



AEROSPACE INFORMATION REPORT

AIR6982™

Issued

2024-03

Arc Damage Assessment of Arc Plume and Physical Damage

RATIONALE

Provide a definition and recommended practice for assessing the damage zone of arc plasma and determining the separation distance of harnesses and other components.

1. SCOPE

This SAE Aerospace Information Report (AIR) describes the means of assessing the damage zone of an electrical arcing event to determine appropriate separation/segregation requirements between a power-carrying wire harness and nearby components.

1.1 Purpose

The purpose of this AIR is to provide a standard practice guide for determining the separation/segregation requirements between wire harnesses and components and assessing electrical arc damage to prevent arc damage hazards on aircraft.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AS4373 Test Methods for Insulated Electric Wire

AS5692 ARC Fault Circuit Breaker (AFCB), Aircraft, Trip-Free Single Phase 115 VAC, 400 Hz - Constant Frequency

AS6019 ARC Fault Circuit Breaker (AFCB), Aircraft, Trip-Free 28 VDC

AS50881 Wiring Aerospace Vehicle

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2.1.2 ASME Publications

Available from ASME, P.O. Box 2900, 22 Law Drive, Fairfield, NJ 07007-2900, Tel: 800-843-2763 (U.S./Canada), 001-800-843-2763 (Mexico), 973-882-1170 (outside North America), www.asme.org.

ASME V&V 10 Standard for Verification and Validation in Computational Solid Mechanics

2.1.3 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D3032 Standard Test Method for Hookup Wire Insulation

2.1.4 Code of Federal Regulations (CFR) Publications

Available from United States Government Printing Office, 732 North Capitol Street, NW, Washington, DC 20401, Tel: 202-51-1800, www.gpo.gov.

14 CFR § 25.1707 System Separation: Electrical Wiring Interconnection Systems

2.1.5 EASA Publications

Available from European Union Aviation Safety Agency, Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu.

EASA AMC-20 General Acceptable Means of Compliance for Airworthiness of Products, Parts and Appliances, Amendment 20

2.1.6 European Standard (EN) Publications

Copies of these documents are available online at <https://www.en-standard.eu/>.

EN 3475 Cables, electrical, aircraft use - Test methods

EN 6059-502 Aerospace Series - Electrical cables, installation - Protection sleeves - Test methods - Part 502: Resistance to electrical arcs

2.1.7 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

AC 25.1701-1 Certification of Electrical Wiring Interconnection Systems on Transport Category Airplanes

2.1.8 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

2.1.9 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

MIL-HDBK-5J Metallic Materials and Elements for Aerospace Vehicle Structures

2.1.10 Other Publications

DOT/FAA/AR-MMPDS Metallic Materials Properties Development and Standardization

2.2 Abbreviations

A	amp
AC	advisory circular
AC	alternating current
AFCB	arc fault circuit breaker
ASME	American Society of Mechanical Engineers
AWG	American wire gauge
C	Celsius
DC	direct current
DVW	dielectric voltage withstand
EASA	European Union Aviation Safety Agency
EWIS	electrical wiring interconnection system
FAA	Federal Aviation Administration
Hz	hertz
kS/s	kilosamples per second
ms	millisecond
s	second
STC	supplemental type certification
TC	type certification
TGS	Thermal Gradient Stratification
V	volt
VAC	volts alternating current
V&V	verification and validation

3. GENERAL

The continuing safe operation and airworthiness of an aircraft depends on the safe transfer of electrical energy by electrical wiring interconnection system (EWIS) components. If an EWIS failure occurs, the separation distance from one EWIS component to another, systems (fuel tanks, fuel pipes, and other hazardous fluid-carrying lines), or structure plays an important role in ensuring that the hazardous failure effects are mitigated to an acceptable level. FAA guidance (refer to AC 25.1701-1) requires applicants to design EWIS with appropriate separation to minimize the possibility of hazardous effects on an aircraft system or its sub-systems.

The term “separation” is a measure of physical distance. The purpose of separation is to prevent hazards of arcing between wires in a single bundle, between two or more bundles, or between an electrical bundle and a non-electrical system or structure. The term “segregation” is a means of achieving a safe separation distance with the use of additional barrier material. This barrier material may be placed on the wire harness, as a shroud between the arcing wire harness and the target, and/or as a protective material on the target.

