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SHOCK, VIBRATION, AND ACCELERATION-LOAD TESTS OF A SNAP-8 MOTOR-DRIVEN LUBRICANT-COOLANT PUMP

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ABSTRACT

A lubricant-coolant pump for the SNAP-8 space power system was subjected to shock, vibration, and acceleration loads in accordance with the SNAP-8 environmental specification. Functional performance tests conducted before and after the test series indicated no discernible performance change. Disassembly and detailed inspection produced no evidence of life-limiting physical damage.

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SUMMARY

A lubricant-coolant pump for the SNAP-8 space power system was environmentally tested (shock, vibration, and acceleration) at the Lewis Research Center in accordance with the SNAP-8 environmental specification. To properly assess the effects of this testing, the pump was electrically and hydraulically tested before and after the environmental test series. In addition, the pump was run deadheaded after each phase of the shock, vibration, and acceleration testing in order to pinpoint any environment resulting in malfunction. In all cases, pump performance and operation, both before and after environmental testing, were identical. Subsequent disassembly and inspection revealed no significant physical damage to the pump. It was concluded that the SNAP-8 lubricant-coolant pump satisfactorily fulfilled the shock, vibration, and acceleration-load requirements of the SNAP-8 environmental specification.

INTRODUCTION

A SNAP-8 lubricant-coolant motor-driven pump (unit number 6/2) was tested in accordance with the shock, vibration, and acceleration-load portion of the SNAP-8 environmental specification. This was done to give assurance that this SNAP-8 component could survive the expected vehicle launch and maneuvering loads as defined in the specification. These loads were simulated by mounting the pump on the various shock and vibration machines located in the environmental laboratory at the NASA Lewis Research Center. This was the first of the major SNAP-8 components to be subjected to the shock and vibration portion of the environmental requirement. In much of the previous literature on SNAP-8, this pump is referred to as the "lubricant-coolant pump motor assembly" or "L/C PMA."

Lubricant-Coolant Pump

The SNAP-8 lubricant-coolant pump (fig. 1) circulates polyphenyl ether (4P3E) which serves as the ball bearing lubricant in both the turbine-alternator and the mercury pump. In addition, it serves as a coolant for the alternator, space seals, mercury pump motor, and various electronic components.

The pump is driven by a 208-volt, three-phase, 400-hertz motor having a design rotating speed of 8000 rpm. It is hermetically sealed, and the fluid, pumped by the centrifugal impeller, circulates through both the motor and the carbon bearings for cooling and lubrication. No external shaft seals or connections, other than electrical, are required. Figure 2 shows a cross-sectional view of this pump. One pump has operated in excess of 24 000 hours without maintenance, and two others have successfully exceeded 12 000 hours of operation.

APPARATUS

Instrumentation

A sketch of the pump showing accelerometer locations is shown in figure 3. The reference axes relevant to the direction of imposed loads are indicated in figure 1. For the shock tests, the accelerometer outputs were fed to an oscilloscope and photographically recorded. During the vibration testing, the accelerometer outputs were conditioned and recorded as G-level versus frequency.

The condition of the L/C PMA, as the various tests were completed, was monitored by use of an acoustic chamber. The pump was run inside this chamber while an acoustic recording was made; prior to environmental testing, a frequency analysis of this recording was made in order to obtain the pump's acoustic "signature." Any significant change in this acoustic signature subsequent to any phase of testing would indicate damage within the pump.

In order to detect any change in the pump's motor characteristics, such as wire or insulation damage, an oscilloscope trace of the motor current was made for the three phases. A significant change in wave form or amplitude would indicate damage due to the previous test.

Test Facilities

The test facilities used to conduct the test series were located in the Structural Dynamics Laboratory of LeRC and included an Avco Shock Machine (fig. 4), the MB Model C60 Vibration Exciter (fig. 5), and the Tri Tech Centrifuge (fig. 6). The pump assembly was mounted on a one-inch-thick aluminum plate having attachment points suitable for installation on all loading machines involved in the test program.

TEST PROCEDURE

General

The test series was conducted with the pump filled with polyphenyl ether 4P3E as would be the case during an actual launch. The inlet and discharge pipes were capped.

The procedure included a functional test after completion of each load series along a particular axis. In this way, the exact type and direction of loading that caused any failures would have been known, and weaknesses more easily resolved. The data taken included pump dead-head pressure rise, motor current in each phase, and the acoustic recording.

