A NEW TEST METHOD FOR THE ASSESSMENT OF THE ARC TRACKING PROPERTIES OF WIRE INSULATION IN AIR, OXYGEN ENRICHED ATMOSPHERES AND VACUUM

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Published Information on the Activities of the
Cooperating Group THD / ERNO / ESA-ESTEC

[1]	F. Dricot, H.J. Reher	Survey of Arc Tracking on Aerospace Cables and Wires. Post-Deadline Proceedings of the XVth Intern. Symp. on Discharges and Electrical Insulation in Vacuum, September 6 – 10, 1992, Darmstadt, Germany, pp. 24 – 30, to be published in IEEE Trans. on Electrical Insulation
[2]	D. König, F.R.Frontzek F. Dricot, H.J. Reher M.D. Judd	Principle of a New Arc Tracking Test of Cables and Wires for Spacecraft. Conference on Electrical Insulation and Dielectric Phenomena (CEIDP), October 18 – 21, 1992, Victoria, BC, Canada, pp. 363 – 369
[3]	ESA/ESTEC	Survey of Arc-Tracking. Final report, October 1991, submitted by MBB/ERNO. Internal paper. Authors: F. Dricot, H.J. Reher
[4]	M.D. Judd	Presentation of Activities in the Field of Arc Tracking of Wire Insulations (ESA/ERNO) Materials And Processes Technical Interchange Meeting, Reston, VA, September 1 – 3, 1992
[5]	ESA/ESTEC	Arc Tracking Test of Wires. Report of Phase 1. January 1993, submitted by ERNO. Internal paper. Authors: F. Dricot, H.J. Reher
[6]	D. König, F.R.Frontzek H.J. Reher, M.D Judd	A New Test Method for the Assessment of the Arc Tracking Properties of Wire Insulation in Air, Oxygen Enriched Atmospheres and Vacuum. 6th Int. Symp. on the Flammability and Sensitivity of Materials in Oxygen Enriched Atmospheres, Noordwijk, May 11 – 13, 1993 (oral presentation)

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(Def. of G.A. Day)

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A kind of electr. discharge mainly between two or more conductors
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Arc Tracking

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A. G. DAY

Tracking

TRACKING is an untidy process; its incidence depends upon the insulation but its inception depends upon several other factors. By definition, tracking is the formation of a permanent conducting path across a surface of the insulation, and in most cases the conduction results from degradation of the insulation itself. It is therefore necessary for organic insulation to be present if tracking is to occur.

The three essentials of the tracking phenomenon are:

(1) the presence of a conducting film across the surface of the insulation,
(2) a mechanism whereby the leakage current through the conducting film is interrupted with the production of sparks,
(3) degradation of the insulation must be caused by the sparks.

Definition of an Arc

Probably the best definition of an arc is that due to Compton: namely,

the arc is a discharge in a gas or vapor with a voltage drop in the cathode region that is *of the order of* the lowest ionization potential of the gas or vapor in which it burns.

The voltage of short arcs is usually in the range 10 - 50 V. This arc drop is divided between *anode* and *cathode* drops (usually of the order of 10 V; often the anode drop is considerably higher than the cathode drop) and the balance in the column that depends on its length. Arc currents are usually from the order of one to many thousands amperes.

ARC TRACKING TESTS

Development of wet arc tracking test methods

Initiated by incidents of arcing recorded under wet conditions: e.g. a failure of a cable bundle on a Monarch Airlines aircraft caused by a leaking toilet.

Development of dry arc tracking test methods

Other incidents of arc ignitions recorded in dry conditions (mechanical damage of insulation, electrical sparks etc.)

Comparison of existing test methods

Conclusion: No appropriate arc tracking test for space application available

Aim:

Development of a new test method suitable for the assessment of the resistance of areo-space cables to arc tracking for different specific environmental and network conditions of spacecrafts

Table 1. Comparison of Test Methods (published at CEIDP, 1992)

Test method comparison	[8]	[9]	[6]	[7]	[12]	[13]	[10]	[11]
1. Electric circuit								
1.1. Power source								
a) AC.200/115V,400Hz	+	+	+	var	–	+	–	–
b) DC	–	–	–	var	var	–	–	–
c) others	–	–	1)	2)	–	–	3)	4)
1.2. Current								
a) same value for all cable sizes and types	+	+	–	–	–	+	1A	5)
b) dependent from the nominal current of the tested cable	–	–	+	+	+	–	–	–
c) dependent from the protective device of the tested cable	–	–	+	+	–	–	–	–
1.3. Relation to recovery voltage	–	–	–	–	–	–	–	–
2. Arc ignition process								
a) wet ignition method	+	–	+	–	–	–	+	–
b) dry ignition method	–	+	+	+	+	+	–	+
3. Arc burning time limited by								
a) protective circuit breaker	+	+	+	+	+	+	+	–
b) self-extinction of the arc	+	+	+	+	+	+	+	+

1) DC, 28 V, 2) DC+AC
3) AC, 100V...600V
4) DC, 220V
5) limited by R = 20 Ω
6) ∠ 10°
7) wet = L, dry = S

(+) = yes; (–) = no
L – large (≤ 8h), S – short
? = no statement
var = variable

[6] Aerospatiale Test 480.202/87A: Electrical Cables. Aerospatiale Test Methods for Investigations of the Arc Tracking Design.

