MND–P–2101

MASTER

SNAP-III......

Thermoelectric Generator Environmental Test

MARTIN
NUCLEAR DIVISION

DISCLAIMER

SNAP-III......

Thermoelectric Generator Environmental Test

MND-P-2101

AUGUST 1959

Report Prepared By:

Louis W. Gross

Approved By:

MARTIN
NUCLEAR DIVISION

LEGAL NOTICE

FOREWORD

This report was prepared by the Nuclear Division of The Martin Company. It describes the effects of simulated space vehicle vibration, acceleration, and shock on the operation and efficiency of a SNAP-III thermoelectric generator. The test specifications were developed by Jet Propulsion Laboratories for the third stage and payload of the Vega Vehicle.

A similar test program to the specifications of the Lockheed Missile Systems Division will be described in Volume II, a classified addendum to this report.

page blank

CONTENTS

page blank

SUMMARY

The SNAP-III thermoelectric generator has been demonstrated to be a reliable device under normal handling. For space vehicle application, however, vibration, acceleration, and shock must be considered.

A SNAP-III generator configuration was selected for testing in accordance with the specifications of the Jet Propulsion Laboratories, Pasadena, California, and those of Lockheed Missile Systems Division, Palo Alto, California. An electrical resistance heater was substituted for the isotopic source of an operational generator. The unit was subjected to vibration, acceleration, and shock intensities simulating the conditions for the third stage and payload of the Vega Vehicle and the WS-117 L Vehicle. Generator performance and efficiency were analyzed for each orthogonal plane of test.

The generator shell, internal structure and pressure, and the hot and cold junction temperatures were not affected during the test.

The only mishap occurred during the third shock (50 g) in the y (vertical) plane. The electrical resistance heater ruptured, but the generator continued to operate on residual heat, with a loss in efficiency. The heater was replaced and the test continued with negligible variation in efficiency.

During the test cycles, some ripple was evident in the generator direct current output. This phenomenon may have been caused by elastic deformations within the generator, due to the environmental forces. The severest dc ripple was observed during the vibration test, but disappeared after the completion of each test cycle.

The test specimen was in operation for the entire test program or approximately 300 hr. Efficiency varied slightly in the vibration cycle and average recovery time was approximately five minutes. In the acceleration and shock phases, there was a negligible variation in efficiency. The average efficiency variation for the entire test was less than five percent of the overall generator performance.

It was concluded that the SNAP-III thermoelectric generator will operate reliably in the environments associated with the Vega and WS-117 L vehicles.

I. INTRODUCTION

On 15 May 1959, tests were begun in the Environmental Dynamics Test Facility at The Martin Company on SNAP-III thermoelectric generator No. 1G4. The unit was fabricated by The Minnesota Mining and Manufacturing Company, St. Paul, Minnesota. The radioisotope was simulated by an electrical resistance heater located in the source cylinder.

The generator was subjected to vibration, acceleration and shock in each orthogonal plane. The test specifications were developed by Jet Propulsion Laboratories for the third stage and payload of the Vega Vehicle and by the Lockheed Missile Systems Division for the WS-117 L Vehicle. The facilities used were a Calidyne vibration shaker, a Genisco centrifuge, and a special shock test rig.

These tests were concluded on 7 July 1959. Additional generators will be tested to prove reliability. The effects of the Vega Vehicle tests on generator performance and recommendations are covered in this report.

Vega vehicle test procedures, preliminary test specifications, and generator component weights are given in Appendices A, B, and C, respectively. The Lockheed Missile Systems Division procedures and specifications for the WS-117 L vehicle tests will be given in Volume II, a classified addendum to this report.

II. DESCRIPTION OF GENERATOR NO. 1G4

The configuration of SNAP-III thermoelectric generator No. 1G4 is shown in Figs. 1, 2 and 3. The copper shell housing the generator internals has a wall thickness of 0.030 in. and the total weight of the thermoelectric unit is 3.845 lb.

The elements, constructed of lead telluride, are approximately 0.225 in. in diameter and 1 in. long (Fig. 4). There are 54 N-type and P-type elements, or 27 pairs of thermoelectric couples, mounted in six vertical rows, with a radial arrangement of nine per row. Each element is loaded axially against a hot junction ring by means of a two-pound spring load from the cold junction end which fits into an aluminum casement ring. Each pair of couples is connected in series. The source cylinder, constructed of stainless steel, houses a Watlow Firerod heater cartridge, rated at 115 v and 125 w. The cylinder fits into a tapered stainless steel cannister ring containing the hot shoe inserts for the thermoelectric elements. Mica sheet and ceramics sprays are incorporated to provide the electrical insulation for each element.

The internal cavities of the generator are filled with a powdered thermal insulator called Min-K1301. The entire unit is hermetically sealed and pressurized with a forming gas of 85% nitrogen and 15% hydrogen at an operating pressure of one atmosphere to prevent corrosion.

The internal instrumentation consists of three iron-constantan thermocouples at the heater, hot shoe and cold shoe stations. The power input and output terminals can be seen in Fig. 3.

The maximum operating hot junction temperature for the No. 1G4 generator is 1100° F for the present internal atmosphere. For evacuated generators the hot junction temperature should not exceed 900° F. Appendix C gives the component weights of this generator.

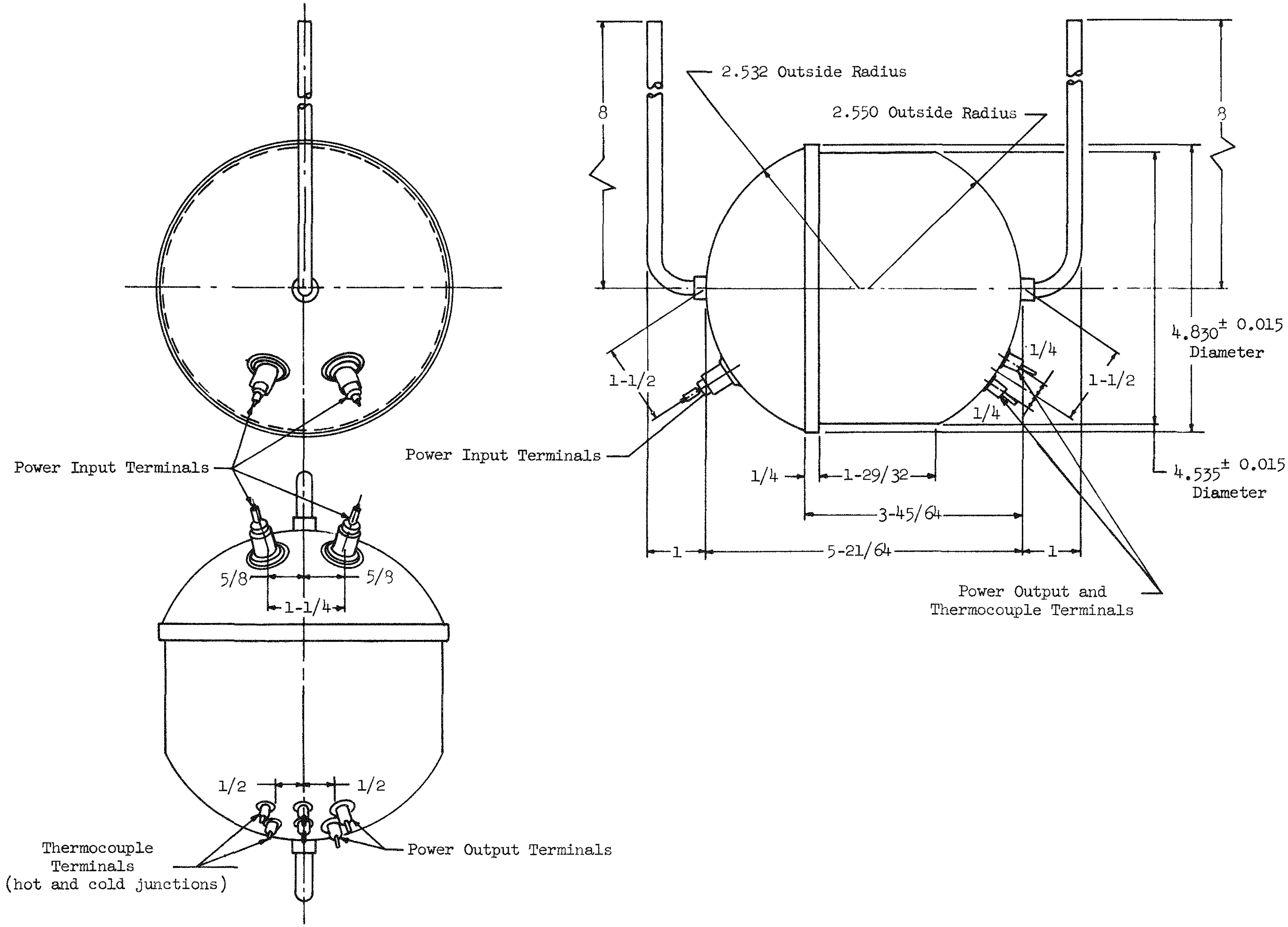


Fig. 1. SNAP III--Exterior Assembly

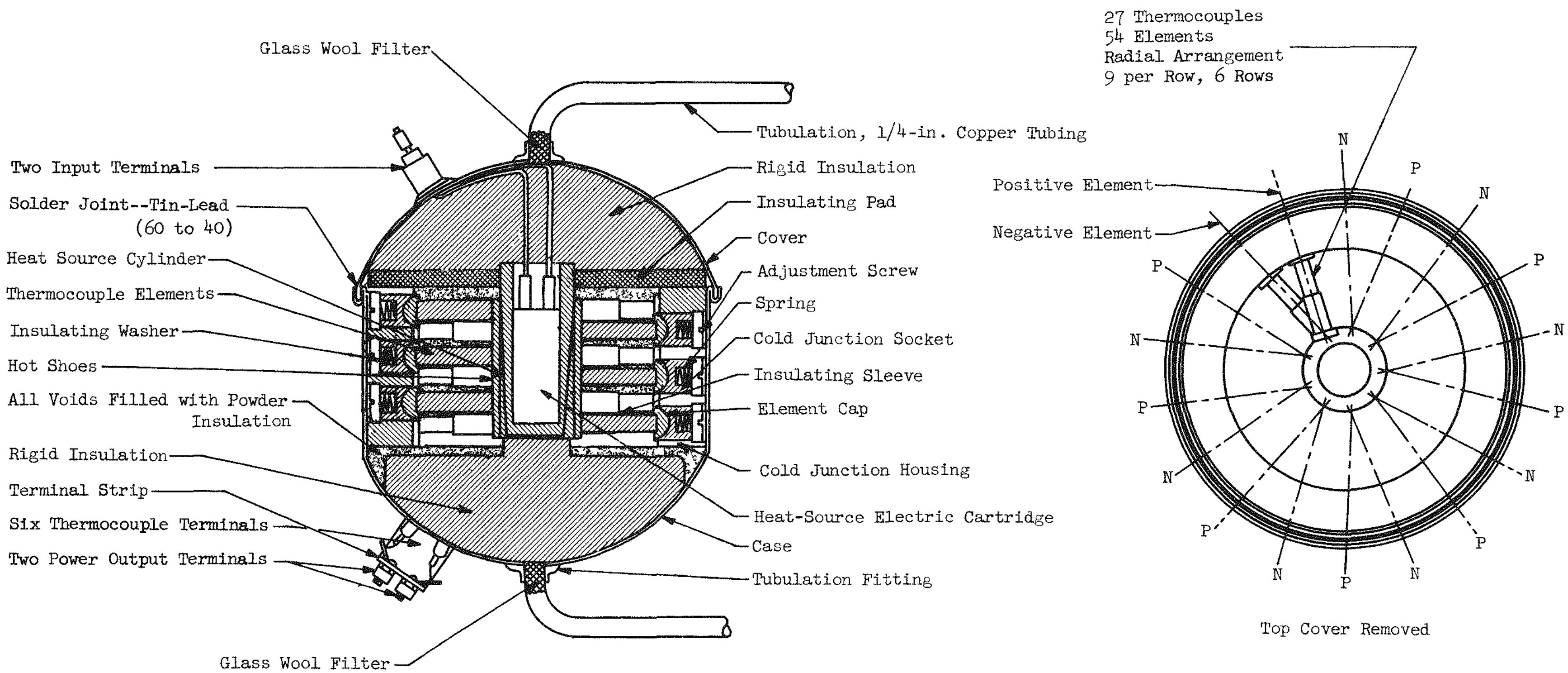


Fig. 2. SNAP III--Interior Assembly

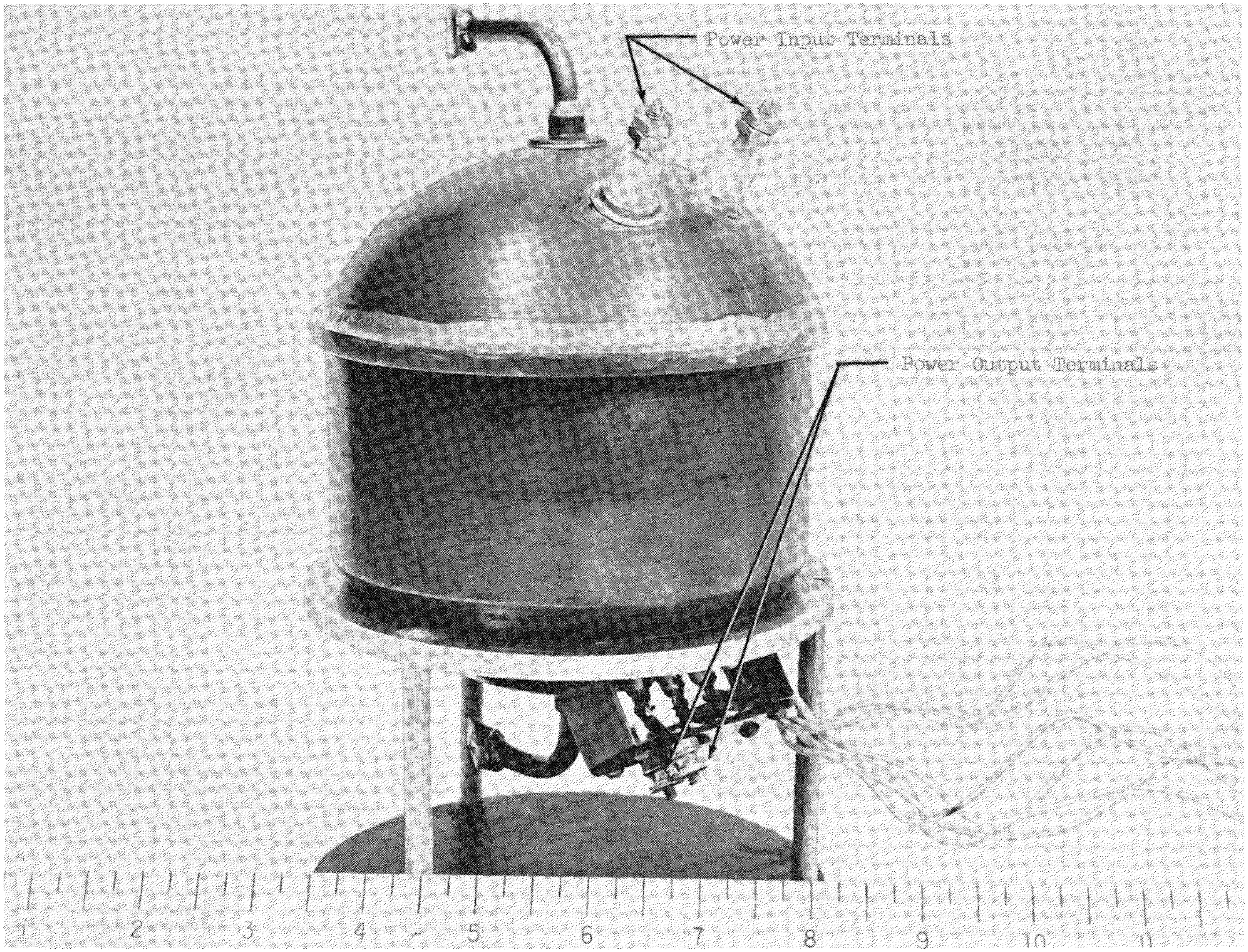


Fig. 3. Thermoelectric Generator No. 1G4

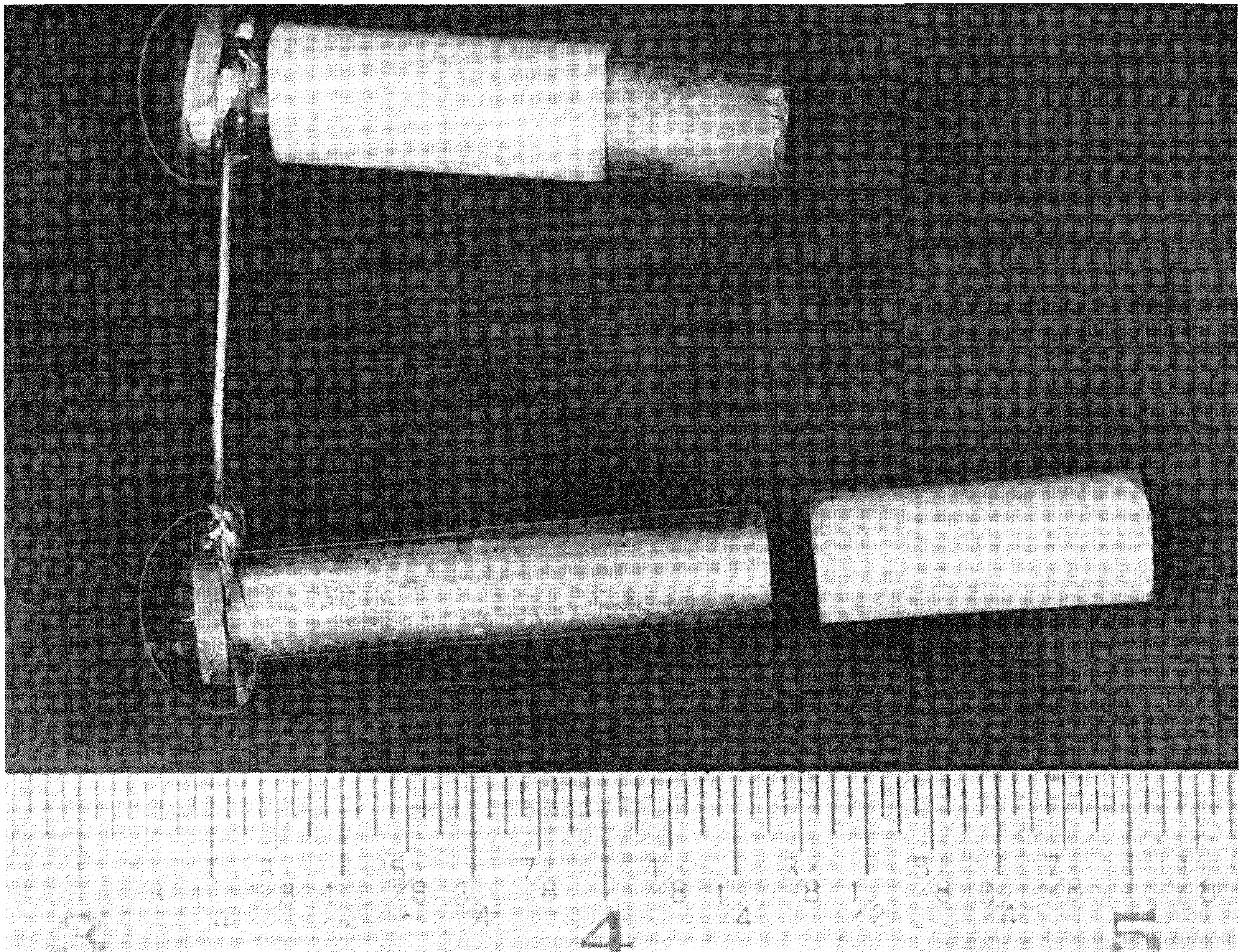
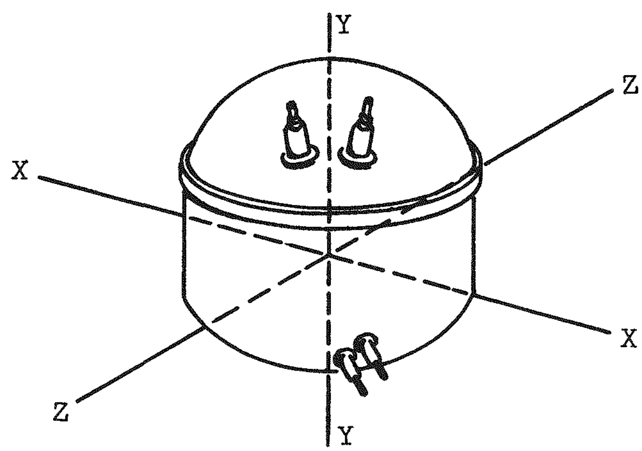


Fig. 4. Thermoelectric Couple with Mica Sleeve Insulator

III. VIBRATION TEST

The vibration test was conducted in the environmental laboratory with a Calidyne Model No. 177A vibration system. (See Figs. 5 and 6) A magnetic tape of the vibration intensities for this test was furnished by Jet Propulsion Laboratory. The tape consisted of a sinusoidal vibration of 5 g rms from 15 to 500 cps, superimposed on a random signal of 5 g rms, band-limited between 15 to 1500 cps for five minutes. The second portion of the tape consisted of a sinusoidal vibration of 8 g rms from 500 to 1500, superimposed on a random signal of 5 g rms, band-limited between 15 to 1500 cps for five minutes. Two test cycles, each 10 min in duration, were to be conducted in each of the three principal orthogonal planes. The test planes are shown in the sketch below.



