NASA TECHNICAL MEMORANDUM

NASA TM X-73322

EXTERNAL TANK GASEOUS OXYGEN LINE SIMULATED LIGHTNING TESTS

By Hubert E. Smith and R. M. Avery
Materials and Processes Laboratory

July 1976

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

MSFC - Form 3190 (Rev June 1971)

1 Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM X-73322		

4. Title and Subtitle	5. Report Date
External Tank Gaseous Oxygen Line Simulated Lightning Tests	July 1976
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No
Hubert E. Smith and R. M. Avery	
9. Performing Organization Name and Address	10. Work Unit No.
George C. Marshall Space Flight Center Marshall Space Flight Center,. Alabama 35812	11. Contract or Grant No.
	13 Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15 Supplementary Notes

Prepared by Materials and Processes Laboratory, Science and Engineering

16 Abstract

Tests were made at MSFC to evaluate the effects of lightning strikes on the Shuttle External Tank gaseous oxygen pressurization line. This line, designed to conduct gaseous oxygen at a pressure and temperature of approximately 4.14×10^6 N/m^2 gage pressure (600 psig) and 302°C (575°F), may also act as a lightning conductor. Questions have been raised as to the potential hazard of this line as a lightning conductor with speculation as to the damage that might occur to the pressurization line, and the adjacent thermal protective surfaces, from a lightning strike. The region of investigation was from above the cone of the launch tower lightning protection to 15.24 km (50 000 ft) altitude.

Tests were performed on samples of thin wall stainless steel tubing filled with gaseous oxygen under simulated flight conditions. These tests were performed according to, and exceeding, the Shuttle Lightning Protection Specification JSC-07636, Revision A, for Component Testing. No specimen malfunctions occurred when the tests were conducted according to JSC specifications.

During the intermediate current tests, when the JSC specifications were deliberately exceeded to cause sample failures, there were no signs of flame, the holes remained small, and the flow of gaseous oxygen extinguished the arc. Some samples did burst along damaged areas during the 400 amp swept stroke tests of 0.79 m/s (2.6 ft/s), but were tested at a simulated velocity far below the test specification requirements of 19.5 m/s (64 ft/s).

Based on the JSC specifications and the results of these tests, it is concluded that a lightning strike will not cause a malfunction of the Shuttle External Tank gaseous oxygen line made of the representative material tested.

17 Key Words (Suggested by Author(s))	18. Distribution Statement
	Unclassified — Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	34	NTIS

MSFC Form 3292 (Rev December 1972) For sale by National Technical Information Service, Springfield, Virginia 22151

ACKNOWLEDGMENTS

Mr. L. K. Swaim, Mr. John R. Rasquin, and Mr. W. J. Reed of the Materials and Processes Laboratory, Marshall Space Flight Center, are to be commended for their dedicated effort in helping to design the test facility, obtaining and making the required components, and supporting the preliminary tests.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

TECHNICAL MEMORANDUM X-73322

EXTERNAL TANK GASEOUS OXYGEN LINE SIMULATED LIGHTNING TESTS

I. INTRODUCTION

Artificial lightning tests have been carried out on samples of stainless steel tubing filled with gaseous oxygen (GOX) at simulated flight conditions of 4.14×10^6 N/m^2 gage pressure (600 psig) and 302°C (575°F). The purpose of these tests was to evaluate possible lightning damage to the GOX line that extends along the outside of the Shuttle External Tank (ET). These tests were performed according to, and exceeding, the Shuttle Lightning Protection Specification JSC-07636, Revision A, for Component Testing. No malfunctions occurred when the tests were conducted according to JSC test specifications.

Some tests, which exceeded the JSC specification, were conducted to deliberately cause a test specimen puncture. These tests were to evaluate the possible damage that could result from the escaping hot GOX in the presence of hot metal or lightning hang-on. Based on a test specification minimum vehicle velocity of 19.5 m/s (64 ft/s) and from the results of these tests, it is concluded that there will be no malfunction of the noninsulated GOX line as a result of a lightning strike.

II. DESCRIPTION OF TESTS

A diagrammatic representation of a lightning model is shown in Figure 1. According to the Shuttle Lightning Protection Test Specification, JSC-07636, Revision A, Appendix A-1, Deviation, the GOX pressurization line will only be required to withstand the lightning model's second return stroke at a vehicle minimum velocity of 19.5 m/s (64 ft/s). This model can be represented for the purposes of testing by a high current, an intermediate current, and a 400 amp continuous current. The current waveforms required by the test specifications for testing the GOX line are as follows:

a. High Current Test — A 10 kHz damped sinusoidal waveform, 50 000 amp peak.

b. Intermediate Current Test — A waveform with 1 ms rise time and a 2 ms fall time to 50 percent amplitude and a peak current of 2500 amps.

c. 400 Amp Continuing Current Test — A 400 amp swept stroke current at a simulated vehicle velocity of 19.5 m/s (64 ft/s).

All of the GOX line samples used in these tests were either 304 or 321 stainless steel tubing, 5.08 cm (2 in.) in diameter with a wall thickness of 0.051 cm (0.020 in.). A stainless steel plate was welded to each end of the sample and fitted with a tubing connector. For the tests, the samples were heated to 302°C (575°F) and filled with GOX, from a continuous flow regulator, to a pressure of 4.14 N/m^2 gage pressure (600 psig) to simulate flight conditions.

A. High Current Tests

The test facility used for the high current test is shown in Figures 2 and 3. A photograph of a typical test current waveform is shown in Figure 5. Tests were conducted with a peak current ranging from 60 000 to 140 000 amps. The external damage to the GOX line sample, after the 140 000 amps simulated lightning strike, is shown in Figure 4.

There was very little damage to the GOX line samples from these high current, short duration tests (Table 1). The test specimens had extensive external metal movement and discoloration (Fig. 4) but very little wall thinning. The wall thinning was only 0.008 cm (0.003 in.) after the test of 140 000 amps.

B. Intermediate Current Tests

The test facility shown in Figures 2 and 3 was used for the intermediate current tests. A photograph of a typical test current waveform is shown in Figure 6, and a photograph of the inside surfaces of five lightning strike tests is shown in Figure 7. Three of these samples are of single strike tests, where no punctures occurred. The other two samples are of multistrike tests in the same area on the specimen to purposely obtain a sample puncture. The external surface area and hole, after a multistrike test, is shown in the photograph of

Figure 8. It was necessary to have a puncture occur from a simulated lightning strike to assess the damage caused from the escaping hot oxygen in the presence of hot metal or a hot spark. Although the actual test current waveform did not meet the test specification curve width, the peak current amplitude was much higher, and the total energy discharged into the sample exceeded specifications.

It should be noted that no problems occurred when the artificial lightning tests were made within test specifications.

Results of single strike tests were as follows:

1. There was extensive external metal movement and discoloration.

2. There was discoloration of the internal wall (Fig. 7).

3. Wall thinned approximately 30 to 50 percent.

4. No puncture of the specimen occurred.

Results of multistrike tests were as follows:

1. First sample punctured with a second strike in the same area causing a small hole, approximately 0.010 cm (0.004 in.) in diameter, Figure 7.

