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SUPERSONIC TRANSPORT LUBRICATION SYSTEM INVESTIGATION

by

W. L. Rhoads and L. B. Sibley

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS3-6267

RESEARCH LABORATORY
SKF INDUSTRIES, INC.
ENGINEERING AND RESEARCH CENTER
KING OF PRUSSIA, PA.

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THIRD SEMIANNUAL REPORT

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ABSTRACT

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Ball bearings and bellows face seals for use on Mach 3 aircraft gas turbine engine mainshafts are being tested with several selected lubricants using both oil-mist and jet lubrication systems, with provisions for inert gas blanketing. Bearing operating temperatures of 600°F and higher are being explored under typical engine load and speed conditions with the seals exposed to 1200°F air and a pressure differential of 100 psi.

600°F screening tests have proceeded in the recirculating rig with several candidate lubricants, and oil-mist testing with Esso 4040 (MIL-L-7808E) has begun under heated conditions. In the recirculating-rig tests with nitrogen blanketing at 600°F, Esso 4040 caused lubrication related bearing failures while Socony Mobil XRM 177F, Sinclair Turbo S 1048 (improved) and Monsanto MCS-293 (in air) all performed satisfactorily. The latter three lubricants will be tested at higher temperature.

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SKF Industries, Inc.

I. INTRODUCTION

This is the third semi-annual report under NASA Contract NAS3-6267 and covers the work done from November 1, 1965, through May 1, 1966.

The performance of aircraft gas turbine mainshaft ball bearings, seals, and lubricants under simulated supersonic transport engine conditions (Mach 3) is being studied using the most advanced materials, designs, and manufacturing techniques available. Both an oil circulating system and a once-through oil-mist system are under investigation, each with inert gas blanketing for high-temperature operation. Five candidate lubricants for each of the two systems are being used in screening evaluations, and a 1000-hour endurance test will be conducted with the two best oils in each system.

II. SUMMARY

During this report period, the recirculating rig has been fully operational on 600°F screening tests, despite considerable delays caused by malfunctioning of the original electric drive system. To date, 600°F screening tests with recirculating lubrication have been run using Esso 4040 (MIL-L-7808E), Mobil XRM 177F, Sinclair Turbo S 1048 (Improved), and Monsanto MCS-293, lubricants, all using a nitrogen blanket. In addition, the Monsanto MCS-293 lubricant was run in an air atmosphere at 600°F. All oils were degassed prior to use. All tests used 459981E design M-50 steel ball test bearings and seals with AM350 metal bellows. Screening test results are summarized in the tabulation given in Enclosure 50 of this report.

All auxiliary equipment (mass spectrometer, nitrogen-helium mixing system, slip-rings, air heater, drive, etc.) is operational. All corrosion resistant components have been installed on the recirculating rig in preparation for future testing with DuPont PR-143 fluid. Auxiliary heater components are on hand and fabrication of all required heater parts is currently being finished so that tests above 600°F may be conducted.

The mist rig has been brought to the point where high-temperature screening tests with Esso 4040 lubricant have begun with all systems operable.

III. CONCLUSIONS

1. The following conclusions are drawn for recirculating lubrication:

a. Esso 4040 (MIL-L-7808E) oil was not found suitable for use, even with nitrogen blanketing, at 600°F screening test conditions due to lubrication-related bearing failures.

b. Mobil XRM 177F and Sinclair Turbo S 1048(Improved) oils were found suitable for use under 600°F screening test conditions with nitrogen blanketing and will be tested at the next higher temperature (700°F).

c. Monsanto MCS-293 fluid was found suitable for operation under 600°F screening test conditions without a nitrogen blanket (open atmosphere baseline test) and will be tested at the next higher temperature.

d. Monsanto MCS-293 fluid in a nitrogen blanket caused a bearing failure in the 600°F screening test. It is thought that this failure was the result of thermal instabilities not necessarily associated with the fluid's lubricating ability. The fluid will be re-tested at higher temperatures.

e. Test seals (using AM350 bellows material in both the air-seal and oil-seal positions) performed adequately under 600°F screening test conditions if the proper pressure balance was maintained.

2. Initial testing on the mist rig under heated conditions with Esso 4040 lubricant (MIL-L-7808E) indicates that an oil-mist lubricated bearing-seal system may operate with only half of the torque and heat generation of a comparable recirculating oil lubricated system. Mist lubricated test bearings have operated satisfactorily for short periods under full load and speed at 250-300°F. Auxiliary heating will be used in future testing at higher temperatures.

3. The recirulcating-oil rig and all associated systems are operating completely satisfactorily for 600°F screening tests. Testing at higher bearing temperatures, while maintaining 500°F oil-in temperature, requires auxiliary bearing heating systems which are currently being installed.

IV. DETAILS OF PROGRESS

1. Background

In gas turbine engines designed for use in advanced generations of supersonic transport aircraft, the mainshaft thrust bearings and the seals used to contain the lubricant in the bearing chamber must be capable of operating at 600°F and above. Since lubricant degradation must be minimized for long-term operation at these high temperatures, nitrogen blanketing may be employed to reduce oxygen to a very low level in the bearing and lubricant system.

Conventional recirculating oil-jet lubrication of the bearing as well as mist lubrication using either nitrogen or air as a carrier for the oil, may be considered for advanced SST engines. In the latter system, the oil is not recovered, thus dispensing with the need for oil recirculation hardware and also relaxing the long-term thermal stability requirements necessary for recirculating oils.

The current state of development of bearings, seals and lubricants is such that operation under the conditions specified for advanced supersonic transport engines is definitely possible, but that extended operation of candidate bearing-lubricant-seal systems is needed to establish temperature limitations and reliability.

2. Research Objectives

It is the purpose of this program of research to investigate the limits of operational feasibility of using the best currently available bearings, seals, and lubricants in high-temperature lubrication systems under conditions simulating those expected in the main propulsion power units of an advanced Mach 3 supersonic transport aircraft. It is expected that this research will result in:

a. Data pertaining to the maximum temperature capability of several of the most promising available lubricants in both circulating and "once-through" nitrogen-blanketed lubrication systems.

b. Operating experience with a lubricant having a Freon additive under supersonic transport engine conditions in both recirculating jet lubrication and oil-mist lubrication systems.

c. Comparison between an inerted and an open recirculating oil system under supersonic transport conditions using the most promising available lubricant.

d. Data on endurance of inerted recirculating and oil-mist bearing and seal systems under simulated supersonic transport engine conditions up to maximum of 1000 hours.

3. Plan of Research

a. Timing of Project Tasks

The research program is divided into six separate tasks described in Appendix I of the Second Semi-Annual Report (2)*. Briefly, these tasks encompass the following:

Task I. Design, construction and check-out of facilities and test systems. (Completed)

Task II Recirculating rig screening test (3 hours at specified test conditions) of 5 candidate lubricants with inert blanketing, a selected lubricant (inerted) with a Freon additive, and another selected lubricant in a base-line open-atmosphere test. (In progress)

Task III Recirculating rig endurance tests (1000 hrs. maximum) of two selected lubricants. (To be started)

Task IV Oil-mist rig screening tests of 5 candidate lubricants in nitrogen and a selected lubricant with a Freon additive. (In progress)

Task V Oil-mist rig endurance tests of two selected lubricants. (To be started)

Task VI Quality assurance procedures for all test hardware, supplies, instrumentation and cleanliness. (In progress).

The phasing of effort is shown in the PERT network presented as Enclosure 1 which is current as of May 1, 1966. This PERT network is revised to include the amended period of performance as granted by Amendment No. 4 (April 18, 1966) to the Contract.

* Numbers in parentheses refer to List of References at the end of this report

Project effort to date has been expended in Tasks I, II, IV and VI which are concerned with the procurement of facilities and test specimens and the screening tests of candidate lubricants in the two test rigs. During the six months covered by this report, the major portion of the effort went into screening tests in the recirculating rig (Task II). As shown in the PERT network, effort during the next semiannual period will be devoted to completion of all screening tests in both rigs (Tasks II and IV) and to the initiation of endurance tests in both the recirculating and mist rigs (Tasks III and V).

b. Test Conditions and Facilities

The general plan of the test apparatus used on this program is shown in Enclosure 2. Two test rigs have been provided, one in which the lubrication system (shown in Enclosure 2) is a recirculating oil-jet system and the other a once-through oil-mist system. Both of these rigs and associated systems have been described in detail in the First and Second Semi-Annual Reports (1,2). An assembly drawing of the test rig is given in Enclosure 3 (both rigs are identical except for the jet rings and the lubrication systems).

The test apparatus is capable of operating an aircraft mainshaft ball bearing and face seal assembly with the candidate lubricants under the following initial conditions:

Oil-inlet temperature, 500°F* ± 10°F
Bearing outer-ring temperature, 600°F
Bearing inner-ring temperature, 610°F or higher
Bearing thrust load, 3280 lbs.
Air temperature at the outboard seal, 1200°F
Pressure drop across the test seal assembly, 100 psi
Shaft speed, 14,000 rpm

If satisfactory performance is obtained under the above conditions with any given lubricant in initial screening tests, the bearing temperature will be increased in 100°F increments to establish the maximum temperature under which the bearing-seal-lubricant combination will operate adequately.

*This temperature is specified for the recirculating oil rig. For the oil-mist rig, the lubricant shall be supplied from a pressurized reservoir at a temperature of 200°F, minimum.

The following lubricants, five in number for each lubrication technique, have been selected:

Recirculating Oils

a) Esso Turbo Oil 4040 (base-line fluid meeting MIL-L-7808E)
b) Sinclair Turbo S Oil, Type 1048, improved (ester-base)
c) Socony Mobil XRM 177F (hydrocarbon)
d) Monsanto MCS-293 (modified polyphenyl ether)
e) DuPont PR-143 (fluorocarbon)

Oil-Mist Lubricants

a) Esso Turbo Oil 4040 (base-line fluid meeting MIL-L-7808E)
b) Union Carbide UCON 50-HB-5100 (polyalkylene glycol)
c) Sun Oil Sunthetic 18H (polyolefin)
d) Socony Mobil XRM 177F (hydrocarbon)
e) Hercules Powder Hercolube F (polyester)

4. Test Elements

a. Test Bearings

The test bearings being used in all 600°F screening tests have a nominal mounted contact angle of 26° and conform to design No. 459901E shown in Enclosure 4. (This design is identical to that designated 459981A discussed in previous semi-annual reports (1,2).) These bearings have balls and rings of M-50 tool steel which retains suitable hot hardness up to 600°F. They have operated satisfactorily in all testing conducted so far with the exception of some instances of excessive cage land smearing, mostly in the mist rig testing, which may be the result of uneven cooling by the mist, as discussed in a later section of this report. (If cage smearing persists in continued mist-rig testing, some modification of cage design will be tried, such as increasing the cage-land clearance or changing to inner-ring-land riding design). Some M-50 bearings manufactured for continued testing did not meet the groove radius requirements of the 459981E design in Enclosure 4 and were reworked to the 459981F design, which is identical to 459981E except that 0.005" larger balls were used to provide stock for the reworking.

For testing at temperatues above 600°F test bearings conforming to design No. 459980J (identical to previously designated 459980) have been made with rings and balls of WB49 tool steel which retains suitable hot hardness up to 1000°F. It was discovered in the manufacture of these bearings, however, that the black oxide surface treatment process used for other tool steel bearing materials has an adverse effect on the WB49 bearing surfaces. This treatment, which has been shown to have a beneficial effect on the performance of bearings made of other steels under marginal lubrication conditions (1), apparently causes a roughening or scalloping effect on WB49 surfaces as shown in the surface traces in Enclosure 5. These traces compare the texture of a 459980J inner ring in a spot where the black oxide coating has been scraped off with the texture of an M-50 bearing ring which has been similarly scraped. (The traces are meaningless in those regions where the coating is not scrapped off, since the tracing stylus does not everywhere penetrate the coating). This roughening of WB49 bearing surfaces has been shown in other tests to have a detrimental effect on bearing performance at high speeds and temperatures (3). In order to provide enough WB49 bearings without black oxide coating for this program, therefore, the existing coated rings have been reworked to design 459980K which is identical to 459980J except that 0.005" oversize balls were used.