Trimetric View of the SNAP-III Thermoelectric Generator

Designation of Orthogonal Planes:
Axis Y Denotes vertical plane
Axis X Denotes lateral plane A
Axis Z Denotes lateral plane B

The frequency response curve for the basic 177A shaker was initially equalized with the system equalizer (see Fig. 7) and a peak notch filter. After the mounting plate and test fixture were attached as shown in Fig. 8, the equalizer and filter were again adjusted to flatten the system response. Figures 9, 10 and 11 show the system equalization calibration. Kronhite band pass filters brought the relative level 3 db down at 1500 cps, and 8.5 db down at 15 cps.

A spectrum analysis of the tape was performed with a Technical Products Company 627 analyzer and 626 oscillator in the Martin Company Dynamic Test Laboratory. Figure 12 shows the rms random and sinusoidal signal to be flat as required through the desired test region of 15 to 1500 cps.

Before each test the generator was allowed to reach a state of equilibrium, when the power input, power output, and hot and cold junction temperatures stabilized. A parallel system of recording enabled visual observation as well as permanently recorded data. The equipment is shown in Fig. 13. A ten minute time history of these generator parameters was recorded before each test to measure the stability of the test specimen.

The tape signal was played into the Calidyne shaker head through the console by an Ampex Model 307-2 recorder, and a coaxial cable from the Dynamics Test Laboratory (Fig. 14).

The vibration tests performed on SNAP-III showed the maximum efficiency drop to be 3.59% of the overall performance in the x and z planes (Tables 1 and 2 and Figs. 15 and 16), and 5% in the y plane (Table 3 and Fig. 17). This drop in efficiency, after reaching its maximum, remained constant until the vibratory force was discontinued. The generator recovered its original level of efficiency in a maximum time of 10 min.

The output voltage was monitored to determine if any D-C ripple was present. The records show that, in the x and z planes, a constant rms oscillation level of 1.20 mv was superimposed on the D-C output of 2.80 v. In the y plane, a sharp peak in the oscillations equivalent to an rms level of 3.60 mv was observed. A sinusoid of a constant 2 g's rms from 15 to 1500 cps was applied in the x, y and z planes to determine the frequency at which this sharp peak occurred. The transient DC signal was found to peak at a frequency of 700 cps in the y plane. (Fig. 18)

DC ripple of constant amplitude was observed in the x and z planes. This ripple disappeared when the vibrator was stopped. A frequency sweep of 0 to 1500 cps was conducted to determine if any generator resonances were present. The output of the accelerometer mounted on the test specimen showed the same g-level as the input from the vibration shaker, therefore there was no resonance.

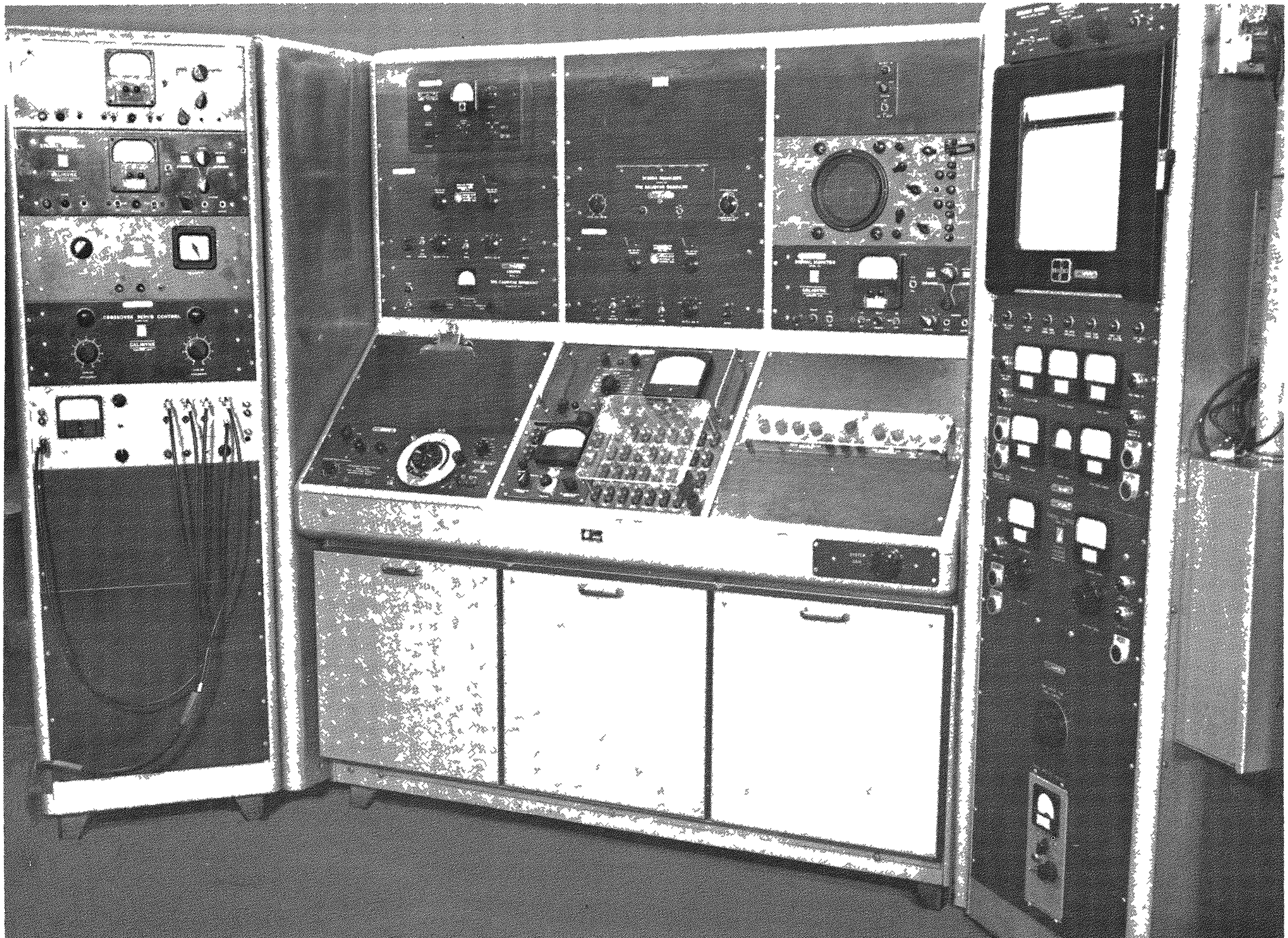


Fig. 5. Calidyne Console Control Panel

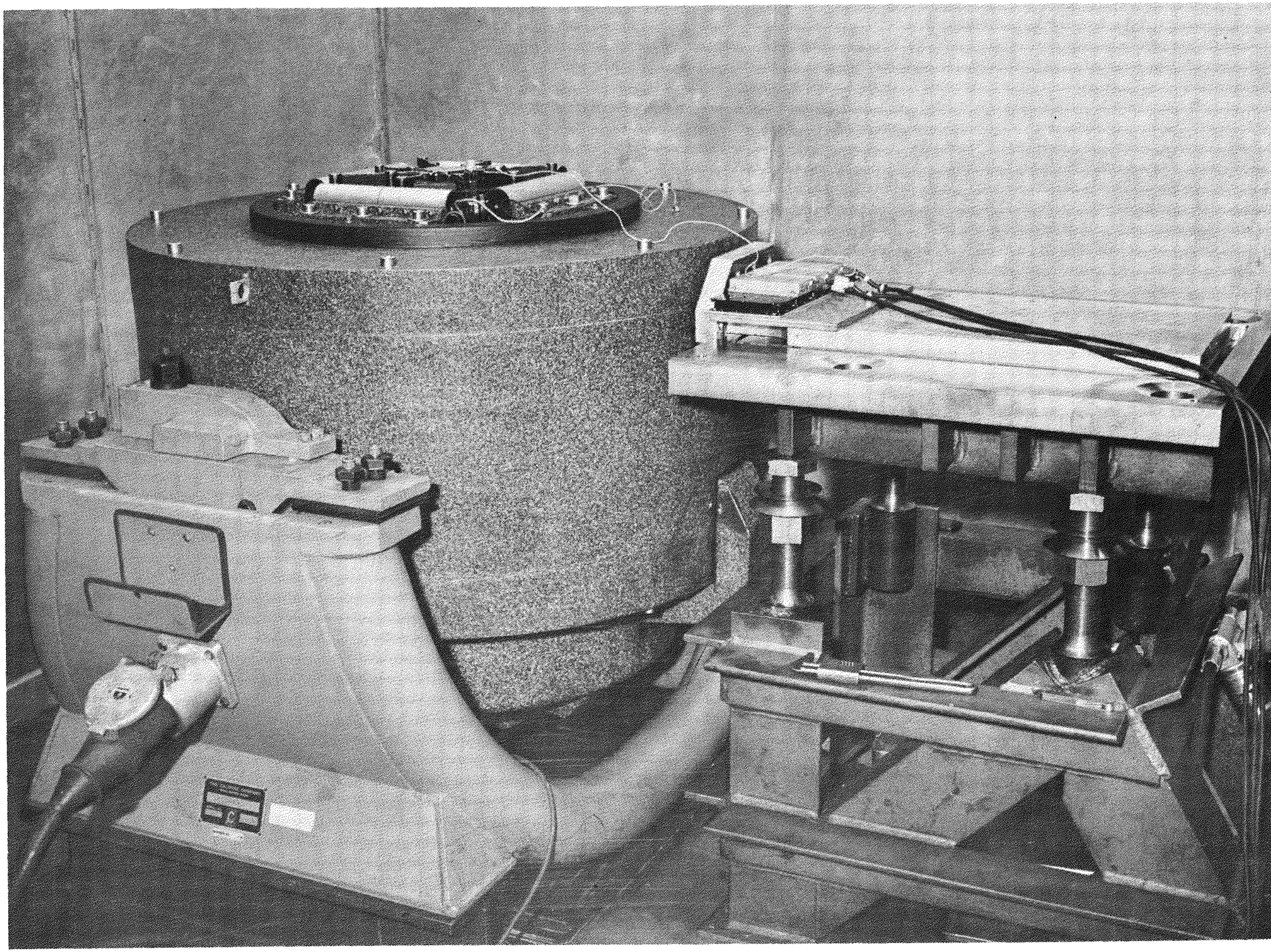


Fig. 6. Calidyne Vibrator Model 177

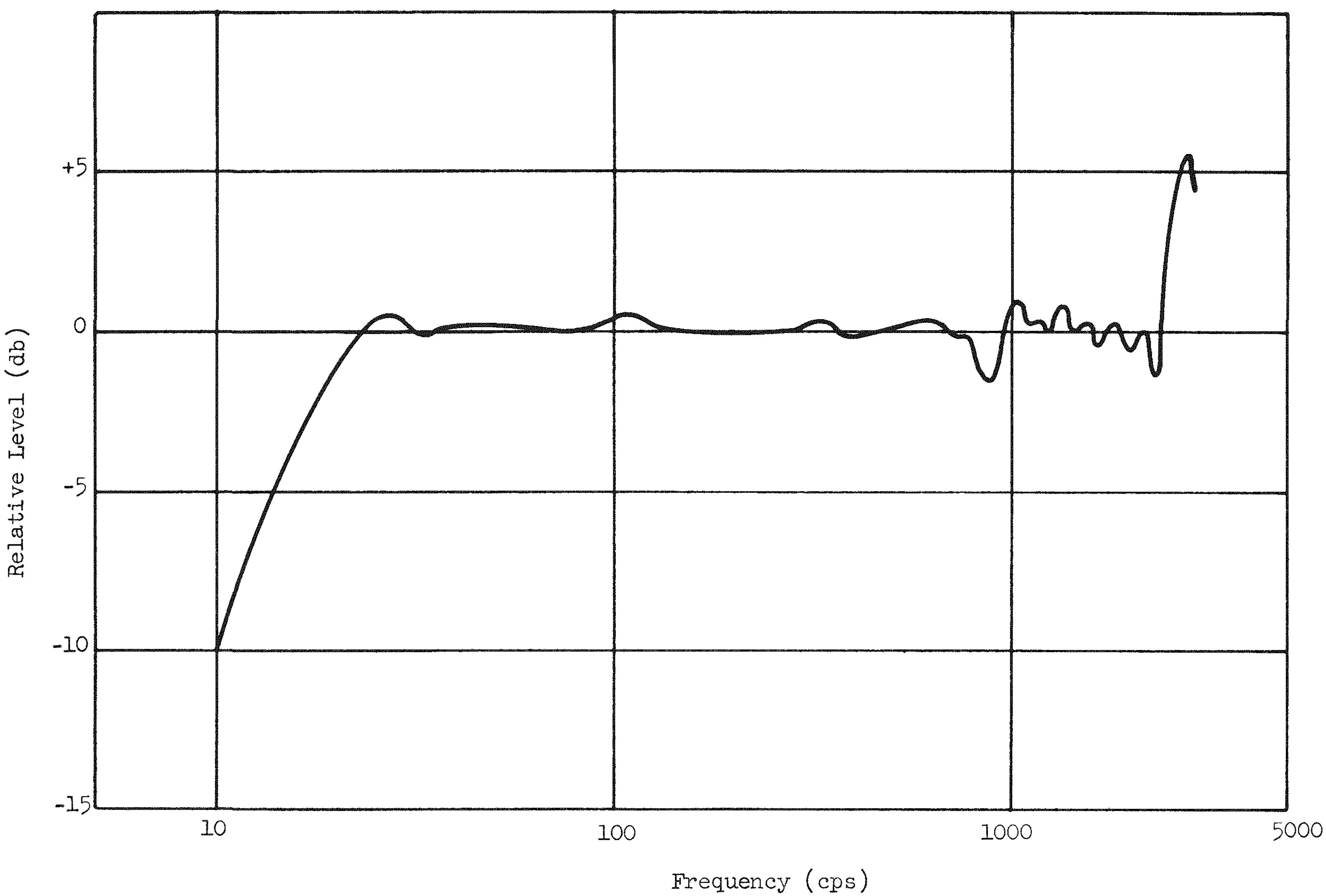


Fig. 7. Equalization of Bare Table with Model 210 Equalizer-Model 177A Calidyne Vibrator

