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SNAP-III......

Thermoelectric Generator Environmental Test

VOLUME II

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MARTIN
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SNAP-III......

Thermoelectric Generator Environmental Test

VOLUME II

MND-P-2101-II

OCTOBER 1959

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Approved By:

MARTIN
NUCLEAR DIVISION

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FOREWORD

This report is a classified addendum to MND-P-2101, SNAP III Environmental Test, and was conducted to the specifications for the WS-117 L Vehicle in accordance with requirements from the Lockheed Missile Systems Division, Palo Alto, California.

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SUMMARY

Thermoelectric generator No. 1G5 is of the same configuration and construction as No. 1G4 reported on in MND-P-2101.

The unit operated for about 250 hours during the entire test program. The efficiency varied approximately 5% of the total performance during the vibration cycle, and remained relatively stable during the acceleration and shock tests. Recovery was complete in all cases.

Oscillatory DC superimposed on the DC output of the generator was observed only during the shock and vibration tests, and disappeared when the environmental forces were discontinued. The maximum DC ripple was 7.4 millivolts rms in the y Plane during the shock and vibration cycles.

It was concluded that SNAP III thermoelectric generator No. 1G5 is reliable in environments simulating the WS-117 L Vehicle.

I. INTRODUCTION

On 9 June 1959, in the Environmental Dynamics Test Facility at The Martin Company, tests were begun on SNAP III thermoelectric generator No. 1G5.

The generator was subjected to vibration, acceleration and shock in each orthogonal plane. The test specification was developed by Lockheed Missile Systems Division for the WS-117 L Vehicle. These tests were concluded on 20 August 1959.

The generator is identical to No. 1G4, tested in Report No. MND-P-2101. Therefore, description and procedures are essentially the same.

WS-117 L test procedures and preliminary test specifications are given in Appendices A and B, respectively.

II. VIBRATION TEST

The specifications for the vibration test performed on SNAP III Generator 1G5 were developed from environmental data submitted by the Lockheed Missile Systems Division. A sinusoidal and random input in each of the three principal orthogonal planes is required. The sinusoidal vibrations for three specific inputs were (1) 5 to 25.5 cps at 1/8 inch amplitude for five minutes, (2) 25 to 2000 cps at 7.5 peak g for five minutes and (3) 2000 to 2500 cps at 10 peak g for five minutes.

The random portion of the test specified two test levels, the first bandlimited from 15 to 2000 cps at a level of 2 g rms for ten minutes, and the second bandlimited from 15 to 2000 cps at a level of 4.5 g rms for five minutes.

The frequency response curve for the basic 177A shaker was initially equalized for a sinusoidal input with the system equalizer and a peak notch filter. After the mounting plate and test fixture were attached, the equalizer and filter were again adjusted to flatten the system response. (Figures 1, 2 and 3.) Kronhite band pass filters were used to bring the relative level down 3 db at 2000 cps and 8.5 db at 15 cps. The frequency survey indicated a shaker armature resonance of 2574 cps, thus establishing the upper limits for the sinusoidal test. Figure 4 is the resonance curve for the Calidyne shaker.

An additional system equalization technique will be incorporated in future tests to substantiate the present method. To make certain that the shaker response is flat with a random signal input, a White noise input band-limited within the desired test range will be fed through the control console into the shaker, and the output response of the shaker to this White noise input will be spectrum analyzed. The filter and equalizer will again be adjusted to flatten the shaker response. This process is repeated until the desired system response throughout a specified frequency range is obtained. To determine the effects of nonlinearities, several White noise inputs of different levels will be fed through the shaker control console, and the output response of the shaker analyzed.

Before each test the generator was allowed to reach a state of equalibrium, as determined when the DC power output and hot junction temperature became constant. A parallel system of recording enabled visual observations as well as permanently recorded data. AC power input, DC power output and hot and cold junction temperatures were recorded for ten minutes before each test to confirm the stability of the generator.

Performance data for the vibration tests are presented in Tables 1 through 6.

The vibration tests performed on SNAP III Generator 1G5 showed the maximum drop in efficiency to be less than 2.5% in all planes during the random tests. Efficiencies during these tests are plotted in Fig. 5. In the sinusoidal test a maximum overall drop of 5.7% was noted in the z plane and less than 2.5% in the x and y planes.

Efficiencies for the sinusoidal tests are plotted in Fig. 6. The efficiency drop remained constant until the vibrations were discontinued. In the z plane, it took approximately 30 minutes for recovery. Since the efficiency drop was negligible in the x and y plane, recovery time was not a factor.

The output voltage, which is a DC signal, was monitored for oscillatory DC. The records indicate a low level DC ripple of 1.1 v rms in the x and z planes, with a much higher level, 7.4 v rms, in the y plane.

These transients in the output voltage disappeared when the vibrations were discontinued.

TABLE 1

Summary of X Plane Random Vibration Data--SNAP III Generator No. 1G5

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	Percent
Pretest	821	123	80.9	0.755	61.08	2.88	1.28	3.6864	6.04
	821	123	80.9	0.755	61.08	2.88	1.28	3.6864	6.04
	821	123	80.9	0.755	61.08	2.87	1.27	3.6449	5.97
	816	123	80.9	0.755	61.08	2.87	1.27	3.6449	5.97
Test 1	816	123	80.9	0.755	61.08	2.87	1.27	3.6449	5.97
	812	123	80.9	0.755	61.08	2.88	1.26	3.6036	5.90
	816	123	80.9	0.755	61.08	2.90	1.26	3.6540	5.98
	816	123	80.9	0.755	61.08	2.91	1.26	3.6666	6.00
Post- and Pretest	812	123	80.9	0.755	61.08	2.91	1.26	3.6666	6.00
	812	123	80.9	0.755	61.08	2.91	1.26	3.6666	6.00
	812	123	80.9	0.755	61.08	2.91	1.26	3.6666	6.00
	812	123	80.9	0.755	61.08	2.91	1.26	3.6666	6.00
Test 2	812	123	80.9	0.755	61.08	2.91	1.26	3.6666	6.00
	812	123	80.9	0.755	61.08	2.91	1.26	3.6666	6.00
	812	124	80.9	0.755	61.08	2.91	1.26	3.6666	6.00
	812	124	80.9	0.755	61.08	2.91	1.26	3.6666	6.00
Post-test	812	124	80.9	0.755	61.08	2.91	1.26	3.6666	6.00
	808	124	80.9	0.755	61.08	2.91	1.26	3.6666	6.00
	812	124	80.9	0.755	61.08	2.91	1.26	3.6666	6.00
	808	124	80.9	0.755	61.08	2.91	1.26	3.6666	6.00

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TABLE 2

Summary of Y Plane Random Vibration Data--SNAP III Generator No. 1G5

	Temperature (^{o}F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	Percent
Pretest	825	122	80.9	0.745	60.28	2.88	1.28	3.6864	6.12
	825	121	80.9	0.745	60.28	2.88	1.28	3.6864	6.12
	825	122	80.9	0.745	60.28	2.87	1.27	3.6449	6.05
	825	122	80.9	0.745	60.28	2.87	1.27	3.6449	6.05
Test 1	825	122	80.9	0.745	60.28	2.87	1.27	3.6449	6.05
	821	121	80.9	0.745	60.28	2.86	1.26	3.6036	5.98
	821	121	80.9	0.745	60.28	2.86	1.26	3.6036	5.98
	821	122	80.9	0.745	60.28	2.86	1.26	3.6036	5.98
Post-test and Pretest	821	122	80.9	0.745	60.28	2.86	1.26	3.6036	5.98
	821	122	80.9	0.745	60.28	2.86	1.26	3.6036	5.98
	821	122	80.9	0.745	60.28	2.86	1.26	3.6036	5.98
	821	122	80.9	0.745	60.28	2.86	1.26	3.6036	5.98
Test 2	821	122	80.9	0.745	60.28	2.86	1.26	3.6036	5.98
	821	122	80.9	0.745	60.28	2.86	1.26	3.6036	5.98
	821	122	80.9	0.745	60.28	2.86	1.26	3.6036	5.98
	821	122	80.9	0.745	60.28	2.86	1.26	3.6036	5.98
Post-test	821	122	80.9	0.745	60.28	2.86	1.26	3.6036	5.98
	821	122	80.9	0.745	60.28	2.86	1.26	3.6036	5.98
	816	122	80.9	0.745	60.28	2.86	1.26	3.6036	5.98
	816	122	80.9	0.745	60.28	2.86	1.26	3.6036	5.98

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TABLE 3

Summary of Z Plane Random Vibration Data--SNAP III Generator No. 1G5

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	Percent
Pretest	821	135	82.1	0.755	61.99	3.00	1.26	3.7800	6.10
	821	135	82.1	0.755	61.99	3.00	1.26	3.7800	6.10
	821	135	82.1	0.755	61.99	3.00	1.26	3.7800	6.10
	821	135	82.1	0.755	61.99	3.00	1.26	3.7800	6.10
Test 1	821	134	82.1	0.755	61.99	3.00	1.26	3.7800	6.10
	821	134	82.1	0.755	61.99	3.00	1.24	3.7200	6.00
	821	134	82.1	0.755	61.99	3.00	1.24	3.7200	6.00
	821	134	82.1	0.755	61.99	3.00	1.23	3.6900	5.95
Post- and Pretest	821	134	82.1	0.755	61.99	3.00	1.23	3.6900	5.95
	816	134	82.1	0.755	61.99	3.00	1.23	3.6900	5.95
	821	135	82.1	0.755	61.99	3.00	1.23	3.6900	5.95
	821	135	82.1	0.755	61.99	3.00	1.23	3.6900	5.95
Test 2	816	134	82.1	0.755	61.99	3.00	1.23	3.6900	5.95
	821	135	82.1	0.755	61.99	3.00	1.23	3.6900	5.95
	821	135	82.1	0.755	61.99	3.00	1.23	3.6900	5.95
	816	135	82.1	0.755	61.99	3.00	1.23	3.6900	5.95
Post-test	812	135	82.1	0.755	61.99	3.00	1.23	3.6900	5.95
	812	135	82.1	0.755	61.99	3.00	1.23	3.6900	5.95
	812	135	82.1	0.755	61.99	3.00	1.23	3.6900	5.95
	812	135	82.1	0.755	61.99	3.00	1.23	3.6900	5.95

TABLE 4

Summary of X Plane Sinusoidal Vibration Data--SNAP III Generator No. 1G5

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	Percent
	821	125	80.9	0.769	62.21	2.99	1.23	3.6777	5.91
Pretest	821	125	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
	821	125	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
	825	125	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
Test 1	825	125	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
	821	125	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
	821	125	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
	821	125	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
Post- and Pretest	821	125	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
	821	125	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
	812	125	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
Test 2	812	125	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
	812	125	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
	812	125	80.9	0.769	62.21	2.96	1.23	3.6408	5.85
	816	125	80.9	0.769	62.21	2.96	1.23	3.6408	5.85
Post- and Pretest	816	126	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
	816	126	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
	812	126	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
Test 3	812	126	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
	812	126	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
	812	126	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
	812	126	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
Post-test	812	126	80.9	0.769	62.21	2.97	1.23	3.6531	5.87
	812	126	80.9	0.769	62.21	2.97	1.23	3.6531	5.87