The EASA view of the term “separation” combines these under a single definition. In EASA document AMC-20, the term “separation” is defined as “... either spatial distance, or physical barrier, between wiring from adjacent structure, systems or wiring; or the practice of installing wiring supporting redundant or multi-channel systems.”

Within this document, “separation” will refer to physically separated components with an air gap, and “segregation” will refer to any physical barrier between components.

Regardless of probability, any single arcing failure should be assumed for any power-carrying wire (refer to FAA AC 25.1701-1 guidance for 25.1709). The intensity and consequence of the arc and its mitigation must be substantiated. The selection of wires and sleeving to be installed on an aircraft must be done showing consideration of each installation and application to minimize the risk of wire damage, including any arc tracking phenomena.

3.1 Objective

The tests designed from this guidance should be conducted with attention to the aircraft electrical system they are intended to represent; failure to do so may yield results inconsistent with system safety objectives. The test design should support EWIS risk assessments and consider voltage level, fault current level, current protection scheme, conductor size, wiring type, support materials, protective materials (barriers, sleeves, etc.), and environmental conditions.

Test results should quantify the amount of arc plasma and ejecta generated by the arcing event into the surrounding area. This information, along with the damage tolerances, should aid in developing an EWIS risk assessment with respect to arcing. It would also provide evidence of adequate arcing protection and safe separation.

3.2 Approach

This AIR provides guidelines that have been found effective in assessing and validating that adequate separation or protection exists to mitigate arcing in EWIS wiring from damaging other EWIS wiring, surrounding systems, and structure. Test fixtures have been identified to quantify arc damage with respect to temperature, plasma, and ejecta over a measured distance from the arc source and provide a means to document damage to wiring, various tubing lines, and structure.

4. ARC DAMAGE ASSESSMENT- SEPARATION REQUIREMENTS

4.1 Anatomy of an Arcing Event

An electrical arcing event consists of several components. These include the following:

- **Arcing wire(s):** These are the wire or wires that initiate the electrical arcing event. They may be alone or part of a wire bundle. There is no voltage or current requirements for a set of wires to be considered “arcing wires”; simply this designation is given to the wires starting the electrical arcing event.
- **Target components:** Items placed near the electrical arcing event are considered target components. These may be wire harnesses, structure, or other aircraft components. The means for assessing the damage will vary depending on the component type.

- Arc plume: An electrical arcing event generates a plume of hot, ionized gas. As the arcing continues, the arc plume quickly develops and expands. If the arc plume comes into contact with nearby objects, the plume can transfer both heat and electrical energy to the objects, making them susceptible to arcing damage even at a distance. Depending on the energy involved, the arc plume will range from zero to several inches.

As the arc plume is ionized, it will also lower the voltage breakdown of air, making it possible for electrical energy from the actively arcing wires to bridge the gap and conduct electricity, which would not be possible otherwise under normal conditions.

- Arc ejecta: During the arcing event, insulation and molten metal may be damaged and ejected. The speed and size of the ejecta will vary, but they may cause damage to nearby components.
- Fault current: This is the maximum current that can occur when a hard short is created at the arc site.
- Arc current: The arc current is less than the fault current due to the resistance in the arcing event.
- Arc voltage: The voltage that appears across the arc gap. The arc voltage will increase with the length of the arc plume. If there is no arc, the arc voltage is zero.
- System voltage: The designed voltage for the distribution system under test. The voltage should take into consideration regulation, normal and abnormal operating conditions, and tolerances.
- High impedance arcing: In a high impedance arcing event (sometimes called “series arcing”), the arc comes from an interrupted connection in a single circuit. In the series arcing event, the electrical current is limited by the circuit load. For example, a circuit using a 20-gauge wire may be limited to a current of less than 10 A. These high impedance events tend to be lower energy than low impedance arcing events, but they may progressively damage components as the arcing continues potentially evolving into a low impedance arcing or cross-circuit activation.
- Low impedance arcing: In a low impedance arcing event (sometimes called “parallel arcing”), the current goes from one wire directly to the structure (ground) or a second wire at a different voltage (ground or a different phase in the case of a multiple-phase power system). The current in the arc does not go through the “complete” circuit and, therefore, is not limited by the load; the arc is in “parallel” with the load. Only the arc resistance, the resistance of wire, and the internal power source impedance limit the current in the arc.
- Cross-circuit activation: During arcing events, it is possible for electrical arcing to create an electrical path from power to unpowered circuits. This can result in the uncommanded activation of components/systems.