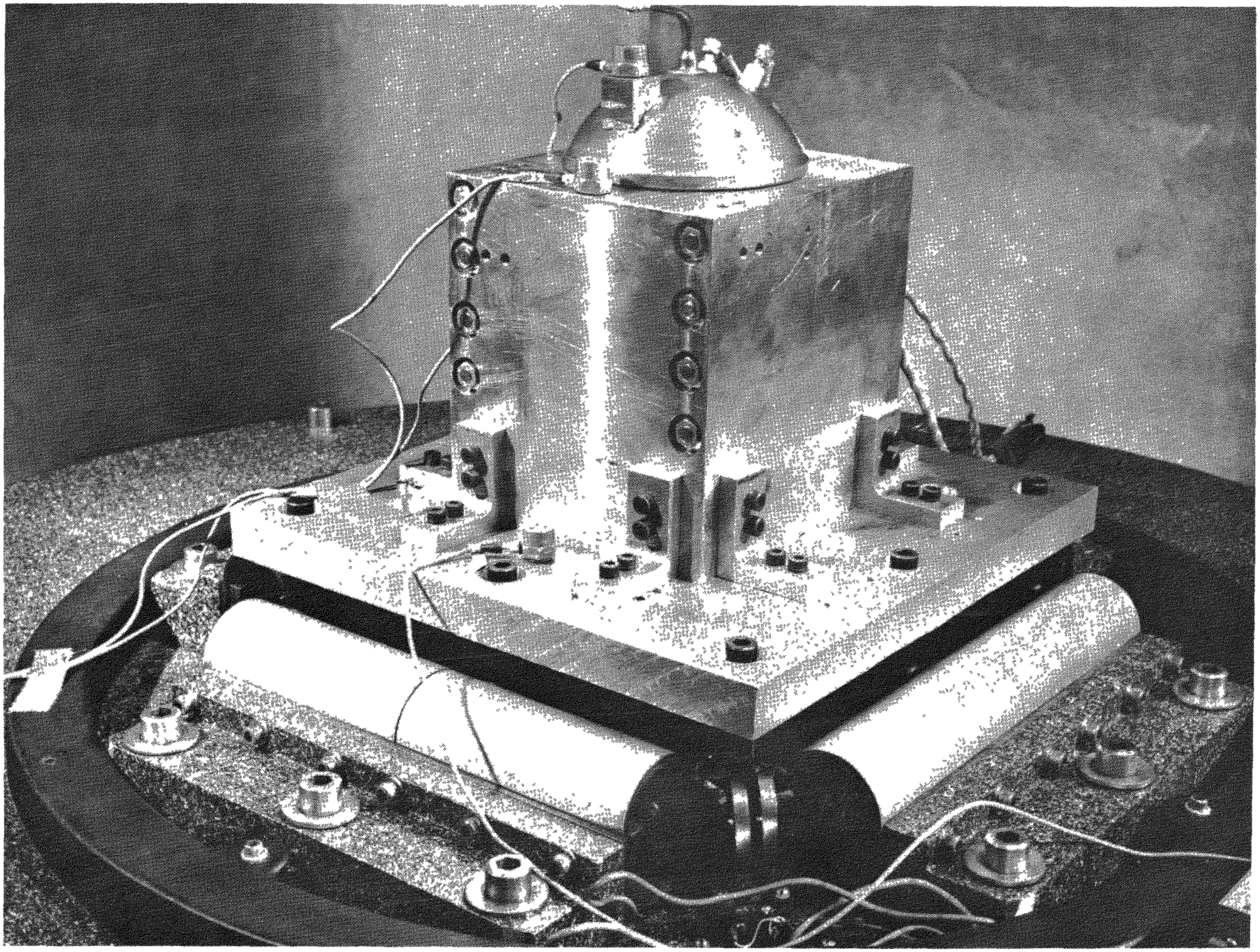


Fig. 8. Test Specimen with Fixture Mounted on Calidyne Vibrator

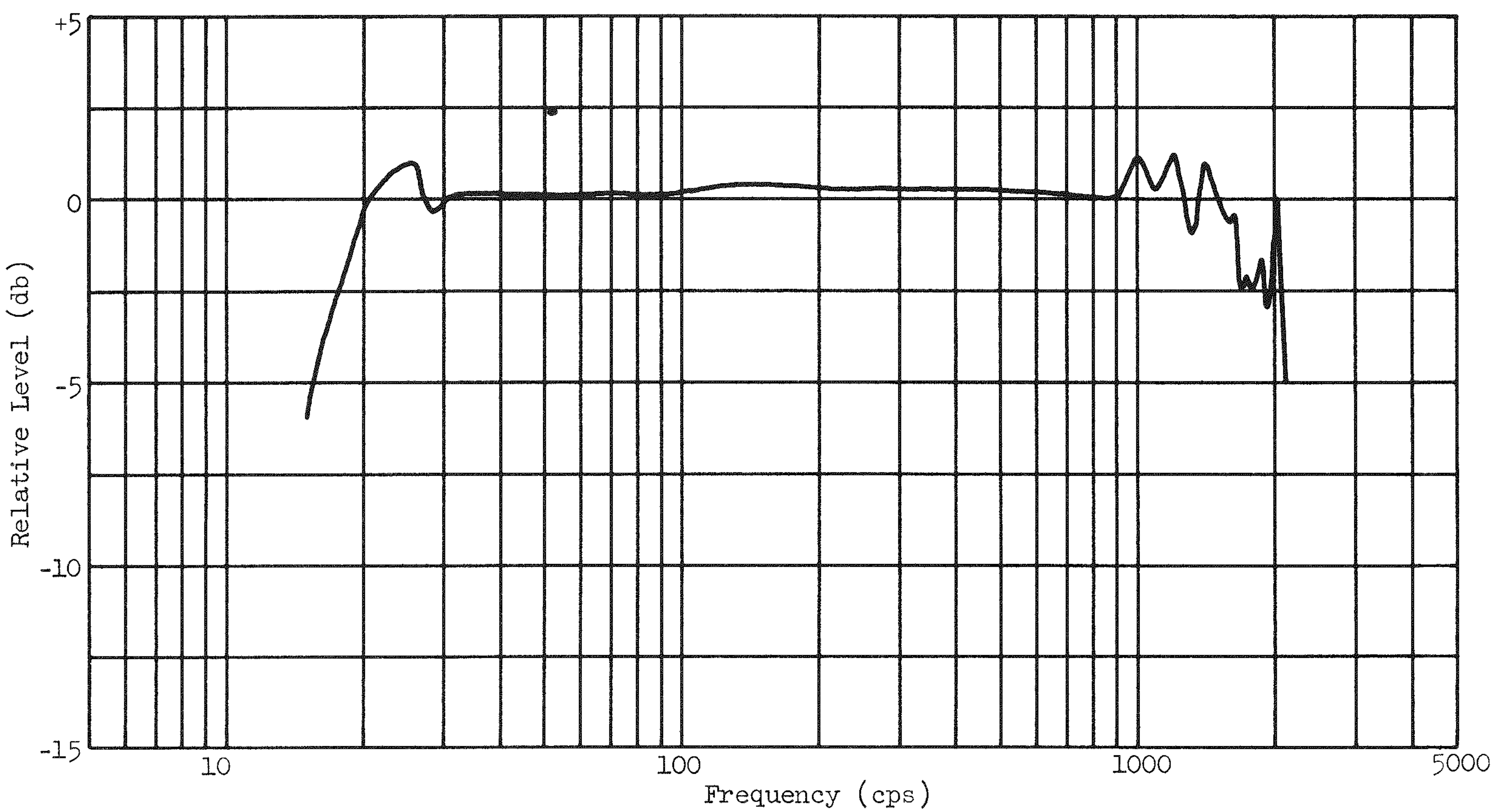


Fig. 9. Y Plane Final Equalization Curve--Model 177A Calidyne Vibrator

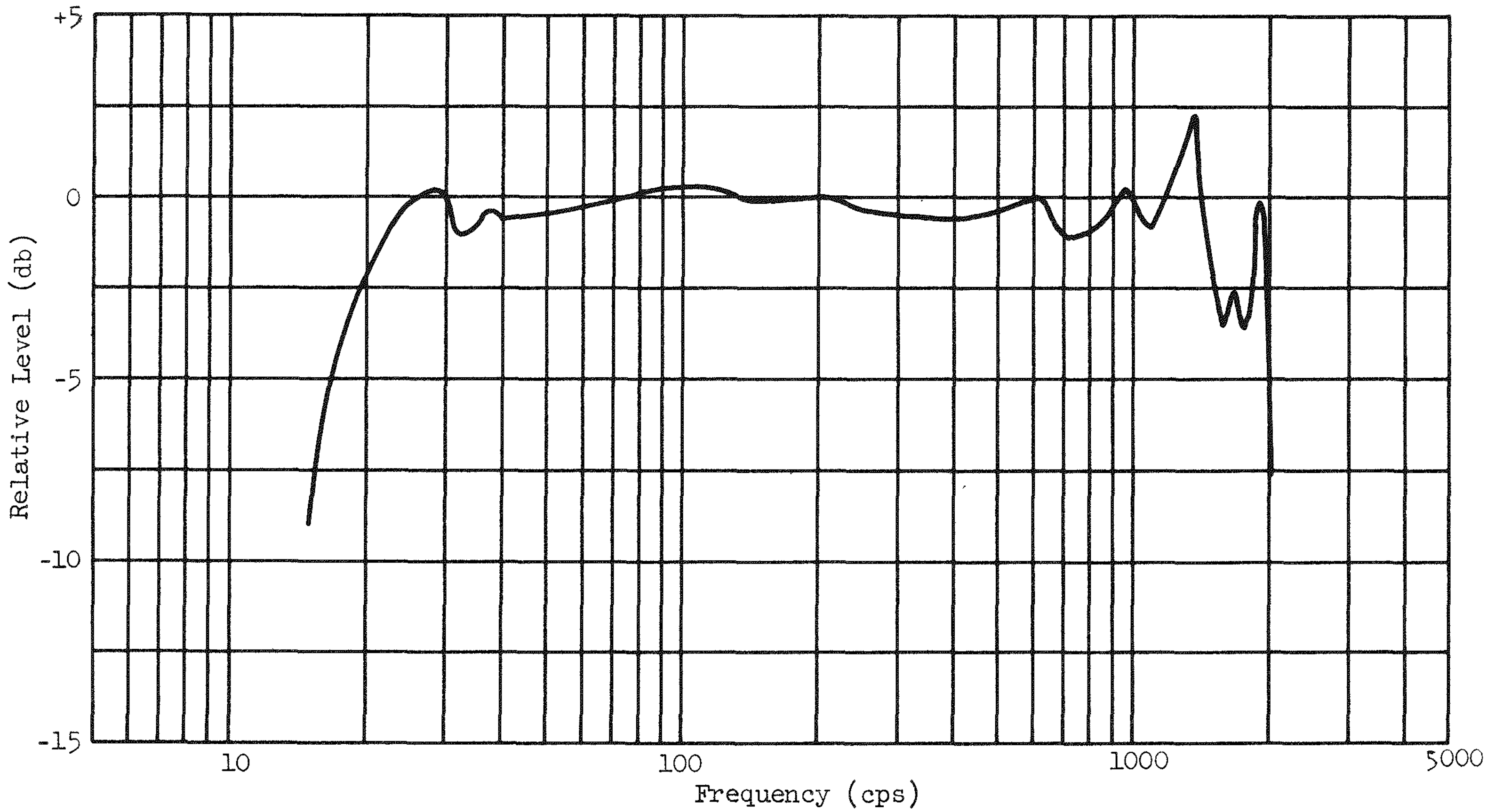


Fig. 10. X Plane Final Equalization Curve

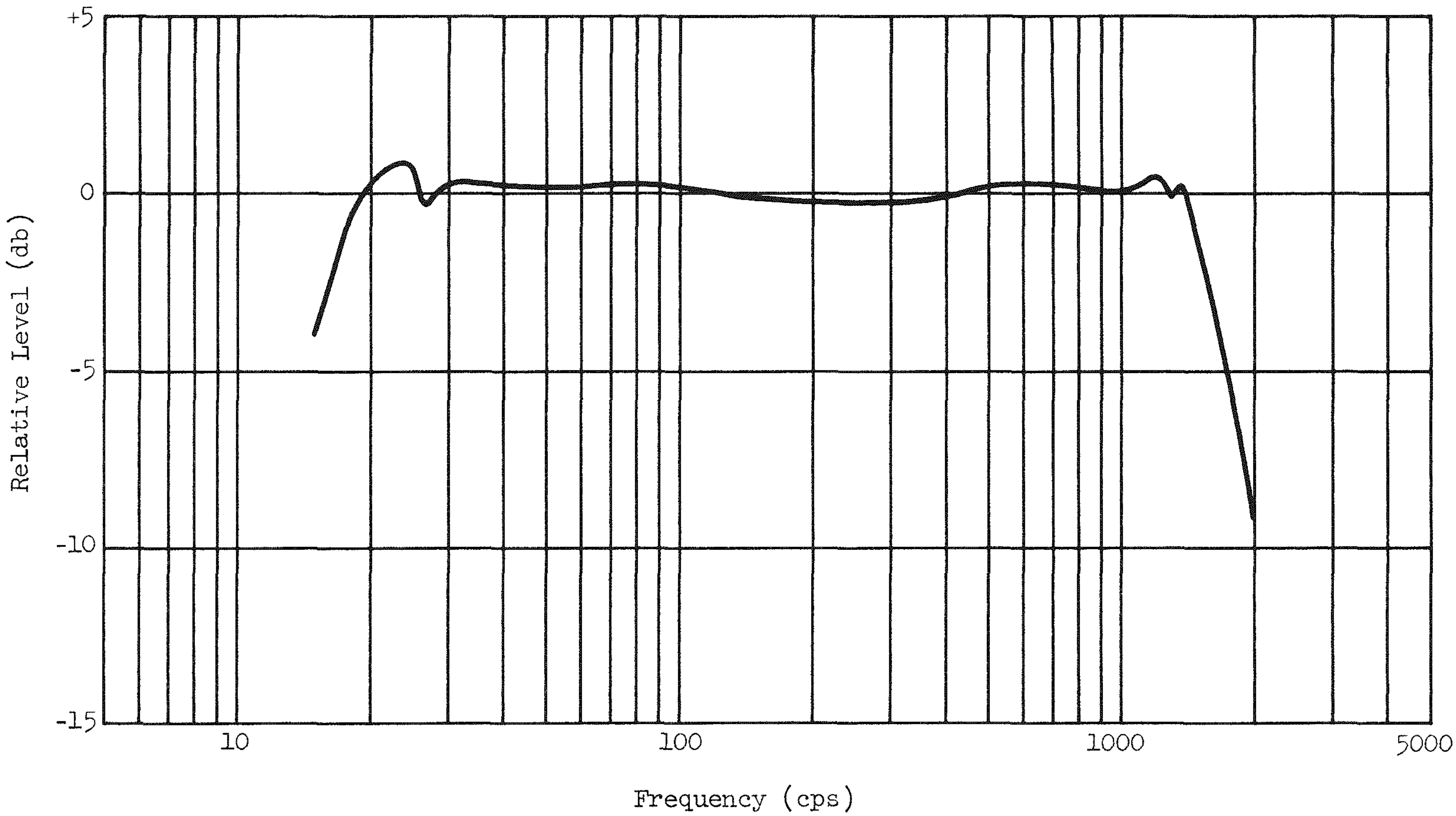


Fig. 11. Z Plane Final Equalization Curve

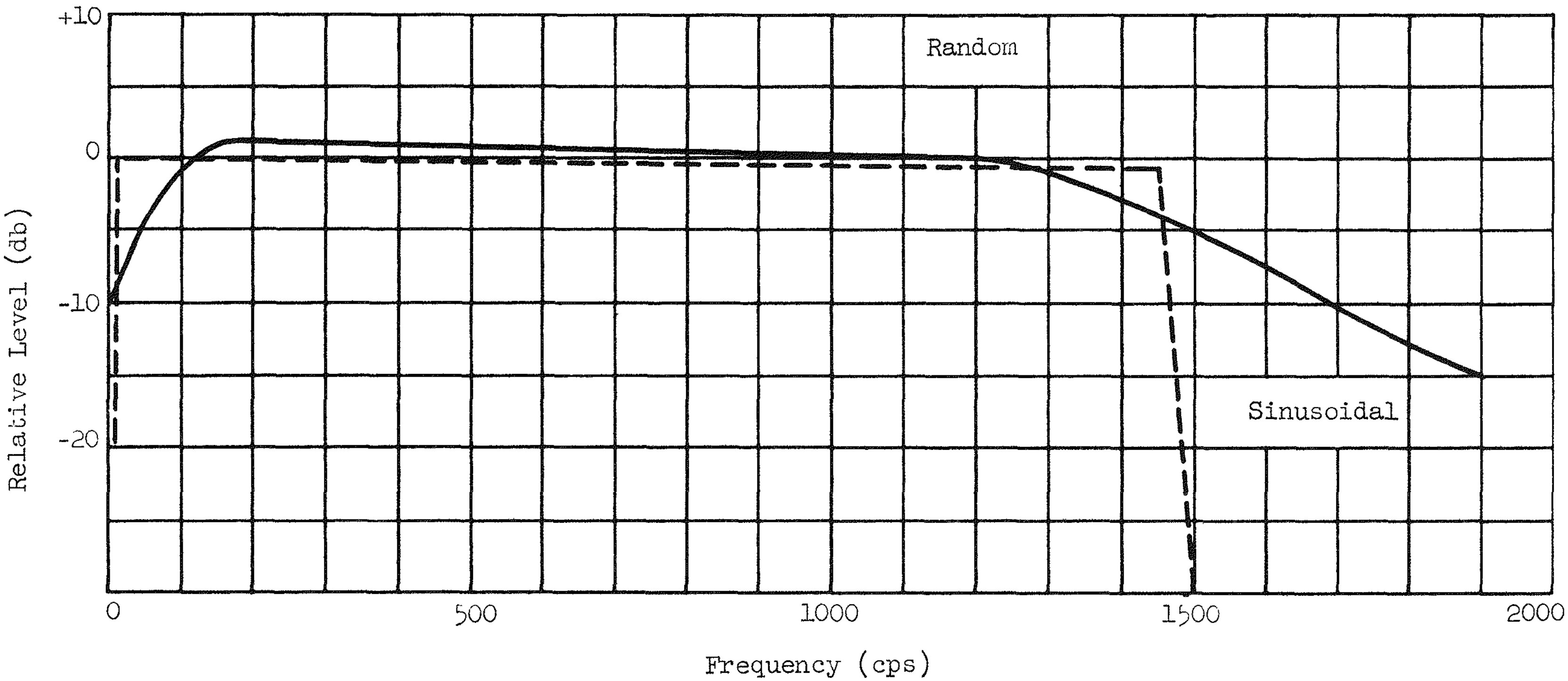


Fig. 12. Spectrum Analysis of the Programmed Vibration of SNAP-III Generator No. 164 from JPL-Furnished Tape

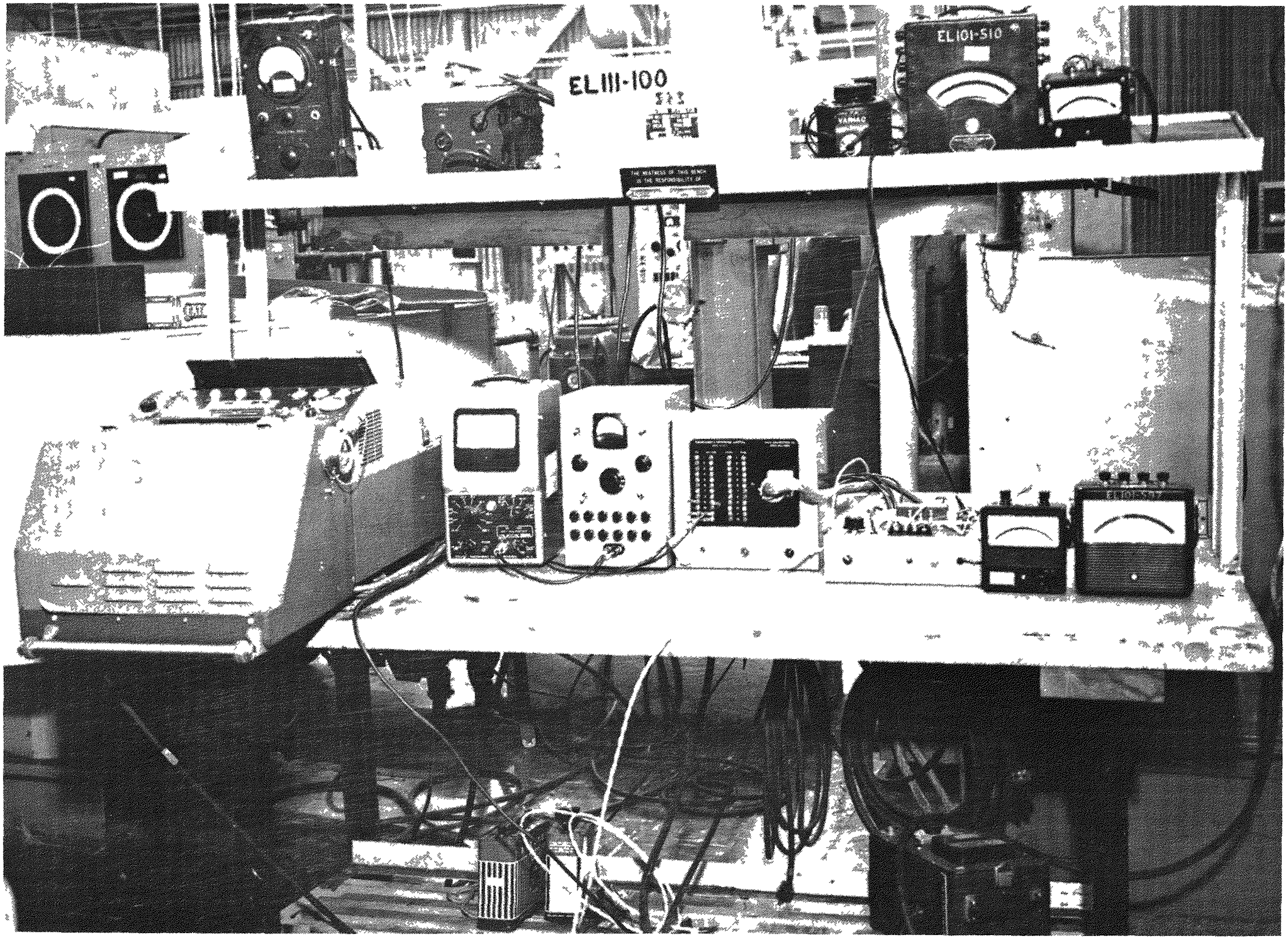


Fig. 13. Test Setup Instrumentation

Fig. 14. Ampex Model 307-2 Tape Playback Unit

TABLE 1

Summary of X Plane Vibration Data--SNAP-III Generator No. 1G4

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	(%)
Pretest	823	121.5	80.8	0.738	59.6	2.72	1.34	3.65	6.12
	823	121.5	80.8	0.741	59.9	2.72	1.35	3.67	6.13
	823	121.5	80.8	0.745	60.2	2.72	1.36	3.70	6.15
Test 1	823	120.5	80.8	0.741	59.9	2.70	1.36	3.67	6.13
	823	121.1	80.4	0.741	59.6	2.70	1.35	3.65	6.12
	823	121.5	80.8	0.741	59.9	2.70	1.35	3.65	6.09
	823	121.1	80.8	0.745	60.2	2.69	1.35	3.63	6.03
Post-test and Pretest	819	120.9	80.8	0.741	59.9	2.70	1.34	3.62	6.04
	819	120.7	80.8	0.741	59.9	2.70	1.34	3.62	6.04
	819	120.7	80.8	0.741	59.9	2.70	1.34	3.62	6.04
Test 2	814	120.3	80.8	0.749	60.5	2.70	1.34	3.62	5.98
	814	120.3	80.8	0.749	60.5	2.69	1.34	3.60	5.95
	814	120.3	80.8	0.749	60.5	2.69	1.34	3.60	5.95
	810	120.3	80.8	0.749	60.5	2.68	1.34	3.59	5.93
Post-test 7	805	119.9	81.2	0.749	60.8	2.69	1.34	3.60	5.94
	805	120.1	81.2	0.749	60.8	2.70	1.34	3.62	5.95
	805	120.1	81.2	0.749	60.8	2.70	1.34	3.62	5.95

TABLE 2

Summary of Z Plane Vibration Data--SNAP-III Generator No. 1G4

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	(%)
Pretest	814	117.5	80.4	0.734	59.0	2.69	1.34	3.60	6.10
	814	117.5	80.4	0.734	59.0	2.69	1.34	3.60	6.10
	819	117.5	80.4	0.734	59.0	2.69	1.34	3.60	6.10
Test 1	814	118.1	80.8	0.734	59.3	2.68	1.33	3.56	6.00
	814	117.9	80.8	0.734	59.3	2.68	1.33	3.56	6.00
	810	117.5	80.8	0.734	59.3	2.69	1.33	3.56	6.00
	810	117.7	80.8	0.734	59.3	2.69	1.33	3.52	5.94
Post-test and Pretest	795	117.9	80.8	0.738	59.6	2.67	1.32	3.52	5.91
	800	117.9	80.8	0.738	59.6	2.67	1.33	3.52	5.91
	805	118.1	80.8	0.734	59.3	2.69	1.33	3.58	6.04
Test 2	810	117.7	80.8	0.734	59.3	2.68	1.33	3.56	6.00
	810	117.7	80.8	0.734	59.3	2.68	1.33	3.56	6.00
	805	117.7	80.8	0.734	59.3	2.67	1.32	3.52	5.94
	800	117.9	80.8	0.734	59.3	2.67	1.32	3.52	5.94
Post-test	800	117.9	80.8	0.738	59.6	2.67	1.33	3.52	5.91
	800	117.7	80.8	0.738	59.3	2.67	1.33	3.52	5.94
	800	117.3	80.8	0.738	59.3	2.67	1.33	3.52	5.94

