Journal of the National Academy of Forensic Engineers®

NATIONAL ACADEMY OF FORENSIC ENGINEERS

http://www.nafe.org
ISSN: 2379-3252

Vol. 38 No. 1 June 2021

Pinched Power Cord is Latent Defect Causing Fire When Appliance Is Not in Use

By Michael D. Leshner, PE (NAFE 559F)

Abstract

After a fatal residential fire, witness statements and burn patterns pointed investigators toward an electrically powered upholstered reclining chair as the origin. A search for exemplar recliners identified slightly different designs of the power supply, which converts house current to low-voltage direct current for driving the motor. Although the fire left no direct evidence of its cause, analysis of unburned exemplars uncovered a design defect in the power supply electrical enclosure design, causing damage to the power cord during assembly. The transformer was found to press against the two-conductor power cord, in a location inside the unit that was concealed after assembly. The newer units did not have this design defect. Investigators developed the hypothesis that over time, the sustained force of the transformer against the cord enabled the insulation to deform such that a short circuit occurred in the power cord and caused the fire — even when the recliner was not in use and if the house wiring circuit had been protected by a circuit breaker. This paper details the investigation, testing, and findings, including dissenting expert opinions. More importantly, it shows how forensic engineers conduct detective work and apply scientific principles to achieve useful results.

Keywords

Fire, electrical, ignition, causation, products, defect, NFPA 921

The Fire

A fire occurred in a residence during the night while three occupants were asleep. One of the residents was awakened by the sound of the fire, and witnessed an upholstered recliner in flames as he ran past it toward an exit. The witness saw flames enveloping the chair and on curtains behind — but nowhere else. The fact that the general origin of the fire was witnessed permitted the exclusion of other electrical appliances in the room of origin. The witness survived with severe burns, and the other two occupants perished in the fire. The chair's electrical power system included an AC power cord, DC power supply, and DC motorized actuator to adjust its position.

Scene Inspection and Evidence Collection

The fire occurred on one of the coldest nights of the winter, and firefighters took a long time to suppress the fire with water. In the morning, the burned building and evidence inside were covered with ice. When fire cause and origin investigators attempted to document the scene and collect evidence, the ice was a significant obstacle — and evidence collection and identification were less than optimal.

Investigators on the scene concluded that the fire originated in a downstairs room where the powered recliner was located. The evidence collected included the remains of the recliner, a nearby power strip, and every electrical item in the room where the fire was observed. The nearby light switches, outlets, and associated wiring and junction boxes were collected. Each bit of evidence was examined carefully using x-ray and destructive examination by experts from all interested parties. The steel articulating frame of the burned recliner remained, with burned remains of the actuator and power supply below. The power actuator for the recliner was damaged, and the nearby power supply and its electrical enclosure were heavily damaged by fire. The power supply cord was found plugged into a receptacle on an adjacent wall.

Considering all the electrical devices in the burned evidence, only one device — the recliner's power supply — remained powered with its circuitry "hot" whenever the power cord was plugged in. All the other electrical devices recovered were examined by all parties, none of which were suggested as points of origin. The power strip located near the chair was generally intact, and damage to

Michael D. Leshner, PE, 47 N. Lockwood Road, Elkton, MD 21921, (410) 964-0311, mike@leshner.com
DOI: 10.51501/jotnafe.v38i1.132

the strip and wiring was consistent with external heating. The power strip was ruled out as well, based on absence of any electrical activity.

Scope of the Assignment

Based on the witness's observations and the plaintiff's Fire Cause and Origin Investigator's report, this author was engaged to look more closely at the recliner and consider whether the evidence might help to determine the cause of the fire.

Investigation

The first assignment for this author involved identification of the recliner's manufacturer. Based on information from the dealer where it was purchased, there were three manufacturers who supplied such products to the store. A new exemplar from each of the three manufacturers was obtained and examined. The steel frame from the fire-damaged evidence was nearly a perfect match with one of the exemplars — with the exception of two weld details.

