QUARTERLY PROGRESS REPORT
SPUR POWER SYSTEM

CONTRACT AF33(657)-8954
FOR PERIOD ENDING JUNE 30, 1963
PROJECT NUMBER 3145
TASK NUMBER 314511

SY-5396-R5

July 15, 1963

GARRETT

AIRESEARCH MANUFACTURING COMPANY
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

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ABSTRACT

This report, submitted by the AiResearch Manufacturing Company of Arizona, Phoenix, Arizona, a division of The Garrett Corporation, describes work accomplished in the period from April 1, 1963, to June 30, 1963, under Phase II of the SPUR program, in accordance with United States Air Force Contract AF33(657)-8954.

The Phase II contract provides for continued analytical and experimental studies in support of the Space Power Unit, Reactor (SPUR) Program. Progress is reported for a total of six tasks.

In addition to a discussion of the work accomplished by AiResearch, the prime contractor, this report contains a discussion of work accomplished by Aerojet-General Nucleonics (reactor system) and Battelle Memorial Institute (material support). The program progress on each of these tasks is discussed in Section II.

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I INTRODUCTION

The Space Power Unit, Reactor (SPUR) Program was initiated by the United States Air Force, in cooperation with the Atomic Energy Commission, in May of 1960. The ultimate objective of the SPUR Program is to develop a nuclear-dynamic space power system capable of supplying 300 kilowatts or more of electrical power, with a design life of 10,000 hours.

The power system will consist of a nuclear reactor as a heat source, the mechanical means of converting thermal energy to electrical energy, a radiator for rejection of waste heat, controls, and all other necessary auxiliary equipment. The thermodynamic conversion system will be a closed-cycle dynamic system, capable of operating unattended under the specified conditions. An electromagnetic-type generator is used to produce the electric power.

A description of the SPUR system and its components is included in the SPUR Phase I Final Report, ASD Technical Report ASD TR 61-656.

The objectives of the Phase II Program are to continue portions of the study and experimental program initiated under Contracts AF33(616)-7379 and AF33(616)-8322 and to investigate several additional areas through analysis and experiment. The major technical work areas discussed in this report are as follows:

Materials testing, including creep-rupture and fatigue evaluation of Mo + 1/2 w/o Ti and Cb + 1 w/o Zr.

Mass-transfer tests of Cb + 1 w/o Zr with two-phase potassium flow.

Liquid-potassium bearing tests.

Properties of reactor clad and structural materials.

II TECHNICAL DISCUSSION

The following paragraphs include a discussion of the program progress through June 30, 1963.

The various tasks are designated by the paragraph number from Contract AF33(657)-8954 and are discussed on subsequent pages.

Tasks accomplished under subcontract are listed below. The remaining tasks were accomplished by AiResearch, the prime contractor.

Battelle Memorial Institute: Three of the materials development tasks, pages 4 through 8.

Aerojet-General Nucleonics: Reactor Loop, pages 27 through 28.

Task 2.2.2.1, Creep-Rupture Properties of Mo + 1/2 w/o Ti

The final test of this series (Test 9) was completed during April. In this test, a hollow tubular specimen containing potassium vapor at 1800°F was stressed at 55,000 psi. Rupture occurred at 153.4 hours with a final elongation of 11.7 percent and a reduction in area of over 90 percent. The minimum creep rate was approximately 0.022 percent per hour. This test correlates well with previous data, and the design curves presented in the last Quarterly Progress Report are not changed by the data of this test.

The metallographic examinations of the specimens from Tests 7, 8, 9, and 10 were completed. Close scrutiny of the inside surface of the hollow specimens at magnifications up to 1000X did not show any evidence of corrosive attack. The microstructures of the three 1800°F specimens appear very similar to that of the as-received material, except that the specimen from the longest test (Test 7) shows more incipient recrystallization than the remaining specimens.

The material investigation activities under this task are complete. A topical report has been prepared and will be submitted for review during July 1963.

Task 2.2.2.2, Fatigue Evaluation of Mo + 1/2 w/o Ti

The test series of Mo + 1/2 w/o Ti specimens in helium or vacuum environments at 1500°F was completed. The data for these tests are summarized on Table 1. Since the test results are not affected by the choice of "inert" atmosphere (helium or vacuum), tests 6F through 10F were conducted with helium-filled specimens, while the remainder were run with open ends in vacuum. It may be noted from Table 1 that, at stresses above 75,000 psi, failure at 1500°F is governed more by creep than by fatigue. The early failure of specimen 16F may have been caused by a material flaw, although none was shown by a superficial examination.

Ten tests were completed with 1500°F potassium vapor inside hollow specimens. Data for the tests is given on Table 2. The initial stress levels were in the same range as those for the vacuum-exposed specimens. However, the first test, at 75,000 psi, resulted in specimen rupture at 24,000 cycles, and several subsequent tests, at progressively lower stresses, were also terminated by specimen rupture at less than 100,000 cycles. At a stress level of 45,000 psi, the fatigue lifetime was increased; and at 40,000 psi, the specimen sustained more than 45 x 10^6 cycles before failure. These data indicate that the fatigue strength of this alloy may be reduced by the potassium vapor atmosphere. Metallographic examination of specimens from both potassium vapor and vacuum/helium atmosphere tests is in progress; it is anticipated that these examinations will suggest reasons for the differences in fatigue life.

Tests at 2000°F in both vacuum and potassium vapor environments will be conducted concurrently in the two facilities during the next report period.

TABLE 1

AXIAL LOAD FATIGUE FOR Mo + 1/2 w/o Ti SPECIMENS
IN HELIUM OR VACUUM ATMOSPHERE AT 1500°F

Test and Specimen No.	Atmosphere	Maximum Stress, 1000 psi	Total Recorded Creep at Failure, in.	Fatigue Lifetime, kilocycles	Specimen Appearance after Test
7 F	Helium	100.0	-	Failed at startup	Bright
12 F	Vacuum	80.0	(1)	7(2)	Bright
11 F	Vacuum	77.5	(3)	24	Bright
8 F	Helium	77.5	(4)	120	Bright
13 F	Vacuum	75.0	0.015	1,069	Tarnished(5)
14 F	Vacuum	72.5	0.040	194	Bright
6 F	Helium	70.0	0.002	2,289	Bright
15 F	Vacuum	70.0	None	3,567(6)	Tarnished(6)
16 F	Vacuum	67.5	(7)	36	Bright
17 F	Vacuum	67.5	–	>102 271(8)	
9 F	Helium	47.5	None	92,650(8)	Bright
10 F	Helium	35.0	None	102,052(8)	Bright
10 FR(9)	Helium	50.0	0.002	525(10)	Bright

(1) Specimen started to creep at 500 cycles, and continued to creep beyond the limit of the instrument scale (approximately 0.040 in.).

(2) Specimen did not fracture but was elongated 3/16 to 1/4 in. near center of test section.