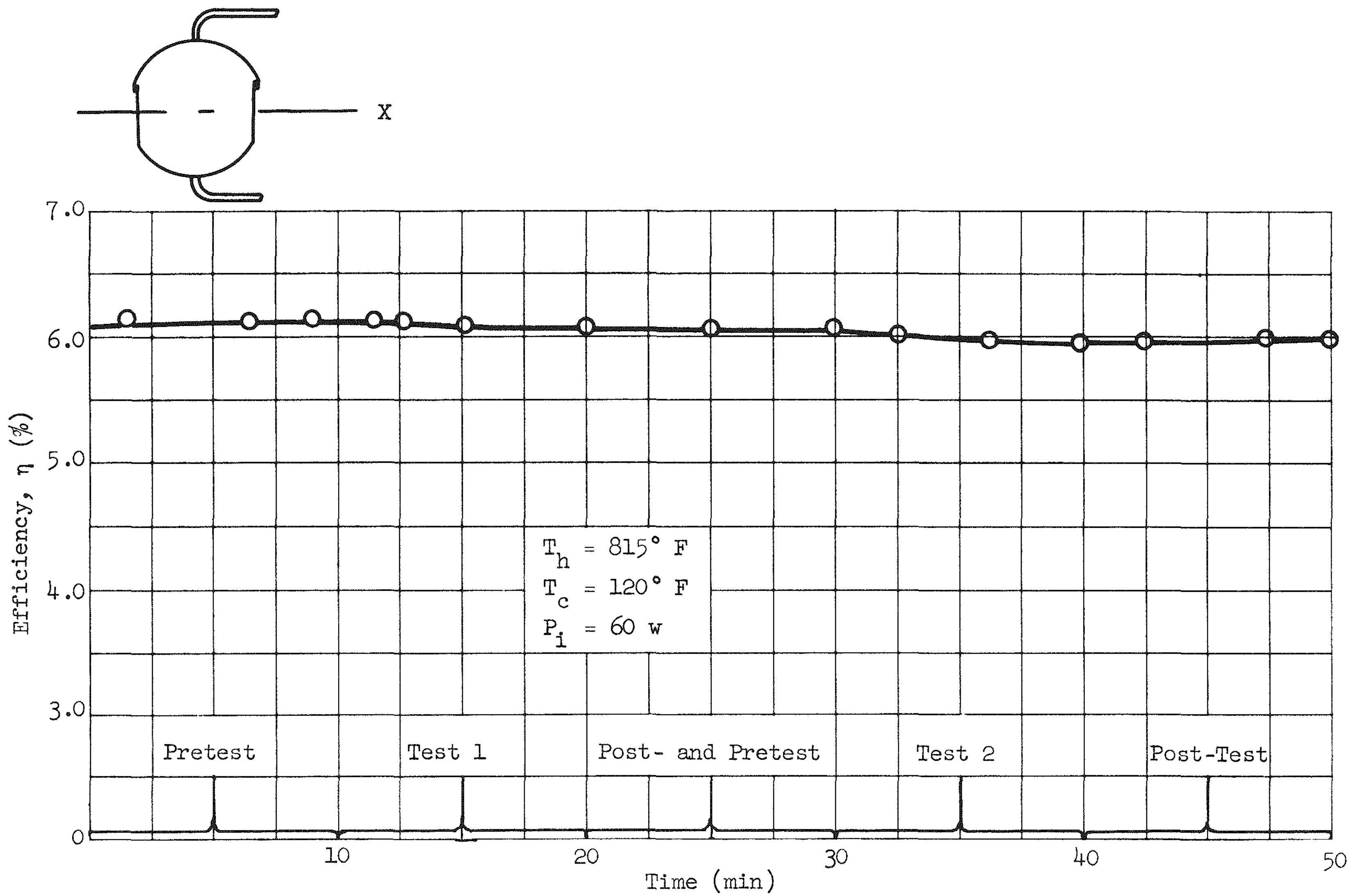


Fig. 15. Efficiency vs Time--X Plane Vibration Test

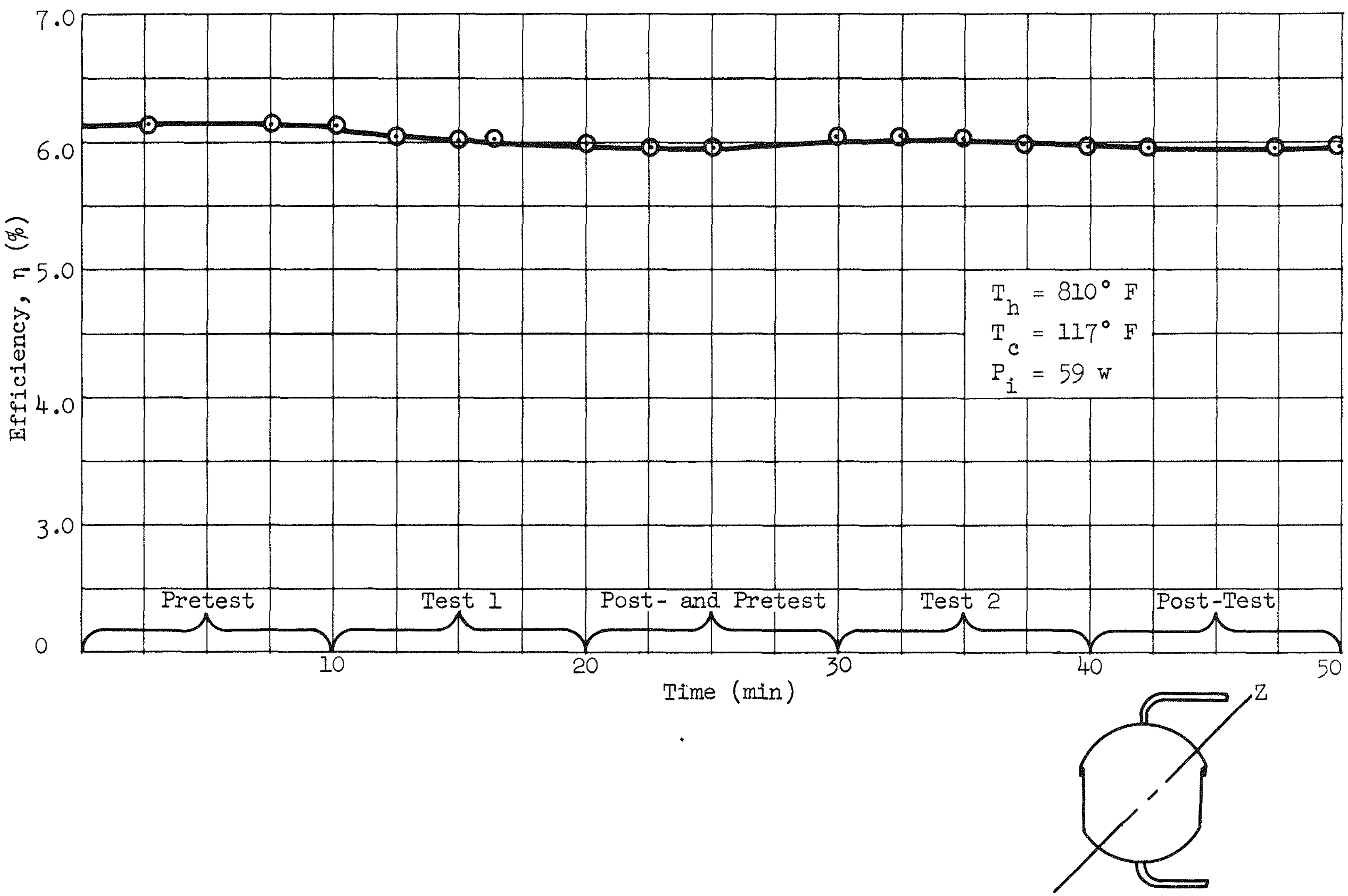


Fig. 16. Efficiency vs Time--Z Plane Vibration Test

TABLE 3

Summary of Y Plane Vibration Data--SNAP-III Generator No. 1G4

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	(%)
Pretest	800	121.9	81.2	0.756	61.4	2.70	1.34	3.62	5.90
	805	122.1	81.2	0.756	61.4	2.70	1.34	3.62	5.90
	805	122.1	81.2	0.756	61.4	2.70	1.34	3.62	5.90
Test 1	800	121.9	81.2	0.756	61.4	2.70	1.34	3.62	5.90
	800	121.9	81.2	0.756	61.4	2.64	1.31	3.46	5.64
	800	121.9	81.2	0.756	61.7	2.64	1.32	3.49	5.66
	800	121.9	80.8	0.734	59.3	2.62	1.27	3.33	5.61
Post-test and Pretest	800	122.3	80.8	0.756	61.1	2.64	1.32	3.49	5.71
	796	121.9	80.4	0.752	60.5	2.64	1.33	3.51	5.80
	792	121.9	81.2	0.756	61.4	2.70	1.34	3.62	5.90
Test 2	814	118.1	80.4	0.734	59.0	2.64	1.29	3.41	5.78
	814	117.9	82.0	0.734	59.0	2.61	1.27	3.32	5.63
	810	117.7	80.4	0.734	59.0	2.61	1.27	3.32	5.63
	805	118.1	80.8	0.734	59.3	2.64	1.26	3.33	5.61
Post-test	810	117.9	80.4	0.734	59.0	2.63	1.29	3.39	5.75
	814	117.9	80.8	0.734	59.3	2.64	1.30	3.43	5.78
	800	117.9	80.3	0.734	58.9	2.64	1.31	3.46	5.87

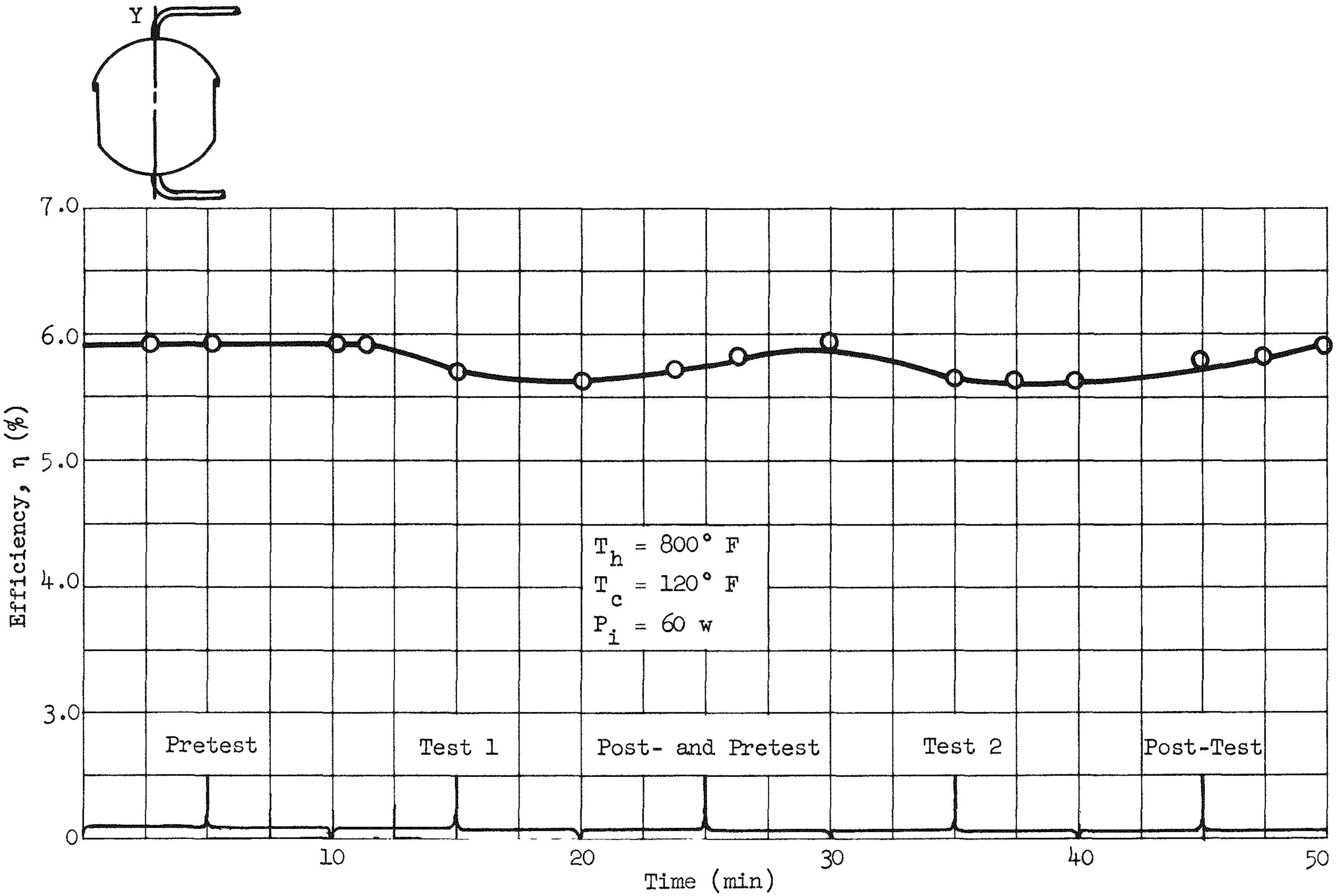


Fig. 17. Efficiency vs Time--Y Plane Vibration Test

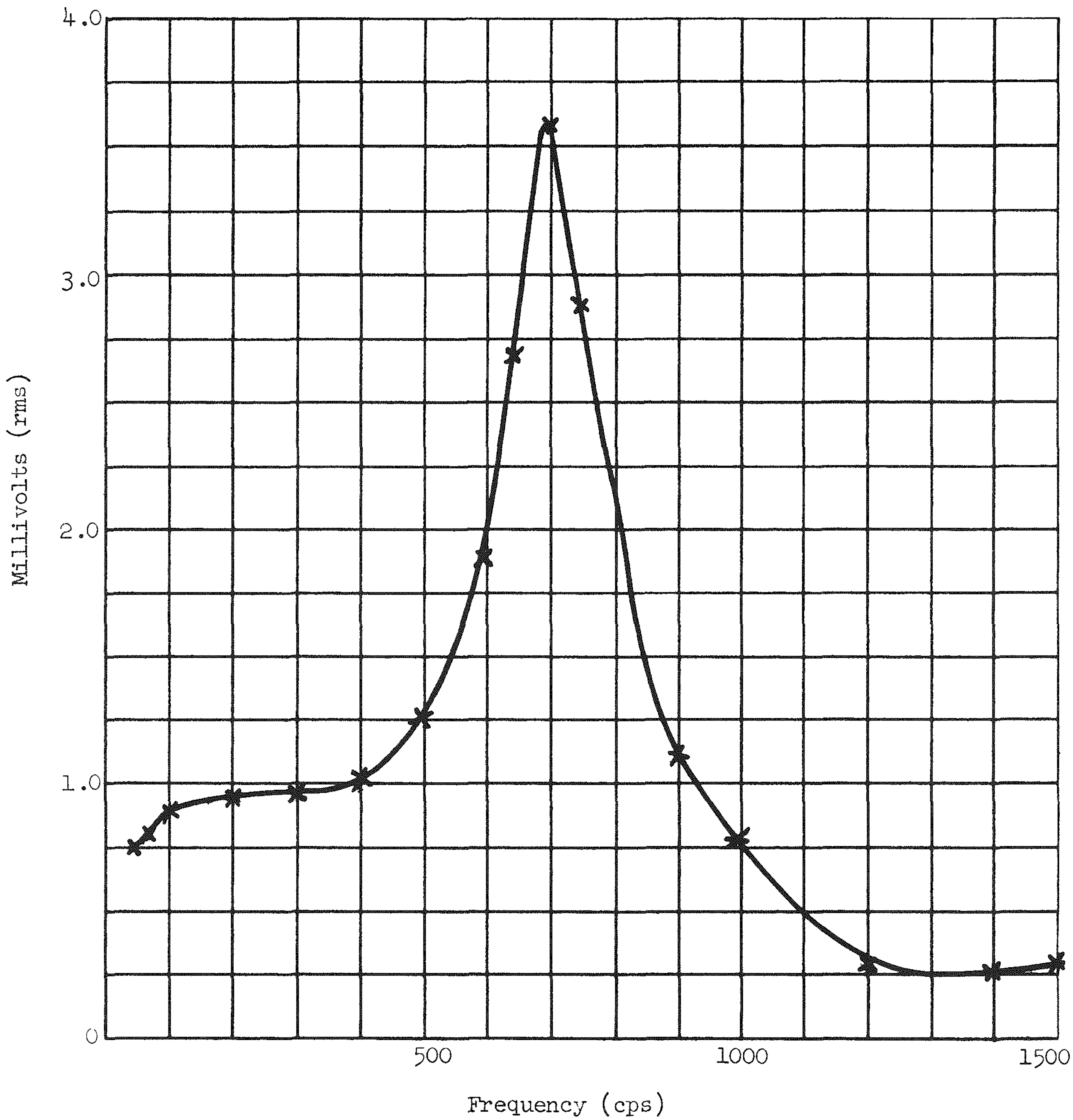


Fig. 18. Y Plane Response Curve--ΔDC

IV. ACCELERATION TEST

The specifications for acceleration test called for a 15 g static acceleration for five minutes in each of the three principal orthogonal planes. A Genisco Accelerator with a maximum weight allowance of one hundred pounds and force of 75 g was used for the test. The centrifuge is shown in Figs. 19 and 20.

The tests were conducted in the steps shown in the chart below. This procedure was followed in all three orthogonal planes.

Step Number	1	2	3	4	5	6	7
Time (min)	10	2	2	5	2	2	10
Level (g)	0	5	10	15	10	5	0
RPM	0	75	105	125	105	75	0

Oscillograph records were taken before, during and after each test to show that stability had been maintained.

The results show the generator to be stable in operation and efficiency under the conditions specified for the tests. The external resistance load, used to match the generator load, was increased due to the power consuming slip ring instrumentation within the centrifuge. This explains the lower pretest efficiencies.

Various stabilized pretest efficiencies were monitored. These remained constant with no change during the entire acceleration test, as shown in Tables 4, 5 and 6, and Figs. 21, 22 and 23.

The generator output did not oscillate during the acceleration phases.

Fig. 19. Genisco Centrifuge and Control Panel

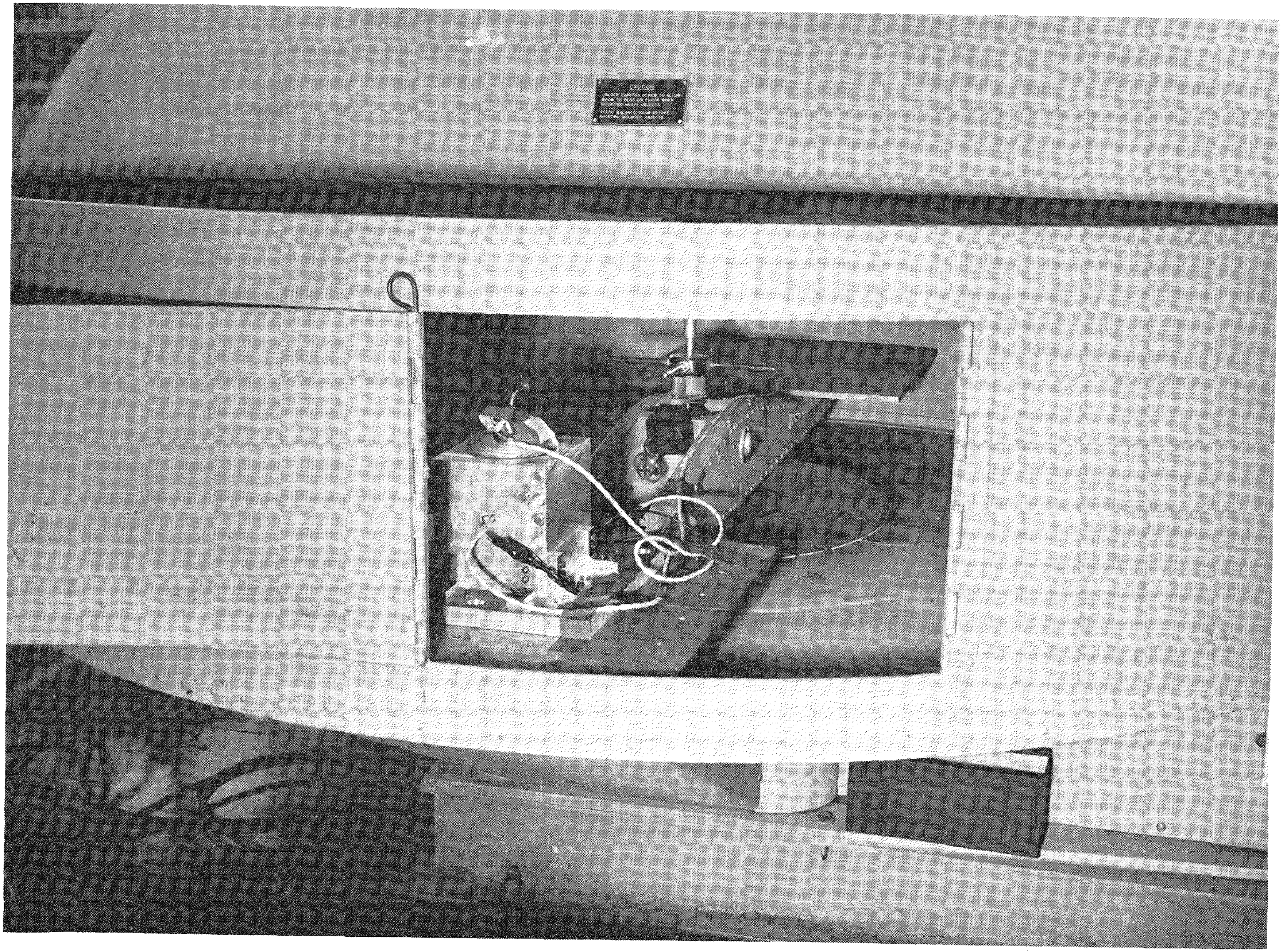


Fig. 20. Test Specimen Mounted in Centrifuge

TABLE 4

Summary of Y Plane Acceleration Test Data--SNAP-III Generator No. 1G4

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	(%)
Pretest	820	124.0	84	0.709	59.5	2.21	1.27	2.81	4.73
	826	124.0	84	0.709	59.5	2.26	1.30	2.94	4.94
	820	124.5	84	0.709	59.5	2.21	1.27	2.81	4.73
5 g	826	124.0	84	0.709	59.5	2.26	1.30	2.94	4.94
	826	124.5	84	0.709	59.5	2.26	1.30	2.88	4.84
10 g	826	124.0	84	0.709	59.5	2.26	1.30	2.94	4.94
	826	124.5	84	0.709	59.5	2.26	1.30	2.94	4.94
*15 g	826	124.0	84	0.709	59.5	2.26	1.30	2.94	4.94
	826	123.5	84	0.709	59.5	2.26	1.30	2.94	4.94
	826	123.0	84	0.709	59.5	2.26	1.30	2.94	4.94
10 g	826	122.5	84	0.714	59.9	2.26	1.30	2.94	4.90
	826	122.0	84	0.714	59.9	2.26	1.30	2.94	4.90
5 g	826	122.0	84	0.714	59.9	2.26	1.30	2.94	4.90
	826	122.0	84	0.714	59.9	2.26	1.30	2.94	4.90
Post-test	826	122.0	84	0.714	59.9	2.26	1.30	2.94	4.90
	826	121.8	84	0.714	59.9	2.26	1.27	2.88	4.80
	826	121.0	84	0.714	59.9	2.26	1.30	2.94	4.90

