NASA TECHNICAL MEMORANDUM

NASA TM X-67945

NASA TM X-67945

SHOCK AND VIBRATION TESTS OF A SNAP-8 NaK PUMP

by A. J. Stromquist, R. B. Nelson, and Lawrence Hibben
Lewis Research Center
Cleveland, Ohio

October, 1971

SHOCK AND VIBRATION TESTS OF A SNAP-8 NaK PUMP

by A. J. Stromquist, R. B. Nelson,* and Lawrence Hibben

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

E-6625

ABSTRACT

The pump used for reactor cooling in the SNAP-8 space power system was subjected to the expected vehicle launch, vibration and shock loading in accordance with the SNAP-8 environmental specification. Subsequent disassembly revealed damage to the thrust bearing pins, which should be redesigned and strengthened. The unit was operational, however, when run in a test loop after reassembly.

*Aerojet General Corporation, Azusa, California

SHOCK AND VIBRATION TESTS OF A SNAP-8 NaK PUMP

by A. J. Stromquist, R. B. Nelson,* and Lawrence Hibben

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

SUMMARY

A NaK pump from the SNAP-8 space power system was subjected to the expected vehicle launch shock and vibration as described in the NASA SNAP-8 environmental specification. This is a hermetically sealed pump with a canned motor and NaK lubricated tilting pad bearings.

After the shock and vibration testing at NASA Lewis Research Center, the NaK pump was sent to the Aerojet General Corporation, the pump contractor, for examination.

The unit was disassembled and all internal parts inspected. This inspection revealed damage to the thrust bearing pivot and anti-rotation pins. These were bent and/or partially sheared.

A partial, intermittent short-to-ground in the stator windings was also discovered. To determine if the observed damage was severe enough to prevent normal operation, the unit was tested in the NaK simulated (H_2O) test loop. The pump performed in a manner identical to its original qualification test in this loop.

Other failures that occurred during the testing were to nonprototypic components; the pump mounting system and a tube connection to a vent valve.

It was concluded that, although the pump was operational after the vibration and shock testing, it is problematical whether it would be reliable in a long duration test with hot NaK. Recommendations are, therefore, that the pins in the thrust bearing assembly be strengthened. The weakness that caused the stator winding intermittent short-to-ground had been previously corrected in subsequent pumps. The failure of the pump mount indicates that the flight-type mount will have to be carefully designed to allow for thermal expansion, thermal isolation, and still

*Aerojet General Corporation, Azusa, California not permit free motion under the launch vehicle loads. It is probable that mount failure in turn caused the observed internal damage. In addition, the record of the shock loads incurred in transit show that a redesign of the shipping container is required.

INTRODUCTION

The SNAP-8 power system is a nuclear power system designed to produce 35 to 90 kW of electrical power. As a part of the SNAP-8 development program, the system components are required to demonstrate capability of enduring the simulated shock, vibration and acceleration loads that are expected during vehicle launch and maneuvering and as defined in the SNAP-8 environmental specification.

One of the components tested for this capability was the NaK (a eutectic alloy of Na and K) pump (identified in previous literature as the NaK pump-motor assembly or NaK PMA).

In each of the major axes this pump was subjected to the specification values of sinusoidal and random vibration and the shock requirements. These shock and vibration tests were conducted at the NASA Lewis Research Center; the results of these tests were determined by a post-test disassembly, examination and evaluation. This included a complete operational hydraulic test of the pump by the Aerojet General Corporation (AGC), Azusa, California, as a part of contract NAS 5-417.

DESCRIPTION OF APPARATUS

NaK pump. - The pump was designed to circulate 895 K (1150° F) NaK through the SNAP-8 nuclear reactor and boiler. A second identical pump is used to circulate 533 K (500° F) NaK from the system radiator through the condenser. A photograph of this pump is shown in figure 1. A cross-sectional view of the pump is shown in figure 2.

The pump assembly consists of a centrifugal pump driven by a hermetically sealed (canned) 400 hertz squirrel-cage induction motor, rotating at 6000 rpm. The rotating components are mounted on a single shaft which is supported by hydrodynamic tilting pad bearings lubricated with NaK. Mounted on the end of the shaft opposite the main impeller is a small recirculating impeller that pumps the NaK used for motor cooling and bearing lubrication through an external, but sealed, cooling and filtration system. Reference 1 is a more complete description of this pump.

Facility. - The shock and vibration testing was conducted in the environmental test laboratory at the Lewis Research Center. Both shock and vibration was done in an MB Electronics, model C210 vibration machine, which is capable of 124 500 newtons (28 000 lbf) at frequencies of up to 2000 hertz. This machine is shown in figure 3. The NaK pump was mounted to the machine through a magnesium table base, and a rigid aluminum mounting fixture. The normal pump mounting base incorporating thermal barriers made of Dow Corning 302 silicon compound and tension springs was retained. This type of mount is required to thermally isolate the hot pump body from the adjacent structure and also allow for thermal growth.

Instrumentation. - The accelerometers, located as indicated in figure 2, were installed as follows:

(1). Main pump volute housing-three individual accelerometers (X, &, and Z axis) cemented to an aluminum block and in turn cemented to the top of the main pump volute housing. Location of the X, &, and Z test axis is shown in figure 1.