[7] ASTM D 09.16 (October 89): Dry Arc Resistance and Fault Propagation.

[8] BSG 230 Test 42: Resistance to Wet Arc—Tracking.

[9] BSG 230 Test 43(Draft): Dry Arc Test.

[10] IEC 112/VDE 0303, Teil 1: Method for Determining the Comparative and the Proof Tracking Indices of Solid Insulating Materials under Moist Conditions (VDE Specification).

[11] DIN VDE 0303, Teil 5: Testing of Electrical Insulating Materials — Low—Voltage High—Current Arc Resisting Test (in German).

[12] NASA TP WSTF—655: Arc Resistance in Space Grade Wires.

[13] NHB 8060.1C Test 18: Arc—Tracking.

Table 1. Comparison of Test Methods (continued)

Test method comparison	Test methods: [8]	[9]	[6]	[7]	[12]	[13]	[10]	[11]
4. Influence from environment conditions								
a) Air under atmospheric pressure	+	+	+	+	+	+	+	+
b) Air with enriched O_2	–	–	–	–	–	+	–	–
c) Vacuum	–	–	–	–	–	?	–	–
d) Mechanical vibration	–	+	–	–	–	–	–	–
5. Preparation and position of the sample								
a) only insulation material used for the cable construction	–	–	–	–	–	–	+	+
b) a part of wire or cable bundle	+	+	+	+	+	+	–	–
c) insulation artificially damaged	+	+	+	+	+	+	–	–
d) position								
– vertical	–	–	–	+	+	?	–	–
– horizontal	–	+	–	–	–	?	+	+
– other	6)	–	6)	–	–	?	–	–
6. Test duration	L	S	7)	S	S	S	S	S
7. Evaluation criteria								
a) Burning time of the arc	–	–	–	+	+	–	–	+
b) Length of the arc path	+	+	–	–	+	+	–	+
c) Insulation resistance measurement	+	+	–	–	–	–	–	+
d) Electric strength test	–	+	–	–	+	–	–	–
e) Continuity test of conductors	+	+	–	–	–	–	–	–
f) Visual evaluation	+	+	+	+	+	+	–	–

[6] Aerospatiale Test 480.202/87A: Electrical Cables. Aerospatiale Test Methods for Investigations of the Arc Tracking Design.

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PRINCIPLES OF A NEW ARC–TRACKING TEST

The following principles have been incorporated into the new test method.

a. Test equipment enables wires to be tested in vacuum, normal air (atmospheric pressure) and in an enriched oxygen atmosphere (at atmospheric and reduced pressure).

b. The supply voltage is adjustable. During test the current is initially set on the nominal current rating (including derating if applied) of the cable. Subsequent tests should be performed at different current values to assess the capability of the wire to withstand stress.

c. The arc is ignited by melting of an ignition wire (filament) ensuring that the influence of the ignition on the arc behaviour is minimised.

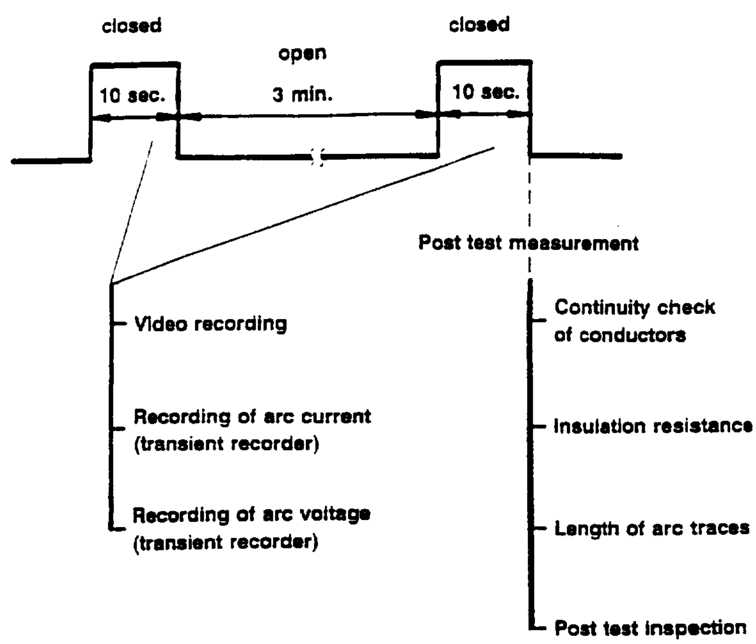
d. Switching cycles are applied to the test voltage (presently 10 sec. on, 3 min. off and a further 10 sec. on).