Since the manufacturer refused to acknowledge the product was theirs, additional exemplars were obtained with manufacturing dates before and after the fire evidence, in order to find an exact match with the welding details on the frame. Two such exemplars were obtained, and their power supply enclosures were different from the new exemplar. Examination of new and old exemplars revealed two critically important results:

- The chair's manufacturer was positively identified (although never admitted), and;
- The design of the power cord and power supply enclosure were revised after the subject product was manufactured.

Exemplar power supplies representing both new and old designs were compared. The significant differences:

	Old Power Supply	Revised Power Supply
Length of AC Power Cord	9 feet	2 feet
Length of DC Cord to Actuator	2 feet	9 feet
Power Supply Location	Under recliner	Outside Recliner

Electrical Inspection

Together with a forensic electrical engineer, the old and new versions of the power supply were examined. It was determined that the product in the burned evidence was of the older design, based on the length of the power cord. The timing of the original purchase was also consistent with the older design.

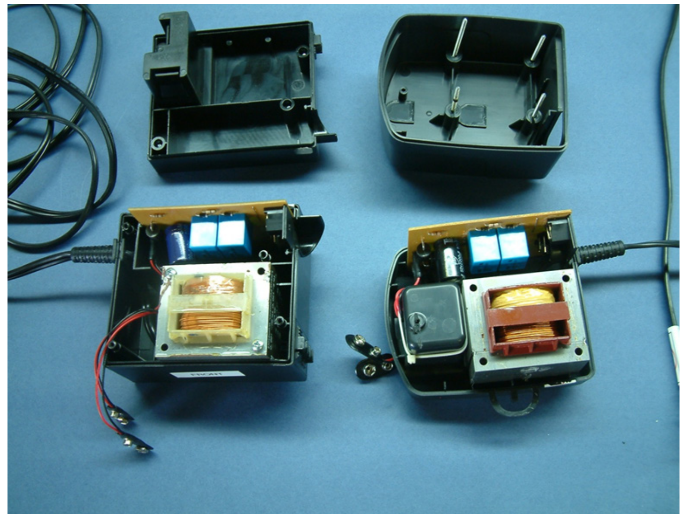

Figure 1
Power supply designs — old (left) and new (right).

Both designs were functionally equivalent, having the same transformer, circuit board, and connections. Revisions in the plastic enclosure provided more space for the wiring and a more direct path for the power cord. The short AC power cord and long DC cord reflected the altered location of the power supply. In the former design, the power supply was permanently mounted under the recliner. In the new design, the short AC power cord made it unlikely that the power supply could find its way under the recliner.

Corrective Actions?

The power supply design changes raised a suspicion that the revisions were corrective actions in response to a recognized problem. Although the discovery record did not indicate any similar incidents, the nature of the design revisions suggested corrective action. Was there something about the older design power supply enclosure and wiring that was problematic? To investigate further, exemplars of both old and new power supply designs were disassembled. In the older design, once the cover was removed, screws securing the transformer prevented inspection of the wiring without removing those screws. **Figure 1** shows the new and older design enclosures with the plastic covers removed. Connections between the power cord and transformer are hidden under the transformer.

In the revised design, the same internal components are used. No screws secure the transformer, and the power