TABLE 5

Summary of Y Plane Sinusoidal Vibration Data--SNAP III Generator No. 1G5

	Temperature (^{o}F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	Percent
Pretest	821	130	80.9	0.774	62.62	2.99	1.24	3.7076	5.92
	816	130	80.9	0.774	62.62	2.99	1.24	3.7076	5.92
	821	130	80.9	0.774	62.62	2.99	1.23	3.6777	5.87
Test 1	821	130	80.9	0.774	62.62	2.97	1.23	3.6531	5.83
	821	130	80.9	0.774	62.62	2.97	1.23	3.6531	5.83
	816	130	80.9	0.774	62.62	2.99	1.23	3.6531	5.83
	816	130	80.9	0.774	62.62	2.97	1.23	3.6531	5.83
Post- and Pretest	821	129	80.9	0.774	62.62	3.00	1.23	3.6900	5.89
	816	129	80.9	0.774	62.62	3.00	1.23	3.6900	5.89
	816	129	80.9	0.774	62.62	3.00	1.23	3.6900	5.89
Test 2	812	130	80.9	0.774	62.62	3.00	1.22	3.6600	5.84
	812	130	80.9	0.774	62.62	3.00	1.22	3.6600	5.84
	812	130	80.9	0.774	62.62	3.00	1.21	3.6300	5.80
	812	130	80.9	0.774	62.62	2.99	1.21	3.6179	5.78
Post- and Pretest	812	131	80.9	0.774	62.62	3.00	1.21	3.6300	5.80
	812	131	80.9	0.774	62.62	3.00	1.22	3.6600	5.84
	812	131	80.9	0.774	62.62	3.00	1.22	3.6600	5.84
Test 3	816	130	80.9	0.774	62.62	3.00	1.22	3.6600	5.84
	816	131	80.9	0.774	62.62	3.00	1.22	3.6600	5.84
	812	131	80.9	0.774	62.62	3.00	1.23	3.6900	5.89
	812	131	80.9	0.774	62.62	3.00	1.22	3.6600	5.84
Post-test	812	131	80.9	0.774	62.62	3.00	1.22	3.6600	5.84
	812	131	80.9	0.774	62.62	3.00	1.21	3.6300	5.80
	812	131	80.9	0.774	62.62	3.00	1.22	3.6600	5.84

TABLE 6

Summary of Z Plane Sinusoidal Vibration Data--SNAP III Generator No. 1G5

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	Percent
Pretest	821	123	82.5	0.755	62.29	2.93	1.26	3.6918	5.93
	821	122	82.5	0.755	62.29	2.93	1.26	3.6918	5.93
	821	122	82.5	0.755	62.29	2.93	1.26	3.6918	5.93
Test 1	821	123	82.5	0.755	62.29	2.93	1.26	3.6918	5.93
	821	123	82.5	0.755	62.29	2.93	1.23	3.6039	5.79
	821	123	82.5	0.755	62.29	2.91	1.22	3.5502	5.70
	821	123	82.5	0.755	62.29	2.90	1.21	3.5090	5.63
Post- and Pretest	821	123	82.5	0.755	62.29	2.90	1.21	3.5090	5.63
	812	123	82.5	0.755	62.29	2.90	1.21	3.5090	5.63
	812	123	82.5	0.755	62.29	2.90	1.21	3.5090	5.63
Test 2	812	123	82.5	0.755	62.29	2.90	1.21	3.5090	5.63
	812	123	82.5	0.755	62.29	2.90	1.21	3.5090	5.63
	812	123	82.5	0.755	62.29	2.87	1.21	3.4727	5.58
	812	124	82.5	0.755	62.29	2.88	1.21	3.4848	5.59
Post- and Pretest	812	126	82.5	0.755	62.29	2.88	1.21	3.4848	5.59
	812	126	82.5	0.755	62.29	2.88	1.21	3.4848	5.59
	812	126	82.5	0.755	62.29	2.88	1.21	3.4848	5.59
Test 3	812	126	82.5	0.755	62.29	2.88	1.21	3.4848	5.59
	812	126	82.5	0.755	62.29	2.88	1.20	3.4560	5.55
	812	127	82.5	0.755	62.29	2.88	1.21	3.4848	5.59
	812	127	82.5	0.755	62.29	2.88	1.21	3.4848	5.59
Post-test	812	127	82.5	0.755	62.29	2.88	1.21	3.4848	5.59
	812	127	82.5	0.755	62.29	2.88	1.21	3.4848	5.59
	812	127	82.5	0.755	62.29	2.88	1.21	3.4848	5.59

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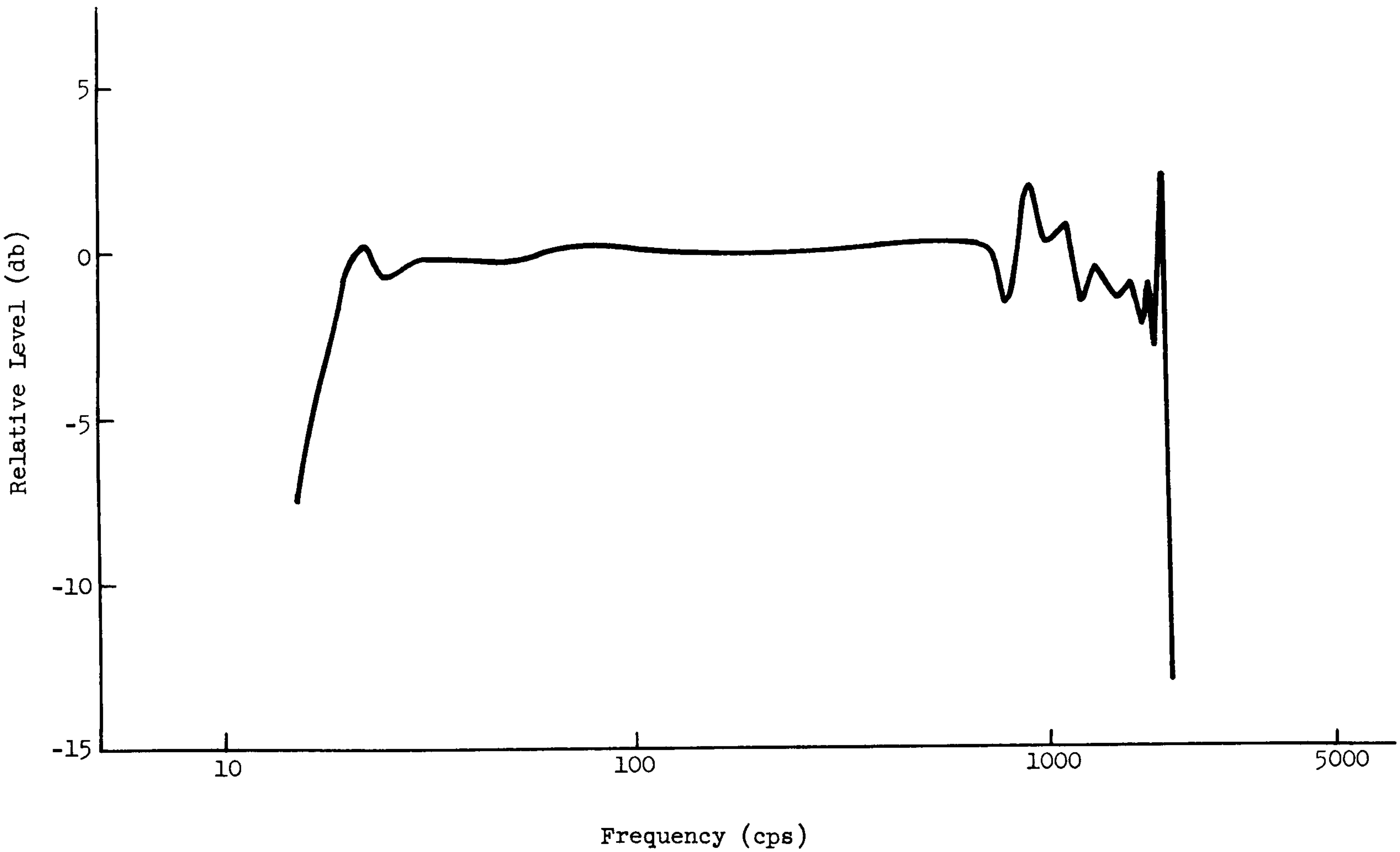

Fig. 1. X Plane Final Equalization Curve--Model 177A Calidyne Vibrator

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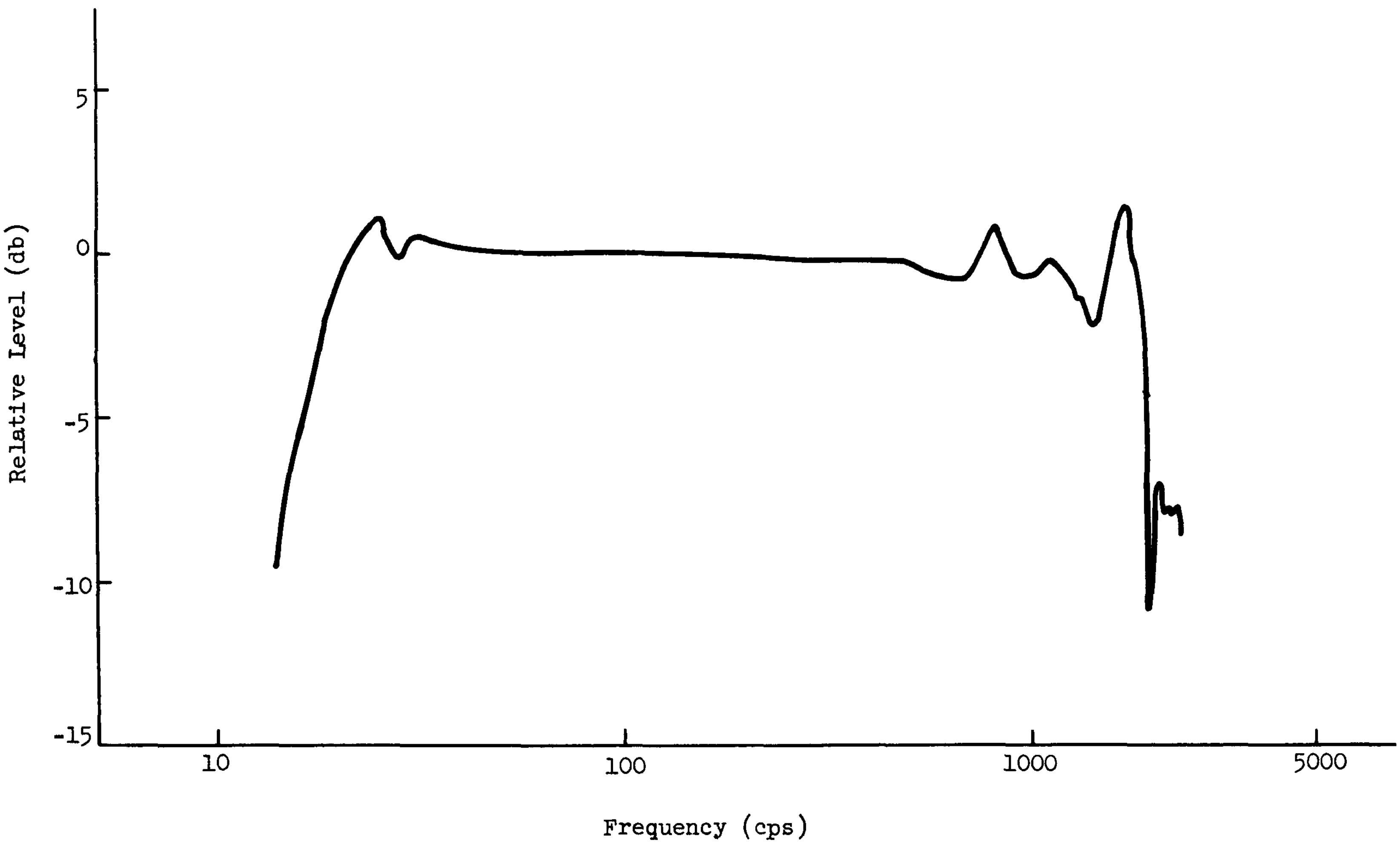

