NASA TECHNICAL MEMORANDUM

NASA TM X-1741

NASA TM X-1741

RESULTS OF ENDURANCE TESTS OF A SNAP-8 TURBINE-ALTERNATOR

by Armen S. Asadourian, Robert J. Frye, Robert P. Macosko, and Richard W. Vernon

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MARCH 1969

NASA TM X-1741

RESULTS OF ENDURANCE TESTS OF A SNAP-8 TURBINE-ALTERNATOR

By Armen S. Asadourian, Robert J. Frye, Robert P. Macosko, and Richard W. Vernon

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – CFSTI price $3.00

ABSTRACT

The SNAP-8 turbine-alternator was tested with mercury vapor in a system endurance run. Considerable long-term endurance and performance information was obtained. The turbine-alternator accumulated 1445 hours (1100 hr continuous) and was subjected to four starts and stops. During the test period, the electrical power output ranged between 36.8 and 45.6 kW. Prolonged operation of the turbine-alternator did not reveal any degradation in performance or operating characteristics.

RESULTS OF ENDURANCE TESTS OF A SNAP-8 TURBINE-ALTERNATOR

by Armen S. Asadourian, Robert J. Frye, Robert P. Macosko, and Richard W. Vernon

Lewis Research Center

SUMMARY

The SNAP-8 turbine-alternator was tested with mercury vapor in a system endurance run. Considerable long-term endurance and performance information was obtained. The turbine-alternator accumulated 1445 hours (1100 hr continuous) and was subjected to four starts and stops. During the test period the electrical power output ranged between 36.8 and 45.6 kilowatts. Prolonged operation of the turbine-alternator did not reveal any degradation in performance or operating characteristics.

INTRODUCTION

The SNAP-8 Rankine-cycle system is being developed to produce 35 kilowatts of usable electrical power for space applications. The system consists of three liquid-metal loops for power generation and an organic fluid loop which is used for cooling and lubrication. A nuclear reactor is utilized as the energy source. This energy is used to boil mercury (Hg), and the Hg vapor is then passed through a turbine-alternator to generate electrical power. One of the major design goals of SNAP-8 is 10 000 hours of operation at full power.

Since the turbine-alternator is the heart of the power conversion system, its reliability and performance are of prime importance. The performance of several SNAP-8 turbine-alternators tested by the contractor are presented in reference 1 and in "Performance of SNAP-8 Turbines" by J. N. Hodgson of Aerojet-General Corporation. However, the much-needed endurance test data are lacking and are required for assurance of the successful operation of the SNAP-8 system.

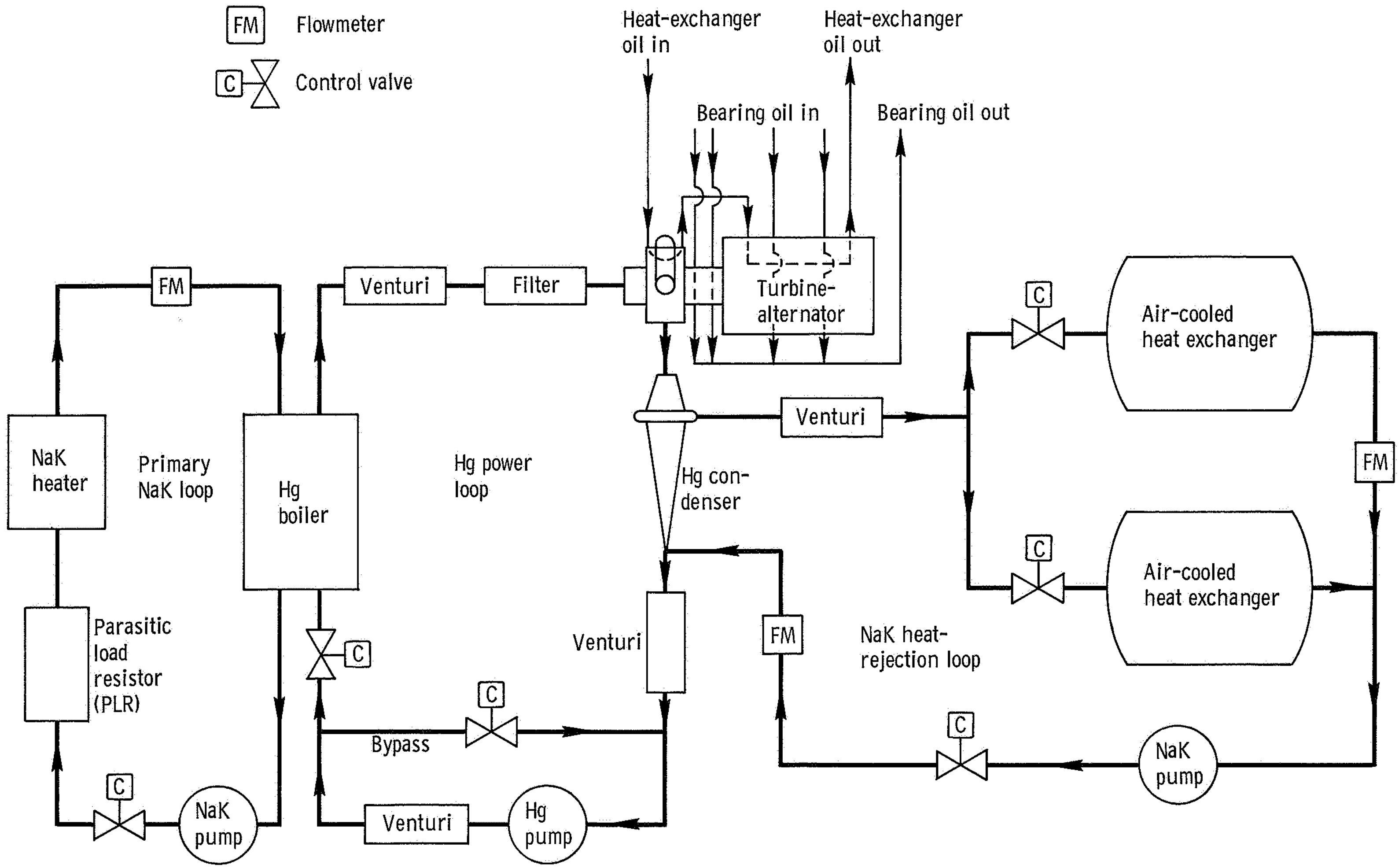


Figure 1. - Schematic diagram of test system.

In order to demonstrate the endurance capability of the turbine-alternator, as well as other components, a test facility with SNAP-8 hardware was constructed at NASA Lewis Research Center, Cleveland, Ohio. During the facility operation the turbine-alternator accumulated 1445 hours (1100 hr continuous) and was subjected to four starts and stops. Excessive Hg leakage at a weld in the piping from the boiler outlet to the turbine caused termination of the test (ref. 2).