(2). Recirculating pump volute housing - a triaxial type cemented to the top of the recirculating pump housing.

(3). Pump mounting bracket - three individual accelerometers mounted to an aluminum block and cemented to the pump mounting bracket. For test runs 2 through 8, they were moved from the bracket to a position on the main pump body immediately above the bracket.

(4). End plate of motor housing - a single accelerometer oriented in the Z-axis, cemented to the end plate of the motor housing, recirculating pump end.

(5). Main motor housing - a single accelerometer oriented in the Z-axis, cemented to the center of the main motor housing in the 3 o'clock position as viewed from the main pump end.

(6). Mount base - a single accelerometer oriented in the Z-axis, cemented to the base of the pump mount.

(7). Main motor housing - a single accelerometer oriented in the Z-axis mounted on the recirculating pump end of the main motor housing in the 9 o'clock position.

(8). Main motor housing - a single accelerometer oriented in the X-axis mounted on top of the main motor housing.

DISCUSSION OF TESTING

Procedure

The pump was shipped from the Aerojet General Corporation, Azusa, California, (AGC) to the NASA Lewis Research Laboratory. A recording accelerometer was included in the shipping case so as to have a history of the shock loads incurred during shipment both before and after the test series. The results of this recording are considered when analyzing the test results.

Because the pump would be filled with NaK at launch, it should also be filled during the shock and vibration testing. To avoid the danger of a NaK filled pump during the testing, a substitute fluid, Brayco 922, was used. A comparison of the two fluids is as follows:

	Brayco 922	NaK
Specific gravity @ 20° C	0.760	0.868
Absolute viscosity @ 20° C	0.000891 $\frac{\text{newton-sec}}{\text{meter}^2}$ (0.891 centipoises)	0.00088 $\frac{\text{newton-sec}}{\text{meter}^2}$ (0.88 centipoises)
Flash point	315 K (108° F)	

The pump was also subjected to a performance test at AGC in water prior to the shock and vibration testing to establish base-line performance in terms of head, flow, and power consumption.

The previously described pump mount was bolted to the vibration machine (shaker) table adaptor. The instrumentation was then connected and a 1G sweep was made to 2000 hertz on the fixture alone in order to determine fixture resonances. The pump was then installed and the remaining instrumentation connected.

The sequence of testing was to complete all of the testing (sinusoidal, random, and shock) in the X-axis first. This was because the shaker was in the vertical position from a previous test. Upon completion of the X-axis tests, the shaker was rotated to the horizontal position and the Y- and Z-axis tests completed. Figure 3 shows the shaker in the X-axis position.

Testing in the X Axis

Sinusoidal vibration. - The first series of tests were conducted shaking in the direction of the X axis. A summary of the inputs and responses for the entire test series is contained in table I. A typical response accelerometer printout is shown in figure 4. The peak responses during the 1.0G sweep were 5.5 and 6.0G's at 275 to 310 hertz on both recirculating and main pump housings. Input to the pump control accelerometer was 1.6G's at this time. The run was completed without incident.

Random vibration. - A random vibration was imposed in accordance with the specification. The random excitation was to be conducted for 3 minutes to the power levels as follows:

20-100 Hz at 3 decibels per octave (dB/Oct) increase
100-600 Hz at 0.4 G^2/Hz
600-2000 Hz at 6 dB/Oct decrease
The total G value overall for this power level is calculated to be 19.7 rms. Response data was not recorded during the random vibration testing.

During the course of the random-X axis testing, the silicone compound thermal isolators in the pump mount failed and allowed the pump to become loose. It is believed that the springs incorporated in the mount housing strap allowed enough motion so that the impact loading on the thermal isolator blocks caused them to crumble. Following completion of the run, the pump mount was modified eliminating the springs and the thermal isolators and making the mount rigid.

Shock. - Following the random vibration testing, the NaK pump was submitted to the specification shock loading which consists of 3 - 15 G shocks (20 milisecond duration) in both directions along each of the three major axes. Response data were not recorded for any of the shock testing.

In addition to the programmed shock testing, the NaK pump received several significant shocks during transit between Lewis and AGC. These data were recorded by an accelerometer packaged with the NaK pump. After completion of the shipment, the accelerometer which was leased from the Impact-O-Graph Corporation, was sent back to them for analysis of the data. This analysis showed that the pump experienced 17 noticeable impacts with four of them equal to or greater than the specification level of 15 G's. They were 22, 15, 15.4 and 23.6 G's. The direction of these impacts was not given.

Testing in the Y Axis

Sinusoidal vibration. - A sinusoidal 1 G scan was run on the NaK pump in the Y axis. The response accelerometers showed that the change to a "hard" mount configuration had raised the natural frequency of the pump-mount combination from approximately 300 hertz to 1180 hertz on the recirculating pump housing and 820 hertz on the main volute housing with maximum G-values of 4.1 and 5.0, respectively.

