TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

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Washington, D.C.

Underwriters Laboratories Inc.®

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Prepared for:

U.S. Consumer Product Safety Commission
Washington, D.C.

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The UL project investigators were Messrs. Peter Boden, Robert Davidson, Walter Skuggevig, and Richard Wagner. Mr. John Stevenson (retired from UL) was a consultant providing technical advice and reviewing services. Mr. David Dini was the project manager.

We are grateful to the manufacturers and inventors who participated in this work.

TABLE OF CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

The CPSC Home Electrical System Fires Project

This project was sponsored by the U.S. Consumer Product Safety Commission (CPSC) as part of the Home Electrical System Fires Project, a priority project for the CPSC in FY94 and FY95. The overall objective of the Home Electrical System Fires Project is to reduce the rates of death, injury and property loss from residential fires associated with electrical wiring systems. The major elements of the Home Electrical Systems Fires Project are to 1) promote electrical inspections of older dwellings to identify flagrant hazards that need correction, 2) stimulate the repair and correction of known hazards, and 3) demonstrate effective, economical electrical products that can upgrade the safety of electrical wiring systems in residences. The objective of these activities is to permit the continued occupancy of these dwellings without electrical symptoms that can cause fires.

The CPSC estimates that there were approximately 41,000 fires involving home electrical wiring systems in 1992. These fires resulted in 320 deaths, 1,600 injuries, and $511 million in property losses. CPSC studies have also shown that the frequency of wiring system fires is disproportionately high in homes more than 40 years old.

Identifying Technology for Reducing Residential Electrical Fires

The purpose of the project reported here was to conduct an in-depth study of technologies to detect and monitor precursory conditions that could lead to or directly cause fires in residential wiring systems in general, and how these technologies could be applied to older residential wiring systems in particular. The project included 1) conducting a comprehensive review of published and unpublished literature on devices and systems that could decrease the likelihood of residential fires, 2) a survey of industry organizations and manufacturers for new products and systems that could decrease the likelihood of residential fires, and 3) the acquisition and analysis of promising devices and systems for ease of installation, reliability, cost and effectiveness in decreasing the likelihood of fires in residential wiring systems, particularly older residential wiring systems.

Literature Search to Identify Technologies

An extensive review of patents and of published and unpublished literature was conducted to acquire relevant information on technology for detecting or monitoring when conditions exist that could cause fires in residential electrical wiring systems. The review focused on innovative new technology or innovative uses for existing technology that is currently available or under development.

The search for published information included the use of a computer-aided information retrieval service through the New England Research Applications Center (NERAC) which has access to extensive data base resources. Numerous documents were surveyed, and seven articles and sixteen patents describing relevant information and promising technology were acquired. The major types of new technologies, or new applications of existing technologies, that were identified fall into the following five general categories:

1. Arc-Fault Detection Technology - This technology is intended to respond to arcing faults in the electrical wiring system by looking for specific signature characteristics of the current, voltage, or electromagnetic fields associated with arcing faults.

2. Modified-Trip Circuit-Breaker Technology - This technology is intended to modify the trip characteristics of conventional residential circuit breakers. Essentially, the technology causes a circuit breaker to trip magnetically (with or without an intentional delay) at levels of overcurrent that would normally result in the circuit breaker tripping thermally. The result is faster response time at levels of overcurrent that would typically correspond to the thermal trip region of a conventional circuit breaker.

3. Ground-Fault Interrupting Technology - This present technology is intended to respond to a ground-fault condition to reduce the risk of electric shock in the residential distribution system. The new application of this technology is to reduce the risk of fire in the residential distribution system.

4. Supplementary Protection Technology - This technology consists of the innovative application of conventional supplemental overcurrent and/or thermal protection technology incorporated at the outlet receptacle or attachment plug in order to respond to specific conditions of temperature or current.

5. Surge-Protection Technology - This existing technology is intended to limit the magnitude of transient overvoltages in the electrical distribution system. Consideration is given to the fact that repeated exposure to transient overvoltages can cause damage to electrical insulation.

Procurement of Products Exemplifying the Technologies Identified

An announcement letter seeking participation in this project was sent to approximately 800 individuals and manufacturers involved in product categories that were pre-identified as possibly having new or innovative electrical system protection technology.

As a result, eleven products were procured in order to evaluate the technologies that they were intended to exemplify.

Findings

The following summarizes the individual and collective findings pertaining to the technologies evaluated.

Arc-Fault Detection Technology - Arc-fault detection (AFD) technology, as exemplified by the involved products, demonstrated a capability of detecting and terminating certain types and levels of arcing fault current (but not all types and levels) that are beyond the present scope of conventional branch-circuit overcurrent protection technology. Consequently, it was found that arc-fault detection technology does indicate promise as a potential means for further reducing the incidence of fires in the electrical wiring system, that are either directly or indirectly caused by arcing faults.

There was a variety of performance of AFD products to the range of testing conducted under this project. Although each of the products both reacted to open the circuit and to apparently prevent ignition of the test indicator in a significant number of cases, none of the products responded in all of the cases tested. In order to fulfill the potential of AFD technology, further development is needed in order to detect and respond to a wider variety of arcing fault conditions. Additional research is needed to obtain a more definitive understanding of the specific type or types of arcing conditions that can directly or indirectly result in fires in the residential wiring system so that AFD technology can be further developed to address those conditions.

Since AFD technology exemplified by the involved products is still developing, the evaluation of this technology with respect to unwanted tripping and operation inhibition was limited to a few tests. Some unwanted tripping and operation inhibition was observed. However, additional work is needed particularly with respect to unwanted tripping and operation inhibition at normal load current levels. For example, it appears that EMI filters may inhibit the operation of some AFDs.

Modified-Trip Circuit-Breaker Technology - Modified-trip circuit-breaker technology as exemplified by the involved products, indicated a capability to cause a conventional circuit breaker to trip magnetically at levels of overcurrent that typically correspond to the thermal trip region of conventional circuit breakers. However, since these approaches to protection are still based on the magnitude and duration of power frequency overcurrent, the challenge of balancing effectiveness, such as reduction in the probability of electrically caused ignition, especially ignition from arcing faults, and the desire to avoid unwanted tripping (and its consequences) over a wide range of inrush currents associated with the normal start up of loads, remains.

In addition, faults involving currents below circuit breaker handle rating remain outside the scope of protection for products analyzed under this category.

Ground-Fault Interrupting Technology - Although ground-fault protection technology, specifically that used in GFCI's (U.S. Ground-Fault Circuit Interrupters) and RCD's (European Residual Current Detectors), are used to provide protection to personnel from electric shock, the low trip current level (nominal 5 mA for GFCI's and 30 mA for RCD's), combined with the fast operating time (within a couple of cycles) makes ground fault protection technology appear to be well suited to reduce the incidence of electrically caused fires. Since the devices only detect currents to ground, the concerns for unwanted tripping are limited to leakage current to ground and not load currents. The limited tests conducted under this project on ground-fault interrupting devices indicate that ground-fault detection technology has the capability to quickly detect and respond to the current arising from a ground fault (including an arcing fault) prior to igniting a fire indicator. A ground-fault interrupting device can only detect and respond to a fault that involves current to ground. It will not detect across-the-line or in-line series arcing faults unless such faults also involve current to ground. In those cases where the ground-fault current is a by-product of an across-the-line or in-line series arcing fault, operation of the ground-fault function may or may not preclude ignition.

Supplementary Protection Technology - The supplementary protection technologies exemplified by the involved products are intended to detect an overtemperature and/or overcurrent condition, or the effects of an overtemperature and/or overcurrent condition arising from the connection of a load(s) to a specific outlet receptacle. The technologies, as exemplified by the devices analyzed, demonstrated a capability of detecting and/or responding to certain types of abnormal conditions involving overtemperature and/or overcurrent and showing that supplementary protection technology can contribute to a reduction in the likelihood of an electrically caused fire. In contrast to the other technologies evaluated in this project which were packaged or could be packaged so as to be permanently installed and continuously monitor conditions on a complete branch circuit or group of branch circuits, the zone of protection provided by supplemental protection technology is very limited and dedicated to specific applications.

When packaged as plug-in devices, reliance is placed on the user to plug the device into a receptacle and to keep it plugged into the receptacle. Also, the load current that can be obtained through these devices may be less than the normal load current that can be supplied by the outlet receptacle. On the other hand, a protection-oriented homeowner can choose a supplementary protective device that matches the particular load without the risk of circuit interruption affecting other electrical loads.

Surge-Protection Technology- All of the previously indicated technologies are intended to mitigate the consequences of a failure or fault in the electrical distribution system.

Another approach is to reduce the likelihood of the fault occurring. Surge-protection technology, by limiting the exposure of the wiring system to transient overvoltages (e.g., from a lightning event or utility switching event), can reduce the likelihood of failure of electrical insulation from occurring. Repeated exposure to high voltages can degrade electrical insulation and ultimately result in an insulation fault. To the extent that a surge-protective device can limit the additional exposure of the electrical distribution system to transient overvoltages, it can help reduce the incidents of electrically caused fires. The overall significance of the reduction depends, however, on the significance of transient overvoltage caused insulation failure relative to other insulation failure modes.

Recommendations

It was determined that no single product or technology in the examined state of development would provide protection against all electrical ignition scenarios likely to be encountered in residential wiring systems. However, the present evaluation of the technologies that the involved products exemplified indicated that the potential exists to further combine certain technologies, once fully developed, into products that should significantly reduce the risk of fire beyond the scope of present conventional overcurrent protection technology.

From the technologies analyzed, arc-fault detection appeared to be very promising, especially when added to residential branch-circuit breakers and combined with other proven technologies such as ground-fault protection. It is recommended that additional research be considered to better define the nature of residential electrical ignition sources, the levels of arc-fault protection needed, and standardized test methods to verify the effectiveness of practical products that would utilize this technology.

I. INTRODUCTION

The Consumer Product Safety Commission (CPSC) estimates that in the year 1992 there were about 41,000 fires involving home electrical distribution systems. These fires resulted in 320 deaths, 1,600 injuries, and $511 million in property loss. A study conducted by CPSC in 1987[1] indicated that the frequency of fires in the electrical system was disproportionately high in homes more than 40 years old.

Approximately one-third of the existing housing in the U.S. in 1987 was built prior to 1950. The residential electrical distribution systems in many older homes that had experienced fire had neither been inspected nor renovated since they were built. For the purposes of this report, the residential electrical distribution system includes the wiring from the point of connection to the electrical utility to the receptacles including circuit extensions such as extension cords. Many older homes were originally wired with an electrical service rated 60 A or less. Some of the very old installations were wired with service rated 30 A, and had only 120 V. Today, new homes are commonly provided with 120/240 V or 120/208 V systems rated 100, 150, or 200 A to meet the demand for safely distributing electrical power.

The disproportionately high incidence of fire in the electrical systems of older homes can usually be attributed to one or more of the following factors:

- Inadequate and overburdened electrical systems
- Thermally reinsulated walls and ceilings burying wiring
- Defeated or compromised overcurrent protection
- Misuse of extension cords and makeshift circuit extensions
- Worn-out wiring devices not being replaced
- Poorly done electrical repairs
- Socioeconomic considerations resulting in unsafe installations

While some of these factors do not cause fires by themselves, combinations of these factors increase the likelihood of a potentially unsafe situation being exacerbated. Eventually, these factors can lead to electrical overheating and/or *arcing faults* that cause fires.

The objective of this project was to conduct an in-depth study of technologies to detect and monitor precursory conditions that could lead to fires in residential electrical wiring systems. The study involved an assessment of products and technology that

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[1] D. McCoskrie, L. Smith. "What Causes Wiring fires in Residences". Fire Journal, Jan-Feb 1990.

could be applied to existing residences to decrease the likelihood of fires. The technologies sought are conceived as supplementary devices to the existing wiring materials and electrical distribution system apparatus.

This report is organized in the following sequence.

1. A **Literature Search** was conducted of published and unpublished information relative to the products and technology for reducing the risk of an electrically initiated residential fire.

2. A **Description of Products and Technology** that were obtained and analyzed in this report is given.

3. A **Basis for Selection of Tests** discusses the mechanisms that could lead to fires in the *residential wiring system* of homes.

4. The details of the **Test Description and Data** is given.

5. The **Test Observations** are discussed.

6. An **Assessment of Products and Technologies** together with conceptual protection schemes by combining technologies is given.

7. Possible **Applications of Technologies** that were evaluated in this report are discussed in detail.

8. A **Summary of Findings** is provided.

9. **Recommendations** are made to help further the objectives, initiatives, and findings of this project.

10. A **Glossary** is included at the end of this report that defines some of the terminology used. The definition of italicized words in the report can be found in the glossary.

II. LITERATURE SEARCH

Published Information

The first phase of this project involved a review of published literature to acquire relevant information regarding technology for indicating when conditions exist that could cause fires in residential electrical wiring systems. The review focused on documents written within the past five years, however, some information collected predates this five-year period. The information obtained includes technology that is currently available and that which is presently being developed. The information is organized as Part A - Patents and Part B - Articles. Each reference includes an abstract or a summary.

Relevant literature including patents and articles was obtained via 1) the contractor's knowledge of existing literature, and 2) a private information retrieval service, the New England Research Applications Center (NERAC) of Tolland, CT. Through NERAC extensive worldwide database resources drawn from U.S. government agencies, professional associations, research and academic societies, and suppliers worldwide were searched for relevant literature in the U.S., Europe, Canada, Japan, and Israel. Databases accessed for patents and information included the U.S. Patent Gazette, Ei Compendex*Plus, Firedoc, Inspec, National Technical Information Service, and the Fire Technology Abstracts.

Seven articles and 16 patents describing relevant information and promising technologies were acquired. The articles were secured from the publications; *Fire Journal, Electrical Contractor, Electrical Times, IEEE Transactions*; and from the U.S. Department of Energy Sandia National Laboratories. An unpublished work from RB Laboratories was procured. Of the 16 patents, 11 are assigned to U.S.-based corporations, one is assigned to a French-based corporation, one is assigned to the U.S. government, and three patents have no assignee.

The search strategy involved probing the data bases with key words and phrases associated with new and innovative technology for reducing residential electrical fires. As the search progressed, the key word and phrases were refined to pinpoint "hits" on the data bases. Some key words and phrases used included: arc detection and detectors, interruption, suppression, *fault* protection and protectors, arc fault detection, residential electrical fires, detection and monitoring of, protection, fires - wiring systems, overheating of conductors, electrical fire prevention, safety, incident of fires, cause of residential fires, and residential electrical fire prevention. The search located 74 citations and 46 patents. These "soft hits" were reviewed and of these seven articles and 16 patents that were considered to be of significant interest were acquired.

Literature Procured

General: The abstracts given below were taken from the associated patent.

Part A - Patents

1. **United States Patent. Patent Number 5,280,404. Date of Patent: Jan. 8, 1994**
   ARC DETECTION SYSTEM
   Inventor: Charles W. Ragsdale
   Assignee: Bio-Rad Laboratories, Inc., Hercules, Calif.

Abstract

An arc detector for detecting electrical arcs across a break in a line carrying a current in an electrical system. Normally, the line carries current, but when the line is broken, current doesn't flow until an arc occurs across the break. The arc detector detects the break using a current sensor for measuring the current, a filter for filtering out unwanted frequencies, an amplifier for amplifying the remaining frequencies into a substantially square wave, a counter for counting square wave transitions, and a latch to hold a detection signal at an output node when the counter counts a preset number of square wave transitions without being reset by a reset switch or a periodic oscillator.

2. **United States Patent. Patent Number 5,223,795. Date of Patent: Jun. 29, 1993**
   METHOD AND APPARATUS FOR DETECTING ARCING IN ELECTRICAL CONNECTIONS BY MONITORING HIGH FREQUENCY NOISE
   Inventor: Frederick K. Blades

Abstract

An arc detector for detecting potentially hazardous arcing in electrical connections comprises detection and signal processing circuitry for monitoring high-frequency noise on the power line characteristic of arcing and distinguishable from other sources of high-frequency noise. If high-frequency noise is present and a gap occurs every half-cycle of the power frequency, arcing is determined to be present, and an alarm is given.

3. **United States Patent. Patent Number 5,208,542. Date of Patent: May 4, 1993**
   TIMING WINDOW ARC DETECTION
   Inventors: Charles J. Tennies, Bruce C. Beihoff, James E. Hansen
   Assignee: Eaton Corp., Cleveland, OH

Abstract

An arc detection method and apparatus is provided for an electric circuit having an electrified conductor connecting a voltage source to a load. The arc detector includes a field sensor sensing an electromagnetic field established about the conductor by the occurrence of an electric arc in the circuit, and generating a field responsive signal in response thereto. Arc discrimination circuitry responds to the field sensor and generates a tentative arc signal in response to a given characteristic of the field response signal. Arc timing window circuitry responds to the arc discrimination circuitry and generates a confirmed arc signal in response to a given timing characteristic of the tentative arc signal.

4. **United States Patent. Patent Number 5,206,595. Date of Patent: Apr. 27,1993**
   ADVANCED CABLE FAULT LOCATION
   Inventors: Carl M. Wiggins, Frank S. Nickel, David E. Thomas, Stephen J. Halko, Thomas M. Salas, Gary H. Shapiro.
   Assignee: Electric Power Research Institute, Palo Alto, Calif.

Abstract

A simple and inexpensive device which is suited for real-time location of a fault occurring anywhere in a residential distribution system by analysis of the propagating fault signal considering the predetermined propagating velocity of the cable.

5. **United States Patent. Patent Number 5,206,596. Date of Patent: Apr. 27, 1993**
   ARC DETECTOR TRANSDUCER USING AN E AND B FIELD SENSOR
   Inventors: Bruce C. Beihoff, Charles J. Tennies, Jerome K. Hastings
   Assignee: Eaton Corporation, Cleveland, Ohio

Abstract

An arc detector antenna transducer for an electric circuit has an electrified conductor connecting a voltage source to a load. The arc detector transducer includes an E field sensor sensing the E field established about the conductor by the occurrence of an electrical arc in the circuit, and a B field sensor sensing the B field established about the conductor by the occurrence of the electrical arc in the circuit.

6. **United States Patent. Patent Number 5,185,686. Date of Patent: Feb. 9, 1993**
DIRECTION SENSING ARC DETECTION
Inventors: James E. Hansen, Bruce C. Beihoff, Charles J. Tennies, Francis S., Richards, Jr.
Assignee: Eaton Corporation, Cleveland, Ohio

Abstract

An arc detection method and apparatus is provided for an electric circuit having an electrified conductor connecting a voltage source to a load, the conductor having a line side extending from the arc detector to the voltage source, and a load side extending from the arc detector to the load. The arc detector includes a field sensor sensing the electromagnetic field established about the conductor by the occurrence of an electrical arc in the circuit, and generating a field responsive signal in response thereto. Direction sensing circuitry detects whether the arc is from the load side or the line side, and generates a direction indicative signal.

7. **United States Patent. Patent Number 5,185,684. Date of Patent: Feb. 9, 1993**
FREQUENCY SELECTIVE ARC DETECTION
Inventors: Bruce C. Beihoff, Charles J. Tennies, Francis S. Richards, Jr., Walter K.O'Neil.
Assignee: Eaton Corporation, Cleveland, Ohio

Abstract

An arc detection method and apparatus is provided for an electric circuit having an electrified conductor connecting a voltage source to a load. A field sensor senses an electromagnetic field established about the conductor by the occurrence of an electrical arc in the circuit, and generates a field responsive signal. Arc discrimination circuitry includes frequency responsive circuitry responding to the field sensor and generating an arc indicative signal in response to a given frequency characteristic of the field responsive signal. The frequency responsive circuitry monitors a plurality of different frequencies of the field responsive signal, and generates the arc indicative signal in response to a given combination of field responsive signal frequencies. A comb filter passes the field responsive signal through a plurality of passbands, and the arc indicative signal is generated in response to a given frequency signature of the field responsive signal.

8. **United States Patent. Patent Number 5,185,685. Date of Patent: Feb. 9, 1993**
<u>FIELD SENSING ARC DETECTION</u>
<u>Inventors</u>: Charles J. Tennies, Bruce C. Beihoff, Jerome K. Hastings, Robert J. Clarey, Walter K. O'Neil.
<u>Assignee</u>: Eaton Corporation, Cleveland, Ohio

Abstract

An arc detection method and apparatus is provided for an electric circuit having an electrified conductor connecting a voltage source to a load. The system senses the electromagnetic field established about the conductor by the occurrence of an electrical arc in the electric circuit, and generates a field responsive signal. Arc discrimination circuitry responding to the field responsive signal and generates an arc indicative signal in response to a given characteristic of the field responsive signal. The system includes an E field sensor and a B field sensor.