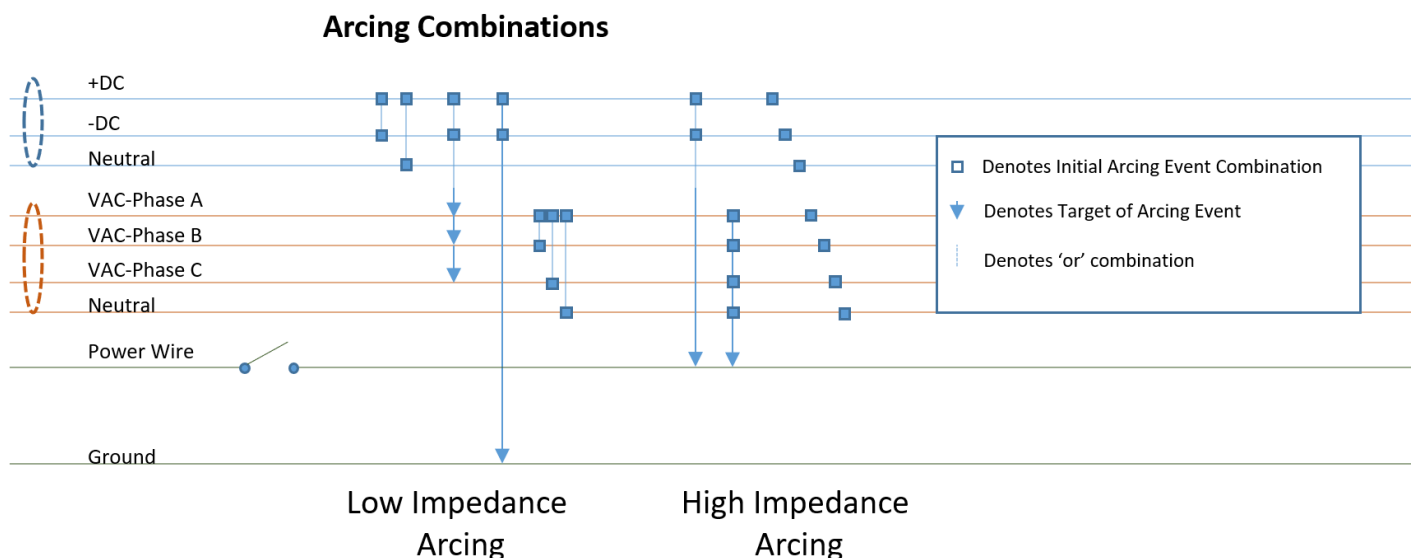


Figure 1 - Graphic representation of arcing potential configurations for low and high impedance arcing events

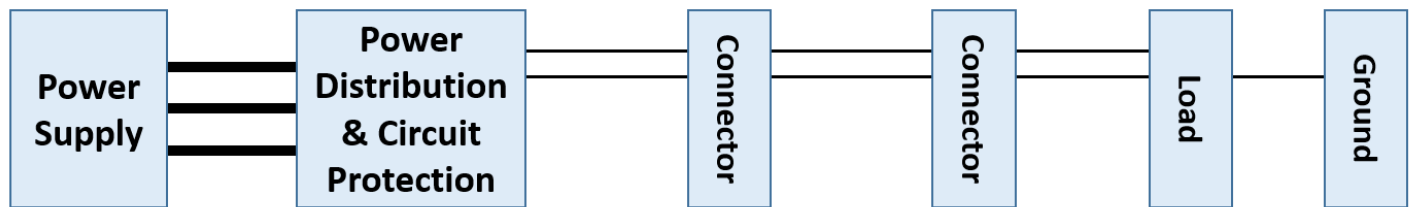


Figure 2 - Simplified power circuit diagram

A simplified system power circuit diagram is shown in [Figure 2](#). In this, an arcing event can occur between the wire and structure (not shown), between the power wire, and/or power wires and any ground. For an electrical arc to start, there must be a conductive path between two voltage potentials, and the contact between the two must be broken. This contact break may occur through mechanical means (such as vibration) or with the heating of the material during high current events; this last scenario can occur when the contact point between the two voltage potentials is small and by the electrical field ionizing gasses in the air gap.