Random vibration. - The random vibration test was conducted at the same power levels in the Y axis as previously described for the X axis. During the course of this run the vent valve on the stator housing broke off at the tube-to-housing weld joint. The run was stopped and a repair made to prevent leakage of the internal fluid. The run was completed without incident.

Shock testing. - Runs 11 through 16 subjected the NaK pump to the required shock testing and completed the testing in the Y axis.

Testing in the Z Axis

Sinusoidal vibration. - The sinusoidal vibration in the Z axis produced maximum G levels at 1750 hertz of 18 G's in the Y axis on the recirculating pump housing and 24 G's in the Z axis on the mounting bracket. Because of a control problem, the input, however, was 2 G's at this frequency as shown by the control accelerometer on the mounting base.

Random vibration. - The random vibration was completed in the Z axis with no visible failures.

Shock testing. - Three 15 G, 11 millisecond shocks in the positive and negative directions completed the NaK pump shock and vibration testing.

The NaK pump was then drained of the test fluid and sent to AGC with the recording accelerometer.

RESULTS - POST TEST EXAMINATION

External Examination

Before disassembly, the pump motor assembly was flushed with freon TF with the pump end in the down position. The flushing contents were filtered to catch any particles for analysis by the materials group.

The general outside condition of the unit revealed the vent valve on the stator housing had broken off at the tube to housing weld joint. The stator housing was deformed around the base mount locating hole (fig. 5) as a result of the failure of the holding strap allowing the stator housing to bounce against the pin in the base. Both of the thermocouple header locating lugs are loose but still intact. A subsequent helium leak check of the winding area showed no leakage to be present. This indicates the ceramic was not cracked through in the lug area. All three pump housing to motor housing pin to lug joints were frozen. Rapping these with a hammer did not dislodge the pins. Dye penetrant inspections of all bolt covers showed no defects.

All phase-to-phase and phase-to-neutral electrical measurements were balanced and closely comparable to pre-environmental test measurements. Insulation to ground resistance showed an infinite reading. The thermocouples had continuity and the speed sensor coil resistance was measured at 200 ohms. This is the acceptable range.

Internal Examination

The pump motor assembly was disassembled according to established procedures. Throughout the disassembly all bolts were removed with comparative ease. However, in some areas the breakaway torque was less than, or in excess of, the allowable tolerances. These values are tabulated in table II. Also shown in table II are the significant clearance measurements.

During disassembly metal particles were found throughout pump motor assembly. A concentration of these particles was found in the thrust bearing area. Also, the entire inside surfaces were coated with Moly Kote, a lubricant used on all bolts during assembly to prevent galling of the threads.

The thrust runner, support rings, and thrust pads show no signs of damage. However, the gimbal ring was chipped in both socket areas which mate with the bearing support ring as shown in figures 6 and 7. The backplate had numerous burnish marks at the interface to the housing. The housing had matching burnish marks related to the backplate and also radial indentations approximately 0.005 of an inch deep in four places matching the configuration of the backplate. The pins at the two socket joints (the side that mates with the support ring) of the motor end thrust bearing gimbal ring have both been partially sheared in the same direction. One pin was loose on the backplate mating side as seen in figures 8 and 9. The motor end backplate and housing have similar damage points as the housing and backplate on the opposite end. The antirotation pins in both housings (pins that keep the backplates from rotating during operation) were both worn to a cone shape as seen in figure 10.

The journal bearings showed minor burnishing only as a result of debris getting in between the pads and the sleeves on the rotor shaft.

The suction housing and impeller vane faces showed marks that were produced by foreign particles getting between the interfaces. The suction housing has one significant scratch approximately π radians (180°) across the face (fig. 11). All other components of the pump motor assembly showed no sign of damage as a result of the environmental test.

Analysis of the previously mentioned particulate material found inside the pump substantiates the source of the material by the damaged areas found during disassembly.

Electrical Evaluation

To further evaluate the stator housing, electrical measurements phase-to-phase, phase-to-neutral, and insulation resistance were taken at elevated temperatures. These measurements were taken in 55.6 K (100° F) increments until 589 K (600° F) was reached. At this temperature all electrical measurements were balanced. The insulation resistance was measured at 1 meg-ohm which is normal at 589 K (600° F).

The stator was oven cooled to room temperatures and electrical measurements were again taken. All phases balanced and were comparable to pre-environmental measurements; however, the insulation resistance to ground had dropped to 30 000 ohms. By rapping the side of the stator housing lightly the resistance fluctuated to 200 000 ohms. As part of the electrical examination, a surge comparison test was performed. An intermittent breakdown in voltage occurred in the phase 2 windings at 500 volts dc and a continuous short occurred at 1000 volts dc. The housing was grounded during this test. This type of test compares the voltage amplitude profile of each phase to the other phases at varying voltages. An ungrounded surge comparison test was performed with no short detected in any phase at 500 ohms, 1000 volts dc. Although the above testing indicated a potential short to ground, it was decided to run the unit in the simulated NaK (water) loop after the stator housing was leak checked. A standard helium leak check was performed on the stator winding area by opening the pinch-off-tube port and pulling a vacuum through this port. Helium was applied to the terminal headers and stator end covers and can with no leak detectable at a leak rate of $1x10^{-7}$ cc/sec. While still under a vacuum the winding area was backfilled with dry nitrogen (dewpoint 236 K (-35° F)) and sealed in the prescribed manner of a welded pinchoff and capping.