2. Second sample punctured with a third strike in the same area causing a larger hole than the first, approximately 0.190 cm (0.075 in.) in diameter (Figs. 7 and 8).

3. GOX flow through the holes extinguished the arc in both samples (Fig. 9).

4. GOX pressure was maintained despite the hole.

5. Metal around the holes was pushed out and ragged due to the outward flow of GOX.

6. High speed (5000 f/s) movie film was made of these tests showing the arc being extinguished.

A summary of the tests, test conditions, and test results are shown in Table 2.

C. High Altitude Tests

These tests were made to determine the comparative effects of a lightning strike at ground level and at a high altitude. A simulated altitude of 15.24 km (50 000 ft) was chosen. The intermediate current test facility (Fig. 2) and current waveform (Fig. 6) were used to perform these tests. The sample and high current electrode were placed inside a vacuum chamber, and two series of tests were made under the same conditions, except for the reduced sample external pressure of 1.17 N/m^2 absolute (1.7 psia) to simulate an altitude of 15.24 km (50 000 ft).

Results of tests at atmosphere pressure were as follows:

1. Five strikes in the same area were required to puncture the sample.

2. The hole was approximately 0.076×0.152 cm (0.030×0.060 in.). Edges were pushed out and jagged.

Results of high altitude tests (15.24 km) were as follows:

1. Twelve strikes in the same area were required to puncture the sample.

2. The hole was so small that a microscope was required to locate the opening.

A summary of the tests, test conditions, and test results are shown in Table 3.

D. 400 Amp Continuing Current Tests

To test and evaluate the 400 amp continuing current portion of the lightning model, five samples were tested: one sample was used for a stationary test (Table 4), and four samples were used for the swept stroke tests (Tables 5 through 8). The facility shown in Figure 10 was used to perform all of the 400 amp tests. A photograph of the test facility and the GOX line sample is shown in Figure 11.

1. 400 Amp Stationary Test. This test, though exceeding specification was performed to assess the damage to the GOX line from a possible burning around the edges of the puncture (causing a large hole) due to the hot GOX and a conceivable lightning current attachment to the line at the point of the puncture. The test was made by initiating the 400 amp arc on the steel tab (Fig. 10), turning the inert gas off, and then moving the arc onto the sample. The arc was then stopped and held over the puncture.

Results of 400 amp stationary test were as follows:

a. Punch through occurred immediately.

b. There was no flame.

c. The hole remained small, approximately 0.178 cm (0.070 in.) diameter.

d. The GOX extinguished the arc.

e. The flow of GOX caused fast erosion of the hot electrode.

A summary of the tests, test conditions, and test results are shown in Table 4.

2. 400 Amp Swept Stroke Tests. The 400 amp swept stroke tests were made by initiating the arc on the steel tab (Fig. 10), turning the inert gas off, and triggering the travel mechanism to sweep the arc along the length of the sample. Several different arc travel speeds were tested with each sample.

Results of 400 amp swept stroke tests were as follows:

a. No puncture occurred with an arc travel speed in excess of 0.91 m/s (3 ft/s).

b. A test was made over a prior arc path (Table 6); the sample burst along the prior arc path upon arc contact with the damaged section (Fig. 12).

c. At 0.79 m/s (2.6 ft/s), the 400 amp arc traveled approximately 18 cm (7 in.) along the sample before a puncture occurred, Table 8. The sample then burst along the traversed path of the arc (Fig. 13).

A summary of the tests, test conditions, and test results are shown in Tables 5 through 8.

III. CONCLUSIONS

When the tests were made in accordance with test specification JSC-07636, Revision A, no failure occurred in any of the test samples. Although there was a definite wall thinning during the intermediate current tests, there were no indications of a probable punch-through; but if a punch-through did occur, it should cause no specific problems because the flow of GOX would tend to extinguish any flame. In the intermediate current tests, when the specifications were exceeded and the samples punctured, there were no signs of flame, the holes remained small, the GOX extinguished the arc, and there was no loss of GOX pressure.

If a severe lightning strike did damage a section of the GOX line and a puncture did result, the damaged section would probably rupture or burst. However, this problem only occurred at simulated velocities of less than 0.79 m/s (2.6 ft/s) which is far below the swept stroke test specification minimum velocity requirement of 19.5 m/s (64 ft/s).

Based on the lightning test specification requirements and the results of these tests, it is concluded that a lightning strike should not cause a malfunction in the GOX line made from the materials tested and if the line is noninsulated. If the GOX line is insulated or covered with a thermal protective material, these tests may not be valid because of the increased lightning hang-on time. Therefore, the addition of any type of insulation to the GOX line will require additional testing of the new line configuration.

