N95-16047

WSTF Electrical Arc Projects

30139
p 18
109652

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NHB 8060.1C Test 18 Validation

Objective

Validate Method Used To Screen Wire Insulation With Arc Tracking Characteristics

Approach

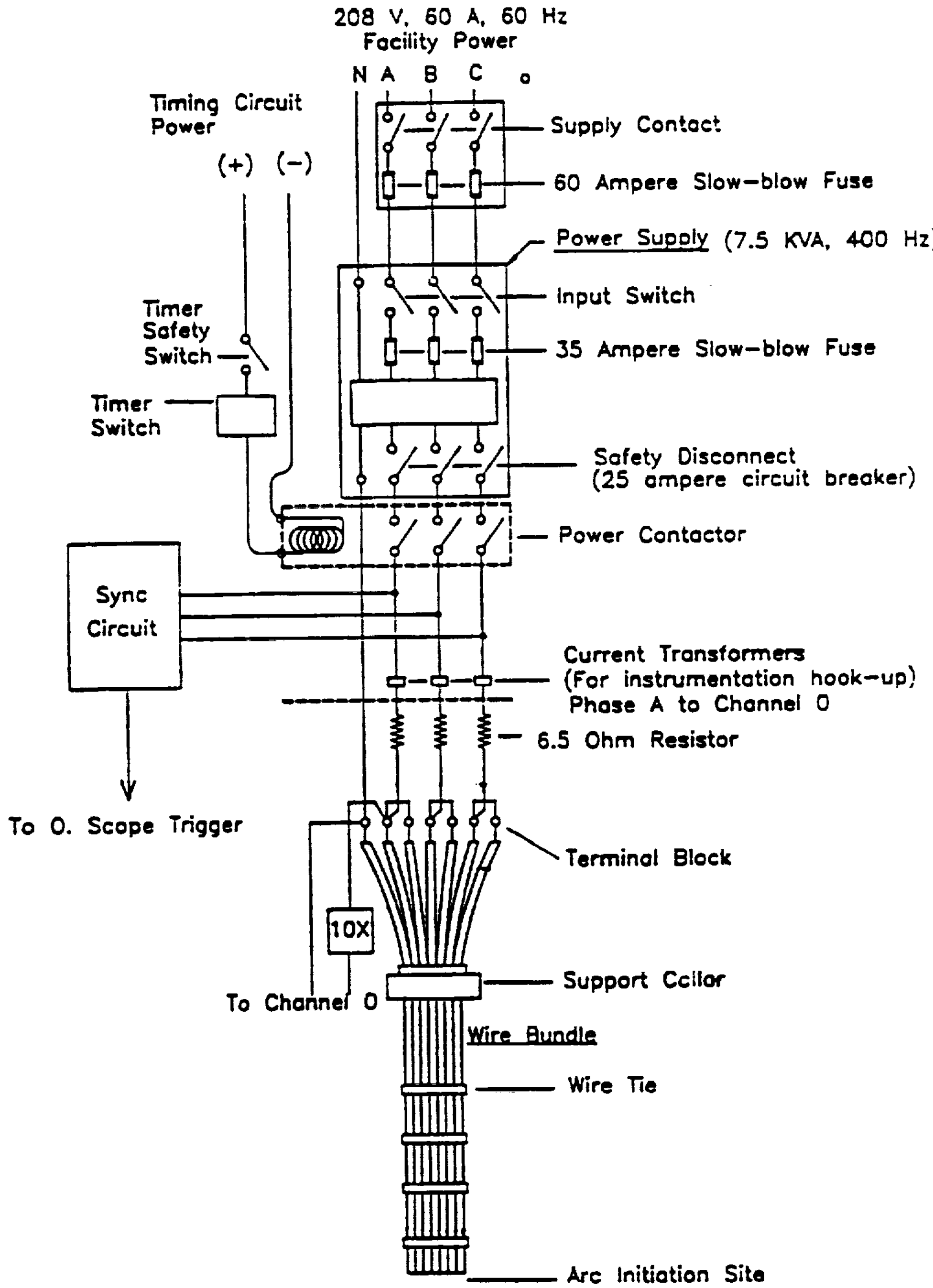
7-wire bundle
Worst Case Power 200 VAC 25 Amps 400 Hz
Induce Failure with Graphite Powder (5 sec)
Remove Power (10 sec)
Restrike (30 sec)

Failure

Propagation

Validation

PTFE, ETFE, Polyimide
Ambient Air
Shuttle Environments



Functional Schematic of Test System Used to Validate NHB 8060.1C, Test 18

Arc Resistance In Space Grade Wires

Objective

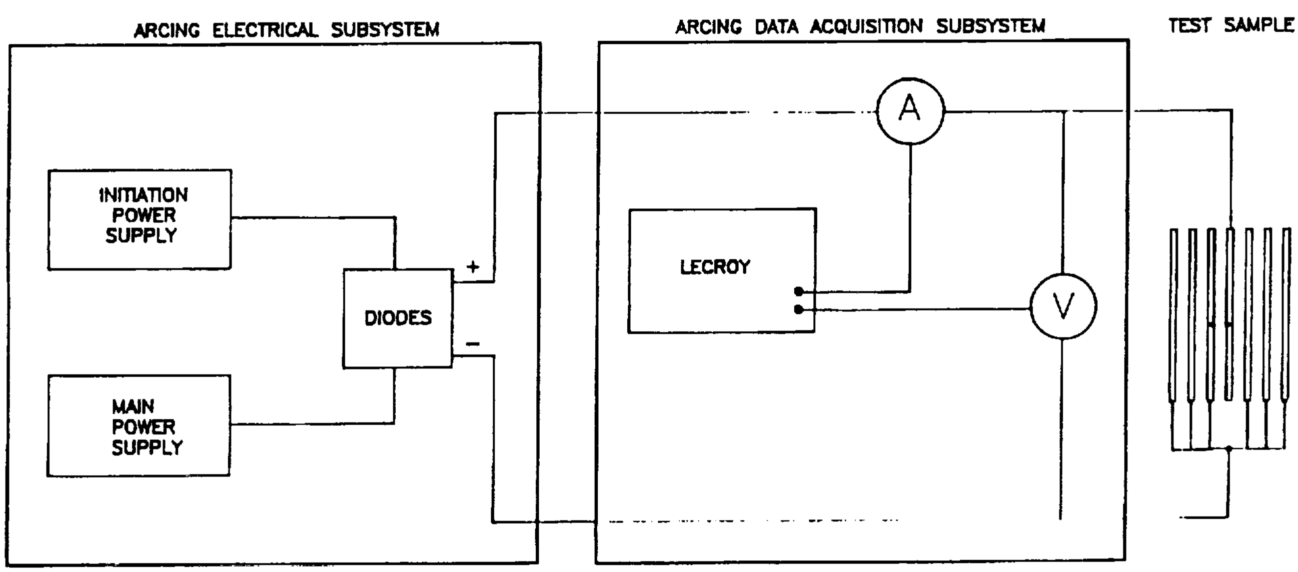
Determine Damage Resistance to Arc as A Function of Source Voltage and Insulation Thickness