Hydraulic Performance Test

The pump motor assembly was reassembled and was tested in the simulated NaK loop to establish post shock and vibration test data. The results of the test closely compared with the pre-shock and vibration test, indicating no change in hydraulic performance. No abnormal conditions were apparent during the test.

Evaluation of Stator Winding

Because of the apparent short circuit in the stator winding, discovered during the electrical testing, some further investigation was performed. The unit was removed from the test loop and disassembled. Several tests were performed on the stator housing to determine the source of the short. These methods used low power in the micro amp range and were ineffective in clearing or sustaining the shorted area. An effort to locate the grounded area using high power was then made by discharging 95 μf capacitance of 1000 volts dc through the windings. A subsequent surge comparison test at 500 and 1000 volts dc confirmed that the "ground" had been "cleared". The stator housing was then disassembled in an effort to pinpoint the "ground" by removing the stator and end covers and carefully chipping the ceramic potting away. The "ground" was discovered where a connection knuckle of the winding had touched the stator housing near the phase 2 lead wire. After removal of the stator can, approximately 30 percent of the area between laminations and stator can had a thin coating of powdered ceramic.

CONCLUSIONS AND RECOMMENDATIONS

The results of the shock and vibration testing showed damage to the mechanical and electrical components of the NaK pump. The damage observed did not prevent operation of the pump in a water test loop, however, after reassembly.

It is problematical whether the gimbal bearing support pins which were partially sheared and bent could remain intact through a long endurance test with hot NaK. It is also problematical whether the debris founds as a result of this damage would have eventually found its way into the bearings and caused further damage. It is possible the recirculation system, which contains a filter, may have removed the debris.

The intermittent short or ground that was found in the stator winding would not have occurred had a later model of this pump been used. It had been recognized earlier in the pump program that this was a weak area and the insulation from winding to ground had been redesigned in this area.

The external damage occurred to nonprototypic parts, the cavity drain tube and the pump mounting system. It is very likely that the loosening of the pump because of the failure of the mount in turn caused vibratory impacts greatly in excess of the normal launch loads. Also, the shock loads incurred during shipment were in excess of the expected launch loads, one by 50 percent.

The recommendations for the SNAP-8 NaK pump to insure capability of surviving the present launch shock and vibration loads are as follows:

1. Design a prototype mounting system that will thermally isolate the pump from the structure while allowing thermal growth and still preload the pump sufficiently to prevent any free motion and consequent amplification of the vehicle loads.

2. A minor redesign of the thrust bearing antirotation and pivot pins to strengthen them.

3. An analysis of the pump housing to motor housing pin to lug joints to determine if clearances should be altered or material changed to prevent freezing of these joints.

REFERENCES

1. Colker, C. P.; Mah, C. S.; and Foss, C. L.: Design and Development of a Canned-Motor Pump for NaK Service. Rep. 3663, Aerojet-General Corp. (NASA CR-72823), Apr. 1971.

TABLE I

Run number	Run description	Test axis	Input amplitude or G level	Input frequency, Hz	Sweep speed, Oct./min	Run duration, min	Maximum responses			
							G level	Frequency, Hz	Axis	Location
1	Sinusoidal	X	1.6	5-2000	1.0	8.6	5.5 6.0	275-310 275-310	X Z	recirculating pump housing main volute housing
2	Random 20G rms overall	X	+3dB/Oct. $0.4G^2$/Hz -6dB/Oct.	20-100 100-600 600-2000		3.0			Not Recorded Not Recorded Not Recorded	
3,4,5	Shock	+X	15			11 msec			Not Recorded	
6,7,8	Shock	-X	15			11 msec			Not Recorded	
9	Sinusoidal	Y	1.0	5-2000	1.0	8.6	3.5 4.1 5.0	138 1180 820	Y Z Y	recirculating pump housing recirculating pump housing main volute housing
10	Random 20G rms overall	Y	+3dB/Oct. $0.4G^2$/Hz -6dB/Oct.	20-100 100-600 600-2000		3.0			Not Recorded Not Recorded Not Recorded	
11,12,13	Shock	+Y	15			11 msec			Not Recorded	
14,15,16	Shock	-Y	15			11 msec			Not Recorded	
17	Sinusoidal	Z	2.0	5-2000	1.0	8.6	18 24	1750 1750	Y Z	recirculating pump housing mount bracket
18	Random 20G rms overall	Z	+3dB/Oct. $0.4G^2$/Hz -6dB/Oct.	20-100 100-600 600-2000		3.0			Not Recorded Not Recorded Not Recorded	
19,20,21	Shock	+Z	15			11 msec			Not Recorded	
22,23,24	Shock	-Z	15			11 msec			Not Recorded	