In order to permit design speed to be attained with the marginal 400-hertz laboratory power supply, the pump was heated to 338 K (150° F). This reduced the viscosity of the 4P3E and consequently reduced the required starting electrical current.

Shock Tests

The shock tests were the first to be performed. The specification required the pump to be capable of withstanding three 20-g shocks in each direction (plus and minus) along three mutually perpendicular axes. The wave shape was to be a half-sine of 10-millisecond duration. Enough elapsed time was allowed between each of the three shocks for the previous vibrations to have damped out. The pump functional test was run after each set of three shocks in any one axis.

Vibration Testing

After completion of the shock testing, the pump was mounted on the MB C60 vibration exciter for the sinusoidal and random-vibration testing. The programed inputs as defined by the Vibration Section of the Specification are as follows:

Sinusoidal sweep. - This test was performed at a frequency range from 2000 to 5 cps at the rate of 1 octave per minute in each of three mutually perpendicular axes at the following input levels.

5 to 22 hertz at 0.36 cm (0.14 in.) double amplitude disp.

33 to 140 hertz at 8.0 g's peak

140 to 240 hertz at 0.02 cm (0.008 in.) double amplitude disp.

240 to 2000 hertz at 24.0 g's peak

Random vibration. - The L/C pump was subjected to random-noise excitation over a frequency interval of 20 to 2000 hertz for 5 minutes in each of three mutually perpendicular directions with loadings as follows:

20 to 200 hertz at 2 dB/octave

200 to 700 hertz at 0.64 g^2/hertz

700 to 900 hertz at 17.5 dB/octave

900 to 2000 hertz at 0.15 g^2/hertz

Acceleration Testing

The L/C PMA was mounted in the centrifuge and subjected to acceleration loads in accordance with the SNAP-8 environmental specification. The loads were imposed for 5 minutes each in the following direction and "G" level combinations:

+X axis, 6 G	+Y axis, 2 G	+Z axis, 2 G
-X axis, 3 G	-Y axis, 2 G	-Z axis, 2 G

A functional test was run between each of the above test runs.

DISCUSSION OF TESTING

Shock Tests

Table I summarizes the shock testing, showing the programed machine inputs in each axis and the responses of the accelerometers mounted on the pump, also for all three axes. In general, the response accelerometers showed little amplification with the maximum being 25 percent in the +X axis. Also, the two mutually perpendicular axes showed no more than 2 to 3 G's with a 20-G input. A sample of the data, which was taken photographically from an oscilloscope, is shown in figure 7. The nonreturn of the trace to the abscissa merely means that vibrations resulting from the shock had not fully damped when the picture was taken.

Vibration Tests

Table II is a summary of the vibration tests showing the inputs and maximum responses at the various test frequencies. During run 20, the weld that attaches the discharge tube to the pump housing cracked. At the time, the input was 24 G's in the X direction at a frequency of approximately 300 Hz. The accelerometer near the weld was reading 60 G's. The test was terminated and the weld repaired. This failure was not considered programmatically significant since in a flight configuration the discharge tube would not have been cantilevered as on the test specimen, but would have continued on to some support bracket. As a preventative measure, the tube was shortened, reducing the loading on the weld. The tests prior to the failure were repeated during runs 20 and 21, and the remainder of the vibration testing was continued without incident.

In the X axis, the 1-G sinusoidal tests showed most of the resonances at 350 to 360 Hz, with the highest amplification factor of 20 at the top of the motor housing (run 21). For the specified X-axis sweep, the resonances occurred from 250 to 300 Hz, the highest response being 110 G's at the discharge tube. In the Y-axis 1-G sweep (run 24), the resonances occurred at 360 Hz and 2000 Hz with amplification factors of 10 at the motor housing and 13 at the discharge tube, respectively. For the specification load-frequency sweep (run 25), maximums of 100 G's were noted at the pump volute and discharge tube at frequencies of 1600 and 1800, respectively.

The 1-G sweep in the Z axis (run 27) showed all resonances to be in the 800- to 1000-Hz range with a maximum value of 18 G's occurring on the pump-motor end cover at 800 Hz. A maximum of 90 G's at 760 Hz occurred at the volute housing during the specified sweep.