9. **United States Patent. Patent Number 5,185,687. Date of Patent: Feb. 9, 1993**
<u>CHAOS SENSING ARC DETECTION</u>
<u>Inventors</u>: Bruce C. Beihoff, Charles J. Tennies, Francis S. Richards, Jr., Walter K. O'Neil.
<u>Assignee</u>: Eaton Corporation, Cleveland, Ohio

Abstract

An arc detection method and apparatus is provided for an electric circuit having an electrified conductor connecting a voltage source to a load. The arc detector includes a field sensor sensing an electromagnetic field established about the conductor by the occurrence of an electrical arc in the electric circuit, and generating a field responsive signal in response thereto. Arc discrimination circuitry responds to the field sensor and generates an arc indicative signal in response to a random chaotic pattern of the field responsive signal.

10. **United States Patent. Patent Number 5,142,646. Date of Patent:Aug.25, 1992**
<u>GROUND FAULT ELECTRICAL PANEL</u>
<u>Inventor</u>: Carl Nachtigall

Abstract

A circuit-breaker panel system supplies power to plural circuits that are ground fault protected and plural circuits that are not ground fault protected. The panel system has two sections. One section, which is not ground fault protected, contains a ground fault circuit-breaker that supplies power to the second section, so that the entire second section is ground fault protected.

11. **United States Patent. Patent Number 5,047,724. Date of Patent: Sept. 10, 1991**
POWER CABLE ARCING FAULT DETECTION SYSTEM
Inventors: Jeffrey Boksiner, Michael Parente
Assignee: Bell Communications Research of N.J.

Abstract

A system for detecting an arcing fault in a telephone central office DC power distribution conductor repeatedly measures the current flow in the distribution line, as with an inductive coupling, and derives a Fourier transform analysis spectrum from such measurements. The power values at intervals across the frequency spectrum are compared with recorded threshold temperatures values encompassing the spectrum typical of an arcing event and an alarm condition is established when such threshold levels are exceeded.

12. **United States Patent. Patent Number 4,931,894. Date of Patent: June 5, 1990**
GROUND FAULT CURRENT INTERRUPTER CIRCUIT WITH ARCING PROTECTION
Inventor: Raymond Legatti
Assignee: Technology Research Corporation

Abstract

A ground fault current interrupter (GFCI) circuit is provided with the additional capacity of detecting and protecting against arcing between a power line and the metal sheath or cover of a power cable. An arc protection winding is located on the core of the GFCI differential transformer and is connected in series with a resistance between the metal sheath and a neutral or return line. By adjusting the number of turns of the arc protection winding and the size of the series resistance, the sensitivity of the arc protection arrangement to arcing current may be set at a desired level.

13. **United States Patent. Patent Number 4,903,162. Date of Patent: Feb. 20, 1990**
FIRE-PREVENTION ELECTRICAL WIRING DEVICE
Inventor: Robert L. Kopelman

Abstract

In a preferred embodiment, a receptacle having multiple electrical outlets includes in the main electrical inlet in electrical series with each of the electrical outlets, a heat-sensitive circuit-breaking element characterized as breaking of electrical circuit passed therethrough when the flow of current exceeds a predetermined amperage, as responsive to increased heat of resistance or other surrounding environmental heat, and as reestablishing circuitry when temperature has cooled down to at least a circuit-breaking temperature, there being preferably included in circuit with the circuit-breaking element a conventional electrical time delay element characterized by delaying reestablishing circuitry therethrough whenever circuitry has been broken, with a time delay of sufficient length to permit a cooling of circuitry to a point below circuit-breaking temperature of the circuit breaking element, to prevent fire hazard from overheated old and/or inadequate house-wiring or insulation thereof.

14. **United States Patent. Patent Number 4,878,144. Date of Patent: Oct. 31, 1989**
SOLID-STATE TRIP DEVICE OF A MOLDED CASE CIRCUIT-BREAKER
Inventor: Jean-Pierre Nebon
Assignee: Merlin Gerin, France

Abstract

A solid-state trip device including an instantaneous trip device formed by arc detectors located in proximity to the main contacts of the circuit-breaker. The light signals emitted by the arc-detectors are transmitted by optical fibers to a light sensitive electronic component which emits an arcing signal. This arcing signal causes tripping of the circuit-breaker only if a fault signal is present.

15. **United States Patent. Patent Number 4,658,322. Date of Patent: Apr. 14, 1987**
ARCING FAULT DETECTOR
Inventor: Neftali Rivera
Assignee: The United States of America as represented by the Secretary of the Navy, Washington, D.C.

Abstract

An arcing fault detector used the thermodynamic conditions created by an arcing fault within a vented electrical equipment enclosure to quickly activate a protective device which causes tripping of the supply circuit breaker(s). A plurality of temperature sensors are located within the enclosure near the top, and a differential pressure sensor is located in the external wall of the enclosure approximately midway between the vents to compare internal and external pressure. The intelligence from the sensors is processed by a fault protector which controls the tripping of the circuit-breaker(s).

16. **United States Patent. Patent Number 4,639,817. Date of Patent: Jan. 27,1987**
PROTECTIVE RELAY CIRCUIT FOR DETECTING ARCING FAULTS ON LOW-VOLTAGE SPOT NETWORKS
Inventors: John H. Cooper, William H. South.
Assignee: Westinghouse Electric Corp., Pittsburgh, Pa.

Abstract

A protective relay for detecting power arcing faults on a low-voltage spot network. The protective relay can monitor the voltage difference between each phase conductor, the voltage difference between each phase conductor and the neutral conductor, or the current on each phase conductor. Using one of these three sets of values, the protective relay first filters the input signal so that only frequencies indicative of a power arcing fault on the low-voltage spot network are analyzed. The signals passed by the filter are amplified, rectified, and averaged and the peak of each signal detected. If the peak has a duration longer than a predetermined value, a fault indication is provided.

Part B - Articles

General: The summaries below were developed from parts of the articles.

1. **The Real Cause of Electrical Fires. R. Blades.** RB Laboratories, Jan 1993.

Summary

"Arcing" refers to electrical discharges across an air gap. It brings to mind short circuits producing visible, short-lived and violent "sparking". According to national fire studies, these explosive events are, in fact, relatively rare as a cause of fires. Electrical fires are more commonly attributed to such things as "circuit overloading", "insulation failure", "overheating", and the like. The purpose of this study is to show that while all these conditions may contribute to the generation of an electrical fire, the resulting phenomena that actually ignites flammable materials in electrical fires is a form of microscopic arcing referred to herein as *Contact Arcing*. The mechanisms of common electrical failures are discussed to explain why this form of arcing is invariably present seconds, minutes, days, weeks or even months in advance of most electrical fires.
A second purpose of this paper is to estimate how many fires in the United States could be prevented nationwide through the widespread use of CA (Contact-Arcing) responsive circuit-breakers.

2. **What Causes Wiring Fires in Residences?**. L.E. Smith, D. McCoskrie. *Fire Journal*, Jan/Feb 1990.

Summary

Available data indicate that fires in electrical distribution systems contribute significantly to the fire problem in the United States, accounting for a consistent portion of that problem year after year. These fires are difficult to evaluate adequately, not only because of the complexity of electrical systems but also because of the difficulty

in identifying pertinent details once a destructive fire has occurred. Few fire departments have the time available to devote to such investigations.

The investigations included in this study are not a statistically valid sample. Therefore, the possibility for bias in selection must be considered. Even so, it seems reasonable to assume that the causes identified depict some major part of the residential electrical distribution system fire problem, even if it does not depict the whole problem.

There are a number of ways in which the fire protection community can work to prevent electrical fires. Some of these possibilities include developing a rehabilitation guide for the electrical system. This would help consumers decide when they need improvements and would provide guidance for having such improvements done by skilled workers in accordance with the NEC, even when funds are limited. One application that might be considered for such a guide is having mandatory inspection of homes in conjunction with change of ownership so that hazardous deficiencies of the electrical system could be corrected at that time. Involvement of organizations such as NFPA, NEMA, IEEE or other knowledgeable groups could help provide the necessary expertise to develop such a guide.

Another possibility is the development of a campaign to inform consumers that repairs must be made properly and to help them recognize that electrical systems, like other products, have a finite life. Local fire departments could play a major role in disseminating this information during their fire safety campaigns.

Finally, the fire protection community should encourage states and other jurisdictions to provide more resources for electrical inspections. Local fire departments again could contribute to this effort by actively informing their local and state governments of the causes and consequences of the fire problem. Moreover, concerns for lower-income households and the costs of these fires to the community should provide local governments with the impetus they need to become involved in this problem.

3. **Protecting the Home with RCDs. M.H. Mullins.** *Electrical Contractor* , May 1989.

Summary

Residual current devices (rcds) are now widely accepted as an essential component to the means of providing circuit protection in the home. While they cannot eliminate all electrical hazards nor guarantee protection under all circumstances, the reduction in risk provided on installations protected by rcds cannot be disputed. The author discussed the various types of rcds available for use in the home circuit protection and takes issue with those who deprecate their use as a main switch.

4. **The Scope for Industrial Application of RCDs**. Clarke, M. *Electrical Times*, April 1988.

Summary

There are many applications in modern commercial and industrial environments where rcd protection is desirable to minimize the risk of electrocution and fire. There is a wide range of suitable equipment available, including compact combined mcb/rcd units for selective protection of high-risk circuits fed from conventional distribution boards.

5. **Description and Testing of an Apparatus for Electrically Initiated Fires Through Simulation of a Faulty Connection.** B. Spletzer, F. Horine, Sandia National Laboratories, June 1986.

Summary

An apparatus has been developed that allows the simulation of a faulty connection in an electrical circuit by placing a small resistance heater at the screw of a terminal strip. The apparatus and associated control system are described in detail. Details of a typical fire produced with the apparatus are presented, along with results of electrical fire initiation attempts with both IEEE-383 qualified and unqualified nuclear power plant cable.

Repeated use of the apparatus has shown that a self-sustaining fire can be reliably initiated in unqualified cable with power levels to the apparatus not exceeding 200W. Such fires may be initiated in approximately 10 min. Large-scale fires have been initiated with the apparatus, indicating that propagation to any desired fire size is possible. Similar efforts with IEEE-383 qualified cable have begun, but the results are not yet conclusive.

6. **The Escalating Arcing Ground-Fault Phenomenon.** J. Dunki-Jacobs, IEEE Trans. on Indus. Appl. Nov/Dec 1986.

Summary

The cause and avoidance of arcing fault burndowns of electrical equipments, particularly those operating in low-voltage solidly grounded systems were well identified and documented in publications appearing in the 1960s. The subsequent occasional appearance of similarly devastating arcing ground fault burndowns in equipments operating on medium-voltage low-resistance grounded systems seemed to be irreconcilable with the presence of the relative high value of the neutral ground resistor. A failure analysis based on-site observations produced a probable scenario of escalating arcing ground faults which explains the mechanism that will render the usual and proper complement of time-overcurrent ground-fault relays inoperative. A

detailed description of the escalation arcing ground fault phenomenon is presented. It further identifies preventative arcing escalation solutions that impact on the specification of switchgear, switchboards, and motor control equipments.

7. **Arcing Faults in Metallic Conduit at 120 and 240V.** J. Fuller, W. Hanna, G. Kallenbach, IEEE Trans. Indus. Appl., May/June 1985.

Summary

Over the years, many fires have been blamed on the failure of electric equipment or wiring in residential or commercial installations. To help resolve the question of whether or not these accusations have substance, many tests have been performed to evaluate various types of wire and insulation in different environments on 120- and 240-V ac circuits. Evidence from a recent fire in a local commercial installation at 208/120V indicated that paper products lying on the exterior of a conduit were ignited due to an internal arc between a conductor and the metallic conduit wall. The fault current did not trip a standard 100 A plastic case panel breaker. Laboratory tests were performed in an attempt to duplicate the conditions and confirm the conclusions. The results are reported.

Unpublished Information

Another phase of the literature search involved a review of unpublished information regarding products or technology intended to reduce fires in residential electrical systems. An announcement letter seeking information was sent to 1) 740 manufacturers of electrical equipment associated with residential electrical distribution products, 2) industry trade associations identified with manufacturers of residential electrical products, 3) individual inventors identified though the literature and patent search, and 4) other interested parties that had contacted UL or CPSC regarding interest in this project. The intent of the announcement letter was to solicit interest and participation in the project. Approximately 800 copies of the announcement letter were distributed to domestic and foreign product manufacturers. A copy of the announcement letter is included in Appendix A.

In addition, a condensed version of the announcement appeared in the January 1995 issue of *Trends*, a magazine published by UL. The announcement indicated that UL is working with the CPSC to identify new technology products for reducing residential electrical fires and invited participation in the project. *Trends* has a circulation of about 30,000 product manufacturers and other parties interested in safety. A copy of the *Trends* article is included in Appendix B.

As a result of the announcements, the following 19 individual inventors and manufacturers inquired regarding participation in the project.

America 2000 Safest Homes, Pebble Beach, CA
Bio-Rad Laboratories, Inc., Hercules, CA
Carl Nachtigall, Winnipeg, Manitoba
Cooper Power Systems, Pewaukee, WI
Cutler-Hammer, Westinghouse Products, Pittsburgh, PA
Delonghi America Inc., Carlstadd, NJ
Ekstrom Ind., Farmington Hills, MI
Felten & Guilleaume, Austria
Kopelman Ideas, Deer Park, NY
Professional Analytical & Consulting Engineers, Inc., Cincinnati, OH
Rivera, Neftali, Vienna, VA
Short Circuit Fire Protectors, Cincinnati, OH
Siemens, Tucker, Ga.
Square D Co., Cedar Rapids, Ia.
Technology Research Corp, Clearwater, Fl.
Wilson-Call, Bakersfield, Ca.
Texas Instruments, Attleboro, MA
Tyte-Wadd, Springfield, Mo
Zlan Ltd, Wylie, Tx.

The 19 interested parties were requested to submit descriptive information such as theory of operation, patents, photographs, drawings, installation instructions, and so on regarding their product. Most of the information received for each product/technology included a detailed description of the product/technology and how it could be used to reduce the risk of an electrical fire. Patent information was included with some responses. The results of this search were used as a decision basis for sample acquisition. After receiving the information, attempts were made to procure samples of products which appeared to be of benefit to this project. Eleven different products were obtained for further evaluation and analysis.

III. DESCRIPTION OF PRODUCTS AND TECHNOLOGY

This report includes the examination of rapidly changing technologies and the examination depicts only a "snapshot" of a rapidly moving target. There will soon be a number of newer generation designs of products that address some of the issues identified in this report.

Eleven products were provided and analyzed under this project. Many of the products submitted were prototypes and not finished and ready for market. The study of these products focused on the technology involved, not the packaging, and not whether the products in their present or envisioned future forms would comply with present codes and standards.

A brief description of each product is provided and additional detail is available from the manufacturers and from patents covering the product. The brief description will provide an idea of the approach taken in each case.

Arc-Fault Detection Technology Products

Arc-fault detectors monitor current looking for specific "signature" characteristics of an arcing fault. These characteristics can be a combination of features including the presence of certain frequencies, the duration of those frequencies, the rate of rise of current, etc. The premise is that these "signature" characteristics of the current indicate the presence of an arcing fault that should be interrupted before a fire develops.

Arc-fault detectors operate in conjunction with a circuit-breaker. The characteristics of the circuit breaker include thermal tripping and instantaneous (magnetic) tripping that are independent of the arc detection function. A discussion of thermal and magnetic tripping of circuit breakers is in the subsequent description of "Modified-Trip Circuit-Breaker Technology Products."

Arc-fault detecting devices submitted for analysis under this project are briefly described as follows.

Product No. 1:
Product No. 1 is an arc-fault detector that requires a minimum of approximately 100 mA of arcing current to function. To avoid unwanted tripping, a delay is used from the time of first recognition of the arcing signature until the time of interruption, and interruption only occurs if the signature persists. The arc-detection feature operates above and below the handle rating of the included 15 A *overcurrent* device. The version submitted for testing under this contract was an arc-fault detection circuit

breaker mounted in a box with a cord and plug, and a receptacle for convenience in testing.

Product No. 2:
Product No. 2 is an arc-fault detector that requires a minimum of approximately 3 A for it to function. It is intended to operate above and below the handle rating of the included 20 A overcurrent device. The device is packaged for installation in the service panel in conjunction with the included overcurrent device.

Product No. 3:
Product No. 3 is an arc-fault detector that is part of a branch-circuit overcurrent protective device rated 20 A. In order to avoid unwanted tripping in response to normal *operational arcing* at *normal load currents*, the product contains a direct arc detection feature which is intended to operate only when the current is above the handle rating of the overcurrent device. Product No. 3 also incorporates ground-fault interrupting technology as described below.

Modified-Trip Circuit-Breaker Technology Products

Circuit breakers are designed to protect the wiring system against overtemperature caused by overcurrent by limiting the duration of the overcurrent condition. An ordinary branch-circuit circuit breaker generally has two modes of tripping: the thermal mode, and the magnetic (or "instantaneous") mode. The thermal mode is designed to protect the wiring system at the lower end of the range of overcurrent, yet allow for inrush and starting currents characteristic of certain appliances. Examples are appliances containing motors, tungsten filament lamps, and so on. The magnetic mode is designed to protect the wiring system at the upper end of the range of overcurrent where fast tripping is needed. In the magnetic trip mode a circuit breaker may be capable of tripping in less than one cycle of 60 Hz current. The products below incorporating modified-trip circuit-breaker technology alter the current versus trip-time characteristic of the circuit breaker to trip more rapidly at currents which would ordinarily cause a thermal mode trip.

Product No. 4:
Product No. 4 is intended to be part of a circuit breaker mounted in the service panel. The accessory is installed by the circuit breaker manufacturer, and is designed to sense overcurrent indicative of a fault or *overload*. When the duration of an overcurrent condition exceeds that permitted by the accessory, an output signal causes the circuit-breaker to trip by means of a shunt-trip coil in the breaker. To avoid unwanted tripping due to tungsten filament lamp inrush, motor starting currents and the like, the permitted duration of overcurrents is a function of the current magnitude. Product No. 4 is not intended to cause tripping of the circuit breaker for current below the handle rating of the circuit breaker.

Product No. 5:
Product No. 5 is an accessory for use with an ordinary circuit breaker, and is intended to be installed on the load terminal of the circuit breaker in series with the ungrounded conductor. A connection is made from the accessory to a current-limiting resistor which in turn is connected to the neutral bus in the panel. When the branch-circuit current through the circuit breaker and accessory reaches a certain level, the accessory draws additional current from the circuit-breaker to the neutral bus through the current-limiting resistor. This additional current is intended to produce a magnetic trip of the circuit breaker.

Ground-Fault Interrupting Technology Products

Ground-fault circuit interrupters rapidly interrupt the current in a grounded circuit when the vectorial sum of all the currents in the current-carrying conductors to the load exceeds a predetermined value, usually a few milliamperes. This vectorial sum is equal to the differential or "residual" current that flows through ground or through the equipment grounding conductor. Since current to ground is usually unintentional and unwanted current, the ground-fault interrupting device need not delay its tripping to accommodate starting loads and the like. Trip times are similar to circuit breakers that trip magnetically.

For a ground-fault device to be effective, the *fault current* must include current to ground. A fault without a component of ground current will not cause tripping. Therefore, these devices can be effective against fire only where a grounded part is present and is so located that it is likely to draw fault current to ground. The details of the physical layout of the circuitry are critical throughout the load circuitry for a ground-fault interrupting device to be effective against fire scenarios.

Product No. 3:
In addition to the AFD technology, Product No. 3 also includes a ground-fault interrupting feature which reacts to line-to-ground faults caused by line-to-ground arcing, or to arc-induced carbon paths which cause leakage currents to ground. These carbon paths to ground may, but not necessarily will, be formed by *series arcing faults* where the fault current is below circuit-breaker handle rating. The differential current rating of the prototype submitted was 5 mA but according to the manufacturer, the differential current rating may be from 5 mA to 30 mA depending on the application. The manufacturer has indicated that the overall arc detector provides maximum benefit in three-wire (grounded) systems and, therefore, recommends such systems. Refer to description on page 15.

Product No. 6:
Product No. 6 is a European residual current device (RCD) rated 30 mA differential current. It has a 230 V rating and is intended for use on 230/400 V, 3-phase wye-

connected circuits used to supply residential wiring systems in Europe. Ordinary branch circuits in Europe have two current-carrying conductors -- one grounded conductor connected to the neutral point of the supply and the other conductor 230 V to ground.

Despite the differences in wiring systems between Europe and the United States, these European devices can be applied to branch circuits in the United States. Product No. 6 does not require line voltage across its terminals in order to trip -- it will trip electro-mechanically due to current through one pole that is in excess of its differential or residual current rating, with no other connections made to the device and will function in a 120 V or 230 V circuit.

Product No. 7:
Product No. 7 is a 120 V split-bus panel. The circuit-breakers on one part of the panel are fed through a single 5 mA ground-fault interrupting device connected to the other part of the panel. Circuits to be protected by the ground-fault interrupting device, such as general-use receptacle circuits, can be wired to the side of the panel protected by the ground-fault interrupting device. Circuits that supply loads having more urgency for uninterrupted service such as lighting, refrigeration, and central heating systems can be wired to the side of the panel not protected by the ground-fault interrupting device.