(3) Specimen creep beyond limit of instrument scale (approximately 0.040 in.) at 20,000 cycles.

(4) Test conducted without creep attachment.

(5) Appearance indicated poor atmosphere.

(6) Exposed to room air at 3,567,000 cycles from sudden leak in system - test stopped.

(7) Specimen did not fracture but test section elongated approximately 3/16-inch.

(8) Specimen did not fail.

(9) Continuation with Specimen 10 F after the runout at higher stress.

(10) Lifetime not consistent with results of other tests as a result of the initial exposure.

TABLE 2

AXIAL LOAD FATIGUE DATA FOR Mo + 1/2 w/o Ti
SPECIMENS IN POTASSIUM ATMOSPHERE AT 1500°F

SPECIMEN NO.	MAXIMUM STRESS, KSI	LIFETIME, KILOCYCLES
2F	75.0	24
3F	70.0	6
4F	70.0	5
5F	65.0	2
26F	60.0	3
27F	55.0	3
28F	50.0	1
31F	45.0	204
30F	42.5	29
33F	40.0	45,071

Task 2.2.2.3, Cantilever Bending Fatigue of Cb + 1 w/o Zr

During April, three tests in 1600°F lithium were initiated but none supplied suitable data for the S-N curve. In one test, the quantity of lithium transferred to the test rig was believed to be insufficient to cover the specimen; in another, a leak developed, contaminating the system; and in the third, the sensing mechanism indicated failure, whereas the specimen had not failed. The test rig and lithium-loading procedure were modified to eliminate the apparent causes of these difficulties, and two successful tests were subsequently conducted One specimen, at 22,000 psi, failed after 185,000 cycles; the other specimen, at 20,000 psi, exceeded 10^7 cycles. The tests will be continued, and it is anticipated that they will be completed in July 1963

Task 2.2.2.4, Mass Transfer Tests with Two-Phase Flow

Upon completion of loop fabrication, including heaters, radiation shields, and heater instrumentation, the loop was installed in the vacuum-pressure chamber. A ventilated plastic clean-room, shown in Figure 1, was then constructed around the entrance of the chamber to prevent gross contamination while completing loop installation.

Figure 2 shows the loop completely installed with insulation, instrumentation, and power connections. After a final inspection of all components, the chamber was sealed and the molecular sieves were evacuated to 1 x 10^{-3} torr and pressurized to 5 psig with high-purity argon gas. The argon purification system, shown in Figure 3, consists of two molecular sieves for hydrocarbon removal and two sets of elevated-temperature purifiers for oxygen and nitrogen removal.

PROTECTIVE PLASTIC ROOM
TWO-PHASE LOOP INSTALLATION

FIGURE 1

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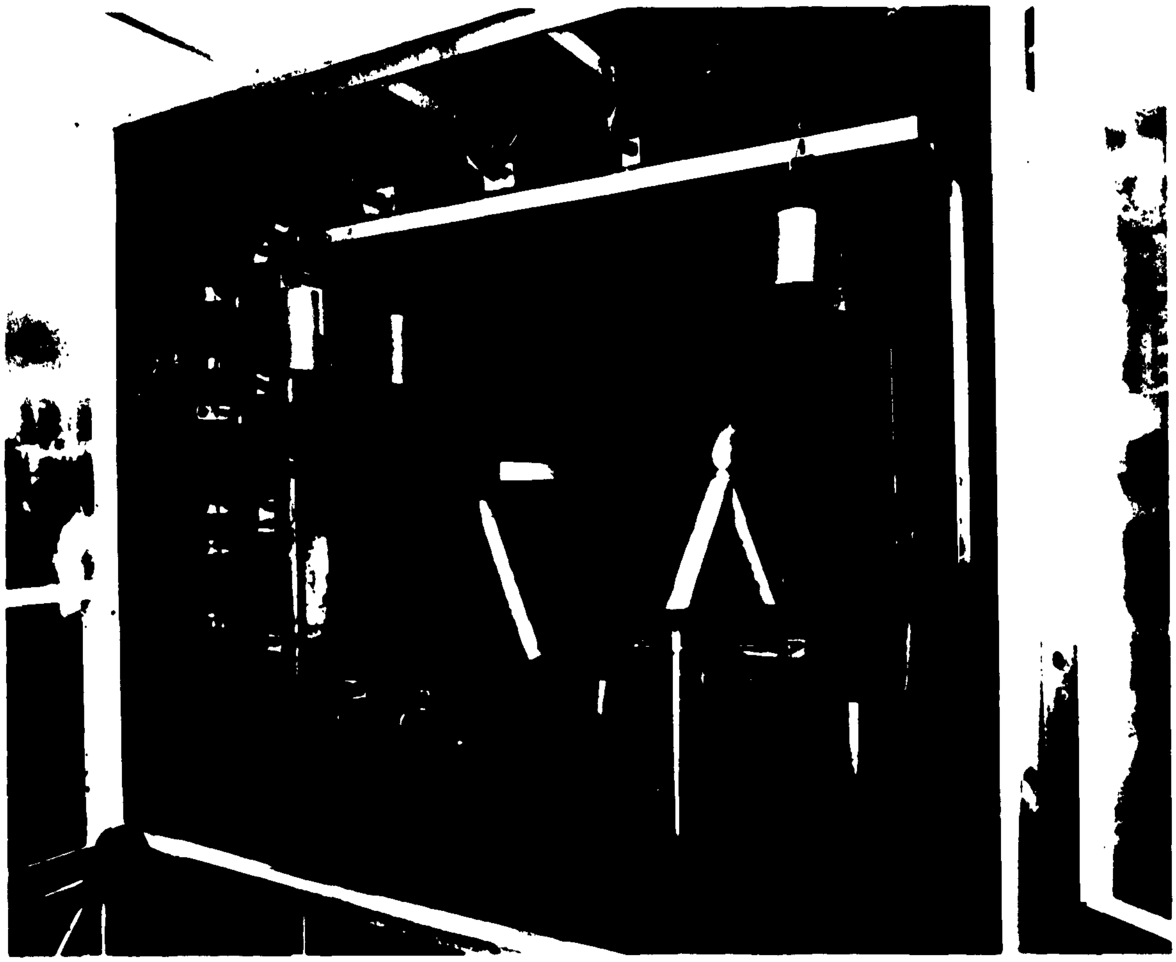