A typical plot of "G" level versus frequency for an accelerometer on the motor housing is shown in figure 8.

Table III shows a summary of the random-noise testing in each axis.

The random-noise vibration testing was run according to specification with the exception of the X-axis test which was 10 dB higher than specification value between 1175 and 1375 Hz. This was probably a peculiarity of the equipment and test specimen at this particular frequency, but it was not a severe overtest because of the narrow bandwidth of the excursion.

Acceleration Tests

The acceleration tests were run according to specification, the X-axis (shaft axis) being selected as the major vehicle axis. These tests were run without incident.

Functional Tests

As previously mentioned, functional tests of the L/C PMA were performed at every axis change for each test series. The parameters measured (deadhead pressure, motor current, and acoustic "signature") showed no significant change during or after the entire test series. This indicated that the pump suffered no gross damage due to the environmental testing.

RESULTS OF POST-TEST EXAMINATION

To ascertain whether the shock, vibration, and acceleration testing had damaged the pump, the unit was sent to the Aerojet Nuclear Systems Company, Azusa, California for performance testing, leakage measurements, and a complete disassembly and inspection.

External Examination

The pump was first externally inspected for damage. No signs of damage were evident. The unit passed the same helium leak test (to 10^{-7} std cc/sec leak limit) as conducted after its initial assembly. The torque required for shaft rotation was 3 in./oz, which was the same as prior to testing. The electrical three-phase and speed pickup resistances were normal with infinite resistance to ground.

Performance Testing

As part of the original assembly of the pump, a performance test was conducted at Aerojet Nuclear Systems Company, Azusa, California. This test consisted of a head-flow curve, power and current consumption, and a net positive suction head test. The original performance test, prior to the environmental testing, was normal, being directly comparable to other L/C pumps tested. Following the environmental testing, an identical test series was run on the pump. This test duplicated the previous findings and established that operationally the pump had not been affected. The test results were point-for-point identical with the original performance test.

Disassembly and Inspection

After the performance test, the pump was completely disassembled and inspected for damage. This was done visually, by dye penetrant, and dimensional check. The only damage found was galls on the motor housing-to-base contact surfaces and two abraded exposed thermocouple wires. The galling is of no consequence since these parts would be welded together when in flight configuration. The thermocouple wires were probably exposed by rubbing against the smooth part of the speed-pickup housing during the vibration testing. In pump operation these thermocouples are not used. In their disassembled position these thermocouples had just been barely exposed and were not grounded.

The rubbing of the thermocouple wire resulted from a doubled-over tight loop created by incorrect assembly. The harness should have curled about 230° counterclockwise from its protrusion through the motor-end bearing housing to the bottom area; this orientation would avoid rub points. The harness was incorrectly wound clockwise through a 130° arc. None of the power leads were affected.

The bearing surfaces and dimensions were carefully checked for abrasion, cracks, out of roundness or squareness. All were satisfactory and within the original drawing tolerances.

CONCLUSIONS AND RECOMMENDATIONS

The lubricant-coolant pump suffered neither operational nor significant physical ill effects from the environmental testing. This component is considered to be able to meet the vehicle launch and lift-off vibration conditions as defined by the SNAP-8 environmental specification and launch vehicle loads. The abrasion of two thermocouple wires in the motor harness requires a slight process modification in that area.

To prevent recurrence of the harness rub, the harness design was modified on a subsequent pump assembly with the following features:

1. Reduce weight and stiffness by removing four pairs of unused thermocouple connections. The two winding end-turn thermocouples were retained.

2. Cover the remaining thermocouple and power-lead wires, already protected with ML-varnished glass sleeving, with an overall Ben Har heat-treated Fiberglas sleeve.

3. With the harness in the final position, wrap the sleeve along with the speed-sensor wire with 1/2-inch-wide Fiberglas tape.

4. Tie the shaped harness in position to an internal post and apply ML varnish, curing eventually at 490 K (420° F). This prevents misorientation.