Approach

7-wire bundle
Power Source Voltage 28 to 300 VDC
Induce Brief (100 msec) Failure With Bridge Wire and Constant Current Source
Allow Normal Propagation With Power Source Voltage
Dielectric Measurement Between All Wires Insitu
Dielectric Evaluation of Each Wire
Visual Inspection

Analysis

Plot Wires Failed on Source Voltage vs Insulation Thickness



Pyrolytic and Arc Damage Properties of Kapton at Low Voltages

Objective

Investigate Propagation Characteristics of Kapton at Low Voltages

An Evaluation of the Pyrolytic and Arc-Damage Properties of Polyimide Wire Insulation for Low-Voltage Applications

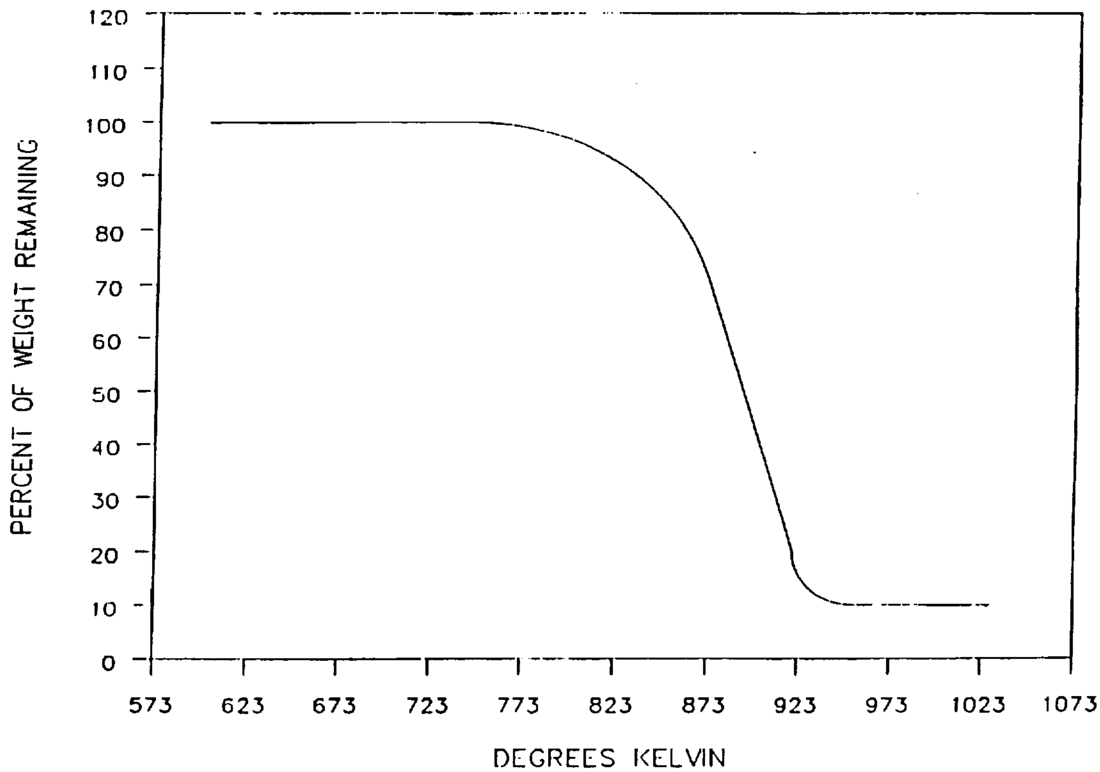
Objective

Investigate Pyrolytic Properties of Polyimide Insulated (Kapton) Wire for Low Voltage (<35 VDC) Applications

