ARC TRACKING OF CABLES FOR SPACE APPLICATIONS

N96-17089

Test Results of Selected Cables

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Contents:

Introduction

B a c k g r o u n d :

- Space Missions with Wiring System Failures

- Failure Modes:
  - ⇒ Pyrolysis
  - ⇒ Arc Tracking
  - ⇒ Fault Arc Propagation

Comparison of existing methods and standards covering different aspects of arcing and arc tracking

⇒ No appropriate arc tracking test for space application available

A i m :

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

TEST CONDITIONS

Test Environments:

⇒Normal Air at atmospheric pressure

⇒Dry gas mixture of 30 Vol.% O_2 and 70 Vol.% N_2 at a pressure of 700hPa (emergency conditions)

⇒Dry gas mixture of 24,5 Vol.% O_2 and 75,5 Vol.% N_2 at atmospheric pressure

⇒Vacuum ($p \leq 10^{-2}$Pa)

Test Voltage:

⇒according to that, expected to be applied in the Board Network

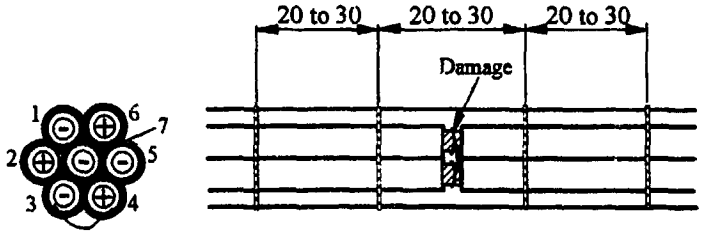
⇒quasi-constant in the range of 125V...132V, DC

Test Current:

⇒Adjustable, depend on rated current

TEST SPECIMEN

- A bundle of seven 200 to 250mm long cables
- The predamage is induced at two cables and placed in the middle of the cable length and at the bottom of the horizontal positioned cable bundle
- Exploding wire igniter is connected to the two predamaged cables



Test Concept

T E S T P R O C E D U R E

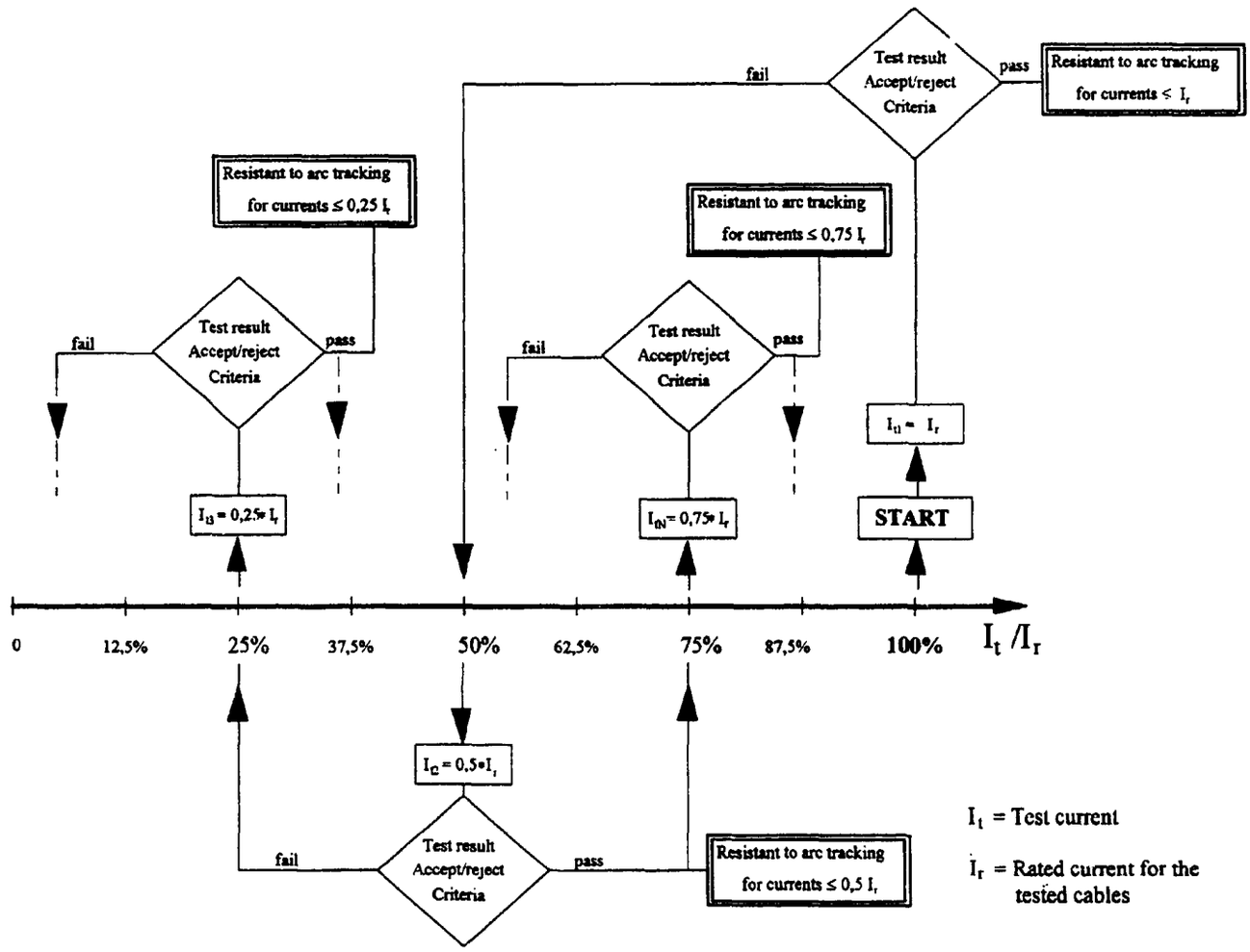
- Assembly of Test Specimen and Installation in the Test Chamber
- Generation of Test Atmosphere (Vacuum, Oxygen Enriched Atmosphere, Normal Air, etc.)
- Adjustment of Test Current
- Activation of Test Recording Devices (Video, Transient Recorder, etc.)
- Arc Initiation:
  - Start up in Switching Cycle: t_s- t_p- t_s
  - As a first approach: t_s= 10s, t_s= 3min
- Performance of Post Test Measurements

T E S T A C C E P T A N C E C R I T E R I A

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
2. All cables of all five test specimens, tested without the predamaged cables, have to fulfill the requirement of insulation resistance test, i.e. the insulation resistance between the cable under test (all other cables of the test specimen are short-circuit) must be higher than 0,5MΩ
3. During the reapplication of the power for 10 seconds, following the three minutes pause, no visible arc or glow activity is acceptable
4. If only one of all tested specimens fail, 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 in different classes with respect to its **arc tracking resistance** for a given test voltage and currents below or equal to the rated current in consideration to the environmental condition.