Fig. 2. Y Plane Final Equalization Curve

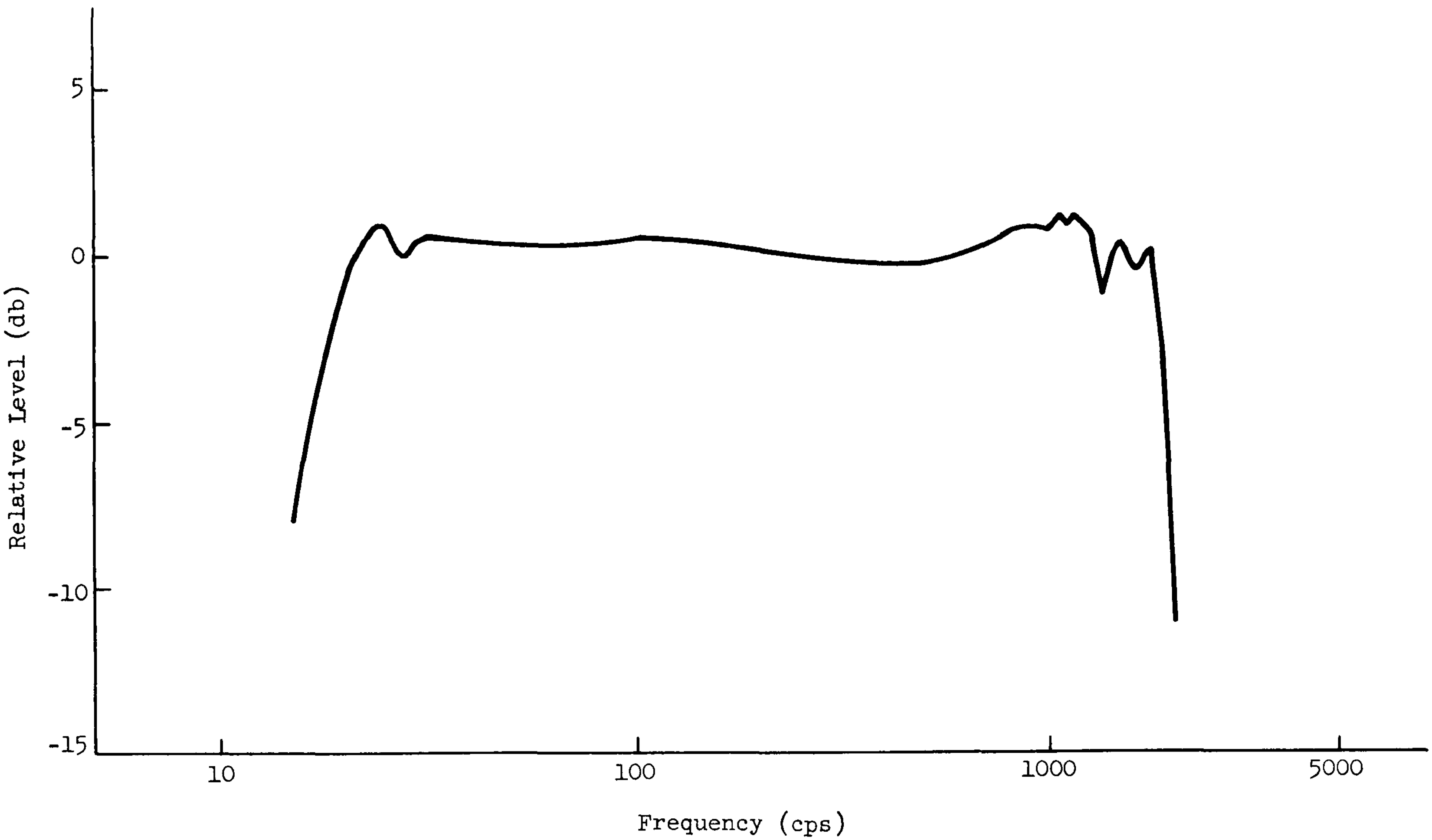

Fig. 3. Z Plane Final Equalization Curve

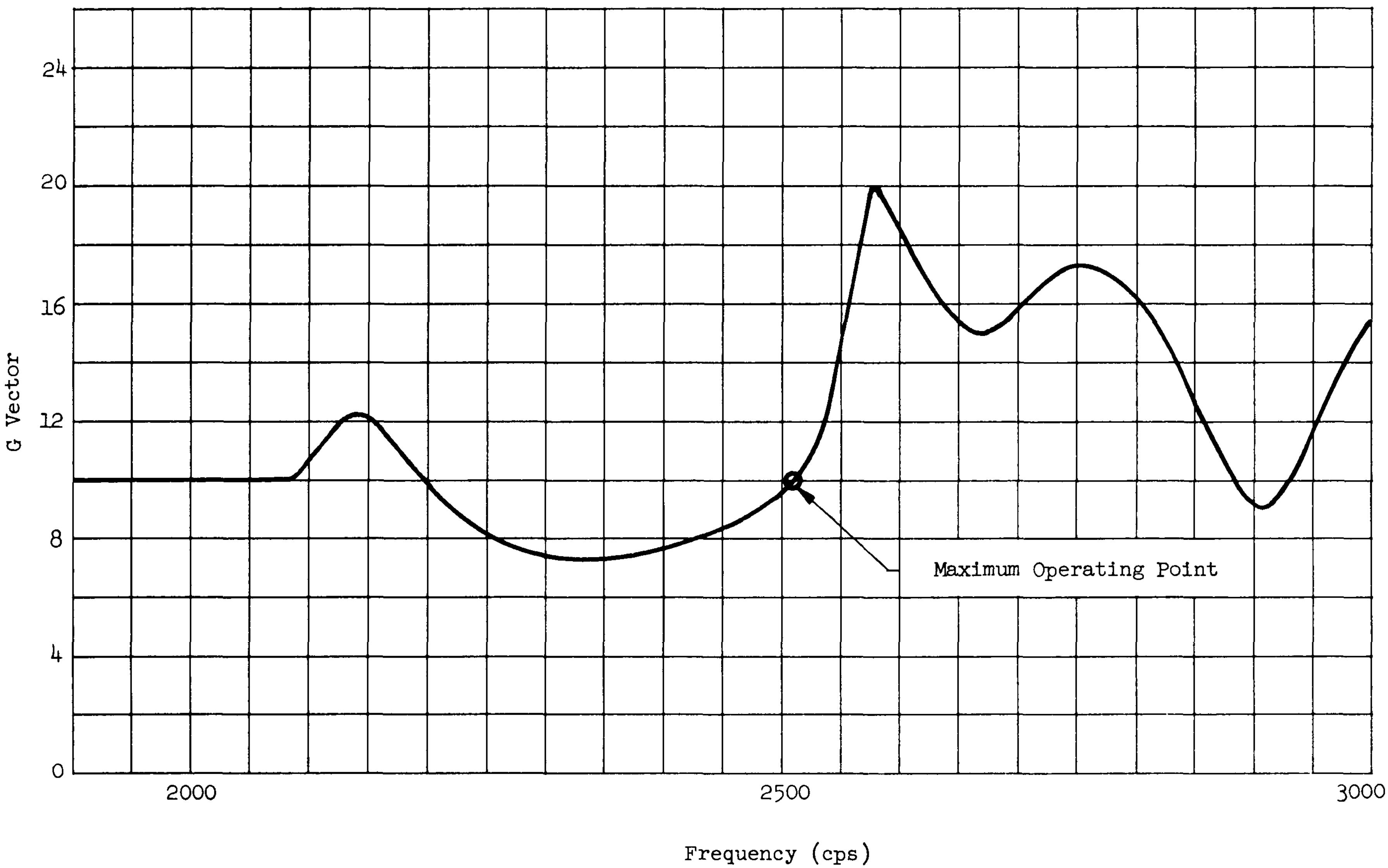

Fig. 4. Resonance Frequency Curve--Calidyne Shaker M-177A

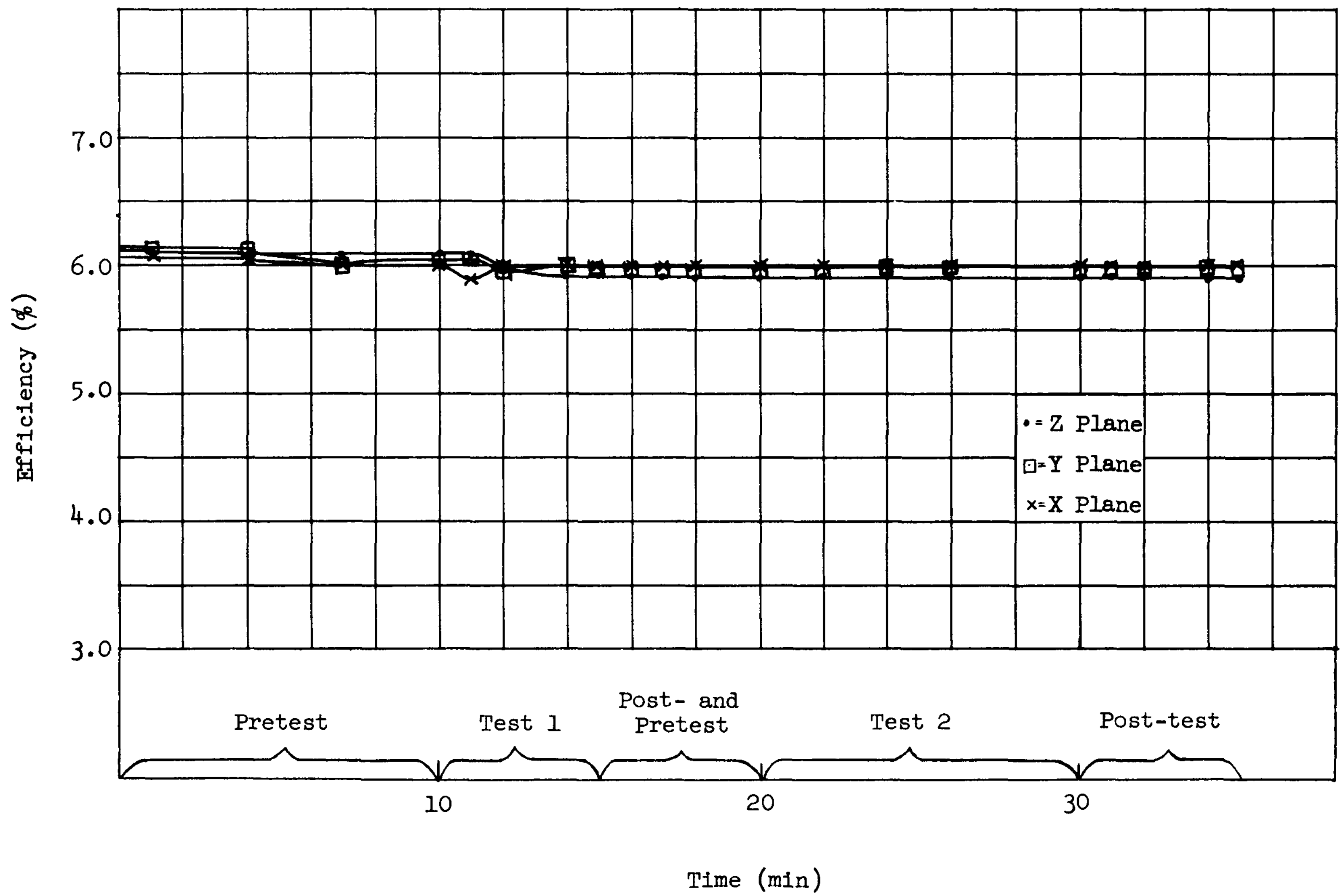

Fig. 5. Efficiency vs Time--Random Vibration Test

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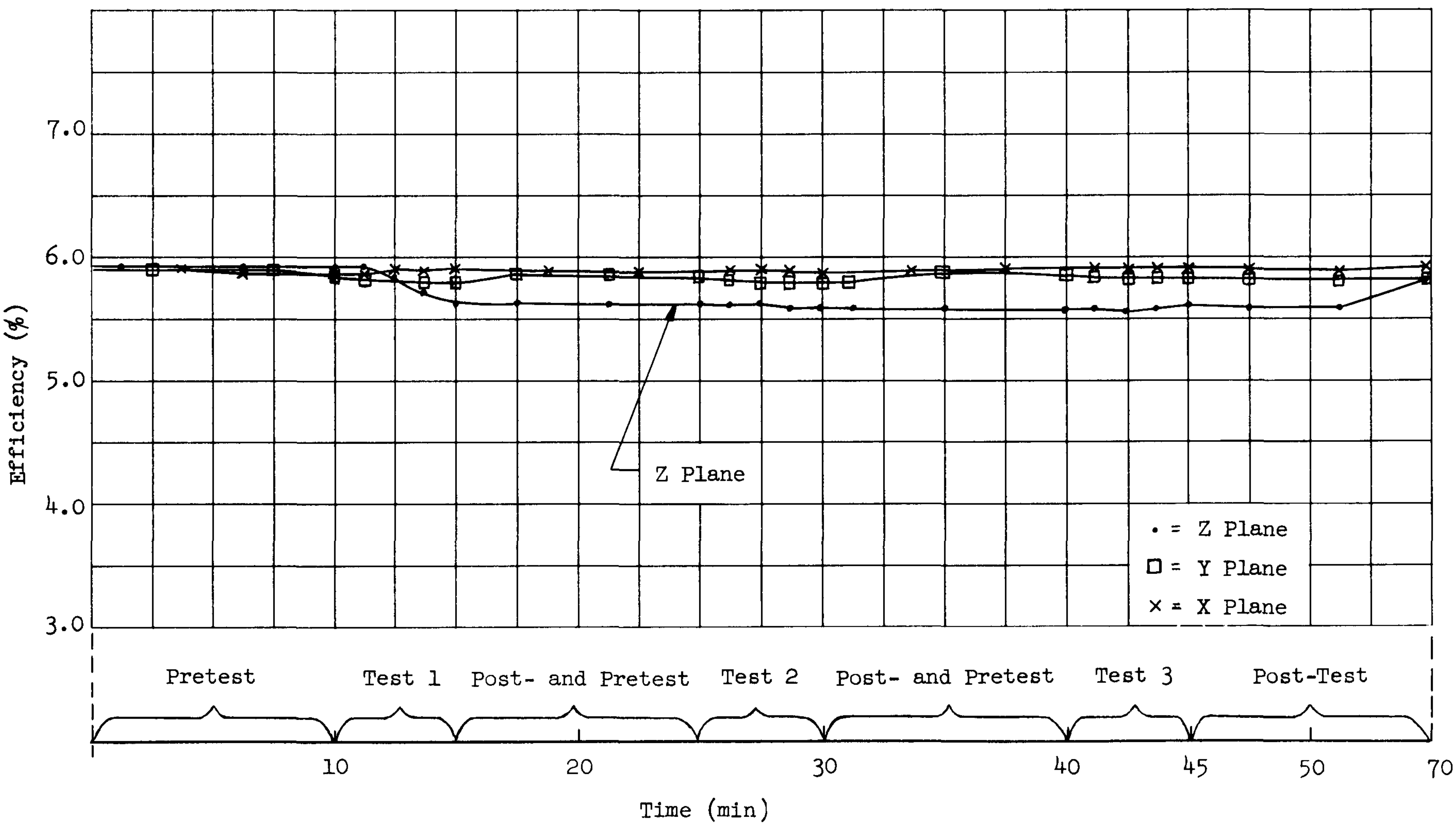

Fig. 6. Efficiency vs Time--Sinusoidal Vibration Test

III. ACCELERATION TEST

The specifications for the acceleration tests performed on SNAP III Generator No. 1G5 called for a 10 g static acceleration for ten minutes in the y plane, and a static acceleration of 2 g for ten minutes in the x and z planes. A Genisco centrifuge with a maximum weight allowance of 100 pounds and a force of 75 g was used for the test.

The test in the y plane was conducted in steps until the maximum level of 10 g was reached. Figure 7 shows generator efficiency during the test. The test level of 2 g in the x and z planes was reached directly. (Figures 8 and 9.)

Oscillograph records were taken before, during and after each test to show that stability had been maintained. These data are shown in Tables 7, 8 and 9.

The results show the generator efficiency to be stable under the conditions specified for the tests. The ΔDC did not appear during these tests. The lower stabilized efficiencies are attributed to the increase in external load caused by a power consuming slip ring installation within the centrifuge.