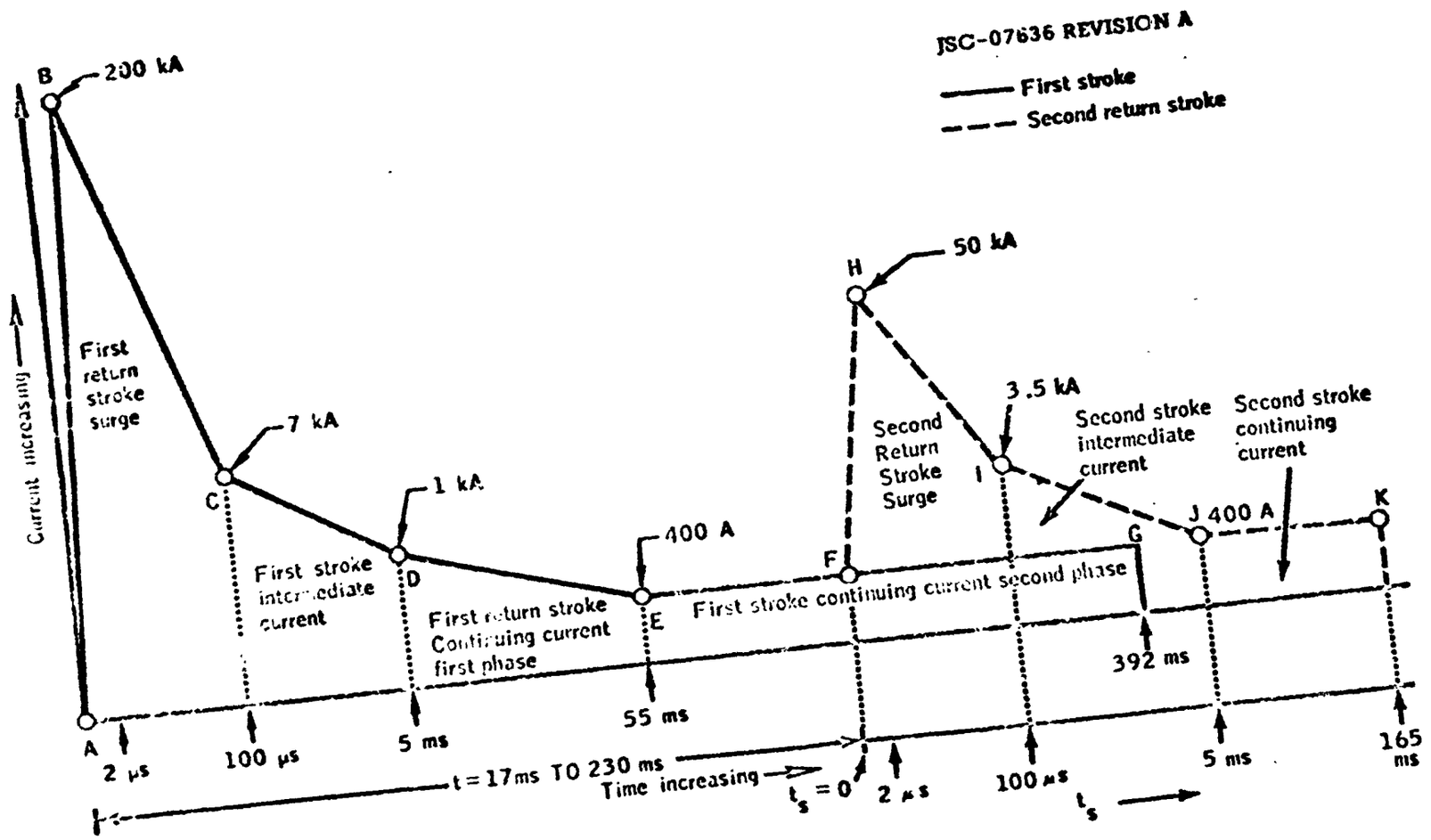

Figure 1. Diagrammatic representation of lightning model (note that the diagram is not to scale).

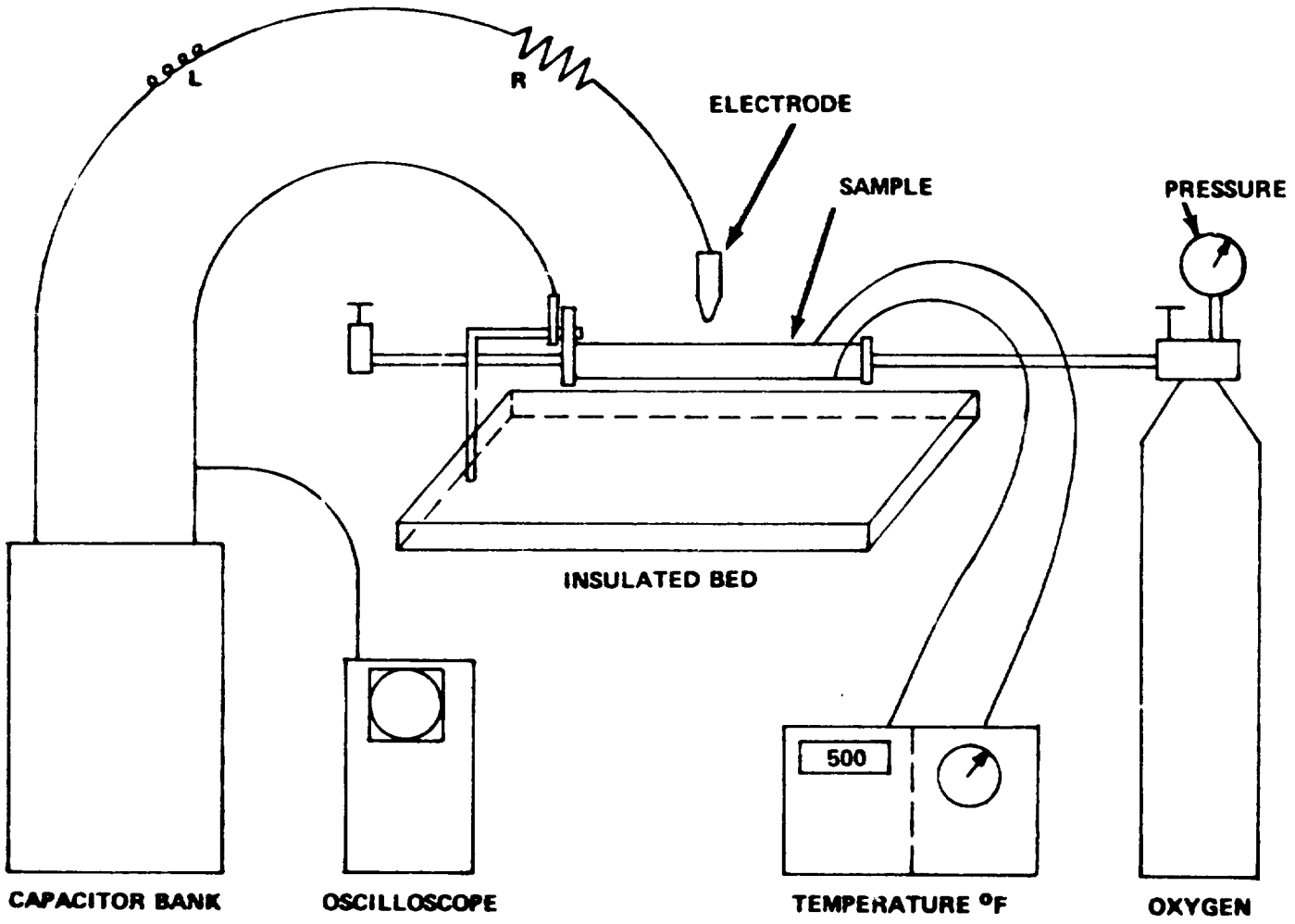

Figure 2. Test facility for high and intermediate current.