TWO-PHASE LOOP PRIOR TO TEST

FIGURE 2

PHOTO NO. P-21165-1
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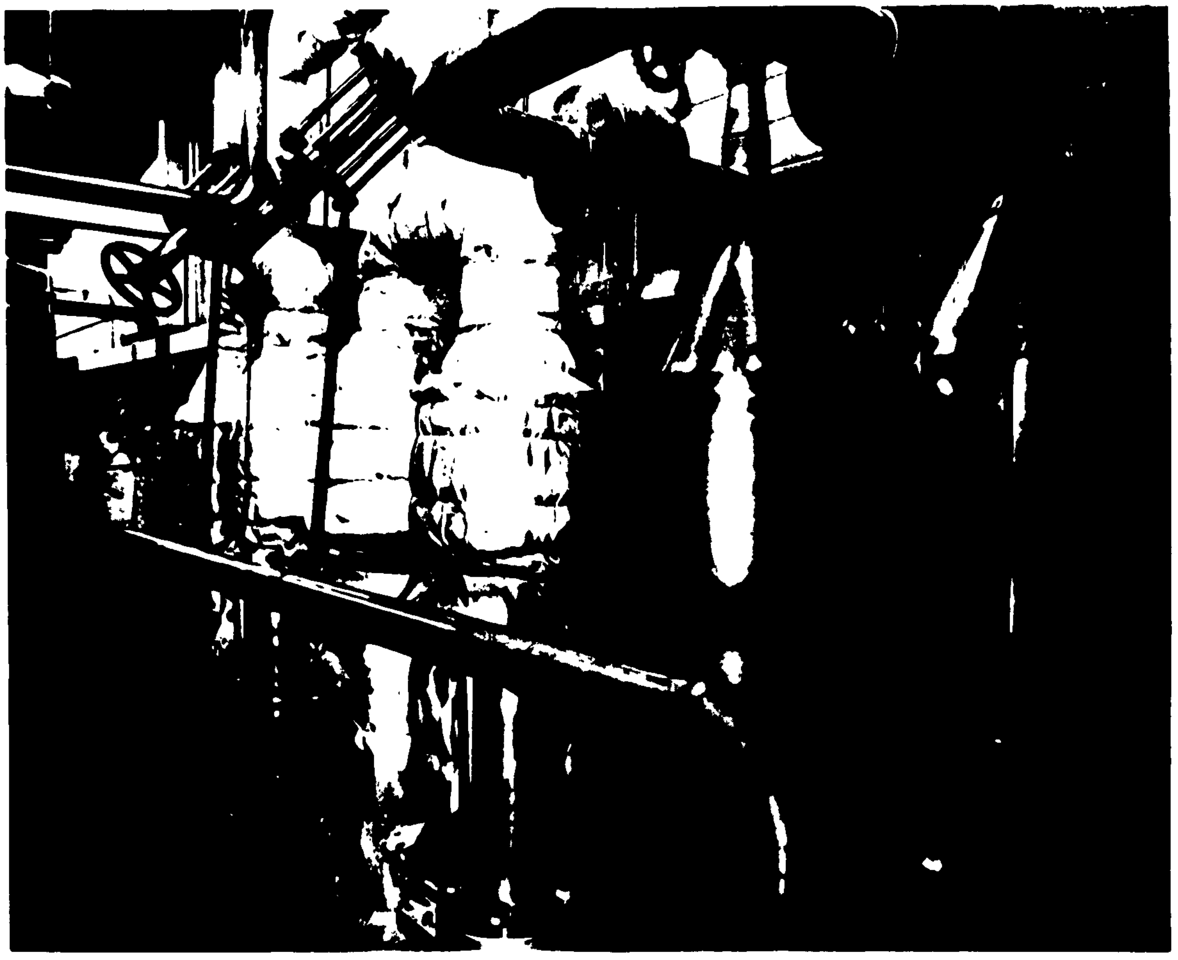

TWO-PHASE LOOP
ARGON PURIFICATION SYSTEM

FIGURE 3

PHOTO NO. P-21169-3
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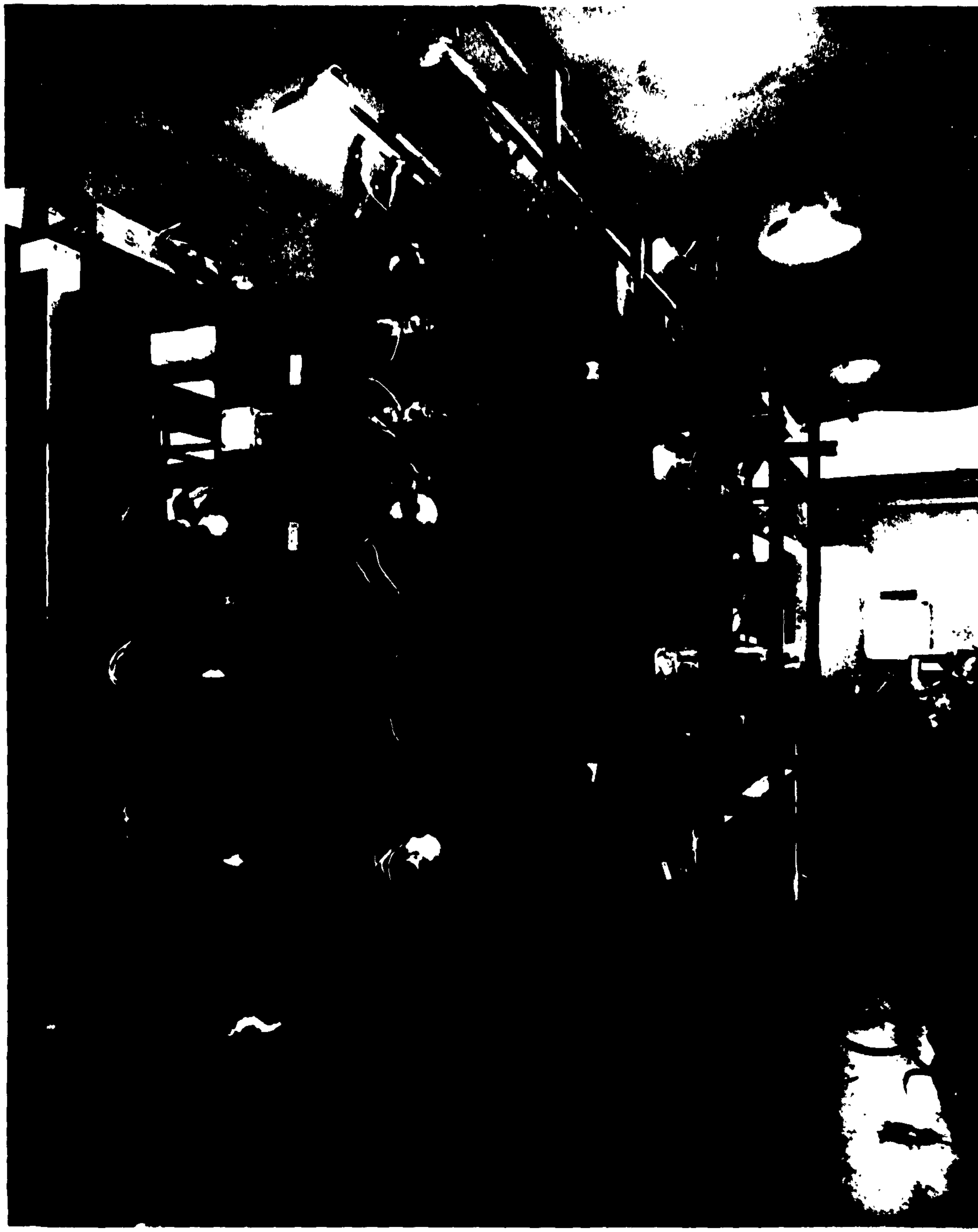
The purifiers were then evacuated to 6×10^{-3} torr and pressurized to 5 psig with high-purity argon gas. Following this the chamber was evacuated to 1×10^{-2} torr and the loop was evacuated, purged, and evacuated two times to an ultimate pressure of 4.5×10^{-3} torr. Radiant, strip and bulb-type heaters, shown in Figure 4, were then installed about the chamber and blower box to perform the elevated-temperature outgassing operation. During this operation the loop was evacuated to 11×10^{-3} torr while heated to 300°F and the chamber and blower box were evacuated to 7×10^{-3} torr while being heated to 200°F. During the elevated-temperature outgassing operation the chamber and blower box were purged two times with high-purity argon gas. After the final evacuation of the chamber and blower box, they were pressurized to 5 psig with high-purity argon gas, and heating of these units was terminated.