Since the system testing consisted primarily of an endurance run, considerable long-term endurance and performance information was obtained. This information is presented in plots of the input and output conditions for the test period.

APPARATUS

The data presented in this report were acquired as part of a complete SNAP-8 system test conducted at Lewis. Figure 1 is a simplified schematic of the test system showing the major components. A more detailed system description and performance evaluation is given in reference 2. As shown in figure 1, a eutectic mixture of sodium and potassium (NaK) was circulated in the primary and heat-rejection loops by centrifugal pumps (refs. 3 and 4). In the primary loop, the NaK transferred heat from the electric heater (reactor simulator) to the Hg boiler. In the heat-rejection loop, waste heat was transferred from the condenser to two air-cooled heat exchangers used in place of the SNAP-8 system radiator.

In the power loop Hg was vaporized in the boiler and then expanded through the turbine. Mercury vapor leaving the turbine was passed through the condenser, where it was returned to the liquid state. A centrifugal pump located at the condenser outlet circulated the Hg through the power loop.

A polyphenyl ether (mix-4P3E) was used to lubricate the turbine-alternator bearings and to cool the alternator and Hg space seal. In figure 1 only the oil lines to and from the turbine-alternator are shown. The oil system was complex since oil was used for cooling and lubricating other SNAP-8 components in the system. A detailed description of the lubricant-coolant (L/C) system is presented in reference 5.

Turbine-Alternator

Figure 2 is a cutaway view of the turbine-alternator. A simplified sketch of the space seal is presented in figure 3. Components that comprise the turbine assembly are shown in figure 4.

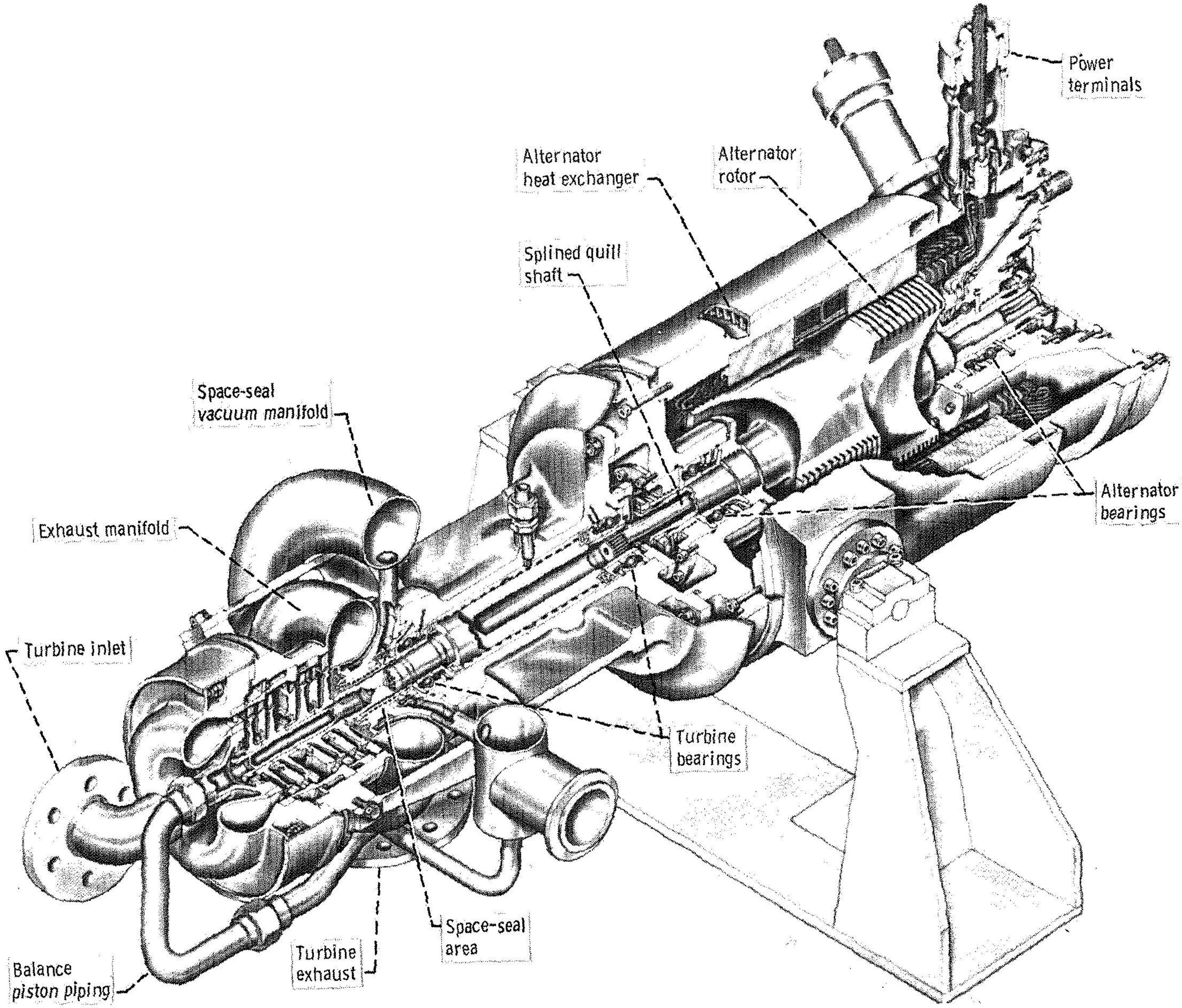


Figure 2. - SNAP-8 turbine-alternator.

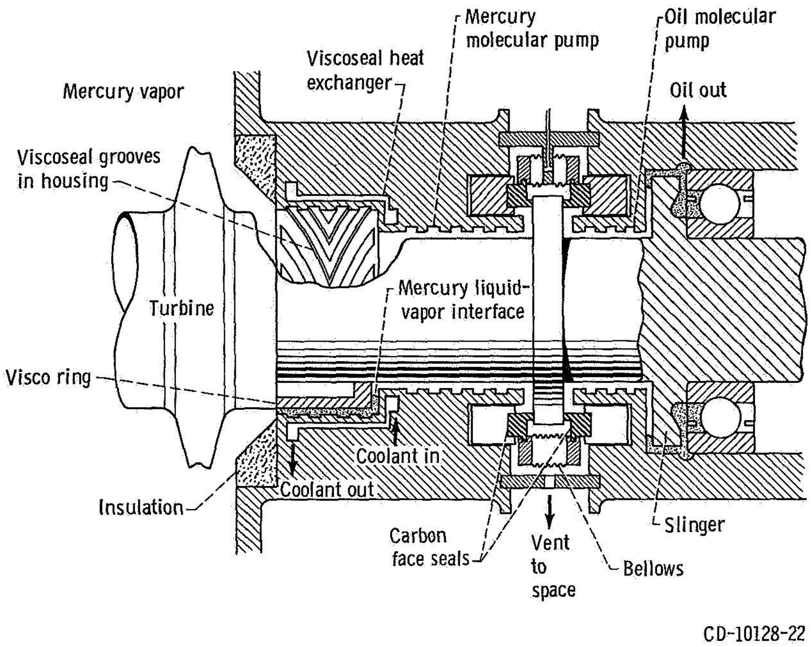


Figure 3. - SNAP-8 space seal.