e. Damage is induced in the cable in a clearly defined location.

f. Evaluation criteria should be based on the test results and on any post test measurements such as:

Remaining "conduction function" of the conductors
Post test insulation state of damaged and/or undamaged cable bundles
Arc duration and path length
Measurement of electrical characteristics during test
Visual records and post test inspection

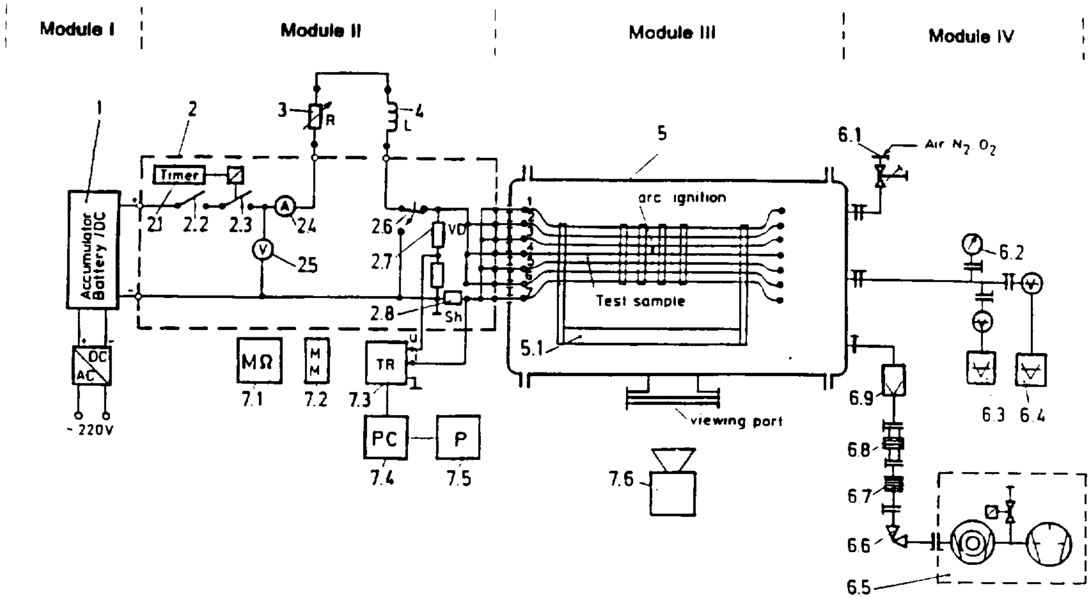
Switching Cycle, Measurements and Evaluation Criteria



Accept/Reject Criteria: still under consideration

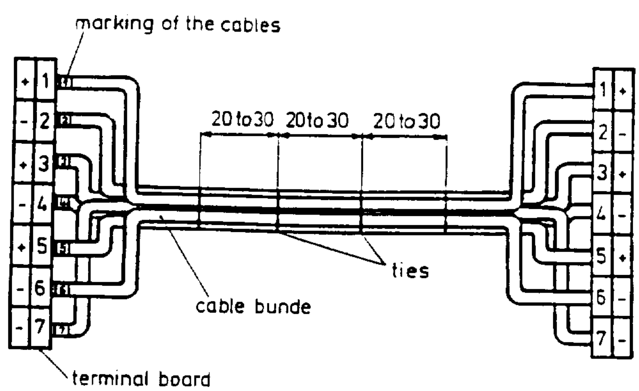
Basic ideas: Simple criteria based on selected post test measurements; support by electrical and optical records taken during test.