TABLE I. - SHOCK LOAD INPUTS AND RESPONSES

Run	Axis test	G level input	Response axis	G level response
1	-X	22	X	20
2	-X	22	Y	2
3	-X	20	Z	0
4	+X	20	X	25
5	+X	19	Y	0
6	+X	19	Z	2
7	+Y	19	X	2
8	+Y	20	Y	23
9	+Y	19	Z	3
10	-Y	20	X	2
11	-Y	20	Y	24
12	-Y	20	Z	4
13	+Z	19	X	2
14	+Z	21	Y	2
15	+Z	20	Z	22
16	-Z	21	X	2
17	-Z	22	Y	3
18	-Z	22	Z	23

TABLE II. - VIBRATION INPUT/RESPONSE SUMMARY

Run	Input axis	Programed input	Response acceler. position	Response axis	Maximum response (G)	Resonant frequency (Hz)
19	X	1.0 G	1	X	2.5	350
			2		1.9	350
			3		13	360
			4		9	350
			5		11	350
			6		11	350
20	X	0.36 cm (0.14") DA* @ 5 - 33 Hz	1	X	43	270
			2		34	270
		8 G @ 33 - 140 Hz	3		70	270
			4		60	270
		0.02 cm (0.008") DA @ 140 - 240 Hz	5		76	270
			6		70	270
		24 G @ 240 - 300 Hz				
21 (Repeat of 19)	X	1.0 G	1	X	1.5	350
			2		2.9	370
			3		20	350
			4		8.5	370
			5		9.5	380
			6		8.8	350
			7		11	370
22 (Repeat of 20)	X	0.36 cm (0.14") DA @ 5 - 33 Hz	1	X	60	250
			2		44	260
		8 G @ 33 - 140 Hz	3		75	280
			4		56	320
		0.02 cm (0.008") DA @ 140 - 240 Hz	5		77	300
			6		77	290
			7		110	270
		24 G @ 240 - 300 Hz				

*DA - double amplitude.

TABLE II. - Concluded. VIBRATION INPUT/RESPONSE SUMMARY

Run	Input axis	Programed input	Response acceler. position	Response axis	Maximum response (G)	Resonant frequency (Hz)
24	Y	1.0 G	1	Y	3.7	2000
			2		2.4	1800
			3		10	360
			4		5.8	1800
			5		6.5	360
			6		6.0	360
			7		13	2000
25	Y	0.36 cm (0.14") DA @ 5 - 33 Hz	1	Y	88	1800
			2		64	1600
			3		80	1900
		8 G @ 33 - 140 Hz	4		100	1600
			5		60	240
		0.02 cm (0.008") DA @ 140 - 240 Hz	6		58	220
			7		100	1800
		24 G @ 240 - 2000 Hz				
27	Z	1.0 G	1	Z	4.0	1000
			2		6.6	1000
			3		10	800
			4		13	1000
			5		11	800
			6		18	800
			7		11	1000
28	Z	0.36 cm (0.14") DA @ 5 - 33 Hz	1	Z	60	700
			2		80	1000/1900
			3		65	750
		8 G @ 33 - 140 Hz	4		90	760
			5		75	680
		0.02 cm (0.008") DA @ 140 - 240 Hz	6		88	700
			7		86	1650
		24 G @ 240 - 2000 Hz				

TABLE III. - RANDOM VIBRATION TEST RUNS

Run	Axis	G-level input	Duration	Overall input	Frequency
23	X	8.7	5 min	25 G	20-200
		17.8			200-700
		8.2			700-900
		12.7			900-2000
26	Y	8.7	5 min	22 G	20-200
		17.8			200-700
		8.2			700-900
		12.7			900-2000
29	Z	8.7	5 min	25 G	20-200
		17.8			200-700
		8.2			700-900
		12.7			900-2000

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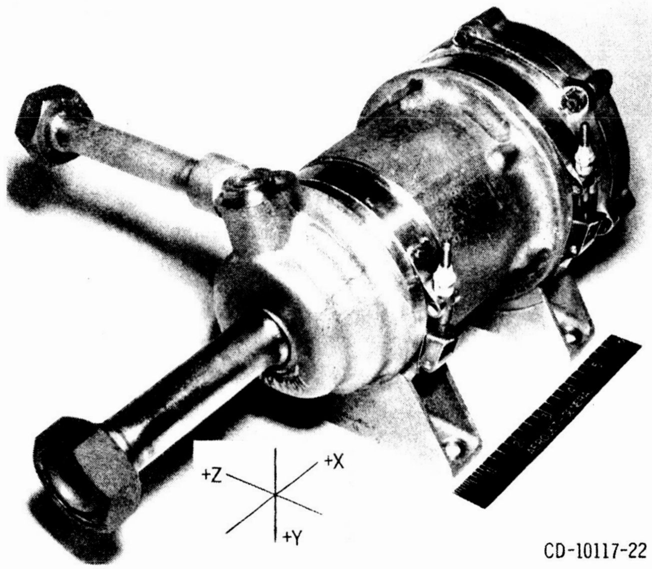

Figure 1. - SNAP 8 lubricant-coolant pump motor assembly.