Product No. 8:
Product No. 8 is a shielded power supply cord with a ground-fault interrupting device installed in the plug. A non-ferromagnetic shield surrounds each current-carrying conductor individually. The shield is connected to the equipment grounding conductor at the plug. A fault involving any current-carrying conductor will involve the shield before it involves any other conductive surface and the fault current will cause the ground-fault interrupting device in the plug to trip. To extend protection to the load beyond the power supply cord, the physical layout of the product served by the cord would need to incorporate similar shielding.

Supplemental Protection Technology Products

Supplemental protective devices are intended to be installed between the receptacle and the plug of an appliance. These devices provide fused-down customized overcurrent protection for certain loads and/or provide sensitivity to high temperatures that might develop at a plug or receptacle. Though not provided in the products submitted, thermal sensing technology can also be incorporated as an integral part of switches, receptacles, and plugs.

Product No. 9:
Product No. 9 is a thermal sensing device that can be made in three forms: a plug, a

receptacle, or as a portable device intended to be used between a receptacle and the plug of an appliance. The version submitted for this work was the portable device. High temperatures in the plug or receptacle adjacent to the device can be sensed by the device and disconnect the load(s) from the circuit. The devices are provided in many ampere ratings and should be selected to fit a particular load. The highest rating of samples available for this project was 8.5 A, but other ratings are possible. The thermal devices in the submitted samples were single-pole, automatic reset types. However, in the future they are planned to be manually reset types in order to avoid hazards including surprise motor start-ups that can occur from automatic resetting, and future production is planned to be double-pole devices to protect both current carrying poles against high temperature.

Product No. 10:
Product No. 10 is a fused plug adapter that is intended to be inserted between a receptacle and the plug of an appliance. It contains a 1/4 dia. x 5/8-inch fuse rated 125 V, 5 A. The device is intended to protect the power supply cord and the connected appliance with an overcurrent device of a much lower rating than the 15- or 20 A branch-circuit overcurrent device.

Surge Protection Technology Products

Insulation in wiring systems without surge protection are continually challenged by transient voltage spikes resulting from lightning and switching. These voltage spikes typically range up to several kilovolts. Years of continual hammering by these spikes can weaken insulation which can eventually break down, increasing the likelihood of a fault.

A surge arrester is a nonlinear device that has very high impedance when the voltage across it is below a certain level, but that has low impedance when the voltage across it exceeds that level. A surge arrester installed across the line or from line to ground at the service equipment of an electrical service draws very little current when the voltage remains at the rated 120 V levels. However, when surges, impulses, etc. occur due to lightning or switching, the surge arrester presents a low impedance to voltages above a few hundred volts. This clips the transient voltage excursion to a level that the insulation in the wiring system can withstand much more easily without a high risk of failure. By reducing the risk of failure of insulation, the risk of fire is also reduced.

Product No. 11:
Product No. 11 is a combination surge arrester and a 125 A rated circuit breaker. The product is in the form of a meter-socket adapter. It plugs into a meter socket, and the meter plugs into it. The location of installation exemplified by the product submitted provides an opportunity to protect the entire residence against potentially damaging

transient overvoltages and overcurrent. Since testing standards are available to evaluate surge-protection technology, no surge suppression testing was conducted. Also, since the rating of the circuit breaker (125 A) was such that it would likely operate in the thermal region at the fault currents used in the tests (limited to 300 A or less), it was not subjected to the tests. Even though no tests were conducted, the circuit breaker in this product can provide some level of overcurrent protection for circuits that may have no protection at all, particularly in older residences where individual overcurrent protection devices may have been defeated.

IV. BASIS FOR SELECTION OF TESTS

The relationship between the efficacy tests conducted under this project and various mechanisms of electrical overheating that may directly cause or lead to ignition in the residential electrical distribution system are described in this section of the report.

An electrically caused fire may occur if electrical energy is unintentionally converted to thermal energy and if the heat so generated is transferred to a combustible material at such a rate and for such a time as to cause the material to reach its ignition temperature. There are two dominant mechanisms involved in converting electrical energy to thermal energy in the electrical distribution system. The first is *Joule heating*, which is commonly referred to as *resistance heating* and *I^2R heating*. The second is *arc heating*. Dielectric heating and induction heating are also possible, but generally represent insignificant heat sources in the residential electrical distribution wiring system at power frequencies.

I^2R Heating

The generation of normal, non-injurious I^2R heat is an unavoidable side effect in the distribution of electrical power since such heating occurs whenever current flows through a conductor. Abnormal I^2R heating (excessive I^2R x time) can also occur and cause overtemperature under the conditions described where I is the current in the circuit, R is the resistance of the conductor in which I^2R heating is occurring, and t is the duration of the condition.

Abnormally High I at Normal R Over Sufficient Time t:
An overcurrent condition (abnormally high I) may occur as the result of an overload, an *across-the-line fault* (e .g., short-circuit), or a *line-to-ground fault* (ground fault). In order for an overcurrent condition to thermally damage a conductor it must persist long enough to generate sufficient thermal energy (= I^2R x time) in the conductor[2]. Present conventional overcurrent protection devices like fuses and circuit breakers are intended to preclude overheating of properly sized conductors that are subjected to overcurrent by limiting the duration of the overcurrent. If the overcurrent protective device is bypassed or defeated, however, the overcurrent condition may persist resulting in overheating possibly causing or leading to a fire. The likelihood that overcurrent protection may be bypassed or defeated is greater in older residences due to inadequate capacity.

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[2] "The Fire Investigation Handbook" from the U.S. Department of Commerce, NBS, Aug 1980, places overheating of wires as a result of overcurrent under the category of "overheated conductors."

Normal I at Abnormally High R Over Sufficient Time t:
This condition may be the result of either a *high resistance series fault* condition such as poor electrical connection, damaged conductor of reduced cross sectional area, or the use of inadequately sized conductors or connectors like undersized extension cords, wiring terminals or wiring connectors, and makeshift wiring extensions.[3] The probability of undersized or damaged wiring being used is likely to be higher in older residences where a greater number of extension cords are used and, therefore, exposed to damage, and where makeshift extensions to the fixed wiring system are made in order to increase the number of outlets on a limited number of branch circuits. Although the resistance in an undersized or faulted wire or wiring connection may be high in terms the normal electrical distribution circuit resistance, it may still be low in terms of the load so as to have a negligible effect on load current. In any case, since an overcurrent condition is not involved, no overcurrent protection device will detect the condition. The "Overheating Conductor; "Hot Plug" and "Glowing Connection" tests conducted under this project represent high resistance series-fault conditions.

Both Abnormally High I and R Over Sufficient Time t:
This condition is simply a combination of abnormally high current at normal resistance and normal current at abnormally high resistance over sufficient time. The probability of this combination of hazardous conditions occurring may be higher in older residences because 1) the availability of fewer branch circuits makes overloading a given circuit more likely, 2) the inadequate capacity of the service makes it more likely that overcurrent protection devices will be defeated or replaced by higher rated devices, and 3) the installation of extension cords and makeshift wiring extensions, in order to increase the number of outlets, increases the probability that inadequately sized wire or damaged conductors may be present. Since conventional overcurrent protection devices are designed to protect properly sized conductors against overcurrent, they may or may not protect undersized conductors subjected to overcurrent, and they may or may not prevent overheating at high resistance faults subjected to overcurrent.

Arc Heating

The electrical discharge of an arc can involve temperatures on the order of several thousand degrees Celsius. In determining the heating effects of an arc, the classical Joule heating formula (I^2R) does not hold well. Although the total power dissipated in the arc is equal to the total voltage drop in the arc times the arc current, power dissipation varies considerably over different regions of the arc.

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[3] "The Fire Investigation Handbook", ibid footnote 2, places high resistance series faults that involve electrical connections and contacts under the category of "glowing connections/contacts" and high resistance faults that involve non conductors or semi conductor materials under the category of "overheating nonmetals."

Arcing can occur in the electrical distribution system in a number of ways. For convenience, arcing scenarios can be categorized as follows.

Non-Contact Arcing:
Non-contact arcing is arcing that does not require direct physical contact between the conductors or "electrodes" where the arcing is taking place. Initiation of the arc can occur in a number of ways and will depend upon a number of variables including the geometries of the conductors, the type and configuration of the insulating medium between the conductors, and the applied voltage.

Arcing Between Conductors Separated by Normal Insulation - The mechanism of initiating an arc between stationary conductors separated by insulation will depend on the type and geometries of the conductors and insulation between them. Paschen's rule indicates that a minimum of about 330 V peak is needed to initiate an arc across an air gap. In the case of typical air clearances in the electrical distribution system, several to tens of kilovolts is required[4]. Transient overvoltages resulting from lightning and switching events are sometimes sufficient to initiate the process. The possibility that such an arcing condition can cause ignition will depend upon the energy associated with the transient and the level and duration of any power frequency follow current. Solid insulation between the conductors increases the required voltage to cause breakdown, except in the case where the surface of solid insulation becomes contaminated (dirt, moisture), in which case arc tracking may occur along the surface of the insulation at normal operational voltages. Surface tracking may be more prevalent in older homes where there is long term exposure of the wiring system and its components to contamination and the effects of contamination. The "Wet Track Arc Fault" tests conducted under this project creates surface arc tracking conditions at normal line voltage.

Arcing Between Conductors Separated by Degraded (carbonized) Insulation - Arcing can also occur at normal operational voltages in the event that organic insulation has somehow become degraded (carbonized). If the carbonized insulation has inadequate ampacity to carry the resulting fault current, the carbon path opens and an arc is established in a manner similar to parting conductors initially in contact as further discussed. It can be demonstrated that such carbonization can occur in the following ways, some of which may be more likely to occur in the wiring systems of older residences.

1. Gradual breakdown through solid insulation due to repeated transient overvoltages.

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[4]"The Fire Investigation Handbook", ibid footnote 2, refers to "Arc Faults" as those which are "caused by high-voltage breakdown of the air gap between a conductor and ground or between two electrical phases of a three-phase distribution system."

2. High voltage electrical tracking across the surface of solid insulation due to repeated transient overvoltages.

3. Line voltage (e.g. 120 Vac) arc tracking (wet tracking) across the surface of the insulation due to deposition of contaminants and moisture on the surface.

4. Thermal decomposition of the insulation due to exposure to a heat source. Examples of heat sources that may cause the decomposition include:

> A. Joule heating at a high resistance series fault (e.g., reduced cross sectional area of a damaged wire, poor electrical connection, etc.),
>
> B. Arc heating at a series arcing fault (e.g., intermittent contact in a broken wire, loose electrical connection, etc.), and
>
> C. Heat from a fire (re: fire reports describing evidence of arcing in cables being the result rather than the cause of a fire).

Decomposed insulation between opposite polarity conductors or between a line voltage conductor and ground can lead to an *across-the-line arcing fault* or a *line-to-ground arcing fault*. The fault current will depend upon the total impedance in the circuit containing the fault. If the decomposed insulation is in series with the load, as in the case of tracking across insulation between terminals of a single pole switch while the contacts are in the open position or in the case of carbonization of insulation at a broken conductor (see closing/parting conductors, below), then the arcing fault condition is referred to as a series arcing fault. In this case, the fault current is generally limited by the load (unless the *series fault* is combined with an overload, *short circuit* or ground fault downstream). Finally, since decomposed (i.e., carbonized) insulation is involved in each of these arcing fault conditions, arcing fault conditions are referred to as carbonized path arcing faults. The "Carbonized Path Arc Fault" and "Partial Carbonized Path Arc Fault" tests conducted under this project are intended to represent the end state, or near end state, of the formation of a carbonized path. Although the technique used to create the carbonized path was to use high voltages, the end result may be considered representative of any of the mechanisms described above.

<u>Contact Arcing</u>:
Contact arcing is arcing that involves direct or indirect physical contact between the conductors or "electrodes" where the arcing is taking place. Some of the mechanisms

are described as follows.

Arcing at Stationary Contacting Conductors - An extremely thin semi-insulative layer of material may be formed at the interface of two conductors that are normally intended to be in good electrical contact. The formation of this layer may be the result of long-term oxidation or of any kind of chemical attack at the contact interface. If one views an oxide coating at the interface between two conductors as an extremely thin dielectric, then the application of even normal voltages in residential circuits (e.g. 120/240 V) across the coating can result in a very high voltage gradient (volts/mil) capable of breaking down the dielectric. According to one theory the ensuing electrical discharge, sometimes referred to as a "micro arc", may create a fine metal bridge through the oxide, momentarily dropping voltage. If the metallic bridge is not capable of carrying the current, it vaporizes due to joule heating. The rupturing of the bridge draws another "micro arc" which, upon extinguishing, allows the voltage at the contact interface to again rise until breakdown occurs at another contact site of the oxide coating. The heat generated by the process helps to continue to oxidize other surfaces. The process of creating and destroying metallic bridges with accompanying electrical discharges (arcs), may continue throughout the contacting surfaces such that the cumulative effect of the micro arcing may generate considerable heat capable of igniting materials and possibly forming a higher resistance electrical alloy at the junction of the two contacting conductors.

The previously described arcing phenomena has been theoretically cited in the literature as being associated with what has been referred to as a "glowing connection" at the terminal screws of receptacles. However, this type of arcing may theoretically occur at any electrical connection in which a thin dielectric forms between the intended surface contact area. This work includes such an arcing condition as being under the general category of series arcing faults, in which the arcing current is generally limited by the load. The phenomenon of "micro arcing" was observed during the "Series Make/Break Contact Arc: Loose Terminal" Test conducted under this project.

Arcing Between Closing or Parting Conductors Making or Breaking a Circuit - This arc initiation mechanism involves circumstances which are favorable to a gas or metallic vapor release by the conductors, either in the form of plain thermal vaporization or as a more direct result of bombardment by the plasma particles. Arcing thus occurs through the gas of metallic vapor. If one of the conductors is liquid, molten, deformable, or of irregular contact surface geometry, then arcing may be generated as a result of a hot point (resulting itself essentially from I^2R heating) at the last point of contact in the case of where a circuit is being interrupted (e.g., conductors initially in contact are parting), or at the first point of contact where a circuit is being established (e.g. conductors that are initially separated and subsequently come into contact).

This type of arcing is associated with normal operational arcing[5] that occurs with any kind of air gap type electrical switching device, except that properly designed switching devices are capable of withstanding such arcing without excessive contact damage or generation of excessive heat. It may also be associated with arcing faults due to the unintentional creation or interruption of current as follows.

1. Conductor motion resulting in unintentional contact between uninsulated opposite polarity conductors or between a line conductor and ground. The subsequent rupturing of the conductors upon contact can draw a violent across-the-line or line-to-ground arcing fault. The "Damped Motion Contact Arc" test conducted in this project represents such an arcing fault.

2. Rupturing (separation) of an initially intact conductor (wire and/or wire connection) that results from an overcurrent condition that the conductor/connector is unable to carry and thus clears the circuit creating an arc (e.g., series arcing fault that is the result of a high resistance fault being unable to withstand an overcurrent condition).[6]

3. Conductor motion resulting in intermittent contact between broken ends of a wire with or without carbon interposed between the broken ends (series arcing fault).[7] The "Series Make/Break Contact Arc: Broken Wire" test and the two "Arc Simulator" tests conducted in this project represents such an arcing fault.

4. Conductor motion resulting in intermittent contact at an intended wiring termination or connector with or without carbon at the contact interface (series arcing fault).[6] The "Series Make/Break Contact Arc: Loose Terminal" test and the two "Arc Simulator" tests conducted in this project represents such arcing faults.

5. Arcing caused by the bridging of conductors by an electrically conductive object. This arc initiation mechanism can result if, for example, the insulation between two insulated conductors is displaced or bridged by a

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[5]Referred to as "on-line arcing/sparking" in "The Fire Investigation Handbook", ibid footnote 2. The hazards associated with arcing/sparking in a flammable atmosphere as discussed in the Handbook is outside the scope of this project.

[6]Referred to in "The Fire Investigation Handbook", ibid footnote 2, as an "exploding wire/contact."

[7]Referred to as "on-line arcing/sparking" in "The Fire Investigation Handbook", ibid footnote 2. The hazards associated with arcing/sparking in a flammable atmosphere as discussed in the Handbook are outside the scope of this project.

sharp conductive object such as a knife, wire cutters, a driven nail, or the like resulting in an across-the-line or line-to-ground arcing fault. Such abuse may be more likely to occur in older residences where the use of extension cords and makeshift wiring is more extensive. The arcing phenomena is essentially the same as discussed except that the arcing occurs at the interface between the conductors and the externally applied conductive object as opposed to direct physical contact between the conductors. The "Point Contact Arc (Guillotine)" Test conducted in this project represents such an arcing fault. Figure 1 illustrates electrical heating mechanisms and representative tests.

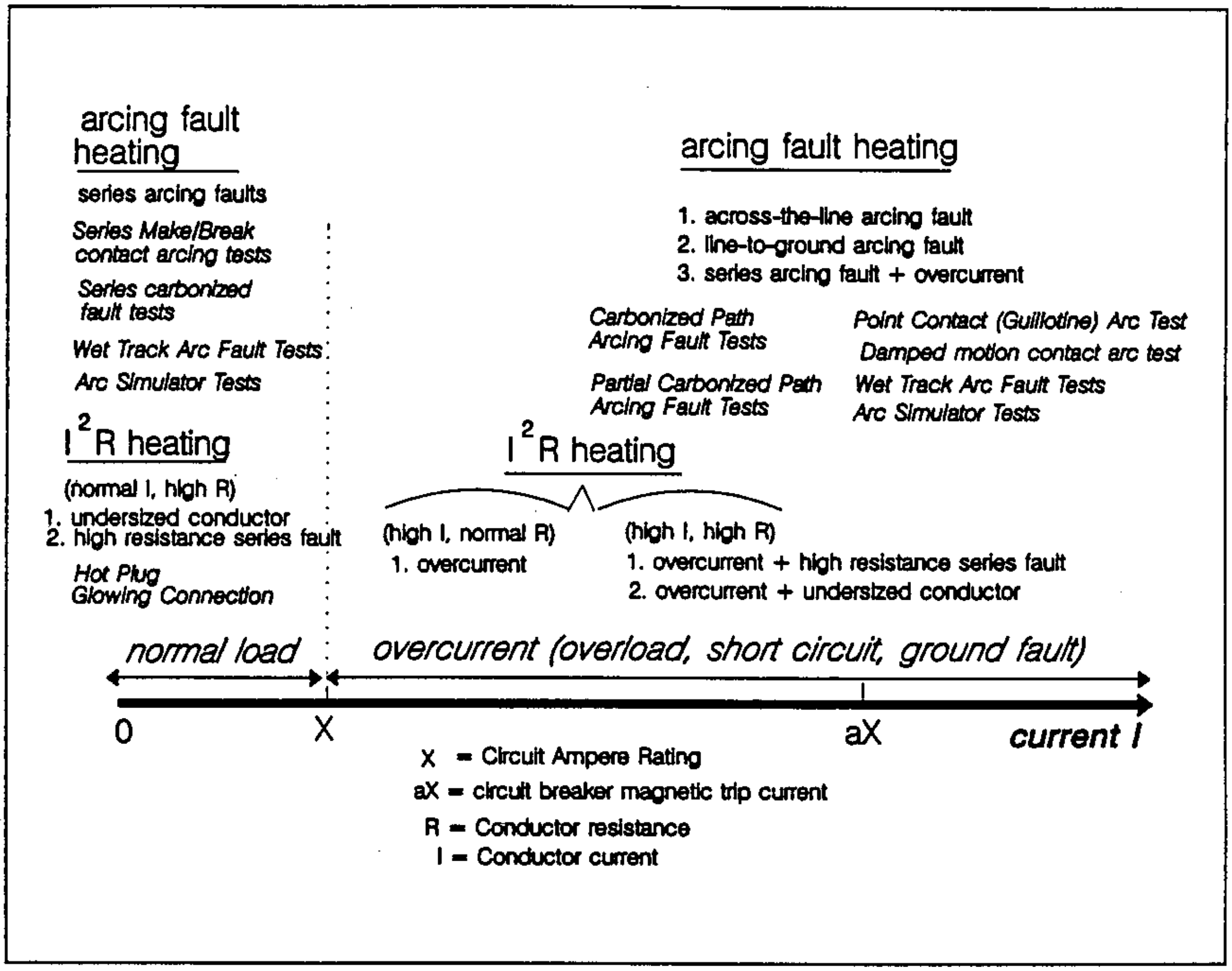


Fig. 1 - Electrical Heating Mechanisms and Representative Tests.

V. TEST DESCRIPTION AND DATA

The selected tests are described and the data developed for each test is presented in this section of the report.

The tests conducted under this project are not intended to determine "acceptability". The tests are intended only to demonstrate the feasibility of performing certain tasks with new technology or with new applications of existing technology. It is important to note that there are no published standards to declare requirements covering many of the products studied in this project. These tests are not intended to imply any assumed expectations for the products studied. These tests are exploratory in that they not only relate to the manufacturer's claims regarding the product, but also extend beyond that to learn more about the limitations.