Approach

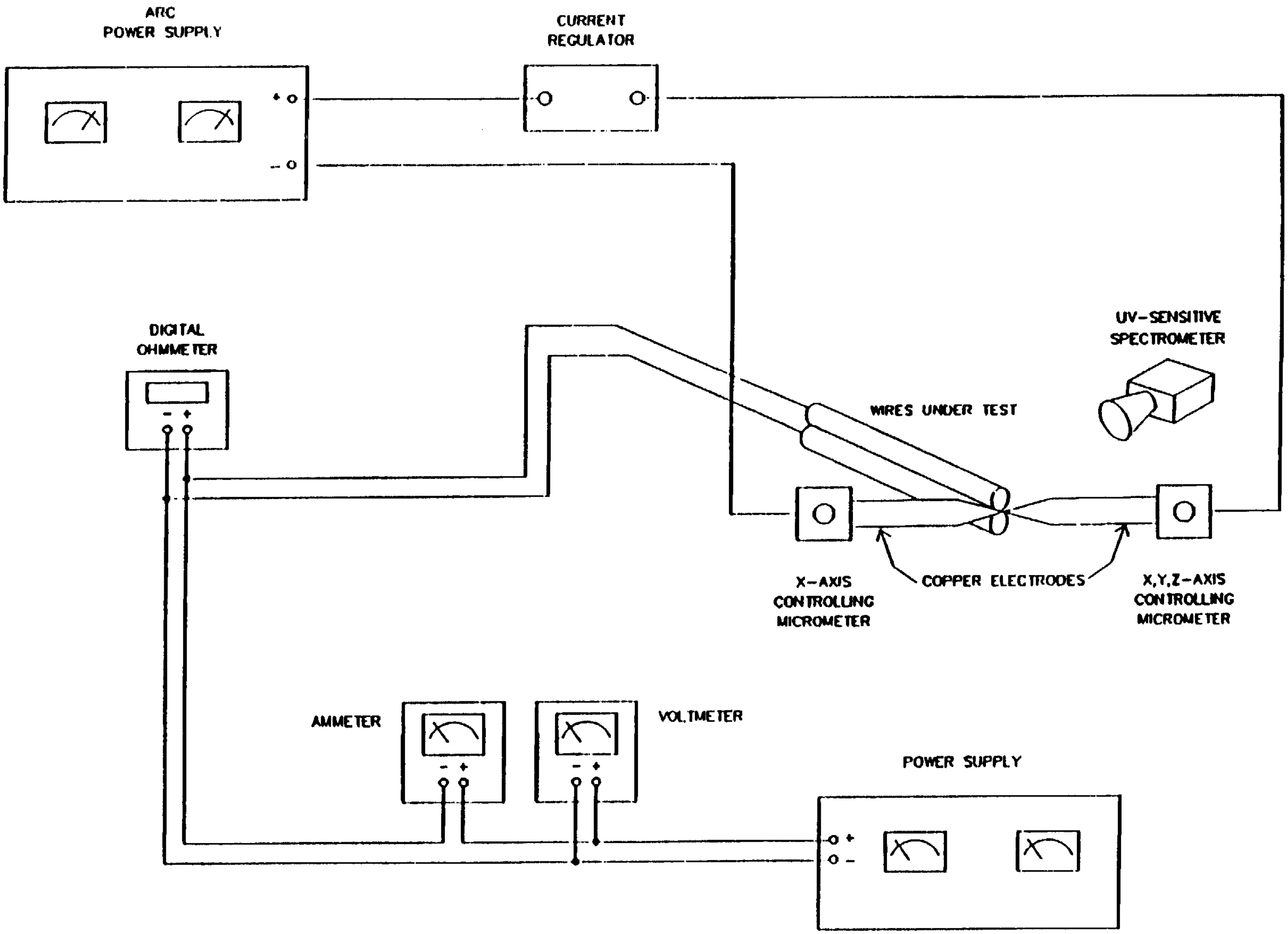
- Measure pyrolytic threshold temperature of Kapton via thermogravimetric analysis
- Measure electrical resistance of pyrolyzed Kapton material (arc induced damage) as a function of arc exposure time
- Measure pyrolytic threshold and propagation rates for energized conductor pairs as a function of voltage and power for 20 & 26 AWG wires
- Assess damage to the insulation of wire adjacent to energized pyrolyzing wires
- Investigate spectral characteristics of the radiative emissions associated with the pyrolytic process as a function of applied voltage
- Develop and evaluate a theoretical model for predicting pyrolytic temperatures as a function of applied electrical power and wire size

Thermogravimetric Test



Thermogravimetric Analysis Procedures

A sample of the polyimide insulation was placed on a small tray. The tray was suspended by a microbalance and placed inside of a small oven contained within an Omnitherm 1500 TGA test system. A quartz tube surrounding the sample was placed inside the oven and attached to the top of the Omnitherm 1500. The top contains a seal through which the microbalance suspension passed into the oven. The maximum temperature (1023 K), rate of temperature increase (5 K/min), and flow rate of dry air through the oven (4 cc/sec) were then set at the control panel. As the temperature increased, the sample reacted with the air flowing through the oven and the weight was recorded by a computer attached to the Omnitherm 1500.


ARC
POWER SUPPLY
CURRENT
REGULATOR
DIGITAL
OHMMETER
UV-SENSITIVE
SPECTROMETER
WIRES UNDER TEST
X-AXIS
CONTROLLING
MICROMETER
COPPER ELECTRODES
X,Y,Z-AXIS
CONTROLLING
MICROMETER
AMMETER
VOLTMETER
POWER SUPPLY

$$e_a = a + bx + \frac{c}{i} + \frac{dx}{i}$$

where

e_a	=	voltage required to sustain the arc at 100 kPa (1 atm) at currents less than 18 A
a, b, c, d	=	constants for copper electrodes (15.2, 10.7, 21.4, and 3.0, respectively)
x	=	gap distance in mm
i	=	arc current

