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SNAP-III....

Thermoelectric Generator Environmental Test

VOLUME III

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SNAP-III.....

Thermoelectric Generator Environmental Test

VOLUME III

MND-P-2101-III

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FOREWORD

This report was prepared by the Nuclear Division of the Martin Company under contract AT(30-3)-217 with the United States Atomic Energy Commission. It describes the effects of simulated space vehicle vibration, acceleration and shock on the electrical output 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, and by the Lockheed Missile Systems Division for the WS117L vehicle.

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SUMMARY

This report summarizes the results of tests on four thermoelectric generators (two each of two different configurations) of the Snap III type to both the J.P.L. and the L.M.S.D. specifications for shock, vibration and acceleration test. The simulated levels were based on the anticipated environments of the Vega (J.P.L.) and WS117L (L.M.S.D.) systems.

All four generators exhibited the same characteristic behavior pattern throughout the vibration portion of the test program, showing a d-c ripple in the generator output only in the Y plane. This behavior of the generator is attributed to the oscillatory change in internal resistance resulting from vibratory elastic deformation of the thermoelectric elements. This produces a transient in the electrical output with a resultant reduction in generator efficiency. The maximum reduction in efficiency was noted in the 700 cps region. A resonance on the generator shell at 1845 cps was noted, but generator electrical output and efficiency were not affected. Upon discontinuance of the induced vibration, the generators returned to normal operating conditions.

While undergoing shock test, a d-c transient was noted at the time of impact, resulting in a slight decrease in efficiency. The generators immediately returned to their normal operating efficiency.

In the acceleration portion of the test no d-c transient was evident in any of the three planes, therefore the generator efficiency remained constant.

Steady state conditions were re-established at the start of each new test phase (i.e., changing planes of excitation, changing from shock to vibration, etc.). Thus, any variation from pretest efficiency was attributed to the external load resistance becoming unmatched due to the change in internal resistance. The important result is that complete generator recovery was consistent in all cases and normal operation continued.

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

As a result of this test program, it was concluded that the Snap III thermoelectric generator will operate reliably in the environments associated with the Vega and WS117L vehicles.

I. INTRODUCTION

On May 15, 1959, tests were begun in the Environmental Dynamic Test Facility at The Martin Company on four thermoelectric generators designated 1G4, 1G5, 1H2 and 1H3. These units were 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 generators were subjected to vibration, acceleration and shock environments in each of the three principal orthogonal planes in accordance with the space vehicle environmental test requirements submitted by the Jet Propulsion Laboratories and Lockheed Missile Systems Division.

These tests were concluded on October 26, 1959. The principal environmental facilities used were a Calidyne vibration shaker, a Genisco centrifuge and a special shock testing rig.

This is the third of three volumes covering the results of the SNAP III environmental test program for generators 1G4, 1G5, 1H2 and 1H3. The test results are divided among the three volumes as follows:

<u>Volume</u>	<u>JPL Specification</u>	<u>LMSD Specification</u>
I	1G4	
II		1G5
III	1G5	1G4
	1H2	1H2
	1H3	1H3

The results of these tests (time versus efficiency) in graphic form follows the written description of each generator operation.

The test procedures described in Volumes I and II are the same as the procedures used here.

II. DESCRIPTION

The configurations of all four SNAP III generators are basically the same as described in Volume I. The main differences are in the thermoelectric element diameters. The four generators used in the test are compared in Table 1.

TABLE 1
Basic Generator Comparison Data

Generator No.	Element Diameter (inches)		Interior Atmosphere	Insulation Material	Average Output (watts)
	P-Type	N-Type			
1G4	0.225	0.210	85% N ₂ 15% H ₂	MIN-K 1301	3.0
1G5	0.225	0.210	85% N ₂ 15% H ₂	MIN-K 1301	3.0
1H2	0.158	0.149	95% Ag 5% H ₂	*Diatomaceous earth and MIN-K 1301	1.5
1H3	0.158	0.149	95% Ag 5% H ₂	*Diatomaceous earth and MIN-K 1301	1.5

NOTE: The 1H series generators are rated at approximately 5% efficiency.
The 1G series are rated at approximately 6% efficiency.

*Diatomaceous earth is used in place of powdered MIN-K 1301 around the elements in the hot junction area.