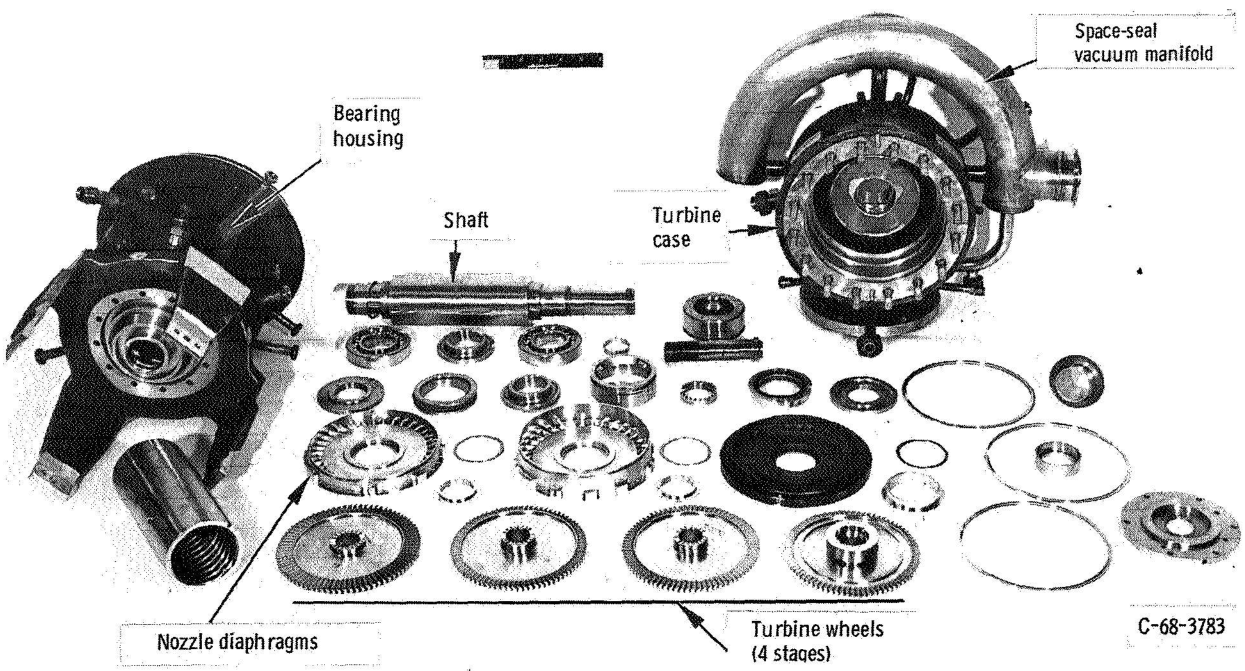


Figure 4. - SNAP-8 turbine-assembly components.

The turbine-alternator consists of two separate assemblies on a common shaft; the turbine assembly and the alternator assembly. The turbine rotor shaft is connected to the alternator rotor shaft with a splined quill shaft (fig. 2). Not shown in figure 2 are a number of oil lines that are required to distribute the L/C fluid to and from the bearings and heat exchangers.

Since the L/C fluid and Hg are in contact with the same shaft, an intermiximg of the two is possible. To prevent this a low-leakage space seal was employed (fig. 3). This seal, which is located between the turbine and its support bearing, consists of a visco pump and a molecular pump in series on the Hg side of the shaft and a series slinger and a molecular pump on the oil side. The Hg visco pump is surrounded by a L/C fluid heat exchanger that provides a Hg liquid-vapor interface by condensing Hg vapor in this area of the seal. The molecular pump returns any Hg or oil boiloff back to the liquid interface. Any molecules that escape the molecular pump are vented to space or, in the case of ground testing, to a vacuum system. The design of the space seal is presented in detail in references 6 and 7. Since the shaft seals are operative only when the shaft is rotating at greater than 50 percent of design speed, carbon face seals are employed in the turbine-alternator during the startup and shutdown phases of operation. The face seals are lifted off, with pressurized bellows, after the turbine-alternator reaches design speed. These seals can be seen in figure 3.

Turbine assembly. - Figure 4 shows the components that make up the turbine assembly. The four-stage impulse turbine is designed to operate with partial-admission (38 percent) first and second stages and full-admission third and fourth stages. The turbine assembly is overhung and supported by two angular contact ball bearings, spring loaded in a back-to-back arrangement. The bearings are lubricated by jet injection of the L/C fluid. Scavenging slinger pumps are used on both sides of each bearing to provide nonflooded bearing operation. To reduce axial bearing loads, the thrust load on the shaft is counteracted by a balance piston located at the extreme overhung position of the turbine. The piping that supplies turbine exhaust pressure to the balance piston is shown in figure 2.

Alternator assembly. - Figure 2 shows the alternator cross section. The alternator is a homopolar inductor machine. It is rated for 80-kilovolt-ampere, 120/208-volt, three-phase, 400-hertz service. It incorporates a brushless solid rotor mounted on angular contact ball bearings. Bearing lubrication is identical to that in the turbine assembly. The L/C fluid is also used to cool the alternator by passing it through a heat exchanger that surrounds the stator. Heat from the rotor is radiated to its surroundings and also is conducted to the inboard slinger seals, where it is rejected to the lubricating oil. Shown in figure 2 are hermetically sealed power output terminals, the splined quill shaft, and the alternator heat exchanger. The alternator rotor-stator cavity was vented to a vacuum system for this test.

Electrical System

The electrical schematic shown in figure 5 is a block-diagram representation of the major SNAP-8 electrical components. The static exciter is connected in series with the alternator output and provides the necessary field excitation. A voltage regulator is used to maintain constant alternator line voltage by regulating the power transfer between the static exciter and the alternator field (ref. 8). The alternator electrical output is then divided among three loads, the parasitic load resistor (PLR), the vehicle load, and the pump load.

The parasitic load was a flight-type parasitic load resistor (PLR) (fig. 1) located in the primary NaK loop. Power dissipated by this resistor was transferred to the primary NaK loop. An auxiliary load bank and transfer switch was provided as a backup in the event of a malfunction of the parasitic load resistor.