The products and technology studied address events that are unpredictable and that can take an extended period of time to develop under natural circumstances. By necessity, the test program contains methods that are designed to expedite testing. The methods used could contribute to some bias or inaccuracies. Wherever possible during the efficacy tests, it was attempted to make the test conditions favorable for the device under test to function as intended. The objective is to show feasibility, and to show where each device has the potential to address fire scenarios.

The tests were divided into three categories: 1) efficacy, 2) operation inhibition, and 3) unwanted tripping.

Efficacy pertains to the ability of the device to perform certain tasks, that is, can the device perform the task? Is it possible under favorable circumstances?

Operation inhibition explores the possibility that a device might be "blinded" to the problem by other equipment that either filters out signals needed to sense a potential hazard or that emits signals that are extraneous to the task, but that confuse the protective device making it ineffective.

Unwanted tripping explores the possibility of tripping due to operational arcing, spurious signals, or due to proper signals under the wrong circumstances.

Tests were performed to demonstrate certain aspects of the performance of the products. Table 1 identifies the products which were subjected to each test. The numbers identifying the products correspond to the product numbers assigned and described in Section III of the report. The rationale for conducting tests on some products and not on others is subsequently described Section VII of the report.

Table 1

Tests Conducted on Products

TEST	PRODUCT NUMBER										
	1	2	3	4	5	6	7	8	9	10	11
Point Contact Arc (Guillotine)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Damped-Motion Contact Arc	✓	✓	✓	✓	✓						
Carbonized-Path Arc Fault	✓	✓	✓	✓	✓	✓	✓			✓	
Partial Carbonized Path Arc Fault	✓	✓	✓	✓	✓	✓			✓	✓	
Rotational Flexing								✓			
Wet-Track Arc Fault	✓	✓				✓					
Arc Simulator Number 1	✓	✓		✓							
Arc Simulator Number 2	✓	✓	✓	✓							
Series Make/Break Contact Arc: Loose Terminal	✓	✓		✓							
Series Make/Break Contact Arc: Broken Wire	✓	✓									
Overheating Conductor: Glowing Connection	✓	✓		✓					✓		
Overheating Conductor: Hot Plug									✓	✓	
Operation Inhibition	✓	✓									
Unwanted Tripping	✓		✓	✓	✓						

Efficacy

Arc Faults:
The arc-fault tests are intended to demonstrate the effectiveness of protective devices to mitigate the effects of arcing in a circuit. A number of different tests are used to explore the response of the products to various arc faults which include the following:

- point contact arc (guillotine)
- damped-motion contact arc
- carbonized path arc fault
- partial carbonized path arc fault
- rotational flexing
- wet track arc fault
- arc simulator number 1
- arc simulator number 2
- series make/break contact arc: loose termination
- series make/break contact arc: broken wire

Although flexible cords were used for a number of these tests, the purpose of the tests was not to test cords or cables. They are tests of devices exemplifying certain technologies to determine the response to arcing that occurs when organic insulation has degraded to form carbonized material through which fault current can flow. The type of cord construction used for the carbonized specimens is not critical for these tests provided that the insulation is an organic material that carbonizes under high-temperature conditions such as from joule heating or arcing. For convenience, essentially all of the arc-fault testing involving wiring was performed with No. 16 AWG SPT-2 power supply cord specimens rather than with jacketed cord specimens or sheathed types of permanently-installed cable specimens. Our previous experience indicated that SPT-2 cord specimens are easier to prepare than jacketed or sheathed specimens and produce more repeatable test results.

Unless otherwise specified, the contacts of the protective device are closed and line voltage is applied to the device prior to introducing the arc fault.

Point Contact Arc (Guillotine):

An SPT-2 power supply cord is supported on a hard surface. Voltage from a 120 V source having approximately 300 A short-circuit capability is placed across the conductors of the cord or cable. No load is connected. A 6-inch square of cotton cheesecloth is loosely bunched and placed on each side of the blade. A dull steel blade is forced down onto the cord or cable until the insulation is severed and contact is made with both conductors. The blade is angled so that contact is made with one conductor before contact is made with the other. Local heating occurs from arcing where the conductors are bridged by the blade across-the-line. Unprotected, fire usually results from ignition of insulation or the ignition of the fire indicator. It is determined whether the protective device under test can interrupt the current before the fire occurs.

Key to Headings and Abbreviations Used in the Presentation of Data on Pages 33-42

Volts -- Open-circuit supply voltage.

Short-circuit Current -- Available current to the test terminals under a bolted fault condition at the terminals. "Test terminals" are either wire-binding posts or a receptacle connected to these posts. A "bolted fault" is a low-impedance, high-integrity connection with no arcing. The addition of the test specimen cord and any impedance associated with the protective device in the circuit reduces the test current.

Trip? (Y or N) -- Indicates whether the protective device opened the circuit.

F.I. Ignite? (Y or N) -- "F. I." means "fire indicator". Indicates whether the cheesecloth fire indicator ignited.

Time (msec) -- The duration of the fault current, in milliseconds.

Max (volts) and Min (volts) -- The readings taken from the digital oscilloscope through a pulse-current transformer. To convert to peak positive and/or peak negative current in amperes, multiply the value by 100 (scaling factor).

UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 1	Arc Fault Detector

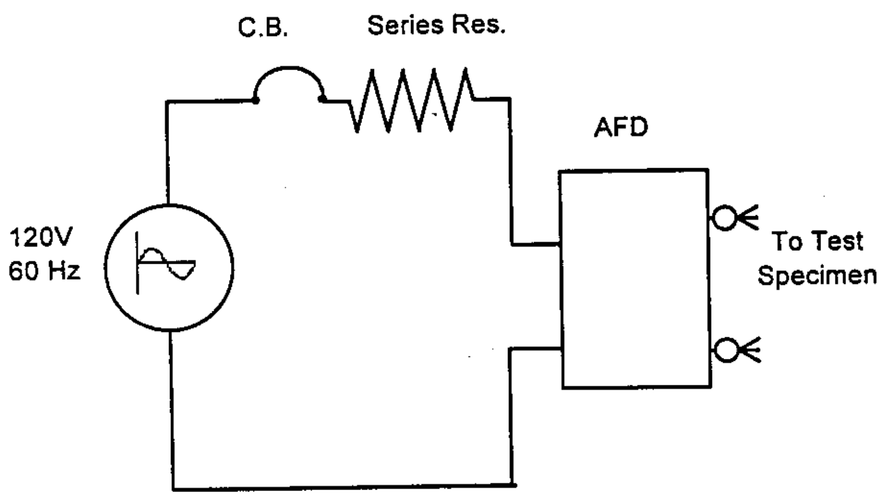
Test Summary

Point Contact Arcing Fault (Guillotine)

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	290	Y	N	33.2	3.20	3.20	
2	118	290	Y	N	39.4	3.20	3.20	
3	118	290	Y	N	37.7	3.20	3.20	
4	118	290	Y	N	39.0	3.20	3.20	
5	118	290	Y	N	30.6	3.20	3.20	
6	118	290	Y	N	37.8	3.20	3.20	

Notes:

Circuit:



UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 2	Arc Fault Detector

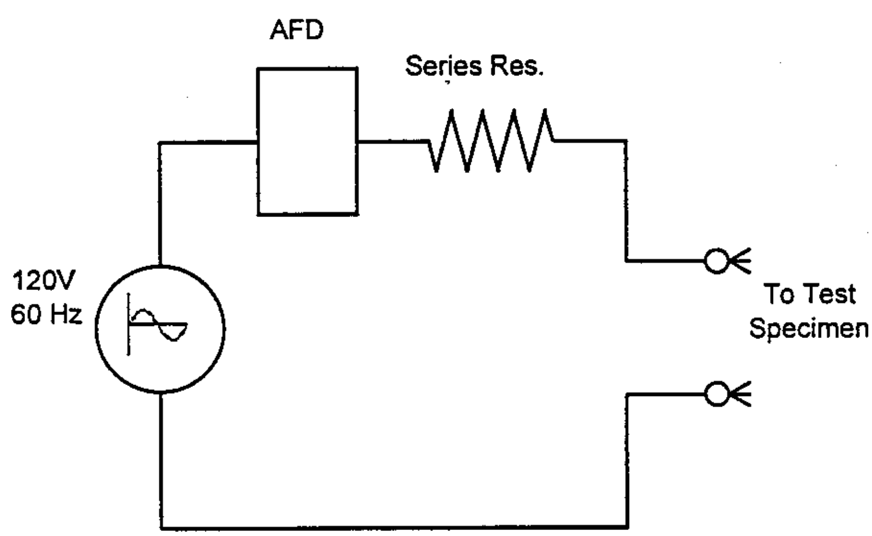
Test Summary

Point Contact Arcing Fault (Guillotine)

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	290	Y	N	7.2	0.00	3.04	
2	118	290	· Y	N	7.2	0.00	2.88	
3	118	290	Y	N	13.6	2.48	2.88	
4	118	290	Y	N	14.1	1.88	4.00	
5	118	290	Y	N	9.9	2.84	1.24	
6	118	290	Y	N	5.7	2.68	0.04	
7	118	290	Y	-	11.2	4.08	2.76	Bolted fault

Notes:

Circuit:



UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 3	Arc Fault Detector

Test Summary

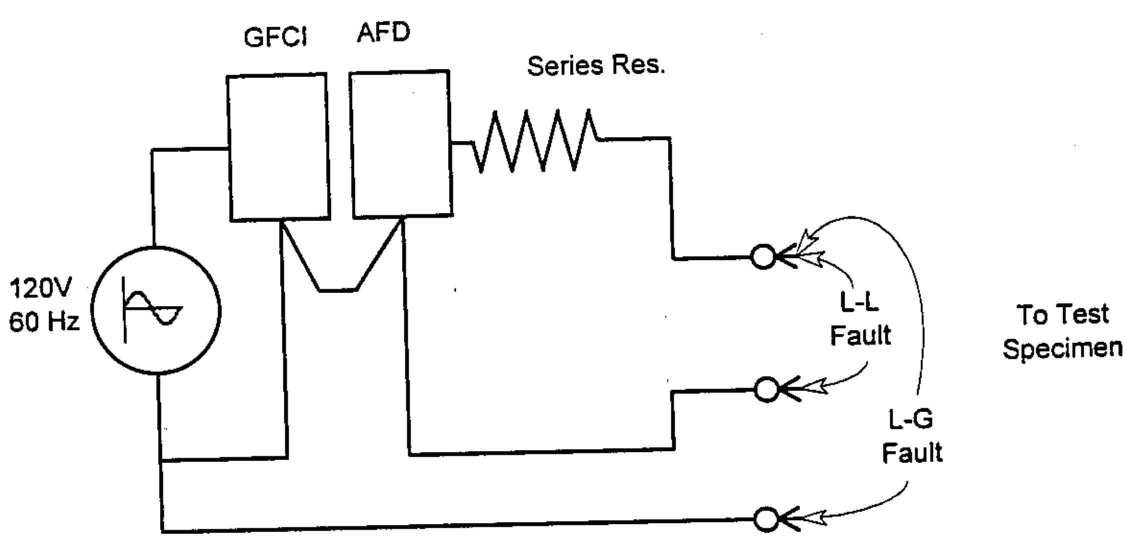
Point Contact Arcing Fault (Guillotine)

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	290	Y-A/G	N	21.5	1.84	3.76	Line-Line Fault
2	118	290	Y-A/G	N	15.5	2.80	2.72	Line-Line Fault
3	118	290	Y-A	N	-	-	-	Line-Line Fault
4	118	290	Y-A	N	15.2	3.84	1.68	Line-Line Fault
5	118	290	Y-A/G	N	13.8	2.96	3.68	Line-Line Fault
6	118	290	Y-A/G	N	16.8	3.92	1.68	Line-Line Fault
7	118	290	Y-G	N	12.2	1.84	1.52	Line-Ground Fault
8	118	290	Y-G/A	N	-	-	-	Line-Ground Fault
9	118	290	Y-G/A	N	13.7	3.84	1.84	Line-Ground Fault
10	118	290	Y-G	N	6.4	2.80	0.08	Line-Ground Fault
11	118	290	Y-G	N	11.3	2.16	2.00	Line-Ground Fault
12	118	290	Y-G/A	N	11.3	1.52	3.92	Line-Ground Fault
13	118	290	Y-A	-	5.1	3.76	0.00	Bolted fault

Notes:

Trip - A=AFD trip
G=GFCI trip

Circuit:



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UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 4	Modified Trip circuit Breaker

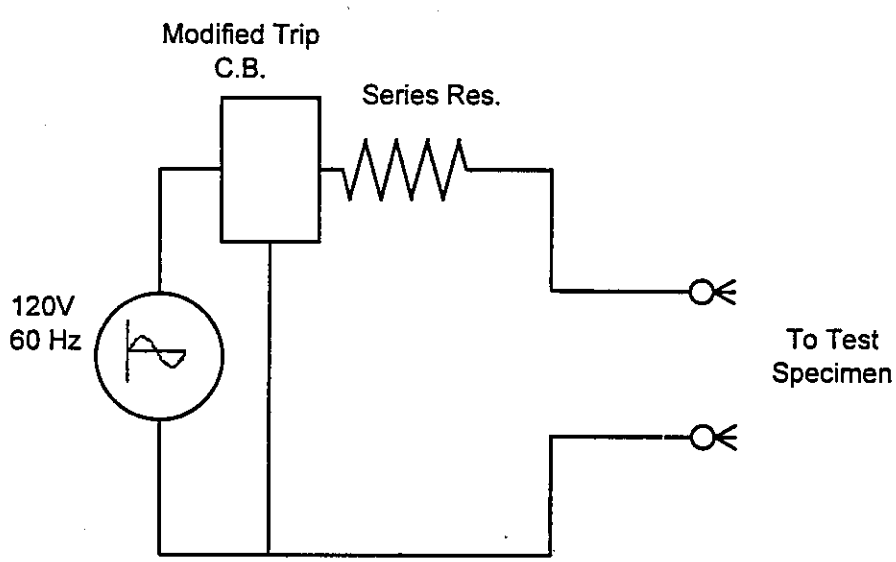
Test Summary

Point Contact Arcing Fault (Guillotine)

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	290	Y	N	7.3	3.12	0.16	Class II device
2	118	290	Y	N	12.9	4.00	2.00	Class II device
3	118	290	Y	N	5.7	2.72	0.08	Class II device
4	118	290	Y	N	10.5	1.84	2.16	Class II device
5	118	290	Y	N	4.9	2.72	0.08	Class II device
6	118	290	Y	N	12.6	2.80	1.36	Class II device
7	118	290	Y	-	6.9	4.08	0.24	Bolted Fault
8	118	290	Y	-	182	4.16	4.16	Bolted Fault w/o accessory connected

Notes:

Circuit:



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Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 5	Modified Trip Circuit Breaker

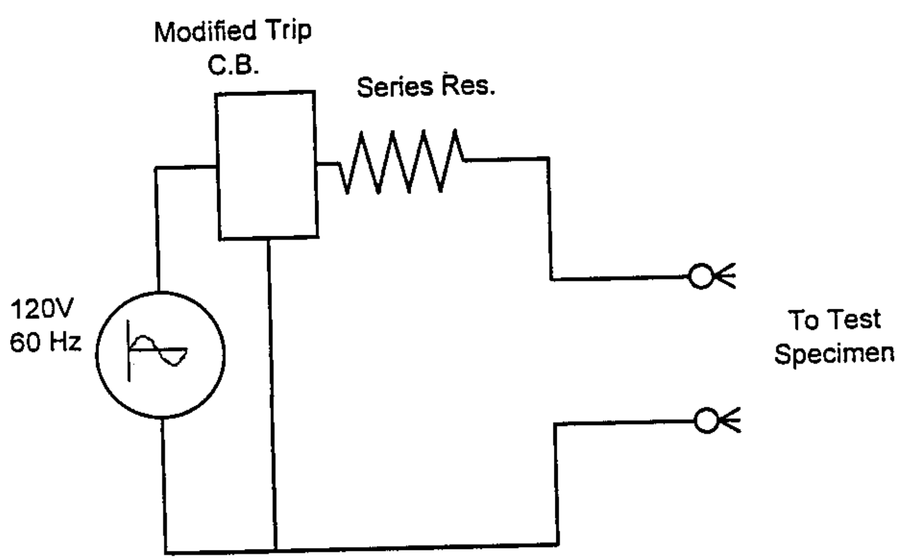
Test Summary

Point Contact Arcing Fault (Guillotine)

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	290	Y	N	10.6	2.76	1.08	
2	118	290	Y	N	4.9	0.00	1.96	
3	118	290	Y	N		-	-	
4	118	290	Y	N	6.5	2.68	0.08	
5	118	290	Y	N			-	
6	118	290	Y	N	7.1	2.92	0.04	
7	118	290	Y	-	8.6	4.08	0.16	Bolted Fault

Notes:

Circuit:



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Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 6	Ground Fault Interrupting Device

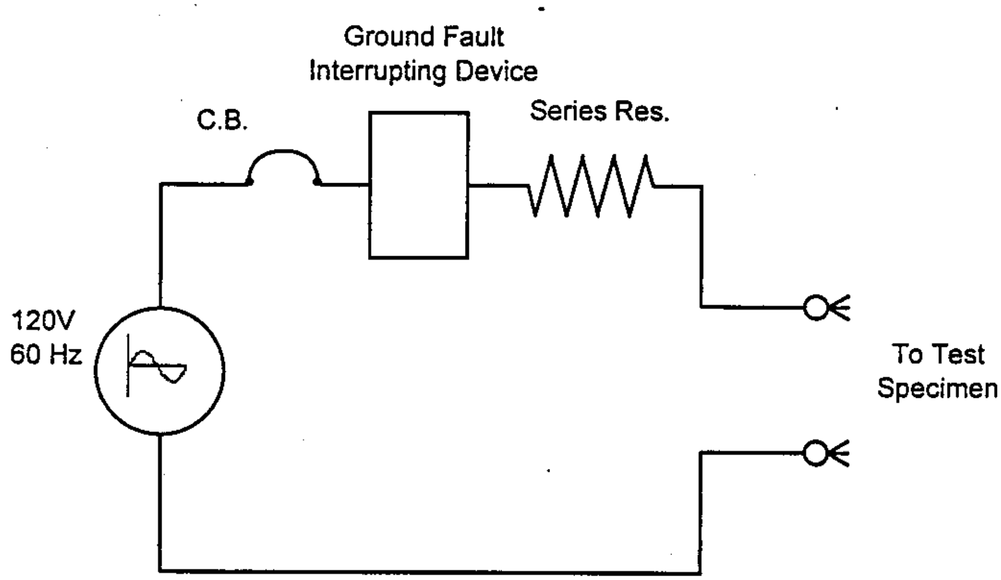
Test Summary

Point Contact Arcing Fault
(Guillotine)

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	290	Y	N	31.3	3.28	4.00	
2	118	290	Y	N	29.7	4.00	4.00	
3	118	290	Y	N	29.2	4.00	4.00	
4	118	290	Y	N	27.4	3.04	3.20	
5	118	290	Y	N	28.9	4.00	4.08	
6	118	290	Y	N	29.4	4.00	4.00	

Notes:

Circuit:



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UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 7	Ground Fault Interrupting Device

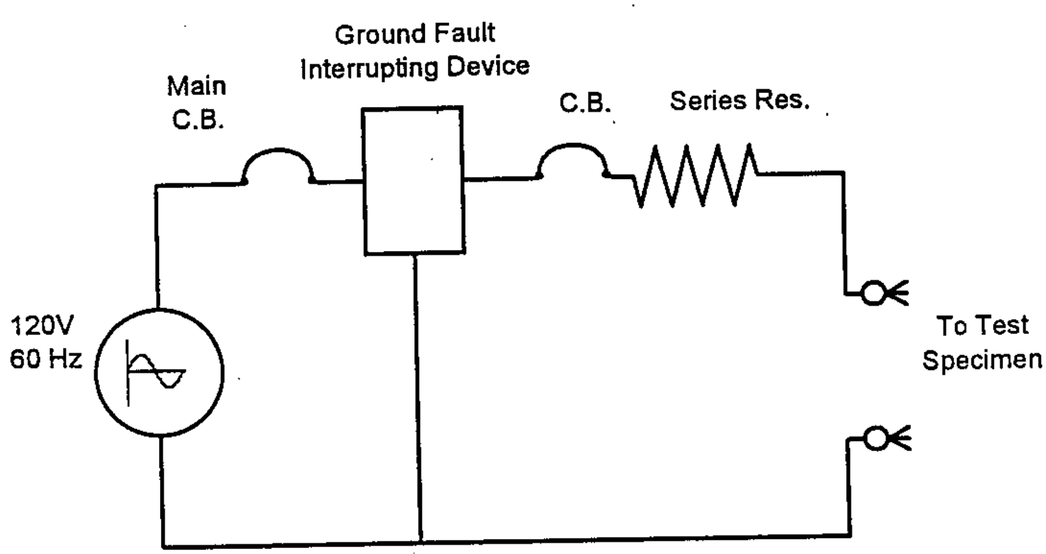
Test Summary

Point Contact Arcing Fault (Guillotine)