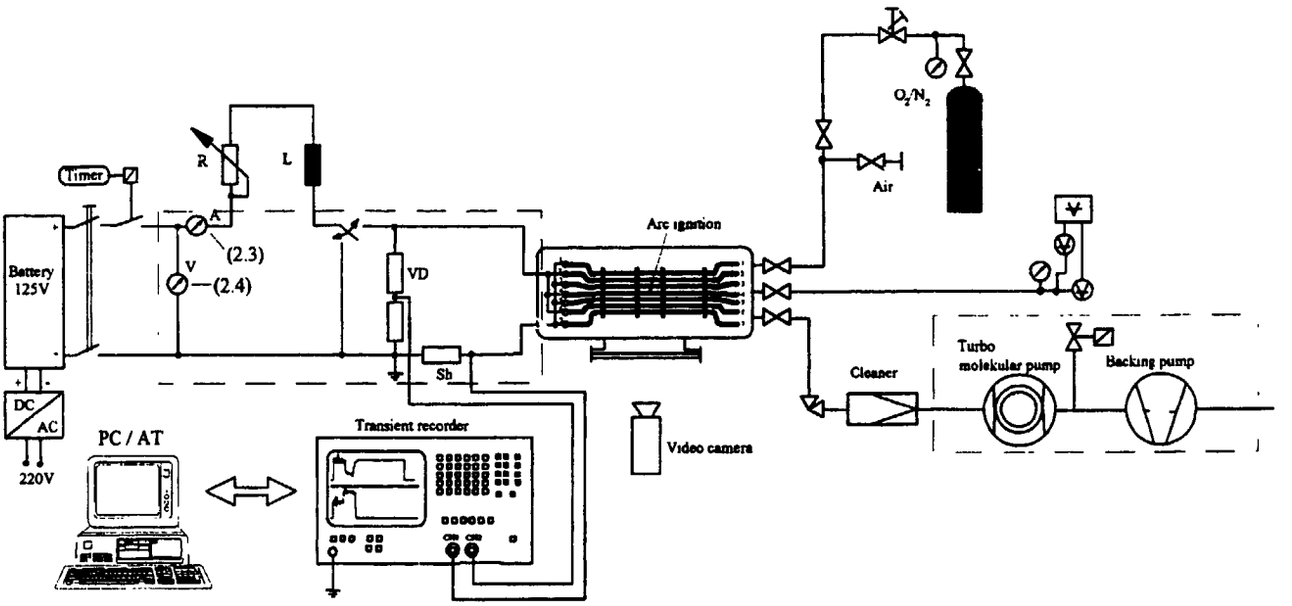
Test Concept



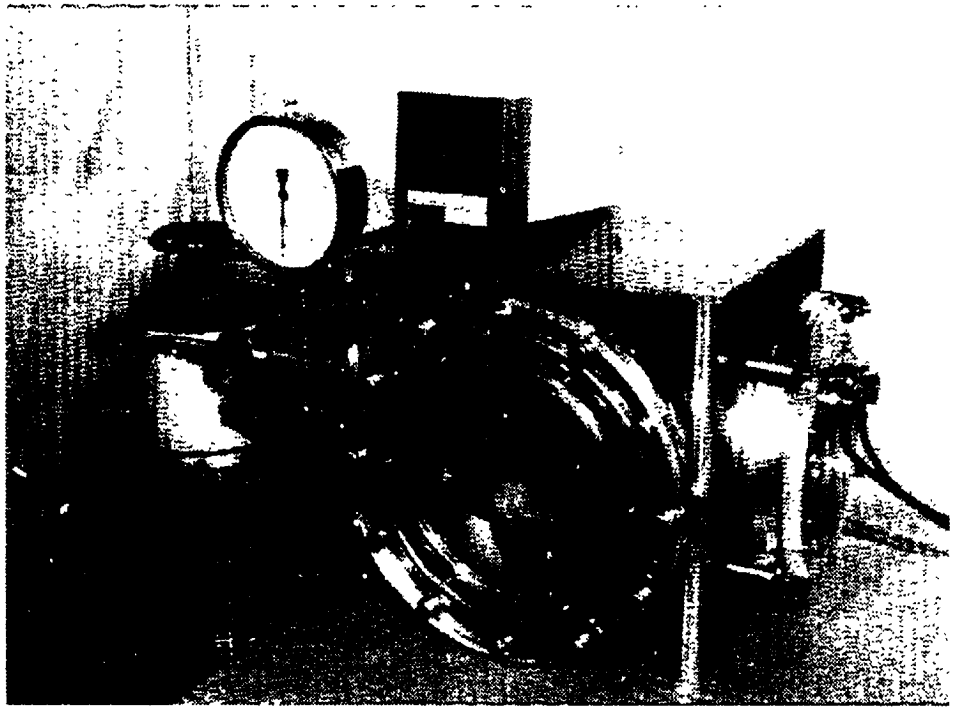
I_t = Test current

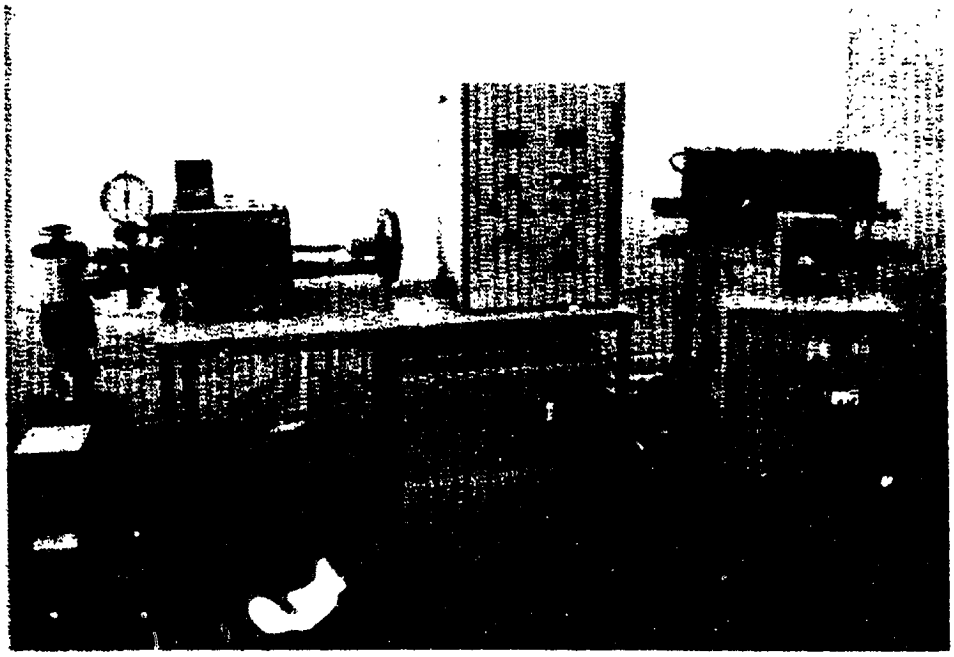
I_r = Rated current for the tested cables