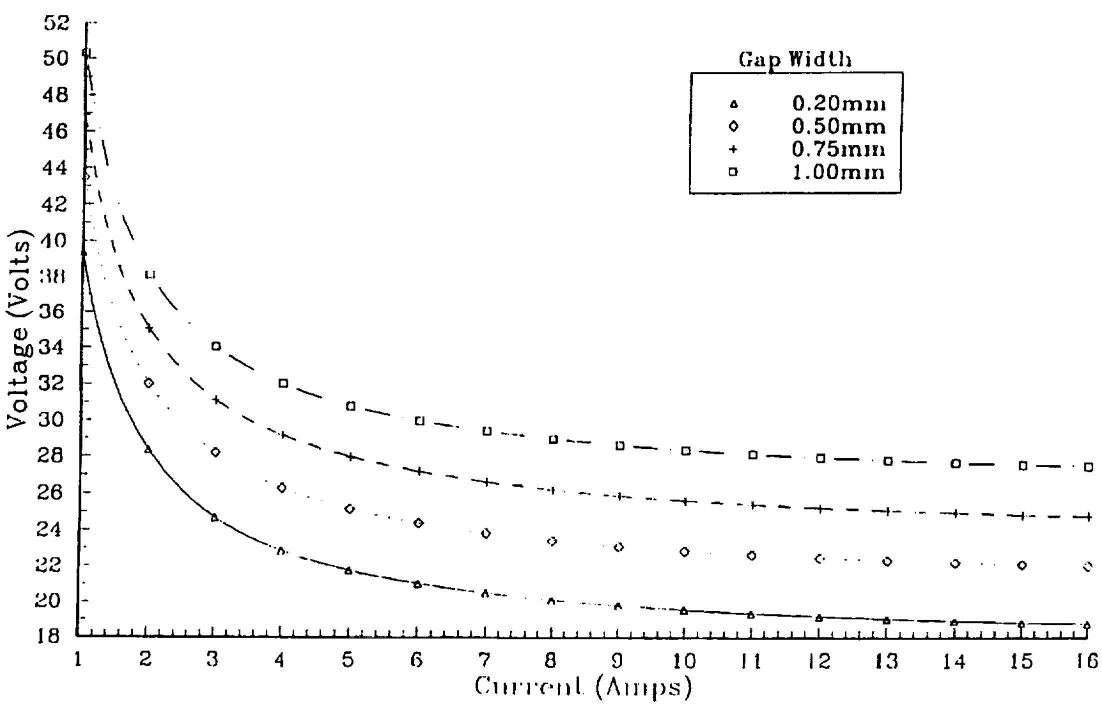


Table 1
Resistance Measurements After Arcs and After Power Application

Resistance (Ω) Measured After				After Power Applied	
2-sec Arc	5-sec Arc	10-sec Arc	Power (Volts, Amps)	Activity	Resistance (Ω)
			20 AWG Wire		
∞[a]	∞	128	28, 4	Sparks	1000
∞	1,400	115	28, 4	Nothing	∞
∞	∞	19,000	28, 4	Nothing	∞
∞	∞	7	28, 4	Pyrolysis	3
∞	∞	546	28, 4	Nothing	∞
∞	28,000	14	28, 4	Sparks	∞
∞	105	2	28, 4	Pyrolysis	2
∞	∞	2000	28, 4	Nothing	∞
∞	870.000	5	28, 4	Pyrolysis	5
∞	∞	8	28, 4	Pyrolysis	1
∞	∞	15	5, 5	Nothing	23
∞	10.000	20	5, 5	Nothing	410
∞	∞	30	5, 5	Nothing	14.000
∞	∞	4	5, 5	Nothing	5.000.000
∞	8.500	50	5, 5	Nothing	10.000.000
			26 AWG Wire		
∞	∞	18	28, 4	Sparks	3500
∞	∞	570	28, 4	Nothing	∞
∞	∞	14	28, 4	Sparks	724.000
∞	240	113	28, 4	Sparks	11.000.000
∞	∞	30	28, 4	Sparks	5.800.000
∞	37	43	5, 5	Nothing	18.000
∞	∞	30	5, 5	Nothing	123
∞	39	7	5, 5	Sparks	1500
∞	∞	190	5, 5	Nothing	∞
∞	∞	25	5, 5	Nothing	136

[a]∞: Greater than 12,000,000 Ω

Drawn Arc Test Procedures

Fifteen sets of 20 AWG and 10 sets of 26 AWG polyimide-insulated wire pairs (15-cm [6.0 in.] long) were constructed. Each pair was held together with common sewing thread to simulate a parallel wire bundle configuration.[1] Each wire pair was positioned horizontally in a metal clamp attached to a metal stand.

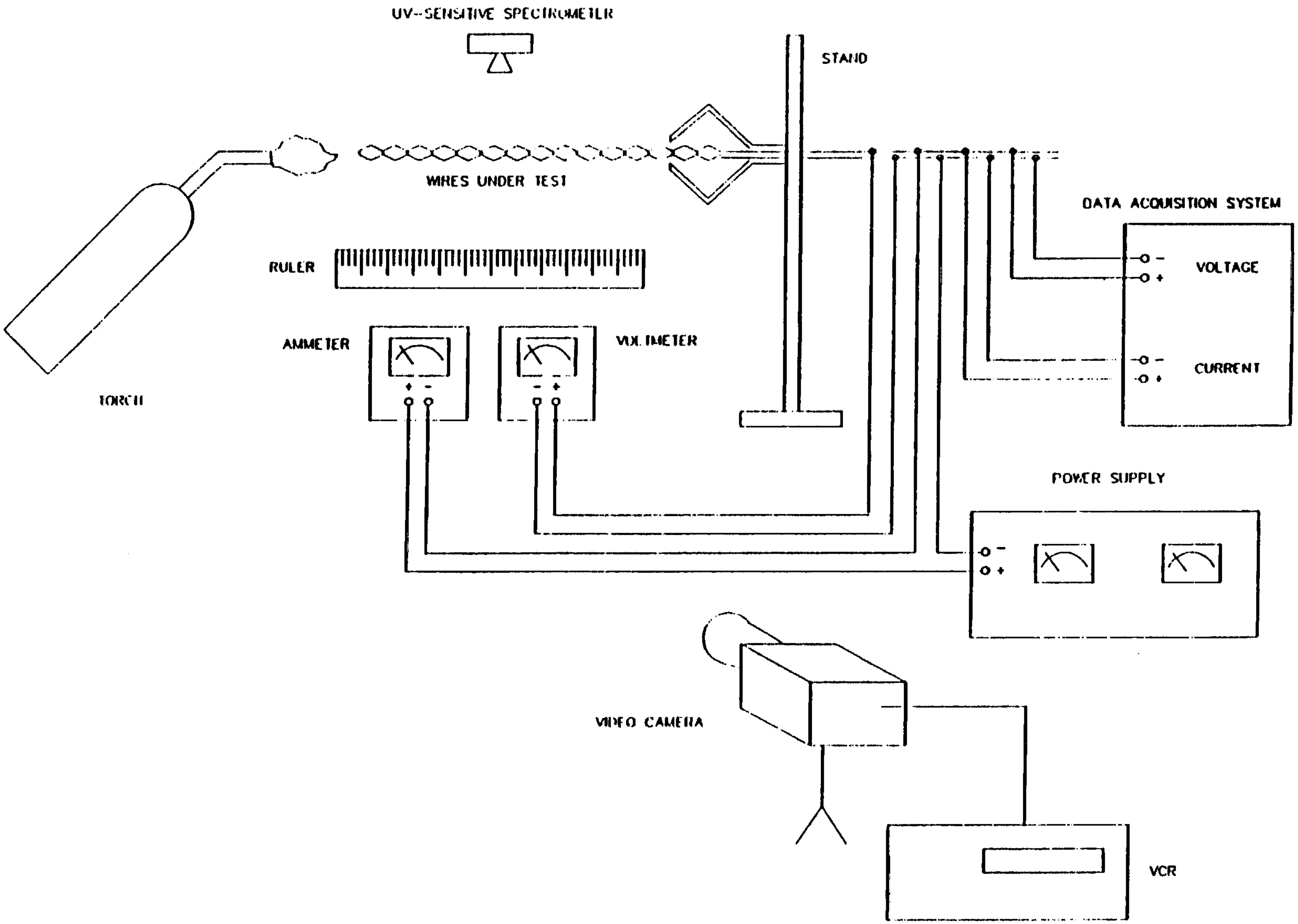
- The ends of the wire insulation were exposed to the drawn arc for 2 seconds.
- The resistance of the pyrolyzed polyimide insulation between the two wires was measured and recorded.
- The drawn arc and resistance measurements were repeated with arcs of 5 and 10 seconds.
- A power supply limited to 28 V open circuit and 4 A short circuit was applied for 1 minute to the wires and any pyrolytic activity was noted.
- The resistance of the pyrolyzed polyimide insulation was measured again after the power supply was turned off.