Arcing can occur in connectors; with mating and demating with power on, with the introduction of gases, fluids, debris, or bent contacts, connectors are as susceptible as wires to arcing faults.

4.2 AC Arcing Events

4.2.1 Low Impedance Arcing Events

AC arcing events are one or more phase arcing events involving an AC power system. A typical signature of a single-phase to ground arcing event is shown in [Figure 3](#). The event initiation is identified by a voltage spike followed by a relatively flat voltage during which there is a high current (the arcing current is dependent on the in-line resistance and the arc resistance). The half-cycle arc event halts with a voltage spike. This repeats as long as:

1. The circuit protection remains closed,
2. The wire bundle does not split apart creating a separation of the wires, and
3. The local ionization reduces the air-breakdown voltage to less than the maximum circuit voltage.

The arc voltage of an AC arcing event is the average voltage between the arc inception and extinction spikes. This voltage will vary depending on several factors, including:

- Pressure
- System voltage
- Separation distance of the electrodes
- Local ionization
- The duration of the arcing event

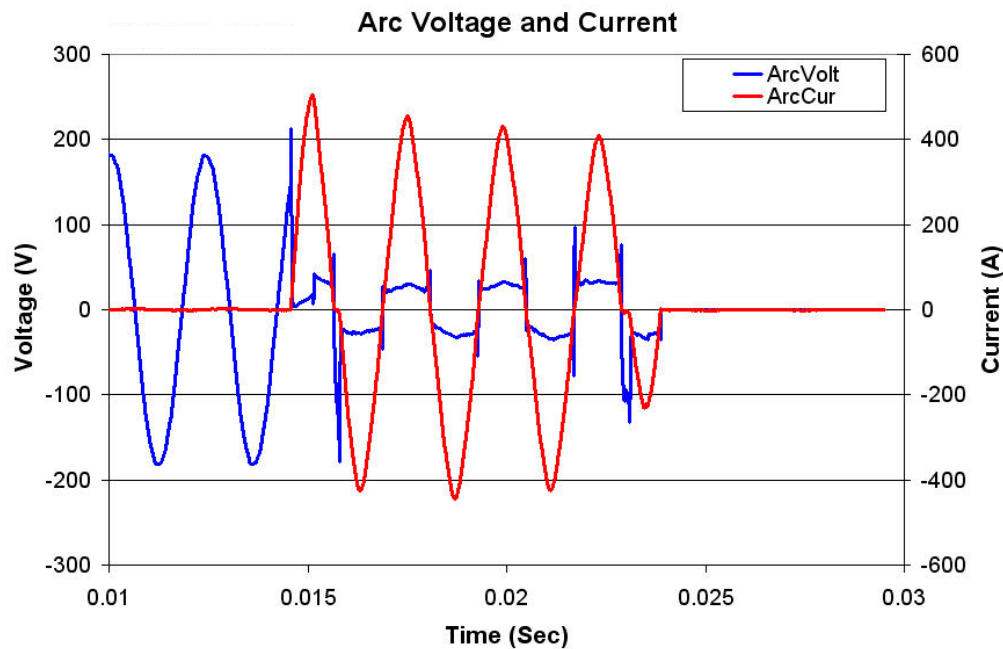


Figure 3 - Capture of the voltage and current waveforms from a representative single-phase 115 VAC, 400 Hz to ground arc test. The system was set with a 250- A_{RMS} fault current. The event started with no contact between the active power wire (20 AWG) and a grounded aluminum structure. At 0.014 second, the power wire made contact with the ground, and a brief shorting event occurred (low voltage drop across the power wire-ground interface), followed by six half-cycles of arcing before the arc fault circuit breaker (AFCB) (refer to AS5692) activated.

4.2.2 AC High Impedance Arcing Events

A high impedance AC arcing event is defined as an event where the voltage is interrupted between the source and the load with arcing completing the connection. The event must be monitored across the break for voltage.

For example, in a 400 Hz 115 V shaker test (refer to AS5692, 4.7.7.6.3), a high impedance AC arcing event definition is defined as being an event where the voltage between stud and lug goes above 100 V for 20% of a half-cycle minimum and the rest of the time (except for approximately 40 μ s before and after the voltage zero crossing) between 15 and 60 V (high impedance arc voltage).