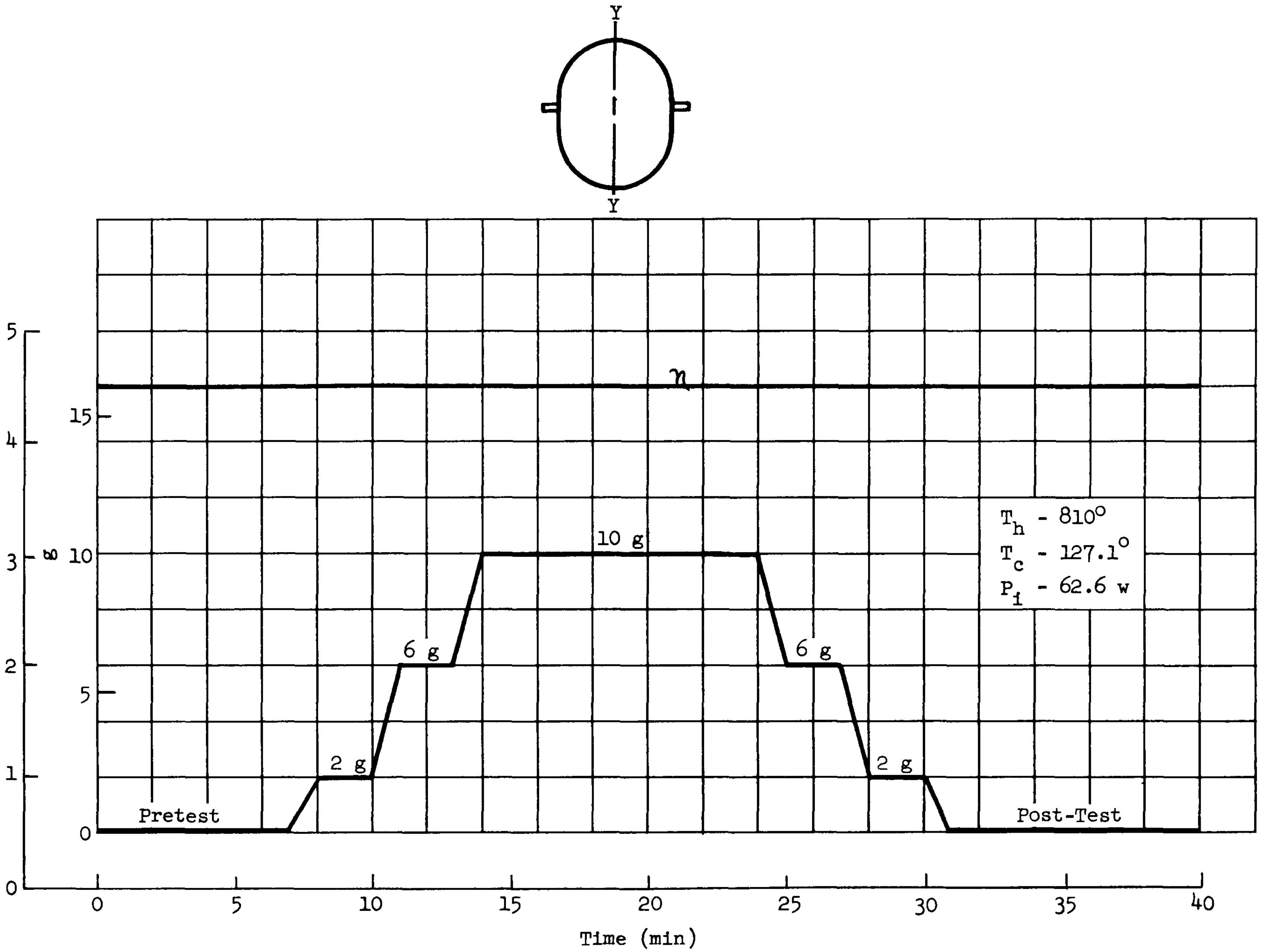

Fig. 7. Efficiency vs Time--Y Plane Acceleration Test

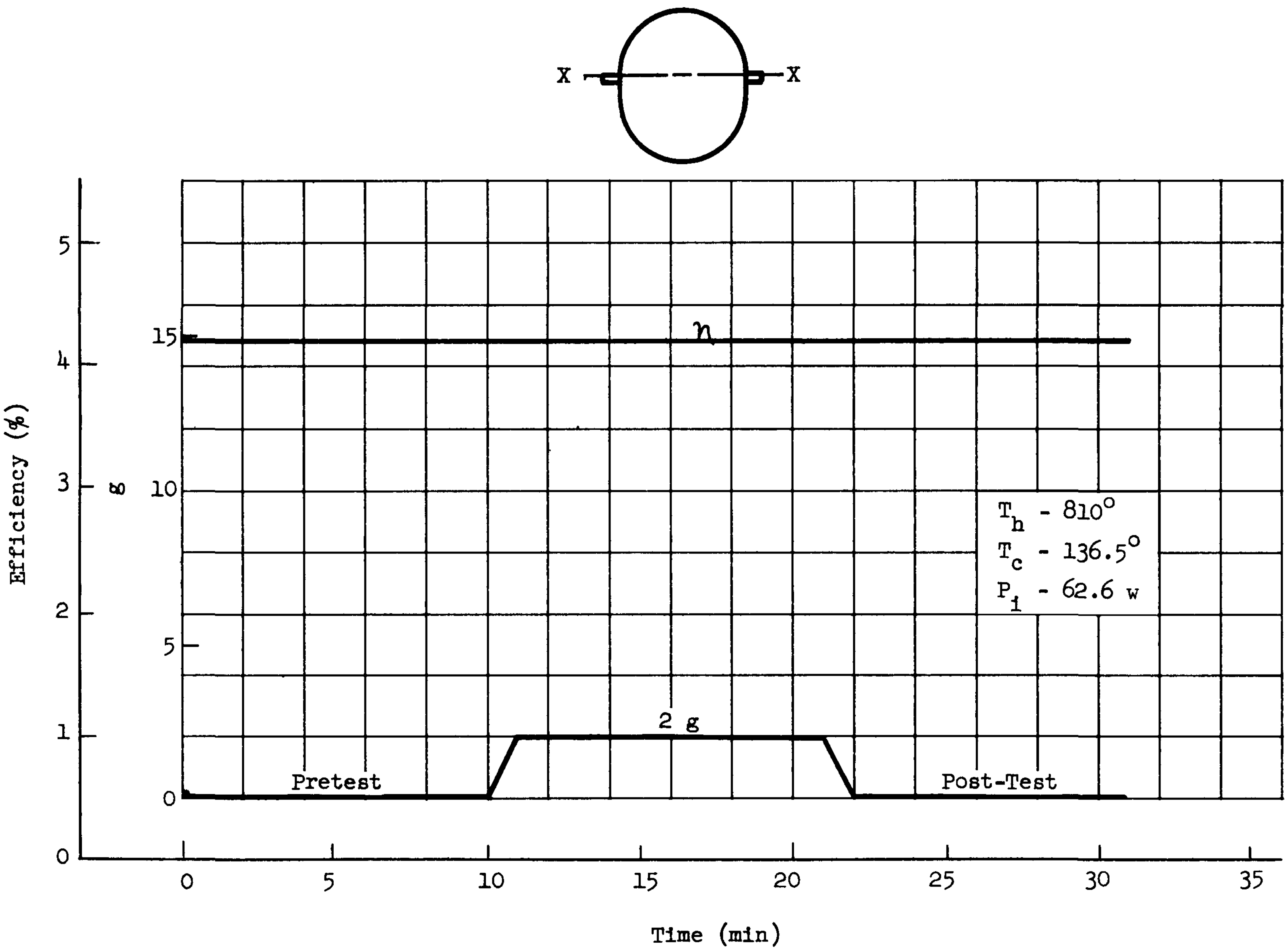

Fig. 8. X Plane Acceleration Test

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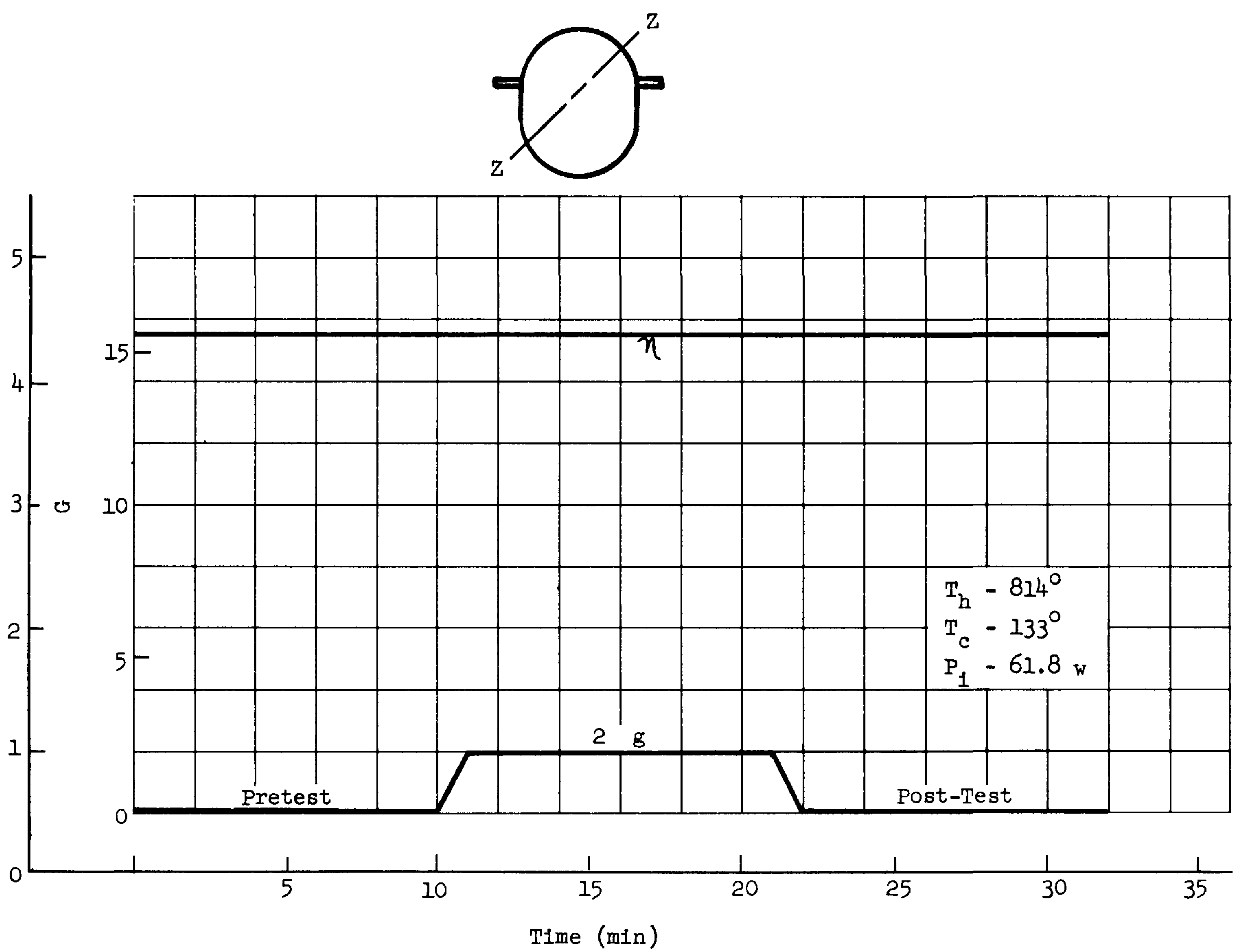

Fig. 9. Z Plane Acceleration Test

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TABLE 7

Summary of Y Plane Acceleration Test Data--SNAP III Generator No. 1G5

	Temperature (^{O}F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	Percent
Pretest	832	126.8	85.0	0.744	63.2	2.24	1.275	2.86	4.5
	832	126.8	85.5	0.748	63.9	2.24	1.275	2.86	4.5
2 g	827	127.0	83.5	0.736	61.5	2.22	1.255	2.79	4.5
	827	127.5	83.5	0.736	61.5	2.24	1.265	2.81	4.6
6 g	822	127.5	84.0	0.740	62.2	2.20	1.240	2.73	4.4
	827	127.8	84.0	0.744	62.5	2.20	1.255	2.76	4.4
10 g	827	127.8	84.0	0.740	62.2	2.20	1.255	2.76	4.4
	827	127.8	84.0	0.740	62.2	2.20	1.255	2.76	4.4
6 g	818	124.8	83.5	0.740	61.8	2.20	1.265	2.78	4.5
	822	124.5	84.0	0.740	62.2	2.20	1.255	2.76	4.4
2 g	822	124.8	84.0	0.740	62.2	2.22	1.265	2.81	4.5
	822	124.8	83.5	0.740	61.8	2.24	1.265	2.83	4.6
Post-test	822	124.5	84.0	0.744	62.5	2.20	1.269	2.79	4.5
	822	124.8	85.0	0.744	63.2	2.24	1.275	2.86	4.5

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TABLE 8

Summary of X Plane Acceleration Test Data--SNAP III Generator No. 1G5

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	Percent
	810	134.5	83.0	0.740	61.42	2.16	1.21	2.61	4.3
Pretest	810	135.0	83.5	0.744	62.13	2.17	1.21	2.63	4.2
	810	135.0	83.0	0.740	61.42	2.16	1.21	2.61	4.3
	810	135.3	83.5	0.760	63.50	2.17	1.21	2.63	4.3
Up to 2 g	810	135.3	83.5	0.760	63.50	2.17	1.21	2.63	4.3
	810	135.6	83.5	0.750	62.80	2.17	1.21	2.63	4.3
	810	136.5	83.5	0.756	63.10	2.17	1.21	2.63	4.2
2 g	810	136.5	83.0	0.748	62.10	2.17	1.21	2.63	4.2
	810	136.8	83.5	0.752	62.80	2.16	1.21	2.61	4.2
	810	136.5	83.0	0.752	62.40	2.18	1.21	2.64	4.2
Post-test	806	136.5	83.5	0.752	62.80	2.17	1.21	2.63	4.2
	810	136.5	82.5	0.748	61.70	2.18	1.21	2.64	4.3

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TABLE 9

Summary of Z Plane Acceleration Test Data--SNAP III Generator No. 1G5

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	Percent
Pretest	818	131.0	83.0	0.740	61.4	2.17	1.21	2.63	4.3
	818	131.0	83.5	0.736	61.5	2.18	1.22	2.66	4.3
	822	131.3	83.5	0.736	61.5	2.19	1.22	2.67	4.3