Figure 1 shows a SNAP III generator undergoing disassembly. Fig. 2 shows the aluminum ring at the cold junction. Under each screw is a pressure spring. Figure 3 shows the thermoelectric element arrangement with mica electrical insulation and partially evacuated MIN-K thermal insulation. The electrical heater terminals are located in the isotopic source cylinder. Figure 4 is a plan view of the thermoelectric element arrangement. The hot shoe is constructed of low carbon steel, flame sprayed with aluminum oxide. Figure 5 is a close-up of the thermoelectric element arrangement. Figure 6 shows the soldered joint at the cold junction end with the electrical interconnecting wire.

Volume I of this report describes the SNAP III generator in more detail.

Fig. 1. Disassembly of SNAP III Generator

Fig. 2. Aluminum Ring--SNAP III Generator

Fig. 3. Thermoelectric Arrangement and Electrical Heater

Fig. 4. Radial Element Arrangement

Fig. 5. Close-up of Elements

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Fig. 6. Cold Junction Area

III. GENERATOR 1G4

The tests on generator 1G4 to the JPL specification were described in Volume I. This chapter covers the No. 1G4 test to the LMSD specification. The test procedure and specification followed are described in Volume II.

A. VIBRATION TEST

The vibration test results for sinusoidal and random motion are basically the same for each generator configuration. The maximum efficiency decrease, which was approximately 4% of the overall performance, occurred in the Y plane (Figs. 7 and 8). Since different steady-state conditions were established at the start of each test, various pretest efficiency points are evident. The input force, identical in each of the three planes, caused the greatest loss in efficiency in the Y plane, and the generator required a longer period of recovery to normal operating efficiency.

The d-c ripple was monitored throughout and showed a peak of 6.5 mv in the Y plane.

A sinusoid one-half the specified test level of from 5 to 2500 cps was applied in the X, Y and Z planes to determine the frequency at which this peak occurred. The d-c ripple was found to peak at 700 cps in the Y plane (Fig. 9).

B. ACCELERATION TEST

The generator output was normal in all three planes as illustrated in Fig. 10. The slight efficiency increase noted during acceleration in the Z plane is believed to be due to a change in ambient environment within the centrifuge and is not a typical reaction. After the test the generator immediately returned to normal operation and this apparent slight efficiency rise may be discounted in the overall evaluation of generator performance.

No transient d-c output resulted from the accelerations applied during this test.

C. SHOCK TEST

As explained in Volume I, the specification was deviated from the shock test due to equipment limitations. Two shocks of 40 g in each

of the principal orthogonal planes were substituted. A facility capable of meeting the pulse shaping requirements will be available soon.

Figures 11, 12 and 13 show the shock wave input to the mounting base, the output through the generator, and transient d-c ripple during the sequence. Figure 14 shows the efficiency variation for each shock in the three mutually perpendicular planes.

The efficiency remained effectively stable during this test phase. The maximum oscillatory d-c of 6.55 mv occurred in the Y plane. Normal operation was resumed after the environmental forces were discontinued.

Fig. 7. Efficiency Versus Time, Generator No. 1G4 X-, Y- and Z- Plane Sinusoidal Vibration Tests--LMSD Specification

Fig. 8. Efficiency Versus Time No. 1G4 X-, Y- and Z-Plane Random Vibration Tests--LMSD Specification

Fig. 9. No. 1G4 Y-Plane Frequency Response Curve--LMSD Specification

Fig. 10. Efficiency Versus Time, No. 1G4 X-, Y- and Z-Plane Acceleration Tests--LMSD Specification

Fig. 11. No. 1G4 Y-Plane Shock Test--LMSD Specification

Fig. 12. No. 1G4 X-Plane Shock Test--LMSD Specification

Fig. 13. No. 1G4 Z-Plane Shock Test--LMSD Specification

Fig. 14. No. 1G4 X-, Y- and Z-Plane Shock Tests--LMSD Specification

IV. GENERATOR 1G5

Volume II of this report covers the results of tests on generator 1G5 to the specification furnished by LMSD. The test to the JPL specification completes the current series of tests on generator 1G5. The test procedures and specifications followed are contained in Volumes I and II.

A. VIBRATION TEST

The vibration test to the JPL specifications revealed a decrease in efficiency in the Y plane only (Fig. 15). The generator returned to normal operating efficiency minutes after the vibrating force was discontinued.

The d-c ripple observed on the generator output reached a maximum of 1.8 mv in the Y plane. To determine the peak of this transient, a frequency survey from 15 to 1500 cps was conducted. A peak in the 750 cps region was recorded (Fig. 16).