Test Equipment

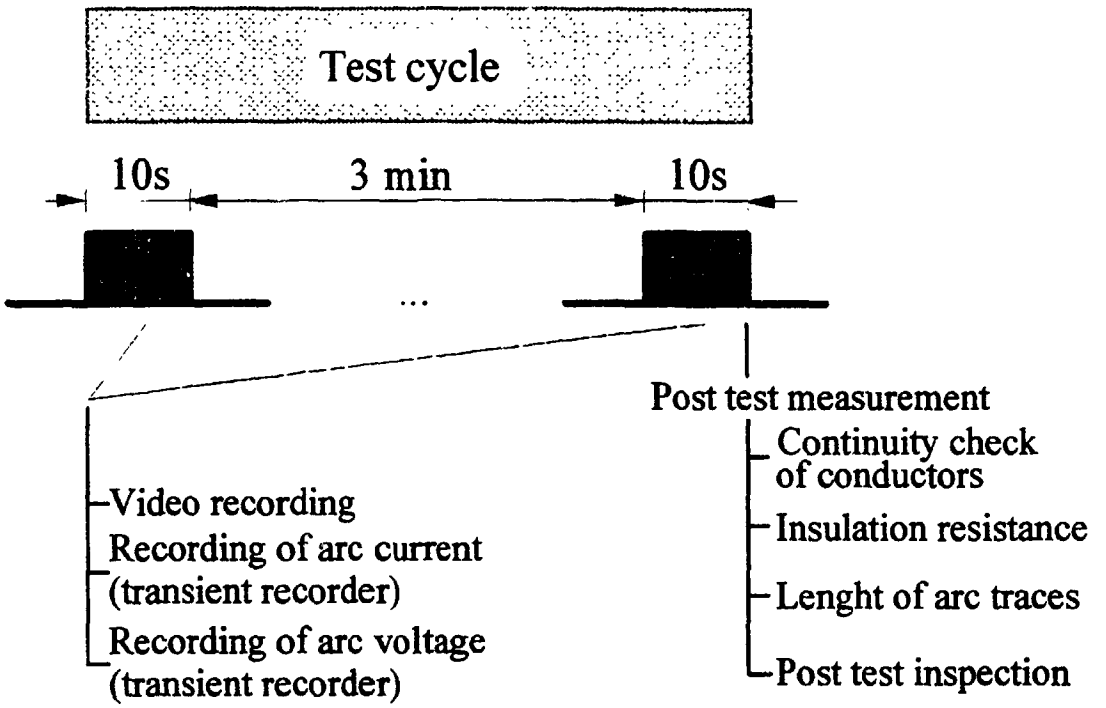


Test Equipment developed and supplied to ESA and DASA





Switching Cycle, Measurements and Evaluation Criteria



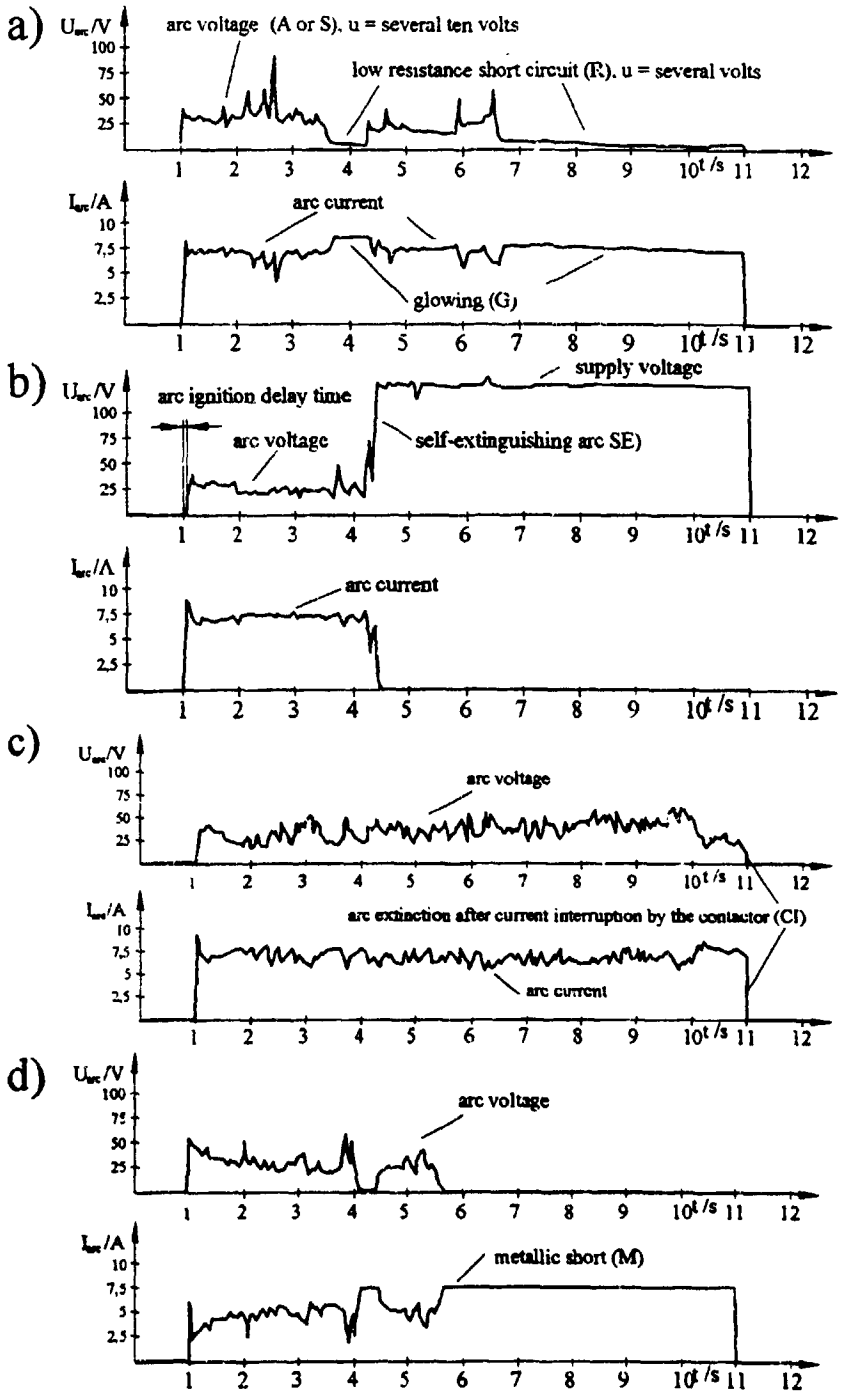
Purpose of the test:

* Determination of the ability of wire insulation materials and cable constructions to resist arc tracking
* Measurement of the Arc Tracking Current Limit

Advantages of the test method:

* Achievement of a distinction between, or a classification of different types of cables with respect to Arc Tracking from material point of view
* The determined "Arc Tracking Current Limit" is an important parameter needed for the design of the electrical supply system and relevant electrical protection measures

Typical Transients of test current I_{arc} and arc voltage U_{arc}



Evaluation of the current and voltage transients

a. Arc extinction caused by low resistance short circuit of conductors (R)

(conductive material generated from molten insulating material and conductors bridging the conductors)

- propagation of glowing insulation down the wire bundle (continued pyrolization)
- arc reignition risks
- damages of adjacent cables, loss of the wire bundle

b. Self-extinguishing arc without reignitions (SE)

- very often no loss in wire bundle performance

c. 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 10s, has to be expected)

- propagation of a fault arc down the wire bundle
- damages of adjacent cables, loss of the wire bundle

d. Arc extinction caused by metallic short circuit of conductors (M)

- lost use of a wire pair within the bundle

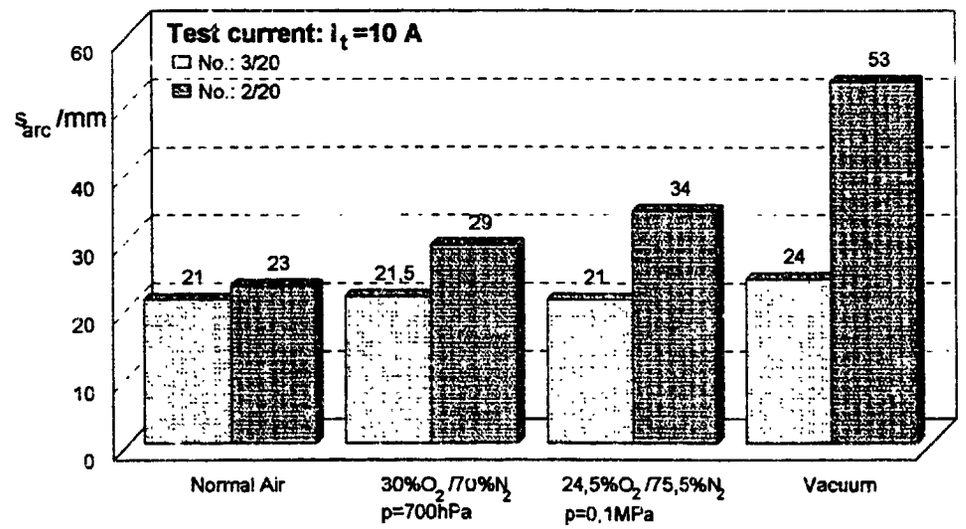
Table of cable types tested

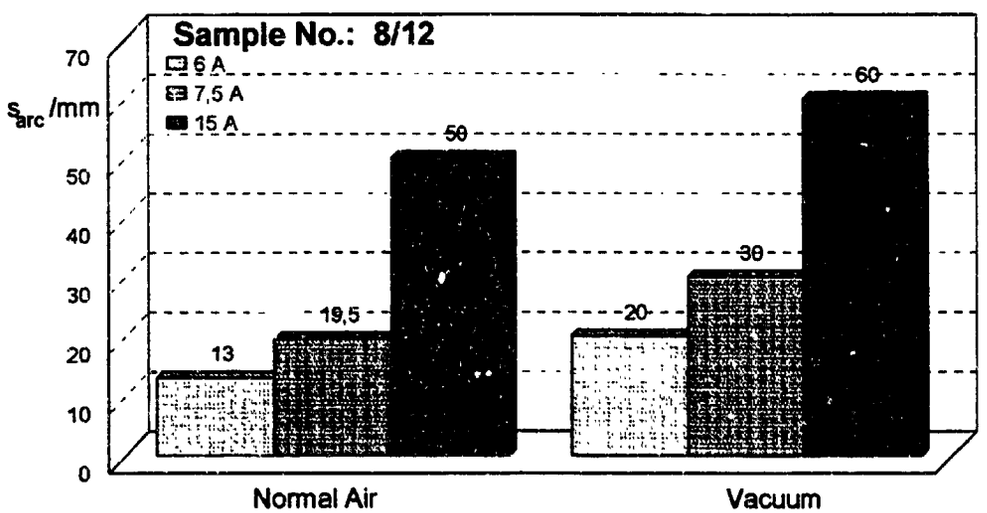
Sample No.	ESA SCC-SPEC	Wire Size [AWG]	Insulation Layers
1/20	3901 001	20	PI PI PI
1/12		12	PI PI PI
1A/20	3901 002	20	PI PI
2/20	3901 007	20	PI PI PTFE
3/20	3901 009	20	PTFE PI PI
4/20	3901 012	20	ETFE
5/20	-	20	Hybrid
6/20	-	20	PTFE PI PTFE
7/20	3901 013	20	PTFE PI
8/12	3901 008	12	PI PI PTFE

AWG: American Wiring Gauge

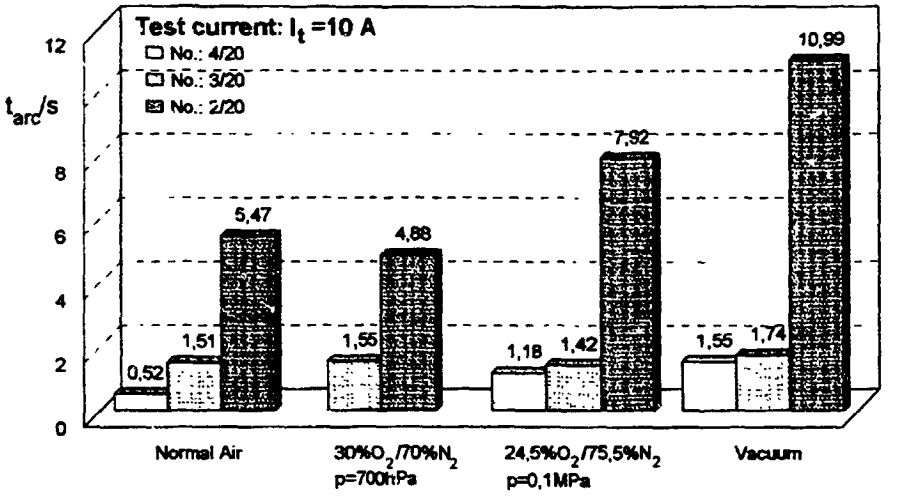
ETFE: Ethylene-Tetrafluoro-Ethylene
PTFE: Polytetrafluorethylene
PI: Polyimide
Conductor material: Copper/Silver