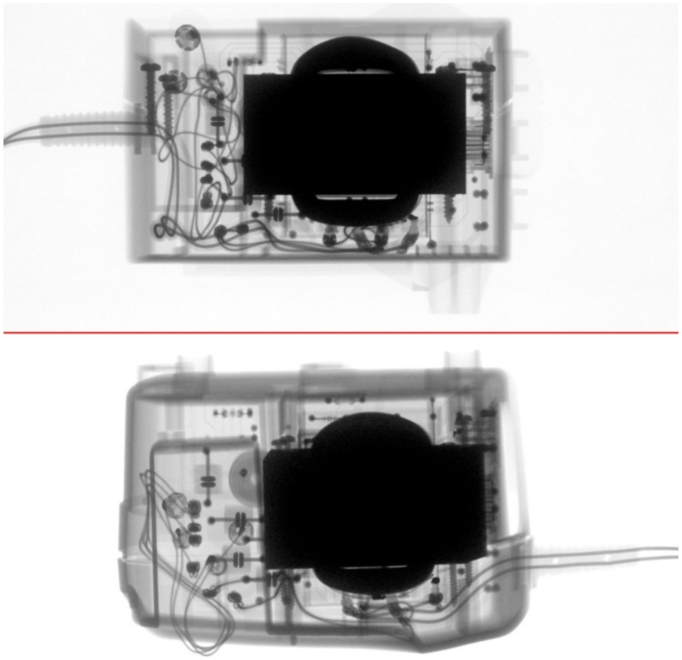

Figure 2
X-ray images of the old design (top) and new (bottom).

cord enters at a different location. All wiring is inspectable as the housing is assembled. **Figure 2** shows x-ray images of the power cord paths and the space between the transformer terminals and the side of the enclosure.

In the older design, the power cord took a tortuous path to the transformer and became compressed against the inside of the enclosure. In the revised design (lower image), the power cord took a direct path to the transformer and has adequate clearance to the inside of the enclosure.

Figure 3 shows the wiring connections under the transformer. While attempting to carefully re-assemble the power supply, the transformer did not fully "nest" into position before the screws were tightened against the transformer. It felt like the wiring was in the way. To prevent damaging the wiring under the transformer by tightening the screws, the transformer was carefully removed again for a closer look at the wiring. **Figure 4** shows significant damage to the power cord insulation from being compressed against the transformer frame and terminals.

Measurement of the enclosure's internal spaces revealed that there was insufficient space to accommodate the wiring connections without compressing and damaging the power cord insulation as the transformer screws are tightened during assembly. **Figure 5** shows the back of the power cord where it was flattened by compression against

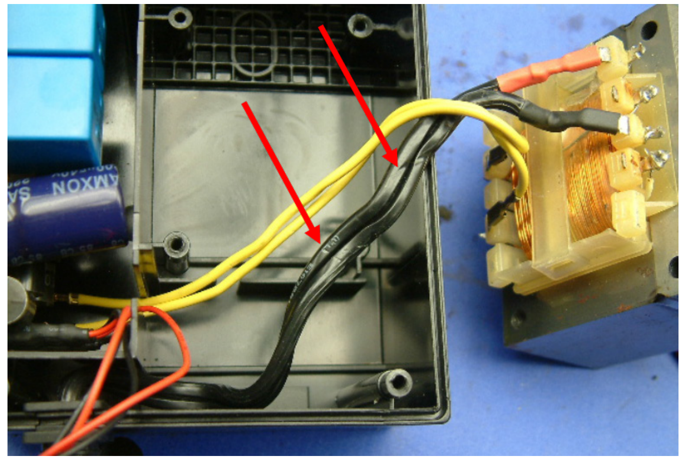

Figure 3
Wiring connections in the older design show evidence of external force (red arrows).

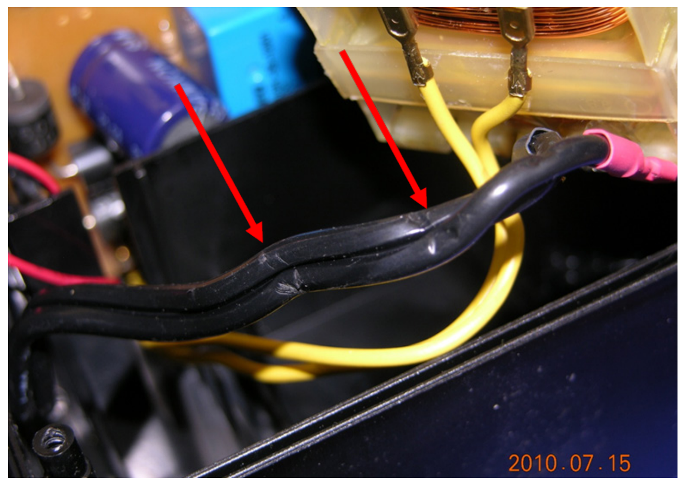

Figure 4
Damaged power cord within enclosure shows evidence of pinching against the transformer terminals (red arrows).