This same sequence of testing was conducted with the power supply limited to 5 V open circuit and 5 A short circuit.

After all the drawn arc testing was completed, an arc was drawn in the field of view of the UV-sensitive spectrometer to record the arc emissions.

[1]Previous testing at WSTF determined that nylon lacing cord acted as a "fire-break" and greatly inhibited propagating pyrolysis.

20 AWG Polyimide-Insulated Wire after 10 Seconds in Drawn Arc Test



Energized Conductor

Energized Conductor Test Procedures

Twenty sets of both 20 and 26 AWG twisted pair, open circuit, polyimide-insulated wires (36-cm [14-in.] long) were constructed. Each wire pair was positioned horizontally in a metal clamp attached to a metal stand. Power supply, data acquisition system, and meter connections were made at the ends of the wires held in place by the metal clamp. A ruler was placed under the wires (to facilitate the measurement of the propagating-pyrolysis rate) and the video system was activated.

- The power supply, limited to 28 V open circuit and 4 A short circuit and connected to the ends of the wires, was energized. Approximate electrical power values necessary to sustain pyrolysis, along with propagating-pyrolysis rates, were recorded with the analog meters and video system. More accurate electrical power values were recorded with the data acquisition system to verify the analog meter readings.

- After sustained pyrolysis was obtained, the power supply current limit was decreased (to 2 A for the 20 AWG wires and to 1 A for the 26 AWG wires), and then increased in 1 A/min increments up to 10 A.

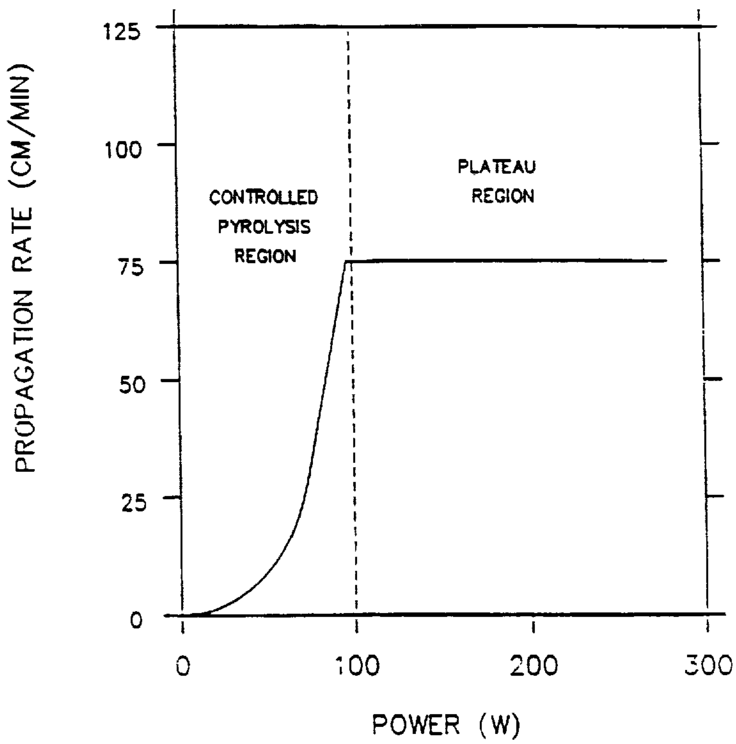
Table 2
Propagating-Pyrolysis Rate of 20 AWG

Voltage (Volts)	Current (Amps)	Power (Watts)	Propagation Rate (cm/min)	Propagation Rate (in./min)
5.3	1.9	10.0	0.5	0.2
4.5	2.9	13.1	0.8	0.3
3.6	4.0	14.4	1	0.4
4.3	4.8	20.6	1	0.5
3.8	5.9	22.4	2	0.9
4.3	6.8	29.2	3.8	1.5
4.3	7.8	33.5	4.3	1.7
4.0	8.9	35.6	6.4	2.5
3.8	9.9	37.6	10	3.8
4	20.0	80.0	25	10
4	24.0	96.0	30	12
16	15.0	240.0	76	30
24	12.0	288.0	76	30
28	11.0	308.0	76	30

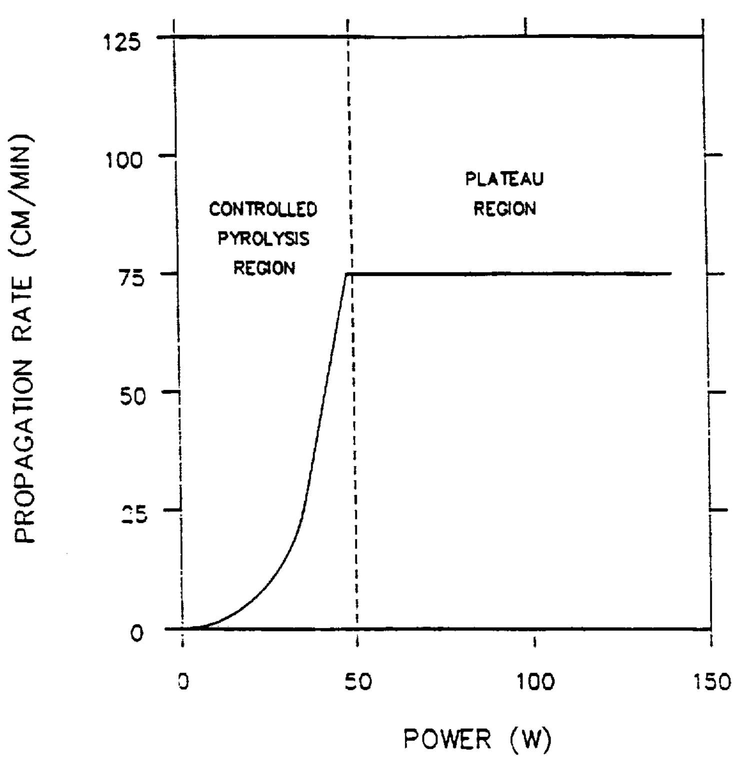
Table 3
Propagating-Pyrolysis Rate of 26 AWG