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	290	Y	N	20.0	3.92	2.80	Line-Ground Fault
2	118	290	Y	N	11.8	1.84	1.68	Line-Ground Fault
3	118	290	Y	N	23.9	3.92	3.20	Line-Ground Fault
4	118	290	Y	N	23.9	3.92	4.00	Line-Ground Fault
5	118	290	Y	N	23.9	3.04	2.96	Line-Ground Fault
6	118	290	Y	Y	23.9	3.92	3.92	Line-Ground Fault

Notes:

Circuit:



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UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used

Product	Device
# 8	Ground Fault Interrupting Device

Test Summary

Point Contact Arcing Fault
(Guillotine)

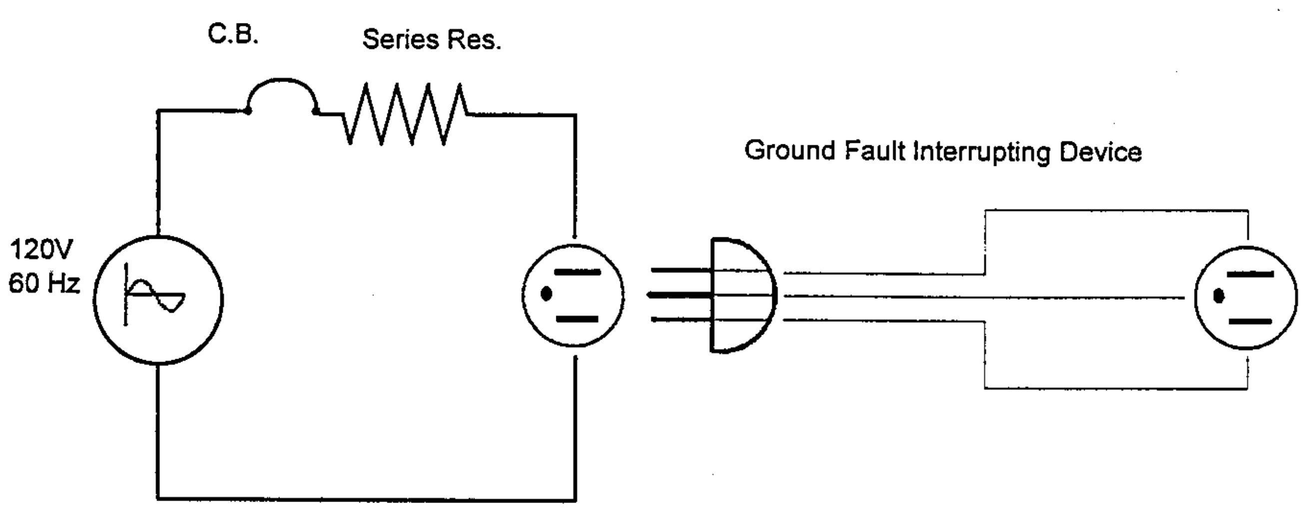
Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Cord Orientation			Comments
1	120	300	Y	N	W			
2	120	300	Y	N	W			
3	120	300	Y	N	W			Did not cut through cord
4	120	300	Y	N	B			
·5	120	300	Y	N	B			
6	120	300	Y	N	B			

Notes:

Cord Orientation: Refers to cord conductor nearest hinge on test apparatus
W=White, B=Black

This test run on cord specimen integral with g-ound fault protection technology.

Circuit



UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 9	Supplementary Protective Device

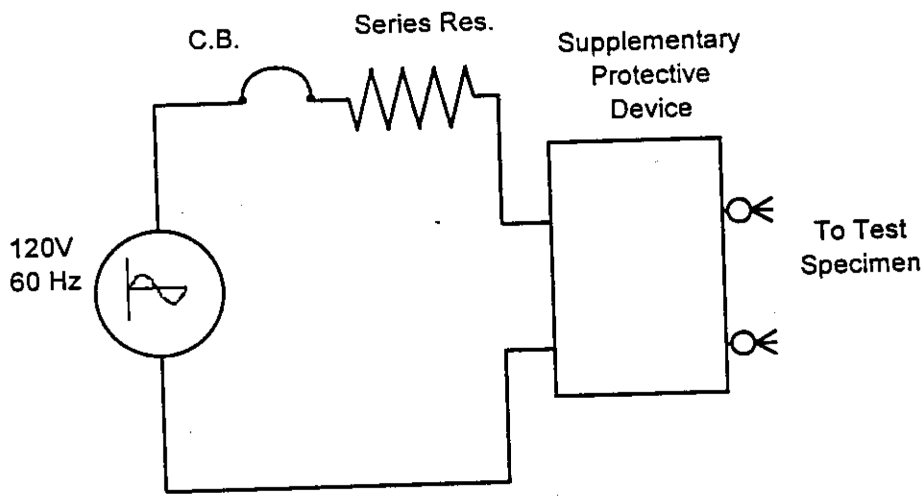
Test Summary

Point Contact Arcing Fault (Guillotine)

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	290	Y	N	-	-	-	Sample # 36
2	118	290	Y	N	-	-	-	Sample # 38
3	118	290	Y	N	23.6	2.72	3.44	Sample # 51

Notes: Each sample subjected to this test remained permanently open following the test

Circuit:



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UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 10	Supplementary Protective Device

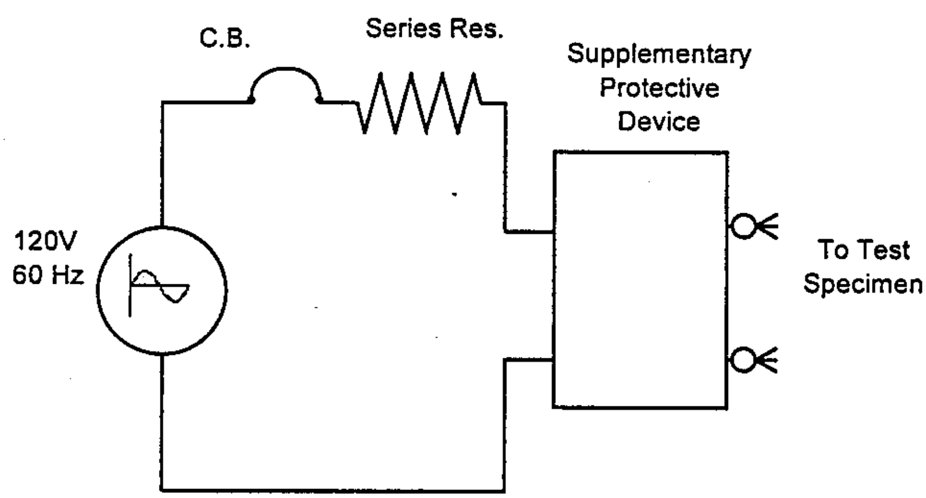
Test Summary

Point Contact Arcing Fault (Guillotine)

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	290	Y	N	-	-	-	Scope did not trigger
2	118	290	Y	N	-	-	-	Scope did not trigger
3	118	290	Y	N	-	-	-	Scope did not trigger

Notes:

Circuit:



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Damped-Motion Contact Arc:
The damped-motion contact arc test fixture provides a mechanism to slowly bring two bare conductors together with a controlled and repeatable motion. This fixture was supplied by one of the participants. The conductors used are typically from a No. 16 AWG SPT-2 cord. One conductor is stripped of its insulation and placed on a supporting surface in the fixture. The end of the other conductor is stripped and the strands are fanned out. The second conductor is mounted in the fixture over the first conductor. Voltage is placed between the conductors from a 120 V supply having approximately 300 A short-circuit capability. An arm with an insulating end slowly descends on the conductors, pushing the fanned-out end of the upper conductor onto the lower conductor, making firm contact between the bare conductors. It is determined whether the device under test can interrupt the arcing fault.

Key to Headings and Abbreviations Used in the Presentation of Data Pages 44 - 48

Volts -- Open-circuit supply voltage.

Available Short-circuit Current -- Available current to the test terminals under a bolted fault condition at the terminals. "Test terminals" are either wire-binding posts or a receptacle connected to these posts. A "bolted fault" is a low-impedance, high-integrity connection with no arcing. The addition of the test specimen cord and any impedance associated with the protective device in the circuit reduces the test current.

Trip? (Y or N) -- Indicates whether the protective device opened the circuit.

Conductor Configuration -- Refers to the configuration of the individual stranding of the upper (moving) conductor. In a vertical "fan" formation, the individual strands are sequentially brought into contact with the lower conductor. In a horizontal fan configuration, the strands are generally brought into contact with the lower conductor simultaneously. The twisted configuration was similar to a solid conductor.

UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V

Product	Device
# 1	Arc Fault Detector

Test Summary

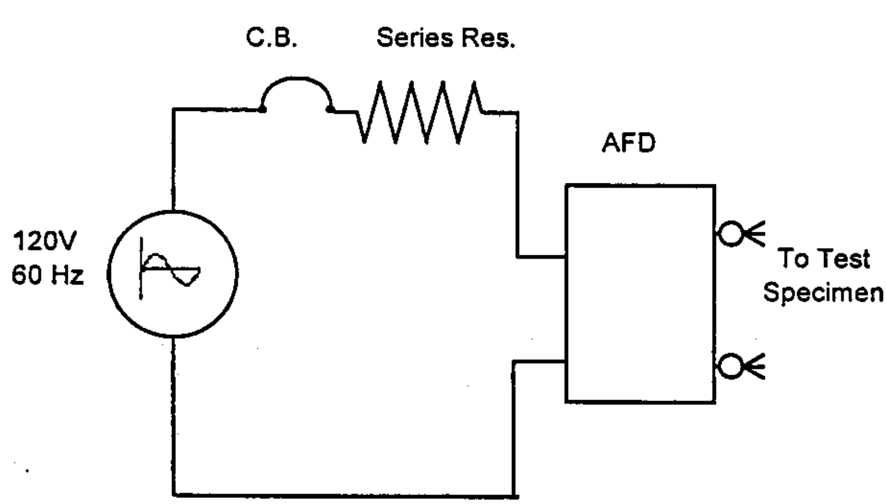
Damped Motion Contact

Run	Volts	Available Short-Circuit Current	Trip (Y / N ?)	Strand Config.	Comments
1	119	300	Y	H	Flash, then trip
2	119	300	N	H	Multiple pops, cord fused open, strands welded
3	119	300	N	H	Multiple pops, cord fused open, balling of strands
4	119	300	Y	H	Flash, then trip
5	119	300	Y	V	Multiple pops, then trip
6	119	300	N	T	Multiple pops, cord fused open
7	120	100	N	V	Back up C.B. thermally tripped
8	120	100	N	T	Back up C.B. thermally tripped
9	120	100	N	H	Back up C.B. thermally tripped

Notes:

Strand Config.
V=Vertical fan
H=Horizontal Fan
T=Twisted Stranding

Circuit:



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UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V

Product	Device
# 2	Arc Fault Detector

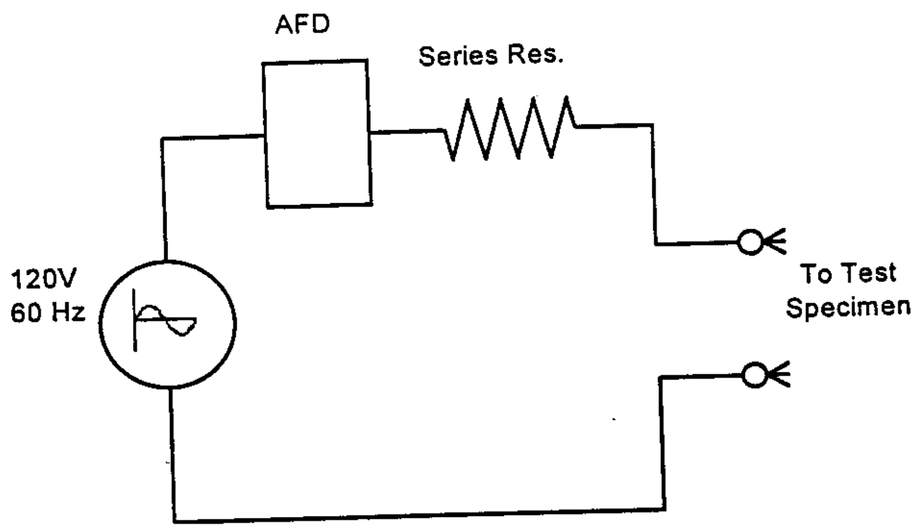
Test Summary
Damped Motion Contact

Run	Volts	Available Short-Circuit Current	Trip (Y / N ?)	Strand Config.	Comments
1	119	300	Y	-	Brief flash
2	119	300	Y	-	Brief flash
3	119	300	Y	-	Brief flash
4	120	300	Y	V	
5	120	300	Y	H	
6	120	300	Y	T	
7	121	100	Y	T	
8	121	100	Y	V	
9	121	100	Y	H	

Notes:

Strand Config.
V=Vertical fan
H=Horizontal Fan
T=Twisted Stranding

Circuit:



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UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V

Product	Device
# 3	Arc Fault Detector

Test Summary

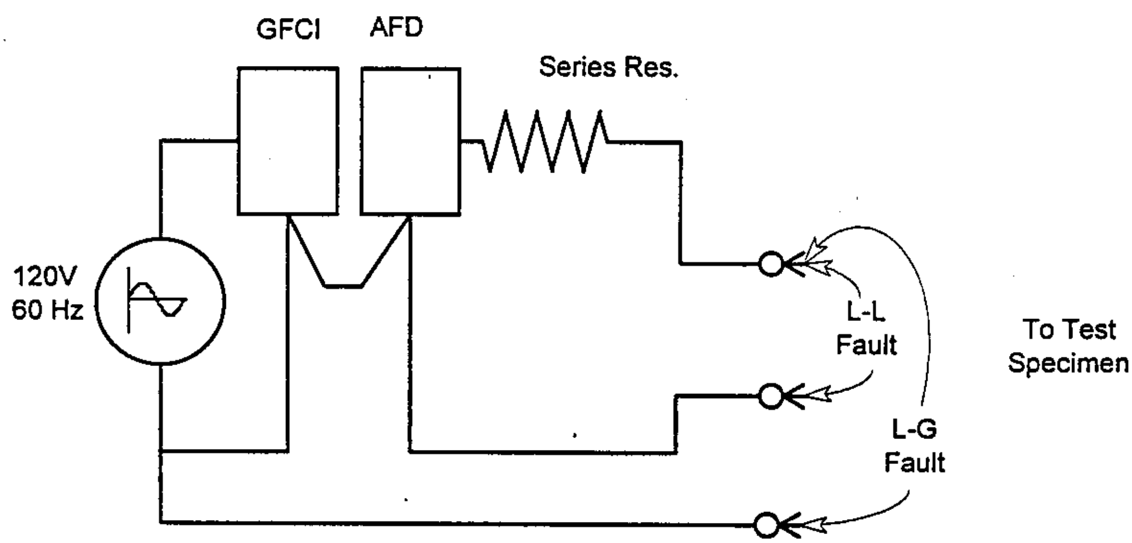
Damped Motion Contact

Run	Volts	Available Short-Circuit Current	Trip (Y / N ?)	Strand Config.	Comments
1	120	300	Y-A	T	Line-Line Fault
2	120	300	Y-A	V	Line-Line Fault
3	120	300	Y-A	H	Line-Line Fault
4	120	300	Y-G/A	T	Line-Ground Fault
5	120	100	Y-A	V	Line-Line Fault
6	120	100	Y-A	T	Line-Line Fault
7	120	100	Y-A	H	Line-Line Fault
8	120	100	Y-G/A	V	Line-Ground Fault

Notes:

Strand Config.	Trip
V=Vertical fan	A=AFD trip
H=Horizontal Fan	G=GFCI trip
T=Twisted Stranding	

Circuit:



UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used	Product	Device
A	150 V	# 4	Modified Trip Circuit Breaker

Test Summary

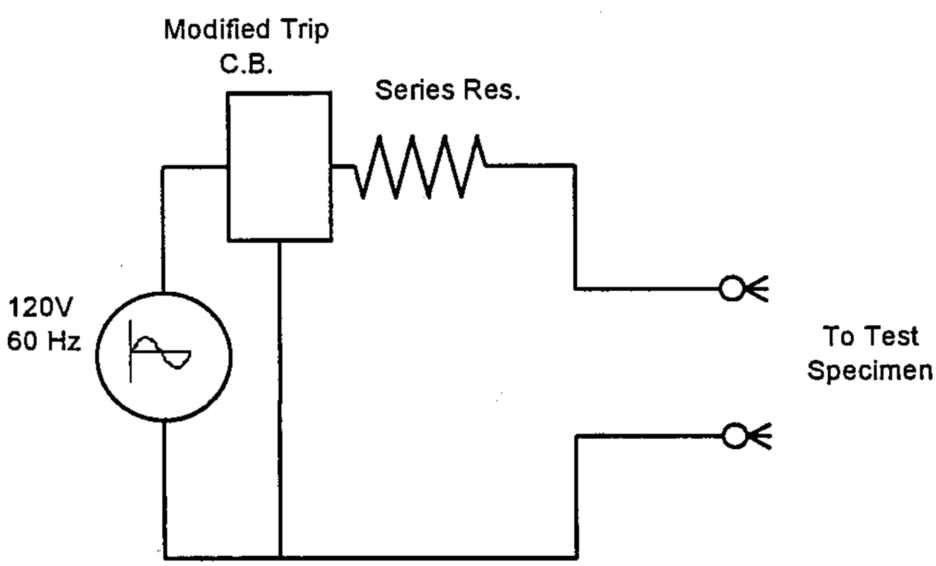
Damped Motion Contact

Run	Volts	Available Short-Circuit Current	Trip (Y / N ?)	Strand Config.	Comments
1	119	300	Y	-	Class I device
2	119	300	Y	-	Class I device
3	119	300	Y	-	Class I device
4	120	100	Y	V	Class II device
5	120	100	Y	T	Class II device
6	120	100	Y	H	Class II device

Notes:

Strand Config.
V=Vertical fan
H=Horizontal Fan
T=Twisted Stranding

Circuit:



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UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V

Product	Device
# 5	Modified Trip Circuit Breaker

Test Summary

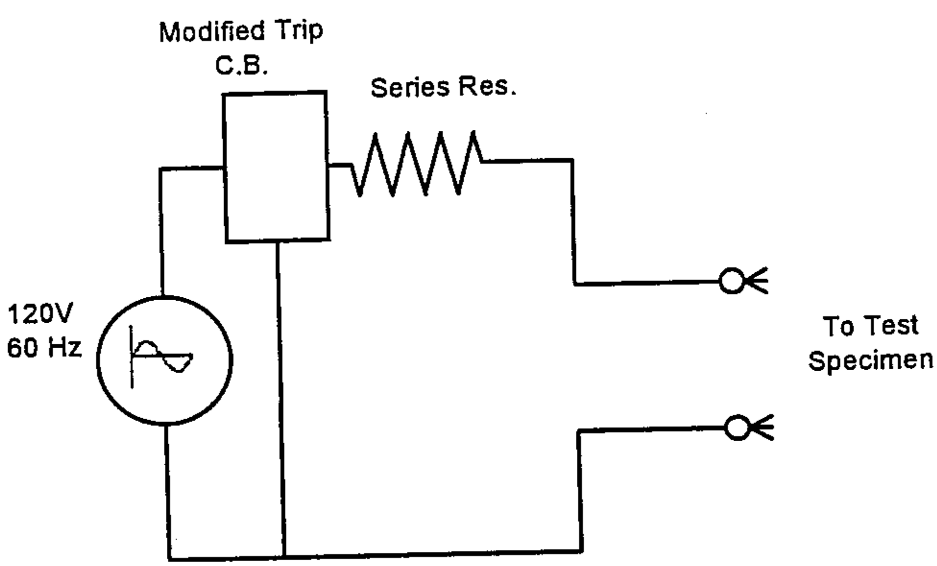
Damped Motion Contact

Run	Volts	Available Short-Circuit Current	Trip (Y / N ?)	Strand Config.	Comments
1	120	300	Y	T	
2	120	300	Y	V	
3	120	300	Y	H	
4	120	100	Y	V	
5	120	100	Y	T	
6	120	100	Y	H	

Notes:

Strand Config.
V=Vertical fan
H=Horizontal Fan
T=Twisted Stranding

Circuit:



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Carbonized-Path Arc Fault:
Carbonized-path arc fault testing represents faults involving a number of current paths:

Series Fault - The fault-current path is through the load and may be limited to a value lower than the handle-rating of the overcurrent protective device.

Across-the-Line Fault - The fault current is limited only by the source impedance, and is generally several hundred amperes.

Line-to-Ground Fault - The fault current flows to ground, either through the load or directly from an energized conductor to ground.