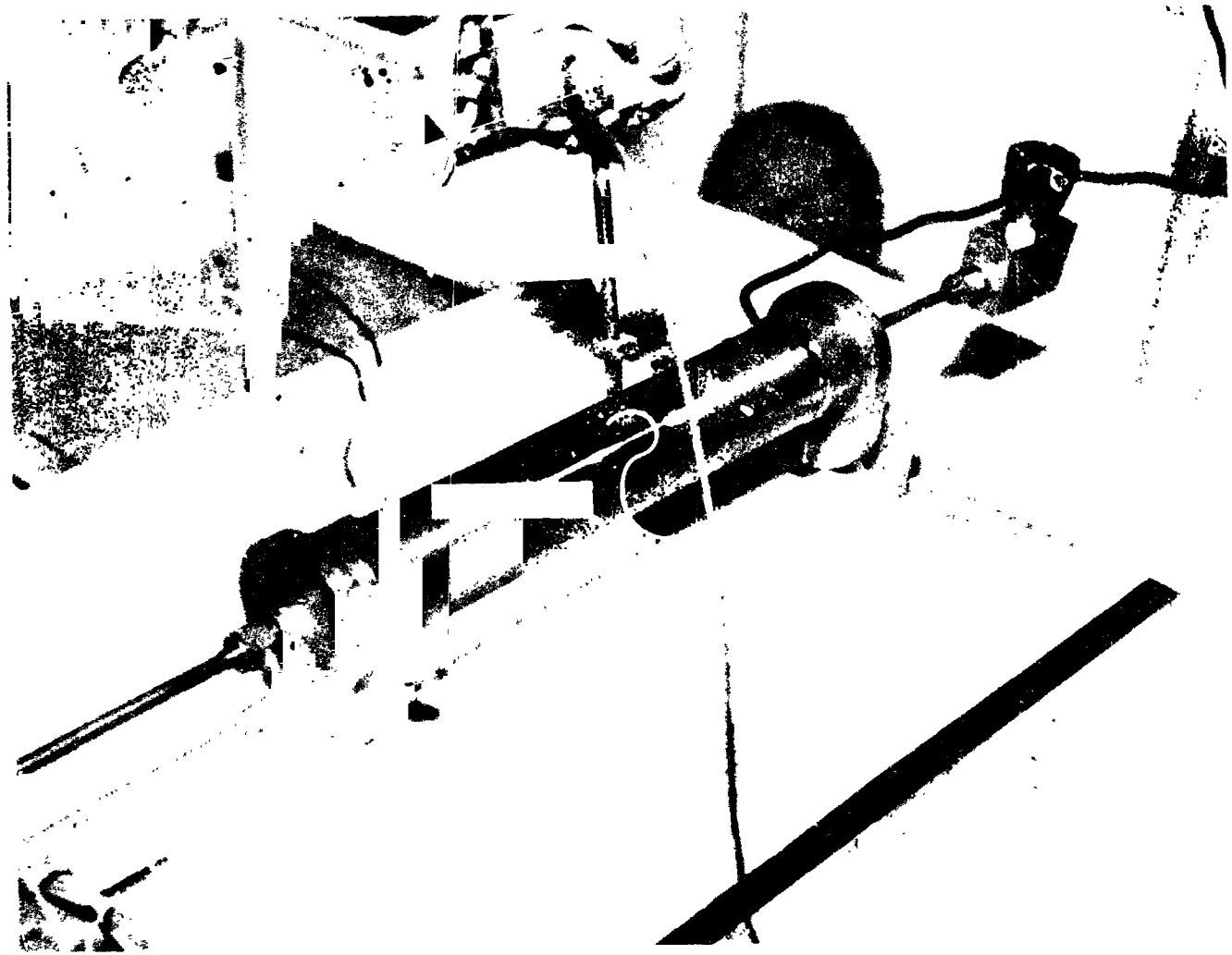

Figure 3. High and intermediate current test facility.

Figure 4. Sample after high current test of 140 000 amps.

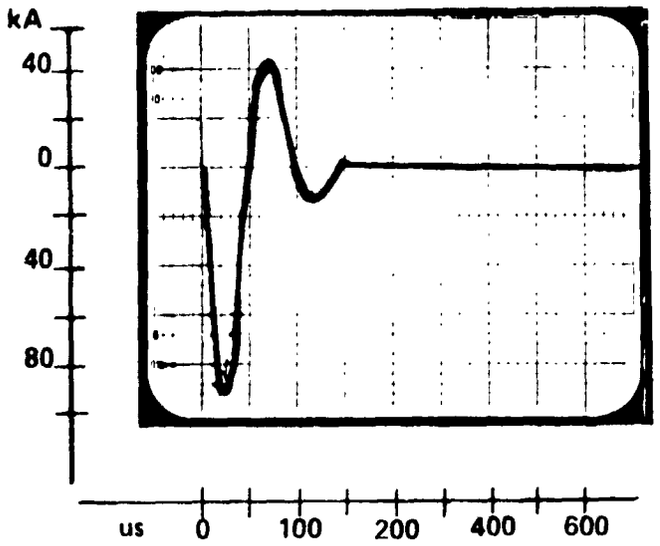

Figure 5. Typical high current waveform.

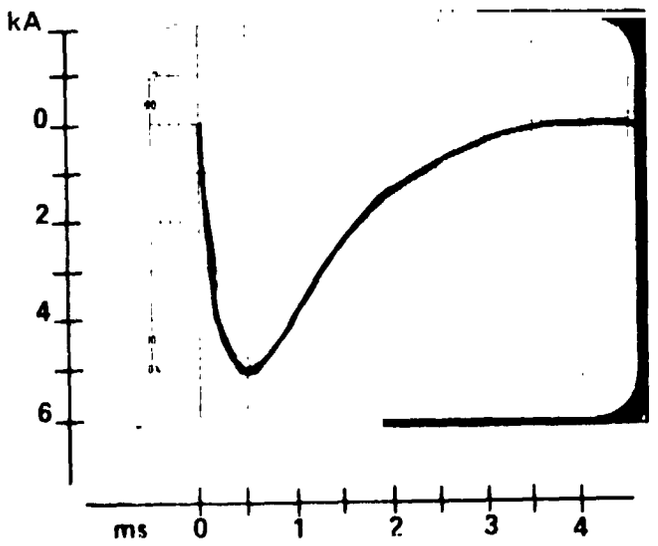

Figure 6. Typical intermediate current waveform.