The modified test bearing designs No. 459980H and 459981D discussed in the Second Semi-Annual Report (2) will not be tested on this program, since the original design has been shown in the initial testing to be entirely workable under the test conditions, except for possible cage modifications, as discussed previously.

At the present time, the following test bearings are on hand:

Used M-50 (unsuitable for further testing)	4
Used M-50 (suitable for further testing)	5
New M-50	10
New WB-49	17
Inner-ring-land riding cages	10

An additional lot of M-50 bearings has been ordered for the endurance testing on Tasks III and V, if needed.

In some of the tests conducted to date, especially in the oil-mist rig, there was some evidence that bearing failure may have been initiated by cage wear and smearing. Some back-up cages of an inner-ring-land riding design have been provided. Also, some standard outer-ring-land riding cages have been made with increased land clearance for any future tests when needed.

Manufacturing problems have prevented the finishing of other back-up cages made of S-Monel coated tool steel and of nitrided nitralloy. Therefore, these unfinished parts will be held until a clear need for them arises.

b. Test Seals

The dual test seal arrangement shown in Enclosure 3 has been used successfully in all testing so far. This arrangement consists of an oil face seal and an air face seal shown in Enclosures 6 and 7, respectively, supplied by the Koppers Seal Company. Both of these seals have an AM350 stainless steel bellows and the carbon face is machined with a dam so located that the bellows is essentially pressure balanced. Carbon pads or lands are provided both inboard and outboard of the sealing dam to distribute the bellows spring force and residual gas pressure unbalance over a large contact area between the carbon and shoulder rings. Tested seals requiring the replacement of carbon rings or the re-chromium plating of the shoulder are reworked by Koppers Company on a subcontract basis. However, the lapping of both carbon and shoulder surfaces between tests is being done by SKF Laboratory personnel using lap plates and techniques supplied by Koppers.

It has been found that, so long as the correct pressure balance is maintained and the carbon sealing surface is intact and not badly scored, the seals perform adequately. So long as approximately one third of the original carbon dam height is remaining (and in good condition) on the test seals, a correct pressure balance is maintained. If excessive wear is present, gas flow through the radial slots in the wear pads on either side of the sealing dam can choke. This causes the design pressure drop (about 100 psi across the oil seal, for example) to occur across an area from the one side of the pads to the opposite side of the sealing dam instead of just across the sealing dam itself.

This pressure drop acting on a larger than designed area disrupts the pressure balance and can increase heat generation in the carbon-chromium rubbing surface or lift the carbon off the runner leading to high leakage.

An area of concern on the air seal was possible relaxation and permanent set in the AM350 bellows on exposure to high temperatures. It has been found that during operation at 600°F test conditions this bellows operates between 900 and 1000°F. No seal has been run more than about 10 hours at these 600°F screening test conditions so that the long-term effect of exposure to these temperatures cannot be evaluated. In the short tests run the bellows did not relax significantly as far as can be ascertained. (It should be noted that free height measurements on seals are difficult and that an error on the order of ± 5-10% could exist). If relaxation difficulty is experienced in future testing (in particular, in endurance runs) two air seals with Inco 718 bellows now on hand will be used.

At the present time, the following seal disposition exists:

Oil Seals - 3 on hand (2 with reworked carbons)	3 reworked due from Koppers (1 of which was rejected for incorrect dam diameter)
Oil Seal shoulders - 2 on hand	2 reworked due from Koppers
Air Seals - 6 on hand (2 with Inco 718 bellows)	
Air Seal shoulders - 4 on hand	2 Inconel shoulders due from Koppers (rejected for undersize bore)

c. <u>Lubricants</u>

Lubricant selection remains unchanged from those described in the Second Semiannual Report (2). Detailed properties data for the selected test lubricants are given in the earlier reports (1,2). Temperature-viscosity properties of the test lubricants are presented in Enclosures 8 (recirculating test oils) and 9 (mist test oils).

The following amounts of the test lubricants are on hand:

LUBRICANT	USED IN	UNUSED AMOUNT ON HAND (GALLONS)
Esso 4040	Both rigs	120
Sinclair Turbo S-1048	Recirculating rig	175
Socony XRM 177F	Both rigs	30*
Monsanto MCS-293	Recirculating rig	20*
DuPont PR-143	Recirculating rig	20*
UCON 50HB5100	Mist rig	150
Sunthetic 18H	Mist rig	10*
Hercolube F	Mist rig	10*

A summary of the acid number and viscosity measurements on test lubricants before and after 600°F screening tests is presented as Enclosure 10.

d. Freon Additive

DuPont Freon 113 was selected as an additive for both a recirculating and a mist lubricant to provide improved boundary lubricating characteristics in inerted lubrication systems, and to increase the spontaneous ignition temperature of the compounded lubricant over that of the base-stock when exposed to air, based on the results of preliminary studies at NASA (4-6). Freon 113 was selected as having the most favorable lubricating characteristics with the tool steels used for the test bearings on this program. In order to select the most promising base-stocks for these Freon-additive tests, preliminary solubility and compatibility tests were conducted at DuPont and reported in Appendix III of the Second Semiannual Report (2). Since these early tests were not conclusive, the following additional testing has been conducted.

Each of the eight candidate lubricants was mixed with 10% (be weight) of Freon 113 and the resulting mixture heated for one hour at 500°F in an open container. In addition, gaseous Freon 113 has been bubbled into each candidate lubricant while it was heated to 500°F, for one hour. The resulting samples were sent to the DuPont Laboratories for analysis of the Freon remaining in the lubricant. These results are presented in Appendix I together with the results of additional compatibility tests in sealed containers conducted at DuPont, which differ from those reported in Appendix III of (2) in that:

*Further quantities of these lubricants are being held on lot control by the supplier.

a) the samples were sealed in air rather than in a vacuum.

b) 10% by weight Freon 113 was used rather than 50% by volume.

c) both WB49 bearing steel and Inconel X-750 samples were sealed in the same capsule rather than in separate capsules.

Of the recirculating oils tested for solubility of Freon 113 (10% Freon content used initially to establish solubility limits, see Table II of Appendix I), the ester-base oils, Esso 4040 and Sinclair Turbo S-1048 (improved), and the polyphenyl ether type lubricant, Monsanto MCS-293, had the most promising solubility characteristics. The Freon compatibility results (see Table I of Appendix I) showed that Freon 113 reacted extensively with the ester oil, Sinclair Turbo S, but that no excessive reaction occurred with Monsanto MCS-293. Therefore, based on these results it has been decided to add 3% (by weight) Freon 113 to the MCS-293 fluid and run under a Nitrogen blanket in the recirculating rig. Sealed capsule compatibility tests will be re-run with Sunthetic 18H, UCON 50HB5100, and Esso 4040 before selecting the base-stock to be used for the Freon additive test in the oil-mist rig.

5. Test Equipment

a. Test Rigs

At this time, the recirculating rig is fully operational for testing at 600°F, on a reliable basis although trouble is still experienced on occasion with air and oil leaks (improved sealing methods are being explored). All corrosion resistant parts necessary to test the DuPont PR-143 fluid have been installed.

The mist rig is now starting tests at elevated temperatures, and is also basically operable, although considerable delays were encountered in the procurement of hardware for this rig to replace that used to operate the recirculating rig. The heat-up time in the mist rig is very long, since there is no preheating of the lubrication system as in the recirculating rig. Auxiliary heaters and a preheat procedure will be used in future testing at screening test conditions.

b. Drive System

Considerable difficulty was experienced with malfunction (severe hunting) of the recirculating rig 75HP drive system (especially around 14,000 rpm) which caused a great deal of lost time. The manufacture was unable to correct this problem so the drive was replaced by an existing 50HP variable speed DC motor and MG set until a new 75HP unit can be provided by the manufacturer (delivery is expected in June, based on a verbal commitment). Maximum test speed obtainable with this temporary motor is about 13,500 rpm. A new pulley is being provided to reach 14,000 rpm.

During early testing on the recirculating rig, the flat belt used to transmit power from the motor to the test rig failed repeatedly. It was found that belt performance depended very heavily on exact alignment between the motor pulley and jackshaft. The necessary procedures have been evolved to secure correct alignment so that belt life has been considerably extended.

c. Nitrogen-Helium Mixing System

With the installation of the Bendix Mass Spectrometer equipment and sample drawing apparatus (discussed in the next section of this report), the continuous mixing system that provides approximately 1% tracer helium in the nitrogen flow to the interseal cavity was checked out on the recirculating rig. The spectrometer indicated that, in first tests, helium was being admitted to the nitrogen flow, but that the quantity was erratic and not proportional to the flow. This effect was traced to an error in the pneumatic valve control system which inverted the mixing control function. Correction of the control system yielded the correct valve actions and a preliminary spectrometer analysis indicated a helium concentration at the desired 1% within a few tenths of a percent, even at a low mixture flow rate. This system is now operational on both rigs. Results of the use of this system are included in the various sections under Test Results.

d. Auxiliary Test Bearing Outer Ring and Housing Heaters

Preliminary testing in the recirculating rig revealed that the test bearing heat generation was considerably lower than expected in the design phase of this program (100 to 200 Btu/min. rejected to the oil, instead of 400 Btu/min. based on previous test data available to SKF Industries, Inc. on bearings having similar internal geometry). It was found that the test bearing outer ring could not be heated higher than 600°F without also increasing the oil-in temperature above 500°F. Reducing the oil flow rate to a low enough level to maintain this 100°F differential between oil-in and outer-ring temperature sometimes resulted in bearing failures apparently caused by thermal instability, as discussed in the section on Test Results.

Therefore, auxiliary heaters were procured for installation in the rig both around the main housing OD and next to the test bearing outer ring on the bearing housing mount, as shown in Enclosure 12. Installation of these auxiliary heaters in the mist rig will be completed in May and in the recirculating rig in June.

e. Hot Air System

The hot air system is now operating satisfactorily on both rigs. The major problems encountered during this report period are explained in detail below.

After one of the runs with Esso 4040 oil a fairly large quantity of magnetic metallic powder was found in the hot air system when it was disassembled after approximately 10 hours at full temperature conditions (Enclosure 19). Through chemical analysis, it was determined that this powder was the product of oxidation of the 316 stainless steel air tube in the air heater. The heater was removed from service until it was established by pressure testing that the tubing was still safe to operate at the temperatures and pressures encountered in service in view of the possible weakening of the heater tube wall. A fully instrumented series of tests (including monitoring of the heater temperature at two points and the air just as it leaves the heater) indicated that at high flow rates 1200°F air into the hot air manifold can be realized without any overheating and damage to the heater. The existing air compressor can be used to supply air flow for both rigs simultaneously only so long as the heat loss in the piping between the heater and the rig can be held at the low level obtained with the present insulation when it is new. However, upon exposure to the temperatures encountered in testing and to the necessary handling during assembly and disassembly of the rigs, this insulation deteriorates to an appreciable extent. A refractory fiber felt insulation believed to be better both mechanically and thermally will be used in future testing.

f. Recirculating Oil System

The hot recirculating test oil system has worked satisfactorily in all 600°F screening tests. In order to maintain a 500°F oil-in temperature, however, it was often necessary to use an oil flow to the test bearing in the 0.5 - 1.0 gpm range, which is below the 1-10 gpm range of the present flowmeter. Therefore, a replacement flowmeter of special Inconel construction, having a flow range of 0.3 to 3 gpm is on order for delivery in June. In the meantime, testing continues with the existing system which has been calibrated below 1 gpm flow by the position of the oil throttle valve in the system.

6. Instrumentation

All instrumentation systems have operated satisfactorily on both rigs during this report period, with the exception of the recirculating rig oil-level sensor which malfunctions by causing excess leakage of test oil out the vent line. (Since the oil level has never dropped dangerously low in all testing so far, and the oil flow rate is monitored continuously, the oil-level sensor will be discarded.) Other instrumentation problems, associated with the mass spectrometer, rotating temperature measurements, vibration sensing and incorporation of the IBM system as a data collector were resolved as discussed in the following sections.

a. Mass Spectrometer

A Model 12-101A mass spectrometer, operating on the time-of-flight principle and supplied by the Bendix Corporation of Cincinnati, Ohio, has been installed. It has been set up to function under the control of the IBM data control system to work in conjunction with the sample handling and valve programmer made by the Nuclide Corporation of State College, Pennsylvania, so that sequential sampling from four chambers can be achieved automatically.