- At least 10 high impedance arcing events in a 100-ms sliding window (called an “arcing period”).
- At least two consecutive arcing periods in a 2-second sliding window (called a “confirmed arcing period”).

The durations defined in (a) and (b) are associated with fault protection standards used in 400-Hz systems. It is not necessary to use these definitions, and they are not applicable for all power system configuration.

4.3 DC Arcing Events

DC arcing events share the same basic properties as AC arcing events with one exception: The DC voltage does not drop to 0 V and, thus, does not have to reignite hundreds of times per second. [Figure 4](#) shows a typical DC arcing waveform. During the arcing event, the voltage and current will remain relatively constant with a slow increase in the arc voltage as the cathode and anode separate. Also, note as the voltage gets higher (above about 70 VDC), the voltage is fairly steady and no longer returns to zero.

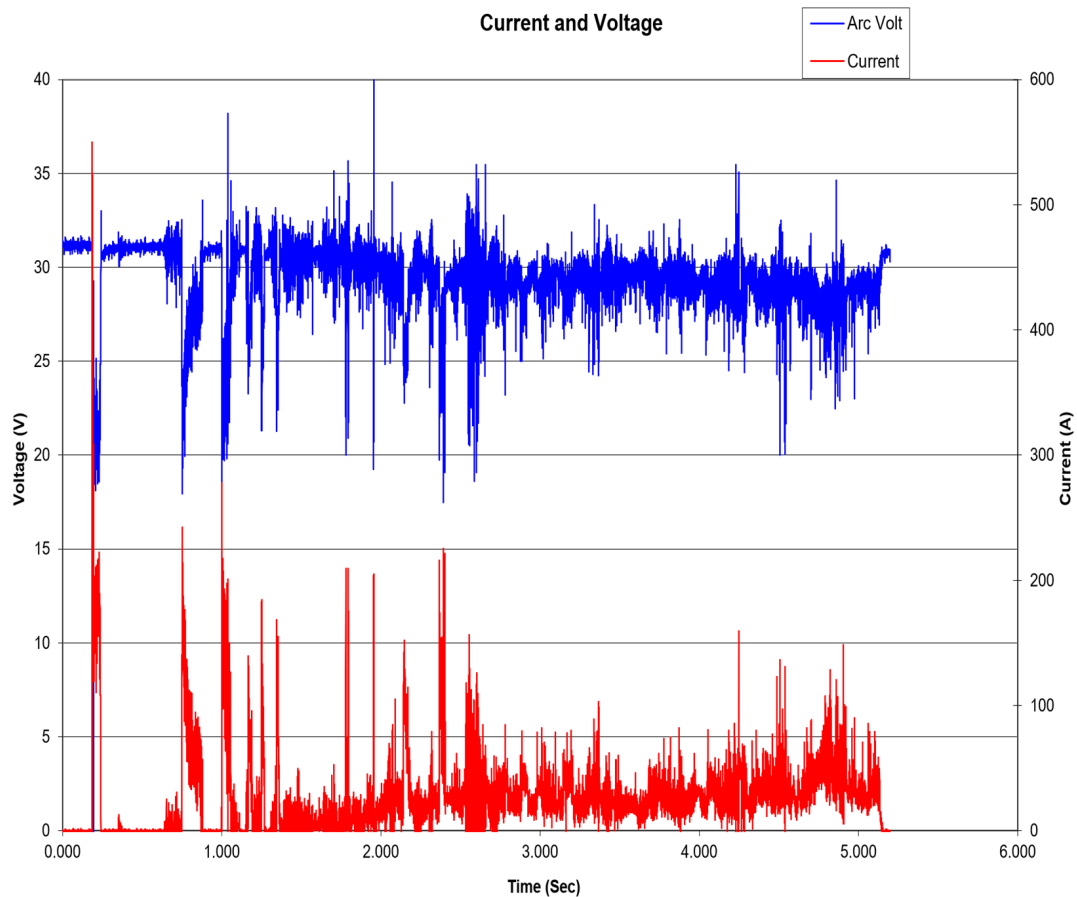


Figure 4 - Example 28 VDC arcing voltage and current waveform

4.3.1 28 VDC Electrical Arcing

4.3.1.1 28 VDC Low Impedance Arcing Events

For this document, a low impedance 28 VDC arcing event includes sufficient arcing in a 100-ms sliding window consisting of (in alignment with the DC arc fault circuit protection standard AS6019):

- A minimum of 20 individual arcing events or a minimum of 20 ms of cumulative arcing events,
- Arc voltage is greater than 8 V and less than 20 V,
- The current is greater than 5X the rated current and for more than 100 μ s.