Average values of arc path length s_{arc}

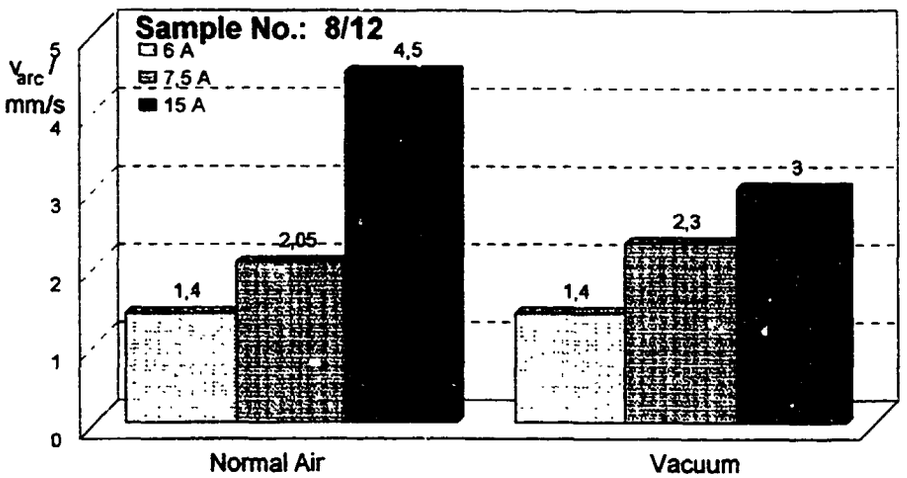


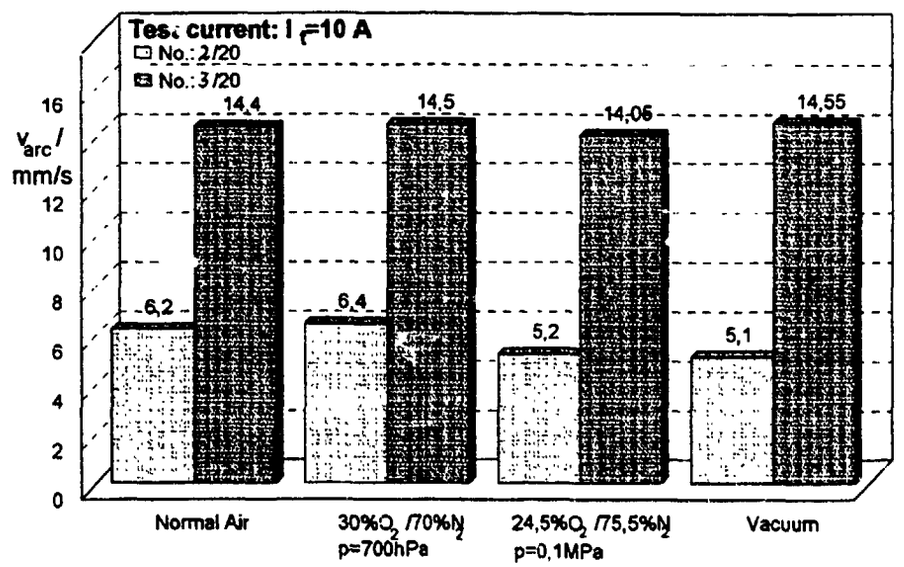


Average values of arc duration t_{arc}

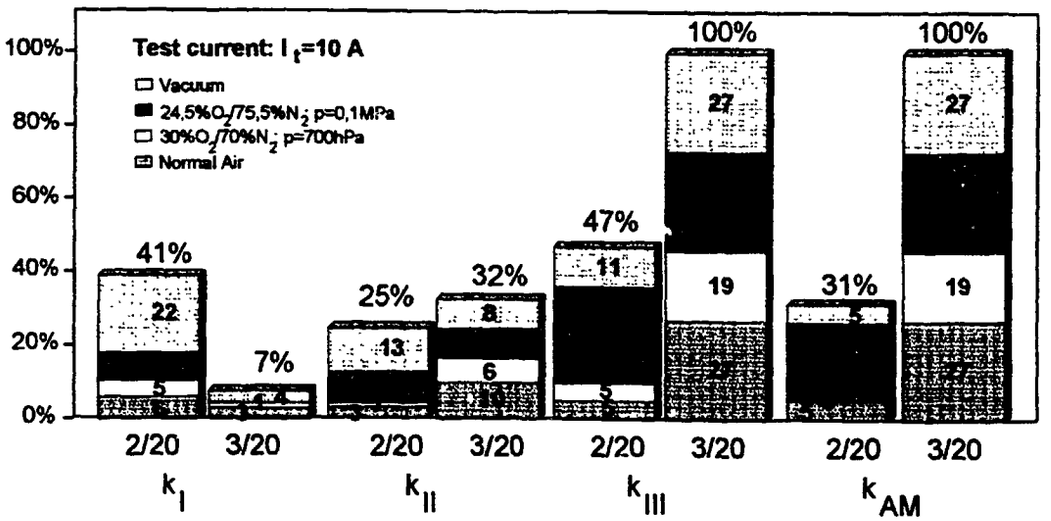


Average values of arc propagation velocity v_{arc}





Values of coefficients k_I, k_{II}, k_{III} and k_{AM} for cables No. 2/20 and 3/20



$$k_I = \frac{\text{Number of cables with damaged conductors}}{\text{Number of cables tested}} \qquad k_{II} = \frac{\text{Number of cables with damaged insulation}}{\text{Number of cables tested}};$$

predamaged cables are not considered

$$k_{III} = \frac{\text{Number of tests, at which during time interval } T_2 \text{ glowing and / or arcing was observed}}{\text{Number of tests performed for a given test current}}$$

$$k_{AM} = \frac{\text{Number of tests, at which during time interval } T_2 \text{ the arc modes R / CI were observed}}{\text{Number of tests performed for a given test current}}$$