Preparations for energizing the gas purification system are now being made.

Task 2.2.4.1.1, Bearing Tests

Test Loop

All components of the potassium system, pumps, flowmeter, valves, filter, hot trap, boiler coil (316 stainless steel), condenser coil (316 stainless steel), sample take-off, etc., were repaired or rebuilt, cleaned, and leak-checked. Installation of the potassium loop has been completed. All 3/8-inch-diameter tubing was replaced with 1/2-inch-diameter tubing. (The 3/8-inch tubing was originally installed in the loop for



TWO-PHASE LOOP
CHAMBER BAKEOUT HEATERS
FIGURE 4

PHOTO NO. P-21228-1
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AiResearch Manufacturing Division

MP-3515

economy reasons, when rubidium running was under consideration.) The Haynes 25 boiler coil and superheater coil required for vapor tests have been replaced with 316 stainless steel for the liquid tests. Time did not permit procurement and incorporation of Haynes 25. The Haynes 25 component will be installed after the liquid tests are completed. A new eddy-current liquid level device was incorporated on the sump to replace the thermocouple method.

Additional pressure regulators, pressure gauges, bubblers, and cold traps for use with the backup seal design were installed in the argon system.

Completion of the teardown analysis indicated that the upper spindle chamber filled with oil during system operation. The filling could have been caused only by the gravity oil drain line being partially or completely plugged with potassium. The head of oil then leaked past the face seal into the lower bearing test section, contaminating the potassium system. From inspection of the face seal it became evident that it had been damaged when a large quantity of 600°F liquid potassium was forced into the upper chamber due to a potassium plug that had formed around the test bearing drain.

An alarm system has therefore been incorporated in the upper oil chamber which will indicate excessive oil level. An automatic shutdown of the oil pump and drive motor has been incorporated into the alarm system. A sight gauge has also been incorporated on the oil reservoir so that a closer watch of fluid level can be made.

The oil system was cleaned, and the new pump and heat exchanger were installed.

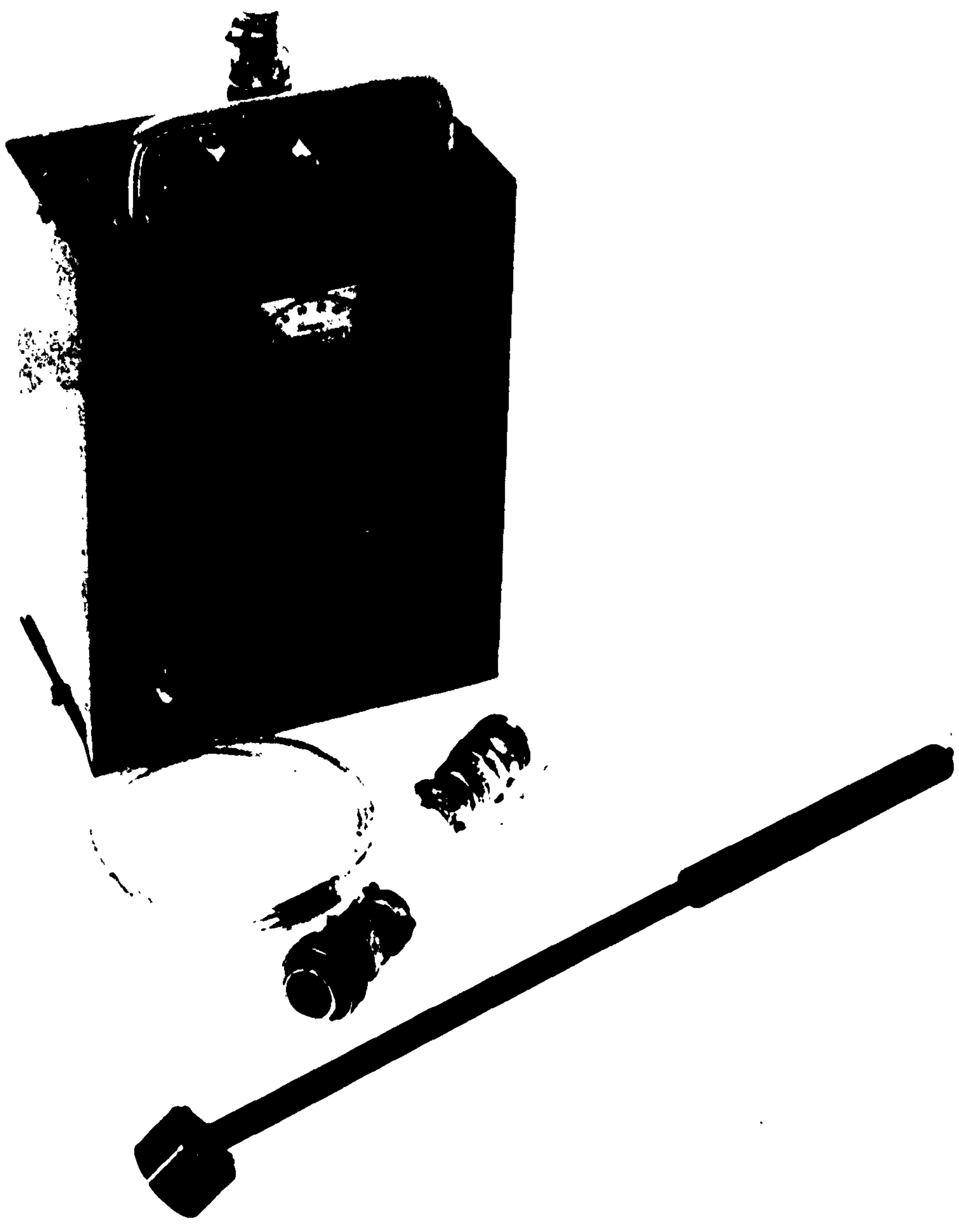
Oil temperature will be maintained as close to 180-190°F as possible with the existing heat-exchanger system. The only change in the hot water system is the use of a centrifugal pump (steel impeller) to replace the existing pump, which has a rubber impeller. The life of the rubber impeller proved to be insufficient for extended usage.