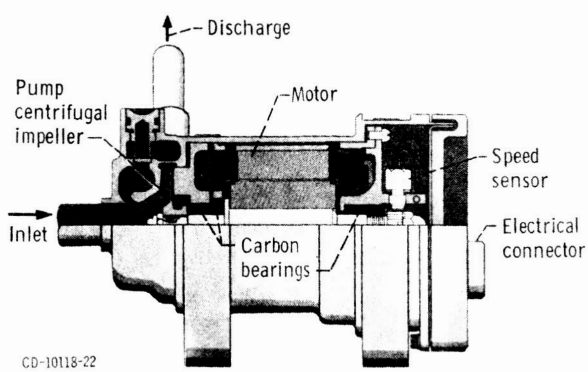

Figure 2. - Sectional view of SNAP 8 lubricant/coolant pump.

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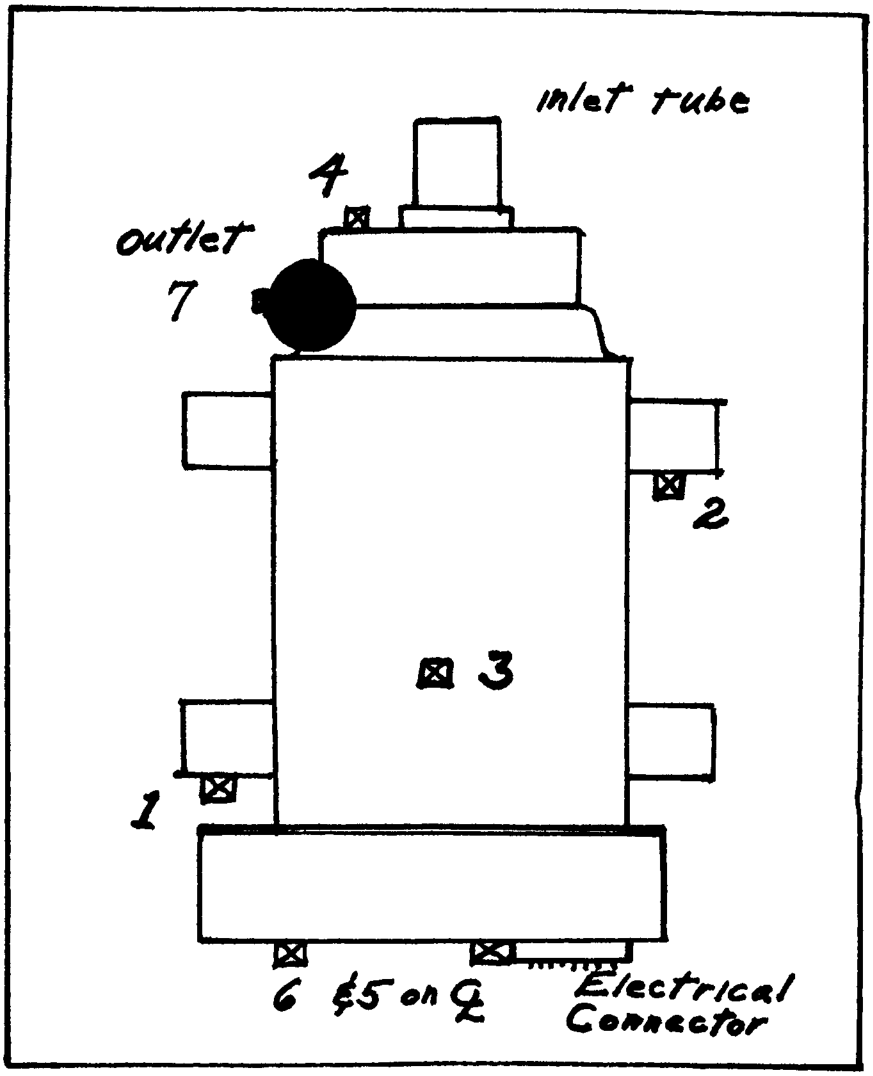

Figure 3. - Location of accelerometers on Snap-8 lubricant-coolant pump-motor assembly.