* In Accordance With the Jet Propulsion Laboratory Specification

TABLE 5

Summary of X Plane Acceleration Test Data--SNAP-III Generator No. 1G4

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	(%)
Pretest	913	121.0	84	0.744	62.5	2.35	1.46	3.45	5.52
	907	121.0	84	0.744	62.5	2.30	1.43	3.28	5.26
	907	121.0	84	0.735	61.7	2.30	1.43	3.28	5.33
5 g	907	121.0	84	0.744	62.5	2.30	1.43	3.28	5.26
	913	121.0	84	0.744	62.5	2.32	1.43	3.32	5.32
10 g	913	122.0	84	0.744	62.5	2.32	1.43	3.32	5.32
	913	122.0	84	0.744	62.5	2.32	1.43	3.32	5.32
*15 g	913	122.0	84	0.744	62.5	2.30	1.43	3.28	5.26
	913	121.0	84	0.744	62.5	2.32	1.43	3.33	5.33
	907	121.0	84	0.744	62.5	2.30	1.43	3.28	5.26
10 g	907	120.0	84	0.744	62.5	2.30	1.43	3.28	5.26
	907	120.0	84	0.744	62.5	2.30	1.43	3.28	5.26
5 g	907	120.0	84	0.744	62.5	2.30	1.43	3.28	5.26
	907	119.0	84	0.744	62.5	2.30	1.43	3.28	5.26
Post-test	907	120.0	84	0.744	62.5	2.27	1.43	3.25	5.20
	907	119.0	84	0.744	62.5	2.30	1.43	3.28	5.26
	907	119.0	84	0.744	62.5	2.30	1.43	3.28	5.26

* In Accordance With the Jet Propulsion Laboratory Specification

TABLE 6

Summary of Z Plane Acceleration Test Data--SNAP-III Generator No. 1G4

	Temperature (°F) Hot Junction	Cold Junction	Input Volts	Amps	Watts	Output Volts	Amps	Watts	Efficiency (%)
Pretest	907	115.8	84	0.743	62.4	2.35	1.43	3.37	5.4
	900	116.0	84	0.743	62.4	2.35	1.43	3.37	5.4
	900	116.0	84	0.743	62.8	2.35	1.43	3.37	5.4
5 g	913	116.0	84	0.737	61.9	2.35	1.46	3.44	5.5
	907	116.0	84	0.737	61.9	2.35	1.46	3.44	5.5
10 g	913	117.8	84	0.737	61.9	2.35	1.43	3.37	5.4
	913	117.8	84	0.743	62.4	2.35	1.43	3.37	5.4
*15 g	920	117.8	84	0.743	62.4	2.35	1.43	3.37	5.4
	920	117.8	84	0.743	62.4	2.35	1.43	3.37	5.4
	920	117.8	84	0.743	62.4	2.35	1.43	3.37	5.4
10 g	913	117.8	84	0.743	62.4	2.35	1.43	3.37	5.4
	913	117.5	84	0.743	62.4	2.35	1.43	3.37	5.4
5 g	913	117.0	84	0.743	62.4	2.35	1.43	3.37	5.4
	913	116.8	84	0.743	61.9	2.35	1.43	3.37	5.4
Post-test	913	116.8	84	0.733	61.9	2.35	1.43	3.37	5.5
	913	116.3	84	0.737	61.9	2.35	1.43	3.37	5.4
	907	116.3	84	0.733	61.9	2.35	1.43	3.37	5.5

* In Accordance With the Jet Propulsion Laboratory Specification

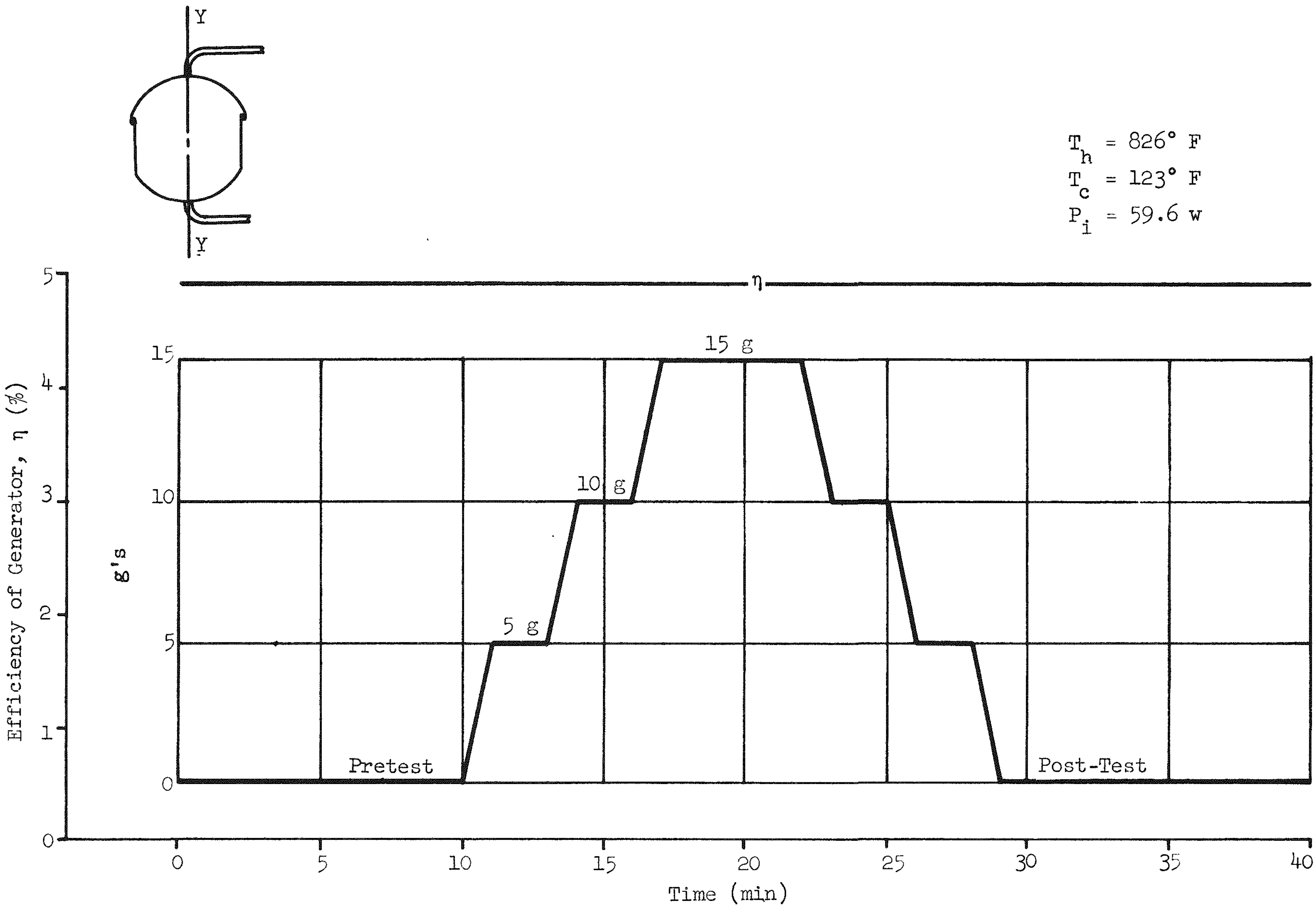


Fig. 21. Efficiency vs Time--Y Plane Acceleration Test

MND-P-2101

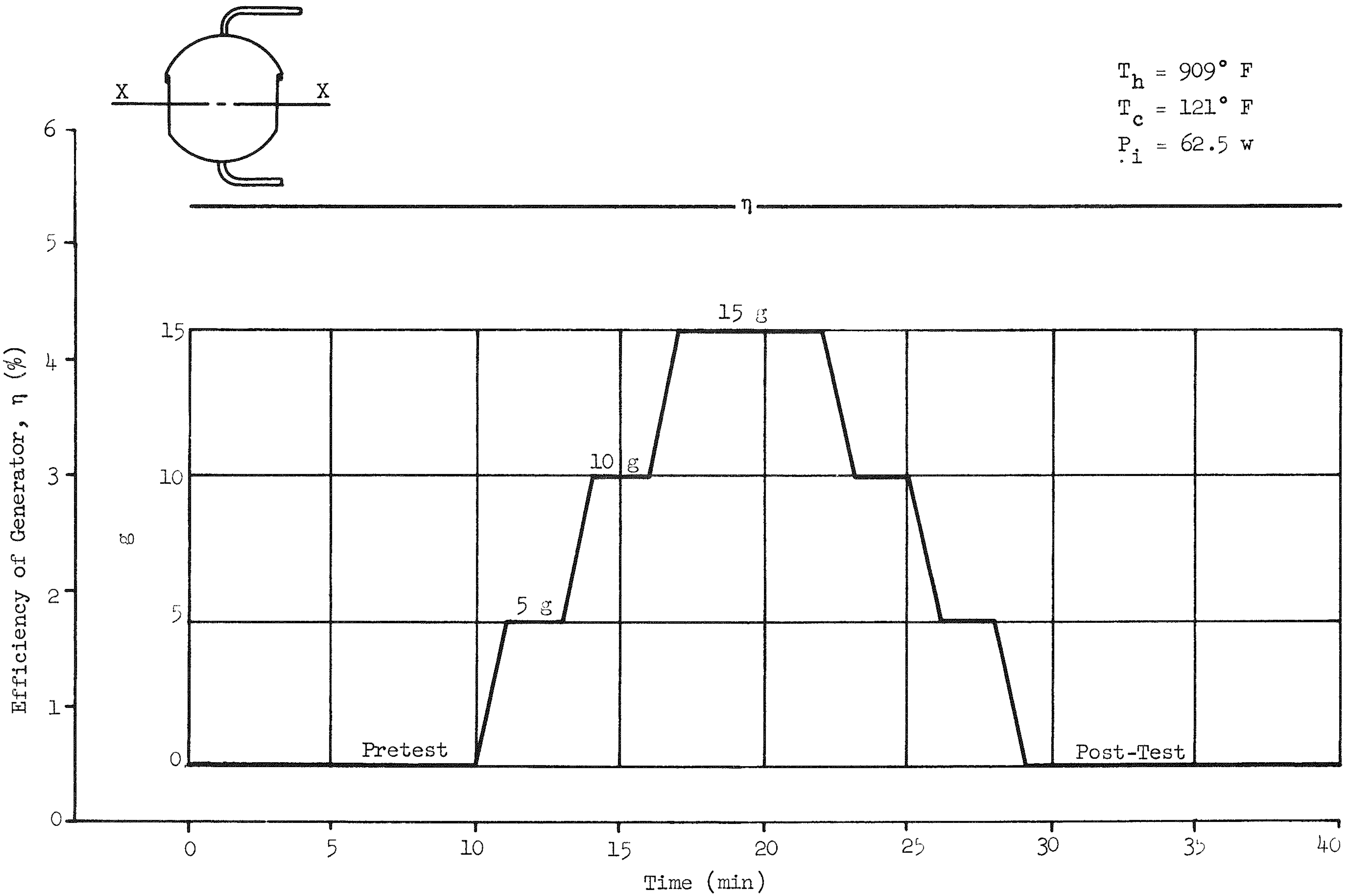


Fig. 22. Efficiency vs Time--X Plane Acceleration Test

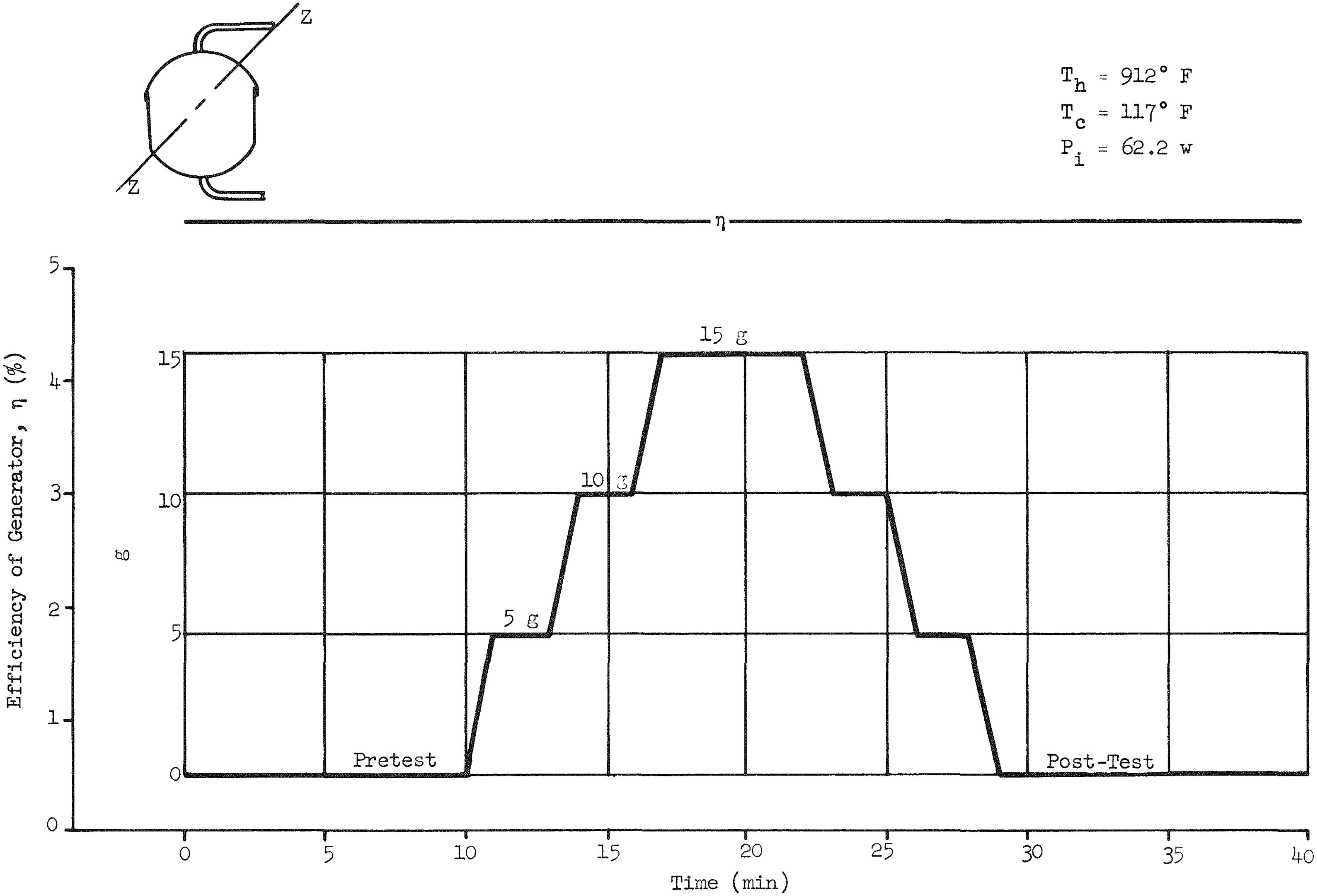


Fig. 23. Efficiency vs Time--Z Plane Acceleration Test

V. SHOCK TEST

The specifications for shock testing the SNAP-III generator called for four shocks in each of the three principal orthogonal planes, with an input force of 50 g and a one ms rise time.

The high impact shock machine (Figs. 24, 25 and 26) used in the test was modified to attain the required rise time and g level. Four of the eight mounting springs on which the impact plate rested were removed. The remaining springs were compressed until the 50 g--one ms rise time requirement was fulfilled. In subsequent trials the shock pulse proved to be reproducible as shown by the recorded pulses of the impact plate.

The SNAP-III generator with its test fixture and mounting plate was bolted to the impact plate of the shock machine. This is shown in Fig. 26. Two Endevco accelerometers (Model No. 2212) were mounted on the fixture located so that the input accelerations and the response accelerations of the generator could be monitored.

Oscillograph records were taken before, during and after each test, to show any deviation in generator efficiency caused by the environmental input to the generator.

Figures 27, 28 and 29 show the output from an accelerometer mounted on the outer shell of the generator. A typical input pulse is shown for each plane. One lead of the heating element simulating the radio isotope failed after the third shock in the y plane, the first plane tested. Figure 30 shows the damaged heater. The heater was replaced and the tests were completed. Efficiency was recovered immediately in all three planes after heater replacement.

Oscillating DC signals similar to the ones noted during the vibration tests were recorded. The records show a peak rms value of 2.7 mv in the x and z planes, and a peak rms level of 5 mv in the y plane, superimposed on the 2.80 VDC generator output. However, the ΔDC disappeared after each shock pulse.

Generator efficiency during the shock tests is shown in Figs. 31, 32 and 33. Tables 7, 8 and 9 summarize generator performance. In the y plane, for the first two shocks, recovery took approximately 6 min. This was due to a shock input of greater than 50 g.

A mocked-up SNAP-III aluminum shell was also shock tested to determine a safe load that may be impacted against a generator shell for ejection at missile launch abort. The generator internals were simulated by filling the shell with sand. Numerous shocks up to 400 g were applied with no damage to the specimen. The dummy shell was constructed of 1100-S aluminum, whose yield point should be compared with actual generator shell materials for structural integrity.