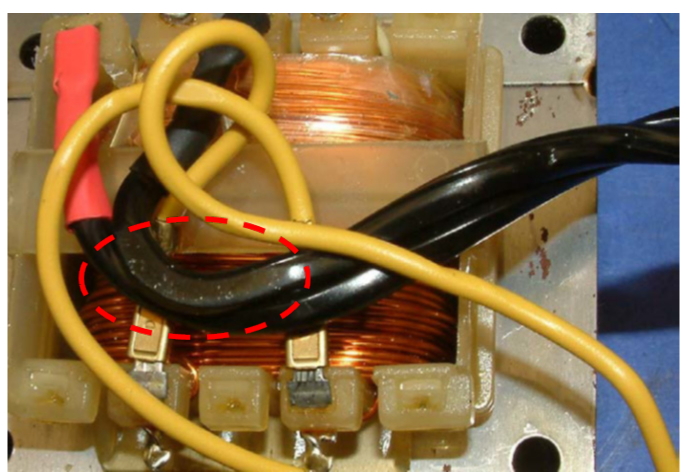

Figure 5
The portion of the power cord inside the ellipse has been flattened from continuous pressure against the inside of the enclosure in a warm environment.

the inside of the enclosure.

Based on the finding of a pinched AC power cord in a single exemplar power supply, another older exemplar was obtained. Another pinched power cord was found as shown in **Figure 6**. This result was expected because the older design electrical enclosure cannot be assembled without applying an external force the power cord, deforming the insulation.

Defect Theory and Hypothesis of Fire Causation

In the older power supply design, the power cord becomes compressed between the transformer and plastic enclosure as screws are tightened to install the transformer during assembly. The enclosure deforms, acting like a spring. The spring force is applied continuously throughout the life of the product.

The power supply is energized continuously, and gets warm. Temperatures within the power supply enclosure were measured at 135°F while powered on the bench, and may become even warmer when located under the chair. The power supply remains warm when the product is plugged into a power source, keeping the power cord insulation warm and soft and enhancing its ability to deform where an external force is applied.

The working theory was that the AC power cord on the product became damaged during assembly, due to a design defect in the electrical enclosure. Over time, insulation on the pinched cord experienced material deformation and allowed some current to flow between the line and neutral conductors of the cord within the enclosure. Such an unintended electrical path tended to begin at a low level of current and develop into an overcurrent (in excess of the current an 18 gauge power cord was intended to carry). The overcurrent caused the power cord to become extremely hot before the cord melted and separated or the circuit breaker tripped. In this case, the circuit breaker tripped, preserving the power cord conductors and plug blades. The hypothesis: An overheated power cord ignited nearby combustible material, initiating the fire.

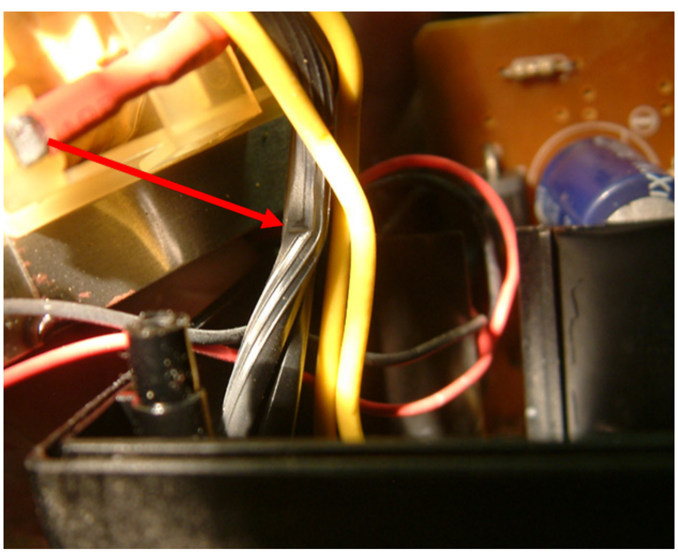

Figure 6
Another exemplar shows evidence
of a pinched power cord (red arrow).