Post-test measurement results:
Continuity check of conductors

Conductors without Continuity (Wire No.)								
Sample No/wire AWG	Insulation Layers*	Test Current I_{test}/A	Normal Atmosphere		24,5Vol.% O_2 75,5Vol.% N_2		Vacuum	
			Te 1	Test 2	Test 3	Test 4	Test 5	Test 6
1/20	PI,PI,PI	10	4	3,4,6	2,3,4,7	-	2,3	4
1A/20	PI,PI	10	7	-	-	3	3	3
2/20	PI,PI,PTFE	10	-	3,4	3	3,4	3	3
3/20	PTFE,PI,PI	10	-	3,4	-	-	4	3
4/20	ETFE	10	-	-	-	-	3	3
5/20	Hybrid	10	2,3,4,7	3,4	-	3	2,3,4	3
6/20	PTFE,PI,PTFE	10	3,4	3	3,4	3,4,7	3,4,6	3
7/20	PTFE,PI	10	3	3,4	4	3,4	3	3
1/12	PI,PI,PI	30	4	-	3	- **	-	-
4/20	ETFE	30	3,4	3,4	NT	3,4	NT	NT

* Material given from the conductor position NT: not tested

** Test current: I_t= 10A

Post-test measurement results:
Insulation resistance check

Insulation Resistance < 0,5 MΩ (Wire No.)								
Sample No/wire AWG	Insulation Layers*	Test Current I_{test}/A	Normal Atmosphere		24,5Vol.% O_2 75,5Vol.% N_2		Vacuum	
			Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
20/1	PI,PI,PI	10	1,2,7	2	2,5,6,7	5,7	2,7	
20/1A	PI,PI	10	5	5,6,7	5,6,7	2,7	1,2,7	
20/2	PI,PI,PTFE	10	-	-	-	-	7	
20/3	PTFE,PI,PI	10	1,2,7	2,5,7	5,6,7	2,7	2,7	
20/4	ETFE	10	-	-	5	-	-	
20/5	Hybrid	10	1,2,7	-	-	-	1,2,5, 6,7	1,2,5, 6,7
20/6	PTFE,PI, PTFE	10	2,5,7	-	-	1,2,5, 7	1,2,5, 6,7	1,2,5, 6,7
20/7	PTFE,PI	10	-	-	-	-	1,2,5, 6,7	2,5,6, 7
12/1	PI,PI,PI	30	2,7	7	7	NT	1,2,5, 6,7	1,2,5, 6,7
20/4	ETFE	30	-	-	NT	-	NT	NT

NT: not tested

Activities during the reapplication of the power

Visible Arc and/or glow activity during the reapplication of the power (Wire No.)								
Sample No/wire AWG	Insulation Layers*	Test Current I_{test}/A	Normal Atmosphere		24,5Vol.% O_2 75,5Vol.% N_2		Vacuum	
			Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
20/1	PI,PI,PI	10	S	NA	G	G	G	G
20/1A	PI,PI	10	NA	NA	G	G	G	G
20/2	PI,PI,PTFE	10	NA	NA	NA	G	NA	NA
20/3	PTFE,PI,PI	10	G	G	G	G	G	G
20/4	ETFE	10	NA	NA	NA	NA	NA	NA
20/5	Hybrid	10	G	NA	NA	NA	NA	NA
20/6	PTFE,PI,PTFE	10	S	NA	NA	S,G	NA	G
20/7	PTFE,PI	10	NA	NA	NA	NA	NA	NA
12/1	PI,PI,PI	30	G	G	G	NA**	G	G
20/4	ETFE	30	NA	NA	NT	NA	NT	NT