B. ACCELERATION TEST

The generator operated normally throughout the acceleration test, as shown in Fig. 17. No d-c transient was observed during the test.

C. SHOCK TEST

Figures 18, 19 and 20 show the shock input to the base plate, the four separate shocks to the generator, and the oscillatory d-c in each principal orthogonal plane.

The generator behaved in a normal manner during this sequence (Fig. 21). The maximum d-c ripple of 21.5 mv occurred in the Y plane. The generator returned to normal operation when the environmental forces were discontinued.

Fig. 15. No. 1G5 X-, Y- and Z-Plane Vibration Tests--JPL Specification

Fig. 16. No. 1G5 Y-Plane Frequency Response Curve--JPL Specification

Fig. 17. No. 1G5 X-, Y- and Z-Plane Acceleration Tests--JOP Specification

Fig. 18. No. 1G5 Y-Plane Shock Test--JPL Specification

Fig. 19. No. 1G5 X-Plane Shock Test--JPL Specification

Fig. 20. No. 1G5 Z-Plane Shock Test--JPL Specification

Fig. 21. Efficiency Versus Time, No. 1G5 X-, Y- and Z-Plane Shock Test--JPL Specification

V. GENERATOR LH2

The same LMSD and JPL specifications and test procedures used for the LG series generators were used for the LH series. As shown in Table 1, the thermoelectric elements are approximately 30% smaller in diameter than those of the LG series.

A. VIBRATION TEST

Figures 22, 23 and 24 show that the generator behavior was basically the same for both the LMSD and JPL specifications. The d-c transient noted in the LG series was evident during the test on the LH series and reached a maximum of 7.6 mv in the Y plane. The generator returned to normal operating efficiency when the environmental forces were discontinued.

A frequency survey conducted from 5 to 2500 cps for the LMSD specification, and from 15 to 1500 cps for the JPL specification, showed the peak to be in the 650 cps region (see Figs. 25 and 26).

A typical calidyne shaker equalization curve and data sheet for the LH2 generator are shown in the Appendix.

B. ACCELERATION TEST

The generator operated in a normal manner during the LMSD specified tests (Fig. 27). However, there was a 2% variation in efficiency in tests to the JPL specification (Fig. 28). This is thought to be a result of a change in the laboratory ambient temperature.

C. SHOCK TEST

The shock test inputs to the generator and the transient ripple on the d-c output are shown for the LMSD specification in Figs. 29, 30 and 31, and for the JPL specification in Figs. 32, 33 and 34.

The generator showed a slight variation in efficiency for the LMSD specification, with a larger variation in efficiency noted for the JPL specification (Figs. 35 and 36). This increased variation was caused by a shock input greater than the prescribed 50 g. In all cases the generator returned to normal operation.

Oscillatory d-c was evident for both environmental specifications. The maximum d-c ripple occurred in the Y plane, and was 9.15 mv for the LMSD specification and 21.8 mv for the JPL specification. These transients disappeared at the conclusion of each shock input and normal generator operation was resumed.

Fig. 22. Efficiency Versus Time, No. 1H2 X-, Y- and Z-Plane Random Vibration Tests--LMSD Specification

Fig. 23. Efficiency Versus Time, No. 1H2 X-, Y- and Z-Plane Sinusoidal Vibration Tests--LMSD Specification

Fig. 24. Efficiency Versus Time, No. 1H2 X, Y and Z Planes--
J.F.L. Specification

Fig. 25. No. 1H2 Y-Plane Frequency Response Curve--LMSD Specification

Fig. 26. No. 1H2 Y-Plane Frequency Response Curve--JPL Specification

Fig. 27. Efficiency Versus Time, No. 1H2 X-, Y- and Z-Plane Acceleration Tests--LMSD Specification

Fig. 28. Efficiency Versus Time, No. 1H2 X-, Y- and Z-Plane Acceleration Tests--JPL Specification

Fig. 29. No. 1H2 Y-Plane Shock Test--LMSD Specification

Fig. 30. No. 1H2 X-Plane Shock Test--LMSD Specification

Fig. 31. No. 1H2 Z-Plane Shock Test--LMSD Specification

Fig. 32. No. 1H2 X-Plane Shock Test--JPL Specification

Fig. 33. No. 1H2 Y-Plane Shock Test--JPL Specification

Fig. 34. No. 1H2 Z-Plane Shock Test--JPL Specification

Fig. 35. Efficiency Versus Time, No. 1H2 X-, Y- and Z-Plane Shock Tests--LMSD Specification

Fig. 36. No. 1H2 X-, Y- and Z-Plane Shock Tests--JPL Specification

VI. GENERATOR LH3

The same specifications and test procedures used for the LG series of tests were used for the tests on generator LH3.