Testing the Hypothesis

The hypothesis was tested by subjecting representative two-conductor plastic power cords (“lamp cord”) to intentional overcurrent. Under five to 10 times rated current, some shorted cords became hot enough for their insulation to melt and briefly burn before a typical circuit breaker tripped. One exemplar cord failed in a near-replication of the incident, and its burning insulation did ignite the upholstery of its exemplar recliner.

As shown in **Figures 7** and **8**, an exemplar power cord was positioned under the product and energized with 60 amps. The cord glowed orange and ignited the fabric within about 20 seconds.

Circuit Breakers

The circuit breaker on the branch circuit supplying the chair was a 20-amp breaker, and it was found to be tripped after the fire. It was not removed from the panel, and its specific model is unknown. However, the typical trip characteristics for a circuit breaker are shown in **Figure 9**. The typical trip curve indicates that a circuit breaker can sustain multiples of its rated current for 10 to 20 seconds or

Figure 7
Ignition of fabric by glowing power cord.

Figure 8
Propagation of fire to fabric.

longer. **Figure 9** represents the performance of a typical circuit breaker.

Circuit breakers are designed to protect wiring in the building, and can tolerate many times their rated capacity for a short time. For example, as shown in **Figure 9**, a typical 20-amp circuit breaker can handle 100 amps for up to 5 seconds, or 40 amps for up to 30 seconds, before tripping. The specific performance curve for the 20-amp circuit breaker model supplying the branch circuit connected to the power supply was not available in the record. However, the fact that a circuit breaker was in the line cannot prevent a short-lived overcurrent in the power cord before the circuit breaker trips. The circuit breaker on the branch circuit feeding the chair was, in fact, tripped.

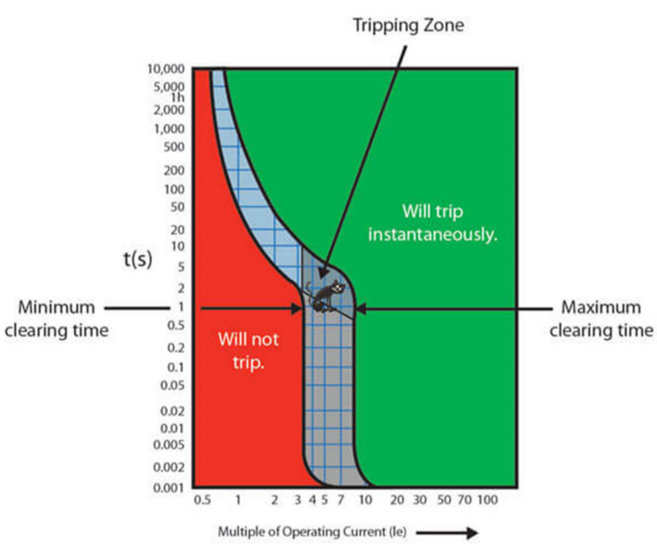

Figure 9
Representative circuit breaker trip curve indicating the time it will take to trip at multiples of its rated operating current[2]. Image reprinted with permission from c3controls, Beaver, Pa.

Observations during exemplar testing revealed that as current in the power cord was increased, the insulation melted, burned, and turned to char as the copper conductors glowed orange, radiating intensely in all directions. In some tests, the copper conductors melted and separated, stopping the current. At a current of about 50 to 60 amps, the copper conductors glowed brightly but remained energized. As observed in the tests described above, there was a period when the copper can become a radiant source of ignition in quasi-steady equilibrium. With power input nearly equal to the radiant power loss, the cord can glow like the inside of a toaster until the circuit breaker trips or the copper conductors melt.