Up to 2 g	814	130.8	84.0	0.744	62.5	2.17	1.21	2.63	4.2
	814	130.8	83.5	0.740	61.8	2.17	1.21	2.63	4.3
	814	130.8	83.5	0.740	61.8	2.17	1.21	2.63	4.3
2 g	810	130.8	83.5	0.744	62.1	2.17	1.21	2.63	4.3
	818	131.0	83.5	0.740	61.8	2.17	1.21	2.63	4.3
	818	131.0	83.5	0.740	61.8	2.17	1.21	2.63	4.3
Post-test	806	133.8	83.5	0.740	61.8	2.17	1.21	2.63	4.3
	810	134.3	83.5	0.744	62.1	2.16	1.21	2.61	4.3
	810	134.5	83.0	0.740	61.4	2.16	1.21	2.61	4.3

IV. SHOCK TEST

This test deviates from the WS-117 L requirement where the specification calls for one shock wave in each orthogonal plane of 40 g amplitude, with a rise time of 2 milliseconds, a dwell time of 3 milliseconds and a decay time of 0.4 milliseconds. This is due to the fact that The Martin Company does not yet have equipment which can meet this requirement. The equipment has been ordered, however, and when it becomes available the generator will be retested to this shock specification. Currently, two 40 g shocks with 1 millisecond rise time were substituted for this requirement. The two shock waves with a 1 millisecond decay time have been determined to be equivalent to the 3 millisecond dwell wave form.

The high impact shock machine used in this test was modified to attain the required rise time and g level. The desired shock pulse was produced, but the dynamic response of the plate caused peaks greater than the impact force during the decay phase of the shock pulse. This made additional modifications necessary.

The test fixture was then suspended by a wire cable from the shock machine, and bungee cord used to ensure contact between the large plate of the impact machine and the test fixture. The force of the hammer hitting the large plate caused the test fixture to swing forward about two inches, where it was caught before it could make contact with the plate again. Figure 10 shows the shock test mounting of the test specimen.

It was determined that the time span between the initial impact of the hammer on the generator and its arrest is sufficient to permit dampening of all generator transients. This procedure was repeated until the specified g level and rise time was attained and repeated for several shocks. Two accelerometers mounted on the fixture then recorded the input and response accelerations of the generator. Oscillograph records