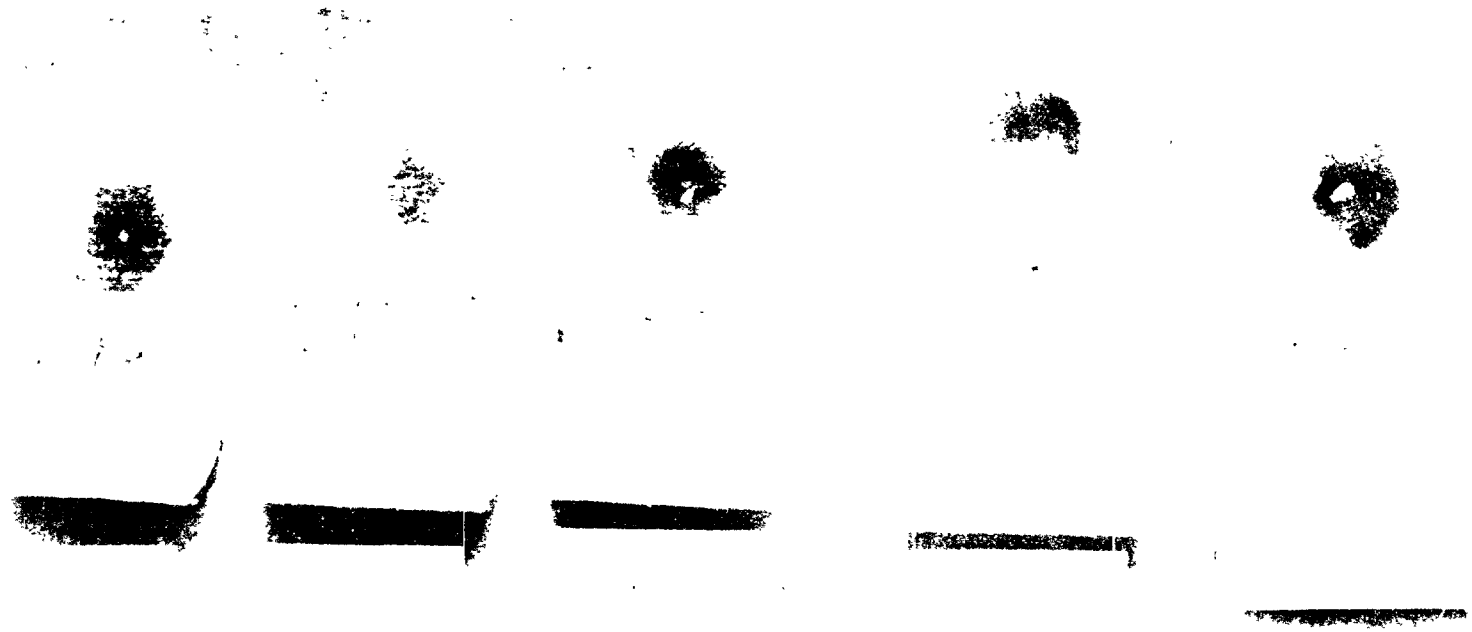

Figure 7. Inside surfaces of 5 intermediate current tests.

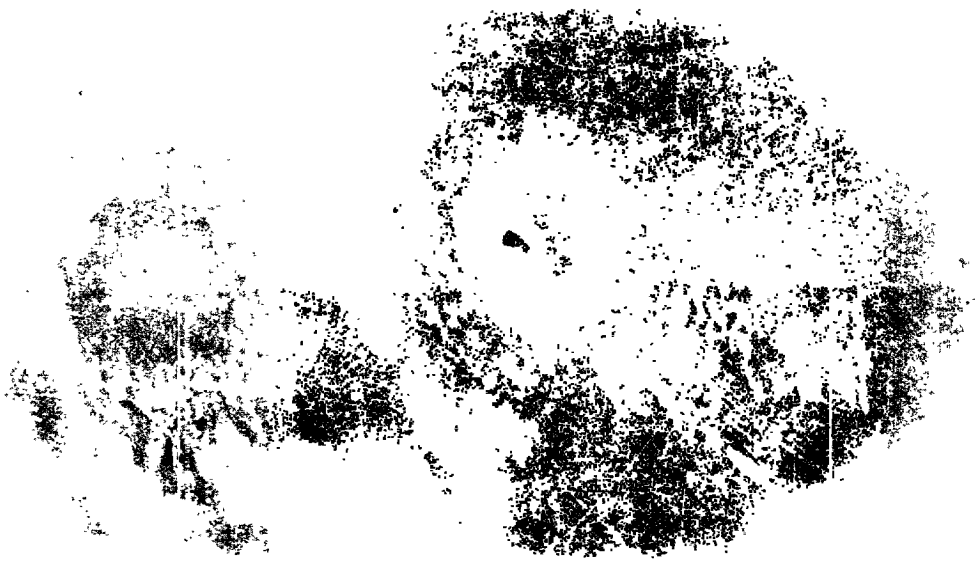

Figure 8. Sample after 3 strikes in same area (hole 0.190 cm diameter).

Time $T_0 = 0$

Time $T_1 = T_0 + 0.6$ ms

Time $T_2 = T_0 + 1.2$ ms

Time $T_3 = T_0 + 1.8$ ms

GOX flow through hole in sample extinguishes arc. Arc and hole were made by the third intermediate current strike in the same area. Hole was 0.190 cm (0.075 in.) diameter.

Figure 9. Intermediate current deliberate puncture test.

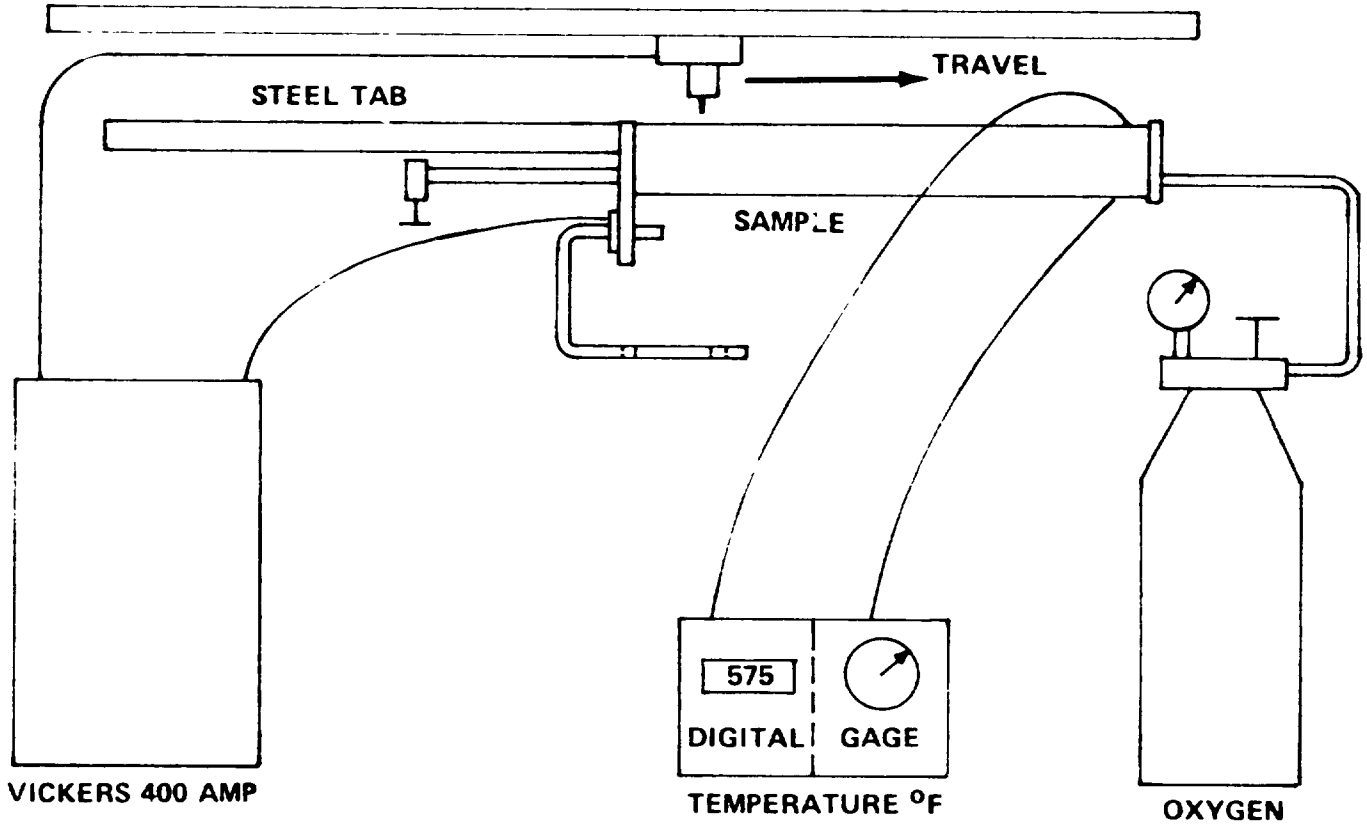

Figure 10. Test facility for 400 amp continuous current.