New coaxial ceramic insulated resistance heaters, known as Aerorod, have been installed. A better balancing of the heater circuits is incorporated, and failure warning lights have been installed.

Figure 5 shows the new portable liquid-level detector to be used during the next tests.

Figure 6 shows the arrangement being used on the delta pressure measuring system. Wiancko pressure transducers will be held at 2000°F in the oven so that any potassium will be molten. This fixed temperature will also help to minimize drift problems associated with temperature changes.

Figure 7 shows a new adaptation to the capacitance film thickness measuring device. A small pneumatic cylinder has been added to the end that will move exactly 0.002 inch when pressurized. With this innovation, checks calibrations can now be made during dynamic tests.



PORTABLE LIQUID LEVEL DETECTOR
FIGURE 5

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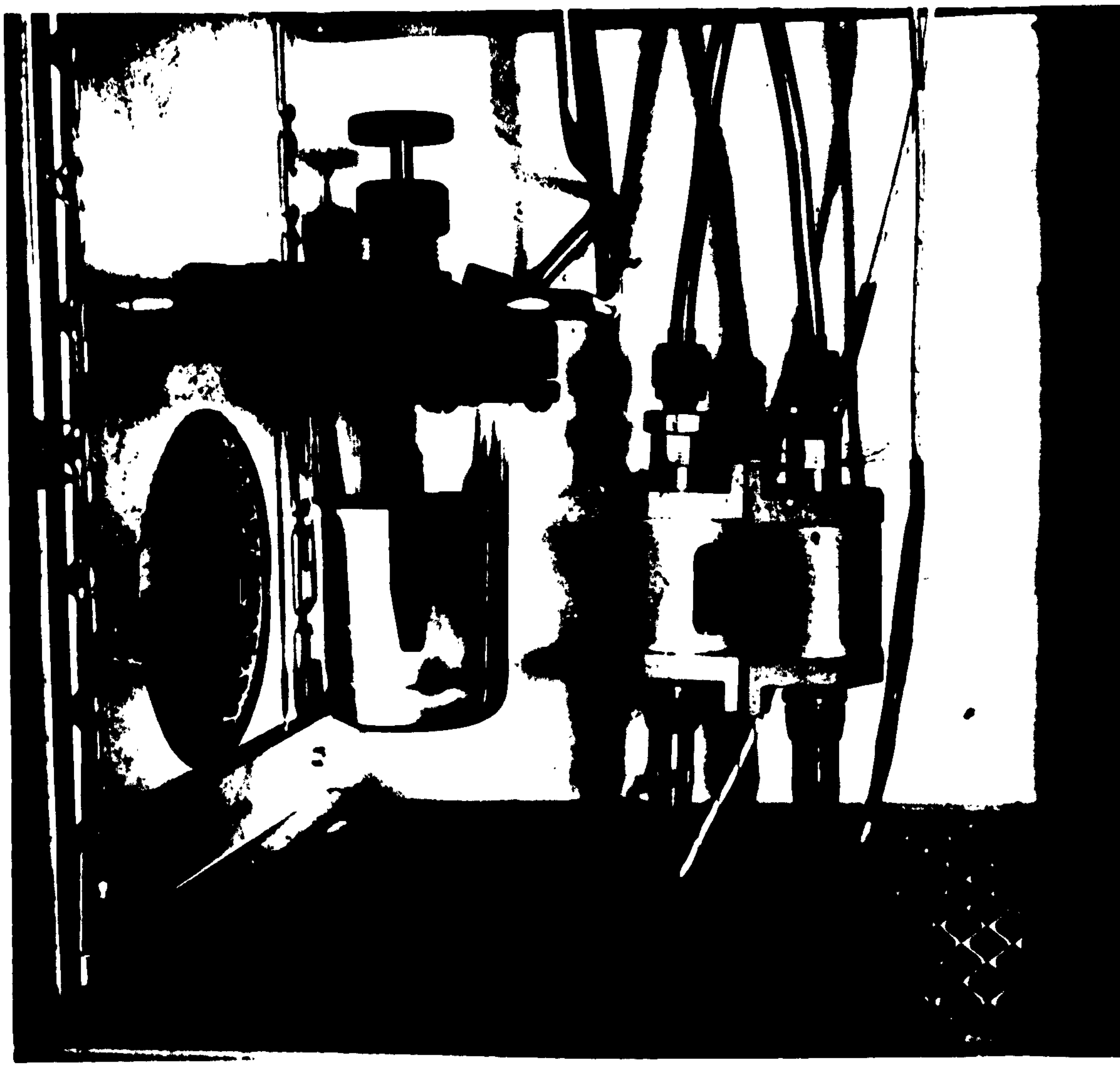
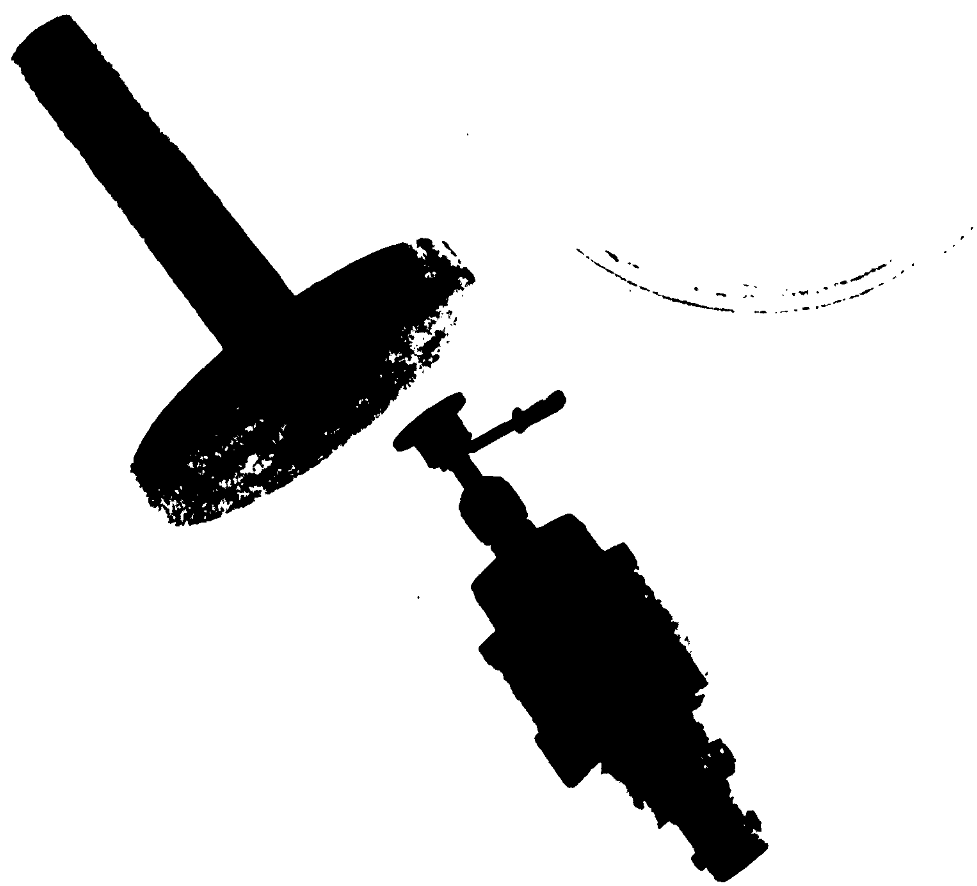