TABLE II. - COMPARISON OF PRE-ENVIRONMENTAL TEST AND POST-ENVIRONMENTAL TEST BOLT TORQUES AND CLEARANCES

Bolt locations	Pre-environmental torque requirements		Post-environmental torque values	
	newton-meters	in-lb.	newton-meters	in-lb.
Pump housing	8.14-10.8	72-96	10.2-11.3	90-100
Recirculation pump housing	8.14-10.8	72-96	5.65-11.3	50-100
Suction housing	5.65-6.2	50-55	2.8-5.65	25-50
Journal bearing housing pump end	8.14-10.8	72-96	10.2-12.4	90-110
Journal bearing housing, recirculation pump end	8.14-10.8	72-96	9.6-10.7	85-95
Recirculation impeller lock nut	11.8-13.6	96-120	17.0	150
Main pump impeller bolt	4.0-4.5	35-40	1.7	15
Thrust bearing	8.14-10.8	72-96	10.2-10.7	90-95
Thrust bearing nut	40.7-46.4	360-420	54.3	480
Journal bearing retainer screws, recirculation pump end	5.3-6.0	47-53	2.6-2.8	23-25
Journal bearing retainer screws, pump end	5.3-6.0	47-53	2.3-2.8	20-25
Thrust bearing holding screws	3.4-4.0	30-35	3.4	30

	Assembly requirements		Post-environmental values	
	millimeters	inches	millimeters	inches
Recirculation impeller to housing clearance	0.228-0.28	0.009-0.011	0.228	0.009
Total axial end play rotor shaft	0.051-0.10	0.002-0.004	0.228	0.009

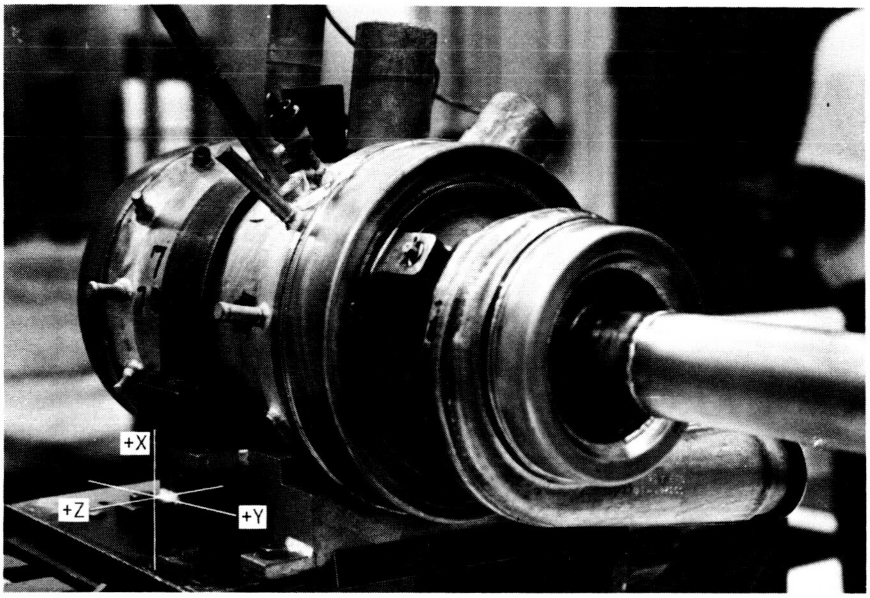

Figure 1. - SNAP 8 NaK PMA used for shock and vibration testing showing test axis.