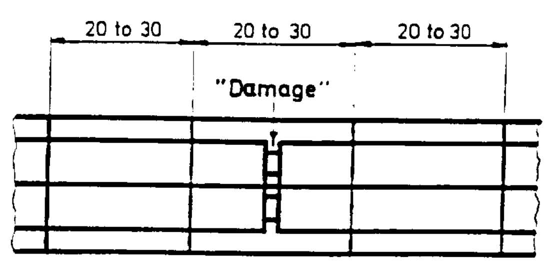
Scheme of the Arc Tracking Test Arrangement



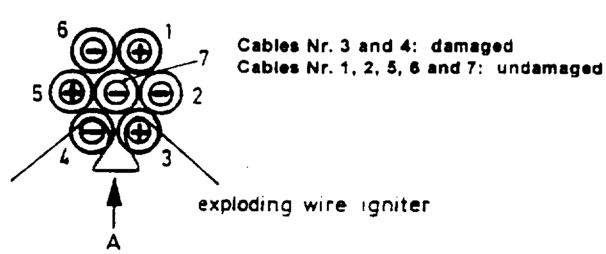
Explanation of Symbols: see [5]

Test sample configuration





View on arrow A



Test Procedure (Draft)

a. Prepare test samples as described earlier and install in chamber.

b. Establish test atmosphere.

c. Adjust current to nominal rating for wire under test.

d. Activate test recording devices (video, transient recorder etc.)

e. Power to the test sample should be activated for 10 seconds to initiate the arc and then deactivated. After a period of 3 minutes power to the sample initiated for a further 10 seconds to test for arc tracking potential and damage.

f. During test the sample shall be observed and video recorded. Arc current and arc voltage are recorded by the transient recorder.

g. After test the following measurements are made:
- Electrical resistance of the conductors of the sample,
- Insulation resistance between damaged and / or undamaged wires. A value of at least 0,5 MΩ at 500 V DC is required.

h. If the test sample fails the test should be repeated on a new sample at a lower test current.

Typical Test Results:
4 different arc extinction patterns

The following four typical arc extinction patterns have been observed:

1. Self-extinguishing arc without reignitions (SE)

2. Arc extinction caused by metallic short circuiting of the conductors (M)

3. Arc extinction caused by low resistance short circuiting of the conductors (R)
(conductive material generated from molten insulating material and conductors bridging the conductors)

4. Arc extinction caused by clearing of the control circuit breaker (CI)
(Under practical conditions a stable arc with a duration exceeding the test duration time of 10 sec. has to be expected)

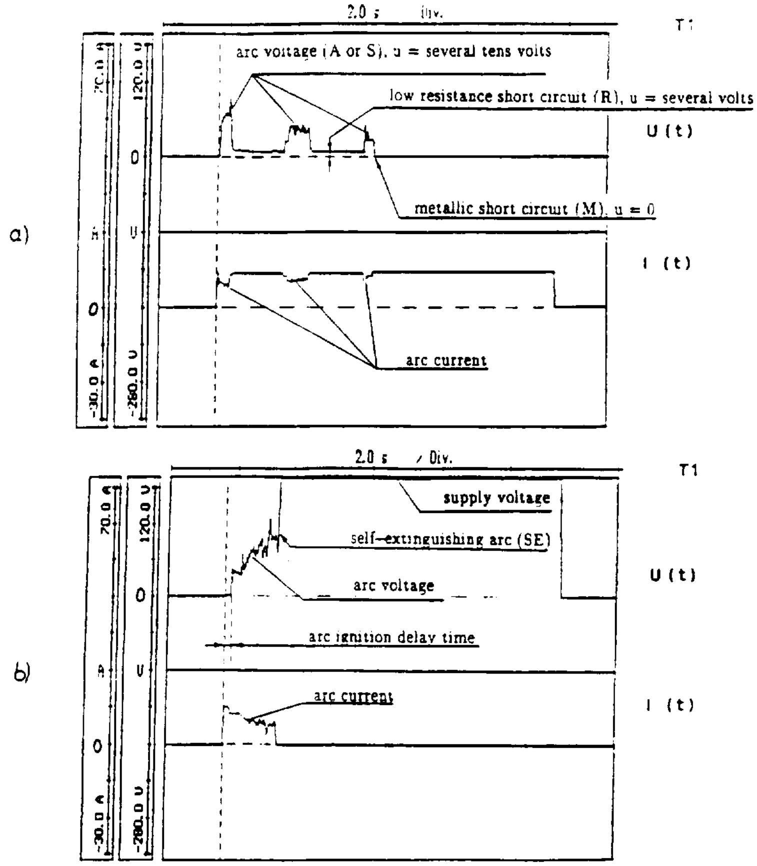


Fig. 4 a/b. Typical records of test current I (t) and voltage U(t) between the conductors during the time T1 of the switching cycle.