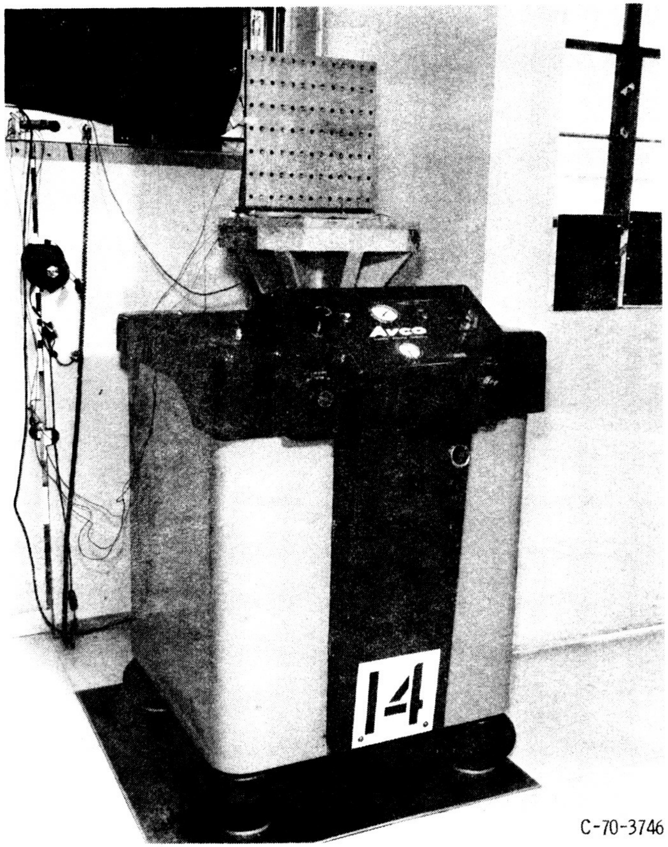

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Figure 4. - Avco shock test machine.

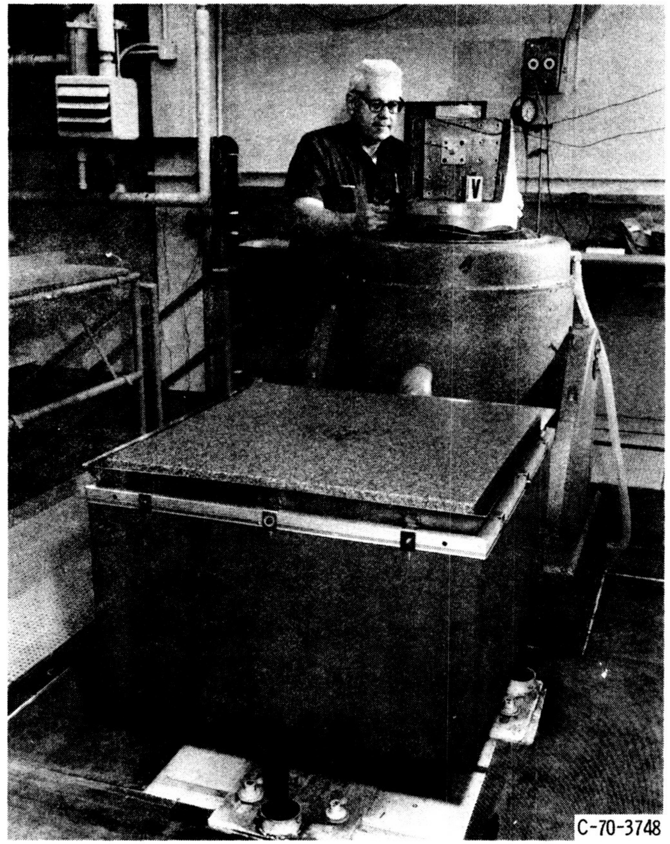

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Figure 5. - MB model C60 vibration exciter.