SEAL DIFFERENTIAL PRESSURE MEASURING SYSTEM
FIGURE 6



FILM THICKNESS MEASURING SYSTEM
FIGURE 7

Test Rig

All design modification drawing changes are complete and all backup seal parts have been finished. A new induction motor rotor was completed, and rework of the bearing carrier, drive shaft, and modifications to the housing were accomplished.

Preliminary checkout of the new seal configuration and of the delta pressure regulating system was initiated as scheduled. A failure of the drive pin (motor to spindle) was experienced, and the rig is being disassembled to establish the cause. The pressure across the face seal numbers held constant at all speeds run

The new 23-slot rotor produced a "cogging" phenomenon at zero speed which resulted in a variable starting torque that was practically zero at one position and increased to a maximum with an approximate 6-degree rotation of the rotor. The "cogging" phenomenon is unexplainable at this time, as a similar slot combination (24/23) was used on the mercury bearing rig and did not exhibit this weakness. An attempt will be made to skew the rotor to rectify the "cogging" phenomenon. The original rotor will be used, with no delay caused in the testing.

Canned Rotor Liquid Potassium Bearing Tests

In March of 1962 the unidirectionally loaded liquid potassium bearing test rig became contaminated with oil. At this time it was considered necessary to build a backup liquid potassium bearing test rig. The essential objectives of this project were: (1) to build a test rig which eliminated the need for dynamic face seals for separating oil and liquid potassium and thus eliminate the oil system completely, (2) use, if possible, an existing design or design concept to minimize development problems, (3) produce an operating liquid metal journal bearing test rig as quickly and efficiently as possible.

A survey was made of all existing equipment, designs, and fixtures available which might be used. From this survey it was decided to use the SNAP II mercury bearing test fixture design modified for potassium. The features that led to the selection of this design were: the simple concept of a rotor supported in a vertical position by one journal and one thrust bearing; the concept of an axial gap pancake motor in which the stator is sealed from the potassium environment; the system had been built and successfully run in mercury; spare parts would be available; and it would require only limited design modifications to enable the use of potassium. Also at this time it was determined that the existing erosion loop could be used as the supporting facility with only minor modifications.

Instrumentation requirements were evolved from the test objectives. It was desirable to be able to observe and record some bearing performance under fixed dynamic loads. To accomplish this, eddy current devices similar to those designed for the SPUR Phase III turbodynamic bearing rig were constructed. These will be placed at 90 degree intervals around the skirt of the rotor and then calibrated with a fixed machined groove depth in the skirt. These probes will allow for film thickness measurements.

Instrumentation was also incorporated for measuring the normal items for establishing bearing performance; rotor speed, bearing fluid flow, vibration, and temperature and pressure of the liquid potassium lubricant before and after the test bearing.

Test objectives that can be achieved with this rig are: bearing performance as determined by visual inspection before and after a 300-hour run, and dynamic performance as determined by film thickness measurements, and power loss estimates.

Design work included: (1) A 99.5 percent alumina pancake seal for the motor stator to keep potassium from the winding, (2) a liquid potassium thrust bearing to support the rotor assembly replacing the original gas thrust bearing, and (3) a can or container in which to mount the test fixture. Design work on the loop involved only the installation of a potassium filtering system and an additional supply line for the thrust bearing.

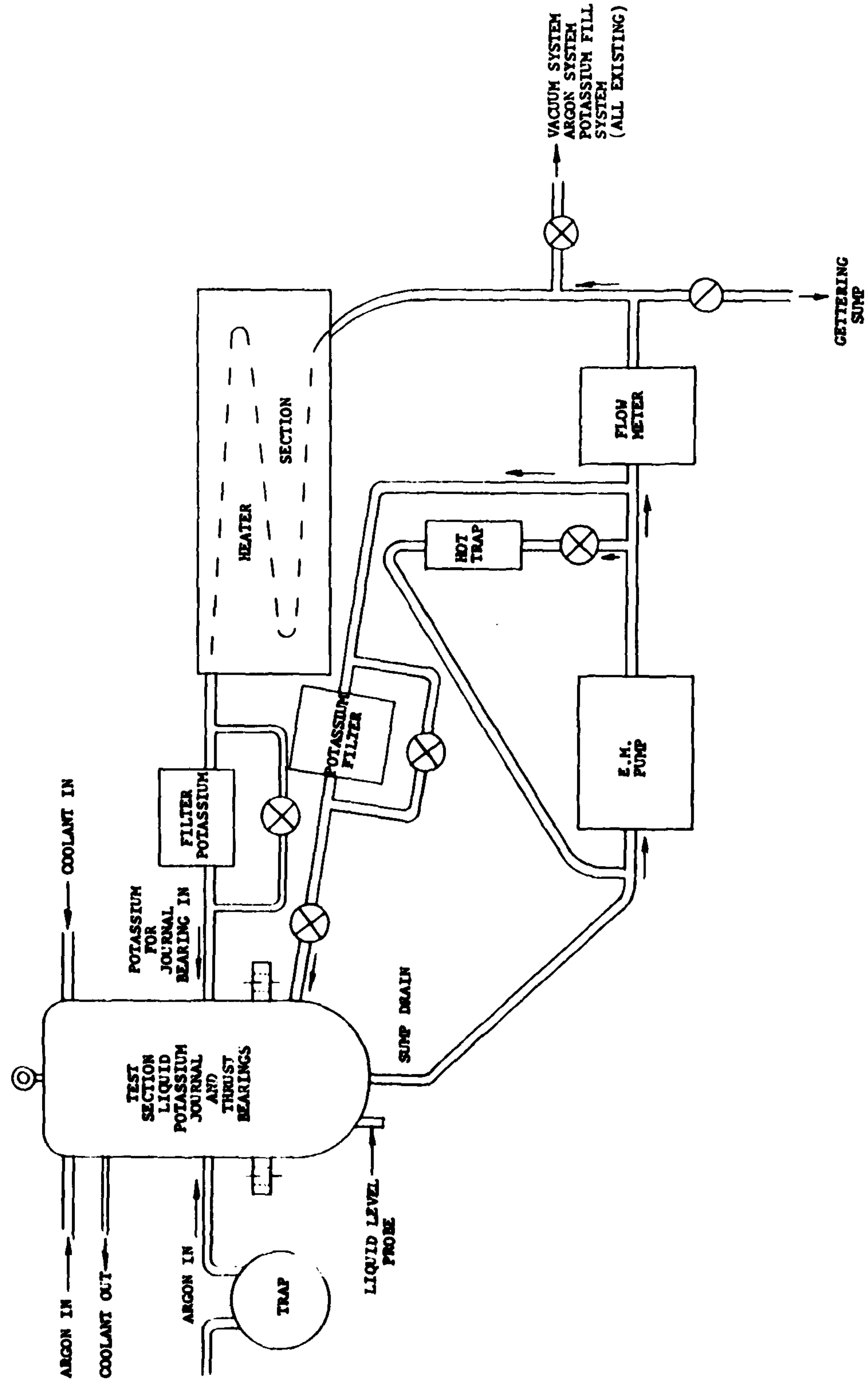
Having completed design by the end of March, materials and components were placed on order. Late delivery and unexpectedly long lead times on the ceramic plates, potassium filters, and unit motor rotor assemblies, caused some delay in the program. A delay of approximately 6 weeks was caused in the program due to difficulty in transferring some of the test fixture components as they were originally purchased under the A.E.C. SNAP Program.