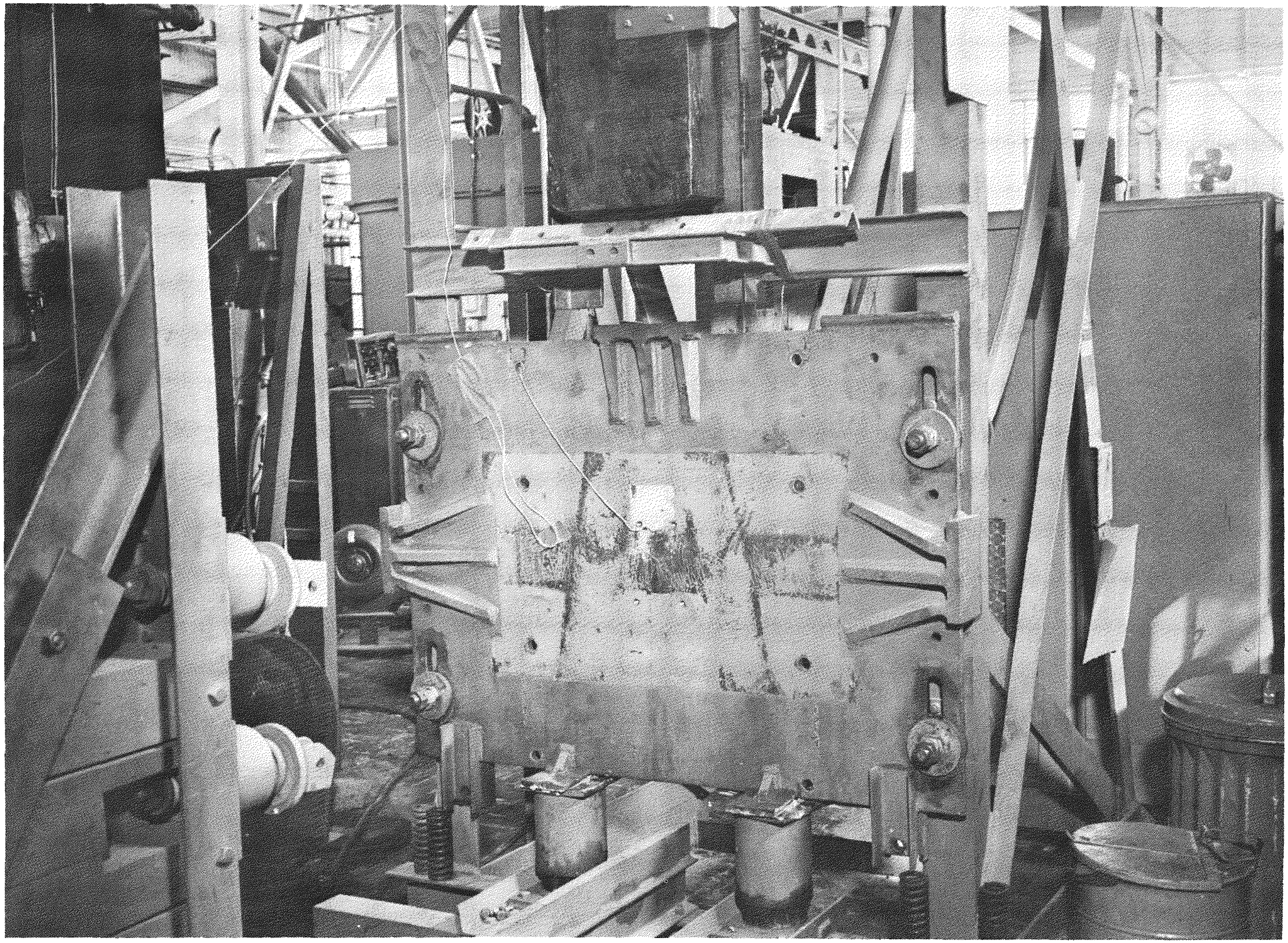


Fig. 24. Shock Tester in Calibrated Position

Fig. 25. Automatic Shock Input Hammer

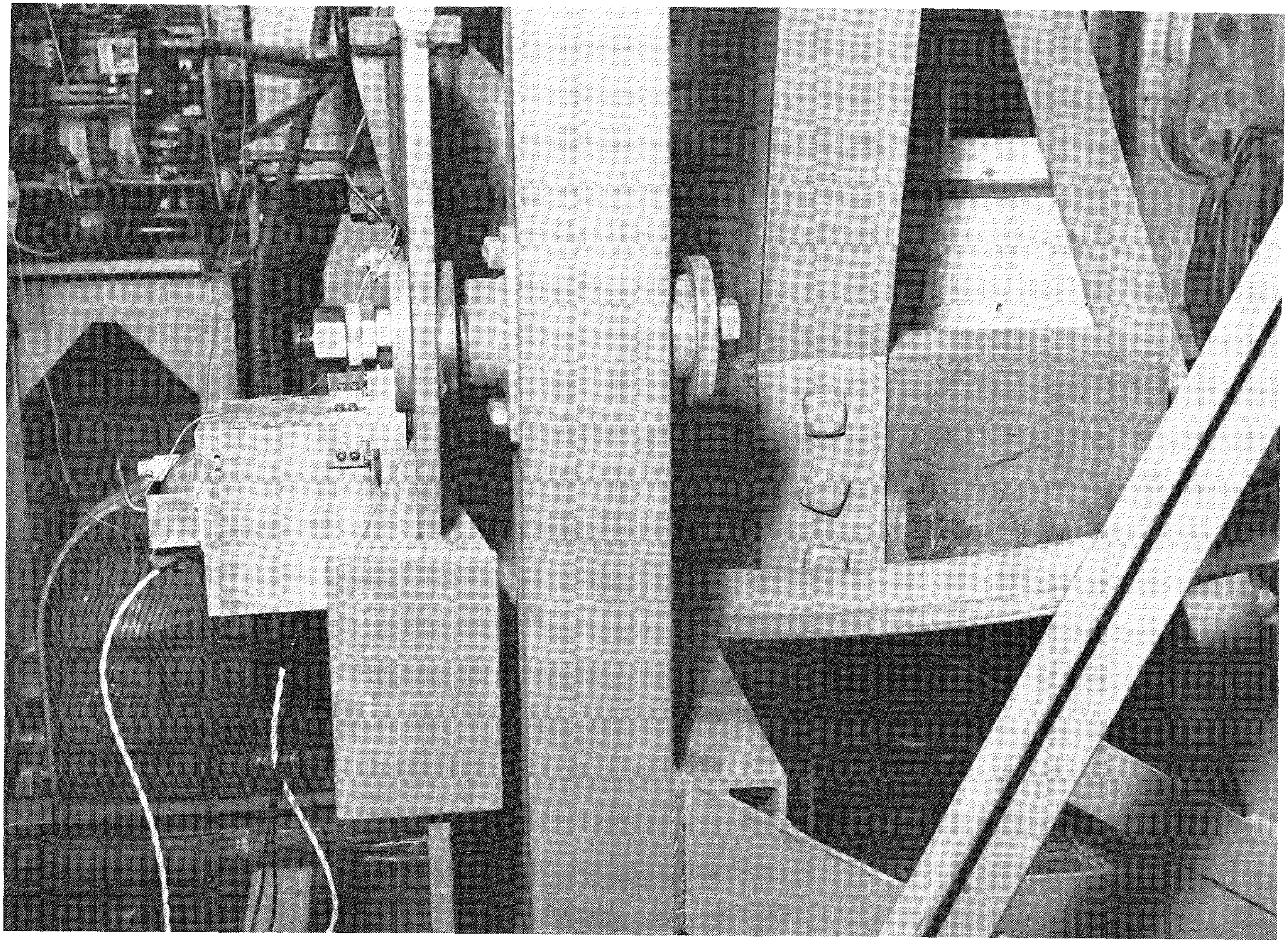


Fig. 26. Test Specimen Mounted on Shock-Test Rig

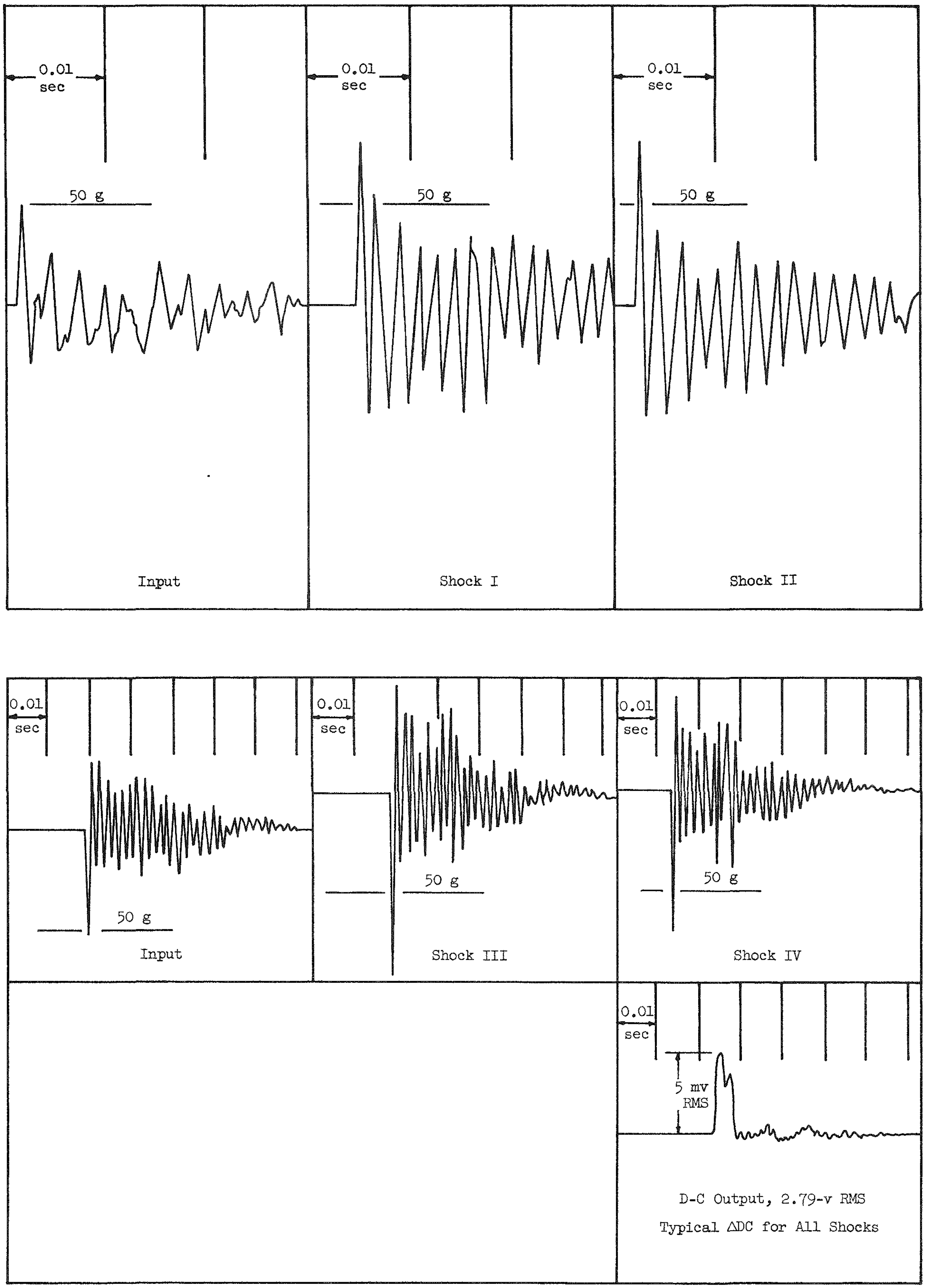


Fig. 27. Y Plane Shock Test

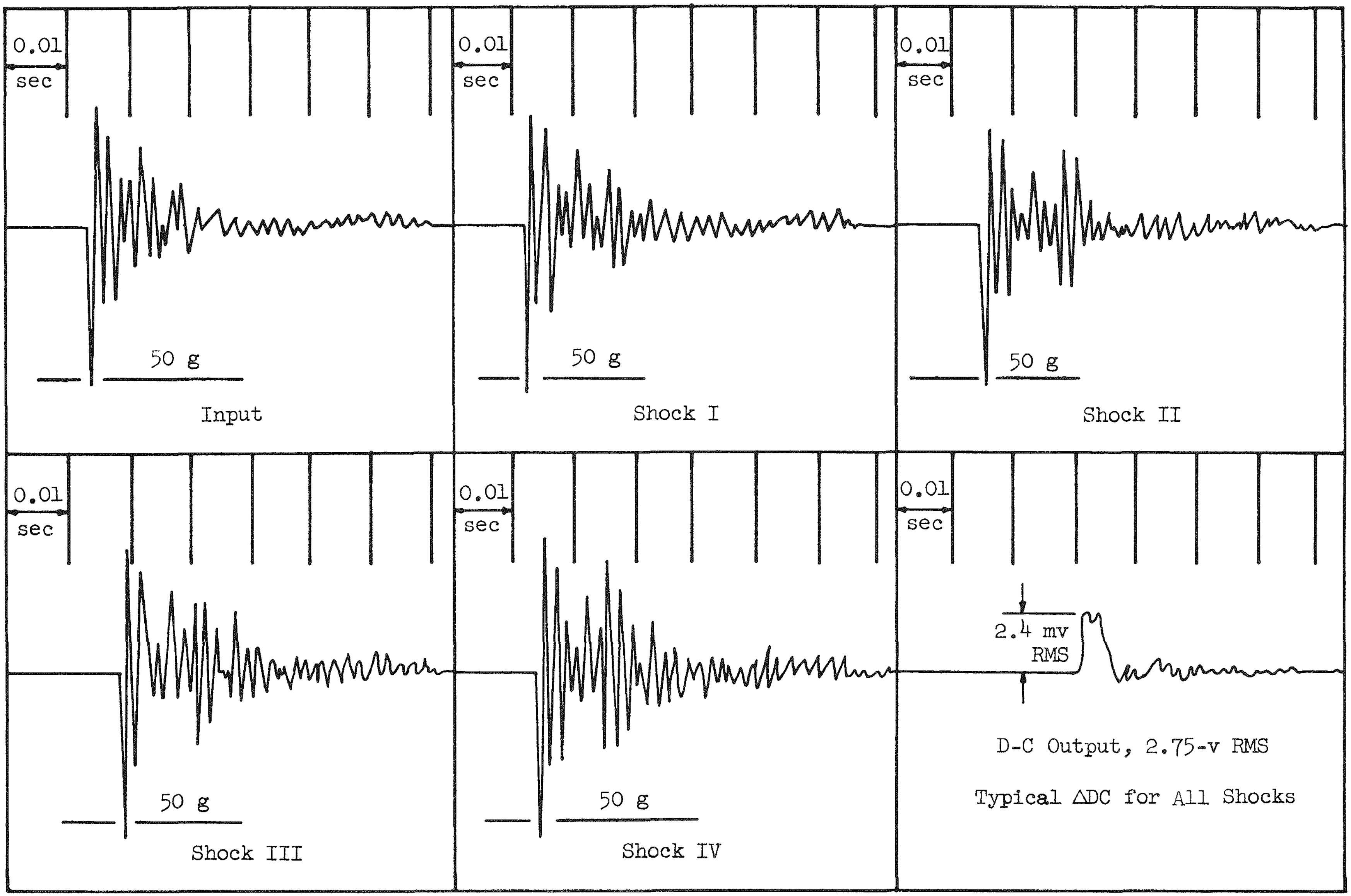


Fig. 28. X Plane Shock Test

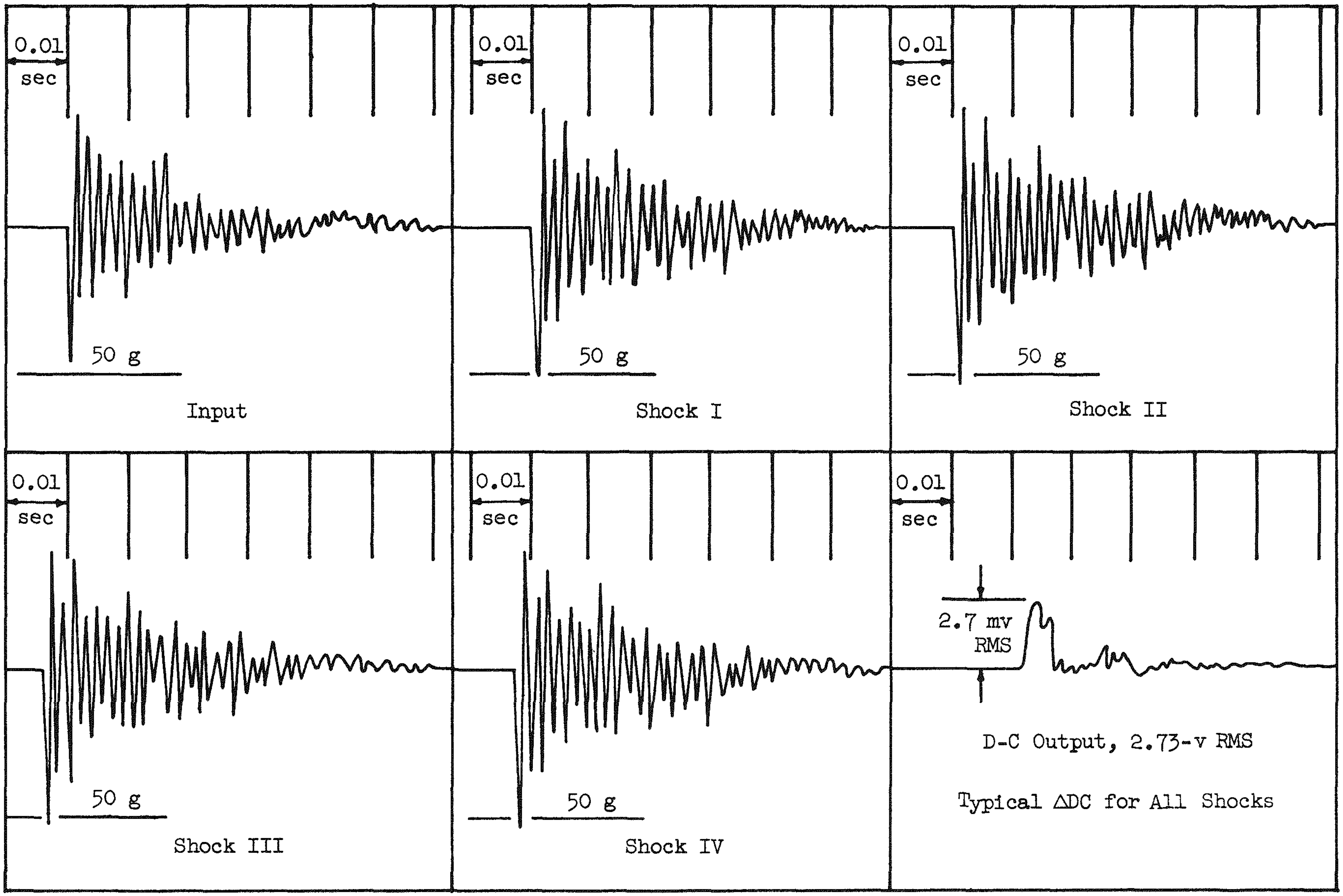


Fig. 29. Z Plane Shock Test

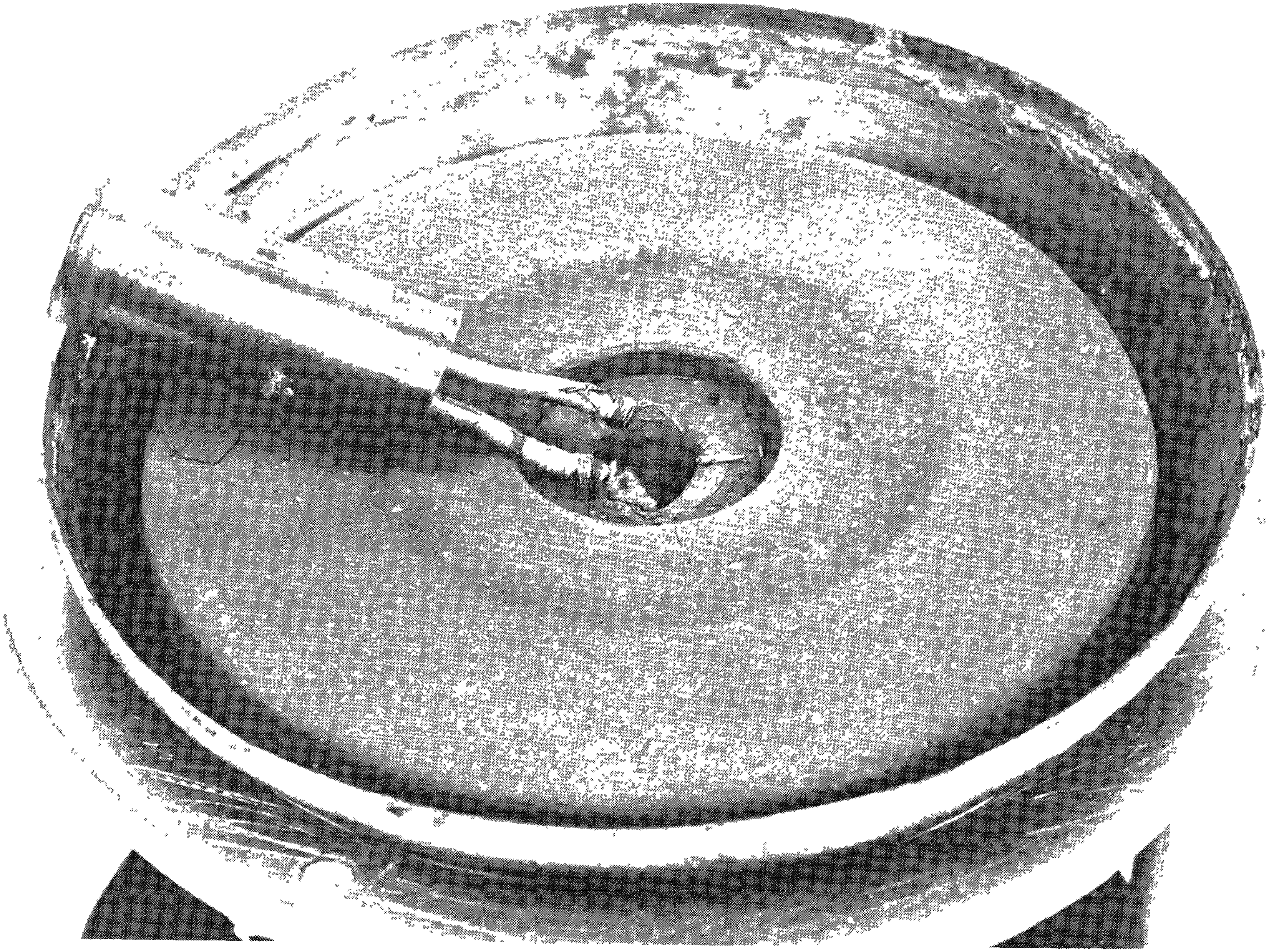


Fig. 30. Separation of Heater Lead

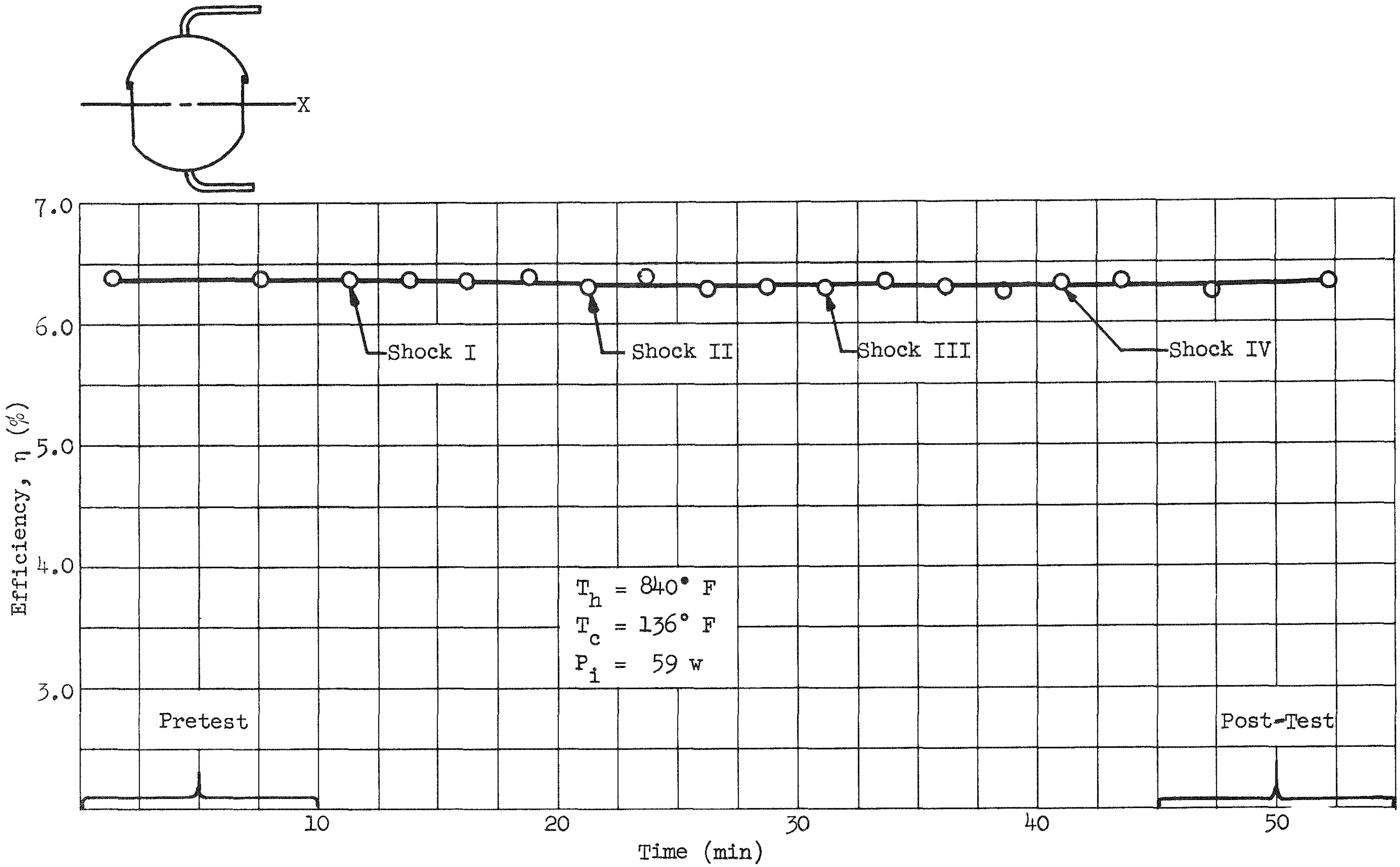


Fig. 31. Efficiency vs Time--X Plane Shock Test

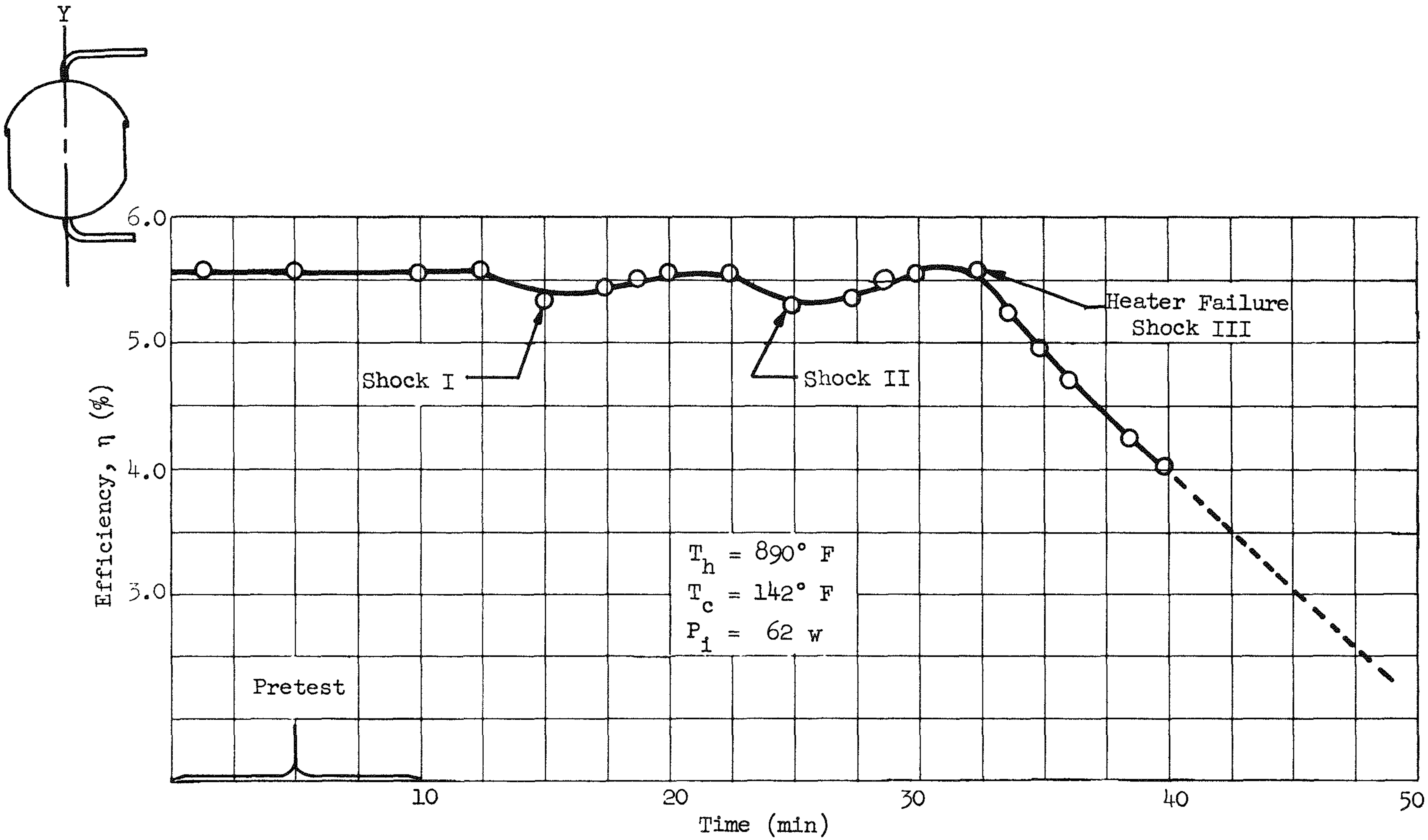


Fig. 32. Efficiency vs Time--Y Plane Shock Test

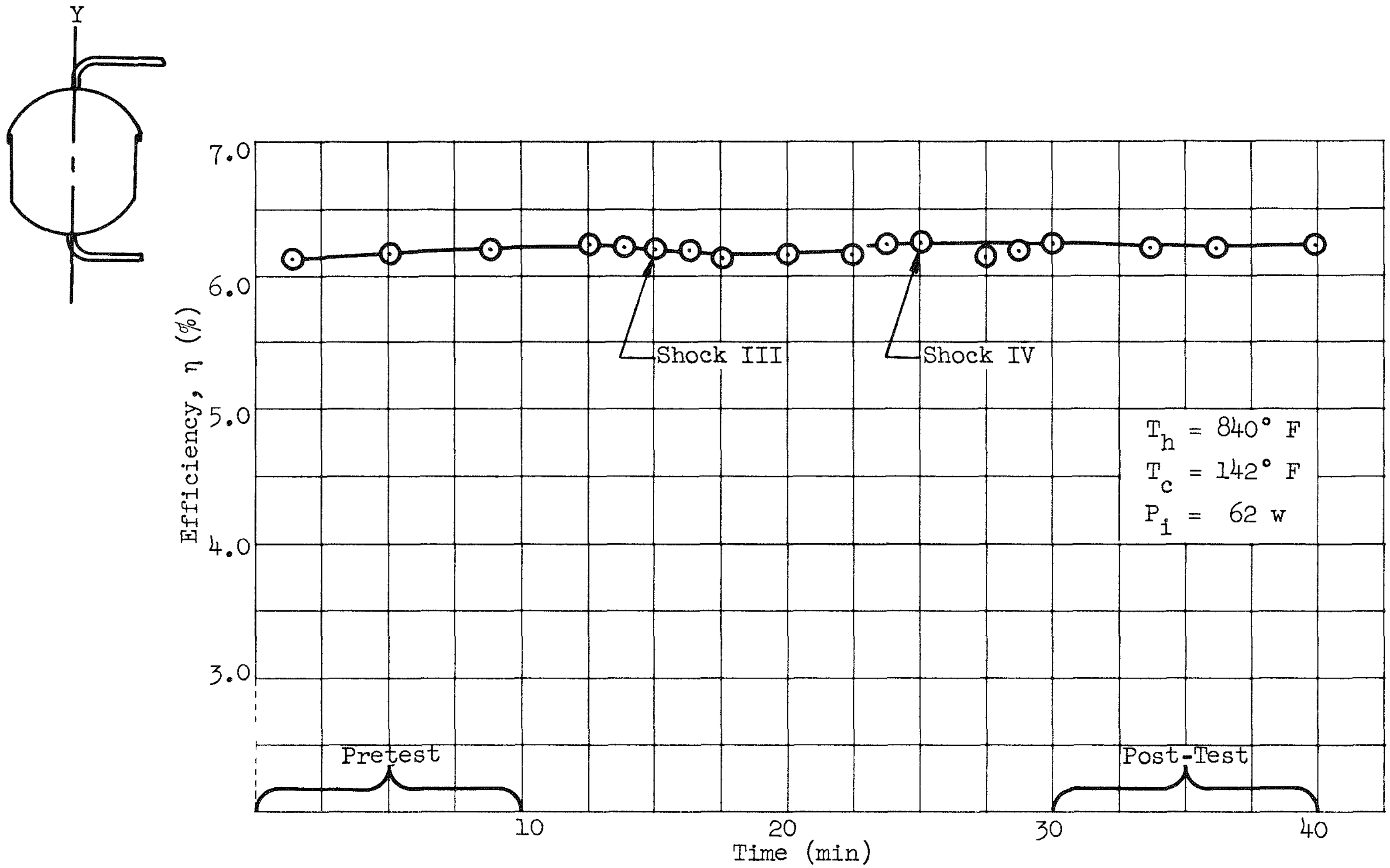


Fig. 32. Efficiency vs Time--Y Plane Shock Test (continued)

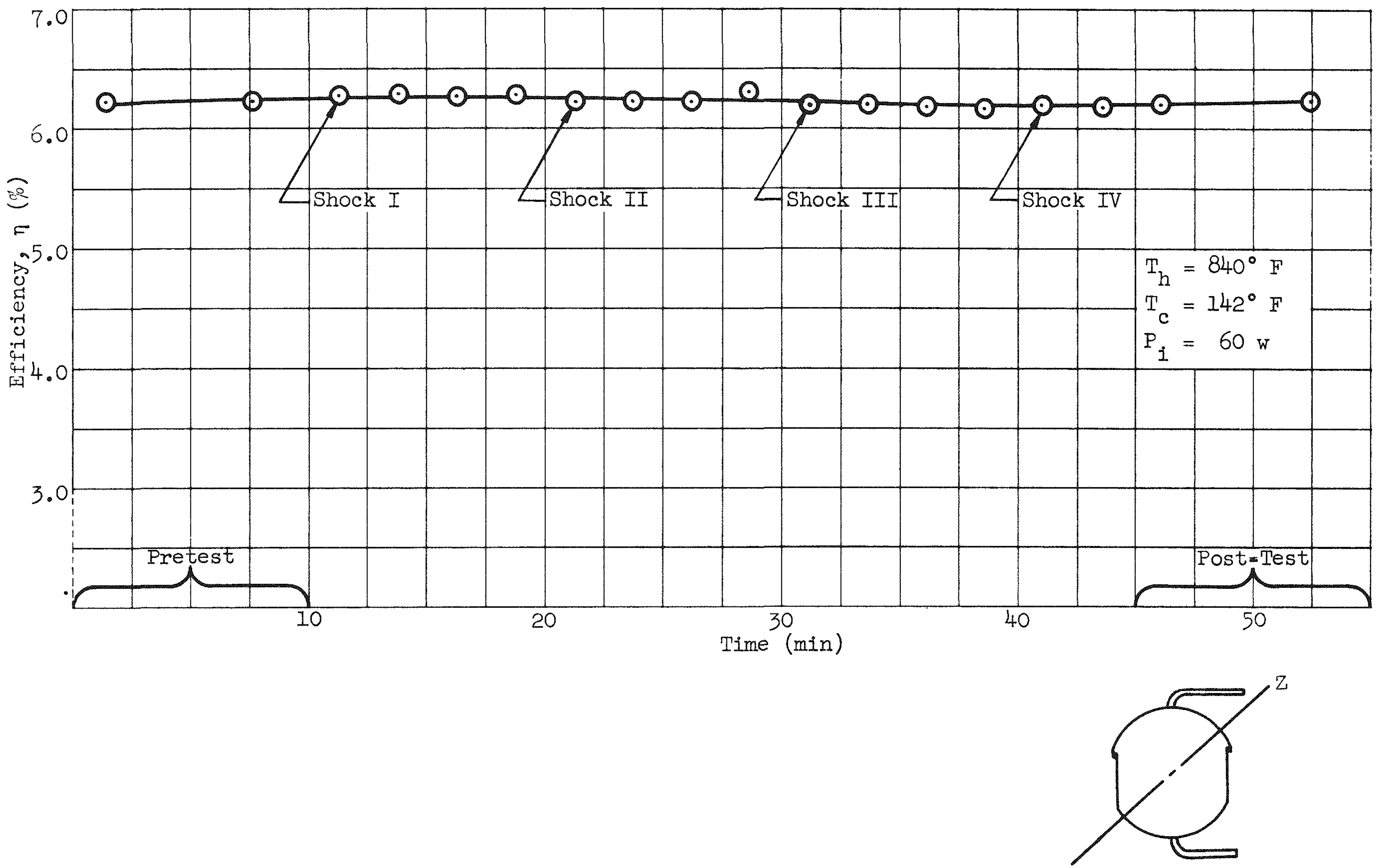


Fig. 33. Efficiency vs Time--Z Plane Shock Test

TABLE 7

Summary of X Plane Shock Test Data--SNAP-III Generator No. 1G4

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	(%)
Pretest	844	136.6	80.8	0.734	59.3	2.75	1.37	3.77	6.36
	844	136.4	80.8	0.734	59.3	2.75	1.37	3.77	6.36
First Shock	844	136.8	80.4	0.734	59.3	2.75	1.37	3.77	6.36
	844	136.8	80.4	0.734	59.1	2.75	1.36	3.74	6.33
Post and Pretest	844	136.8	80.4	0.734	59.1	2.75	1.36	3.74	6.33
	844	137.0	80.8	0.734	59.3	2.75	1.37	3.77	6.36
Second Shock	840	136.3	80.4	0.734	59.1	2.75	1.35	3.71	6.28
	840	136.3	80.8	0.734	59.3	2.75	1.36	3.74	6.31
Post and Pretest	840	136.4	80.4	0.734	59.3	2.75	1.35	3.71	6.26
	840	136.6	80.4	0.734	59.1	2.73	1.36	3.71	6.28
Third Shock	836	137.4	80.8	0.734	59.3	2.75	1.35	3.71	6.26
	836	137.6	80.4	0.734	59.1	2.75	1.36	3.74	6.33
Post and Pretest	836	137.6	80.8	0.734	59.3	2.75	1.35	3.71	6.26
	836	137.6	80.8	0.734	59.3	2.73	1.35	3.69	6.22
Fourth Shock	836	137.8	80.8	0.734	59.3	2.75	1.36	3.74	6.31
	836	138.0	80.4	0.738	59.3	2.75	1.36	3.74	6.31
Post-test	836	138.0	80.8	0.738	59.6	2.73	1.36	3.71	6.22
	836	138.0	80.8	0.734	59.3	2.75	1.36	3.74	6.31

TABLE 8

Summary of Y Plane Shock Test Data--SNAP-III Generator No. 1G4

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	(%)
	893	124	83.6	0.695	58.1	2.40	1.34	3.21	5.55
Pretest	893	124	83.6	0.695	58.1	2.40	1.34	3.21	5.55
	893	124	83.6	0.695	58.1	2.40	1.34	3.21	5.55
	893	124	83.6	0.695	58.1	2.40	1.34	3.21	5.55
First Shock	893	126	83.6	0.695	58.1	2.36	1.32	3.11	5.36
	893	128	83.6	0.695	58.1	2.37	1.33	3.15	5.43
	893	128	83.6	0.695	58.1	2.39	1.33	3.17	5.47
	893	128	83.6	0.695	58.1	2.40	1.34	3.21	5.55
	890	126	83.6	0.695	58.1	2.40	1.34	3.21	5.55
	890	126	83.6	0.695	58.1	2.34	1.31	3.06	5.28
Second	890	128	83.6	0.695	58.1	2.35	1.32	3.10	5.34
Shock	890	129	83.6	0.695	58.1	2.37	1.33	3.15	5.43
	890	129	83.6	0.695	58.1	2.40	1.34	3.21	5.55
Third Shock	900	126	83.6	0.695	58.1	2.40	1.34	3.21	5.55
	900	126	83.6	0.695	58.1	2.33	1.30	3.02	5.21
Heater	900	123	0	0	0	2.30	1.25	2.87	4.93
Failed	900	120	0	0	0	2.27	1.20	2.72	4.69
	900	118	0	0	0	2.23	1.10	2.45	4.22
	900	115	0	0	0	2.20	1.05	2.31	3.98