The IBM computer initiates a gas sampling sequence by way of the Nuclide sample handling system. The sampling sequence is as follows: Pump and purge 0-4 minutes, admit gas to the spectrometer at the end of the 4th minute, stabilize for readout 4-6 minutes, read at the end of the 6th minute.

The signals from the mass spectrometer may be recorded in any combination of the following three ways:

(1) Pen-chart record.
(2) Manual read-out of the meter on the electrometer circuit.
(3) A selected peak (such as Helium) can be recorded by the IBM computer as a millivolt signal, which is a function of the concentration of the selected ion.

Pre-analyzed gas samples have been procured for sensitivity test and calibration of the spectrometer. Tests show that this instrument is capable of detecting by both manual and computer monitoring, less than 100 parts per million (0.01%) of helium in a balance of nitrogen. A helium calibration curve was obtained by introducing the pre-analyzed gas samples containing 1.0%, 0.1% and 0.01% helium in nitrogen. Over this range, a linear relationship between concentration and response was obtained. A similar calibration curve for oxygen was also completed using pre-analyzed samples containing 1.0% and 0.1% oxygen in nitrogen. Methane calibration is now being performed with the Honeywell recording system which was just received.

The instrument was utilized manually to analyze gas samples from the recirculating rig during the XRM-177F and Turbo S runs. The oxygen content in both the interseal and test bearing cavities was between 0.04 and 0.05% during both runs.*

During the test with MCS-293 oil under nitrogen blanketing, an attempt was made to operate the mass spectrometer automatically with the computer. The results obtained are questionable because of a solenoid valve failure in the spectrometer which resulted in improper purging of the sample chambers giving non-representative samples and because of an error in the computer program such that the location of sampling was questionable. These points have been remedied.

During the open atmosphere MCS-293 test, a mass spectrometer analysis of the atmosphere in the test bearing chamber was obtained, as shown in Enclosure 49. However, the mass spectrometer was not utilized for test seal leak detection due to a temporary sticking linkage in the helium tracer mixing system. The positive displacement meter was used to monitor seal leakage in this test, and the mixing system worked satisfactorily in subsequent tests.

b. Slip Rings and Connector Assembly

Mercury wetted slip-ring units having 16 rings shown in Enclosure 13, were constructed as discussed in the Second Semiannual Report (2) and have been used successfully on both rigs. Testing with the first units having stainless steel rings was not satisfactory, due to overheating and rubbing of some surfaces, to shorting between rings and to lack of good electrical contact through the channels, presumably since the mercury did not wet the stainless steel consistently. The design was modified to provide larger clearance spaces, the insulating plastic parts were coated with a non-wetting fluorocarbon film and copper rings and inserts were substituted for the mercury-wetted stainless steel parts. Screening tests have been conducted with one such modified unit with very promising results. Temperature errors associated with the use of non-thermocouple materials in the slip-rings, discussed in Appendix V, are minimized by cooling

*It has since been discovered that the mass spectrograph gave erroneously high oxygen analysis because of excessive broadening of the nitrogen peak. This difficulty has now been corrected.

both the rotating and stationary connectors to essentially the same temperature. The lack of significant temperature error will be verified in special calibration tests.

Preliminary bench testing of a single mercury-wetted copper slip-ring indicated that prolonged running will result in excessive amalgamation and thickening of the mercury, thus requiring periodic overhaul of the slip-ring assembly. For this reason, special steps were taken to provide efficient cooling of the mercury-wetted parts to retard this amalgamation and no overhaul of a complete assembly has yet been required.

c. Radio Transmitter System

In order to provide back-up instrumentation for the thermocouple slip rings, a thermocouple telemetry system was purchased from Industrial Electronetics Corporation, Melbourne, Florida. This system utilizes an FM transmitter and receiver to provide a means of measuring temperature without a metallic connection between the thermocouple and the readout device. The system is shown in block diagram form in Enclosure 14.

A voltage-controlled subcarrier oscillator is used to generate an output frequency which is proportional to the thermocouple emf. The subcarrier frequency modulates the carrier frequency of the RF oscillator to provide an FM output signal from the transmitter. Since the RF carrier frequency is in the 88-108 MHZ range, a standard FM broadcast tuner is used to receive the transmitted signal. The received signal is demodulated to remove the RF carrier and then fed to a discriminator which converts the modulating frequency to a voltage proportional to the thermocouple output voltage. An adjustable DC "bucking voltage" is used to provide reference junction compensation. Power for the transmitter is obtained from 9-volt batteries.

The mechanical arrangement of the transmitter is shown in Enclosure 15. The transmitter is completely encapsulated in epoxy which is molded to fit concentrically on the rotating shaft. Four 9-volt mercury batteries, connected in parallel, are used to provide power for the transmitter. The batteries are contained in a housing which is also mounted on the shaft and rotates with the transmitter. Tests conducted in the SKF Laboratory have shown that battery performance is not affected by the shaft rotation.

The receiver is located outside the test cell. An antenna, consisting of a length of coaxial cable passing through the wall of the test cell and terminating within a few feet of the transmitter, is used to insure good reception of the transmitted signal. The receiver output signal is in the 0-2 volt range. A precision voltage divider is connected across the receiver output to permit measurement of the telemetered temperature using conventional thermocouple instrumentation. It is planned to monitor this temperature on the IBM system, and therefore the reference junction compensation was adjusted for a junction temperature equal to the IBM cabinet temperature. Since the actual junction temperature at the transmitter varies considerable during the course of a test, a stationary thermocouple, located near the transmitter, is used to measure the actual junction temperature for later correction of the transmitted temperatures measured by the rotating thermocouple.

Calibration of the system was accomplished by measuring the voltage produced at the receiver output terminals with the thermocouple immersed in a small portable furnace. The furnace temperature was measured using a platinum thermocouple, whose calibration is traceable to the National Bureau of Standards, in conjunction with a portable precision potentiometer. The reference junction temperature throughout the calibration was 72°F. Enclosure 16 presents a plot of receiver output voltage vs. temperature. It is seen that, at any given temperature, the receiver output voltage is greater than the output voltage of an Iron-Constantan couple by a factor of 75. Therefore, a voltage divider, in a ratio of 75:1, was connected across the receiver output in order to provide a voltage equal to the thermocouple emf. A measurement accuracy of +0.4% to 3.5%, corresponding to an error of 35°F at 1000°F and 3°F at 750°F is obtained using this method, which is considered satisfactory.

d. Vibration Sensing System

A vibration sensing system has been incorporated for use on both the recirculating and mist test rigs. An ultra-high temperature accelerometer can be mounted in any of three planes to sense rig housing vibration. The signal is applied to an accelerometer amplifier system located in the corridor console area. After amplification, the vibration signal is rectified, filtered and applied to a level discriminating circuit (Figure 1, Enclosure 17).

During each test, after the shaft has reached the required test speed, the amplifier gain is adjusted to produce an arbitrary level, from one to seven, on the linear vibration panel meter. If the average vibration should increase to a level of eight, the level discrimination will effect a rig shutdown and light the vibration shutdown lamp.

Frequency response of the level discriminator is shown in Figure 2, Enclosure 17. If it is desired to monitor a particular frequency, a bandpass filter may be inserted between the amplifier and the level discriminator.

Provisions have been made for mounting the accelerometer to be sensitive to vibrations in any of the three orthogonal axes of each rig. During future tests typical vibration spectra will be obtained about these three axes to find the best position to detect impending bearing failure.

The vibration detector is a redundant failure detection system and was not used on tests to date. No difficulty was encountered in early detection of failures of screening tests, but the vibration detector will serve well in endurance tests.

e. IBM Collection of Data

A program has been developed for the SKF Laboratory's IBM system to collect and summarize all test data. This program has been used successfully during the screening tests to augment the manual recording of data. A few points have malfunctioned in each test, but it is expected that manual data logging will be completely replaced by the IBM system when reliable operation can be demonstrated.

All data points on the rig(s) are sampled every six minutes and the information stored in memory. On command (given by the test-off signal) the following information is printed out for each point:

(1) the first, second, fourth and seventh points after the start signal.
(2) the last three points preceeding shutdown.
(3) the maximum, minimum, and average values of the point (taken between the eighth point after start-up and the third point before shutdown).

(4) the two points immediately preceeding the maximum value.

If upon examination of this summary more detailed information is desired, all data for each point may be printed out.

V. TEST RESULTS

1. Recirculating Rig - 600°F Screening Tests

All tests run in the recirculating rig during this report period used the original 459981A (now designated 459981E) bearings of Series I design (M50 material). All test seals (air and oil) were fitted with AM350 bellows. Testing is reported in chronological order. Specified test conditions are described on Page 6 of this report and in Appendix I of the Second Semi-Annual Report (2).

Temperature-viscosity properties of the recirculating test oils are given in Enclosure 8. Inner-ring temperatures were obtained during several of the later tests from temperature sensitive paints used on some of the rotating parts not exposed to oil, but were not available on a continuous basis for any of the tests because of slip-ring problems.

Test oil was supplied to the test bearing by jet rings, one on each side of the bearing, as described in the previous reports. All tests were conducted using six 1/16" diameter jets per ring. Test oil was supplied to the roller bearing by means of one jet ring having three 1/16" diameter jets. The flow meter measures only the oil going to the test bearing. The cleaning procedure described in Appendix VI was developed to eliminate contamination when changing from one test oil to another.

Enclosure 18 presents a summary of the heat rejected through the test oil, based on oil temperatures and flow rates observed during testing.

a. Esso 4040 (MIL-L-7808E) (Nitrogen Blanket)

Two test bearings were tested using this oil at flow rates between approximately 0.5 and 5 gpm. Several runs were made with each bearing. Summaries of the data for several hot runs are given in Appendix II, pages 2-1 to 2-6.

Using the first test bearing (No. 924104), about 5.5 hours of testing was accomplished at test bearing outer-ring temperatures between 400 and 600°F. Of this time, 1.8 hours were at full screening test conditions with the exception of oil-inlet temperature which was about 550°F (see data sheets). Oil flow was in the 5 gpm region.

Full test conditions were reached on two occasions, once for 1.5 hours and once for 0.3 hours. The first test was terminated when the drive belt began breaking up and one of the pieces cut the oil supply line to the jackshaft. The second test was terminated when the test bearing chamber vent line failed at an elbow and caused about half of the test oil to be lost. This failure can probably be attributed to fatigue caused by vibration. Attempts to restart the test after this were thwarted by recurrent shear-pin failures in the drive system, indicating a significant increase in torque over that required to operate the rig earlier in this test.

Total seal leakage through both the oil and the air test seals, except for transients at each start-up, varied between 1.6 and 9.6 scfm during these runs, with the highest flow occurring at the end of the test. (Permissible maximum is 5 scfm through either test seal.)

After the second of these runs, it was found that the hot air inlet piping to the manifold was buckled and twisted, as shown in Enclosure 19. In addition, the connection to the heater was bent, although this condition did not indicate temperature damage to the heater itself, according to the manufacturer. Upon disassembly, several grams of a magnetic metal powder was found in the hot-air manifold (see Enclosure 19), as discussed in an earlier section of this report under Hot Air System. Some of the same powder was found in the hot-air exit from the air heater.

The acid number of the oil increased significantly during the test (from 0.44 for new, degassed oil to 0.80 for the last sample tested, Enclosure 10) even though a considerable amount of new oil was added to the system to replace losses due to leakage and other causes. There was very little evidence of oil deposits in the rig, as shown in Enclosure 20.

The rig seal (Enclosure 21) was found to be in good condition (with the exception of the silicone rubber damping ring which has been replaced in subsequent tests with asbestos) as was the oil seal (Enclosure 23). The carbon surface of the air seal was badly scored (Enclosure 22). From the rounded condition of the radial slots located inboard from the dam and the presence of the metallic power in the hot-air manifold, it is concluded that seal damage was caused by the abrasive action of the metal powder coming from the air heater. The condition of this seal appears to explain the high leakage rate (approximately 9.6 scfm) seen toward the end of the second run at full test conditions.