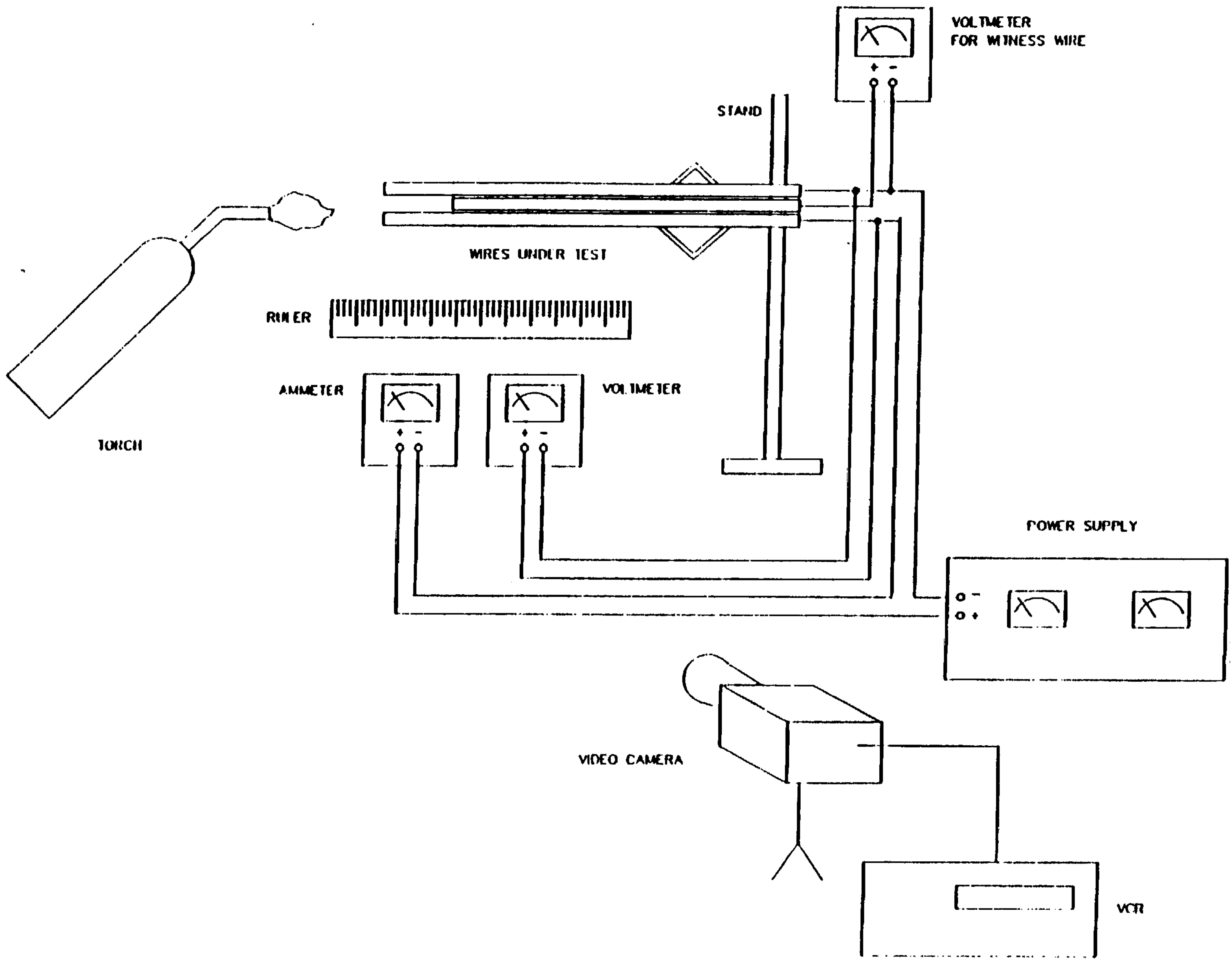
Voltage (Volts)	Current (Amps)	Power (Watts)	Propagation Rate (cm/min)	Propagation Rate (in./min)
2.7	0.9	2.4	<1	<0.4
3.8	1.9	7.2	1	0.4
2.9	2.7	7.8	1	0.5
2.8	3.6	10.1	2	0.6
2.4	4.6	11.0	2.5	1.0
2.1	5.7	12.0	2.8	1.1
1.9	6.6	12.5	3.3	1.3
2.0	7.7	15.4	4.1	1.6
2.0	8.7	17.4	6.4	2.5
3.1	9.9	30.7	9.1	3.6
4.0	10.0	40.0	31	12
15.0	3.3	49.5	76	30
18.0	4.5	81.0	76	30
28.0	3.4	95.2	76	30
30.0	4.0	120	76	30
35.0	4.0	140	76	30

20 AWG


125
100
75
50
25
0
PROPAGATION RATE (CM/MIN)
CONTROLLED
PYROLYSIS
REGION
PLATEAU
REGION
0
100
200
300
POWER (W)

26 AWG


125
100
75
50
25
0
PROPAGATION RATE (CM/MIN)
CONTROLLED
PYROLYSIS
REGION
PLATEAU
REGION
0
50
100
150
POWER (W)