The PLR, together with the saturable reactor and speed-control amplifier, functions as the turbine speed regulator. By parasitically loading the alternator to match the power developed by the turbine, constant-speed operation is attained. The speed-control amplifier detects changes in alternator line frequency, which is directly proportional to turbine speed, and supplies a control signal to the saturable reactor, which controls the electric power to the PLR (ref. 9). For example, in the case of an increase in turbine speed, the speed control senses an increase in alternator line frequency and allows more

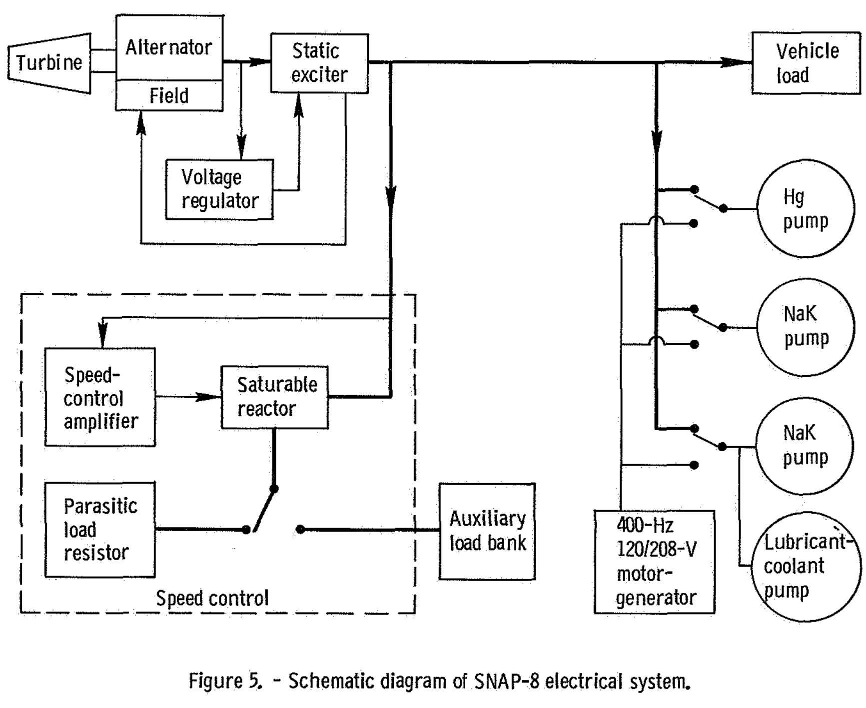


Figure 5. - Schematic diagram of SNAP-8 electrical system.

current to pass through the saturable reactor. This resulting increase in parasitic load power puts an additional load on the alternator and increases the turbine shaft torque required. A reverse process occurs for a decrease in turbine speed.

The vehicle load was a fully adjustable 125-kilovolt-ampere, 0.75-power-factor (pf) lagging load bank used to simulate possible future mission electrical loads.

The pump load consists of the four pumps (fig. 5) needed to maintain loop operation. A 400-hertz, 120/208-volt motor-generator set was used as an auxiliary power source for these pumps during startup and until satisfactory loop performance was obtained. The pump loads were then transferred to the alternator and operated with alternator power for the remainder of the run.

Instrumentation

Static pressures in the turbine were measured by inductive, slack-diaphragm, Bourdon-tube absolute pressure transducers. This type of transducer may be calibrated at room temperature and used at elevated temperatures (700° to 1300° F (644 to 978 K)) with negligible zero shift.

The Hg weight flow was measured at the boiler inlet with a calibrated venturi flowmeter. The pressure drop from the inlet to the throat of the venturi was measured by using a slack-diaphragm differential pressure transducer with the same temperature characteristics as the absolute pressure transducer.

The turbine-alternator speed was indicated by an electromagnetic reluctance probe which sensed the movement of a multiple tooth gear on the rotating shaft. All temperatures were measured by Instrument Society of America (ISA) standard calibration K (Chromel-Alumel) thermocouples.

The oil flow to the turbine-alternator was measured with turbine flowmeters. Temperatures were measured with ISA standard calibration J (iron-constantan) thermocouples. Complete information on the oil-loop instrumentation is given in reference 5.

Most of the data presented in this report were recorded on a computerized digital data system that scanned 400 data points in less than 20 seconds (ref. 10). Additional data were acquired from panel meters and digital counters in the control room.

The alternator output, parasitic load, and vehicle load electrical power measurements were made with true rms electrodynamometer wattmeters. True rms thermoelement-type voltmeters were used for both voltage and current readings. Current measurements were made by measuring the voltage across a precision shunt placed in the current transformer secondary circuit. All power instrumentation provided direct-current analog outputs which were recorded on the computerized digital data system. In general, the instrumentation used for pressure, flow, temperature, speed, and power measurements was accurate to ±1 percent. For detailed information on all the instrumentation used see reference 11.

OPERATING PROCEDURE

As stated earlier, the turbine-alternator was operated as part of an integrated SNAP-8 endurance test. The overall system startup and steady-state operation are discussed in references 2 and 5.

In brief, the turbine-alternator was started by first allowing a very low Hg flow into the preheated Hg boiler. The low vapor flow from the boiler into the turbine gradually heated the turbine inlet piping and manifold to 1000° F (811 K) and minimized the thermal shock on the turbine. After reaching a turbine inlet vapor temperature of 1000° F (811 K), the boiler inlet Hg flow control valve was opened and the Hg flow was set for 5000 to 6000 pounds per hour (2260 to 2720 kg/hr). The turbine inlet vapor temperature increased rapidly to over 1200° F (922 K). This flow rate and this temperature were sufficient to bring the turbine-alternator to rated speed (12 000 rpm) and to assure sufficient power input to the speed control for safe operation (8 kW, approx.).

The speed control was overridden during startup until the turbine-alternator reached 11 200 rpm, and it was then manually engaged. After verifying that the turbine-alternator and other system components were performing satisfactorily, the system power was increased in stepwise manner until the maximum power output was reached (45 kW, approx.). At this time the system pump loads were transferred from facility power to alternator power. Alternator power not needed for pump operation was dissipated in the parasitic load resistor and the vehicle load bank.

This generalized startup procedure was followed for all turbine starts that occurred during the course of this test.

DISCUSSION

The data presented herein are plotted against a time scale (in days). Data points were recorded at the same time of day and are 24 hours apart. The data plots begin on the second day due to instrumentation problems on the first day of operation.