Connecting the Dots

When the burned evidence and exemplar evidence for this fire were evaluated in concert, the theory of a design defect as the cause of the fire was well supported. The older design power supply was present in the product determined to be the origin of the fire by the plaintiff's fire cause and origin investigator. A design defect was found in both exemplar power supplies of the same design, pinching and damaging the power cord within the enclosure as the product was assembled. Accordingly, it was reasonable to conclude that the same defect was present in the fire evidence. In the normal use of this product, the power cord lay on the floor and came very close to the furniture's fabric. Testing confirmed that an overheated power cord was capable of igniting the fabric.

There was a solid basis to prove that a design defect existed in the product, damaging the power cord. Such damage was capable of causing a fire. Even without any direct evidence of the fire's cause, sufficient evidence existed for the plaintiff's forensic engineering experts to support their opinion that the design defect caused the fire.

Subsequent Remedial Measures

While subsequent remedial measures are not evidence of a defect[3], the design changes that occurred in this product were precisely what a prudent manufacturer would have done to correct a problem after becoming aware of the problem. The manufacturer never admitted that the design was revised to correct a problem, or that they were the manufacturer of the subject chair. However, the "subsequent remedial measures" effectively moved the power supply out from under the product and eliminated the pinch-points on the power cord within the power supply enclosure. Together with the rest of the evidence, the design revisions provided a clue that led to further investigation and a theory of causation.

Dissenting Opinions

Defense experts correctly pointed out that evidence from the fire was not collected according to best practices for evidence recovery, due to the heavy ice at the scene. All that remained of the power supply was the transformer, bare wires, and a bit of the printed circuit board, making identification of the point of failure remote or impossible, due to the extent of fire damage.

Since no specific evidence of electrical activity was found, defense experts labeled the cause as undetermined. It was argued that if the cause was within the power supply enclosure, there should be some evidence of electrical activity in the recovered debris. It was also argued that because the condition of the recovered evidence was poor, some other electrical devices in the area could not be ruled out conclusively. The defense experts did not propose any alternative theory of fire causation and performed no testing.

Afterthoughts

Fires tend to destroy or obscure evidence of their cause, and often leave few clues, aside from burn patterns. In this case, the evidence supporting a cause determination did not rely on the fire evidence. The investigation of unburned exemplars revealed critical evidence of the fire's cause.

NFPA 921 *Guide for Fire & Explosion Investigations*[1] does suggest that investigators may obtain historical exemplars for suspect products. In this case, the exemplars were obtained to inspect details of the steel frame. The recognition of a design change in the power supply was serendipitous.

Once revisions in the power supply and its change in placement to outside the product were recognized, a theory of causation began to take shape. Hands-on inspection of the older design power supply added substantial weight to the theory, exposing the design defect. Without the recognition of a defect in the exemplars, no reasonable explanation for the fire would have been found, based on the fire evidence alone.

The investigative path in this case was initially directed toward proof of the product manufacturer's identity. After collection of several exemplar chairs, the plaintiff's experts noted the design changes to the chair's power supply that occurred after the subject chair was manufactured. NFPA 921[3] advised inspection of unburned exemplars to understand the operation more fully and explore ignition scenarios. Hands-on internal inspection of the old and new power supply exemplars uncovered the design defect.

NFPA 921[3] describes retaining specialized experts such as mechanical or electrical engineers when the origin and cause investigator does not have the expertise for the investigation. In this case, the inspection of exemplars led the forensic engineers in an unexpected direction. Recognition of the defect and resulting theory of causation evolved as a result of "getting to know the product."

References

1. *Guide for Fire and Explosion Investigations*, NFPA 921-2014, National Fire Protection Association, Quincy, MA, 2014.

2. c3controls, Beaver, PA. *Understanding Trip Curves*. Accessed: July 4, 2021. [Online]. Available: https://img.c3controls.com/image/upload/resources/c3controls-Understanding-Trip-Curves.pdf.

3. U.S. House. 115th Congress, 51st Session (2017, Dec. 1. *Federal Rules of Evidence, Rule 407. Subsequent Remedial Measures*. [Online]. Available: https://www.uscourts.gov/sites/default/files/evidence-rules-procedure-dec2017_0.pdf.