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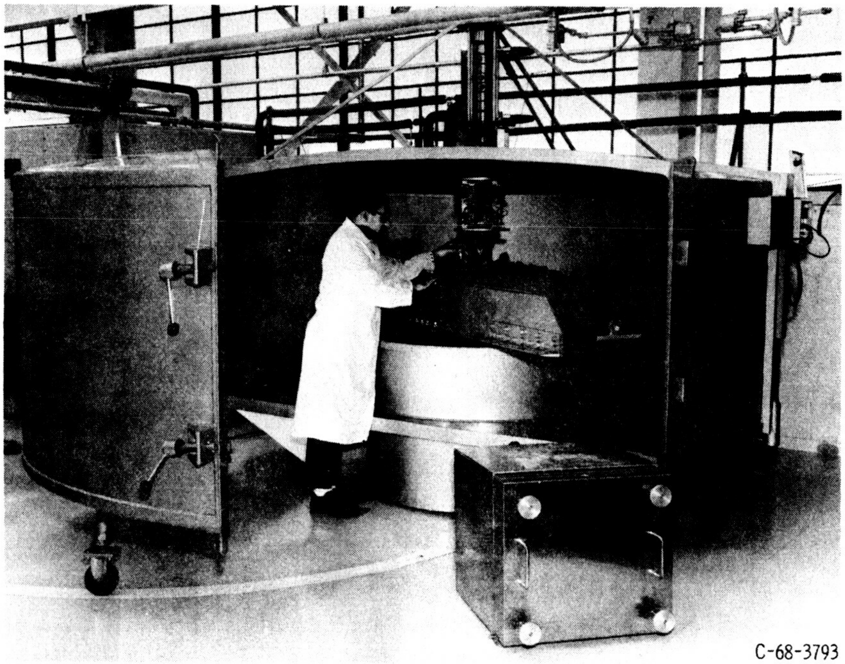

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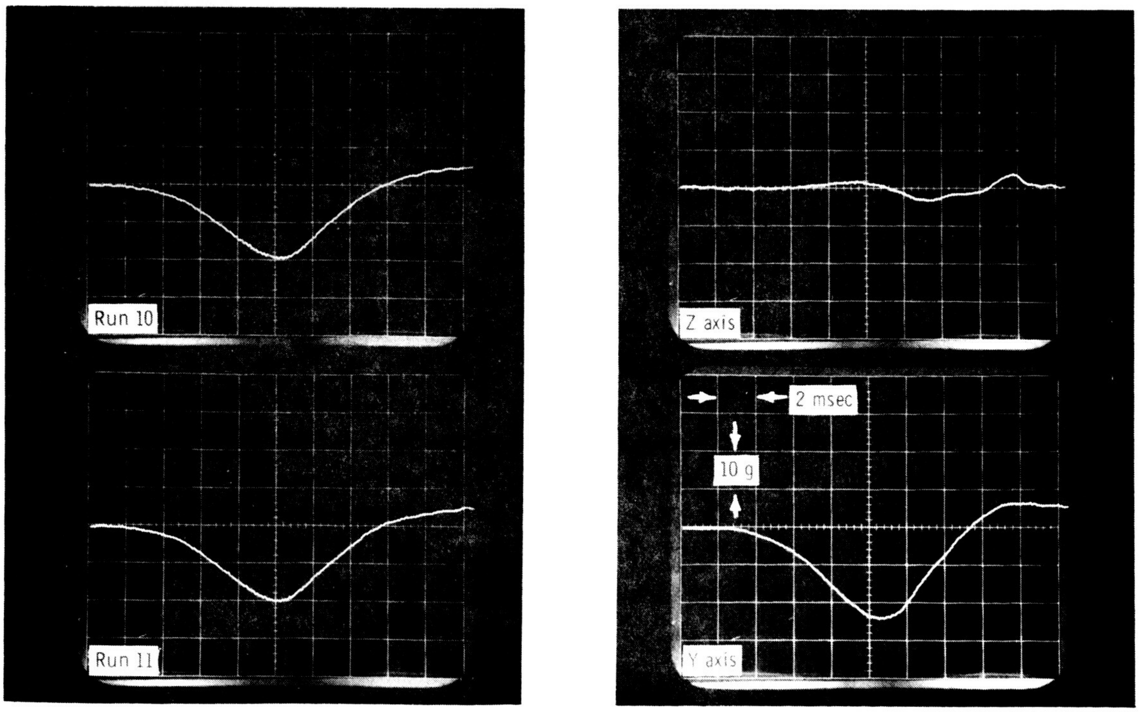
Figure 6. - Trio tech centrifuge.