	844	142.3	82.0	0.763	62.9	2.79	1.405	3.92	6.14
Pretest	848	142.3	81.6	0.763	62.3	2.77	1.395	3.86	6.20
	840	142.0	82.0	0.756	62.0	2.77	1.395	3.86	6.23

TABLE 8 (continued)

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	(%)
Third Shock	844	142.3	81.6	0.760	62.0	2.79	1.395	3.89	6.27
	844	142.0	81.6	0.760	62.0	2.77	1.395	3.86	6.23
	840	142.0	82.0	0.763	62.6	2.79	1.395	3.89	6.21
Post-test	840	142.3	82.0	0.760	62.3	2.76	1.395	3.85	6.18
	840	142.3	82.4	0.763	62.9	2.77	1.395	3.86	6.14
	840	142.5	82.4	0.760	62.6	2.77	1.395	3.86	6.17
Pretest	840	143.0	81.6	0.763	62.3	2.76	1.390	3.84	6.16
	836	143.3	81.2	0.760	61.7	2.77	1.395	3.86	6.26
	836	143.3	81.2	0.756	61.4	2.77	1.395	3.86	6.29
Fourth Shock	836	142.5	82.4	0.760	62.6	2.77	1.395	3.86	6.17
	836	142.5	81.6	0.760	62.0	2.77	1.395	3.86	6.23
	836	142.5	81.6	0.756	61.7	2.77	1.395	3.86	6.26
Post-test	832	144.0	81.6	0.760	62.0	2.77	1.395	3.86	6.23
	836	144.3	81.6	0.763	62.0	2.77	1.395	3.86	6.23
	840	144.3	81.6	0.756	61.7	2.77	1.395	3.86	6.26

TABLE 9

Summary of Z Plane Shock Test Data--SNAP-III Generator No. 1G4

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	(%)
Pretest	844	142.5	80.8	0.741	59.9	2.73	1.37	3.74	6.24
	840	142.3	80.4	0.741	59.6	2.72	1.37	3.73	6.26
First Shock	840	142.3	80.8	0.741	59.9	2.73	1.38	3.77	6.29
	844	142.3	80.8	0.741	59.9	2.73	1.38	3.77	6.29
Post and	840	142.0	80.8	0.741	59.9	2.73	1.37	3.74	6.24
Pretest	844	142.5	80.8	0.741	59.9	2.73	1.39	3.77	6.29
Second Shock	840	142.3	80.8	0.741	59.9	2.72	1.37	3.73	6.23
	840	142.5	80.8	0.741	59.9	2.72	1.37	3.73	6.23
Post and	840	142.7	80.8	0.741	59.9	2.72	1.37	3.73	6.23
Pretest	840	143.3	80.8	0.741	59.9	2.73	1.39	3.79	6.33
Third Shock	836	142.8	80.8	0.741	59.9	2.72	1.37	3.73	6.23
	836	142.8	81.2	0.741	60.2	2.72	1.37	3.73	6.20
Post and	836	142.8	80.8	0.741	59.9	2.72	1.37	3.73	6.23
Pretest	836	142.8	80.8	0.741	59.9	2.72	1.39	3.78	6.31
Fourth	832	142.5	80.8	0.741	59.9	2.71	1.36	3.69	6.16
Shock	832	142.5	80.8	0.741	59.9	2.71	1.36	3.69	6.16
Post-test	845	142.5	80.8	0.741	59.9	2.71	1.37	3.71	6.19
	845	142.9	80.8	0.741	59.9	2.72	1.37	3.73	6.23

VI. CONCLUSIONS

The generator operated for 300 hr during the test program Slight losses in efficiency were caused by changes in contact area at the hot shoe junction as the unit was subjected to environmental forces These accelerations cause elastic deformations along the axial length of the thermoelectric elements, reducing the contact pressure of the hot shoe against the heat ring and unseating of the bond the lead telluride rod to the hot shoe. This results in (1) increased electrical resistance at this contact point, which lowers output voltage and unmatches the external load (2) less thermal contact area. These factors all contribute to a variation in efficiency. Of these effects, the most significant is the direct loss in efficiency due to higher internal resistance. The maximum efficiency variation observed was 5% of overall generator output.