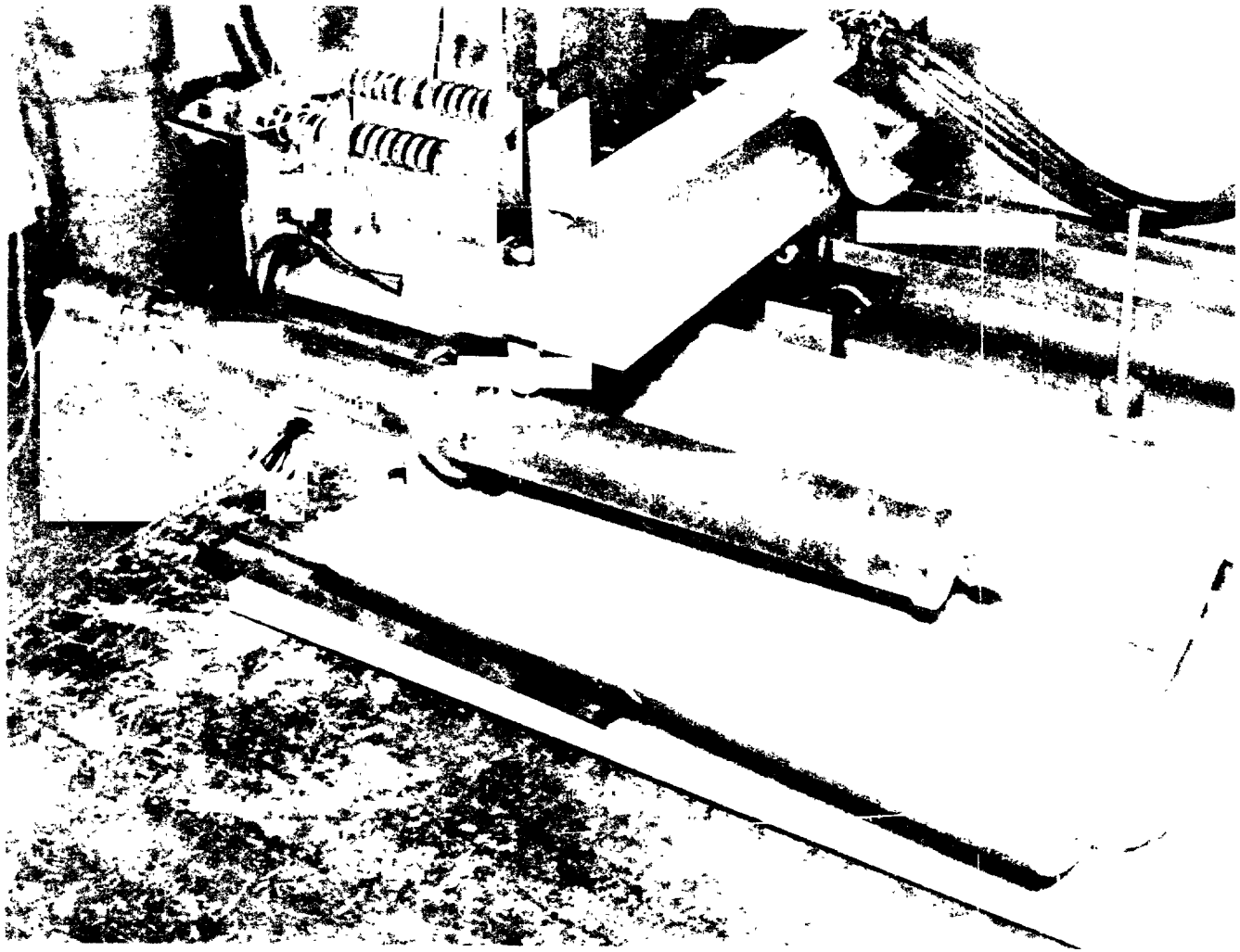

Figure 11. Test facility for the 400 amps continuous current tests.