Examination of the bearing showed that the rollers of the rig roller bearing were, after one of the earlier runs in this test series, badly glazed and dented, even though still operable, apparently from extraneous debris that had entered the roller bearing. (The source of debris, a corroded low-carbon steel spacer ring, was eliminated in subsequent tests.) The condition of the roller tracks on the inner and outer rings was considered good with relatively little glazing present.

Evidence of considerable surface distress (glazing and micropitting) was seen in both the inner and outer ring ball tracks in the test bearing, shown in Enclosure 24. In addition, there was heavy cage pocket wear (Enclosure 25), the silver plating being worn through in some spots. Some slight wear on the OD of the cage was also seen. The balls appeared in good condition, except for some glazing and slight pitting. Some varnish deposits were seen on the test bearing.

There was the possibility that the test bearing failure may have been influenced by the loss of test oil which caused termination of the second of the above mentioned runs. It was also desired to go to a lower oil flow rate in an attempt to secure the 100°F temperature differential specified between the inlet oil temperature and the outer ring of the test bearing. It was accordingly decided to retest with new bearings. Two runs were made on the replacement bearings.

During the first of these runs (in conjunction with a check-out of the hot-air heater), the test bearing was at full load and speed for about 5 hours with an oil flow of 1 gpm. Of this, approximately 0.5 hours was at full temperature conditions (580°F bearing outer ring, 650°F bearing housing, 1180°F air-in and 500°F oil-in). Seal leakage during this run (with the exception of starting transients) was in the 1-4 scfm range.

It was observed that during this test the temperature differential between the oil supply and the bearing outer-ring operating temperature was about 80°F, for an oil flow of approximately 1 gpm. In previous tests, it was found that the differential was on the order of 40-50°F for an oil flow of 3-5 gpm.

During the next run, a test bearing failure occurred after about 1.4 hours running as the bearing was being brought up to test conditions. Oil flow was between 0.5 and 1 gpm. Other conditions were:

Speed - 14,000 rpm
Load - 3280 lbs.
Seal Leakage - 1-2 scfm (after the usual initially higher rate)
Test Bearing Outer Ring Temperature - 560°F
Oil-In - 500°F
Test Bearing Housing - 550°F
Hot Air Manifold - 1100°F

Examination of the test bearing (Enclosures 26 and 27) showed very heavy wear in the cage pockets and land areas. The ball path on the outer ring appeared in good condition; however, the loaded inner ring showed some signs of smearing. The balls and test seals appeared in good condition.

Based on the results of these tests and compared with those from subsequent tests with other oils, it is concluded that the Esso 4040 lubricant tested causes lubrication distress in the test bearing (glazing, micropitting, some smearing) at 600°F test conditions and will not be tested at a higher temperature.

b. Socony Mobil XRM 177F (Nitrogen Blanket)

This oil is the most viscous to be used in the recirculating rig. At a temperature of 500°F, the viscosity of this oil is over four times greater than the Esso Turbo 4040 oil (MIL-L-7808E) used previously (4 cs vs. 0.9 cs). Two hot runs were made with one test bearing. Data sheets for these runs are included as Pages 2-7 and 2-8 of Appendix II.

During the first run, the bearing was tested at full load and speed with the outer-ring temperature of 600°F maintained for about 2 hours. Temperatures satisfying contractual requirements were reached everywhere except at the oil inlet (550°F instead of 500°F) and the test bearing housing (approximately 525°F instead of 575°F). The latter was limited by housing heater failures. Oil flows in the 1 to 4 gpm range were used. Seal leakage rates were rather high, being in the 4.0 to 4.5 scfm range. Shutdown was caused by malfunction of the drive system (hunting).

During the second run, the bearing outer-ring temperature was maintained within the range 575-600°F for about one hour. All temperatures monitored were within requirements except the test bearing housing (450-500°F partly due to burned-out heaters) and the hot air manifold (1000°F) due to deterioration of the thermal insulation. Oil flow was approximately 1 gpm.

It was observed that the seal leakage rate started at about 10 scfm and increased to over 20 scfm during the test. Mass spectrometer readings established that the leakage was from the interseal cavity to the test bearing cavity (0.71% helium in the interseal cavity and 0.57% in the test bearing cavity). Because of this high leakage rate into the test bearing chamber, the bearing chamber vent choked and caused the bearing cavity pressure to increase (to between 20 and 50 psi instead of 6 psi). This pressure acts against the hot air loading pressure so that the load on the test bearing fluctuated between about 2600 and 3100 lbs. The mass spectrometer indicated that oxygen content in both the bearing and interseal cavities was below 0.04%. Termination of the test was caused by excessive seal leakage.

Examination of the oil seal showed considerable coking around the carbon pads and in the bellows. In addition, the seal runner was severely worn as shown in Enclosure 30. During subsequent consultation with Koppers Co. (the seal subcontractors), it was determined that this high leakage was most probably caused by too little remaining carbon dam height. If the dam height is too shallow, gas flow through the radial slots on the inboard side of the sealing dam can choke. This results in the pressure drop of approximately 100 psi occurring across an area from the inside of the inner pads to the outside of the sealing dam instead of just across the sealing dam. This pressure drop decreases the force opposing the spring force which increases carbon and runner surface wear and heat generation (this seems to account for the badly worn seal runner face). Since the surfaces are then in poor condition, high leakage can occur.

Examination of the test bearing, which had approximately 12 hours running time at varying loads, speeds and temperatures in addition to the abovementioned 3 hours around 600°F, showed it to be in excellent condition (Enclosures 28 and 29). Only very slight cage pocket wear was found. The roller bearing was also in excellent condition.

The test oil did not increase in acid number from 0.055. Viscosity (at 100°F), however, increased from 443.4 cs to 471.8 cs, which is significant in this short test. No evidence of coking was found in the rig, although black deposits were found in the filter. Analysis of these deposits at Socony Mobil Laboratory indicated that the anti-wear additive in this oil was more concentrated in the deposits than in the bulk used oil.

Based on its good performance during these two runs, XRM 177F will be run at the next higher temperature (700°F).

Photographs of the test oil seal and test bearing are included as Enclosures 28 to 30.

c. <u>Sinclair Turbo S-1048 Improved (Nitrogen Blanket)</u>

Two runs were made using this oil. In the first run, shutdown was caused by high air leakage before test conditions were reached. Rather high seal leakage (7-8 scfm) was noted using the same seals (cleaned and re-lapped) that had been used in the previous test with Mobil XRM-177F. Damage to the oil seal runner was similar to that seen after the previous XRM-177F test. The explanation of this is the same as that for the XRM-177F test.

Using a new oil seal, a second run was made. Approximately 3.3 hours of testing at a bearing temperature between 590° and 625°F, full load, and a speed of about 13,500 rpm was realized. Of this, about the last 0.5 hour was at full test conditions. Seal leakage was in the 6 to 8 scfm range. It was later found that the sealing dam on the oil seal had been cut incorrectly by the supplier having a larger than desired dam diameter. This caused a larger lift-off force which led to the high leakage. Test oil flow was in the 0.5 - 1 gpm region. The full 100°F temperature differential between the inlet oil and test bearing temperature was realized. The mass spectrometer showed that the oxygen content in both the test chamber and the interseal cavity was between 0.04 and 0.05% during the test. Data sheets for these runs are included as Pages 2-9 and 2-10 in Appendix II.

Upon disassembly both the test bearing and roller bearing were found to be in excellent condition. No signs of oil coking were observed. Oil viscosity (at 100°F) decreased from 38.9 cs to 37.4 cs. The acid number did not increase from 0.22. Accordingly, Sinclair Turbo S is considered acceptable at 600°F and will be tested at higher temperatures.

Photographs documenting this test are included as Enclosures 31 through 37.

d. Monsanto MCS-293 Fluid (Nitrogen Blanket)

Testing of this fluid (a modified polyphenyl ether) was conducted in two stages using a new bearing and oil seal. In the first stage, full 600°F test bearing outer-ring temperature conditions were realized for about 0.5 hours at which time the bearing temperature suddenly increased to about 700°F (oil flow was in the 0.5 to 1 gpm region). After shutdown it was found that the test shaft turned freely without any signs indicative of bearing distress. Accordingly, the test was resumed (after correcting high air leakage). After about 0.2 hours at 600°F, the bearing temperature suddenly increased to about 900°F and the bearing seized (oil flow during this phase was approximately 1 gpm). Seal leakage in both phases was low, around 1 scfm. In both cases speed was 13,500 rpm and the load was about 3200 pounds.

Upon disassembly, it was found that the cage was moderately worn in the outer land and cage pocket areas. The outer ring was badly flaked in the bottom of the groove, both halves of the inner ring and balls were badly smeared due to the seizure, and all components showed signs of high temperature. No signs of oil coking were observed in the rig. The failure was clearly due to a thermal instability in the bearing attributable to insufficient lubrication and/or cooling by the oil. It is not known whether the bearing failure was due to the inadequate lubricating ability of the oil or to an inadequate oil flow in view of the given level of lubricating ability (the same or lower oil flows were satisfactory with two other oils.) The oil flow rate was kept low to obtain the required 100°F temperature differential between the inlet oil and the test bearing outer ring. The oil will be tested at 700°F using a higher oil flow (the required 200°F temperature differential will be supplied by the auxiliary housing heaters). The data sheet for these runs is included as Page 2-11 in Appendix II.

Attempts to use the mass spectrometer both with manual control and with automatic control by the computer, produced data of questionable validity since a solenoid valve failure caused an improper purging of the sample chambers giving non-representative samples.

Oil viscosity (at 100°F) increased from 24.8 cs to 24.9 cs. The acid number did not increase from 0.055. A large number of small, dark (sludge) particles (which have been sent to Monsanto for analysis) were caught in the filter and were suspended in the oil. It is learned that experiments conducted with this fluid at other facilities produced at times similar particles which on the previous experience of Monsanto are believed to be polymers of the base fluid associated with steel wear fragments.

Prior to the test with this fluid, a series of temperature sensitive paints were applied to numerous locations both outside (on the housing) and inside the test rig (on the seal shoulders) in order to learn more about the temperature distribution in the rig during operation. Long term exposure to air on the outside of the rig tended to obscure any clearcut results, but the paints on the air and oil seal shoulders performed adequately. The temperature of the air-seal shoulder was about 950°F while the temperature of the oil-seal shoulder was about 750°F. The oil seal shoulder may well have been heated by the test bearing during its seizure so that the temperature of this shoulder during normal 600°F screening tests could be lower.

Photographs of the seals and test bearing components are included as Enclosures 38 through 41 .

e. Monsanto MCS-293 Fluid (Open Atmosphere)

The length of this test was about 3.2 hours at test conditions (590-620°F bearing outer ring temperature, full load, 13500 rpm speed, 625-690°F test bearing housing temperature, and 1160-1180°F hot air temperature.) The nitrogen normally used in the test chamber and interseal cavity was replaced by compressor air. In order to insure an adequate quantity of oil to prevent any thermal instabilities, the oil flow was maintained at 1 gpm during the test. This necessitated an oil-inlet temperature of 515-520°F (instead of 500°F) to achieve the desired outer-ring temperature. Seal leakage decreased from about 10 scfm to about 4 scfm as the seals ran-in.

Upon disassembly , it was found that the test bearing was in very good condition with the cage pockets showing light wear and the outer lands slight wear. The oil-seal carbon sealing surface was somewhat scored and polished. No indications of coking were found in the rig or on test elements. Oil viscosity after the test was 26.5 cs (@ 100°F) compared to 24.8 cs for new oil. The acid number did not increase from 0.055. The oil was considerably darker (seemingly from suspended particles) than that from the nitrogen blanketed run; however the duration of this run was considerably longer.

Photographs of the seals and test bearing components are included as Enclosures 42 to 45. The data sheet is included as Page 2-12 in Appendix II.

Temperature sensitive paints indicated that the temperature of the air-seal shoulder was between 900 and 950°F, and both the oil-seal shoulder and the test bearing seat were between 750 and 800°F.

A typical oscilloscope trace showing the mass spectrometer analysis of the test bearing chamber atmosphere in this test is given in Enclosure 49. This trace will be used for comparison with subsequent analyses during higher temperature testing with MCS-293 lubricant. Seal leakage data in this test were obtained with the positive-displacment meter, since mass spectrometer data on seal leakage could not be obtained due to a malfunction of the helium mixing system, which has since been corrected.