A. VIBRATION TEST

The greatest efficiency variations for both specifications were in the Y plane (Figs. 37, 38 and 39). The post-test increase in efficiency for the X plane sinusoidal test, LMSD specification, can be attributed to a change in laboratory ambient temperature. The important fact is that recovery was complete in all cases.

The d-c ripple was evident only in the Y plane for both specifications, and reached a 4.0-mv maximum. A frequency survey to determine the peak of this d-c ripple was conducted and showed a peak in the 700-cps region (Figs. 40 and 41).

A typical data sheet for the LH3 generator is shown in the Appendix.

B. ACCELERATION TEST

The acceleration tests to both specifications showed normal operation throughout the test phase (Figs. 42 and 43).

C. SHOCK TEST

The shock test inputs to the generator and the ripple on the d-c output are shown for the LMSD specification in Figs. 44, 45 and 46, and for the JPL specification in Figs. 47, 48 and 49.

The generator showed a slight efficiency variation in the Y plane for both the LMSD and JPL specifications (Figs. 50 and 51). In both cases recovery was complete.

Oscillatory d-c was evident for both environmental specifications. The maximum d-c ripple occurred in the Y plane, and was 23.2 mv for the LMSD specification, and 22.7 mv for the JPL specification. These transients disappeared after each shock input, and normal generator operation was resumed.

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Fig. 37. Efficiency Versus Time, No. 1H3 X-, Y- and Z-Plane Sinusoidal Vibration Tests--LMSD Specification

Fig. 38. Efficiency Versus Time, No. 1H3 X-, Y- and Z Plane Random Vibration Tests--LMSD Specification

Fig. 39. Efficiency Versus Time, No. 1H3 X-, Y- and Z-Plane Vibration Tests--JPL Specification

Fig. 40 No. 1H3 Y-Plane Frequency Response Curve--LMSD Specification

Fig. 41. No. 1H3 Y-Plane Frequency Response Curve--JPL Specification

Fig. 42. Efficiency Versus Time, No. 1H3 X-, Y- and Z-Plane Acceleration Tests--LMSD Specification

Fig. 43. Efficiency Versus Time, No. 1H3 X-, Y- and Z-Plane Acceleration Tests--JPL Specification

Fig. 44. No. 1H3 Y-Plane Shock Test--LMSD Specification

Fig. 45. No. 1H3 X-Plane Shock Test--LMSD Specification

Fig. 46. No. 1H3 Z-Plane Shock Test--LMSD Specification

Fig. 47. No. 1H3 Y-Plane Shock Test--JPL Specification

Fig. 48. No. 1H3 X-Plane Shock Test--JPL Specification

Fig. 49. No. 1H3 Z-Plane Shock Test--JPL Specification

Fig. 50. Efficiency Versus Time, No. 1H3 X-, Y- and Z-Plane Shock Tests--
LMSD Specification

Fig. 51. Efficiency Versus Time, No. 1G3 X-, Y- and Z-Plane Shock Tests--
JPL Specification

VII. CONCLUSIONS

A comparison was made of the four generators, each of which was tested to both the JPL and LMSD specifications. The operating time of each generator during the entire test program is as follows:

1G4	736 hours
1G5	790 hours
1H2	629 hours
1H3	438 hours

In general, all the generators showed the same variations and transients throughout the environmental test program. The 1H generators showed a greater deviation in power output than did the 1G generators. This could be due to an increase in element displacement of the 1H series for a given input force because of the reduced element diameter (i.e., decreased stiffness).

Overall decreases in efficiency are attributed mainly to the change in generator internal resistance. When this occurs, the external load resistance is unmatched with the internal resistance of the generator. Figure 52 is a typical performance curve taken from Ref. 1. For maximum power output, an optimum external load compatible with the internal generator resistance is required. It is obvious that an unbalanced condition immediately reduces the maximum power output and decreases the overall efficiency. Therefore, a change in resistance across any thermoelectric element within the generator can cause this variation. A new, but lower, maximum power output may be obtained with an adjusted external load resistance. This is shown by the dotted line in Fig. 52.