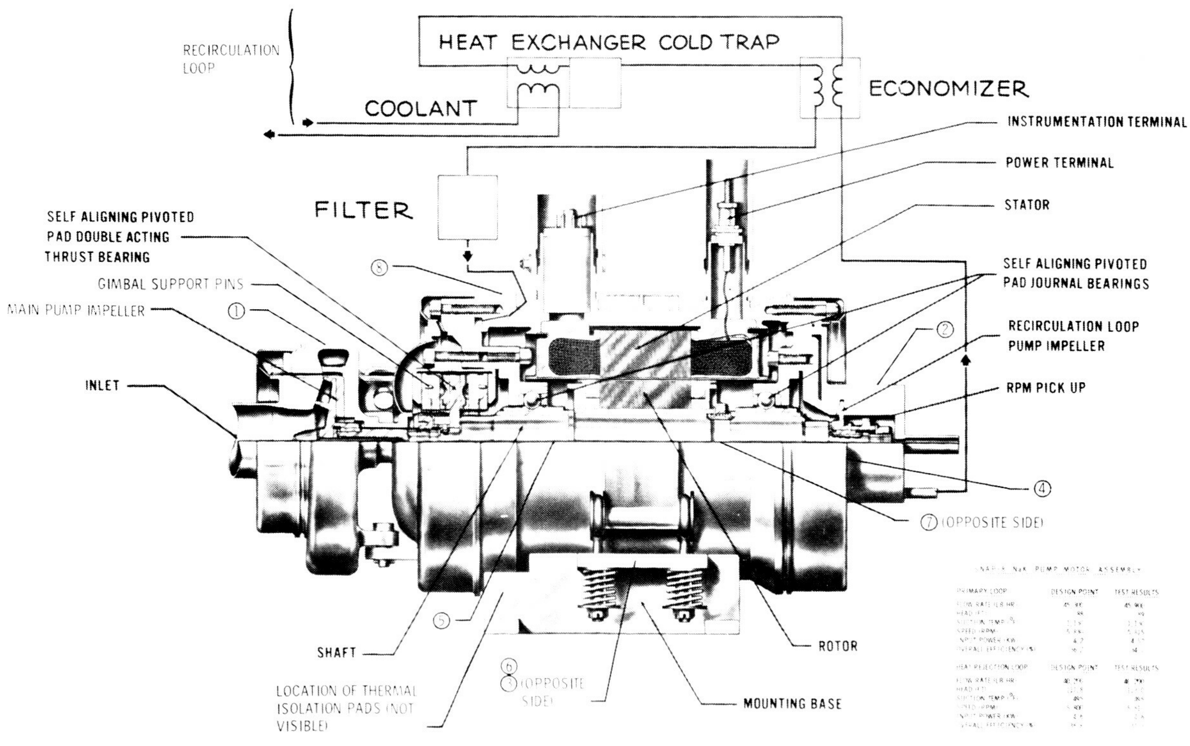

Figure 2. - SNAP 8 NaK PMA - (numerals indicate accelerometer positions).

E-6625

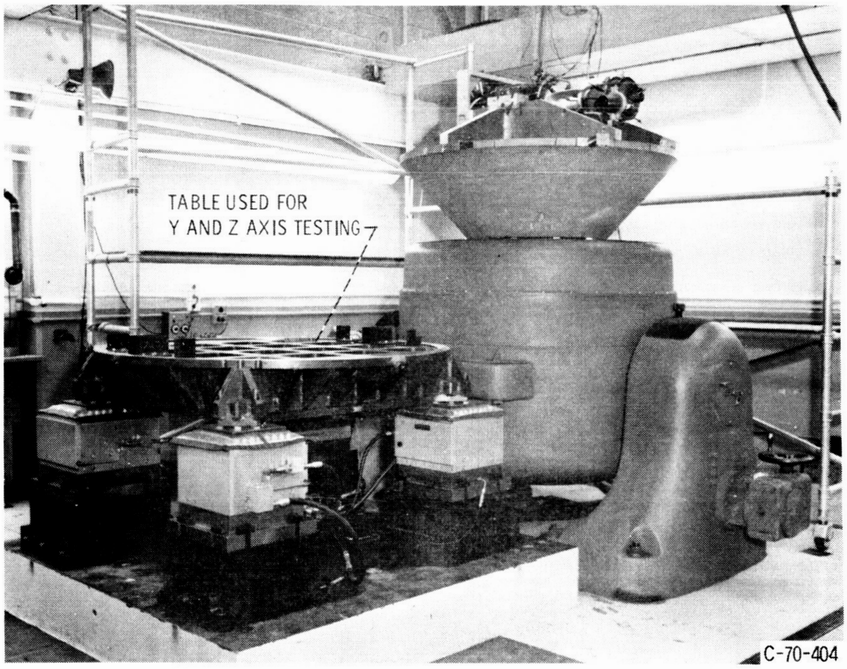

Figure 3. - MB Electronics C210 vibration and shock machine in position for X axis testing.

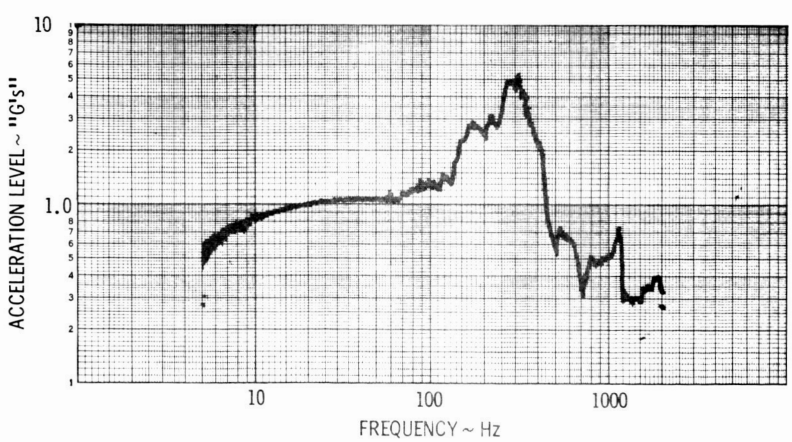

Figure 4. - Response of recirculating pump housing accelerometer - X axis, X-axis input.