Progressions - The effects of the current flowing through a series fault causes the development of other faults including across-the-line and/or line-to-ground.

The three test specimen configurations shown in Figure 2 are used for this test.

Configuration 1 - Series Carbonization-Path Fault with Opposite Polarity Available -- A carbonized path is introduced across the gap formed by a broken conductor in a power supply cord serving a load. When a shorting-switch across the faulted cord is opened, the load current flows through the carbonized insulation surrounding the open in the conductor. Line voltage exists between the two current-carrying conductors in the cord. Unless the series fault is detected and interrupted early, heating can cause an across-the-line fault to develop in the cord.

Configuration 2 - Series Carbonization-Path Fault without Opposite Polarity Available -- A carbonized path is introduced across a broken conductor in a power supply cord in the same manner as configuration 1, but the load is located on the line side of the cord and there is no opposite polarity in the cord. This might represent a cord used in a pendant switch circuit. The reason for conducting this test is to investigate the ability of a protective device to detect series arcing by itself without the possibility of a progression to across-the-line arcing.

Configuration 3 - Across-the-Line or Line-to-Ground Carbonized-Path Fault -- A carbonized path is introduced between conductors of the cord representing across-the-line or line-to-ground. Fault current is limited only by the source impedance. In this test, the fault is switched on between the line end of the cord and the load end of the protective device.

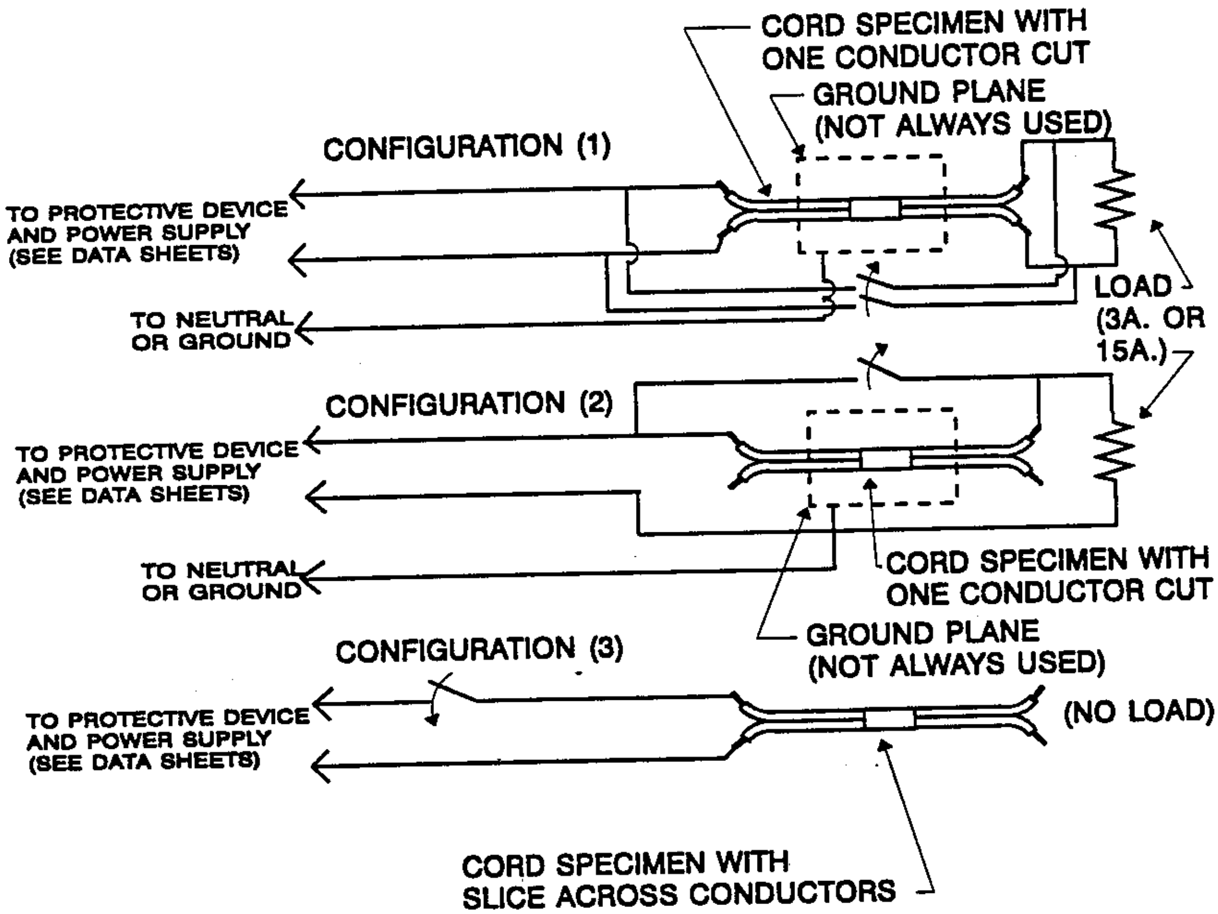


Fig. 2 - Representations of Fault Configurations for Carbonized-Path Fault Testing.

In any of these circuits, a ground plane supporting the cord may be introduced as a supporting surface for the cord specimen. If it is included in the test, the ground plane provides the opportunity for the fault to develop into a ground-fault. If no ground-plane is included, the fault will be only across-the-line. In some cases, one of the conductors in the cord was connected to ground instead of the line.

Carbonized paths generally take a long time to materialize in actual practice. For practical reasons, all carbonized-fault tests are performed using a process that accelerates the formation of the carbonized-fault path. The following method is used to prepare the faulted and carbonized cord specimens.

For configurations 1 and 2, one of the insulated conductors of a 14-inch long specimen of SPT-2 power supply cord is severed at the mid-point. The other conductor and its insulation is not damaged. The ends of the cord specimen are stripped of insulation approximately one inch to facilitate connections. The severed conductor is pulled into the insulation at either side of the cut by pulling on the conductor at both exposed ends. The severed ends of the insulation are then repositioned together and wrapped with a single layer of polyvinyl chloride (PVC) electrical tape.

For configuration 3, the insulation covering both cord conductors is sliced to reveal the conductors. The exposed conductors are not cut. The ends of the cord specimen are stripped of insulation approximately one inch to facilitate connections. The damaged part of the cord is wrapped with a single layer of PVC electrical tape.

In each case, the PVC tape is supplemented by a few overwraps of fiberglass cloth tape to exclude oxygen from the cut/repair and to enhance the mechanical integrity of the cord during the subsequent conditioning. The cord is then subjected to a three-step carbonization process that accelerates the carbonization of the cord in the vicinity of the cut/repair.

Step 1 - The two stripped conductors at one end of the test specimen are twisted together. The two conductors at the opposing end are connected to the secondary output of a high-voltage (neon sign) transformer having a secondary output voltage of 15 kV and an available short circuit secondary current of 30 mA. The voltage is applied for a few seconds to begin carbonizing the insulation material, bridging between the separated conductors at the mid-point of the cord specimen with a carbonized path.

Step 2 - The carbonization of the PVC bridging between the broken ends of the conductor at the cut is increased by the application of a 3.24 kV transformer secondary supply for a few more seconds, until the visible release of volatile material (smoke) emitted from the taped area subsides. Tungsten filament lamps totaling 1000 W are placed in the transformer primary in order to limit the transformer secondary current to approximately 300 mA.

Step 3 - Just prior to conducting the carbonization-path fault test, the carbonized path formed by the previous steps is placed in series with a 150 W incandescent lamp, and energized at 120 V. The carbonized path is considered to be completed when the lamp glows normally.

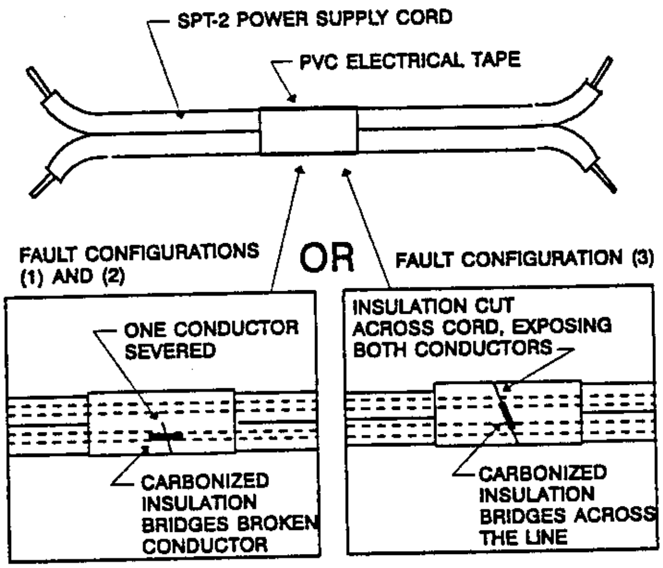


Fig. 3 - A Specimen of Damaged Cord Ready for Accelerated Carbonization.

The cord is connected to a 120 V circuit to supply a load through the "mended" but carbonized cord. The source impedance limits the available short circuit current to approximately 300 A maximum. This current is further reduced by the specimen and protective device impedances. A resistive load impedance is used to select *series fault currents* of 2 A, 5 A, 10 A, 15 A, and 22.5 A. Current passing through the carbonized material causes local heating and arcing in the fault-current path. A fire indicator consisting of a folded over six inch square of cotton cheesecloth wrapped around the taped section of cord may be used.

In the case of the series fault, a shorting switch is used to initially bypass the fault. Voltage is applied and the shorting switch then opened to determine whether the protective device under test can interrupt the circuit before the series arcing either ignites the fire indicator, or develops into an across-the-line arcing fault which may ignite the fire indicator.

Key to Headings and Abbreviations Used in the Presentation of Data Pages 54-68

Volts -- Open-circuit supply voltage.

Short-circuit Current -- Available current to the test terminals under a bolted- fault condition at the terminals. "Test terminals" are either wire-binding posts or a receptacle connected to these posts. A "bolted fault" is a low-impedance, high-integrity connection with no arcing. The addition of the test specimen cord and any impedance associated with the protective device in the circuit reduces the test current.

Series-Load Current -- Refers to the load current in the circuit before the switch is opened in configurations 1 and 2.

Trip? (Y or N) -- Indicates whether the protective device opened the circuit.

F.I. Ignite? (Y or N) -- "F. I." means "fire indicator". Indicates whether the cheesecloth fire indicator ignited.

Time (msec) -- The duration of the fault current, in milliseconds. Reported for configuration 3 tests.

Max (volts) and Min (volts) -- The readings taken from the digital oscilloscope through a pulse-current transformer. To convert to peak positive and/or peak negative current in amperes, multiply the value by 100 (scaling factor). Reported for configuration 3 tests.

UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
B	5 A, 20 A

Product	Device
# 1	Arc Fault Detector

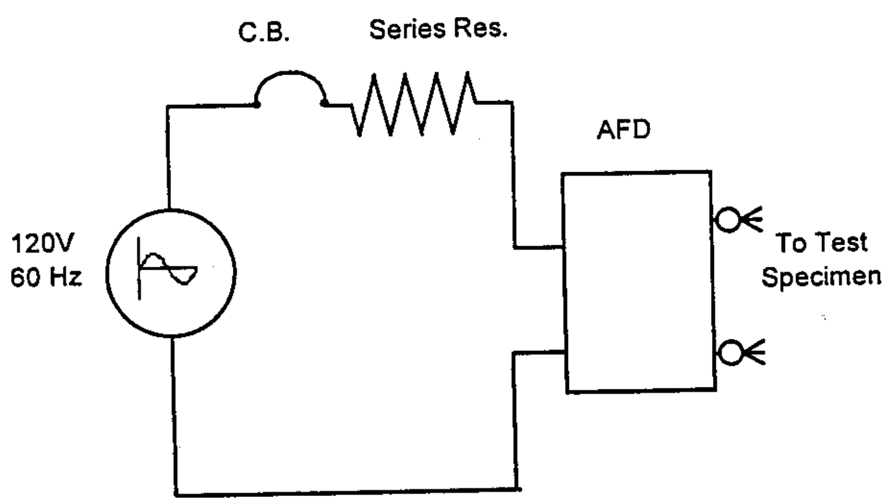
Test Summary

Series carbonized path fault (Configuration #1)

Run	Volts	Current	Trip (Y / N ?)	F.I. Ignite (Y/N)?	Comments
1	120	14.8	Y	Y	
2	120	14.8	Y	Y	
3	120	14.8	N	Y	
4	120	14.8	Y	N	
5	120	14.8	N	Y	
6	120	14.8	N	Y	
7	121	2.94	Y	N	
8	121	2.94	Y	N	
9	121	2.94	Y	N	
10	121	2.94	N	N	Brief flash, cord fused open
11	121	2.94	Y	N	
12	121	2.94	Y	N	

Notes:

Circuit:



UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
B	5 A, 20 A
C	50 A

Product	Device
# 2	Arc Fault Detector

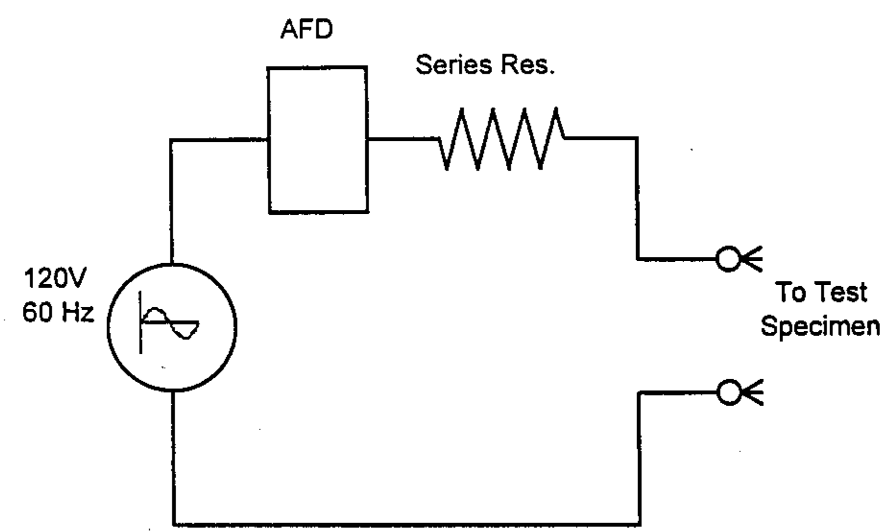
Test Summary

Series carbonized path fault (Configuration #1)

Run	Volts	Current	Trip (Y / N ?)	F.I. Ignite (Y/N)?	Comments
1	118	2.95	Y	Y	Long period of smoke, then line-line fault
2	118	2.95	Y	Y	Series ignition
3	118	2.95	N	N	Cord fused open
4	118	2.95	Y	N	Quick trip
5	118	2.95	Y	N	Hole burned through F.I. but did not flame
6	118	2.95	Y	N	Hole burned through F.I. but did not flame
7	118	15	Y	N	Quick trip
8	118	15	Y	N	Quick trip
9	118	15	Y	N	Quick trip
10	118	15	Y	N	Quick trip
11	118	15	Y	N	Quick trip
12	118	15	Y	N	Quick trip
13	119	39.5	Y	N	Quick trip
14	119	39.5	Y	N	Quick trip
15	119	39.5	Y	N	Quick trip

Notes:

Circuit:



UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
B	5 A, 20 A

Product	Device
# 3	Arc Fault Detector

Test Summary

Series carbonized path fault
(Configuration #1)

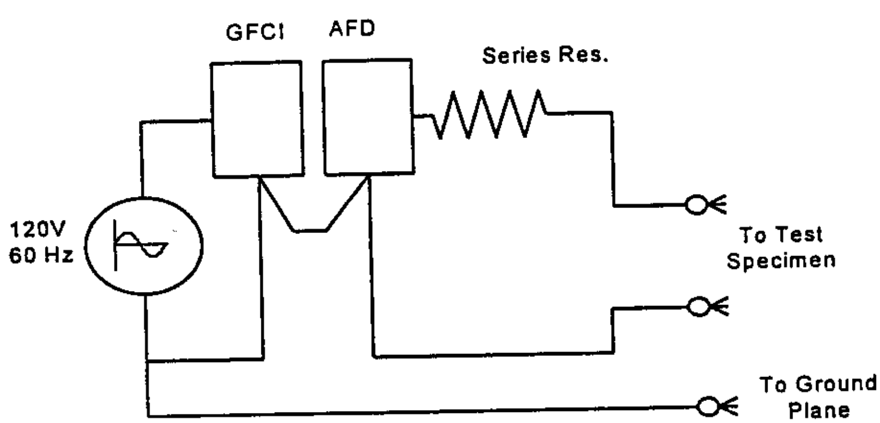
Run	Volts	Current	Trip (Y / N ?)	F.I. Ignite (Y/N)?	Comments
1	119	15	N	Y	Series ignition
2	119	15	N	N	Cord fused open
3	119	15	N	N	Cord fused open
4	119	15	N	Y	Series ignition
5	119	15	N	N	Cord fused open
6	119	15	N	Y	Series ignition
7	119	2.91	N	N	Cord fused open
8	119	2.91	N	Y	Series ignition
9	119	2.91	N	N	Smoke but no ignition
10	119	2.91	N	Y	Series ignition
11	119	2.91	N	N	Cord fused open
12	119	2.91	N	Y	Series ignition
13	119	15	Y-G	N	Ground plane added
14	119	15	N	N	Ground plane added
15	119	15	Y-G	N	Ground plane added
16	119	15	N	N	Ground plane added
17	119	2.94	N	N	Ground plane added
18	119	2.94	Y	N	Ground plane added
19	119	2.94	Y	Y	Ground plane added
20	119	2.94	Y	N	Ground plane added

Notes:

Trip

G=GFCI trip

Circuit:



UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
B	5 A, 20 A
C	50 A

Product	Device
# 4	Modified Trip Circuit Breaker

Test Summary

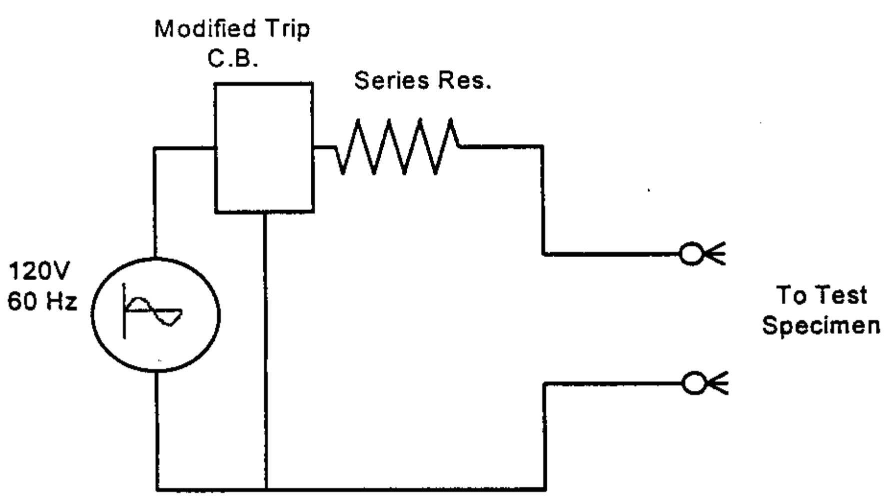
Series carbonized path fault (Configuration #1)

Run	Volts	Current	Trip (Y / N ?)	F.I. Ignite (Y/N)?	Comments
1	118	15	N	Y	Series ignition
2	118	15	N	Y	Series ignition
3	118	15	N	N	Cord fused open
4	118	15	N	Y	
5	118	15	N	N	Cord fused open
6	118	15	N	Y	
7	119	2.9	N	N	Cord fused open
8	119	2.9	N	N	Cord fused open
9	119	2.9	N	N	Cord fused open
10	119	2.9	N	Y	Smoke, then series ignition
11	119	2.9	N	N	Smoke, but did not ignite
12	119	2.9	N	Y	Series ignition
13	119	39.5	N	N	Cord fused open
14	119	39.5	N	Y	Arcing and ignition
15	119	39.5	N	Y	Arcing and ignition

Notes:

Test stopped as soon as F.I. ignited

Circuit:



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UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
B	5 A, 20 A

Product	Device
# 10	Supplemental Protective Devices

Test Summary

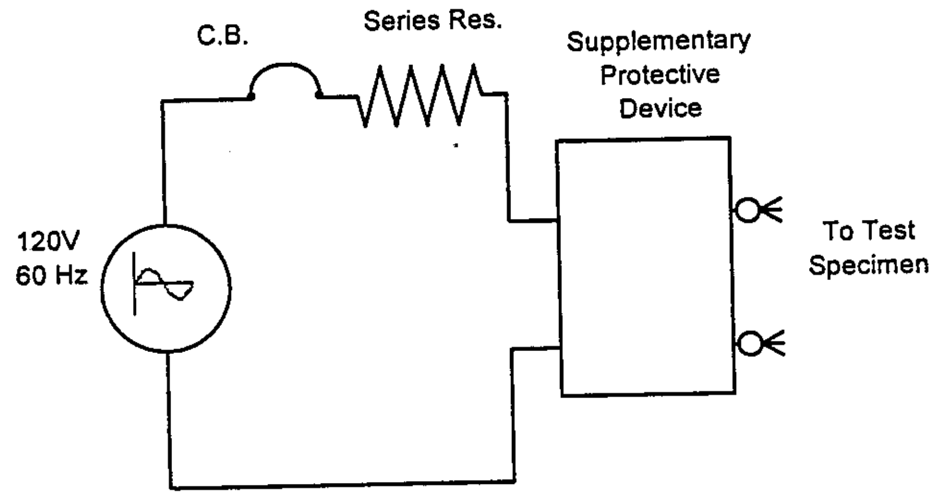
Series carbonized path fault
(Configuration #1)