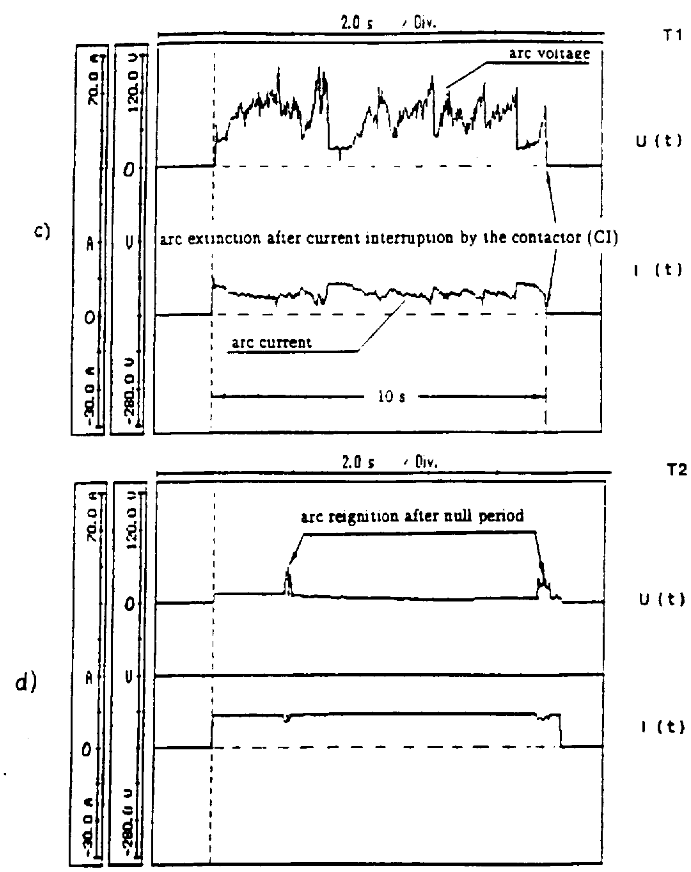


Fig. 4 c/d. Typical records of test current I(t) and voltage U(t) between the conductors during the time T1 (c) and the time T2 (d) of the switching cycle.

Arc Tracking Test of Wires
Experimental Results

Abbreviations

M -	Metallic short circuit	Information from recording of current and voltage with a transient recorder
R -	Low resistance short circuit	
SE -	Self-extinguishing arc	
CI -	Arc extin-ction after the current interruption by the contactor	
NR -	No arc reignition	
A -	Massive arcing	Information from video recording
S -	Short arcing	
CF -	Consuming fire	
SF -	Short duration fire	
G -	Glow if current flows	
SS -	Short spit	
NA -	No action	
Y -	Yes	After test electrical measurements
N -	No	

Table A. 8

Sample No.: 7/20 — Wire size: AWG 20

Test voltage: 125 V — Test current: 10 A

Switching cycle: Time 1: 10 s — Null period (Power off): 3 min. — Time 2: 10 s

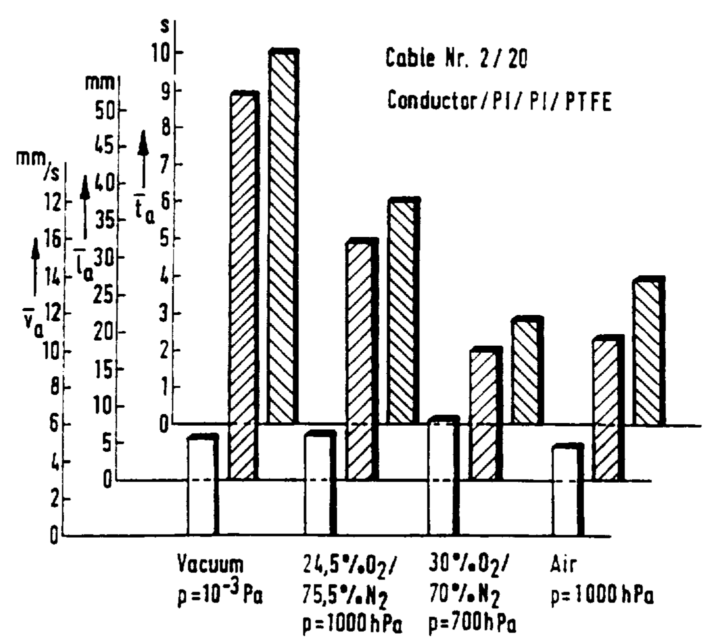
Post test measurements		Environmental Conditions: Normal atmosphere		Atmosphere with enriched oxygen		Vacuum	
	Test No.	1	2	3	4	5	6
1. Arc duration in s	T_1	0.35	0.43	1.4	0.85	1.1	1.6
	T_2	0	0	0	0	0	0
2. Total burn length in mm		13	10	15	11	16	18
3. End to end wire continuity check. Wire No.:	1	Y	Y	Y	Y	Y	Y
	2	Y	Y	Y	Y	Y	Y
	3	(N)	(N)	Y	(N)	(N)	(N)
	4	Y	(N)	(N)	(N)	Y	Y
	5	Y	Y	Y	Y	Y	Y
	6	Y	Y	Y	Y	Y	Y
	7	Y	Y	Y	Y	Y	Y
4. Insulation resistance lower than 0.5 MΩ measured for the following wires:			3 4			3 4	3 4
						1 2 5 6 7	1 2 5 6 7
5. Observations							
A) Transient recorder: Time 1		SE	M	SE	SE	SE	SE
Time 2		NR	M	NR	NR	NR	NR
B) Video recorder: Time 1		S	S	A,SF	S,SF	S	S
Time 2		NA	NA	NA	NA	NA	NA

