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Kapton Wire Concerns for Aerospace Vehicles

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J. Van Laak

Maintenance Operations Manager

DE 111

NASA Johnson Space Center

Agenda

- Background
- Shuttle Status
- Test/Research Programs
- Recommendations for Shuttle
- Recommendations for Freedom
- Conclusions

Background

- o Rapid growth of electrical system size and weight
- o Aerospace industry evolved new requirements
  - Smaller conductors and thinner insulation films
  - Higher temperature insulation materials
  - Improved abrasion resistance
- o Kapton has high temperature rating and good abrasion resistance
- o New failure modes introduced but not recognized
  - Conductive char formation
  - Energy density of harnesses increased
- o Fly by wire vehicles raise the criticality of the electrical system
- o Arc-tracking facts:
  - Two kinds: wet and dry
  - Requires an initiating event (i.e., insulation damage)
  - Not a combustion process
  - An extended ignition source (time and space)
  - Failure can cascade through a harness (flashover)
  - Flashover can fail an entire harness
  - Failure propagates rapidly
  - Conventional circuit protection does not prevent
  - Substantial failure history in DOD (500+) and NASA (5+) arc propagating events
  - Use of Kapton wire has been severely restricted by many agencies

Shuttle Status

- o NASA HQ investigation concluded that the risk of Kapton arc-tracking/flashover is a credible threat to the orbiter
  - Risk of another arcing event over life of program is high
  - Risk of loss of mission/early return is moderate
  - Risk of loss of vehicle is at least an order of magnitude less than risk resident in the propulsive elements
- o Risk can be substantially lessened
  - Orbiter not originally engineered with consideration for these failure modes
  - Maintenance and inspection can compensate for many shortcomings
- o Pre-STS-26 rationale not valid
  - Depended on four fundamental elements

    Aerospace quality wire installation will preclude wire damage

    Physical protection installed in high traffic areas

    Circuit protection will prevent damage propagation

    Redundancy separation will preclude crit 1 events
- o Detailed review of rationale revealed the following:
  - Quality of wire installation and maintenance:

    Shuttle built to 1970's "aerospace Standard" & did not account for arc-tracking/flashover failure modes

    Wire damage and short circuits fairly common

    Most damage not due to negligence

Status (cont)

- Physical protection installed in high traffic areas:
  - Level of effort reflected low credibility of threat
  - Rubber pads used to crawl on wiring in ECLSS bay
  - Some convoluted tubing applied at high traffic points
  - Sheetmetal cable covers installed on VESS
  - Other protection defined but not implemented

- Circuit protection to prevent damage propagation
  - Not designed to detect/prevent arcing
  - Resistance to inadvertent tripping is critical
  - JSC Orbiter breadboard shows ineffective for 28 volt DC events
  - JSC data inconclusive for 115 volt AC events
  - STS-6 event was in AC harness & destroyed harness

- Redundancy separation of critical functions precludes Crit 1 events
  - Requirements allowed exceptions in certain areas
  - These exceptions not recorded or tracked
  - FMEA/CIL review of wiring deleted from program

<u>JSC testing and flight experience have demonstrated that failure propagation can result in loss of an entire harness</u>

Rationale for Flight

- o Rationale adequate for continued flight for time being
  - Wiring generally well installed and maintained
  - Physical protection installed at highest risk locations
  - Additional protection being installed as practical
  - Training and hardware inspection highlight concerns
  - Flight rules preclude resetting tripped circuit breakers
  - Small number of crit 1 harnesses and low risk of crit 1 event
  - Continued attention required to control risk
  - Risk is unacceptably high for inclusion in new builds

Testing/Research

- o NASA development of new insulation materials is not practical
- o Improved understanding of insulation material properties in a systems level context is critical
- o New testing programs address NASA requirements:
  - WSTF program to determine minimum energy level to sustain arc-propagation in MIL-W 81381 (Kapton) wire

    4 watts for 26 awg wire

    8 watts for 20 awg wire
  - WSTF program to determine physics-based limits of insulation resistance to arc-propagation
  - Analytical math model development (Battelle)

Recommendations for Shuttle

- o Increase emphasis on mitigating this risk
- o Physical protection must be stressed
  - Add protection where logical before damage is noted
- o Thorough, dedicated inspections should continue regularly
- o Redundancy and its limits should be understood:
  - Crit 1 harnesses should be identified
  - re-routing/replacement when practical
  - Special inspection/protection when not
  - Should understand downmoding to crit 1 harnesses when all remaining redundancy is in one harness

Recommendations for Station

- o Do not use Kapton wire (MIL-W 81381) for any power circuits
- o Do not ban the use of Kapton
  - May be ideal for low power signal wires
  - OK for use as structural applications such as solar array blankets
  - Flexible circuits have shown susceptibility to arc-tracking
  - Kapton may be safely used in correctly designed hybrid wire constructions (i.e., TKT) to improve abrasion resistance
- o Electrical systems should be designed to preclude arc-propagation regardless of insulation material

Conclusions

- o Arc-propagation poses a significant and credible threat to mission safety and success in aerospace vehicles
- o Wire construction has a significant impact on the probability of arc-propagation
  - Resistance to damage
  - Formation of conductive char
- o If permitted, arc-propagation can result in the failure of any wire bundle above a critical energy potential
  - Includes primary power cabling if bundled with returns
- o Station should be designed to tolerate reasonable levels of wire damage without failure propagation to adjoining wires
- o Kapton (MIL-W 81381) wire or its equivalent should not be utilized in new builds for power applications