The above results indicate satisfactory performance of the MCS-293 in an open atmosphere at 600°F, so that baseline screening tests at higher temperatures will be run.

2. Mist Rig Testing

The mist rig has been brought to the point where screening tests have now begun under heated conditions. All systems have operated satisfactorily, including the copper-element slip-rings for rotating instrumentation.

a. Esso 4040 (MIL-L-7808E) - Nitrogen Blanketed

Two short, heated runs have been made in the mist rig using 459981E bearings (M-50 and test seals with AM350 bellows. The roller bearing used had an out of round outer ring (approximately 0.020" in the free state) and had a slightly increased readial looseness (about 0.002"), based on previous unheated test results in this rig (2).

In the first run the rig was brought up to full load and a speed of about 13,500 rpm. Nitrogen flow to the test bearing totaled about 50 scfm (40 scfm of this going through the mist generator which was heated to 200°F). With the setting on the mister at full open and the nitrogen flow used, approximately 0.04 lbs. per minute of oil was being delivered to the bearing. No hot air was used, but the rig housing heaters were on full (test bearing housing temperature was in the 200-300°F region).

At full speed and load the test bearing outer-ring temperature seemed to stabilize at about 260°F with the inner-ring temperature being about 290°F as measured by the copper-element slip rings. The 10 scfm cooling nitrogen was cut off after about five minutes at the above conditions. Test bearing inner and outer ring temperatures promptly jumped about 10°F. After several minutes operation like this the nitrogen flow through the mister was reduced to about 33 scfm at which time the test bearing failed (33 scfm through the mister is safely above the mist cut-off point which is less than 20 scfm).

Seal leakage during this test was in the 5 to 10 scfm range. It was found on disassembly that some metallic powder from the previous overheating of the air heater remained in the heater coils (see section on hot-air system) despite all cleaning and had damaged the air seal carbon surface giving these high leakages. The air heater has now been cleaned even more thoroughly and no debris were found in the next test.

Upon disassembly it was found that the test bearing cage had smeared in the outer land area and one rail was cracked. The inner and outer races and balls were in relatively good condition. Photographs of the test bearing components are shown in Enclosures 46 and 47 .

It appears that the cage expanded excessively in the radial direction due to insufficient cooling. In the present set-up oil mist is supplied to and exhausted from both sides of the test bearing. Mist and nitrogen is supplied by means of jet rings and exhausted through large ports in the middle of the rig as well as through a small one on the hot-air end. It is possible that by misting on both sides of the bearing cooling gas (at least in sufficient quantities) does not flow through the bearing to cool the bore and OD of the cage. Possible remedies would be to use more cooling gas, to use an outer-land riding cage (as presently used) with more radial looseness or an inner-land riding cage, or to remove the rear jet ring and block off the small exhaust in the front (hot-air) side which would force the nitrogen to flow through the bearing. The first alternative was tried in the next test and the latter alternative will be tried in future tests.

The second run was made with an identical test bearing and the same roller bearing which had been run in all the circulating tests. Nitrogen flow through the mistor was 39 scfm (giving about 0.04 pounds per minute oil delivered to the bearing with the mist oil temperature of 200°F) with 40-45 scfm cooling nitrogen.

The rig was run for about 30 minutes under full load at a speed of about 13,500 rpm. At the end of this period the roller bearing failed, apparently due to the same phenomenon as in the test bearing failure in the previous run. Manifold hot-air temperature at this time was about 900°F, test bearing housing temperature was about 400°F, test bearing inner-ring temperature was about 310°F, and the outer ring was about 245°F. Test conditions for this run, together with those for the previous run, are tabulated in Appendix III, which shows that the heat rejection rate to the gas was very low (70-100 Btu/min). Even though the test bearing temperatures had a definite increasing slope at termination of the test, it is doubtful if 600°F on the outer ring would have been achieved. (Enclosure 48 presents test-bearing inner and outer ring, roller bearing outer-ring, and torque pen-chart records for this test). In the next test, the mist rig will be preheated statically to a test bearing temperature of about 500°F with all heaters on (including air heater and air flow), but without oil mist or cooling nitrogen flow, before start-up of both the rig and the oil mist at the same time. In addition, the auxiliary heaters described previously may be used to reduce the heat-up time.

VI SCHEDULING OF REMAINDER OF SCREENING AND ENDURANCE TESTS

The projected scheduling of testing is outlined in detail in the PERT diagram, Enclosure 1, which shows that screening tests at temperatures higher than 600°F will be run with those oils that show promising performance at 600°F in both the recirculating and mist rigs, followed by the selection of oils for endurance testing.

Typed:cdt

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APPENDIX I

DUPONT REPORTS ON FREON ADDITIVE TESTING

APPENDIX I

DU PONT REPORTS ON FREON ADDITIVE TESTING

"FREON" PRODUCTS LABORATORY

E. I. du Pont de Nemours & Company

TECHNICAL REPORT

Report Number: KSS-5528

Subject: The Stability of Oil Systems Containing "Freon-113" Fluorocarbon and the Analyses of Mixtures of Oils and "Freon-113"

Company: SKF Industries, Inc.
King of Prussia, Pennsylvania

By: H. A. Palmatary Date: April 15, 1966

Approved By: R. A. Gorski

Introduction:

SKF is considering the use of "Freon-113" fluorocarbon as an additive to an oil lubricating system. These systems are for use in Supersonic Transport and will be subjected to temperatures of about 500°F. This report supplements KSS-5103-A and deals with a more realistic concentration of "Freon-113" in the oils for the anticipated end use.

Object:

1. To determine the effect of "Freon-113" fluorocarbon on the stability of the candidate oils at 500°F for 24 hours.
2. To determine the concentration of "Freon-113" in the fluorocarbon/oil mixtures prepared at one atmosphere of pressure and 500°F by SKF.

Results:

In the stability tests, the Du Pont PR-143 oil was unaffected by both the elevated temperature and the "Freon-113", except for a slight discoloration of the steel strip. The other oils (Table I, Encl. 11) were affected slightly by the elevated temperature. "Freon-113" improved the appearance of the Monsanto MCS-293 very slightly, slightly worsened the appearance of the Socony 177-F, and completely solidified the Herculube F and Turbo S-1048.

The analyses of the oil samples made by SKF are summarized in Table II. These concentrations have not been corrected for condensation of the vapors of "Freon-113" into the oils when these mixtures were cooled from 500°F to room temperature.

Experimental:

The stability tests were run in sealed "Pyrex" tubes (7/16" I.D. x 5-1/2") which were cleaned with distilled water and C. P. Grade acetone, air flushed to remove the acetone, heated to 100°C for several hours, and then desiccated for approximately 24 hours prior to use. The two metal strips (Inconel X-750 and a steel alloy), 2 ml of oil (enough to completely immerse the metals), and the quantity of "Freon-113" necessary to give a 10 wt % solution in the oil were placed in the tube. The amount of "Freon-113" added to the system was determined by using the following approximate densities for the oils: Socony 177F, 0.84 g/cc; Monsanto MCS-293, 1.19 g/cc; Du Pont PR-143, 1.91 g/cc; Herculube F, 1.01 g/cc; and Turbo S-1048, 0.93 g/cc. After adding the "Freon-113" to the test system, the tube, with one atmosphere of air above the liquid, was sealed by means of a female type Neoprene stopper. The tube contents were then frozen in liquid nitrogen and the tube was sealed. The tubes were then stored upright in an oven for 24 hours at 500°F.

The metals, supplied by SKF, were segments of cylinders about 1" long. The steel alloy was "quartered" from a cylinder of about 1/4" radius. The Inconel X-750 was "halved" from a cylinder of about 3/16" radius. The rough-cut edges were sanded with 120 grit paper. The specimens were then washed with fresh "Freon-113" and desiccated before use.

Upon completion of the test the tubes were inspected (Table I), photographed (Encl.11), and then sent to Dr. H. E. Mahncke of SKF.

The gas chromatographic analyses and details of preparations of the oil/fluorocarbon mixtures provided by SKF are summarized in Table II.

TABLE I

COMPATIBILITY OF INCONEL AND STEEL WITH "FREON-113" FLUOROCARBON IN VARIOUS OILS

Test Conditions: 1. 24 Hours at 500°F in sealed tubes

A. Inconel X-750 and a steel alloy with 2 ml of indicated oil
B. Inconel X-750 and a steel alloy with 2 ml of indicated oil plus 10 wt % "Freon-113"
C. One atmosphere of air in a sealed system at 75°F

Oils	Condition	Liquid Changes(a)	Metal Changes
Socony-177F	A	Liquid: Slightly hazy Tube Walls (Vapor Phase) - Sli. white haze 80% of surface and ca. 25 v. sli. deposit spots (dark brown). V. sli. ring at liquid-vapor interface.	None
Socony-177F	B	Liquid: Light brown but transparent. Tube: Sli. but significant brown deposit 50% of surface and sli. liquid condensate 100% of surface.	None
Monsanto MCS-293	A	Liquid: V. dark red (not transparent) Tube: Five v. sli., dull white deposit spots.	Inconel: No change Steel: Sli. tarnish 90% of one cut surface.
Monsanto MCS-293	B	Dark red color.	Inconel: Sli. spotty tarnish-5% Steel: Sli. tarnish-10%
Du Pont PR-143	A	No change.	Inconel: No change Steel: "Blued" on cust surface "Blued" and tarnish on round surface - 100%
Du Pont PR-143	B	No change.	Inconel: No change. Steel: "Blued" on cut surface, Sli. discoloared on round surface.
Du Pont PR-143	B	No change.	Inconel: No change. Steel: "Blued" on cut surface, Sli. discolored on round surface.
Herculube F	A	Liquid: Light yellow Tube: Ca. 12 v. sli. dark brown brown oil gel spots	None
Herculube F	B	Liquid: Black and completely solidified	Could not see metals.
Turbo S-1048	A	Liquid: Dark red.	None
Turbo S-1048	B	Liquid: Black and completely solidified	Could not see metals.

(a) - The oils were clear and water-white initially except the Monsanto MCS-293 which had a very slight haze, and the Turbo S-1048 which was light brown.

APPENDIX I (Cont.)

TABLE II

CONCENTRATION OF "FREON-113" FLUORCARBON IN VARIOUS OILS

Test Conditions:

A. Oil plus 10 wt % "Freon-113" heated one hour at 500°F.

B. "Freon-113" bubbled into the oil at 500°F.

Oils	Concentration of "Freon-113" in Oils (Wt %)*	
	Condition A	Condition B
Socony XRM-177F	0.09	0.92
Monsanto MCS-293	0.19	0.58
DuPont PR-143	0.03	0.52
Herculube F	0.003	0.29
Turbo S-1048	0.37	0.08
Sunthetic 18H	0.20	1.29
Ucon 50 HB 5100	0.07	0.01
Esso 4040	0.54	0.81

* Not corrected for condensation of the vapors of "Freon-113" in going from the test temperature of 500°F to 75°F.