At the present time loop modification work is completed to the point of installing the test fixture and filter assemblies. Modification work accomplished includes replacing a leaking valve, installing the thrust bearing bypass line and throttling valve, hot flushing the loop, draining the loop, installing a new potassium shipper, and building the filter and filter bypass assemblies. No major difficulties were encountered in this area.

All instrumentation equipment has been fabricated and checked and is ready for assembly into the test rig.

The unit can and support has been fabricated, instrumentation installed, and readied for installation. The loop is shown schematically in Figure 8.

The test fixture itself consists of three main components: the bearing housing and test bearing, the rotor assembly, and the stator assembly. These components are described below and are shown in Figure 9.

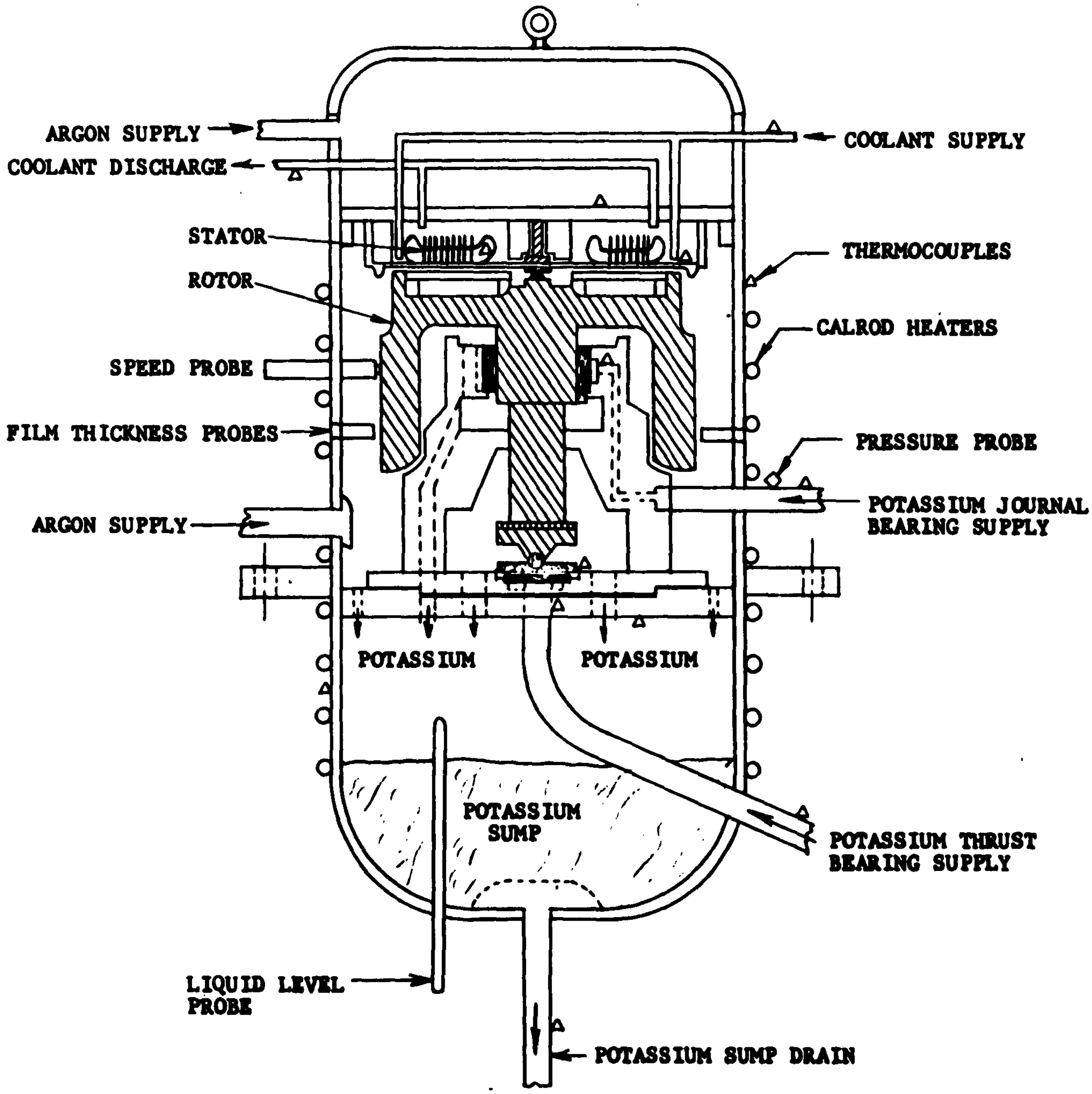


LIQUID METAL BEARING TEST LOOP
JOURNAL AND THRUST BEARINGS
FIGURE 8

BEARING OPERATING CONDITIONS:
24,000 RPM
LIQUID POTASSIUM AT 600°F
25 - 30 PSIG

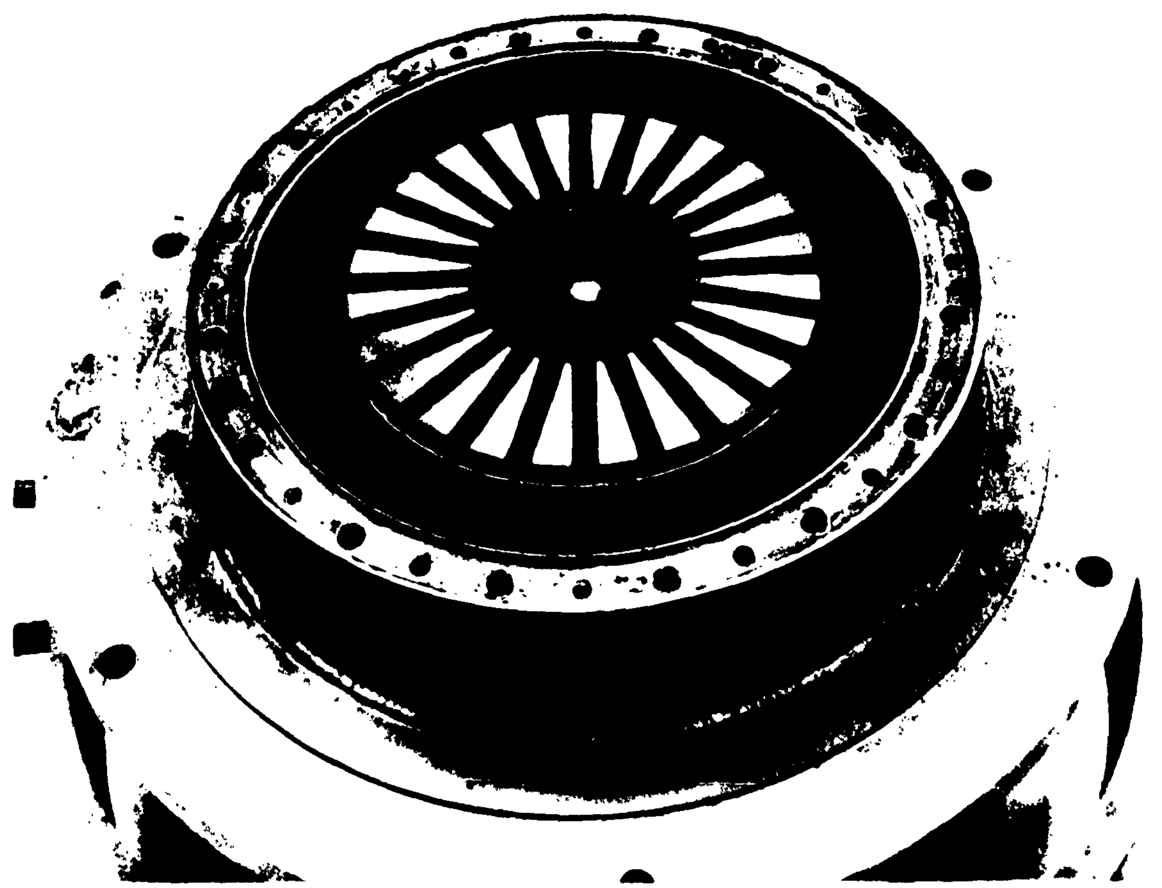
LIQUID METAL JOURNAL AND THRUST BEARING TEST UNIT

FIGURE 9



The bearing housing assembly consists of a Mo + 1/2 w/o Ti test bearing which is pressed into a Mo + 1/2 w/o Ti housing. The lubrication lines, drains, and pressure taps are built into the housing. The rotor assembly consists of a Mo + 1/2 w/o Ti sleeve, and a tungsten carbide journal which are pressed onto the shaft of a Mo + 1/2 w/o Ti rotor such that the center of the journal is located at the center of gravity of the rotor. Installed in the top of the rotor is the pancake motor rotor which consists of an iron core and nickel rings and bars. The motor stator assembly, shown in Figure 10, is mounted directly above the rotor assembly with the air gap between the two. The stator assembly consists of an iron stator core wound with copper wire and potted with a high temperature epoxy. A ceramic plate seal is installed between the stator core face and the rotor motor assembly. The back of the stator assembly is designed as a liquid coolant chamber to cool the stator. This coolant chamber is completely sealed from both the stator and the rotor and therefore from potassium.

At the present time the stator assembly is completed and ready for installation into the can. The rotor assembly is completed except for the process of balancing, stresscoating and overspeed checks, and calibration for the unbalance dynamic load. This work is currently being done and should be completed by July 15, 1963. The bearing housing is completed and it is anticipated that final assembly of the test fixture and installation into the unit can will be completed by July 19, 1963. The test unit will be installed on the loop and the entire system is scheduled to be checked out by July 26, 1963, so that the planned potassium fill can be accomplished by July 29, 1963.



