal linkage shape, it is theorized that either the properties of the thermal linkage or the special compound that coats the thermal linkage can change with heat and time. The amount of special compound that coats the thermal linkage may also influence the effects of thermal aging, but this was not investigated.

Improper bending of the wire lead may result in cracking of the epoxy seal, thus allowing solder to flow out and oxygen to enter the TCO and alter the functioning temperature of the TCO. Oxygen along with heat and time may also be a combination that could be accelerating the changes in the properties for the thermal linkage and the special compound.

The testing of these motors showed that the winding temperatures can reach sufficiently high temperatures to ignite the motor during a lock-rotor condition, if the TCO fails to activate. During a lock-rotor condition for these tests, the TCO temperature may reach temperatures at or above 140°C before the TCO activates; thus, short periods of "on" time may thermally age the TCO and alter the functioning temperature of the TCO. Testing showed the TCO can experience temperatures up to 140°C in less than 20 minutes. Staff surmised that a fan entering into a lock-rotor condition may experience multiple events of thermal heating if the fan is not energized for sufficient time to cause the TCO to activate. These multiple heating events may have compounding effects on the TCO properties, thus causing the TCO to delay or fail to activate.

Figure 59 shows Fan sub 60 temperatures for normal and lock-rotor operation. In normal operations, the TCO temperature stabilizes at around 68ºC. For lock-rotor condition, the TCO activates at a TCO temperature around 142ºC after 20 minutes. This would suggest that an exhaust fan that is in lock-rotor condition, but is operated for less than 20 minutes, can have the TCO heated to temperatures up to 142°C. If the exhaust fan is operated for more than 3 minutes, the TCO is experiencing temperatures above normal operation.