E-6625

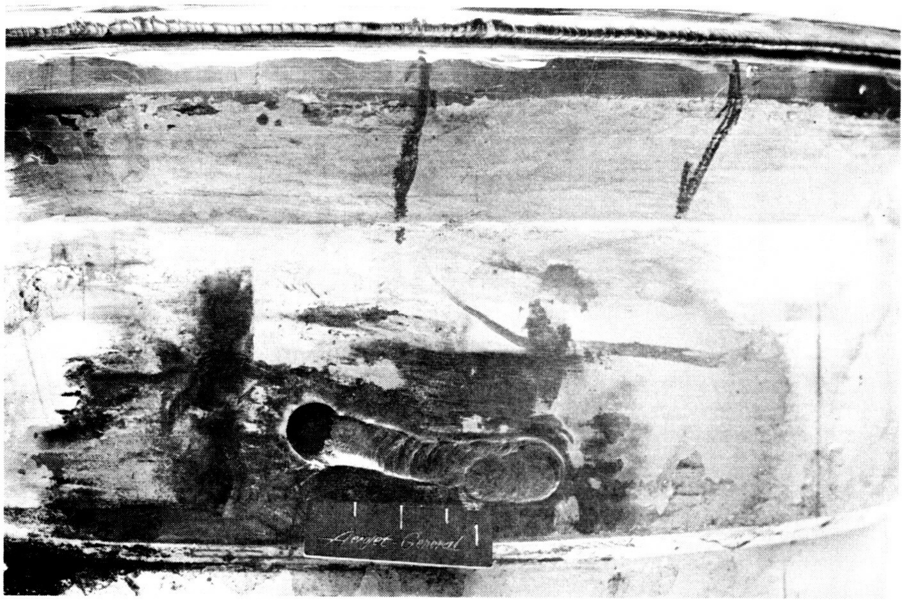

Figure 5. - Result of stator housing bouncing on base mount locating pin during environmental testing.

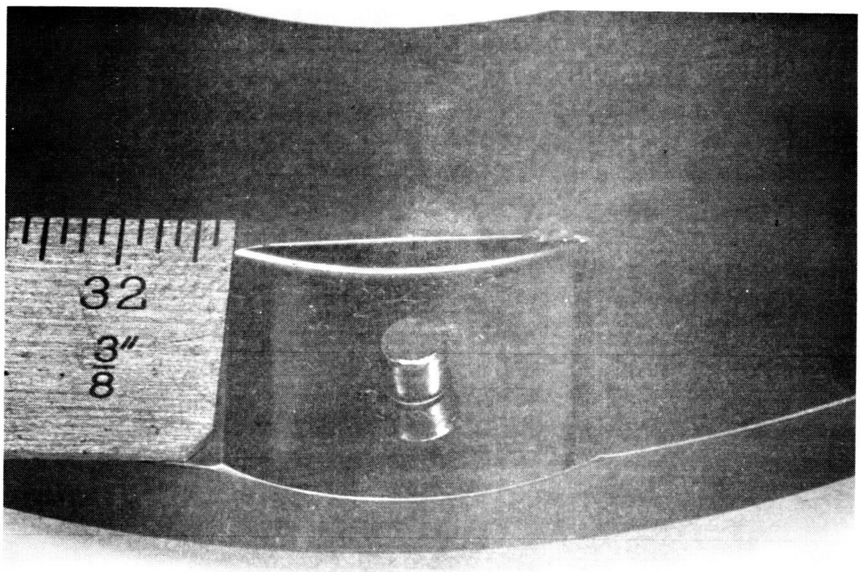

Figure 6. - Thrust bearing gimbal ring.

E-6625

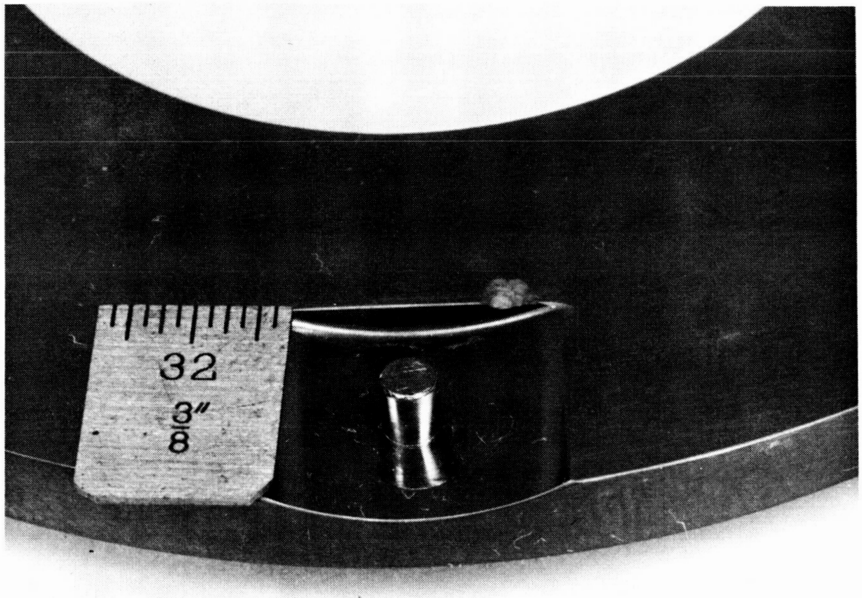

Figure 7. - Pump end thrust bearing gimbal ring.