The effect of time on Hg flow rate through the turbine and on turbine-alternator inlet temperatures and pressures is shown in figure 6. The Hg weight flow was measured at a liquid station. The quality of the Hg vapor has been shown from heat balance calculations (ref. 12) to be 88 to 100 percent during the test. A quality of 95 percent was obtained on the 15th day (325 hr) of operation. Therefore, in all the following discussions Hg weight flow is used as the vapor flow through the turbine-alternator. The Hg weight flow fluc-

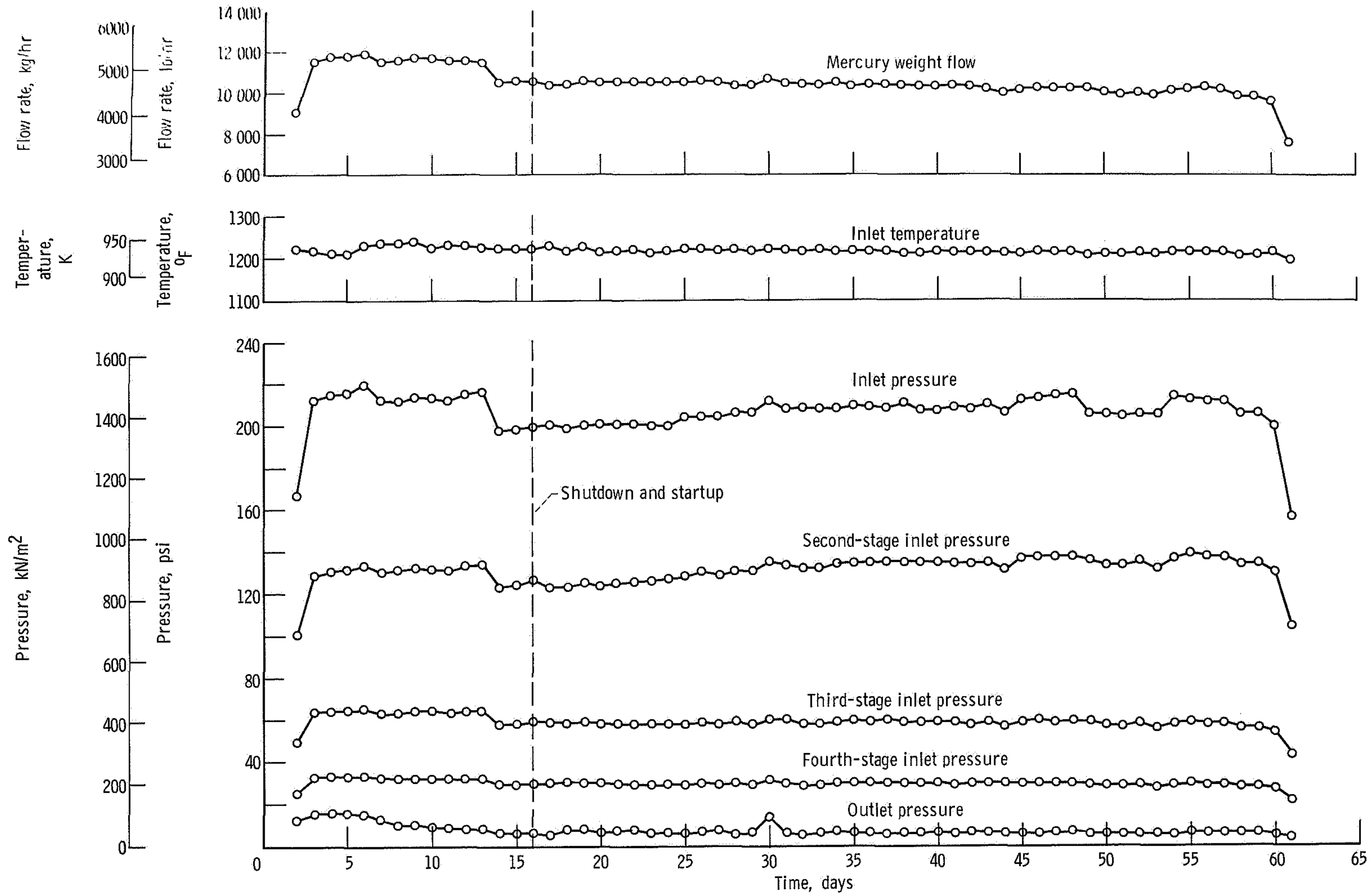


Figure 6. - Turbine-alternator inlet parameters.

between 9500 and 11 700 pounds per hour (4310 and 5310 kg/hr) during the test. During operation there were several fluctuations in the weight flow caused by planned system change, with the exception of an unplanned change which occurred on the 13th day (277 hr). The system change was caused by the loss of the parasitic load resistor and resulted in a decrease in the thermal power available to the boiler. At this point the auxiliary load bank was utilized as part of the turbine-alternator speed control. Another excursion occurred on the 30th day (682 hr) and was related to changes in system operating conditions. Changes from the 58th day (1353 hr) to the end of the test were due to manual changes in operating point in preparation for shutdown.

Changes in the turbine-alternator inlet temperature were very small from the 20th to the 59th day (442 to 1377 hr) with fluctuations between 1204° and 1220° F (924 and 933 K). The first portion of the test period shows variations of slightly larger magnitudes that were caused by changes in system operating conditions.

The turbine-alternator pressure plots demonstrate the expected results in the various stage pressures with minor disturbances in the inlet pressure for the entire test. The inlet pressure was measured upstream of the turbine in the vicinity of the boiler outlet. The actual inlet pressure to the turbine-alternator may have been influenced by changes in line losses and a gradual blockage of the inlet filter screen shown in figure 7 (taken from "Disassembly and Inspection of Turbine Assembly Unit 6/2 P/N 098500-ID, Veo No. 0539 S/N A-3 After 1391 Hours Operation in W01" by R. S. Foley of Aerojet-

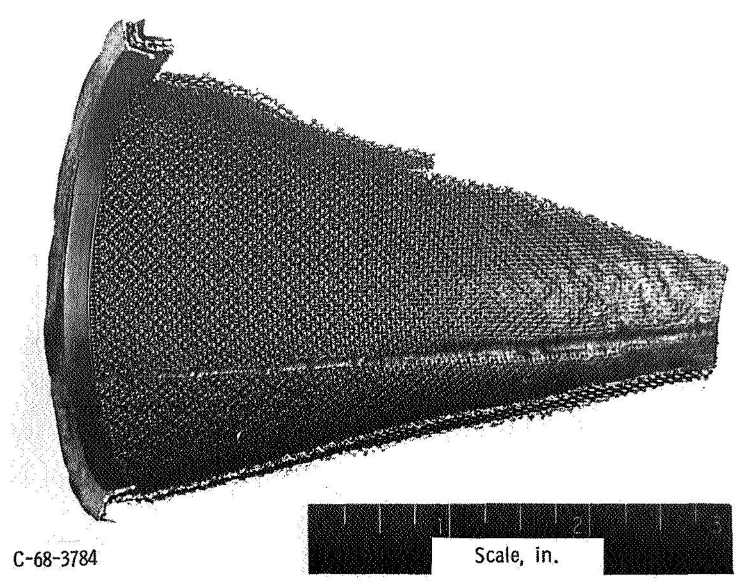


Figure 7. - Mass transfer on inlet filter screen (sectioned).