Table A. 9

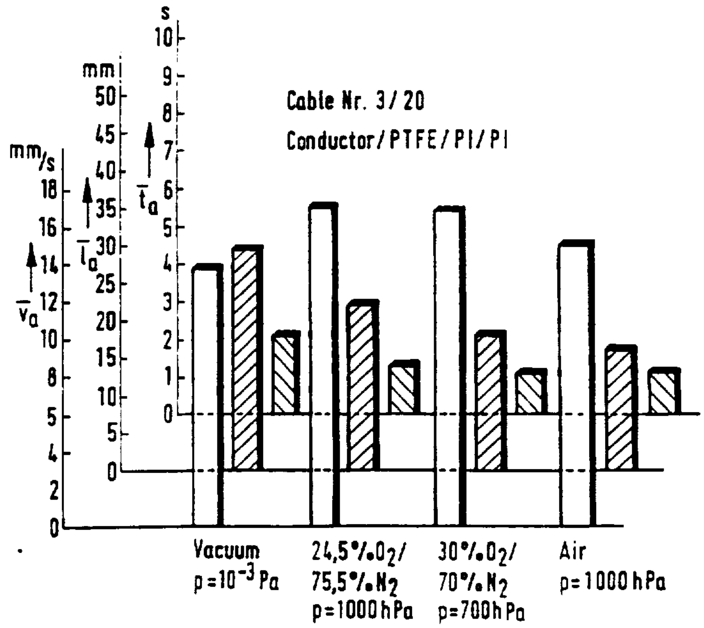
Sample No.: 1/12								Wire size: AWG 12
Test voltage: 125 V								Test current: 30 A
Time 1: 10 s		Switching cycle Null period (Power off): 3 min.						Time 2: 10 s

		Environmental Conditions					
		Normal atmosphere		Atmosphere with enriched oxygen		Vacuum	
Post test measurements	Test No.	1	2	3	4*	5	6
1. Arc duration in s	T_1	1.2	1.4	2.9	1.8	0.72	1.4
	T_2	0	0	0	0	0	0
2. Total burn length in mm		12	24	40	9	21	13
3. End to end wire continuity check. Wire No.:	1	Y	Y	Y	Y	Y	Y
	2	Y	Y	Y	Y	Y	Y
	3	Y	Y	(N)	Y	Y	Y
	4	(N)	Y	Y	Y	Y	Y
	5	Y	Y	Y	Y	Y	Y
	6	Y	Y	Y	Y	Y	Y
	7	Y	Y	Y	Y	Y	Y
4. Insulation resistance lower than 0.5 MΩ measured for the following wires:		3, 4	3, 4	3, 4	3, 4	3, 4	3, 4
		2, 7	7	7	2, 7	1, 2, 5, 6, 7	1, 2, 5, 6, 7
5 Observations							
A) Transient recorder: Time 1		R	R	R	R	R	R
Time 2		R	R	R	R	R	R
B) Video recorder: Time 1		A,CF	A,CF	A,CF,G	A,SF,G	A,G	A,G
Time 2		SF,G	CF,G	G	NA	G	G

* – test current 10 A



Average values of arc duration $\bar{t}_a$, length of arc traces $\bar{l}_a$ and arc propagation velocity $\bar{v}_a$ for cable Nr. 2/20 tested under different environmental conditions.
Number of tests for each environmental condition N=5.



Average values of arc duration $\bar{t}_a$, length of arc traces $\bar{l}_a$ and arc propagation velocity $\bar{v}_a$ for cable Nr. 3/20 tested under different environmental conditions.
Number of tests for each environmental condition N=5.