(a) Control accelerometer; Y axis.

(b) Response accelerometer; run 10.

Figure 7. - Typical shock test data from control and response accelerometers.

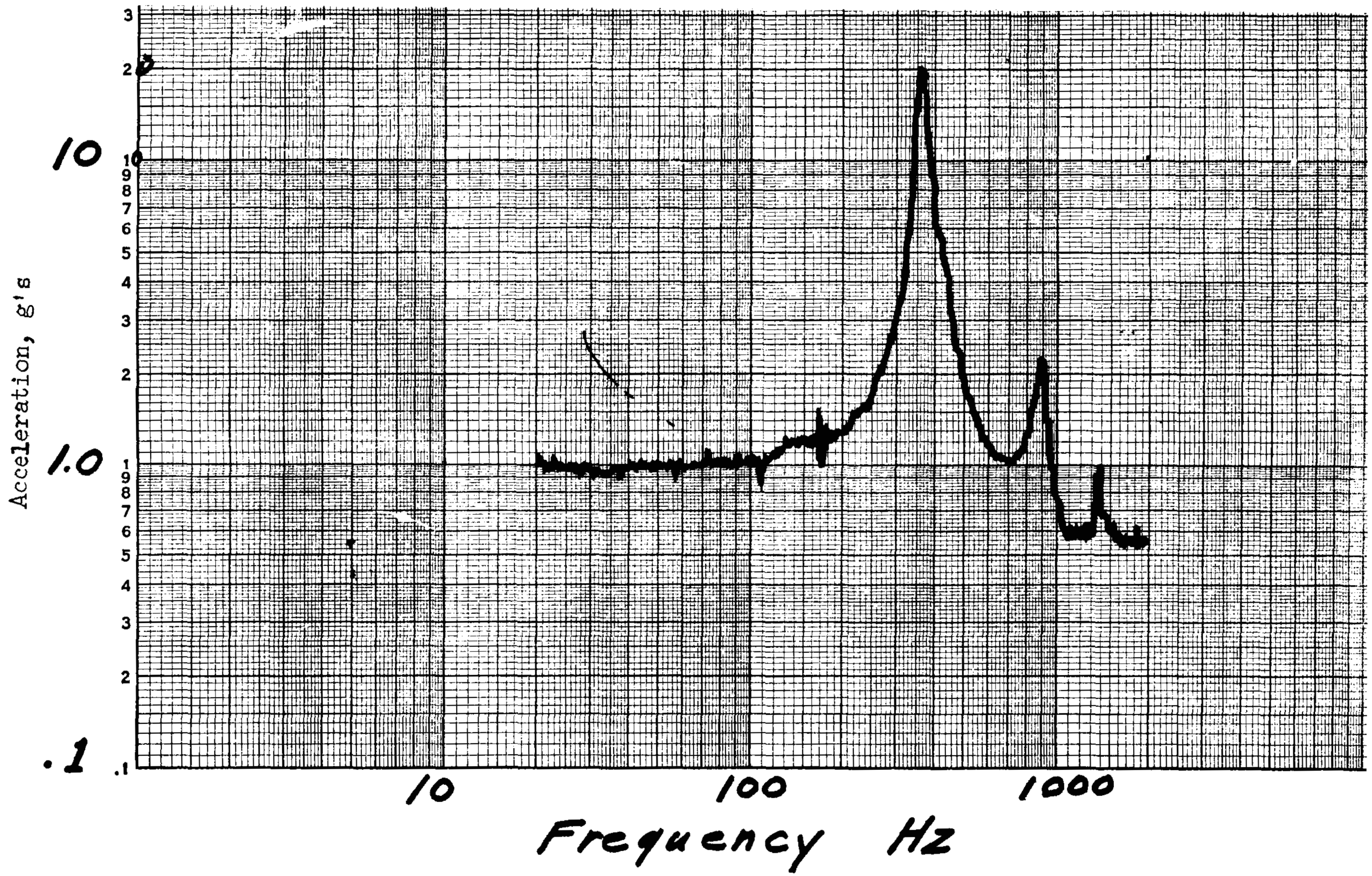


Figure 8. - Response of accelerometer 8 during X axis, 1G sweep at a rate of 1 octane/minute.