APPENDIX II

TEST DATA SUMMARY RECIRCULATING RIG

APPENDIX II

TEST DATA SUMMARY
RECIRCULATING RIG

TEST BEARING # 924104

OIL USED ESSO 4040

ROLLER BEARING # ____

DATE 12/15/65

Running Time, Hours	0.2	0.6	1.4	1.7	1.8	2.1	2.3	2.5	2.6	2.7	3.2	
Speed, RPM	1,250	1,250	4,000	8,000	10,000		14,000		12,000	14,000	14,000	
Motor Power, Volt x Amps	575	575	2,950	9,000	11,250		20,250		15,750	20,250	20,250	
Air Manifold Press. (psi)	78	106	105	105	105		105		—	—	105	
Bearing Cavity Press. (psi)	11	11	2	4	5	T	4	D	—	—	6	
Seal Cavity Press. (psi)	102	110	112	112	112	R	111	E	—	—	111	
Hot Air Flow (scfm)	54	45	42	42	42	A	42	E	—	—	36	
Test Oil Flow (gpm)	5	5	5	5	5	T	5	P	—	—	5	
Total Seal Leakage (scfm)	7.4	—	3.7	—	3.7	S	3.7	S	3.7	—	2.9	
Test Bearing Outer Ring (°F)	370	390	440	445	470	E	510		410	435	490	
Roller Bearing Outer Ring (°F)	362	388	420	425	450	R	500	D	405	415	470	
Oil Seal Housing (°F)	250	265	530	535	560		610	E	525	555	640	
Air Seal Housing (°F)	120	130	930	930	930	:	930	C	950	900	995	
Test Bearing Housing (°F)	365	400	425	430	430	P	470	U	420	400	480	
Roller Bearing Housing (°F)	325	355	380	380	390	O	420	D	390	365	485	
Air Seal Bellows (°F)	162	180	695	705	700	T	710	E	790	670	790	
Hot Air in Manifold (°F)	—	—	960	1000	—	S	1000	R			1200	
Oil Inlet (°F)	—	—	400	450	—		500		—	—	470	
Oil Outlet (°F)	302	315	330	350	350		390		320	330	390	

AMP. METER ON M.G. SET STARTED HUNTING

SLIP RING FAILURE

TEST BEARING # 924104 ROLLER BEARING # ______

OIL USED Esso 4040 DATE 12/16/65

Running Time, Hours	0.1	0.2	0.3	0.5	0.7	0.75	1.0	1.1	1.4			
Speed, RPM	14000	14,000	14,000	14,000	14000		14,000	14,000	14,000			
Motor Power, Volt x Amps	22,000	22,000	22,000	22,000	22000		22,000	22000	22,000			
Air Manifold Press. (psi)	108	108	108	108	108	T	108	108	108			
Bearing Cavity Press. (psi)	8	8	6	6	5	R	11	8				
Seal Cavity Press. (psi)	110	110	110	110	110	A	110	110	110			
Hot Air Flow (SCFM)	22	22	22	62	80	T	65	85				
Test Oil Flow (GPM)	5	5	5	5	5	S	5	5				
Total Seal Leakage (SCFM)	7.4	7.4	1.8	1.8	1.8	E	5.5	5.5				
Test Bearing Outer Ring (°F)	230	310	405	490	550	R	370	450	525			
Roller Bearing Outer Ring (°F)	220	265	370	450	520		345	425	505			
Oil Seal Housing (°F)		270	440	580	665		380	475				
Air Seal Housing (°F)		355	830	1000	1085	:	675	850				
Test Bearing Housing (°F)		200	375	465	535	P	335	410				
Roller Bearing Housing (°F)		200	300	370	430	O	280	340				
Air Seal Bellows (°F)		245	500	685	795	T	380	540				
Hot Air in Manifold (°F)			820	1200		S	900	1100				
Oil Inlet (°F)			350	500			380	470				
Oil Outlet (°F)		240	300	400	440		300	370				

→ LOW COMPRESSOR PRESS.

TEST BEARING # 924104

OIL USED ESSO 4040

ROLLER BEARING # ________

DATE 12/21/65

Running Time, Hours	0.0	0.2	0.6	0.9	1.2	1.5	1.9	2.4	2.7	3.1	3.7	
Speed, RPM	—	14,000	14,000	14,000	14,000	14,000	14,000	14,000		12,000	14,000	
Motor Power, Volt x Amps	—	20,000	20,000	20,000	20,000	20,000	20,000	20,000		11,000	20,000	
Air Manifold Press. (PSI)	104	106	105	105	105	105	105	105	T	105	105	
Bearing Cavity Press. (PSI)	5	15	13	6	6	6	6	6	R	6	6	
Seal Cavity Press. (PSI)	110	111	111	111	111	111	111	111	A	111	111	
Hot Air Flow (SCFM)	55	50	49	40	36	36	35	36	T	30	—	
Test Oil Flow (GPM)	5	5	5	5	5	5	5	4	S	5	5	
Total Seal Leakage (SCFM)	10.4	8.9	7.4	3.7	1.5	1.5	1.5	3.3	E	7.4	1.5	
Test Bearing Outer Ring (°F)	360	405	538	590	585	599	599	600	R	500	560	
Roller Bearing Outer Ring (°F)	330	425	525	570	560	570	570	570		440	540	
Oil Seal Housing (°F)	320	340	481	635	730	755	760	750		440	600	
Air Seal Housing (°F)	235	—	591	865	1080	1105	1110	1110	:	730	1070	
Test Bearing Housing (°F)	305	440	550	600	620	640	640	630	P	450	540	
Roller Bearing Housing (°F)	295	380	455	480	510	515	530	530	O	400	470	
Air Seal Bellows (°F)	235	275	525	710	785	930	930	915	T	550	810	
Hot Air in Manifold (°F)	—	—	600	900	1140	1200	1200	1200	S	800	1100	
Oil Inlet (°F)	—	—	500	500	550	555	555	555		450	500	
Oil Outlet (°F)	285	380	431	475	460	475	475	465		360	440	

→ BROKEN BELT

TEST BEARING # 924104 ROLLER BEARING # ______

OIL USED ESSO 4040 DATE 12/29/65

RUNNING TIME, HOURS	0.0	0.3	0.6	0.9	1.1							
SPEED, RPM	—	14,000	14,000	14,000	14,000							
MOTOR POWER, VOLT X AMPS	—	19,000	19,000	19,000	19,000							
AIR MANIFOLD PRESS. (PSI)	104	104	104	104	104							
BEARING CAVITY PRESS. (PSI)	9	5	5	5	4							
SEAL CAVITY PRESS. (PSI)	110	114	108	110	110							
HOT AIR FLOW (SCFM)	32	26	24	56	54							
TEST OIL FLOW (GPM)	5	5	5	5	5							
TOTAL SEAL LEAKAGE (SCFM)	8.9	7.4	14.8	3.7	8.9							
TEST BEARING OUTER RING (°F)	300	450	535	590	600							
ROLLER BEARING OUTER RING (°F)	300	440	525	590	605							
OIL SEAL HOUSING (°F)	—	540	520		720							
AIR SEAL HOUSING (°F)	750	900	1000	1100	1110							
TEST BEARING HOUSING (°F)	300	410	525	605	625							
ROLLER BEARING HOUSING (°F)	285	345	475	580	525							
AIR SEAL BELLOWS (°F)	400	625	700	830	860							
HOT AIR IN MANIFOLD (°F)	900	1050	1150	1180	1175							
OIL INLET (°F)	—	—	—	—	—							
OIL OUTLET (°F)	310	340	415	480	500							

TEST BEARING # 924108

OIL USED ESSO 4040

ROLLER BEARING # ____

DATE 1/20/66

Running Time, Hours	0.2	0.6	0.9	1.6	2.1	2.5	2.9	3.0	3.1	3.4	3.7	3.8
Speed, RPM	4,500	11,000	14,000	14,000	14,000	14,000	14,000	14,000	14,000	14,000	14,000	14,000
Motor Power, Volt X Amps	8,000		12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Air Manifold Press. (psi)	106	106	106	106	106	106	106	106	106	106	106	106
Bearing Cavity Press. (psi)	10	4	4	3	3	3	3	3	3	3	3	3
Seal Cavity Press. (psi)	111	111	111	111	111	111	111	111	111	111	111	111
Hot Air Flow (SCFM)	30	20	20	20	22	20	20	—	60	70	70	—
Test Oil Flow (GPM)	1	1	1	1	1	1	1	1	1	1	1	1
Total Seal Leakage (SCFM)	5.9	3.0	1.5	1.5	0.7	1.5	0.7	—	0.7	2.2	3.7	—
Test Bearing Outer Ring (°F)	240	410	490	540	540	560	560	550	550	580	580	—
Roller Bearing Outer Ring (°F)	230	—	—	—	—	—	—	—	—	—	—	—
Oil Seal Housing (°F)	265	410	545	710	760	765	770	770	790	795	785	750
Air Seal Housing (°F)	365	520	690	850	905	920	925	930	1030	1065	1070	1065
Test Bearing Housing (°F)	220	425	470	640	680	675	675	670	670	665	660	650
Roller Bearing Housing (°F)	190	310	395	480	515	520	520	520	520	52.0	525	525
Air Seal Bellows (°F)	280	410	470	745	800	805	815	815	855	880	875	850
Hot Air in Manifold (°F)	410	600	760	918	960	980	990	—	1090	1110	1110	1105
Oil Inlet (°F)	250	350	430	490	500	500	500	500	500	500	500	500
Oil Outlet (°F)	220	350	390	525	555	550	550	550	550	555	555	560

TEST BEARING # 924103

OIL USED ESSO 4040

ROLLER BEARING # ______

DATE 1/25/66

Running Time, Hours	0.3	0.7	1.1	1.3	1.6							
Speed, RPM	4,000	10,000	14,000	14,000	14,000							
Motor Power, Volt X Amps	1500	4800	9600	9600	9600							
Air Manifold Press. (psi)	106	106	106	106	106							
Bearing Cavity Press. (psi)	19	8	3	3	3							
Seal Cavity Press. (psi)	111	111	111	111	111							
Hot Air Flow (scfm)	68	64	62	60	60							
Test Oil Flow (gpm)	0.5 to 1	0.5 to 1	0.5 to 1	0.5 to 1	0.5 to 1							
Total Seal Leakage (scfm)	12.6	4.4	1.5	1.5	—							
Test Bearing Outer Ring (°F)	260	400	480	520	560							
Roller Bearing Outer Ring (°F)												
Oil Seal Housing (°F)												
Air Seal Housing (°F)												
Test Bearing Housing (°F)												
Roller Bearing Housing (°F)												
Air Seal Bellows (°F)												
Hot Air in Manifold (°F)	700	970	1000	1050	1100							
Oil Inlet (°F)	260	360	440	480	500							
Oil Outlet (°F)												

TEST BEARING # 924103

OIL USED XRM-177 F

ROLLER BEARING # 1-0-C

DATE 2/14/66

Running Time, Hours	0.0	0.8	1.5	1.9	2.3	2.7	3.1	3.7	4.0			
Speed, RPM	—	14,000	14,000	14,000	14,000	14,000	14,	14,000	14,000			
Motor Power, Volt x Amps	—	23,000	23,000	23,000	23,000	23,000	23,000	23,000	23,000			
Air Manifold Press. (psi)	105	105	105	105	105	105	105	105	105			
Bearing Cavity Press. (psi)	6.	4	6	5	5	5	5	5	—			
Seal Cavity Press. (psi)	111	111	111	111	111	111	111	111	111			
Hot Air Flow (scfm)	42	40	56	70	70	74	76	68	—			
Test Oil Flow (gpm)	3	4	4	4	4	4	3	3	—			
Total Seal Leakage (scfm)	1.8	4.4	4.4	3.7	4.4	4.4	4.4	3.7	—			
Test Bearing Outer Ring (°F)	330	520	560	585	600	610	600	590	625			
Roller Bearing Outer Ring (°F)	310	—	—	—	—	—	—	—	605			
Oil Seal Housing (°F)	240	520	600	625	650	668	670	720	650			
Air Seal Housing (°F)	130	690	800	920	975	990	1020	1030	1095			
Test Bearing Housing (°F)	260	405	440	470	490	515	510	490	480			
Roller Bearing Housing (°F)	240	385	440	470	480	490	480	460	455			
Air Seal Bellows (°F)	170	545	655	700	730	760	780	790	765			
Hot Air in Manifold (°F)	—	800	960	1120	1170	1200	1210	1200	1200			
Oil Inlet (°F)	—	500	500	520	530	550	550	480	—			
Oil Outlet (°F)	315	505	550	570	580	592	580	540	545			

TEST BEARING # 924103

OIL USED XRM 177F

ROLLER BEARING # 1-0-C

DATE 2/17/66

RUNNING TIME, HOURS	0.0	0.3	0.6	0.8	1.1	1.4	2.1	2.8				
SPEED, RPM		14,000	14,000	14,000	14,000	14,000	14,000	14,000				
MOTOR POWER, VOLT X AMPS												
AIR MANIFOLD PRESS. (PSI)	106	106	106	106	106	106	106	106				
BEARING CAVITY PRESS. (PSI)	25	19	25	25	25	25	25	25				
SEAL CAVITY PRESS. (PSI)	111	110	111	111	111	111	111	111				
HOT AIR FLOW (SCFM)		50	50	62	54	82	65	45				
TEST OIL FLOW (GPM)		0.8 to 1	0.8 to 1	0.8 to 1	0.8 to 1	0.8 to 1	0.8 to 1	0.8 to 1				
TOTAL SEAL LEAKAGE (SCFM)		8.9	—	—	—	—	20.7	20.7				
TEST BEARING OUTER RING (°F)		450	500	520	550	550	600					
ROLLER BEARING OUTER RING (°F)							550					
OIL SEAL HOUSING (°F)							425					
AIR SEAL HOUSING (°F)							815					
TEST BEARING HOUSING (°F)		250	325	350	410	425	470					
ROLLER BEARING HOUSING (°F)							415					
AIR SEAL BELLOWS (°F)							570					
HOT AIR IN MANIFOLD (°F)												
OIL INLET (°F)		320	550	450	460	470	520					
OIL OUTLET (°F)		360	450	460	500	500	540					