* Material given from the conductor position NT: not tested

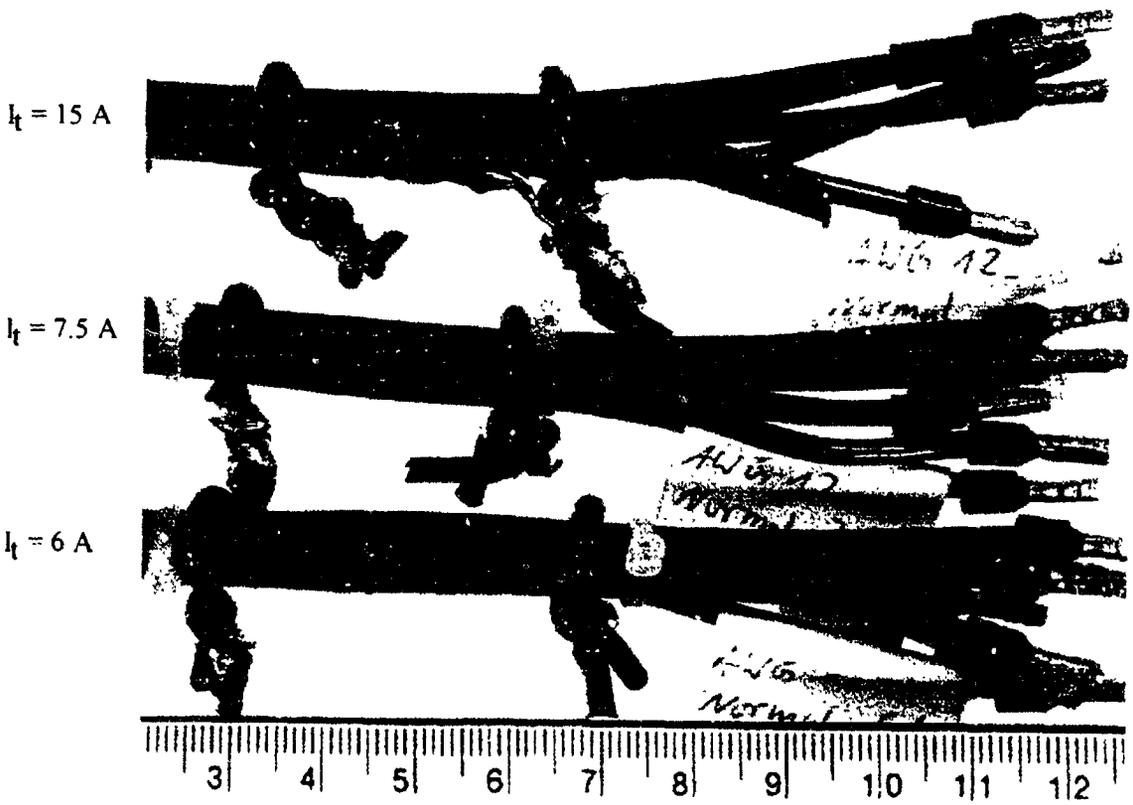
** test current 10A

Abreviations: G : Glow
A : Massive Arcing
S : Short Arcing
NA: No action

Test specimen after test cycle
Sample No.: 8/12; Normal Air

Cable type : AWG 12

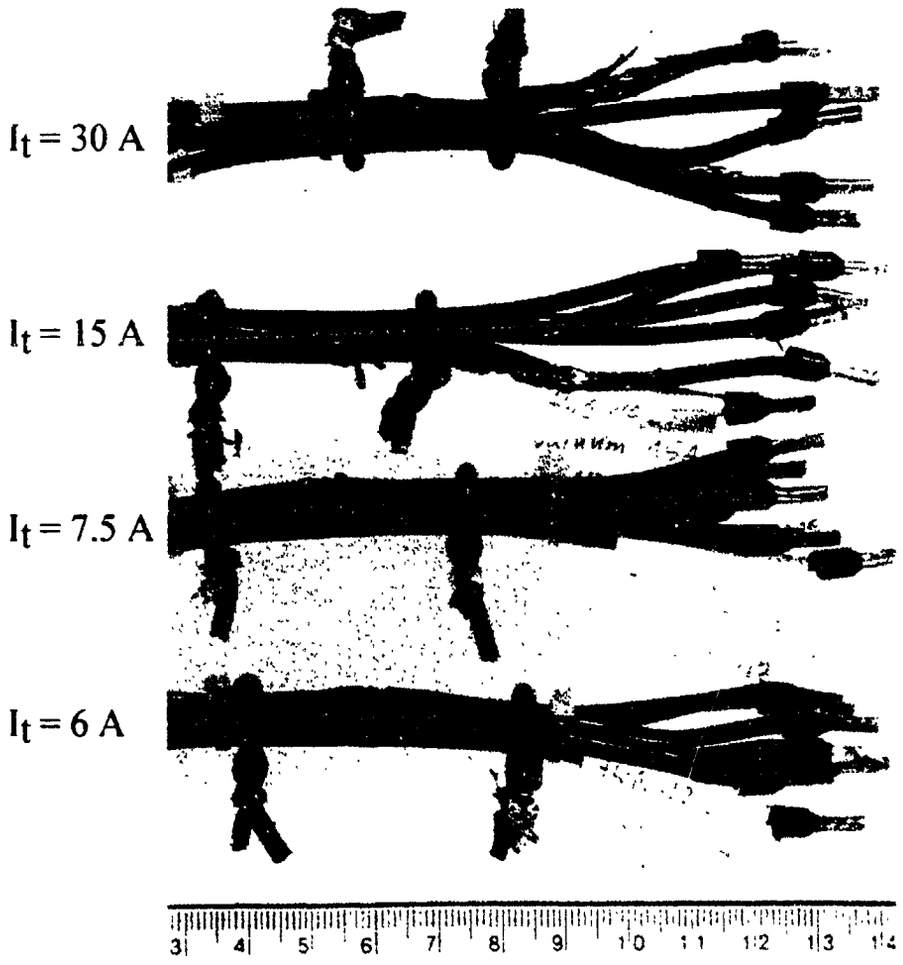
ESA - Specification:	3901 008
Rated Current:	I_r = 23 A
Insulation material:	PI/PI/PTFE
Conductor material:	Cu, Ag coated
Atmosphere:	Normal Air
Test Current:	I_t : different



Test specimen after test cycle
Sample No.: 8/12; Vacuum

Cable type : AWG 12

ESA - Specification:	3901 008
Rated Current:	I_r = 23 A
Insulation material:	PI/PI/PTFE
Atmosphere:	Cu, Ag coated
Conductor material:	Vacuum
Test Current:	I_t : different



Test specimen after test cycle
Sample No.: 2/20; I_t = 10A

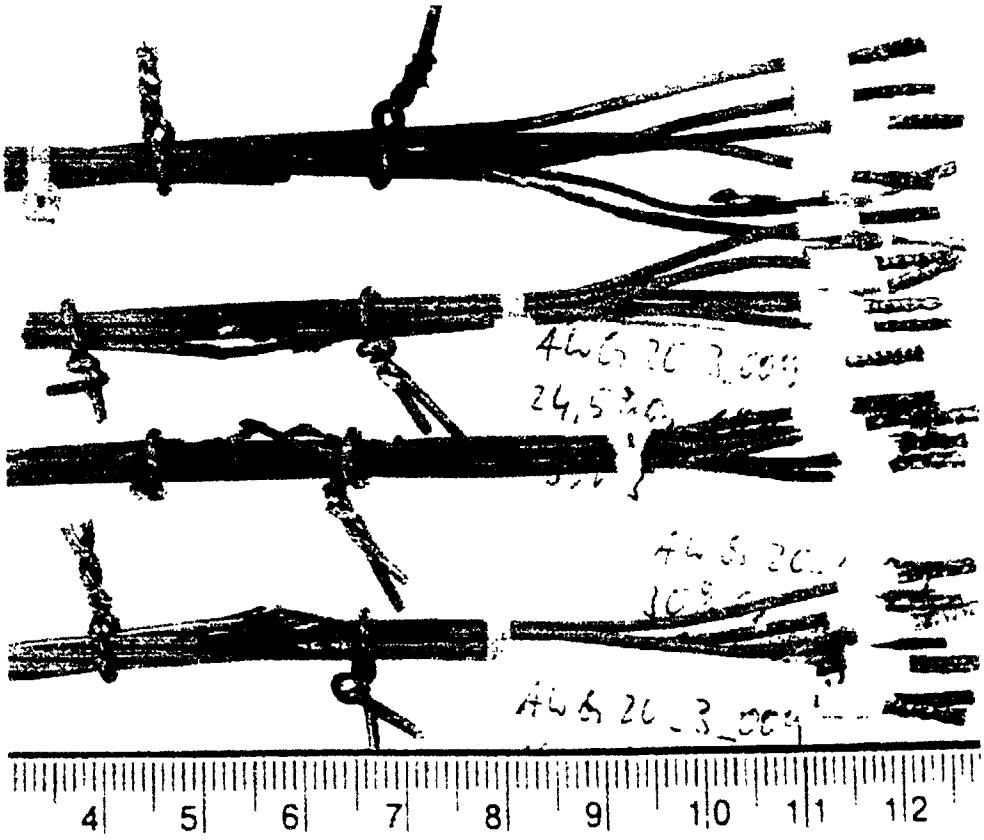
Cable type : AWG 20

ESA - Specification: 3901 007
Rated Current: I_r = 7.5 A
Insulation material: PI/PI/PTFE
Conductor material: Cu, Ag coated
Test Current: I_t= 10 A
Atmosphere: different