VOLTMETER
FOR WITNESS WIRE
STAND
WIRES UNDER TEST
RULER
AMMETER
VOLTMETER
TORCH
POWER SUPPLY
VIDEO CAMERA
VCR

Adjacent Wire Pyrolysis Test Procedures

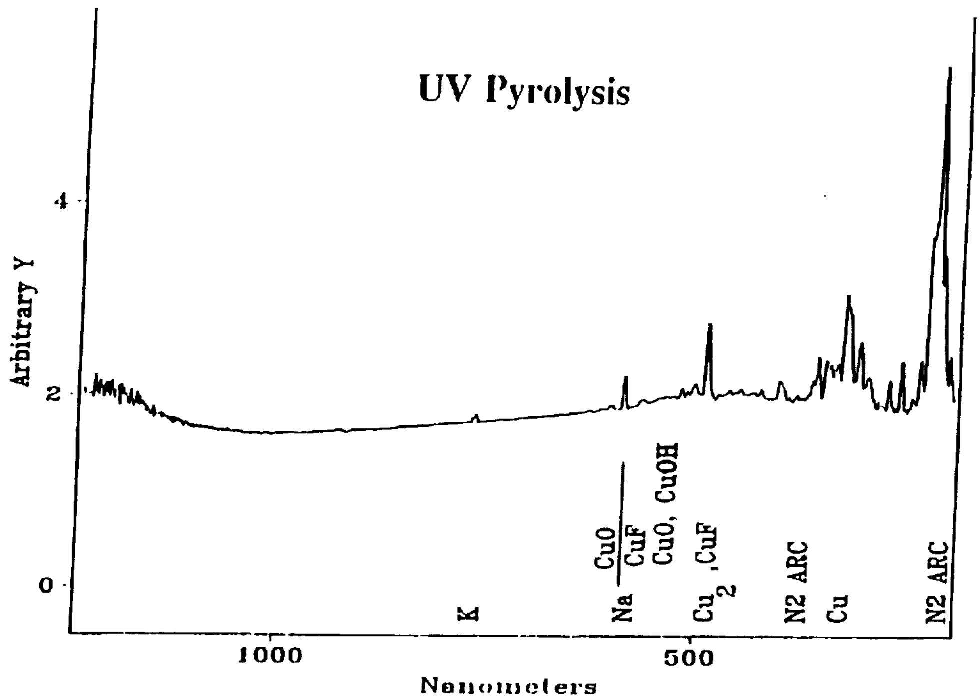
Five sets of three 36-cm (14-in.) long, polyimide-insulated wires were constructed from both 20 and 26 AWG wire. Each set was held together in a parallel configuration with common sewing thread to simulate a parallel wire bundle configuration. Each wire set was positioned horizontally in a metal clamp attached to a metal stand. To study the effects of pyrolysis on an adjacent wire, the middle wire was shortened by 5-cm (2 in.) The voltmeter was placed in parallel with the middle wire and the negative side of the power supply to measure voltage across the wire insulation during pyrolysis.

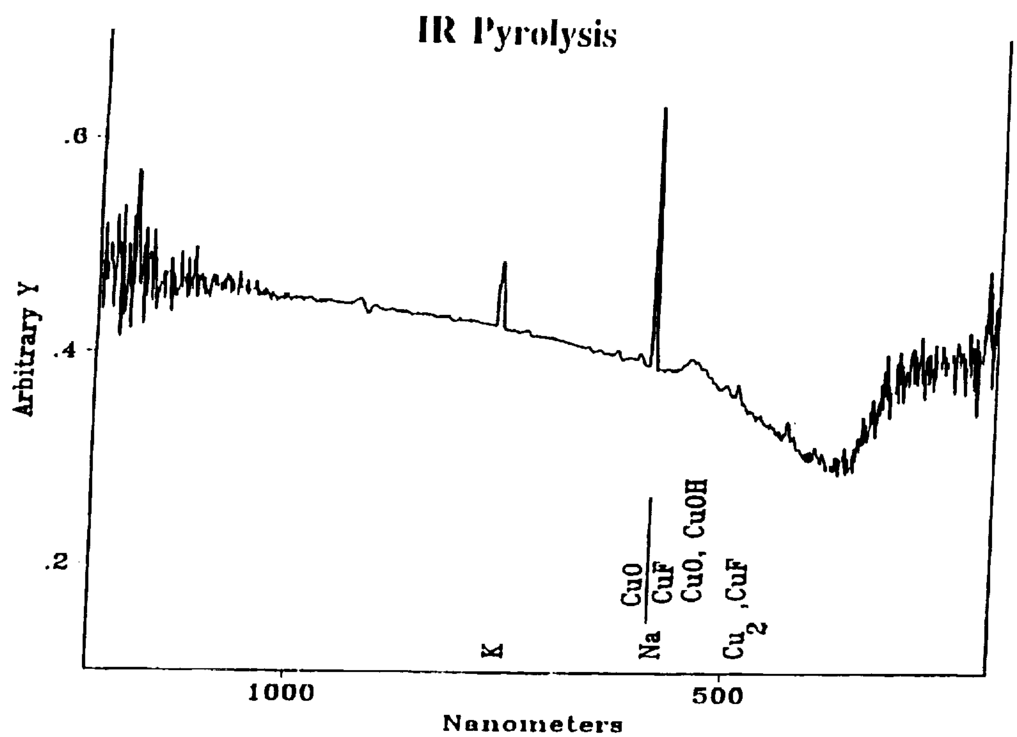
- The two outside wires were energized with 28 V and 10 A (to ensure pyrolysis), while the middle (adjacent) wire was left as an open circuit.
- The video recording system was activated and the propane torch was used to pyrolyze the ends of the 36-cm (14-in.) wires.

Spectrometer Test Procedures

Twenty sets of both 20 and 26 AWG twisted pair, open circuit, polyimide-insulated wires (36-cm [14-in.] long) were constructed. Each pair of previously pyrolyzed wire was positioned horizontally in a metal clamp attached to a metal stand, and then placed into the spectrometer's field of view. Power supply and meter connections were made at the ends of the wires held in place by the metal clamp. A ruler was placed under the wires (to facilitate the measurement of the propagating-pyrolysis rate) and the video system was activated.

- The voltage limit was set to 5 V for 20 AWG wires (15 V for 26 AWG wires) and increased in 5 volt increments (up to 28 V for 20 AWG wires and to 40 V for 26 AWG wires).
- At each voltage increment, the current was increased slowly until rapidly propagating pyrolysis occurred or the maximum power supply current level was reached. When characteristic arc emissions were detected, the minimum voltage threshold to support arc emissions was recorded.