CANNED ROTOR BEARING TEST RIG
MOTOR STATOR ASSEMBLY

FIGURE 10

Task 2.3.3, Properties of Reactor Clad and Structural Materials

The project was delayed during April because of trouble with pressure regulators that failed to meet control specifications. The regulators were returned to the vendor. Various methods of regulation were considered, and regulator vendors were recanvassed. It was decided to try a new regulator that had been missed in the first evaluation at the start of the project. Two regulators were obtained and were installed at the end of the month. Precise and stable regulation was then achieved.

Attempts to improve the axial furnace temperature profile were stopped when uniformity within 3°F over a length adequate for the 4-1/2-inch capsules of Runs I and II was achieved. Further adjustment is needed for the 10-inch Run III capsules, and this will be done as time is available before that run starts.

Discussions were held with the vendor who is final machining the Cb + 1 w/o Zr and B-66 capsule parts. Apparently work hardening, resulting from the rough machining, left a surface not amenable to diamond grinding. The wheel loaded up, and abnormal wear of the wheel occurred. (A significant portion of this firm's business is grinding Cb alloys, and this had not occurred before.) The Cb + 1 w/o Zr and B-66 parts were stress-relieved in the creep furnace for one hour at 2000°F and one hour at 2200°F, respectively, and returned to the vendor to complete the machining. Difficulties have been experienced with this vendor, resulting in additional delays to this task. Approximately 30 hours of diamond grinding remain to complete the work, and a second vendor is being sought in order to accelerate the program.

The stainless steel capsule was leak-checked in the creep furnace at the operating temperature with no indication of a leak. Preparations were started to fill the capsule with lithium; however, an accident occurred with the purification and loading apparatus that necessitated shutdown and dismantling for repair. After the repairs were accomplished, a critical part failed during reassembly, requiring a second disassembly and repair. The second reassembly was started; and initiation of Test I is scheduled for the last week of July 1963.

The reworked tantalum furnace liners were received, and an attempt was made to assemble one with the furnace block, into the furnace tube. The furnace tube was found to be too out-of-round and tapered for the liner to fit properly. Attempts were made to grind the liner without satisfactory results. The OD of the block was reduced, and the liner was split and rewelded to a smaller diameter. The parts were then reassembled in another attempt to fit the liner, without success. It will now be necessary to obtain a thinner liner; however, the liner will not be required for Test I, since its primary purpose is to protect the columbium capsules from impurities diffusing through the furnace tube.