TEST BEARING # 924101 ROLLER BEARING #

OIL USED SINCLAIR TURBO S DATE 2/28/66

RUNNING TIME, HOURS	0.2	0.6	0.8	1.1	1.5							
SPEED, RPM	14,000	14,000	14,000	14,000	14,000							
MOTOR POWER, VOLT X AMPS	16,000	14,000	14,000	14,000	14,000							
AIR MANIFOLD PRESS. (PSI)	106	106	106	106	106							
BEARING CAVITY PRESS. (PSI)	25	15	—	15	25							
SEAL CAVITY PRESS. (PSI)	111	111	—	111	111							
HOT AIR FLOW (SCFM)	56	56	75	68	78							
TEST OIL FLOW (GPM)				2	2							
TOTAL SEAL LEAKAGE (SCFM)	14.8	11	—	7.4	7.4							
TEST BEARING OUTER RING (°F)			610	550	550							
ROLLER BEARING OUTER RING (°F)												
OIL SEAL HOUSING (°F)			600									
AIR SEAL HOUSING (°F)			1020									
TEST BEARING HOUSING (°F)			390									
ROLLER BEARING HOUSING (°F)			320									
AIR SEAL BELLOWS (°F)			770									
HOT AIR IN MANIFOLD (°F)												
OIL INLET (°F)	400	450	—	470	490							
OIL OUTLET (°F)			480									

TEST BEARING # 924101 ROLLER BEARING # 1-0-C

OIL USED SINCLAIR TURBO-S DATE 3/2/66

RUNNING TIME, HOURS	0.3	0.4	1.2	1.4	1.7	2.0	2.3	2.8	3.2	3.8	4.2	4.5
SPEED, RPM	14,000	14,000										
MOTOR POWER, VOLT X AMPS	13,000	13,000	13,000	13,000	13,000	12,000	10,000	10,000	10,000	10,000	10000	10,000
AIR MANIFOLD PRESS. (PSI)	106	106	105	105	105	105	106	106	106	106	106	106
BEARING CAVITY PRESS. (PSI)	28	25	10	13	12	11	11	11	11	11	11	12
SEAL CAVITY PRESS. (PSI)	112	112	111	111	112	112	112	111	111	111	111	112
HOT AIR FLOW (SCFM)	60	53	59	54	52	54	52	52	52	72	72	72
TEST OIL FLOW (GPM)	2	1	0.5-1	0.5-1	0.5-1	0.5-1	0.5-1	0.5-1	0.5-1	0.5-1	0.5-1	0.5-1
TOTAL SEAL LEAKAGE (SCFM)	—	7.4	—	6.7	6.3	7.0	—	—	—	—	8.0	6.3
TEST BEARING OUTER RING (°F)	380	450	580	601	615	625	—	622	615	615	595	600
ROLLER BEARING OUTER RING (°F)	310	320	465	490	500	505	500	505	510	500	500	500
OIL SEAL HOUSING (°F)	225	435	645	660	670	675	670	665	665	660	660	655
AIR SEAL HOUSING (°F)	270	755	1070	1065	1070	1070	1070	1065	1065	1050	1075	1075
TEST BEARING HOUSING (°F)	250	320	400	430	460	480	475	480	485	480	580	610
ROLLER BEARING HOUSING (°F)	210	265	310	330	345	350	350	360	355	360	450	470
AIR SEAL BELLOWS (°F)			770	785	790	795	785	785	785	785	790	
HOT AIR IN MANIFOLD (°F)	850	930	1200	1200	1200	1200	1200	1200	1200	1190	1200	1200
OIL INLET (°F)	320	380	460	480	500	490	485	502	500	480	480	492
OIL OUTLET (°F)	310	390	480	502	530	535	525	530	530	525	525	525

TEST BEARING # 924/102

OIL USED MCS 29[illegible] N_2 BLANKET

ROLLER BEARING # 1-0-C

DATE 3/21/66

RUNNING TIME, HOURS	0.1	0.9	1.2	1.7		2.1	2.3	2.7	3.1	3.3		
SPEED, RPM	13,500	13,500	13,500	13,500		13,500	13,500	13,500	13,500	13,500		
MOTOR POWER, VOLT X AMPS												
AIR MANIFOLD PRESS. (PSI)	106	106	106	106	/	106	106	106	106	106		
BEARING CAVITY PRESS. (PSI)	8	5	—	5		32	16	12	13	—		
SEAL CAVITY PRESS. (PSI)	112	112	—	112		112	112	112	112	112		
HOT AIR FLOW (SCFM)	48	64	—	—		32	30	55	64	—		
TEST OIL FLOW (GPM)	2	2	0.5-1	0.5-1		1.5	1.5	1	1	—		
TOTAL SEAL LEAKAGE (SCFM)	1.3	0.3	—	—		10	3	0.7	0	—		
TEST BEARING OUTER RING (°F)	455	580	600	700		350	440	540	600	870		
ROLLER BEARING OUTER RING (°F)	305	490	530	530		255	340	440	510	530		
OIL SEAL HOUSING (°F)	260	750	850	870		225	485	610	780	825		
AIR SEAL HOUSING (°F)	220	990	1090	1090		250	680	925	1050	1070		
TEST BEARING HOUSING (°F)	425	600	620	640		295	450	520	510	625		
ROLLER BEARING HOUSING (°F)	395	480	500	515		250	375	430	515	530		
AIR SEAL BELLOWS (°F)	225	900	1020	1040		—	550	800	955	1000		
HOT AIR IN MANIFOLD (°F)	440			—		350	895	1065	1100	1100		
OIL INLET (°F)	—	480	505	500		300	360	425	500	—		
OIL OUTLET (°F)	360	500	540	540		290	380	450	530	560		

TEST BEARING # 924105 ROLLER BEARING # 1-0-C

OIL USED MCS-293 OPEN ATMOSPHERE DATE 4/6/66

RUNNING TIME, HOURS	0.1	0.4	1.3	1.6	2.1	2.7	3.6	3.7	4.5	4.8		
SPEED, RPM	13,500	13,500	13,500	13,500	13,500	13,500	13,500	13,500	13,500	13,500		
MOTOR POWER, VOLT X AMPS	13,000	12,000	11,000	11,000	11,000	10,000	11,000	10,000	10,000	10,000		
AIR MANIFOLD PRESS. (PSI)	104	105	105	105	105	105	105	105	105	105		
BEARING CAVITY PRESS. (PSI)	22	5	3	3	3	7	3	4	4	2		
SEAL CAVITY PRESS. (PSI)	109	110	111	111	111	111	111	111	111	111		
HOT AIR FLOW (SCFM)	48	52	60	60	58	55	50	50	50	50		
TEST OIL FLOW (GPM)	1	1	1	1	1	1	1	1	1	1		
TOTAL SEAL LEAKAGE (SCFM)	17.4	3.7	8.1	10.4	11.8	3.3	2.4	3.7	5.9	—		
TEST BEARING OUTER RING (°F)	350	470	565	603	615	610	605	612	612	620		
ROLLER BEARING OUTER RING (°F)	345	380	520	570	570	560	565	570	570	560		
OIL SEAL HOUSING (°F)	220	210	610	630	635	760	760	750	760	770		
AIR SEAL HOUSING (°F)	125	220	1065	1085	1105	1105	1100	1105	1105	1105		
TEST BEARING HOUSING (°F)	255	450	625	660	670	660	680	695	690	670		
ROLLER BEARING HOUSING (°F)	235	370	500	550	560	550	560	560	560	560		
AIR SEAL BELLOWS (°F)	155	210	920	920	1005	—	—	—	—	—		
HOT AIR IN MANIFOLD (°F)	220	260	1165	1160	1170	1180	1180	1170	1180	1180		
OIL INLET (°F)	—	—	485	520	525	520	515	515	515	515		
OIL OUTLET (°F)	300	380	500	550	555	553	555	550	550	550		

APPENDIX III

MIST TEST DATA SUMMARY

LAST VALUES BEFORE SHUTDOWN

APPENDIX III

MIST TEST DATA SUMMARY
LAST VALUES BEFORE SHUTDOWN

Run No.	1	2
Speed RPM	13,500	13,500
Air Manifold Press. (psi)	106	106
Bearing Cavity Press. (psi)	6	6
Seal Cavity Press. (psi)	111	112
Hot Air Flow (scfm)	60	55
Seal Leakage (scfm)	5+	2.5
N_2 Flow Through Mister (scfm)	40	39
Cooling N_2 Flow (scfm)	10	41
Test Bearing Outer Rings (°F)	275	245
Test Bearing Inner Ring (°F)	300(approx.)	310
Roller Bearing Outer Ring (°F)	220	285
Oil Seal Housing (°F)	200	290
Air Seal Housing ("F)	130	455
Test Bearing Housing (°F)	300	400
Roller Bearing Housing (°F)	165	320
Hot Air In Manifold (°F)	110	900
Mist Inelt (°F)*	130	155
Gas Outlet (°F)	185	190
Air Seal Shoulder (°F)	170	330
Oil Seal Shoulder (°F)	240	310
Torque (in-lbs.)	-	60
Test Bearing Load (lbs.)	3280	3280
Heat Rejection (Btu/min)	70	110

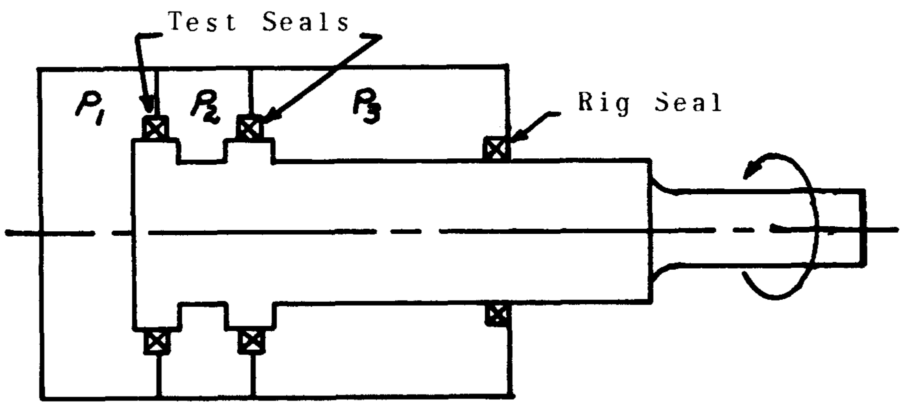
* Measured Between Mister and Rig
Cooling N_2 Inlet Temp. Approx. 75°F

APPENDIX IV

CALCULATIONS OF THE LOAD APPLIED TO THE TEST BEARING BY PNEUMATIC PRESSURE

APPENDIX IV

CALCULATIONS OF THE LOAD APPLIED TO THE TEST BEARING BY PNEUMATIC PRESSURE



Let P_1 be pressure in hot air chamber.
P_2 be pressure in inter-seal cavity.
P_3 be pressure in bearing chamber.

The pressure P_1 acts over the entire hot air end of the test rig as shown.

Assuming the hydraulic diameters of the two test seals are identical, then there is no net thrust due to the pressure P_2.