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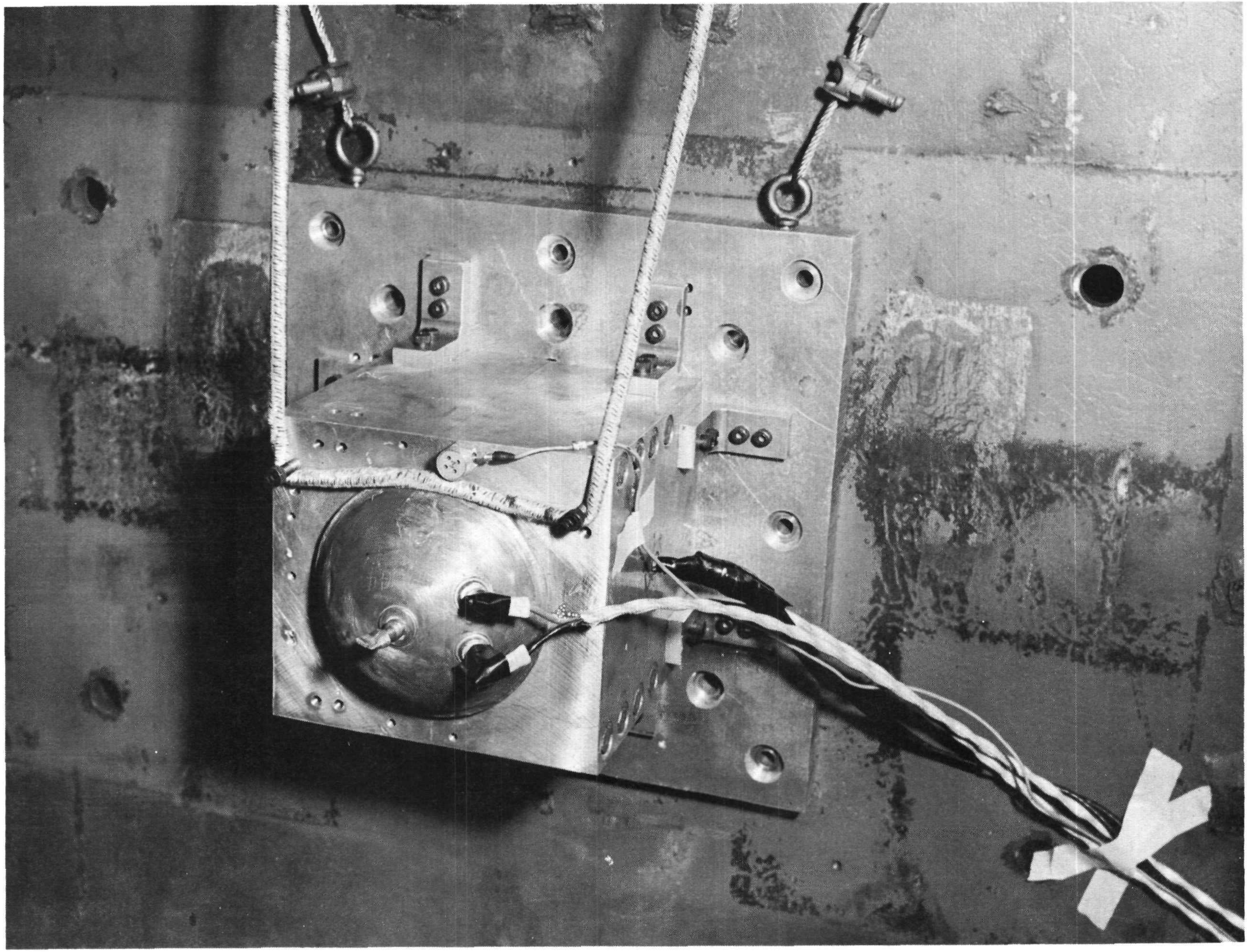

Fig. 10. Shock Test Mounting of Test Specimen

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taken before, during and after each test monitored deviations in generator efficiency caused by the environmental input to the generator. Tables 10, 11 and 12 show the shock test efficiency data.

The input to the generator and the output from an accelerometer mounted on the generator shell are shown for each shock pulse in Figs. 11, 12 and 13. The efficiency remained relatively constant throughout the shock test. The maximum variation was 3.7% of the efficiency. Recovery was complete within 5 minutes in all three planes. Figures 14, 15 and 16 show generator efficiency vs time.

DC ripple signals were recorded. The records show peak rms values of 7.4 millivolts in the y plane, 5.9 millivolts in the x plane, and 6.9 millivolts in the z plane superimposed on an output DC signal of 2.60 volts. These disappeared with the conclusion of each test cycle.

TABLE 10

Summary of Y Plane Shock Test Data--SNAP III Generator No. 1G5

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	Percent
	826	143	82	0.725	59.45	2.57	1.255	3.225	5.42
	826	143	82	0.725	59.45	2.57	1.255	3.225	5.42
Pretest	826	143	82	0.725	59.45	2.57	1.255	3.225	5.42
	826	143	82	0.725	59.45	2.57	1.255	3.225	5.42
	826	143	82	0.725	59.45	2.57	1.255	3.225	5.42
	826	143	82	0.725	59.45	2.57	1.255	3.225	5.42
First Shock	826	143	82	0.725	59.45	2.57	1.250	3.213	5.40
	826	143	82	0.725	59.45	2.57	1.235	3.174	5.34
Post- and Pretest	826	143	82	0.725	59.45	2.57	1.225	3.148	5.30
	826	143	82	0.725	59.45	2.57	1.235	3.174	5.34
	826	143	82	0.725	59.45	2.57	1.235	3.174	5.34
	826	143	82	0.725	59.45	2.57	1.235	3.174	5.34
	826	143	82	0.725	59.45	2.56	1.235	3.162	5.32
Second Shock	826	143	82	0.725	59.45	2.54	1.225	3.112	5.23
	826	143	82	0.725	59.45	2.54	1.225	3.112	5.23
Post- and Pretest	826	143	82	0.725	59.45	2.56	1.235	3.162	5.32
	826	143	82	0.725	59.45	2.56	1.235	3.162	5.32
	826	143	82	0.725	59.45	2.57	1.235	3.174	5.34

TABLE 11

Summary of X Plane Shock Test Data--SNAP III Generator No. 1G5

	Temperature (°F)		Input			Output			Efficiency
	Hot Junction	Cold Junction	Volts	Amps	Watts	Volts	Amps	Watts	Percent
	826	141	82	0.725	59.45	2.60	1.235	3.211	5.40
	826	141	82	0.725	59.45	2.60	1.235	3.211	5.40
Pretest	826	141	82	0.725	59.45	2.60	1.235	3.211	5.40
	826	141	82	0.725	59.45	2.60	1.235	3.211	5.40
	826	141	82	0.725	59.45	2.60	1.235	3.211	5.40
	826	140	82	0.725	59.45	2.60	1.235	3.211	5.40
	826	140	82	0.725	59.45	2.57	1.225	3.148	5.30
	826	140	82	0.725	59.45	2.57	1.200	3.048	5.19
First Shock	826	140	82	0.725	59.45	2.57	1.200	3.084	5.19
	826	140	82	0.725	59.45	2.59	1.225	3.172	5.34
	826	140	82	0.725	59.45	2.59	1.225	3.172	5.34
	826	140	82	0.725	59.45	2.59	1.225	3.172	5.34
	826	140	82	0.725	59.45	2.57	1.225	3.148	5.30
Second Shock	826	140	82	0.725	59.45	2.57	1.225	3.148	5.30
	826	140	82	0.725	59.45	2.57	1.200	3.048	5.19
Post-test	826	140	82	0.725	59.45	2.57	1.200	3.048	5.19
	826	140	82	0.725	59.45	2.57	1.200	3.048	5.19
	826	140	82	0.725	59.45	2.59	1.225	3.172	5.34
	826	140	82	0.725	59.45	2.59	1.225	3.172	5.34

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TABLE 12

Summary of Z Plane Shock Test Data--SNAP III Generator No. 1G5

	Temperature (°F) Hot Junction	Cold Junction	Input Volts	Input Amps	Input Watts	Output Volts	Output Amps	Output Watts	Efficiency Percent
	831	121	82	0.725	59.45	2.60	1.235	3.211	5.40
	831	121	82	0.725	59.45	2.60	1.235	3.211	5.40
Pretest	831	121	82	0.725	59.45	2.60	1.235	3.211	5.40
	831	121	82	0.725	59.45	2.60	1.235	3.211	5.40
	831	121	82	0.725	59.45	2.60	1.235	3.211	5.40
	831	121	82	0.725	59.45	2.60	1.235	3.211	5.40
First Shock	831	121	82	0.725	59.45	2.59	1.225	3.172	5.34
	831	121	82	0.725	59.45	2.57	1.200	3.084	5.19
Post- and Pretest	831	121	82	0.725	59.45	2.57	1.200	3.084	5.19
	831	121	82	0.725	59.45	2.59	1.225	3.173	5.34
	831	121	82	0.725	59.45	2.59	1.225	3.173	5.34
	826	121	82	0.725	59.45	2.59	1.225	3.173	5.34
Second Shock	826	121	82	0.725	59.45	2.59	1.225	3.173	5.34
	820	121	82	0.725	59.45	2.57	1.200	3.084	5.19
	820	121	82	0.725	59.45	2.57	1.200	3.084	5.19
Post- and Pretest	820	121	82	0.725	59.45	2.59	1.200	3.108	5.23
	820	121	82	0.725	59.45	2.59	1.225	3.173	5.34
	820	121	82	0.725	59.45	2.59	1.225	3.173	5.34