Since good thermal contact at the hot junction is important to generator efficiency, it might be expected that some of the loss in efficiency occurring while the unit was under test would be permanent because of bond separation between the couples and the hot shoes. However, the generator showed 100% recovery after every test, with a maximum recovery time of 10 min in the Y plane vibration test This self-healing begins when environmental accelerations having disappeared, the spring pressure forces the element and hot shoe back to their static relationship. Source heat then causes a sintering effect which restores the bond at the hot shoe.

DC ripple occurred only during the vibration and shock tests. The maximum value measured was 3.60 mv rms. The frequency of the ripple always matched the frequency of the vibration test input and resonance occurred at 700 cps as indicated by a greater ripple magnitude at this vibration frequency. In each case, the DC transient disappeared when the accelerations were discontinued.

Resonances of the springs are estimated to be above the frequency band of the test specification, so the spring design is considered satisfactory. Both the springs and the Min-K-1301 thermal insulator provide good damping qualities. After the heater failed during the shock test, the generator continued operating on residual heat. When the generator was opened for heater replacement, no damage or dislocation of the internal components was found.

These tests of the SNAP-III thermoelectric generator showed that it is a rugged device for space vehicle applications.

APPENDIX A

TEST PROCEDURE

LIST OF EQUIPMENT

Description	Type	Range
True RMS Voltmeter	Ballantine Model 643	0 - 100 v
Crystal Accelerometer and Cathode Follower Amplifier	Endevco 2212	Serial Number 1298
2 Oscillographs	CEC 5-117	50 channel
Voltmeter AC	Weston	0 - 200 v
Ammeter DC	Weston	0 - 10 amp
Variac A.C.	V 5	1 amp
Thermocouple Control Unit	TC -2	Multi-channel (12)
Thermocouple Ref. Junction	RJ 1-12TP	Multi-channel (12)
Millivac Voltmeter	MV - 17C	0 - 1KC DC
DC Ammeter	Weston	0 - 1.5 amps and 7.5
DC Voltmeter	Weston	0 - 5 volts
Shunt Heating Element	Weston 622	50 amp
AC Ammeter	Weston	0 - 2.5 amp

SPECIAL TEST EQUIPMENT

Vibrator, Calidyne and Associated Control Console	Model No. 177	Random Motion
Centrifuge "G" Accelerometer	Genisco	0 - 75 g
High Impact Shock Tester	L.A.B. The Barry Corporation	200-2000 ft lb
Ampex Tape System	Model No. 307-2	

1.0 General

In accordance with Preliminary Test Specification for the Third Stage Payload of the Vega Vehicle, all tests shall be performed under ambient laboratory conditions.

2.0 Operational Test Procedure Thermoelectric Generator

2.1 The test specimen shall undergo a pretest operational checkout as follows:

(1) Apply 60 w power to heater.

(2) Allow test specimen to reach equilibrium.

(3) Measure specimen EMF (Seebeck Voltage) at no load voltage.

(4) Short circuit specimen and measure current flow.

(5) Apply load resistance (equivalent to internal resistance) and measure power output.

(6) Measure hot and cold junction temperatures, power input and output before, during and after each test phase.

2.2 The following information is to be recorded during each test cycle:

(1) Input voltage and current.

(2) Hot and cold junction temperature.

(3) Output voltage and current.

(4) Heater temperature (optional).

(5) Δ component, if any, on DC output.

(6) Environment input and output (g levels for vibration, acceleration, shock).

2.3 The test specimen shall undergo a post-test operational check-out in accordance with paragraph 2.1.

3.0 Calibration Procedure

3.1 Accelerometer Calibration

(1) Mount Endevco accelerometer on an optical wedge on the bare exciter table and vibrate sinusoidally at 2 g rms, determined by varying the frequency and monitoring constant amplitude displacement.

(2) Measure output of acceleration on a Ballantine Model No. 643 True RMS Voltmeter. Plot measured output (mv) vs frequency (cps).

(3) With the accelerometer still mounted on bare exciter table, vibrate at a frequency of 15 to 1500 cps and vary the amplitude (in.) through the control panel.

(4) Measure output of acceleration on a Ballantine Model No, 643 True RMS Voltmeter. Plot measured output (mv) vs amplitude (in.)

(5) Convert to plots of g vs cps.

3.2 Determination of System Sensitivity

(1) Mount Endevco accelerometer on bare exciter table, connecting output through proper cabling to the cathode follower-amplifier.

(2) Operate shaker at ± 2 g rms sinusoidally and measure output on Ballantine Model No. 643 True RMS Voltmeter.

3.3 Determination of Fixture Resonant Frequencies

(1) Mount test fixture on Calidyne Vibrator, Model No. 177.

(2) Attach an Endevco accelerometer on thermoelectric generator and fixture.

(3) Shake sinusoidally in three mutually perpendicular planes sweeping from 15 to 1500 cps recording output of accelerometers on an oscillograph.

3.4 Equalization of System Response (Calibrations)

3.4.1 With the test fixture and accelerometer mounted to the shaker head, operate a sinusoidal sweep from 5000 to 10 cps at ± 2 g.

3.4.2 Record output from previously calibrated accelerometer (Paragraph 3.1) on a Bristol Recorder (part of shaker control console) as frequency vs decibels.

3.4.3 Based on the response curve obtained in paragraph 3.4.2, adjust the system Equalizer and Peak Notch filters if necessary, to obtain a flat response of the system within the pass band defined by the specification 15 to 1500 cps. Run additional frequency response curves as required.

3.4.4 The shaker output is to be controlled by a tape, furnished by the Jet Propulsion Laboratories, Pasadena, California, and play back unit Ampex Model 307-2, which provides the parameters as outlined in the specification. Adjust the limiter to clip random peaks at a 3 σ level.

4.0 Unit Test

4.1.1 Installation of Test Specimen

(1) Install test specimen on test fixture.

(2) Attach fixture with specimen to shaker table.

4.1.2 Instrumentation Procedure

(1) Apply power to thermoelectric heater pins and voltage regulator.

(2) Allow the test specimen to reach equilibrium.

(3) Perform paragraph 2.1 to measure generator operation.

(4) To further monitor test specimen performance during testing, a parallel system of instrumentation will be used to give a visual indication of power output and hot and cold junction temperature. A CEC 5-117 oscillograph connected in parallel with the meters will give a permanent record of the test (Diagram 1).

(5) Install previously calibrated accelerometer on the test fixture as close as applicable to the test specimen to determine fixture frequency and vibration input to the test specimen. More than one accelerometer may be used, depending on system response as determined by paragraph 3.3. Monitor accelerometer output on an oscillograph.

4.1.3 Vibration Tests

(1) With the test specimen operating, vibrate in the vertical direction (Y axis) at levels specified in Appendix B specification, paragraph 4.4.4.

(2) Monitor meters and take sample records on oscillograph of generator operational characteristics.

(3) Check test specimen according to instrumentation specified procedure paragraph 2.2.

(4) Repeat steps 1, 2 and 3, changing plane of vibration to lateral plane. (X axis)

(5) Repeat steps 1, 2 and 3, changing plane of vibration to lateral plane (Z axis)

(6) Check test specimen in accordance with paragraph 2.1.

(7) Repeat paragraph 4.1.3 Vibration Test for a total of two vibration test cycles.

4.2 Acceleration Tests

4.2.1 Installation of Test Specimen

(1) Attach test fixture with specimen by clamping to centrifuge in such a manner as to allow the major axis to extend in a radial direction with respect to the centrifuge center of rotation.

4.2.2 Instrumentation

(1) Follow procedure of paragraph 4.1.2.

4.2.3 Testing

(1) With the test specimen operating in the Y axis, apply the levels specified in Appendix B specification paragraph 5.4, by controlling the speed of rotation.

(2) Monitor meters, and take sample records on the oscillograph.

(3) Check test specimen according to procedure in paragraph 2.1.

(4) Repeat 4.2.3.1 and 4.2.3.2 changing the plane of the test specimen to the X axis.

(5) Check test specimen according to specified procedure paragraph 2.1.

(6) Repeat 4.2.3.1 and 4.2.3.2 changing the plane of the test specimen 90° to the Z axis.

(7) Check test specimen according to specified procedure in paragraph 2.1.

4.3 Shock Test

4.3.1 Installation of Test Specimen

(1) Attach test fixture with specimen to the shock test machine, in such a manner so that the major axis extends in the Y axis (vertical direction).

4.3.2 Instrumentation

(1) Follow procedure of paragraph 4.1.2.

(2) Install calibrated Endevco accelerometer to the test specimen to measure pulse shape. Monitor output of accelerometer on an oscillograph.

4.3.3 Testing

(1) With the test specimen operating apply the levels specified in Appendix B specification, paragraph 6.4,

by raising the hammer of the shock test machine to a predetermined height, for a free fall-drop.

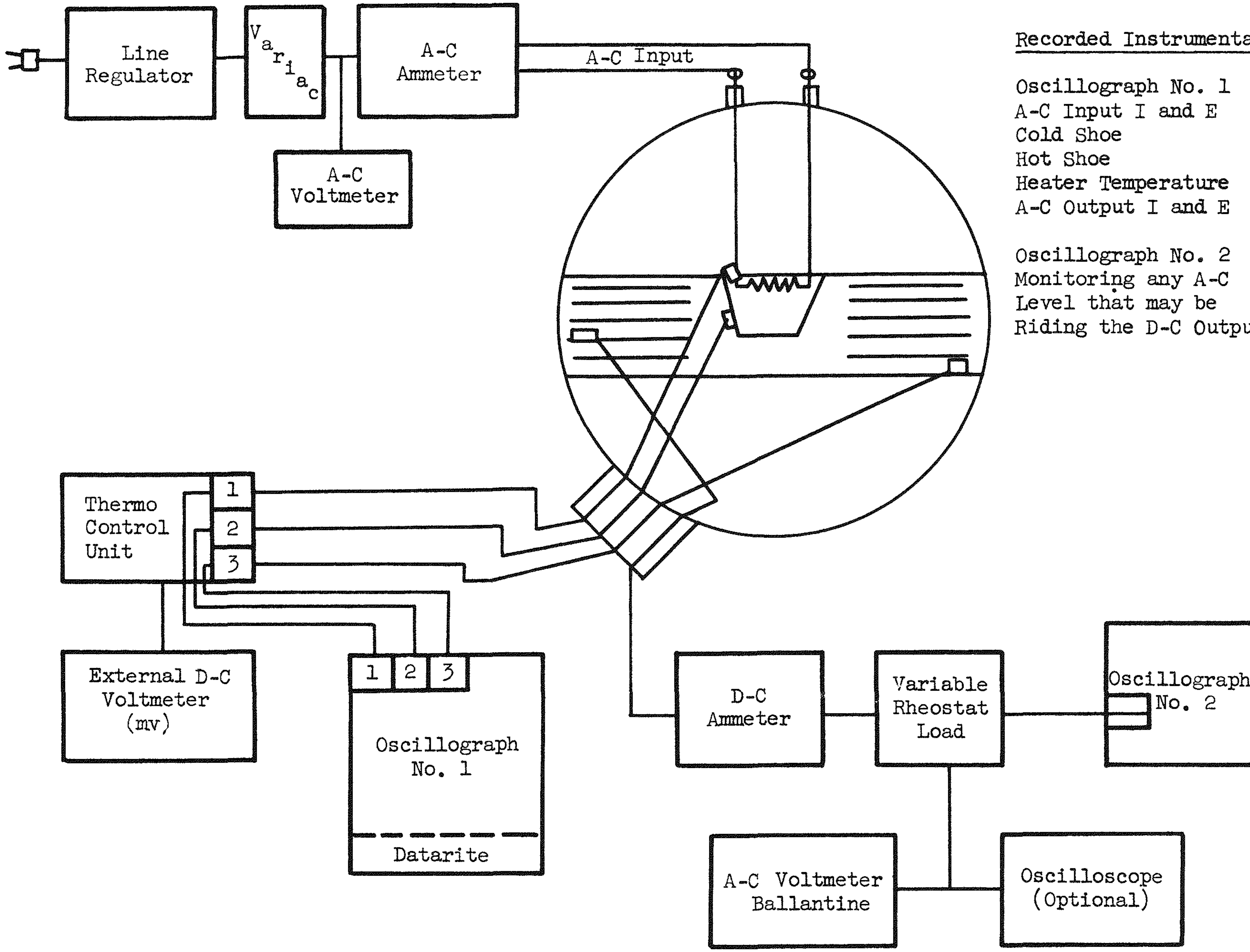
(2) Monitor pulse shape on an oscillograph.

(3) Check out test specimen according to paragraph 2.1.

(4) Repeat paragraphs 4.3.3.1 to 4.3.3.4 changing plane

(5) Repeat 4.3.3.1 to 4.3.3.4 changing plane of the test

(6) Check out test specimen according to specified



Recorded Instrumentation

Oscillograph No. 1
A-C Input I and E
Cold Shoe
Hot Shoe
Heater Temperature
A-C Output I and E

Oscillograph No. 2
Monitoring any A-C
Level that may be
Riding the D-C Output.

Diagram 1. Schematic of SNAP-III Thermoelectric Instrumentation

APPENDIX B

PRELIMINARY TEST SPECIFICATION FOR SNAP-III-F THERMOELECTRIC GENERATOR FOR THE PAYLOAD OF THE VEGA VEHICLE

Contract No. AT(30-3)-217

1.0 Scope

Specification for vibration, shock and acceleration tests in accordance with Test Procedure (Supplement No. 1) for a thermoelectric generator.

2.0 Requirements

Equipment shall be capable of satisfactory operation for nonflight, ambient temperature, pressure and humidity at sea level conditions (non-explosive atmosphere).

2.1 Test Procedure - As set forth in Appendix A.

2.2 Hazards - Not applicable.

2.3 Preparation for Delivery - Not applicable.

3.0 Test Specimen

The test specimen shall be considered as a hermetically sealed, and inaccessible container. Internal operational characteristic will be examined by external instrumentation.

4.0 Vibration Tests

4.1 Mounting - The test specimens shall be mounted by means of a suitable fixture directly to the vibration table.

4.2 Operation - The test specimen shall be operative for the entire test cycle.

4.3 Monitoring - Suitable recording equipment may be used to monitor outputs from the test specimen and instrumentation.

4.4 Vibration Levels - With the test specimen in operation vibrate in a vertical direction (first plane) by applying the following:

Time (sec)	Type of Signal	RMS G Level
0-15	Noise(1) (calibration)	2
15-30	None	0
30-32	Noise(1)	12.5
32-332	Noise(1) plus sinusoid(2)	7.05
	Noise alone	5
	Sinusoid alone	5
332-632	Noise plus sinusoid(3)	9.5
	Noise alone	5
	Sinusoid alone	8

(1) White Gaussian noise, band-limited between 15 and 1500 cps.

(2) Sinusoid swept from 15 to 500 cps at a rate increasing directly with frequency.

(3) Sinusoid swept from 500 to 1500 cps at a rate increasing directly with frequency.

4.4.1 Repeat procedure of Section 4.4 changing the direction of vibration 90° to the major horizontal axis (second plane) of the specimen.

4.4.2 Repeat procedure of Section 4.4 changing the direction of vibration 90° to the major horizontal axis (third plane) of the specimen.

4.4.3 Checkout: the test specimen shall undergo a specified electrical checkout after vibration in each plane..

4.4.4 Repeat 4.0 for a total of two test cycles.

5.0 Acceleration Tests

5.1 Mounting - The test specimen shall be mounted on the centrifuge successively in three planes so that each of the three major axis of the test specimen in turn extend in a radial direction with respect to the centrifuge center of rotation.

5.2 Operation - The test specimen shall be operative during testing.

5.3 Monitoring - Suitable recording equipment may be used to monitor outputs from the test specimen and instrumentation.

5.4 Acceleration Levels - The applied static acceleration of 15 g shall be attained, stabilized and maintained for a period of 5 min in each of the three mutually orthogonal directions.

6.0 Shock Tests

6.1 Mounting - The test specimen shall be mounted by means of a suitable fixture to a special shock test rig.

6.2 Operation - The test specimen shall be operative during testing.

6.3 Monitoring - Continuous recording during testing shall be provided by suitable recording equipment.

6.4 Shock Levels - The test specimen shall be subjected to four (4) 50 g shocks in each of the three mutually orthogonal directions. The wave form of this shock is to include an acceleration of 50 g magnitude with a rise time of less than one (1) ms.

6.5 Checkout - The test specimen shall undergo a specified electrical checkout after shock test in each plane.

APPENDIX C

I. Weights of All Component Parts of 3M-1G4

Quantity		Part	Total Weight (gm)
1	1	Cover Assembly 8 in. of Tubing	150.7
1	2	Case Assembly 8 in. of Tubing	339.2
1	3	Rigid Insulation Top	35.0
1	4	Rigid Insulation Bottom	34.2
54	5	Adjusting Screw and Insulating Washer (0.9 gm each)	48.6
54	6	Spring 0.45 gm each	24.3
54	7	Cold Junction Socket 2.17 gm each	117.2
54	8	Insulating Sleeve 0.15 gm each	8.1
27	9	Element Cap (Pair and Wire) 4.11 gm each	111.0
1	10	Cold Junction Housing	337.8
1	11	Heat Source Elect. Cartridge	35.2
1	12	Heat Source Cylinder	93.1
1	13	Heat Source Sleeve	63.0
54	14	Thermocouple Elements 5.3 gm each	286.2
1	15	Insulating Pad	5.0
27	16	Hot Shoes 1.6 gm each	43.2
1	17	Name Plate	14.0
			1,745.8 gm
		Total Overall Assembled Weight	1,853.8 gm
		Of 3M-1G4 Gen	3.845 lb

II. Spring Force on Elements

1. Force at room temperature 72° F - approximately 2.2 lb
2. Force at operating temperature of 1100° F hot junction - 5.1 lb
3. Adjusting screw thread pitch - 20 threads per in.
4. Spring rate - 175 lb/in.
5. Screw setting - 1/3 turn from free length of spring (0.0166 in. of travel)
6. Calculated expansion of elements at operating temperature of 1100° F Hot junction - 0.0126 in.

III. Compressive Strength of Min-K Insulation, 1301

5%	94.0 psi
10%	200.0 psi

IV. Mechanical Properties of PBTE

1. Weight density - 0.2944 lb/in.^{3} or 8.15 gm/cc
2. Compressive strength at room temperature 10,000 psi
3. Tensile strength at room temperature 1,000 psi
4. Coefficient of expansion 18×10^{-6}/°C