PRELIMINARY TEST RESULTS
ARC TRACKING TEST OF WIRES

TABLE 1. TEST SAMPLE 1/12 (Cable size AWG 12)

Test–Nr.	Path length of damaged cable insulation in mm	Number of cables with insulation resistance < 0.5 MΩ
1 N	12	2
2 N	24	1
1 E	40	1
2 E	9	2
1 V	21	5
2 V	13	5

N – Normal atmosphere, E – Oxygen enriched atmosphere, V – Vacuum

Conclusion: The path length of damaged cable insulation seems to be not correlated with the results of post-test measurements of the cable insulation resistance

High number of tests → 2/20, 3/20

Sample No.	ESA SCC-SPEC	No. of Cores	Wire Size AWG	Material Plating	Insulation Layers
1/20	3901 001	1	20	Co/Silver	PI PI PI (protective coating)
1/12		1	12	"	" " "
1 A/20	3901 002	1	20	"	PI PI (protective coating)
2/20	3901 007	1	20	"	PI HR616 PI HR616 PTFE 50 % max. overl.
2/12		1	12	"	" " "
3/20	3901 009	1	20	"	PTFE expanded PI HR616 PI HR616
3/12		1	12	"	" " "
4/20	3901 012	1	20	"	ETFE extruded
6/20	-	1	20	"	PTFE tape PI 51 % overl. PTFE varnish
7/20	3901 013	1	20	"	PTFE expanded PI coating
5/20	-	1	20	"	

ETFE = Ethylene Tetrafluoro-Ethylene PI = Polymide PTFE = Polytetrafluorethylene

TEST ACCEPTANCE CRITERIA (Draft)

1. For a defined test voltage, test current and for a defined environment, all conductors of all five test specimens tested have to pass the continuity test and

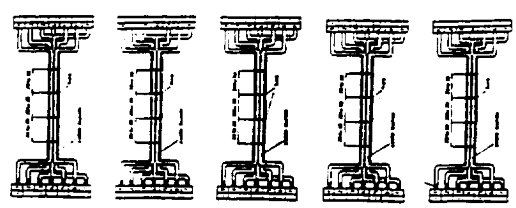
2. All cables/wires of all five test specimens tested without the predamaged cables/wires have to fulfil the requirements of insulation resistance test, i.e. the insulation resistance between the cable/wire under test and the other cables/wires of a test specimen short-circuited must be higher then 0.5 MΩ.

3. During the re-application of the power for 10 seconds following the three minutes pause no visible arc and/or glow activity is acceptable.

4. If only one cable/wire of all tested specimens fails, additional three specimens have to be tested. If during these additional test series the Accept criteria 1, 2 and 3 are fulfilled, the cable has passed the test successfully.

If these requirements have been met for the specified environmental conditions then the cable tested shall be classified as <u>resistant to arc tracking</u> for a given test voltage and currents below or equal to the test current with respect to this environmental condition.