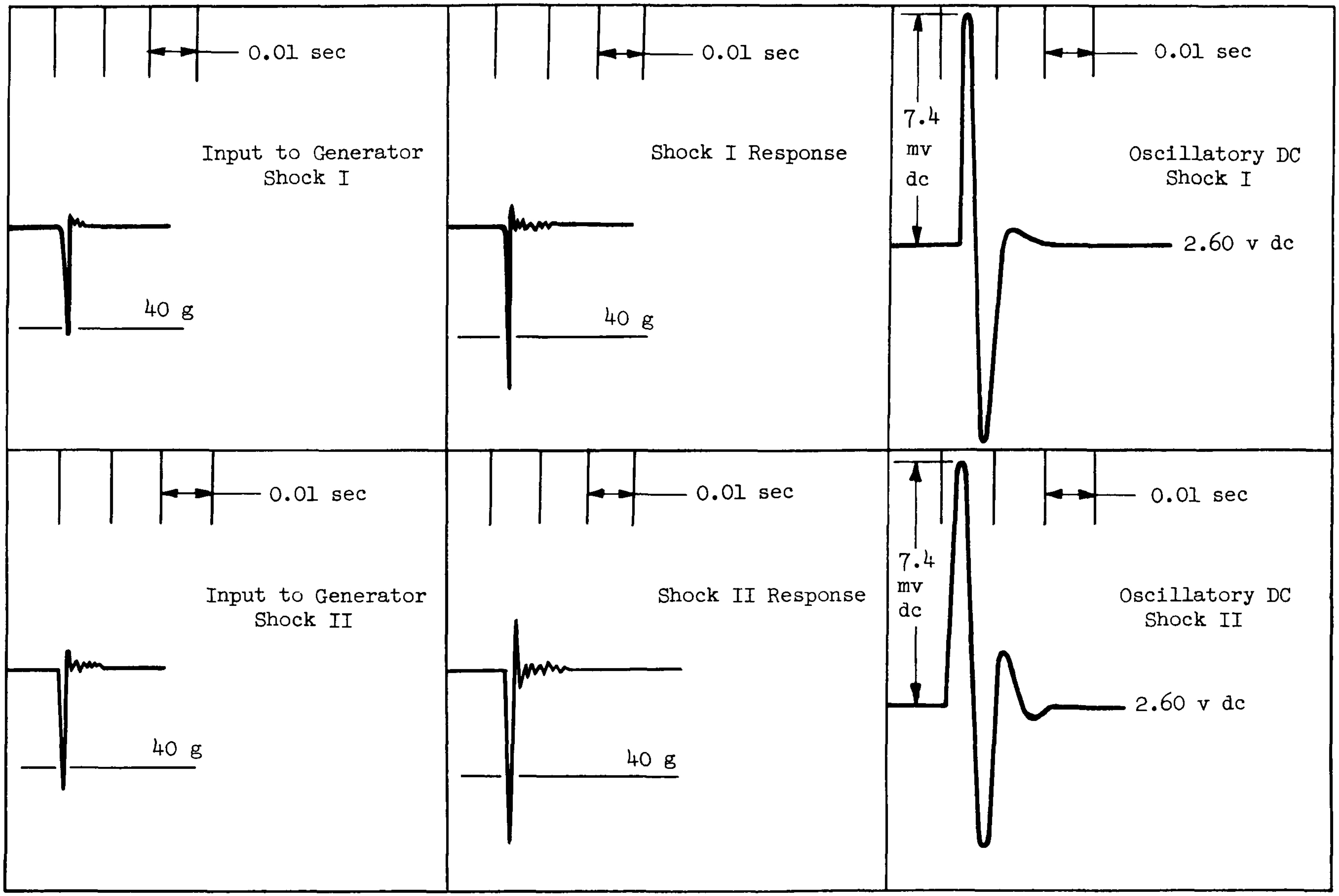

Fig. 11. Y Plane Shock Impact

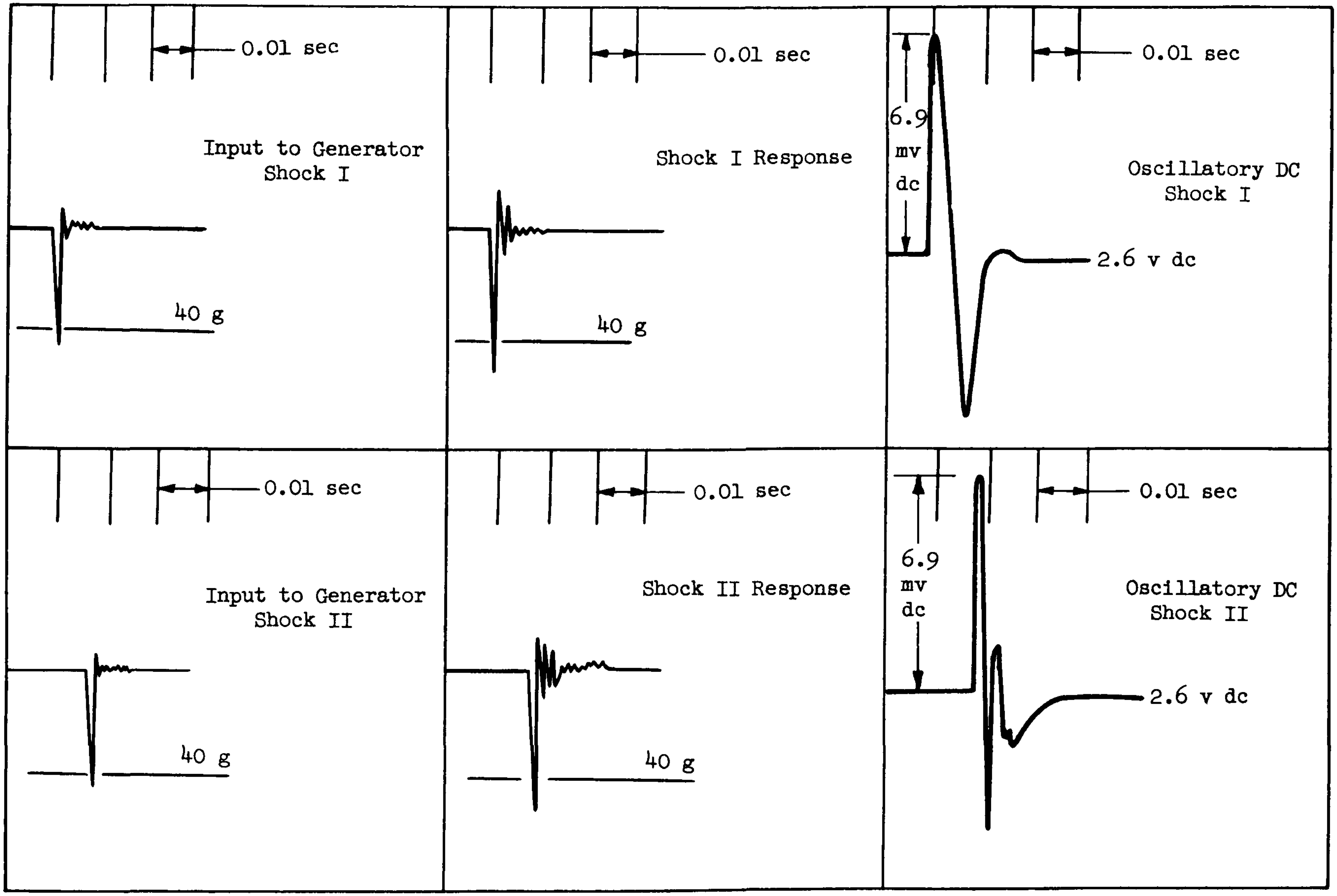

Fig. 12. Z Plane Shock Impact

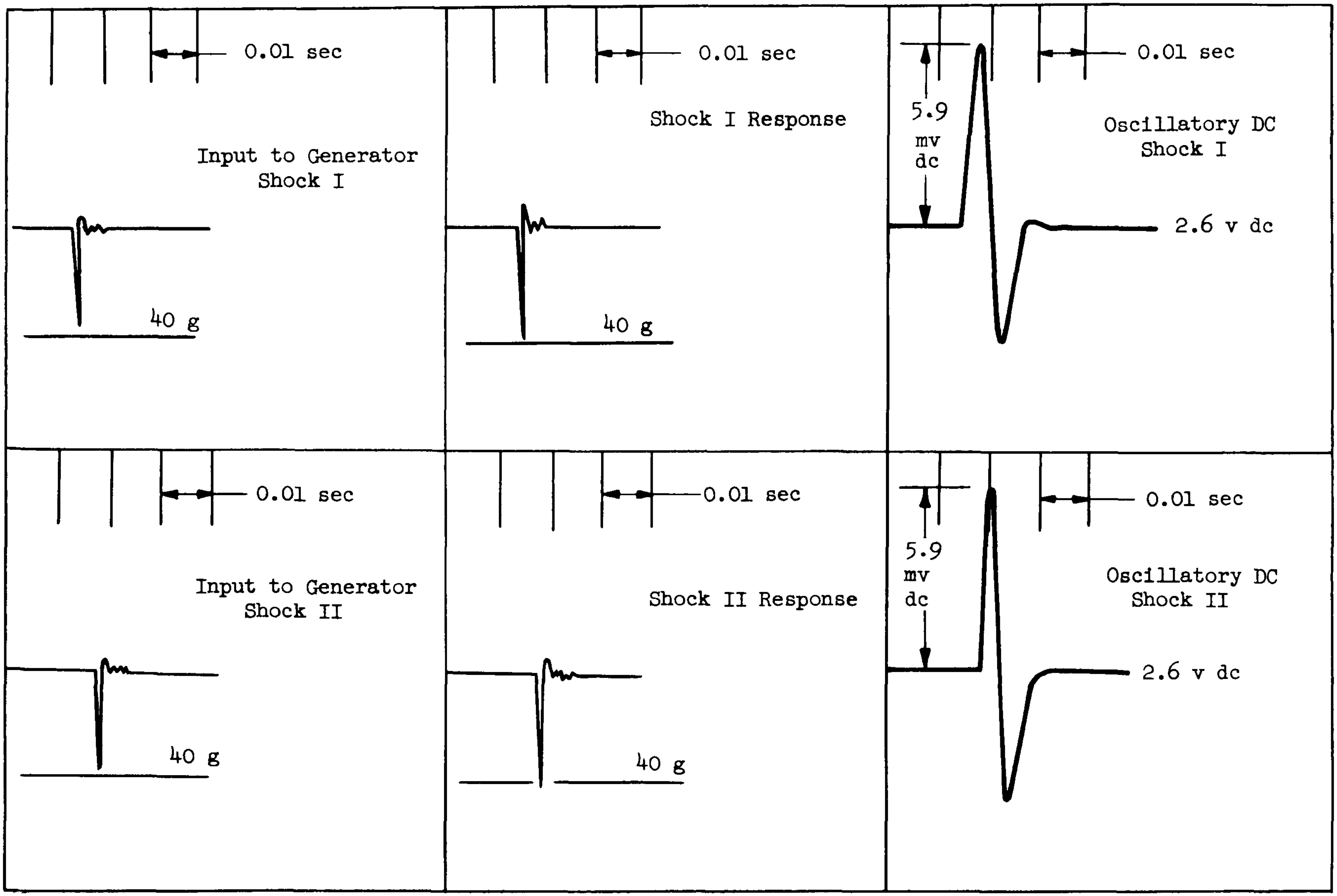

Fig. 13. X Plane Shock Impact

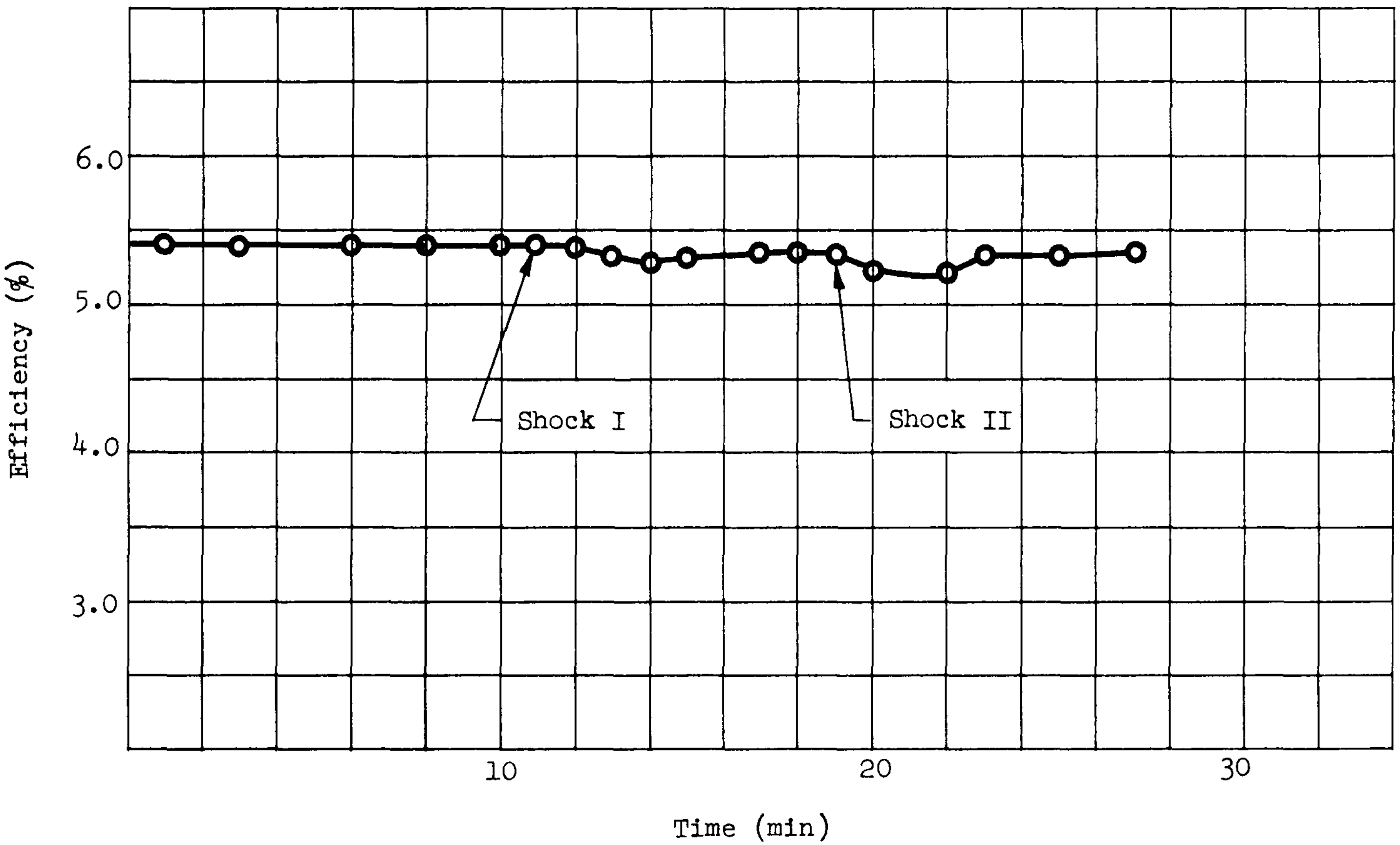

Fig. 14. Y Plane Shock Test

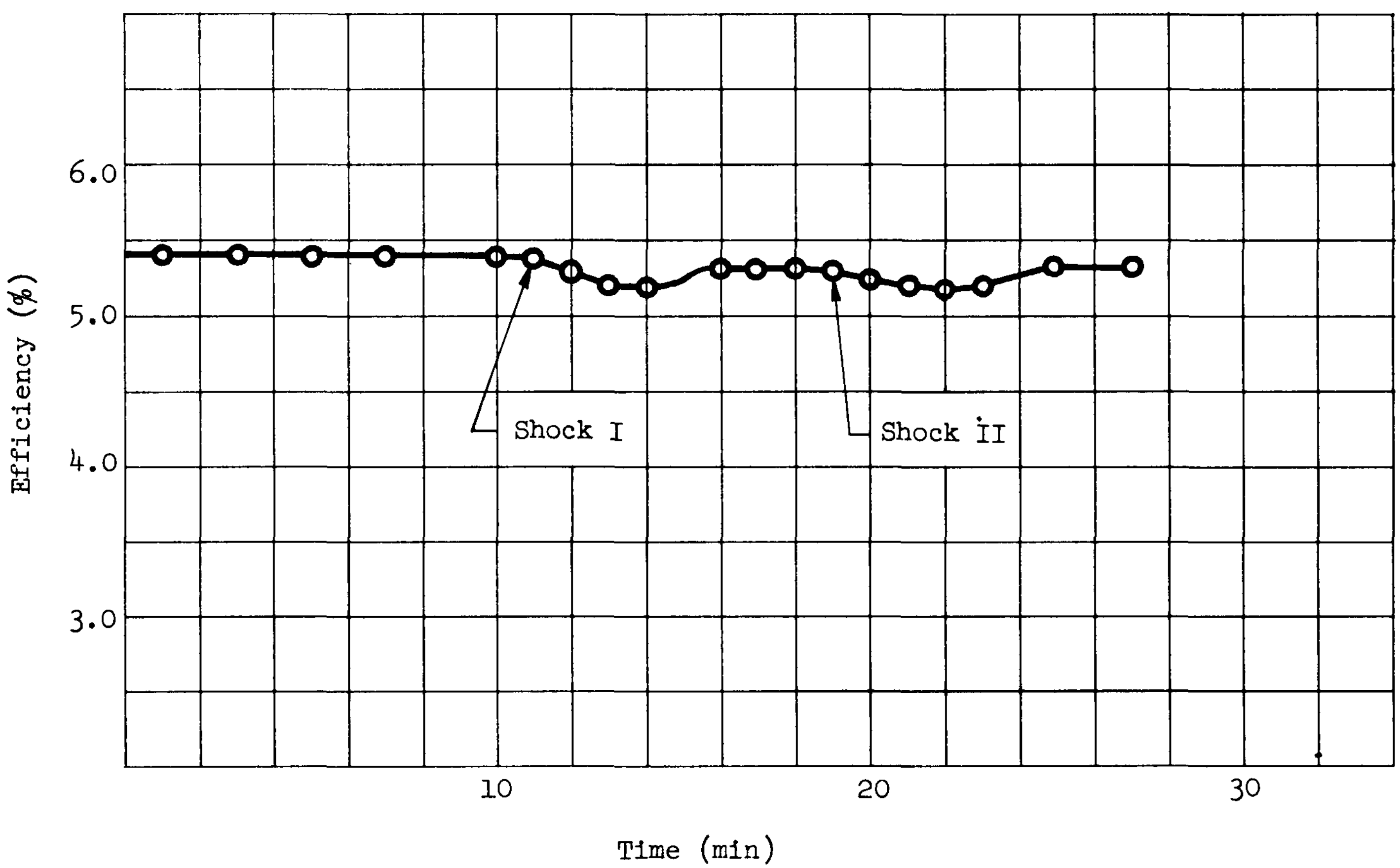

Fig. 15. X Plane Shock Test

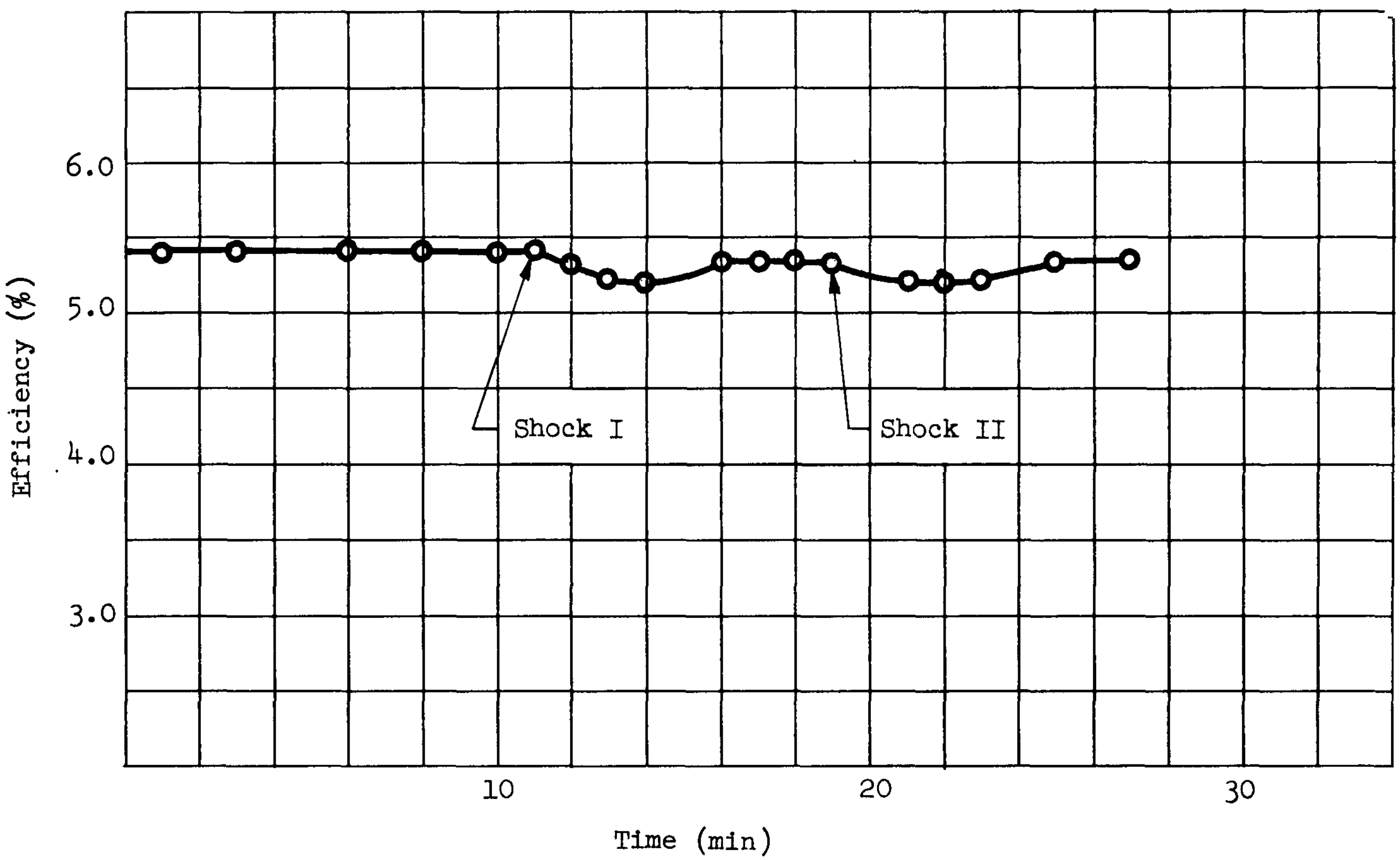

Fig. 16. Z Plane Shock Test

V. CONCLUSIONS

The generator operated for 250 hours 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 the bond of 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 and (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 30 minutes in the z 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.

Ordinarily, tests in the x and z planes produce similar results because the generator component arrangement is the same in these two test planes. Therefore, since x plane vibration test efficiency recovery was normal, the longer recovery time observed in the z plane vibration test was attributed to greater accelerations resulting from a loose fit found between the generator and fixture after this test.

The y plane absorbs the severest vibration inputs, because the forces are perpendicular to the thermoelectric elements.

DC ripple occurred only during the vibration and shock tests. The maximum value measured was 7.4 mv rms. 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.

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 volts
Crystal Accelerometer and Cathode Follower Amplifier	Endevco 2212	Serial Number 1298
2 Oscillographs	CEC 5-117	50 channel
Voltmeter AC	Weston	0 - 200 volts
Ammeter DC	Weston	0 - 10 amps
Variac AC	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 amps
AC Ammeter	Weston	0 - 2.5 amp

SPECIAL TEST EQUIPMENT

Description	Type	Range
Vibrator, Calidyne and Associated Control Console	Model No. 177	Random Motion
Centrifuge "G" Accel-erator	Genisco	0 - 75 g
High Impact Shock Tester 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 Lockheed Missile Systems Division, 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) Oscillation, if any, of DC output.

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

2.3 The test specimen shall undergo a post-test operational checkout 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 2000 cps and vary the amplitude (in.) through the control panel.

(4) Measure output of acceleration on a Ballantine Model 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 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 2000 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 $\pm$ 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 2000 cps. Run additional frequency response curves as required.

3.4.4 Calibrate the shaker output by setting a servo control to maintain a constant g level for the given sinusoid frequency of 5 to 24.5 cps, 25 to 2000 cps and 2000 to 2500 cps.