UV Pyrolysis
Arbitrary Y
4
2
0
K
Na
CuO
CuF
CuO, CuOH
Cu
2
,CuF
N2 ARC
Cu
N2 ARC
1000
500
Nanometers


IR Pyrolysis
Arbitrary Y
.6
.4
.2
K
Na
CuO
CuF
CuO, CuOH
Cu
2
,CuF
1000
500
Nanometers

Electrical Power In = Heat Loss of Decomposition Zone

$$P_{in} = Q_{Loss} \tag{1}$$

Assuming that convection heat losses are negligible, and that steady-state conditions exist, then:

$$P_{in} = \epsilon\sigma(T^4 - 300^4)\alpha_{eff} + \sum_{j=1}^{n}\left[\frac{k_j A^j_{eff}(T - 300)}{l_j}\right] \tag{2}$$

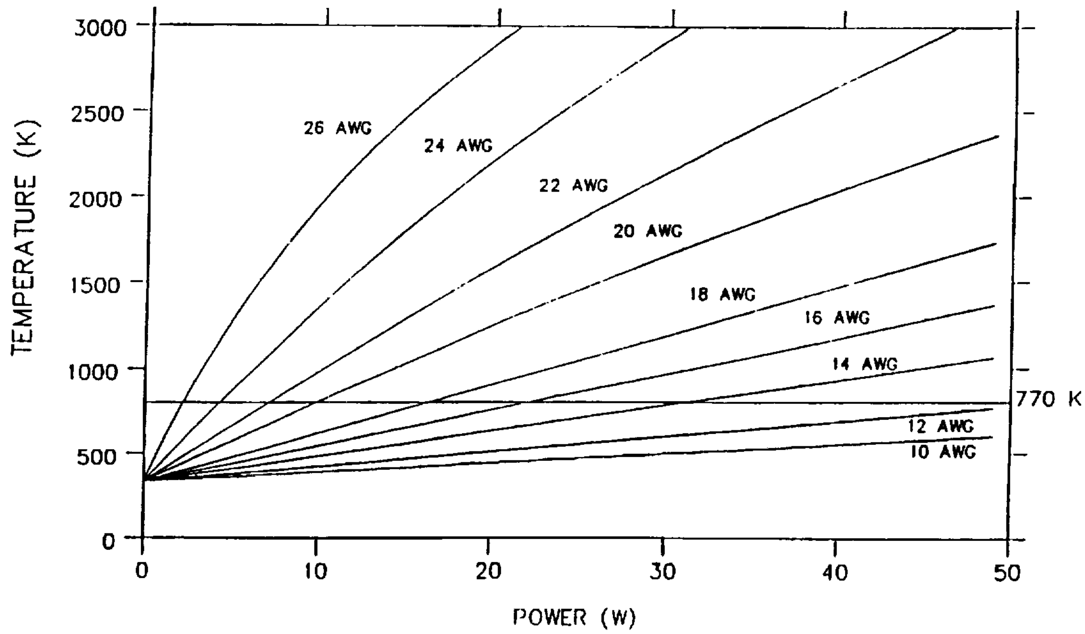
where the second term is the sum of conductive heat losses from the decomposition zone, and where

ϵ = emissivity $\approx$ 1.0
σ = $5.67 \times 10^{-12}\ \frac{\mathrm{W}}{\mathrm{cm^2K^4}}$
T = steady-state temperature of decomposition zone
α_{eff} = effective area of decomposition zone (0.035 cm^2 for 20 AWG wire)
n = number of materials
k_j = coefficient of thermal conductivity
A^j_{eff} = effective area of conductor (heat loss) material
l_j = length of heat flow path for conductor (heat loss) material

Solving the fourth order polynomial for its real root yields the temperature as a function of electrical power (Figure 15).

Table I
Typical Constants for Steady-State Equation for Heat Transfer of 20 AWG Wire Pairs

Material	k_j $\left[\frac{\mathrm{W}}{\mathrm{cm\ K}}\right]$	A^j_{eff} (cm^2)	l_j (cm)
Air	2.5×10^{-4}	0.05	0.1
Kapton (20 Ga)	3.0×10^{-3}	0.01	1.0
Copper (19-32 Ga)	4.0	0.005	1.0



Conclusions

- Thermogravimetric Decomposition Threshold Temperature of Kapton Insulation Material Measured in Air 773 K

- Resistance of Pyrolyzed Kapton Insulation < 150 ohms. Damage Occurs Within 5 Seconds of Arc-Induced Exposure.

- Pyrolytic Thresholds and Propagation Rates Measured:

  - Electrical Power Pyrolytic Thresholds
    20 AWG Kapton Wire = 10 WATTS
    26 AWG Kapton Wire = 2.5 WATTS

  - Pyrolytic Propagation Rates

    Nonlinear Rate from 10-100 WATTS for 20 AWG
    Plateau Rate: 76 cm/min 100-300 WATTS

    Nonlinear Rate from 2.5-50 WATTS for 26 AWG
    Plateau Rate: 76 cm/min 50-150 WATTS

    Crossover Region Between Nonlinear and Plateau Indicated Electrically as a Switching Region from Resistive Heating Damage to Arc Damage

Conclusions

- Adjacent Wire Insulation Damage by a Pyrolysis Zone
  - 2 Seconds with 280 WATTS (28 VDC @ 10 A) for 20 AWG

- Pyrolytic Spectral Characteristics Measured in Air

  - Resistive Heat Damage -- Planck IR Radiation Emissions
    - < 16 VDC @ 20 AWG
    - < 28 VDC @ 26 AWG

  - Arc Damage -- Ultraviolet Emissions Peaks (190-350 NM)
    - > 16 VDC @ 20 AWG
    - > 28 VDC @ 26 AWG

  - Arc versus Resistive Heating Damage Mechanisms Are Not Completely Understood, But Thresholds Are Considered to be Related to the Minimum Voltage (Potential) Required to Ionize Air for a Specific Wire Spacing

- Theoretical Model
  - Predicts pyrolytic temperature versus electrical power
  - Benchmarked with 20 AWG and predicted 26 AWG
  - Model demonstrates the significance of the conductors to remove heat from the pyrolytic zone