4.3.1.2 28 VDC High Impedance Arcing

A high impedance 28 VDC arcing event includes an arcing event where (in alignment with the DC arc fault circuit protection standard AS6019):

- The arc voltage is between 8 and 25 VDC
- The current is below 80% of rated current for more than 100 μ s
- Within a 100-ms window
 - A minimum of 10 individual arcing events, or
 - A minimum of 10 ms of cumulative arcing events

An example is shown in [Figure 5](#). In this example, a 28 VDC wire is mounted on a vibration platform and repeatedly makes contact with a high impedance return. The periods of direct contact are shown where the current through the system is high and the voltage drop across the wire-target interface is low. The periods of separation are shown where the current is zero and the voltage is high. The high impedance arcing occurs during the transition period between shorting and loss of contact. As the wire moves farther from the target, the voltage increases and the current decreases.

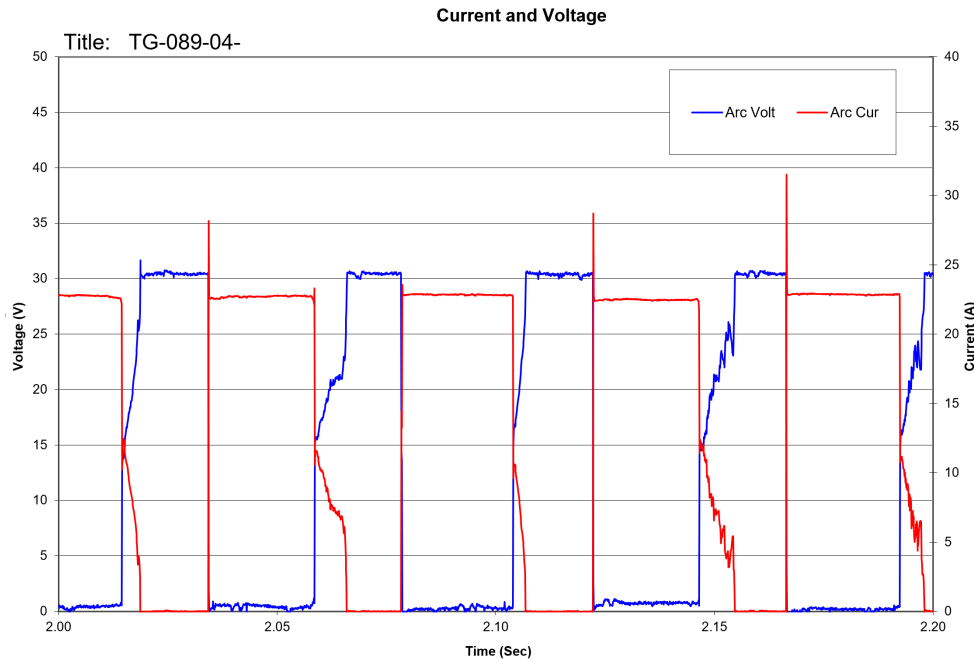


Figure 5 - 28 VDC high impedance arcing event on vibration fixture

4.3.2 270 VDC Electrical Arcing

4.3.2.1 270 VDC Low Impedance Arcing

For this document, the 270 VDC arcing definition for low impedance arc testing includes:

- An arc voltage greater than 30 V.
- The current is greater than 5X the rated current and for more than 100 μ s.

4.3.2.2 270 VDC High Impedance Arcing

For this document, the 270 VDC arcing definition for high impedance arc testing includes:

- A measurable voltage increase across the circuit discontinuity. The voltage drop is dependent on the circuit load and would be proportional to 0.1 to 0.5 Ω of in-line resistance added to the circuit.
- Circuit current change proportional to the voltage change in (a) for more than 100 μ s.

To illustrate the properties of 270 VDC high impedance arcing, a series arcing test was performed in accordance with AS6019. The configuration of this test is shown in [Figure 6](#). In this test, wires are connected to a terminal board, with the connection screws only loosely bound down, allowing for the terminal to move and make/break contact.