5 TEST SPECIMENS OF 7 CABLES/WIRES EACH



IF ONLY ONE CABLE/WIRE FAILS → ADDITIONAL 3 TESTS

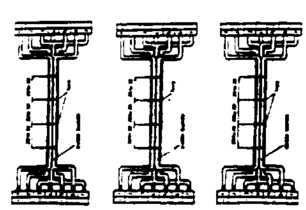
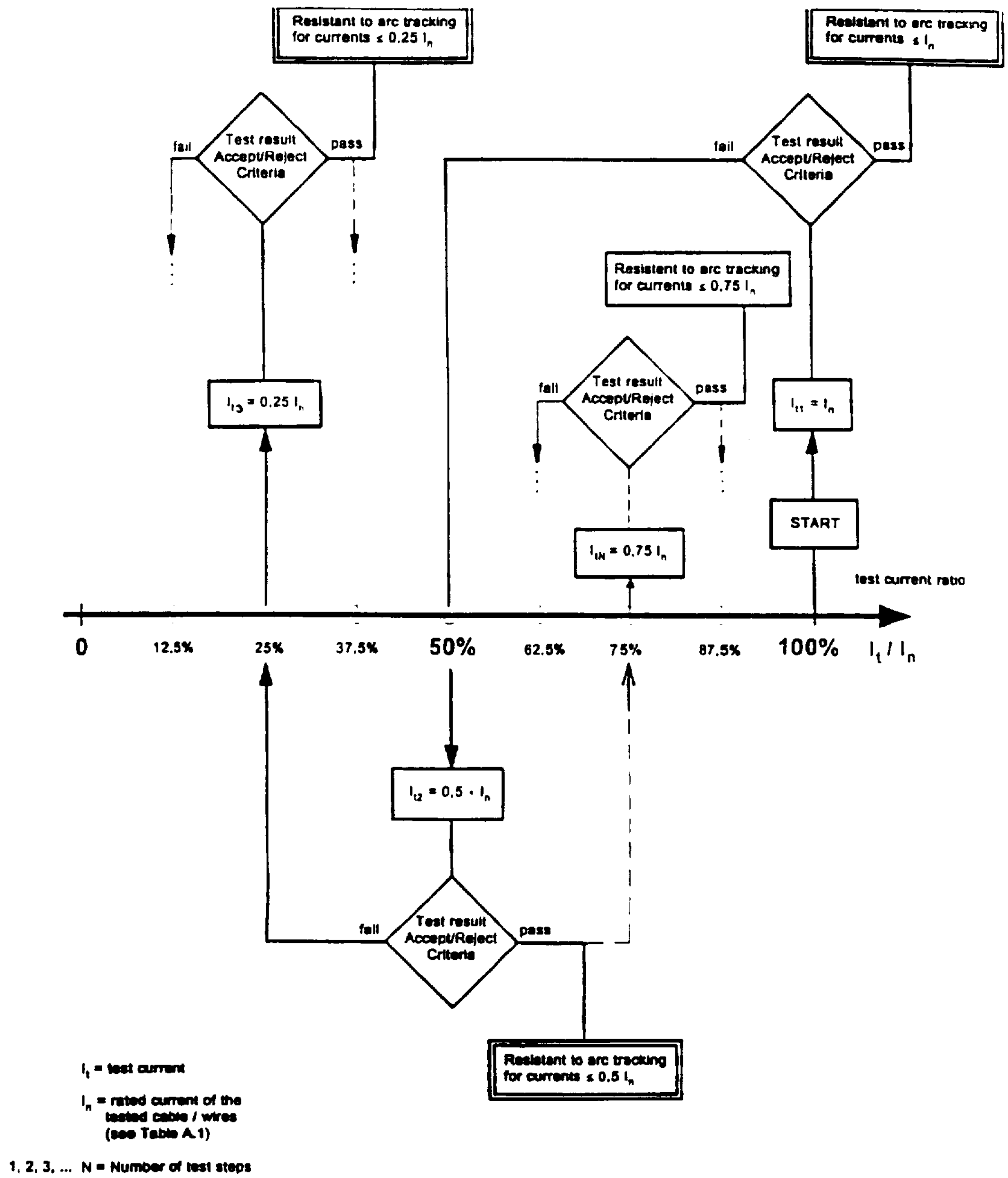


Table 2 Test Results and Acceptance Statement

Cable specification: ESA SCC-Spec. 3901/007 Cable size: AWG 20 (0,52 mm²) Rated current: 7,5A at max. ambient temperature of 85°C						
Test voltage: 125 V Environmental conditions (E.C.): 1. Normal atmosphere (N) 2. Vacuum (V)						
Test-current	E.C.	Test - Nr.	Criterion 1 Number of cables that fail the continuity check of conductors (1...7)	Criterion 2 Number* of cables with an insulation resistance ≤ 0,5MΩ (1...5)	Criterion 3 Visible arc or glow activity during re-application of the power (Yes/No)	Accepted Yes/No
10A	V	1	1	2	N	N
	N	1	2	2	N	N
7,5A	V	1	1	1	N	N
		2	1	1	N	N
	N	1	0	0	N	Y
		2	0	0	N	Y
		3	0	0	N	Y
		4	0	0	N	Y
		5	0	0	N	Y
Test Result: **The above specified cable is resistent to arc tracking for current values ≤ 7,5 A at the rated voltage of 125 V and for the environmental conditions defined as:** **Normal atmosphere, p = 0,1 MPa**						■ Yes □ No

* without the pre-damaged cables Nr. 3 and Nr.4

Procedure for an estimation of the arc tracking current limit



Conclusion

A brief summary of the results obtained is given below. However, it should be remembered that the conclusions drawn are based on limited series of tests and further work needs to be done to investigate the effects of different parameters. In addition, presently accept/reject criteria can be given only as a draft. Modifications may become necessary, if required by findings from a more extensive data base.

The results can therefore be summarised as follows:

a. The proposed test method appears to be a useful tool for the assessment of wire insulation systems under arc tracking stress.

b. The equipment can be easily adapted for tests at different realistic electrical network conditions incorporating circuit protection.

c. The test system works equally well whatever the test atmosphere.

d. Initial test results confirm published results of the available literature in that pure Kapton insulated wire has bad arcing characteristics and ETFE insulated wire is considerably better (in air).

e. Initial test results indicated that for certain wires arc tracking effects are increased at higher oxygen concentrations and significantly increased under vacuum. Although this letter point had been suggested from theoretical considerations it is believed that this is the first time this has been demonstrated in practice.

f. All tests on different cable insulation materials and performed in different environment including enriched oxygen atmospheres resulted in a more or less rapid extinguishing of all high temperature effects at the beginning of the post-test phase. In no case a self-maintained fire was initiated by the arc.