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 Ref. 1 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.

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 Reference 1 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 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 Reference 1 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 paragraph 4.3.3.1 to 4.3.3.4 changing plane of the test specimen 90° to the X axis.

(5) Repeat 4.3.3.1 to 4.3.3.4 change plane of the test specimen 90° to the Z axis.

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

APPENDIX B

PRELIMINARY TEST SPECIFICATION FOR SNAP-III THERMOELECTRIC GENERATOR FOR THE LOCKHEED MISSILE SYSTEMS DIVISION

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 Supplement No. 1.

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 characteristics 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 <u>Vibration Sinusoidal</u> - With the test specimen in operation, vibrate in a vertical direction (first plane) applying a sinusoidal input to the following environment:

(1) 5 to 24.5 cps at 1/8 in. amplitude (0-peak) ($\approx$4.5 g) for 5 min.

(2) 25 to 2000 cps at 7.5 g for 5 min.

(3) 2000 to 2500 cps at 10 g for 5 min.

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

4.5 <u>Vibration Random Motion</u> - With the test specimen in operation, vibrate in a vertical direction (first plane) applying random motion input to the following environment:

(1) Frequency range 15 to 2000 cps; power density 0.01 g^2/cps (maximum) $\approx$ 4.5 g rms; time 5 min.

(2) Frequency range 15 to 2000 cps; power density 0.002 g^2/cps (effective) $\approx$2 g rms; time 10 min.

4.5.1 Repeat procedure of Section 4.5 changing the direction of vibration 90° to the major axis (second plane) of the specimen.

4.5.2 Repeat procedure of Section 4.5 changing the direction of vibration 90° to the major axis (third plane) of the specimen.

4.5.3 Checkout - The test specimen shall undergo a specified electrical checkout during and after vibration in each plane.

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 acceleration of 10 g shall be attained, stabilized, and maintained for a period of 10 min in the longitudinal axis.

5.4.1 The applied acceleration of 2 g shall be attained, stabilized and maintained for a period of 10 min in the remaining two lateral axis at right angles to the longitudinal axis.

6.0 Shock Tests

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

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 two (2) 40 g shock in each of the three mutually orthogonal directions. The wave form of this shock is to include an acceleration of 40 g magnitude with a rise time of one millisecond.

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