Test specimen after test cycle
Sample No.: 3/20; I_t = 10A

Cable type : AWG 20

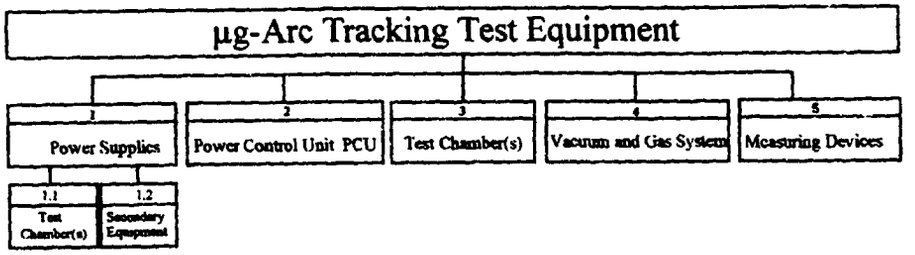
ESA - Specification: 3901 009
Rated Current: I_r = 7.5 A
Insulation material: PTFE/PI/PI
Conductor material: Cu, Ag coated
Test Current: I_t = 10 A
Atmosphere: different

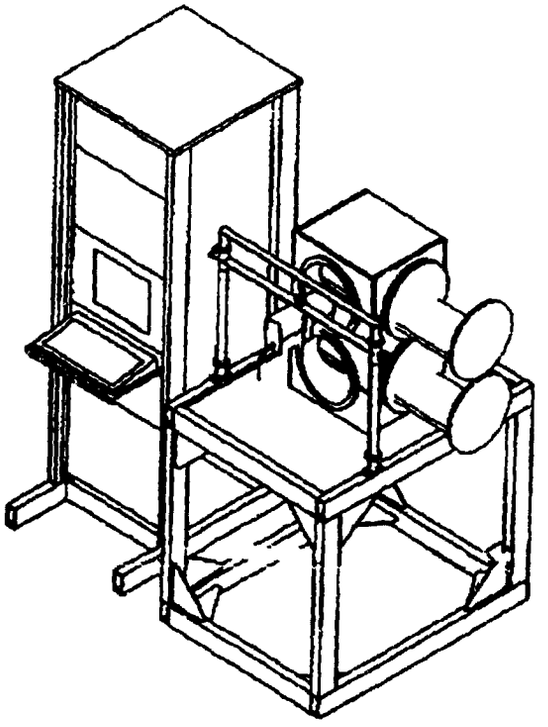


Test parameters applied at arc tracking tests „On earth“ of cables AWG 20/2 and AWG 20/3

		Environmental condition																													
		Rated Voltage $U_r = 125$ V												Voltage Range																	
														28V	60V	115V	230V	270V	28V	60V	230V	270V	28V	60V	115V	230V	270V	28V	60V	115V	230V	270V
Cable Type		Vacuum	Normal air 1000mbar	Enriched oxygen 24,5Vol.%O_2 1000mbar	Enriched oxygen 30Vol.%O_2 700mbar	Fungal growth		Moisture		Dry		Heating (T≈200°C)		Vacuum					Normal air 1000mbar				Enriched oxygen 24,5Vol.%O_2 1000mbar										
						Normal air	Vacuum	Normal air	Enr. 24,5%	Normal air	Enr. 24,5%	Normal air	Vacuum																			
AWG 20/2	I_{max}=7.5A	III	III	III		III	III					II	II		II	II	II	II	II	II	II	II		II	II	II	II				
	I_{max}=10A	IIII II	IIII II	III II	IIII																										
AWG 20/3	I_{max}=7.5A	III	III	III		III	III	III	III	II	II	II	II	I	II	II	II	II	II	II	II	II		II	II	II	II				
	I_{max}=10A	IIII II	IIII II	IIII II	IIII																										

Main units of the planned µg-Arc Tracking Test Equipment





Conclusions

- The available test results indicate that the new test method appears to be valid and suitable for testing and screening the arc tracking characteristic of aerospace cables

- The results obtained provide information about consequences expected after reapplication of power and assess the ability of cable to further operate after arc tracking events

- The new test provides knowledge with respect to the behaviour of cables under arcing conditions for different environments including that of vacuum, which has not been taken into account in all test methods available up to now. In many cases vacuum has turned out to be an important worst-case parameter

- The test system works equally well whatever the chosen test atmosphere. The tests do not take much time compared to other known arc tracking tests. The new test method and the assembled test equipment allows one to achieve a distinction between or classification of different types of cables from a material point of view

- Further testing work needs to be done to investigate the important parameters having influence of arc tracking consequences on aerospace cables of different type and size

- A second test set up has been constructed for ESA/ESTEC and is presently located in the laboratories of DASA at Trauen

- A construction of a new equipment, based on the principles described above, to investigate the phenomenon under microgravity conditions (parabolic flight) is under work

List of Publications

(1) König D.; Frontzek, F. R.; Dricot, F.; Reher H.-J.; Judd M.D.: Principles of a New Arc Tracking Test of Cables and Wires for Spacecraft. Proc. of the Conference on Electrical Insulation and Dielectric Phenomena (CEIDP), October 18-21. 1992, Victoria, Canada, pp.363-369

(2) König, D.: A New Test Method for the Assessment of the Arc Tracking Properties of Wire Insulation in Air, Oxygen Enriched Atmospheres and Vacuum. Proc.of the Second NASA Workshop on Wiring for Space Applications, October 6-7, 1993, Cleveland, Ohio, USA, pp.173-188

(3) Dricot, F.; Reher, H.J.; Frontzek, F.R.; König, D.: Arc-Tracking Test of Wires. Final Report. Report No. ESA CR(P) 3734, 1994

(4) Frontzek, F.R.; König, D.; Judd, M.D.; Reher, H.J.: Phenomena of Fault Arc Propagation on Cables and Wires for Space Applications in Vacuum, Oxygen Enriched Atmosphere and Air. Proc. of the XVIth Intern. Symp. on Discharges and Electrical Insulation in Vacuum, May 23-30, 1994, Moscow-St.Petersburg, Russia, pp.452-458

(5) König D.; Frontzek, F. R.; Reher, H.-J.; Judd, M.D.: A new Test Method for the Assessment of the Arc Tracking Properties of Wire Bundles in Air, Oxygen Enriched Atmosphere and Vacuum. Proc. of the 1994 IEEE Intern. Symp. on Electical Insulation (ISEI), June 5-8, 1994, Pittsburgh, PA, USA, pp.145-150

(6) Dricot, F.; Reher, H.-J.: Survey of Arc-Tracking on Aerospace Cables and Wires. IEEE Trans. on Dielectrics and Electrical Insulation, Vol.1, No.5, October 1994, pp.896-903

(7) Frontzek, F. R.; König, D.; Judd, M. D.; Reher, H.-J.: Fault Arc Propagation on Cables and Wires for Space Applications in Vacuum, Oxygen Enriched Air and Air. IEEE Trans. on Dielectrics and Electrical Insulation, Vol.2, No.2, April 1995, pp.190-197