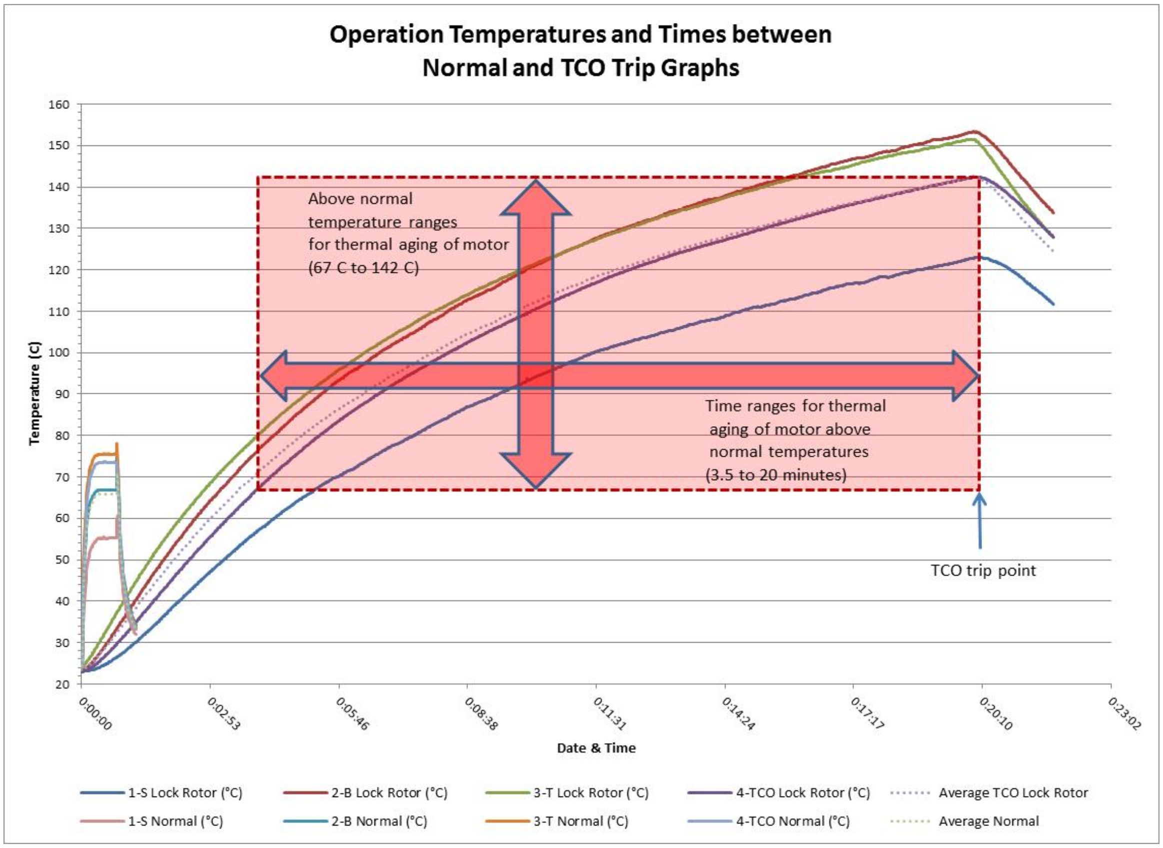


Figure 59. Potential thermal aging of the motor between normal and TCO trip conditions

Aging in UL Standards

UL 60691, Thermal-Links – Requirements and Application Guide, Section 11, Temperature test addresses aging for thermal links. Similar to the Thermal-Element Stability Test that was in UL 1020, UL 60691 incorporates the same aging test. The Aging Tests assess whether aging at high temperatures has a deleterious effect on the thermal links. The TCO is subjected to a series of test steps where the conditioning temperature and period change. If a TCO trips, the remaining TCOs are tested at the next step. The test is considered successful if all TCOs have functioned after the first two steps. In summary, the six steps are as follows;

- Step 1 If requested by the manufacturer, the specimens are subjected to a temperature chosen between Tf–15 K and Th for a period of 3 weeks. At the conclusion of the test, at least 50 percent of the specimens shall not have functioned.

- Step 2 Tf – 15 K for 3 weeks. At the conclusion of the test, at least 50 percent of the specimens shall not have functioned, unless the specimens have already been submitted to Step 1, in which case all specimens may have functioned.
- Step 3 Tf – 10 K for 2 weeks.
- Step 4 Tf – 5 K for 1 week.
- Step 5 Tf – 3 K for 1 week.
- Step 6 Tf + 3 K for 24 hours.

UL 60691specifies in Annex C, Conductive Heat Ageing Test. The test is conducted on thermal links with a T_f rating of 175°C or above and is optional for thermal links with a T_f rating less than 175°C. The section includes an exception, where the test does not need to be performed if the thermal link is eutectic type and is constructed without contacts. This test was most likley derived in the early 1990s when there were a high number of fire incidents with coffeemakers. To address TCOs failures that were being caused by thermal conductive heat aging, UL develeoped the Conductive Heat Ageing Test. The TCOs typically used in coffeemakers are higher-rated, pellet-type TCOs.

UL 507, *Standard for Electric Motors,* and UL 1004-3, *Standard for Safety Thermally Protected Motors*, do not account for thermal aging of the motor as a system before the motor is operated in lock-rotor conditions. As seen in the testing, the installation of the TCO and thermal aging may cause the TCO not to function at T_f. Thus, incorporating a performance aging test is a realistic evaluation of the system to verify whether aging at high temperatures, but at less than the functioning temperature, has a deleterious effect on the motor and its safety components. A fan that has entered into a lock-rotor condition may experience multiple events of thermal heating if the fan is not energized for sufficient time to cause the TCO to activate. These multiple-heating events may have compounding effects on the TCO properties, thus causing the TCO to delay or fail to activate.

9.0 Conclusion

Although the tested motors were compliant with the voluntary standard, consistent with their UL listing, thermal aging of the motors can cause the TCOs to fail to activate. A contributing factor to the failures may have been the improper bending of the TCO wire leads and cracking of the epoxy seal around the wire leads. During thermal aging, the melting properties of the solder linkage and the special compound in the TCO may be altered, which may cause a delay in the TCO activating and in some cases, failure to activate. If the TCOs in the motors fail to open during a lock-rotor condition, the motor may overheat and ignite.

The results of this testing support changes to UL 60691 to include conductive heat aging of all eutectic-type TCOs, incorporating a thermal aging performance test within UL 507. If similar motor applications have a sufficient operating window between normal and lock-rotor that could allow thermal aging of the motor such changes may also be appropriate to UL 1004-3.