Run	Volts	Current	Trip (Y / N ?)	F.I. Ignite (Y/N)?	Comments
1	118	2.95	N	Y	Smoke, then ignition
2	118	2.95	Y	Y	Long period of smoke, then ignition *
3	118	2.95	Y	Y	Long period of smoke, then ignition *

Notes:

* Series carbonized path fault progressed to a line - line fault

Circuit:



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UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
B	5 A

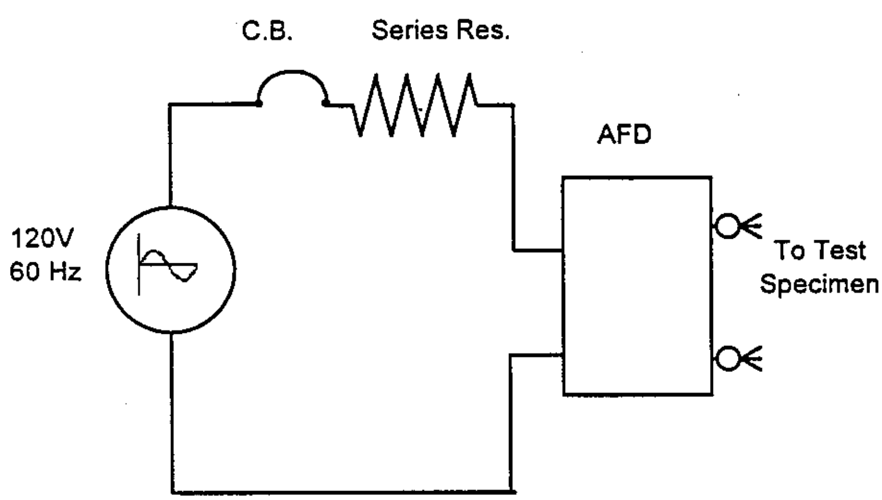
Product	Device
# 1	Arc Fault Detector

Test Summary
Series carbonized path fault
(Configuration #2)

Run	Volts	Current	Trip (Y / N ?)	Ignition of F.I. (Y/N)?	Comments
1	119	2.91	Y	N	2 s trip
2	119	2.92	Y	N	2 s trip
3	119	2.92	Y	N	1 s trip
4	119	2.92	Y	N	1 s trip
5	119	2.92	Y	N	Cord fused open
6	119	2.92	Y	N	1 s trip

Notes:

Circuit:



UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
B	5 A

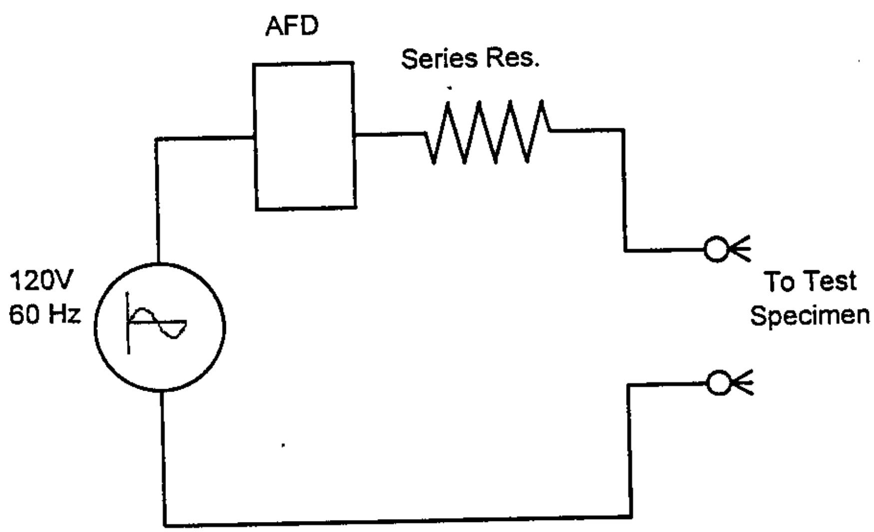
Product	Device
# 2	Arc Fault Detector

Test Summary
Series carbonized path fault
(Configuration #2)

Run	Volts	Current	Trip (Y / N ?)	Ignition of F.I. (Y/N)?	Comments
1	119	2.92	N	N	Cord fused open within 5 s
2	119	2.92	N	N	Cord immediately fused open
3	119	2.92	Y	N	8 s trip
4	119	2.92	Y	N	5 s trip
5	119	2.92	N	N	Cord fused open within 10 s
6	119	2.92	N	N	Cord fused open immediately

Notes:

Circuit:



UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
B	5 A

Product	Device
# 3	

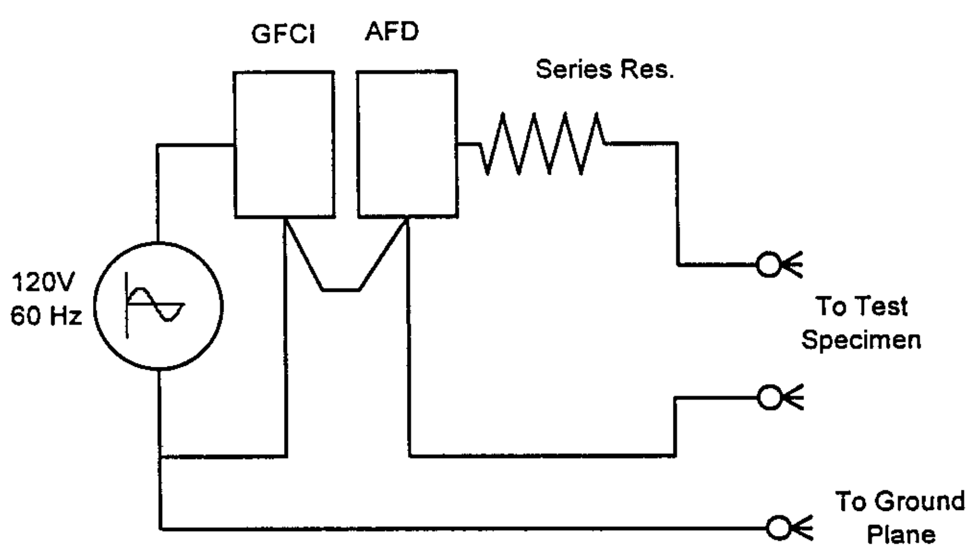
Test Summary

Series carbonized path fault
(Configuration #2)

Run	Volts	Current	Trip (Y / N ?)	Ignition of F.I. (Y/N)?	Comments
1	118	2.91	N	Y	Long period of smoke, then ignition
2	118	2.91	N	N	Cord fused open
3	118	2.91	N	N	Cord fused open
4	118	2.91	N	Y	Smoke for 7 m, then ignition
5	118	2.91	N	Y	Smoke for 9 m, then ignition
6	118	2.91	N	Y	Short period of arcing, then ignition
7	118	2.91	Y-G	Y	Ground plane added
8	118	2.91	N	N	Ground plane added, cord fused open
9	118	2.91	Y-G	N	Ground plane added
10	118	2.91	Y-G	N	Ground plane added
11	118	2.91	Y-G	N	Ground plane added
12	118	2.91	Y-G	N	Ground plane added

Notes: Trip
G=GFCI trip

Circuit:



UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 1	Arc Fault Detector

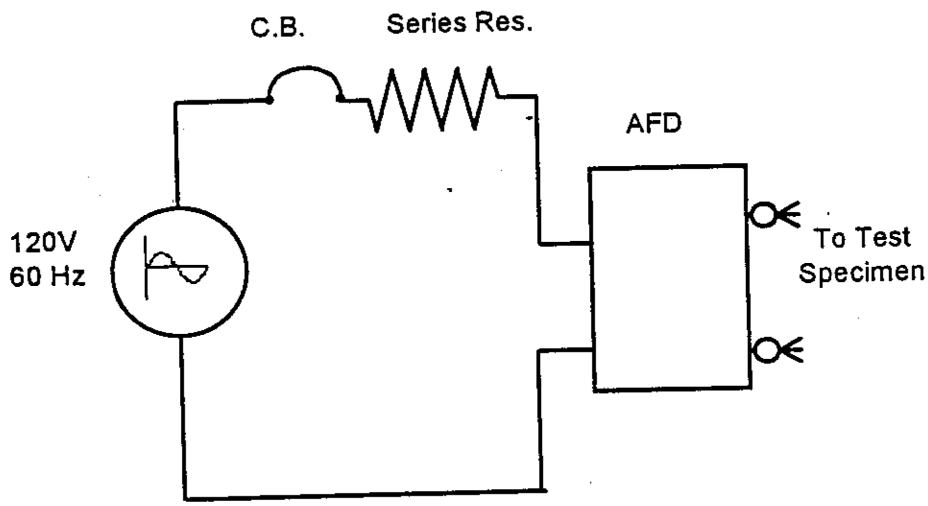
Test Summary

Carbonized Path Fault (Configuration #3)

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	100	N	Y	224.8	1.02	1.06	AFD by-passed for Step #3
2	118	100	N	Y	414.5	1.02	1.06	AFD by-passed for Step #3
3	118	100	N	Y	243.5	0.96	1.06	AFD by-passed for Step #3

Notes:

Circuit:



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UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 2	Arc Fault Detector

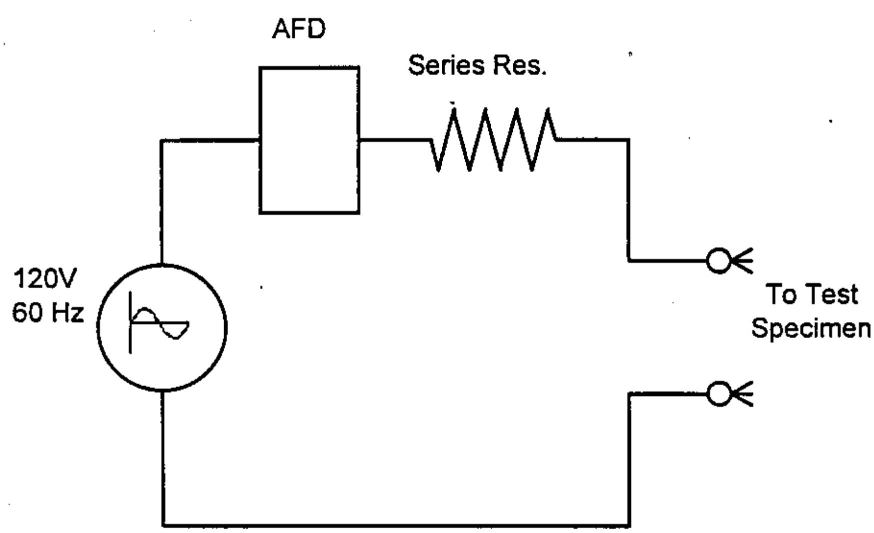
Test Summary

Carbonized Path Fault
(Configuration #3)

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	100	Y	Y	81.8	1.04	1.12	AFD by-passed for Step 3
2	118	100	Y	N	19.6	0.86	0.46	AFD by-passed for Step 3
3	118	100	Y	N	19.2	1.08	1.02	AFD by-passed for Step 3
4	118	100	Y	N	122.2	1.10	1.14	AFD by-passed for Step 3
5	118	100	Y	N	24.0	0.96	0.98	AFD by-passed for Step 3
6	118	100	Y	Y	91.4	1.10	1.14	AFD by-passed for Step 3

Notes:

Circuit:



UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 3	Arc Fault Detector

Test Summary

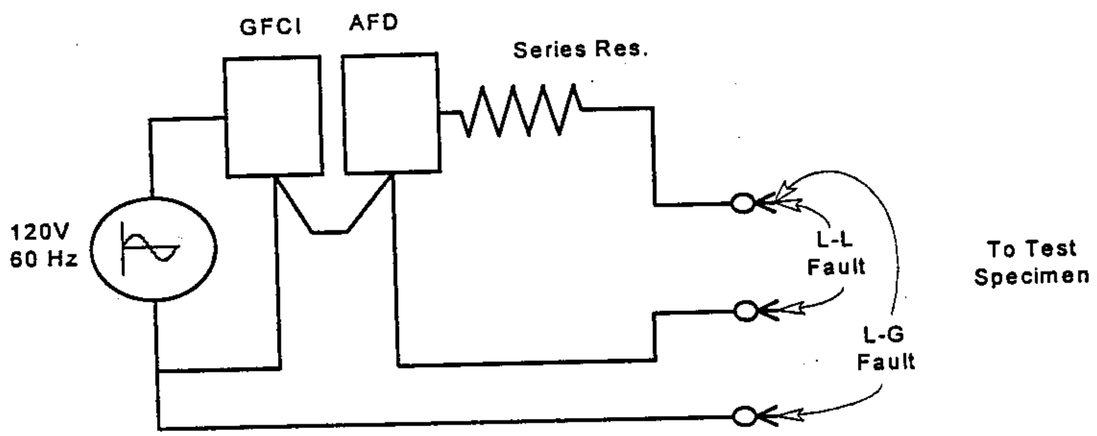
Carbonized Path Fault
(Configuration #3)

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	100	Y-G	N	18.0	0.56	0.56	Line-Ground Fault
2	118	100	Y-G	N	14.8	0.80	0.40	Line-Ground Fault
3	118	100	Y-G	N	17.3	0.86	0.68	Line-Ground Fault
4	118	100	Y-G	N	7.7	0.78	0.02	Line-Ground Fault
5	118	100	Y-G	N	12.4	0.20	0.46	Line-Ground Fault
6	118	100	Y-G	N	12.5	0.56	0.72	Line-Ground Fault
7	120	100	Y-A	Y	233.2	1.12	1.12	Line-Line Fault
8	120	100	Y-A	Y	148.4	1.10	1.12	Line-Line Fault
9	120	100	Y-A	Y	124.0	1.08	1.10	Line-Line Fault
10	120	100	Y-A	Y	115.2	1.08	1.10	Line-Line Fault
11	120	100	Y-A	Y	214.2	1.14	1.22	Line-Line Fault
12	120	100	Y-A	Y	162.4	1.12	1.14	Line-Line Fault
13	120	294	Y-G/A	N	17.0	2.08	2.64	Line-Line Fault
14	120	294	Y-G/A	Y	19.6	2.88	2.88	Line-Line Fault
15	120	294	Y-G	N	24.2	2.84	2.88	Line-Line Fault
16	120	294	Y-A	Y	39.0	2.76	2.84	Line-Line Fault
17	120	294	Y-A	Y	31.4	2.88	2.88	Line-Line Fault
18	120	294	Y-A	N	23.4	2.84	2.88	Line-Line Fault

Notes:

Trip A=AFD
G=GFCI

Circuit:



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UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 4	Modified Trip Circuit Breaker

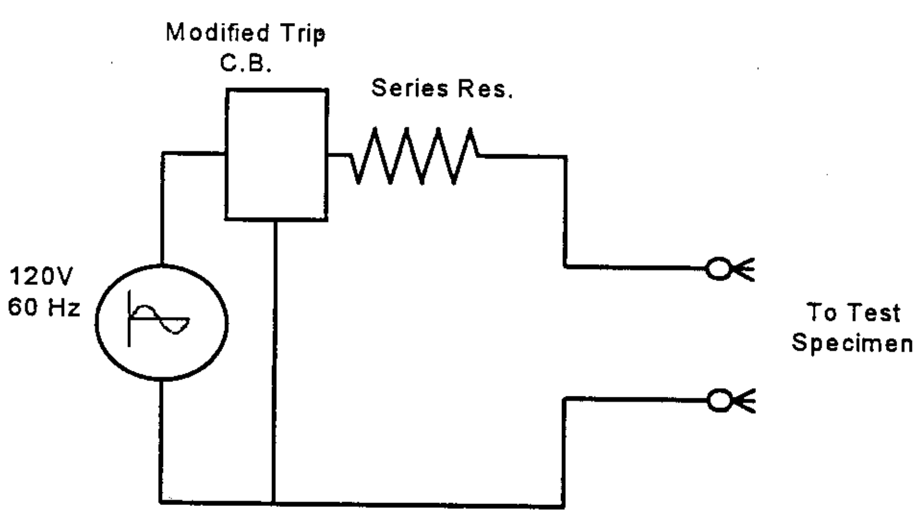
Test Summary

Carbonized Path Fault
(Configuration #3)

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	100	Y	Y	105.4	1.16	1.16	Class I device
2	118	100	Y	N	91.3	1.16	1.16	Class I device
3	118	100	Y	Y	83.4	1.16	1.16	Class I device
4	118	290	Y	Y	97.4	3.04	2.96	Class I device
5	118	290	N	Y	156.6+	3.04	2.96	Class I device
6	118	290	N	Y	265.0	3.04	3.04	Class I device
7	118	290	Y	N	14.7	2.96	2.00	Class II device
8	118	290	Y	N	5.2	0.00	2.48	Class II device
9	118	290	Y	N	6.1	0.00	2.96	Class II device
10	118	100	N	Y	250.6+	1.14	1.14	Class II device
11	118	100	N	Y	292.2	1.10	1.12	Class II device
12	118	100	N	Y	193.0	1.12	1.18	Class II device

Notes:

Circuit:



TRE4.XLS

UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 5	Modified Trip circuit Breaker

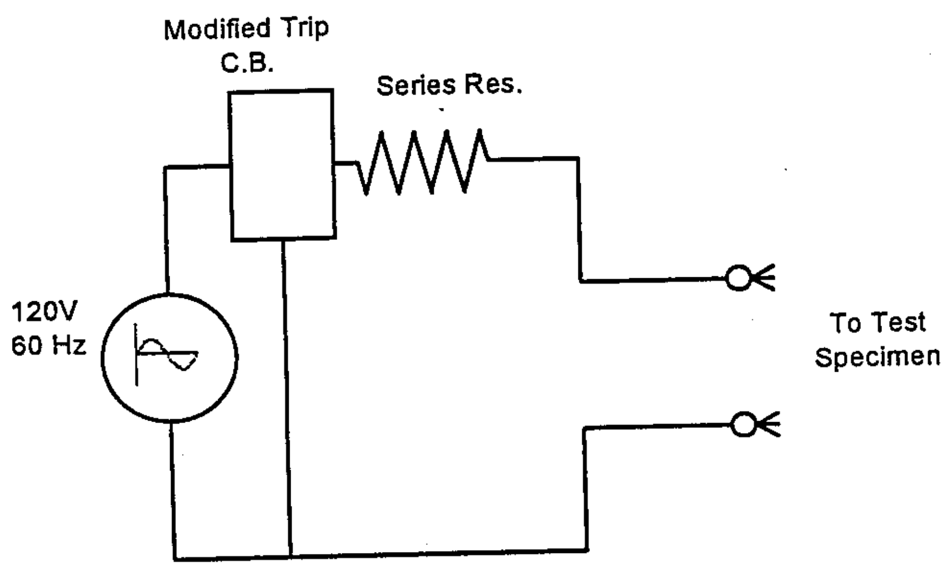
Test Summary

Carbonized Path Fault
(Configuration #3)

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	100	Y	N	32.8	1.08	0.96	
2	118	100	Y	N	24.0	0.96	1.04	
3	118	100	Y	N	23.2	1.04	1.04	
4	118	290	Y	N	13.6	2.24	2.72	
5	118	290	Y	N	16.0	2.40	1.92	
6	118	290	Y	N	14.8	2.00	2.24	

Notes:

Circuit:



TRE5.XLS

UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

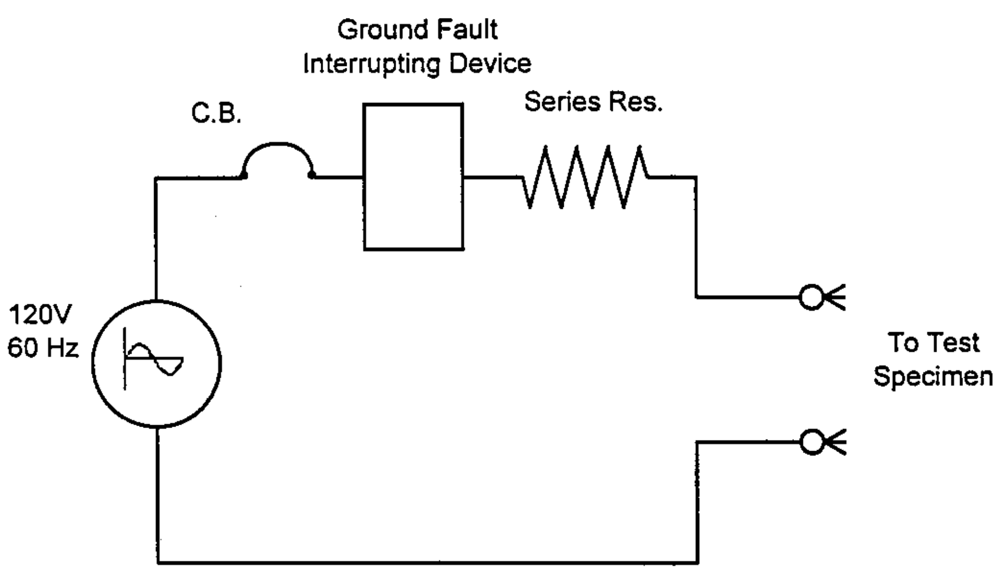
Instr.	Range Used	Product	Device
A	150 V	# 6	Ground Fault Interrupting Device
E	var.	Test Summary	
			Carbonized Path Fault (Configuration #3)

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	100	Y	N	24.6	1.04	1.16	
2	118	100	Y	N	33.0	1.04	1.12	
3	118	100	Y	N	28.6	0.40	0.60	
4	118	100	Y	N	31.8	0.88	1.12	
5	118	100	Y	N	32.0	1.04	1.08	
6	118	100	Y	N	30.2	0.76	0.96	
7	118	290	Y	N	23.3	3.04	2.88	
8	118	290	Y	N	24.3	2.80	2.80	
9	118	290	Y	Y	28.5	3.04	2.96	

Notes:

Following Runs 4, 5 and 6, the device was shorted out and the F.I. ignited

Circuit:



TRE.XLS

UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 7	Ground Fault Interrupting Device

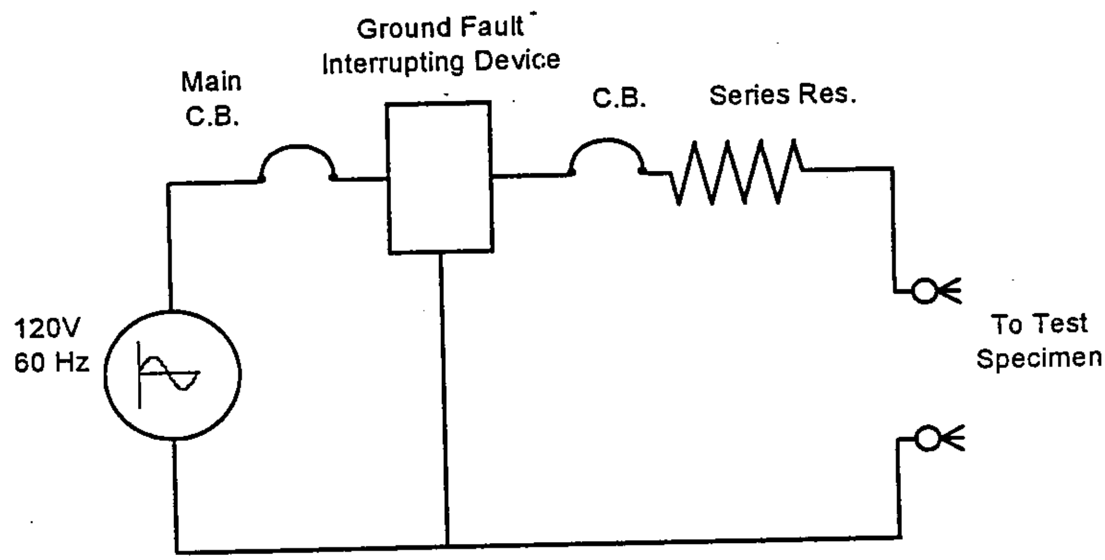
Test Summary

Carbonized Path Fault
(Configuration #3)

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	100	Y	N	24.5	0.92	0.54	
2	118	100	Y	N	23.7	1.02	0.88	
3	118	100	Y	N	17.0	0.98	0.70	
4	118	100	Y	N	16.0	0.78	0.78	
5	118	100	Y	N	21.0	0.36	0.44	
6	118	100	Y	N	17.2	0.64	0.34	

Notes:

Circuit:



TRE7.XLS

Partial Carbonized-Path Arc Fault:
The partial carbonized-path arc fault test is the same as that previously described except that the carbonizing process used to accelerate the deterioration of the cord is abbreviated. Step 3 is eliminated and Step 2 is modified as follows: The 1,000 W lamp is replaced by 640 W to reduce the amount of carbonization artificially produced. In addition, the fiberglass tape is carefully removed with a minimum of mechanical handling that might disturb the carbonized insulation under the PVC tape. The cord is then ready for connection in the test circuit. Prepared specimens are shown in Figure 2. In those cases where the specimen was too fragile to handle, such as after preparation of full carbonization, the fiberglass tape was left in place.

Arc-detection devices that are designed to intercede in the earlier stages of development of the fire scenario are subjected to this test. Some devices might be able to interrupt a circuit in the early stages of development of an arcing scenario, but might not be designed to "race" to open the circuit before a fire occurs when the carbonization of the insulation has progressed to advanced stages. An early detection device is not designed to let arcing cause the deterioration of insulation to advance to the point where fire is imminent. The partial carbonized-fault path test offers the opportunity to see whether the device can detect earlier stages, and still retain the advantages of quickly creating a carbon path for test purposes.

Key to Headings and Abbreviations Used in the Presentation of Data Pages 71-78

Volts -- Open-circuit supply voltage.

Short-circuit Current -- Available current to the test terminals under a bolted-fault condition at the terminals. "Test terminals" are either wire-binding posts or a receptacle connected to these posts. A "bolted fault" is a low-impedance, high-integrity connection with no arcing. The addition of the test specimen cord and any impedance associated with the protective device in the circuit reduces the test current.

Series-Load Current -- Refers to the load current in the circuit before the switch is opened in configurations 1 and 2.

Trip? (Y or N) -- Indicates whether the protective device opened the circuit.

F.I. Ignite? (Y or N) -- "F. I." means "fire indicator". Indicates whether the cheesecloth fire indicator ignited.

Time (msec) -- The duration of the fault current, in milliseconds. Reported for configuration 3 tests.

Max (volts) and Min (volts) -- The readings taken from the digital oscilloscope through a pulse-current transformer. To convert to peak positive and/or peak negative current in amperes, multiply the value by 100 (scaling factor). Reported for configuration 3 tests.

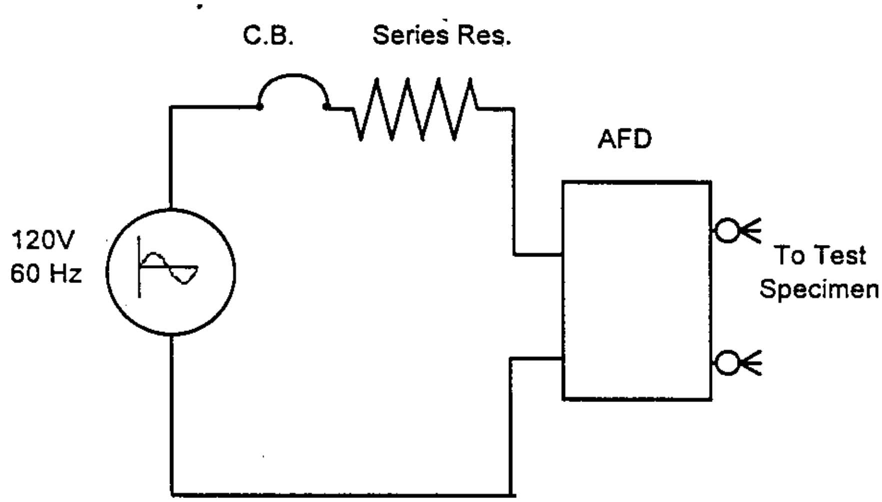
UNDERWRITERS LABORATORIES INC. - TEST RECORD			
Project No.: 94ME78760	File No.: USNC233		Applicant: CPSC
TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES			

Instr.	Range Used	Product	Device
A	150 V	# 1	Arc Fault Detector
E	var.	Test Summary	
		Partial Carbonized Path Fault	

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	119	100	N	N	330.8	0.98	1.00	Cord fused open
2	119	100	- N	Y	471.0	0.98	1.00	Cord fused open
3	119	100	N	N	-	-	-	Scope did not trigger
4	119	100	N	-	456.5+	1.28	1.30	Bolted fault
5	119	290	N	Y	128.5	2.00	2.08	Cord fused open
6	119	290	N	Y	75.4	1.68	1.72	Cord fused open
7	119	290	N	N	6.6	1.28	0.08	Cord fused open
8	119	290	N	N	10.0	1.84	0.04	Cord fused open
9	119	290	Y	-	54.0	3.04	3.12	Bolted fault

Notes:

Circuit:



TRF.XLS

UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 2	Arc Fault Detector

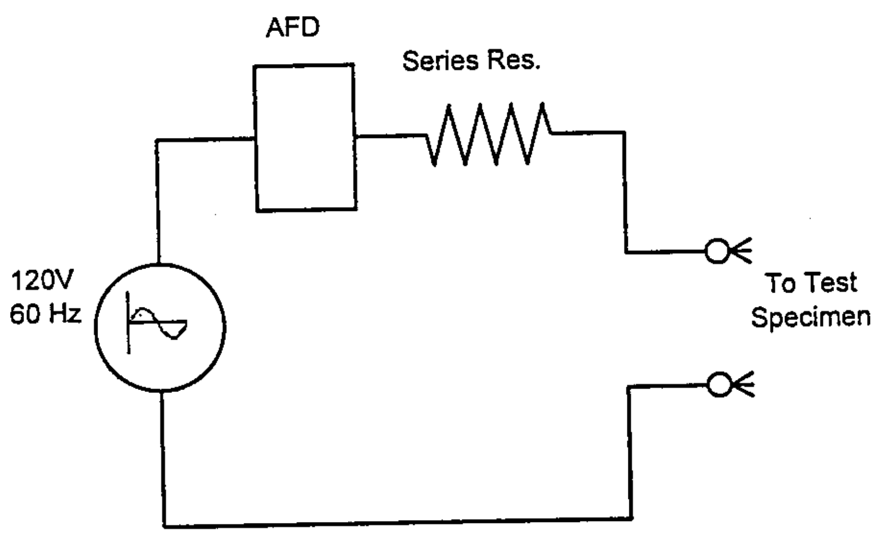
Test Summary

Partial Carbonized Path Fault

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	119	300	N	Y	36.8	1.92	2.16	Multiple arcs
2	119	300	N	N	4.2	0.80	0.00	Cord fused open
3	119	300	N	N	5.5	1.44	0.00	Cord fused open
4	119	300	Y	N	6.5	2.48	0.00	
5	119	300	N	N	14.4	1.52	2.40	
6	119	300	Y	Y	22.4	2.00	2.00	
7	119	100	Y	N	13.0	0.12	0.44	
8	119	100	Y	Y	-	-	-	Scope false trigger
9	119	100	Y	Y	23.2	0.96	0.88	

Notes:

Circuit:



TRF.XLS

UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 3	Arc Fault Detector

Test Summary

Partial Carbonized Path Fault

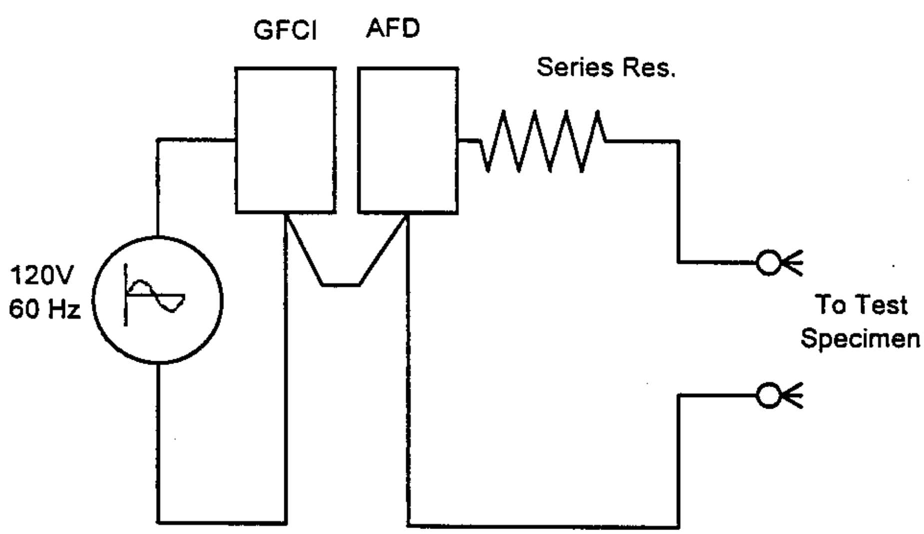
Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	119	300	Y-A	Y	14.8	2.64	2.32	
2	119	300	Y-A	Y	14.6	2.08	2.00	
3	119	300	N	N	4.9	2.32	0.00	Cord fused open
4	119	300	Y-A	Y	21.3	2.24	2.16	
5	119	300	N	N	5.5	0.08	1.84	Cord fused open
6	119	300	Y-A	Y	22.4	2.72	2.64	
7	119	100	N	N	12.2	0.48	0.80	Cord fused open
8	119	100	Y-A	Y	63.7	1.04	1.04	
9	119	100	Y-A	Y	15.4	1.04	0.44	

Notes:

Runs 1-9 performed on repaired sample

Trip A=AFD
G=GFCI

Circuit:



UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 4	Modified Trip Circuit Breaker

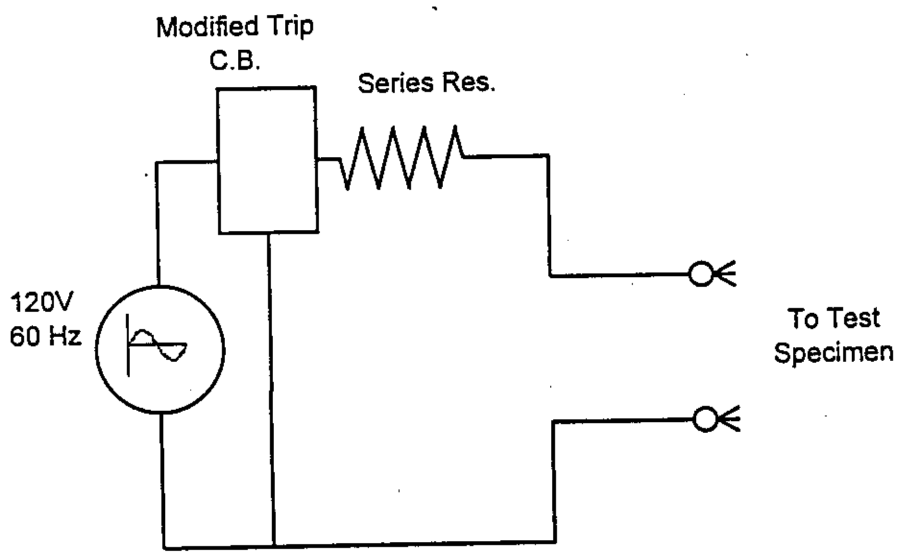
Test Summary

Partial Carbonized Path Fault

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	119	300	Y	Y	13.0	2.00	2.64	
2	119	300	N	N	4.0	1.36	0.00	Cord fused open
3	119	300	Y	Y	20.7	2.00	2.24	
4	119	300	N	N	3.7	0.08	1.76	Cord fused open
5	119	300	Y	N	12.7	0.64	2.88	
6	119	300	N	Y	21.5	1.92	1.68	
7	119	100	N	N	76.8	1.04	1.04	Cord fused open
8	119	100	N	Y	39.1	0.92	0.92	
9	119	100	Y	Y	-	-	-	Scope false trigger

Notes:

Circuit:



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UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 5	Modified Trip Circuit Breaker

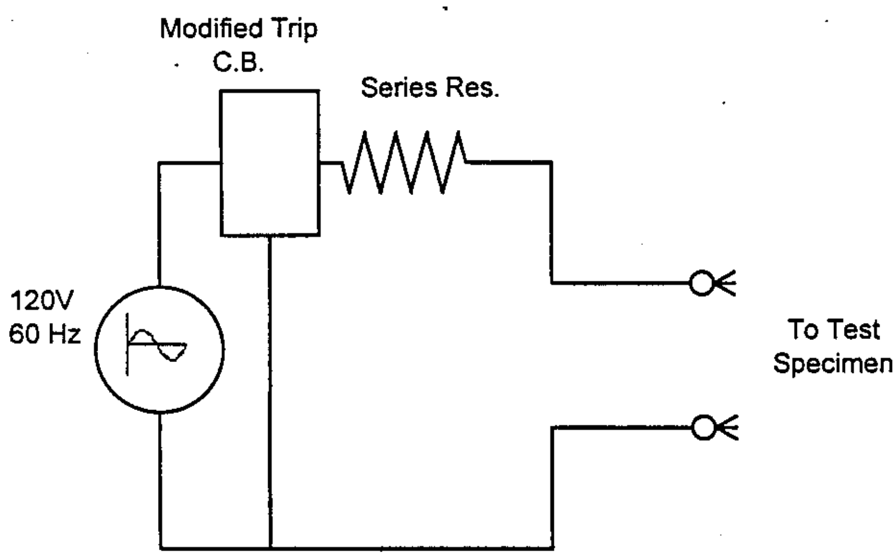
Test Summary

Partial Carbonized Path Fault

Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	119	300	N	Y	12.1	0.72	1.12	Cord fused open
2	119	300	Y	Y	0.1	0.08	1.84	
3	119	300	Y	Y	1.8	1.76	2.12	
4	119	300	Y	N	1.4	1.44	0.04	
5	119	300	N	Y	1.9	1.92	0.60	
6	119	300	Y	N	0.0	0.04	1.80	
7	119	100	N	N	0.0	0.00	0.52	Cord fused open
8	119	100	Y	N	0.6	0.64	0.96	Multi-bursts of arcing
9	119	100	Y	N	1.1	1.08	0.96	

Notes:

Circuit:



UNDERWRITERS LABORATORIES INC. - TEST RECORD

Project No.: 94ME78760 File No.: USNC233 Applicant: CPSC

TECHNOLOGY FOR DETECTING AND MONITORING CONDITIONS THAT COULD CAUSE ELECTRICAL WIRING SYSTEM FIRES

Instr.	Range Used
A	150 V
E	var.

Product	Device
# 6	Ground Fault Interrupting Device

Test Summary

Partial Carbonized Path Fault

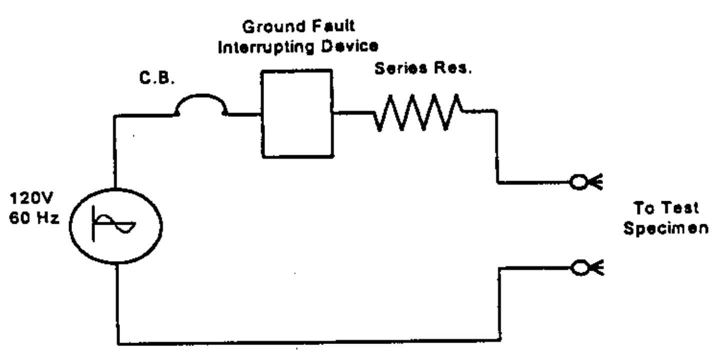
Run	Volts	Short-Circuit Current	Trip? (Y / N)	F.I. Ignite? (Y / N)	Time (msec)	Max (volts)	Min (volts)	Comments
1	118	100	Y	-	4.3	0.54	0.02	Step 1
2	118	100	Y	N				Step 2
3	118	100	N	-	4.2	0	0.64	Step 1
4	118	100	Y	N	6.2	0	0.4	Step 2
5	118	100	N	-				Step 1
6	118	100	Y	N	19.95	0.08	0.6	Step 2
7	118	100	N	-				Step 1
8	118	100	Y	N	19.95	0.072	0.416	Step 2
9	118	100	N	-				Step 1
10	118	100	Y	N	23.1	0.384	0.128	Step 2
11	118	100	N	-				Step 1
12	118	100	Y	N	23.5	0.84	0.184	Step 2
13	118	100	Y	N	16.8	0.04	0.072	
14	118	100	Y	N	8.6	0.026	0.236	
15	118	100	Y	N	11.4	0.048	0.48	
16	118	100	Y	N	21.4	0.136	0.168	
17	118	100	Y	N	24	1.008	1.016	
18	118	100	Y	N	15.8	0.84	0.74	

Notes:

For Runs 1, 3, 5, 7, 9 and 11, the cord specimen was connected to the 120 V supply following completion of only Step 1 to determine if a sufficient partial carbonized path was established to cause the ground fault interrupting device to trip.

In Runs 2, 4, 6, 8, 10 and 12, Step 2 conditioning was completed on the same cord used for the previous odd numbered run and the cord then connected to 120 V.

Circuit:



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