General Corp.). An increase in the turbine-alternator outlet pressure on the 30th day (682 hr) was a result of planned changes in system operating conditions.

In order to show the changes in turbine stage pressure ratios, these ratios on a day early in the test and one late in the test are shown below. Design ratios are also listed for comparison (ref. 13). Differences in the stage ratios between the 6th and 57th days (109 and 1330 hr) can be attributed to a lower Hg flow rate on the 57th day.

Stage	Design pressure ratio	Pressure ratio on 6th day (109 hr)	Pressure ratio on 57th day (1330 hr)
1(st) First	1.63	1.65	1.54
2(nd) Second	2.04	2.05	2.36
3(rd) Third	2.00	1.97	2.00
4(th) Fourth	2.00	2.2	4.85

The large change in the fourth-stage pressure ratio resulted from a low condenser inlet pressure. This did not affect the previous stage since the fourth stage was choked. The inlet pressure on the 6th day (109 hr) was the highest achieved during the test, 219.5 psia (1515 kN/m^2), and the closest to the design value of 265 psia (1828 kN/m^2). The inlet pressure was limited by a low mercury weight flow.

Plots of the turbine-alternator losses, speed, efficiency, and alternator output power are presented in figure 8. The data points in this figure are time-related to those in figure 6 and can be used for a direct comparison of operating conditions.

The alternator output power ranged from 36.8 to 45.7 kilowatts (0.625 to 0.70 pf) throughout the duration of the test, which is well below the design value of 60 kilowatts at 0.75 power factor. Reduced power output was due to 4-percent-oversize first-stage nozzle areas in the turbine, which were larger than design, and below-design Hg flow rate. On the 30th day (682 hr) of operation, the power decrease was caused by a change in turbine backpressure from 6 psia to 16 psia (41.4 kN/m^2 to 110 kN/m^2), which was the result of system changes. Corresponding to this power fluctuation was a decrease in alternator heat-exchanger and turbine-space-seal heat-exchanger thermal power losses.

The turbine-alternator speed varied only 77 rpm (0.58 percent) above the design value of 12 000 rpm. This is well within the speed control's design limits of 11 800 to 12 120 rpm (±1 percent, ref. 9).

The turbine-alternator efficiency (alternator power output divided by total enthalphy change) data illustrate that the efficiency varies from 37.5 to 38.3 percent for the total test with the exception of the last two days. Because of off-design operation the efficiency was well below the design value of 49.5 percent.

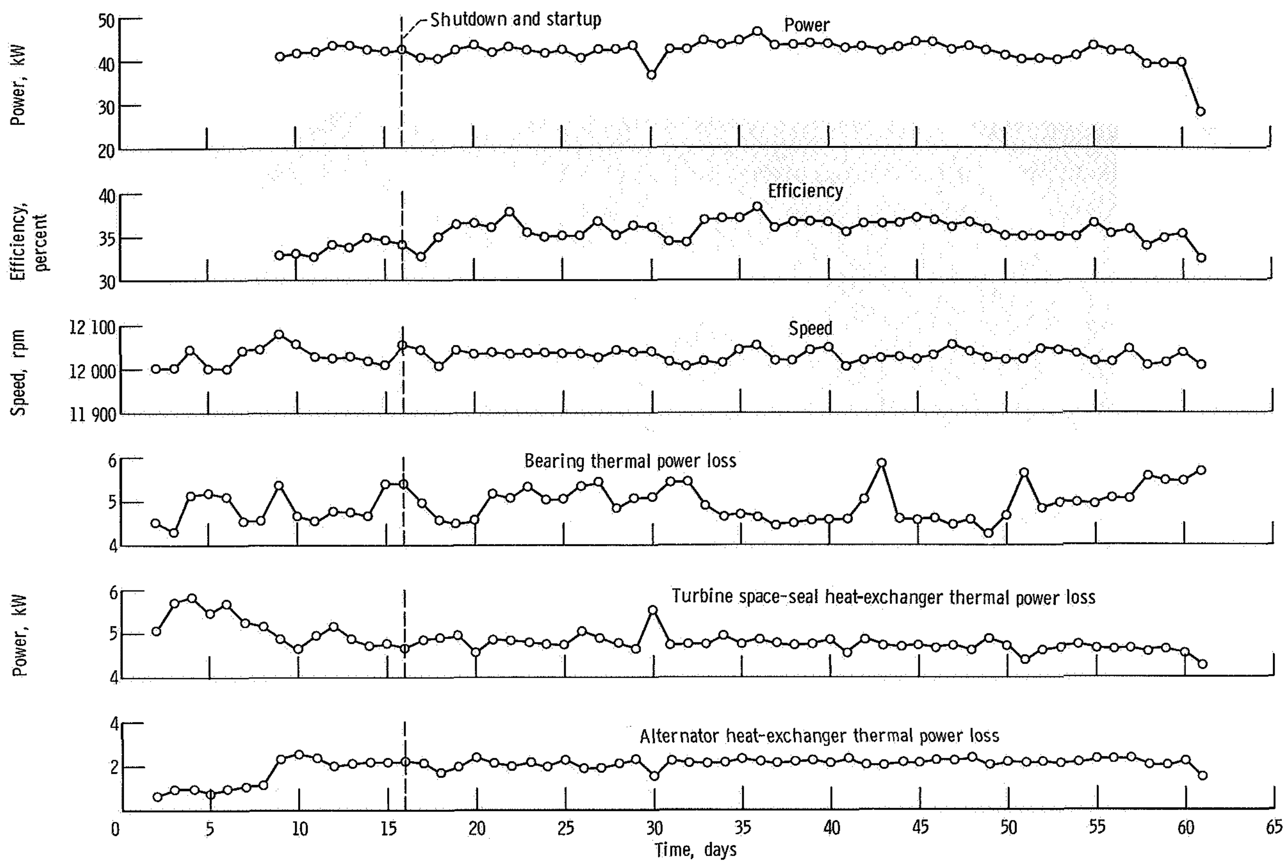
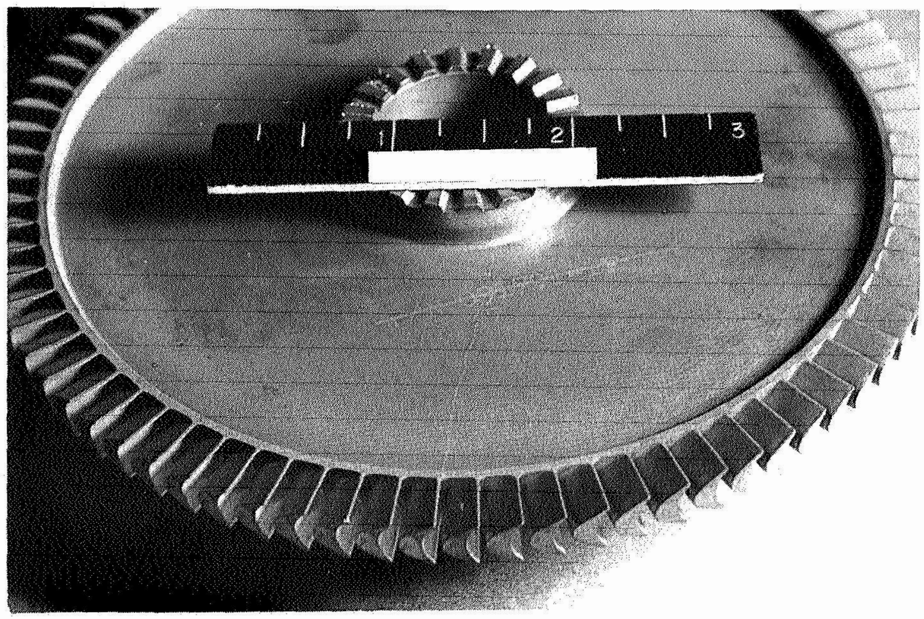