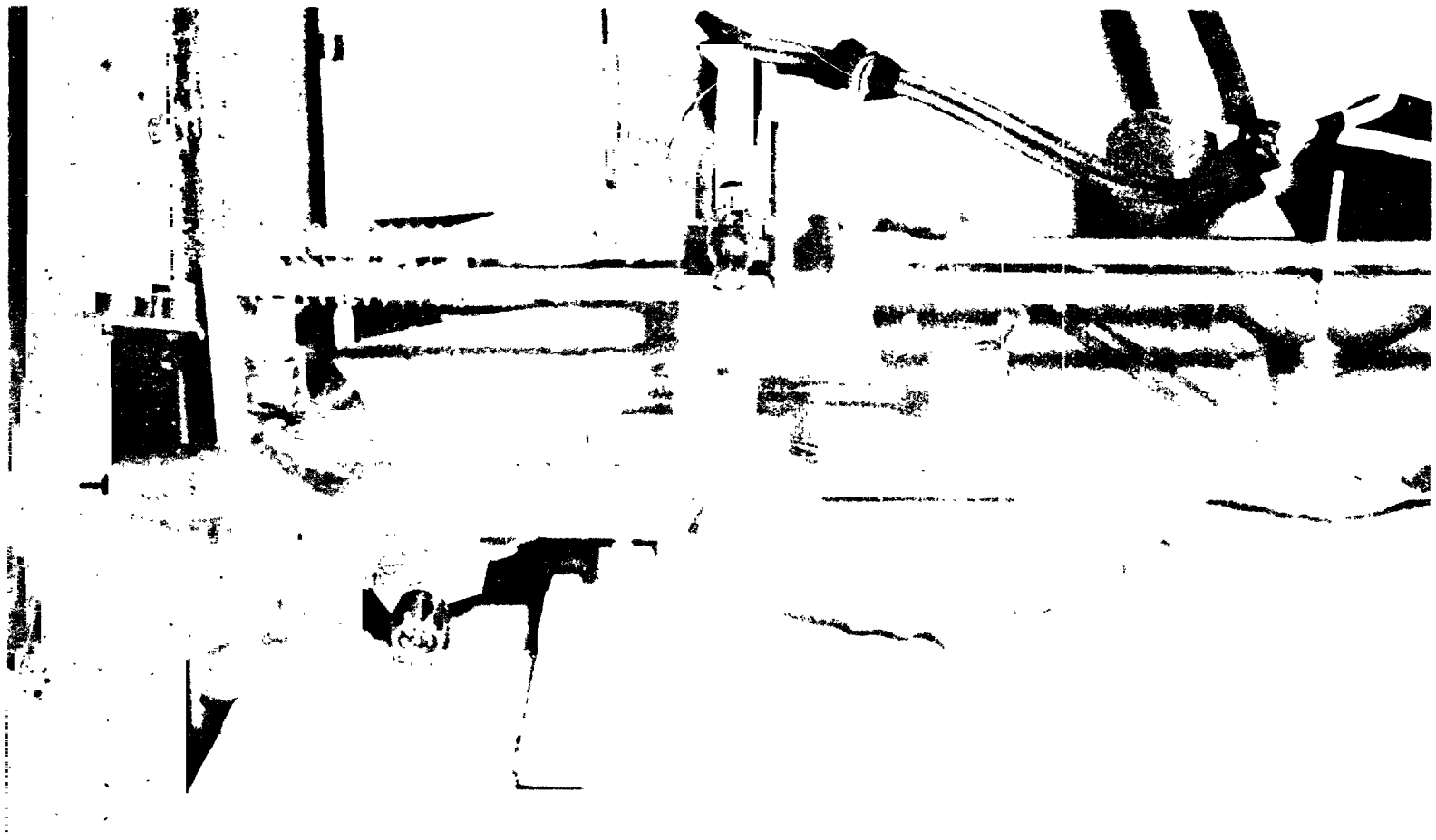

Figure 12. 400 amp continuous current facility and test sample after a test over a prior arc path.

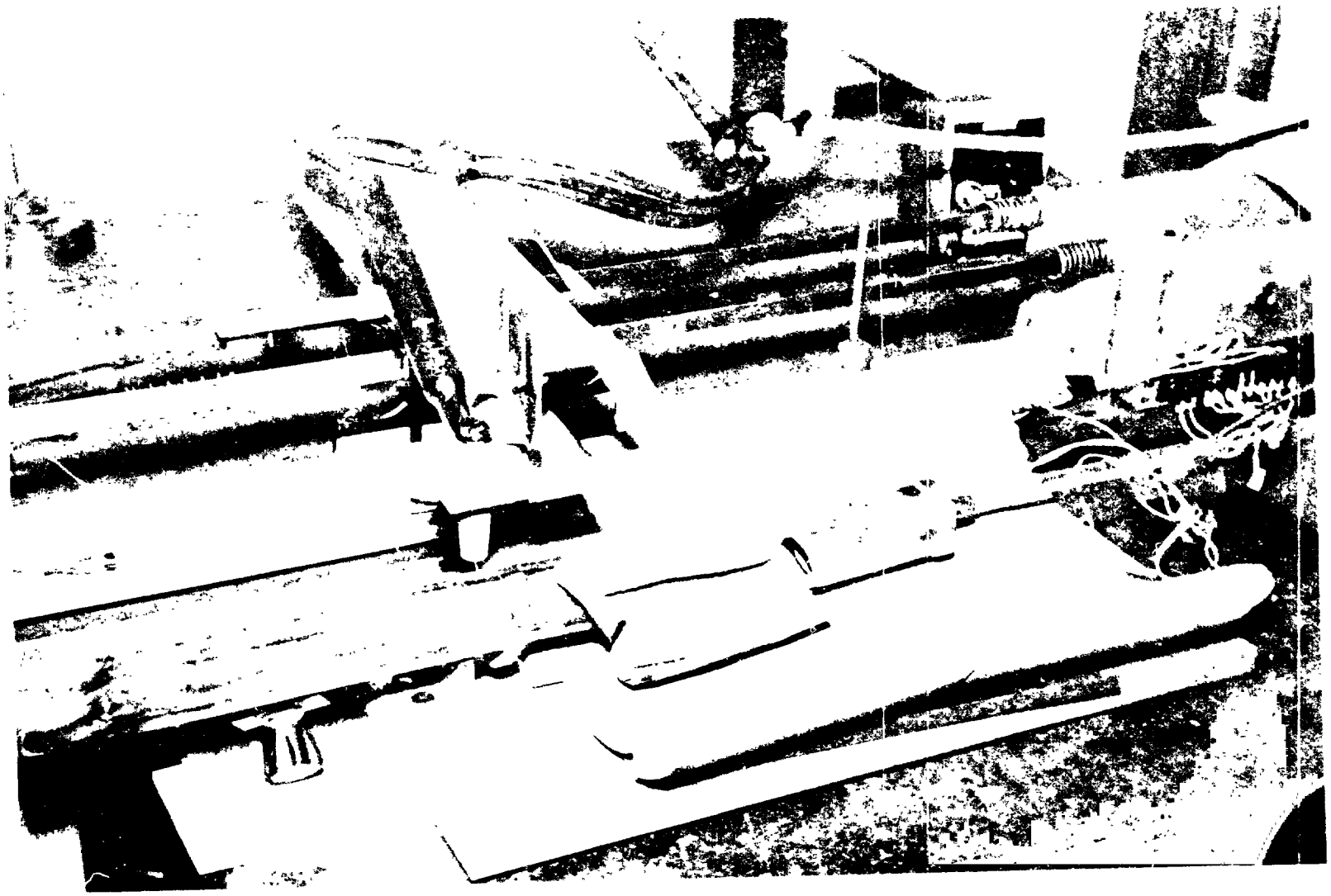

Figure 13. 400 amp test facility and test sample after the test of 0.79 m/s (2.6 ft/s) arc travel speed.

TABLE 1. HIGH CURRENT TESTS

Test Conditions	
GOX pressure	4.14×10^6 N/m^2 gage pressure (600 psig)
GOX temperature	302°C (575°F)
Test current waveform	Figure 5
Test facility	Figure 2
Capacitor bank	360 μf, 18 000 J
Test facility R	Distributed line resistance
Test facility L	Distributed line inductance
Material	304 stainless steel
Wall thickness	0.051 cm (0.020 in.)
Diameter	5.08 cm (2 in.)
Length	27.94 cm (11 in.)

Test Strike No.	Peak Current (kA)	Results
1	60	Slight surface damage and discoloration
2	90	Slight surface damage and discoloration
3	140	Considerable surface metal movement and dark discoloration with a minor wall thinning of approximately 0.008 cm (0.003 in.)

TABLE 2. INTERMEDIATE CURRENT TESTS

Test Conditions	
GOX pressure	4.14×10^6 N/m^2 gage pressure (600 psig)
GOX temperature	302°C (575°F)
Test current waveform	Figure 6
Test facility	Figure 2
Capacitor bank	720 μf, 36 000 J
Test facility R	1.35 ohms
Test facility L	400 μH
Material	304 stainless steel
Wall thickness	0.051 cm (0.020 in.)
Diameter	5.08 cm (2 in.)
Length	27.94 cm (11 in.)