When the restoration process begins within the generator, a reversal of the above takes place. The internal resistance is restored to its original magnitude as the thermoelectric elements return to their static relationship. The dotted line plot in Fig. 52 reverts to the original solid curve, where maximum power output is resumed in normal operation.

The d-c transients on the power output may be caused by motion of the thermoelectric couple and hot shoe. Since the oscillograph records show complete continuity in the power output, electrical contact was maintained at all times. The motion may have been of a rocking nature,

where the contact area of the thermoelectric element changed in unison with the environmental force rather than elastic deformation of the elements themselves. In all cases, the transient d-c disappeared when the environmental forces were discontinued.

The greater efficiency variations occurred in the generators containing the thinner elements (1H series). It is therefore recommended that generator design be optimized on the keynote of rigid generator internal components. This should reduce d-c transients in the system.

In all cases the internal pressure was maintained, indicating adequate sealing design. There was no damage to the electrical insulating materials, as the output of the generator was unimpaired. It is concluded that the current design of the SNAP III generators is applicable to space vehicle environments as defined by the JPL and LMSD specifications.

Fig. 52. Power Output Versus Load Resistance for SNAP-III

REFERENCE

1. Huffman, Fred N., and Gross, Louis W., "Performance Data and Environmental Test Result of SNAP III," August 26, 1959.

APPENDIX

Summary of Generator No. 1H2 Vibration Tests--LMSD Specification

X Plane									
Phase	Temperature (°F)		Input			Output			Efficiency, η (%)
	Hot	Cold	Volts	Amperes	Watts	Volts	Amperes	Watts	
Pretest	696	115	43.2	0.744	32.1	2.21	0.636	1.406	4.38
Test I						2.21	0.636	1.406	4.38
Post- and Pretest						2.21	0.636	1.406	4.38
Test II						2.23	0.636	1.418	4.42
Post- and Pretest						2.23	0.636	1.418	4.42
Test III						2.21	0.636	1.406	4.38
Post-test						2.21	0.636	1.406	4.38
Y Plane									
Pretest	712	114	44.0	0.750	33.0	2.32	0.672	1.559	4.72
Test I						2.29	0.668	1.530	4.64
Post- and Pretest						2.29	0.668	1.530	4.64
Test II						2.16	0.642	1.387	4.20
Post- and Pretest						2.29	0.668	1.530	4.64
Test III						2.23	0.652	1.453	4.40
Post-test						2.28	0.668	1.523	4.62
Z Plane									
Pretest	688	114	43.1	0.718	30.9	2.33	0.590	1.375	4.45
Test I						2.31	0.585	1.351	4.37
Post- and Pretest						2.31	0.585	1.351	4.37
Test II						2.28	0.581	1.325	4.29
Post- and Pretest						2.31	0.585	1.351	4.37
Test III						2.31	0.585	1.351	4.37
Post-test						2.31	0.585	1.351	4.37

Summary of Generator No. 1H3 Vibration Tests--JPL Specification

X Plane									
Phase	Temperature (°F)		Input			Output			Efficiency, η (%)
	Hot	Cold	Volts	Amperes	Watts	Volts	Amperes	Watts	
Pretest	708	110	43	0.808	34.74	2.135	0.685	1.462	4.21
Test I						2.115	0.678	1.434	4.13
Post- and Pretest						2.217	0.692	1.534	4.42
Test II						2.135	0.685	1.462	4.21
Post-test						2.195	0.698	1.532	4.41
Y Plane									
Pretest	716	105	43	0.808	34.74	2.217	0.692	1.534	4.42
Test I						1.875	0.600	1.125	3.24
Test I						2.125	0.670	1.424	4.10
Post- and Pretest						2.15	0.683	1.468	4.23
Test II						1.67	0.530	0.885	2.55
Test II						2.09	0.661	1.381	3.98
Post-test					2.115	0.67	1.417	4.08	
Z Plane									
Pretest	696	105	43	0.808	34.74	2.135	0.685	1.462	4.21
Test I						2.133	0.680	1.450	4.17
Post- and Pretest						2.183	0.698	1.513	4.36
Test II						2.143	0.688	1.474	4.24
Post-test						2.162	0.690	1.492	4.29

Fig. A-1. No. 1H2 Y-Plane Final Equalization Curve, Model 177A Calidyne Vibrator--LMSD Specification