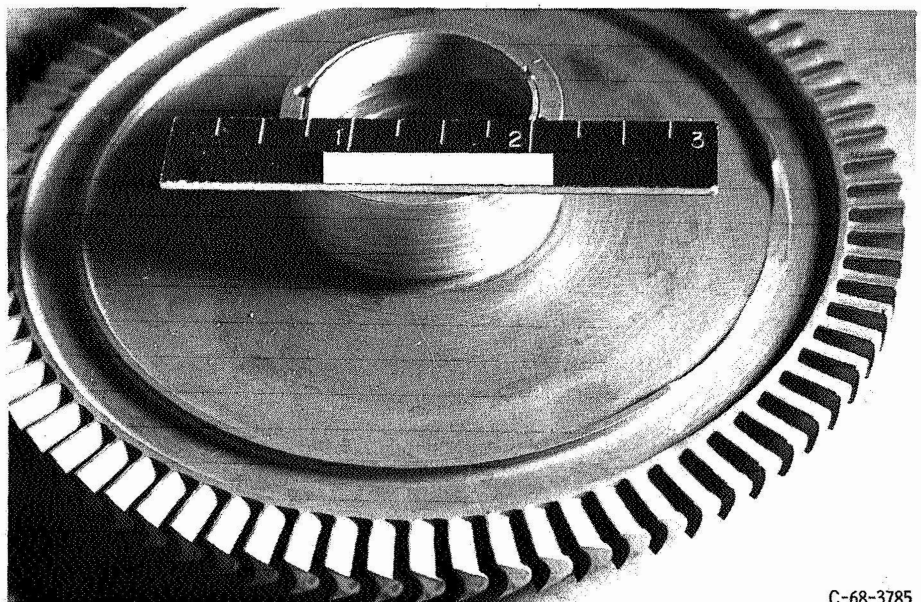
Figure 8. - Turbine-alternator operating parameters.

Plots of the turbine-alternator bearing and slinger loss data show considerable fluctuations with a gradual increase in rejected power towards the latter portion of the test. The variations in the thermal losses can be attributed to difficulty in simultaneously measuring the temperature rise across the bearings and slingers and the oil flow. In addition, the oil flow was changing rapidly and was lagged by the temperature rise (ref. 5).

Disassembly and inspection of the turbine-alternator after 1445 hours of operation determined that the turbine-end bearing showed wear due to operation under an unbalanced rotating load. Operation under these conditions may have resulted in a gradual increase of thermal power dissipation. Further examination of the turbine-alternator showed evidence that the unbalanced load condition may have resulted from the crack in the first-stage wheel (fig. 9, taken from "Disassembly and Inspection of Turbine Assembly Unit 6/2 P/N 098500-ID, Veo No. 0539 S/N A-3 After 1391 Hours Operation in W01" by R. S. Foley of Aerojet-General Corp.). This wheel was manufactured from Stellite 6B material with a ductility of 3.5 percent at 1200° F (922 K). Wheels used in previous tests have had similar failures (refs. 14 and 15). Turbine wheels of current design are fabricated from S816, a material more resistive to cracking and of greater ductility



(a) Exit side.



C-68-3785

(b) Inlet side.

Figure 9. - First-stage wheel showing crack from hub to blade root.

(20 percent) at 1200° F (922 K) than Stellite 6B. Although these problems were present, the turbine-alternator exhibited normal operating and shutdown characteristics at the end of 1445 hours.

The data plot of the turbine-space-seal heat exchanger thermal losses illustrates a condition of relatively little change for the entire test. Several data points for the first 9 days (181 hr) of the test and one taken of the 30th day (682 hr) indicate larger rejection rates than those for the other days. These increases are due to a 10-psi (68.9-kN/m^2) increase in turbine-alternator outlet pressure, which results in elevated operating temperatures at the outlet. This raises the temperature in the space-seal area and increases the amount of heat rejected.

The alternator heat rejection was low (8 kW) for the first 8 days (157 hr) of operation since the alternator current was also low during this period. On the 9th day (181 hr), the system pump loads (a total of four) were transferred to turbine-alternator power. The increased alternator load with a large lagging power factor (0.62) caused a current increase in the alternator and a resultant increase in alternator losses. The decrease in losses on the 30th day (682 hr) can again be attributed to planned system changes and a reduced power level. Average losses for the 1445-hour test were

(1) Turbine-alternator bearings and slingers, 5 kW

(2) Turbine-space-seal heat exchanger, 4.8 kW

(3) Alternator heat exchanger, 2.0 kW

Alternator electrical data are presented in figure 10. These data were taken at the same time of day as those in figures 6 and 8, and can be used for direct comparison.

Problems with power instrumentation during the first 9 days (181 hr) of operation prevented compiling of complete data plots for the parameters in figure 10. There are also changes evident for the last day of operation as system conditions were changed in preparation for shutdown. The data points for alternator line frequency have been calculated from the turbine-alternator speed, which is directly related to alternator frequency.

The plot of alternator line frequency shows minor fluctuations during the test and is directly proportional to a change in speed of the turbine-alternator. The total deviation of line frequency was from 400 to 402 hertz (0.58 percent) and was well within the design limits of 396 to 404 hertz (± 1 percent).

The data plots of the alternator terminal voltage, current, and power factor indicate average values of 120.5 volts, 175 amperes, and 0.67 pf, respectively, during the test. There are minor fluctuations in these curves that can be attributed to changes in the alternator load.