Test Strike No.	Sample No.	Peak Current (kA)	Results
			Photographs of the results of these tests are shown in Figure 7.
1	1-15-2	5.5	Single strike — extensive external damage, internal wall discoloration, wall thinning to 0.028 cm (0.11 in.), no puncture.
2	2-15-1	5.0	Single strike — extensive external damage, internal wall discoloration, wall thinning to 0.036 cm (0.014 in.), no puncture.

TABLE 2. (Concluded)

Test Strike No.	Sample No.	Peak Current (kA)	Results
3	1-2-20-2	5.5	First strike — extensive external damage.
4	1-2-20-2	5.0	Second strike same area — puncture, small hole 0.010 cm (0.004 in.) diameter, edges are pushed out and very ragged, GOX flow through hole extinguished arc (Fig. 9). GOX pressure was maintained.
5	1-21-3	5.0	Single strike - extensive external damage, internal wall discoloration, no puncture
6	2-3-4-21-3	5	First strike - extensive external damage
7	2-3-4-21-3	5	Second strike same area - more damage
8	2-3-4-21-3	5	Third strike same area - puncture, 0.190 cm (0.075 in.) diameter hole, edges pushed out and ragged. See Figure 8. GOX pressure was maintained. Some very good high speed movie film (500 frames/second) was taken of this test.

TABLE 3. HIGH ALTITUDE TESTS

Test Conditions

The atmospheric pressure tests and the simulated high altitude tests were conducted under the same conditions, except for the reduced sample external pressure to simulate 15.24 km (50 000 ft) altitude. These tests were made together for the purpose of comparing results. The intermediate current waveform of 5 kA peak was used for the tests.

GOX pressure	4.14×10^6 N/m^2 gage pressure (600 psig)
GOX temperature	302°C (575°F)
Test current waveform	Figure 6
Test facility	Figure 2
Capacitor bank	720 μf, 36 000 J
Test facility R	1.35 ohms
Test facility L	400 μH
Material	321 stainless steel
Wall thickness	0.051 cm (0.020 in.)
Diameter	5.08 cm (2 in.)
Length	30.48 cm (12 in.)

Test Strike No.	Peak Current (kA)	Results
1-5	5	At atmospheric pressure of 1.01×10^5 N/m^2 (14.7 psia), five strikes in the same area were required to puncture sample. The hole was approximately 0.076×0.152 cm (0.030×0.060 in.) pushed out and jagged.
1-12	5	At a pressure of 1.17×10^4 N/m^2 absolute (1.7 psia) simulating an altitude of 15.24 km (50 000 ft), twelve strikes in the same area were required to puncture the sample. The hole was so small that a microscope was required to find the opening.

TABLE 4. 400 AMP STATIONARY TEST

Test Conditions

GOX pressure	4.14×10^6 N/m^2 gage pressure (600 psig)
GOX temperature	302°C (575°F)
Test current	400 amps continuous
Test facility	Figure 10
Material	321 stainless steel
Wall thickness	0.051 cm (0.020 in.)
Diameter	5.08 cm (2 in.)
Length	30.48 cm (12 in.)

Test Procedure

1. Initiate arc on steel tab (Fig. 10)
2. Turn off inert gas.
3. Move arc onto sample.
4. Hold arc and hot electrode above puncture.

Test Results

1. Hole occurred immediately.
2. No flame, the hole remained small approximately 0.178 cm (0.070 in.)
3. The GOX extinguished the arc.
4. The flow of GOX eroded the hot electrode.

TABLE 5. 400 AMP SWEPT STROKE (SAMPLE 1)

Test Conditions		
Test current		400 amps continuous
Test facility		Figure 10
Material		321 stainless steel
Wall thickness		0.051 cm (0.020 in.)
Diameter		5.08 cm (2 in.)
Length		30.48 cm (12 in.)
Test Strike No.	Arc Travel, m/s (ft/s)	Results
		GOX pressure — atmospheric
		GOX temperature — ambient
1	0.46 (1.5)	Sample pressurized after test — no leak.
2	0.31 (1.0)	Sample pressurized after test — no leak.
		GOX pressure — 4.14×10^6 N/m^2 gage pressure (600 psig)
		GOX temperature — ambient
3	0.46 (1.5)	Punctured upon arc contact with sample.
		GOX extinguished arc.

TABLE 6. 400 AMP SWEPT STROKE (SAMPLE 2)

Test Conditions	
GOX pressure	4.14×10^6 N/m^2 gage pressure (600 psig)
GOX temperature	Ambient
Current	400 amps continuous
Test facility	Figure 10
Material	321 stainless steel
Wall thickness	0.051 cm (0.020 in.)
Diameter	5.08 cm (2 in.)
Length	30.48 cm (12 in.)

Test Strike No.	Arc Travel, m/s (ft/s)	Results
1	2.89 (9.5)	No puncture
2	2.71 (8.9)	No puncture
3	2.44 (8.0)	No puncture
4	2.26 (7.4)	No puncture
5	1.80 (5.9)	No puncture
6	1.49 (4.9)	No puncture
7	0.79 (2.6)	Sample burst. This test was over the same arc path as test number 6. Sample burst along the prior path upon arc contact (Fig. 12).

TABLE 7. 400 AMP SWEPT STROKE (SAMPLE 3)

Test Conditions	
GOX pressure	4.14×10^6 N/m^2 gage pressure (600 psig)
GOX temperature	302°C (575°F)
Test current	400 amps continuous
Test facility	Figure 10
Material	321 stainless steel
Wall thickness	0.051 cm (0.020 in.)
Diameter	5.08 cm (2 in.)
Length	30.48 cm (12 in.)

Test Strike No.	Arc Travel, m/s (ft/s)	Results
1	1.80 (5.9)	No puncture
2	1.49 (4.9)	No puncture

TABLE 8. 400 AMP SWEPT STROKE TEST (SAMPLE 4)

Test Conditions	
GOX pressure	4.14×10^6 N/m^2 gage pressure (600 psig)
GOX temperature	302°C (575°F)
Current	400 amps continuous
Test facility	Figure 10
Material	321 stainless steel
Wall thickness	0.051 cm (0.020 in.)
Diameter	5.08 cm (2 in.)
Length	30.48 cm (12 in.)

Test Strike No.	Arc Travel, m/s (ft/s)	Results
1	1.58 (5.2)	No puncture
2	1.13 (3.7)	No puncture
3	0.91 (3.0)	No puncture
4	0.79 (2.6)	Sample burst. At 0.79 m/s (2.6 ft/s), the 400 amp arc traveled 18 cm (7 in.) along the sample before a puncture occurred. The sample then burst along the traversed arc path (Fig. 13).

APPROVAL

EXTERNAL TANK GASEOUS OXYGEN LINE SIMULATED LIGHTNING TESTS

By Hubert E. Smith and R. M. Avery

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

R. L. GAUSE
Chief, Engineering Physics Division

R. J. SCHWINGHAMER
Director, Materials and Processes Laboratory

☆U.S GOVERNMENT PRINTING OFFICE 1976-641 255/520 REGION NO 4