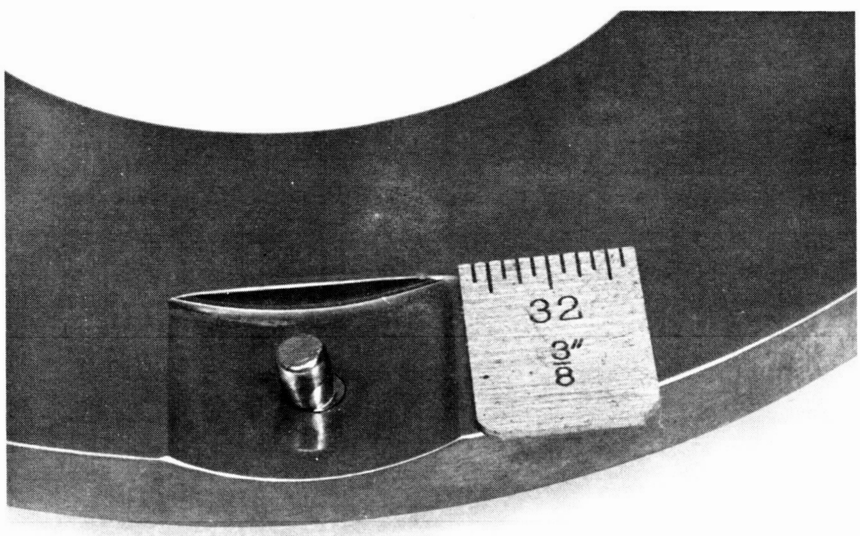

Figure 8. - Motor end thrust bearing gimbal ring with partially sheared and bent pin.

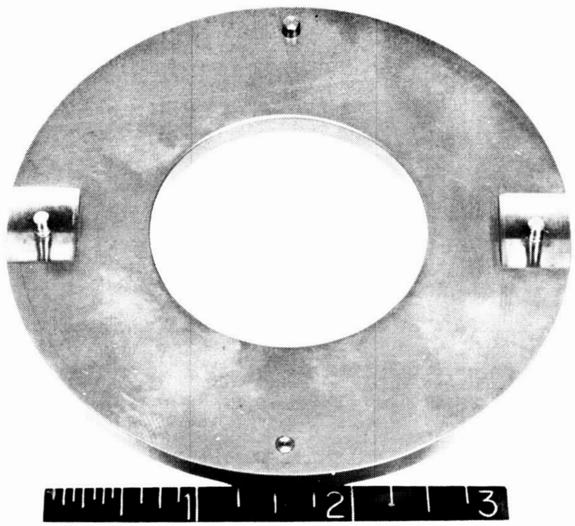

Figure 9. - Motor end thrust bearing gimbal ring showing loose pin.

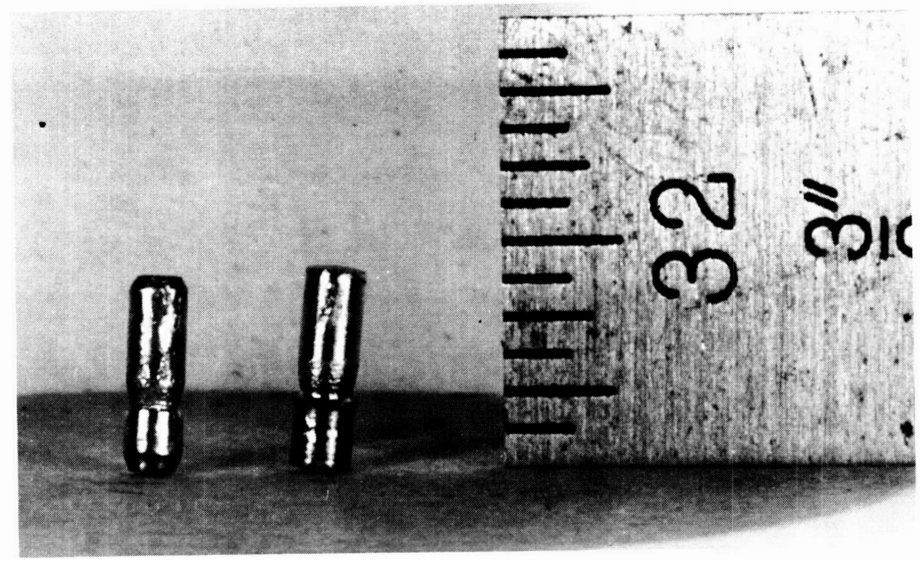

Figure 10. - Pump end thrust bearing anti-rotation pins. Wear produced by action on end plate. Bottom part of pins were in the housing.

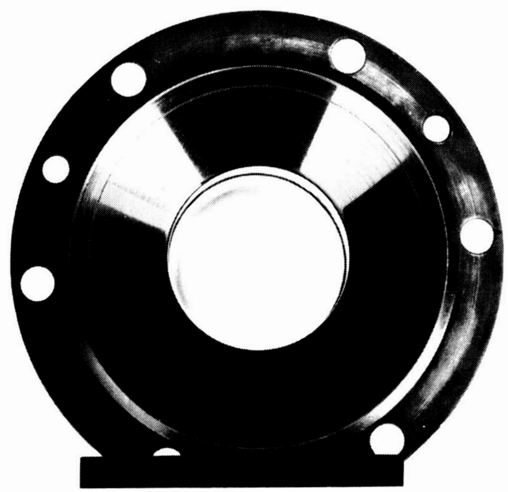

Figure 11. - Suction housing of NaK pump showing scratches.