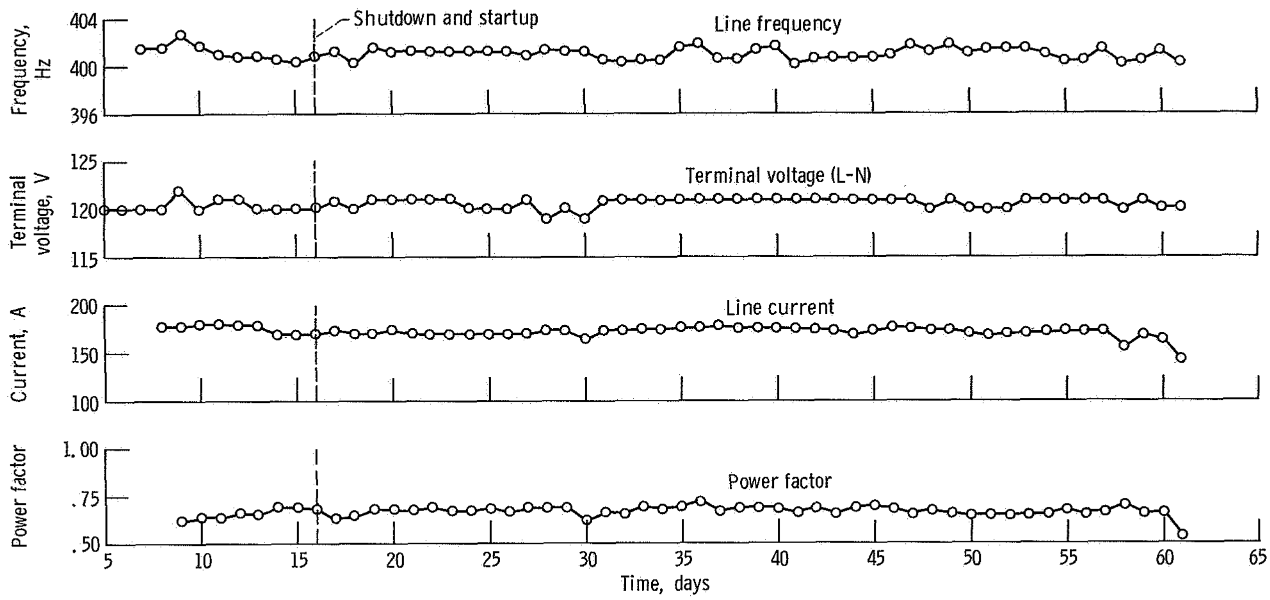


Figure 10. - Alternator electrical parameters.

CONCLUDING REMARKS

Evaluation of data obtained during operation of the SNAP-8 turbine-alternator resulted in the following observations:

1. The turbine-alternator operated in a SNAP-8 system for 1445 hours with no significant change in performance. During the test run, the turbine-alternator was subjected to four shutdowns, all of which exhibited normal characteristics.

2. The turbine-alternator electrical power output ranged between 36.8 and 45.6 kilowatts for the test period. This power output was below the design value of 60 kilowatts at 0.75 power factor, since first-stage nozzle areas in the turbine were larger than design and the mercury flow rate was less than design.

3. The speed controller maintained a steady turbine-alternator speed of 12 000 to 12 077 rpm (0.75 percent), well within the design control of 12 000±120 rpm.

4. Turbine pressure ratios were very near design values and showed no changes after prolonged operation.

5. Inspection of the turbine-alternator after 1445 hours of operation disclosed a crack in the first-stage turbine wheel and irregular turbine-end bearing wear. The irregular bearing wear resulted from an unbalanced load condition, which has been attributed to the crack in the first-stage wheel. This wheel was manufactured from Stellite 6B, material which is extremely brittle. Turbine wheels of current design are fabricated from S816, a material more resistive to cracking.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, October 31, 1968,
120-27-04-35-22.

REFERENCES

1. Cherry, M. G.: Operation of Turbine-Alternator Assembly. 3/2 in. RPL-2. Rep. TM 4832:65-1-288, Aerojet General Corp., 1965.
2. Macosko, Robert P.; Hanna, William T.; Gorland, Sol H.; and Jefferies, Kent S.: Performance of an Experimental SNAP-8 Power Conversion System. NASA TM X-1732.
3. Gorland, Sol H.; Hecker, Thomas P.; and Lottig, Roy A.: Performance and Evaluation of Two Liquid-Metal Pumps for Sodium-Potassium Service. NASA TM X-1765.
4. Gorland, Sol H.; Lottig, Roy A.; and Hecker, Thomas P.: Performance and Evaluation of a Liquid-Metal Pump for Mercury Service NASA TM X-1766.
5. Block, Henry B.; Kruchowy, Roman; and Gallagher, James D.: Performance of the SNAP-8 L/C Subsystem. NASA TM X-1731.
6. Lessley, R. L.; and Hodgson, J. N.: Low-Leakage Dynamic Seal to Space. Paper No. 65-GTP-14, ASME, Mar. 1965.
7. Hodgson, J. N.: Designing a Molecular Pump as a Seal-to-Space. Paper No. 65-GTP-15, ASME, Mar. 1965.
8. Dryer, A. M.; and Male, R. L.: Exciter-Regulator for the SNAP-8 Power System. IEEE Trans. on Aerospace, vol. AS-3, no. 2, Suppl., June 1965, pp. 560-567.
9. Nice, A. W.; and Bradley, S. L.: SNAP-8 Electrical System. IEEE Trans. on Aerospace, vol. AS-2, Apr. 1964, pp. 867-873.
10. Staff of Lewis Research Center: A Central Facility for Recording and Processing Transient-Type Data. NASA TN D-1320, 1963.

11. Deyo, James N.; and Wintucky, William T.: Instrumentation of a SNAP-8 Simulator Facility. NASA TM X-1525, 1968.

12. Albers, James A.; Soeder, Ronald H.; and Thollot, Pierre A.: Performance of SNAP-8 Double Containment Tantalum-Stainless Steel Mercury Boiler. NASA TN D-4926.

13. Cherry, M. G.: Pretest Report - Testing of Turbine-Alternator Assembly. (P/N 096800-1, S/N 4-2) In PCS-1, Phase IV, Step 2. Rep. TM 4932.66-380, Aerojet-General Corp., 1966.

14. Waters, W. M.: Failure Analysis of the SNAP-8 Turbine-Alternator Assembly 3/2, S/N 4-3. Rep. TM 4932:65-5-332, Aerojet-General Corp., 1965.

15. Mah, C. S.: Failure Analysis of SNAP-8 Turbine Assembly. P/N 096800-1, S/N 4-4, Buildup 1/5. Rep. TM 4932:67-471, Aerojet General Corp. 1967.

NASA-Langley, 1969 —— 3 E-4683

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546