If d_T be the hydraulic diameter of a test seal and d_R be the hydraulic diameter of the rig seal then the thrust generated is given by:

$$T = P_1 \frac{\pi}{4} d_T^2 - P_3 \frac{\pi}{4}(d_T^2 - d_R^2)$$

$$= \frac{\pi}{4}\left\{d_T^2(P_1 - P_3) + d_R^2 P_3\right\}$$

Now d_T = 6.370"
and d_R = 4.500"

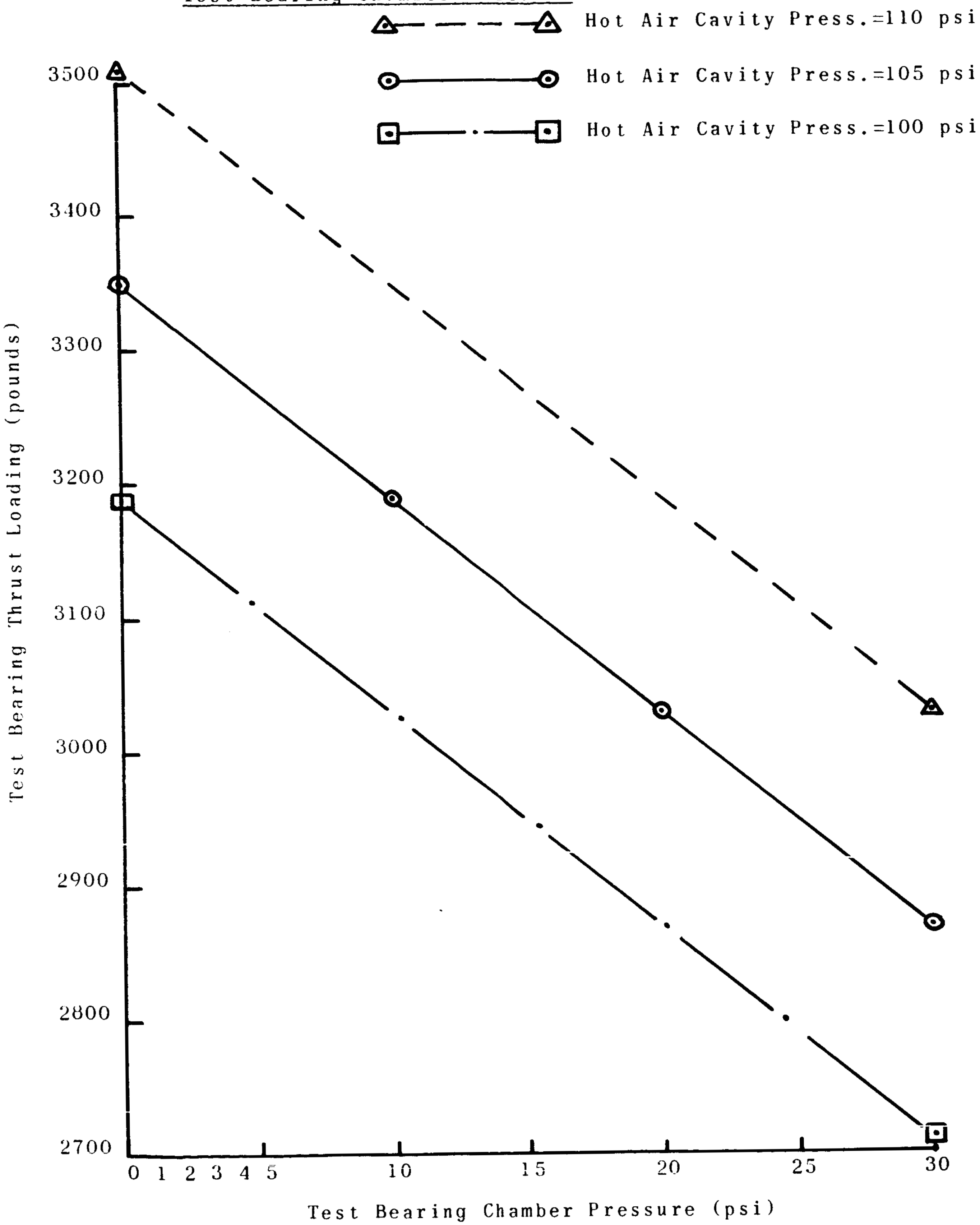
So that

$$T = 31.9\,(P_1 - P_3) + 16.0\,P_3$$

It has been found that P_1 is effectively constant during operation. Assuming P_1 is constant then and varying P_3 figure 1 is generated (for P_1 = 100, 105, and 110 psi).

APPENDIX IV (Cont.)

Fig. 1 Test Bearing Thrust Loading vs. Test Bearing Chamber Pressure



APPENDIX V

SST THERMOCOUPLE SLIP RINGS - TEMPERATURE ERRORS

APPENDIX V

SST THERMOCOUPLE SLIP RINGS - TEMPERATURE ERRORS

The errors in the rotating temperature measurements which are caused by the use of dissimilar metals in the slip ring assembly may be estimated as described in the following paragraphs.

When a thermoelectric material is heated at one end and the other end is cooled or held at a constant temperature, a voltage drop is developed across the material. This voltage, known as the Seebeck voltage, is related to the temperature difference across the sample by the equation (7, 8):

$$E = \alpha \Delta T$$

where E = Seebeck voltage

ΔT = temperature difference across the sample

α = thermoelectric power expressed in millivolts/degree

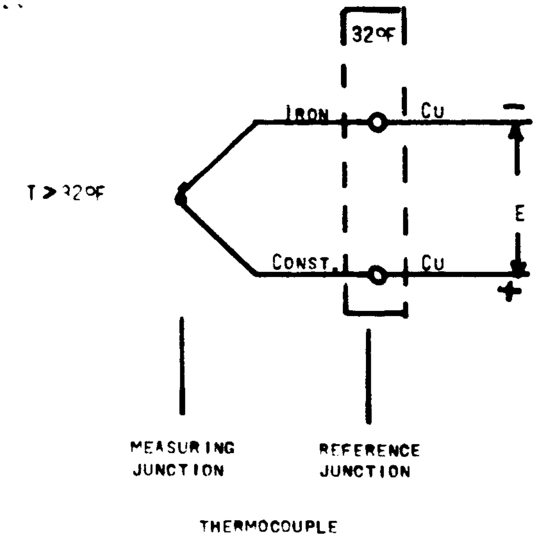
Please note that the above equation applies to a <u>single</u> thermoelectric material. A thermocouple may, therefore, be regarded as a series combination of thermal emf's produced by temperature differences across two different materials. Figure 1 of the attached sketch shows the equivalent circuit for an Iron Constantan couple having a reference junction at a temperature $T = 32°F$.

The equivalent circuit of Figure 1 may be extended to the SST thermocouple system for rotating temperature measurements as shown in Figures 2 and 3. Temperatures shown are the approximate maximum values estimated at each of the points shown. From Figure 3 it it seen that the stainless steel (or copper) elements will produce opposing emf's in the thermocouple circuit between the rotating connector (point 2) and the stationary connector (point 5).

APPENDIX V (Cont.)

Therefore, the emf measured at the reference junction (point 6) will be equal to the emf generated by an I-C couple having junctions at 600°F and 150°F plus the emf of a similar couple with junctions at 100°F and 32°F. The temperature measured through the slip rings will, therefore, be lower than the temperature at the measuring junction (point 1) by an amount equal to the temperature difference between points 2 and 5. Thus the use of stainless steel (or copper) slip rings in the thermocouple assembly will always result in a measurement error equal to the difference between the temperatures of the rotating and stationary connectors. This error can, of course, be corrected if the temperature at each connector is known.

APPENDIX V (Cont.)



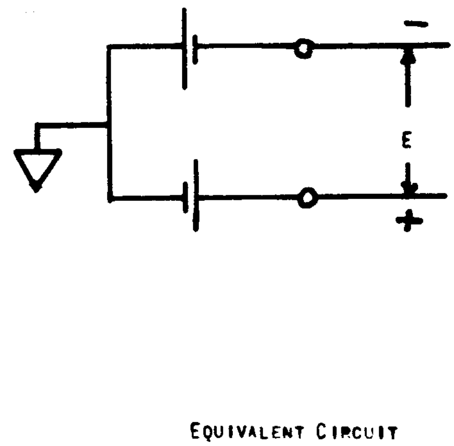


Figure 1 Equivalent Circuit for I-C Couple

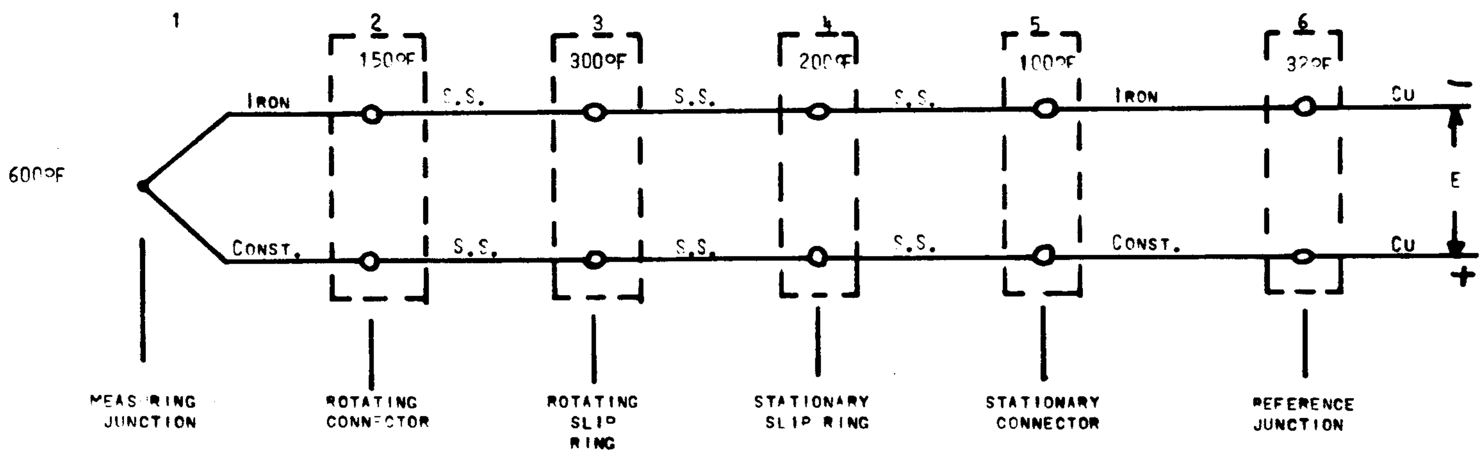


Figure 2 Thermocouple Slip Ring Assembly

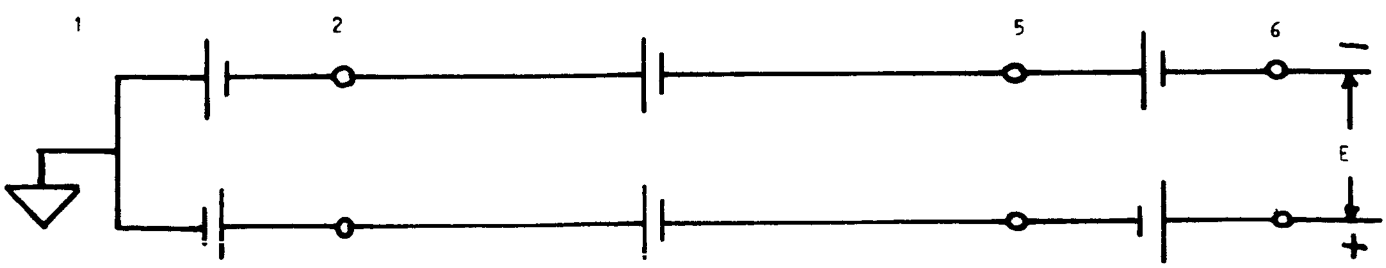


Figure 3 Equivalent Circuit

APPENDIX VI

CLEANING PROCEDURES FOR

RECIRCULATING RIG OIL SYSTEM

APPENDIX VI

CLEANING PROCEDURES FOR RECIRCULATING RIG OIL SYSTEM

In the screening tests in the recirculating rig, lubricants of quite different types are being used, so it is important that the oil system and all rig parts to which the lubricant is exposed be cleaned thoroughly before changing to each new oil, in order to prevent harmful contamination of the lubricants. A cleaning procedure has been developed for this purpose, consisting of the following steps.

1. The oil system is drained and filled with about 3 gallons of Cities Service Solvent No. 26 (creosol base with emulsifying agent) which is heated to about 150°F and circulated for several hours.

2. The solvent is drained and the system is filled with water which is circulated and repeatedly refilled with fresh water until the water drains out clear (no clouding).

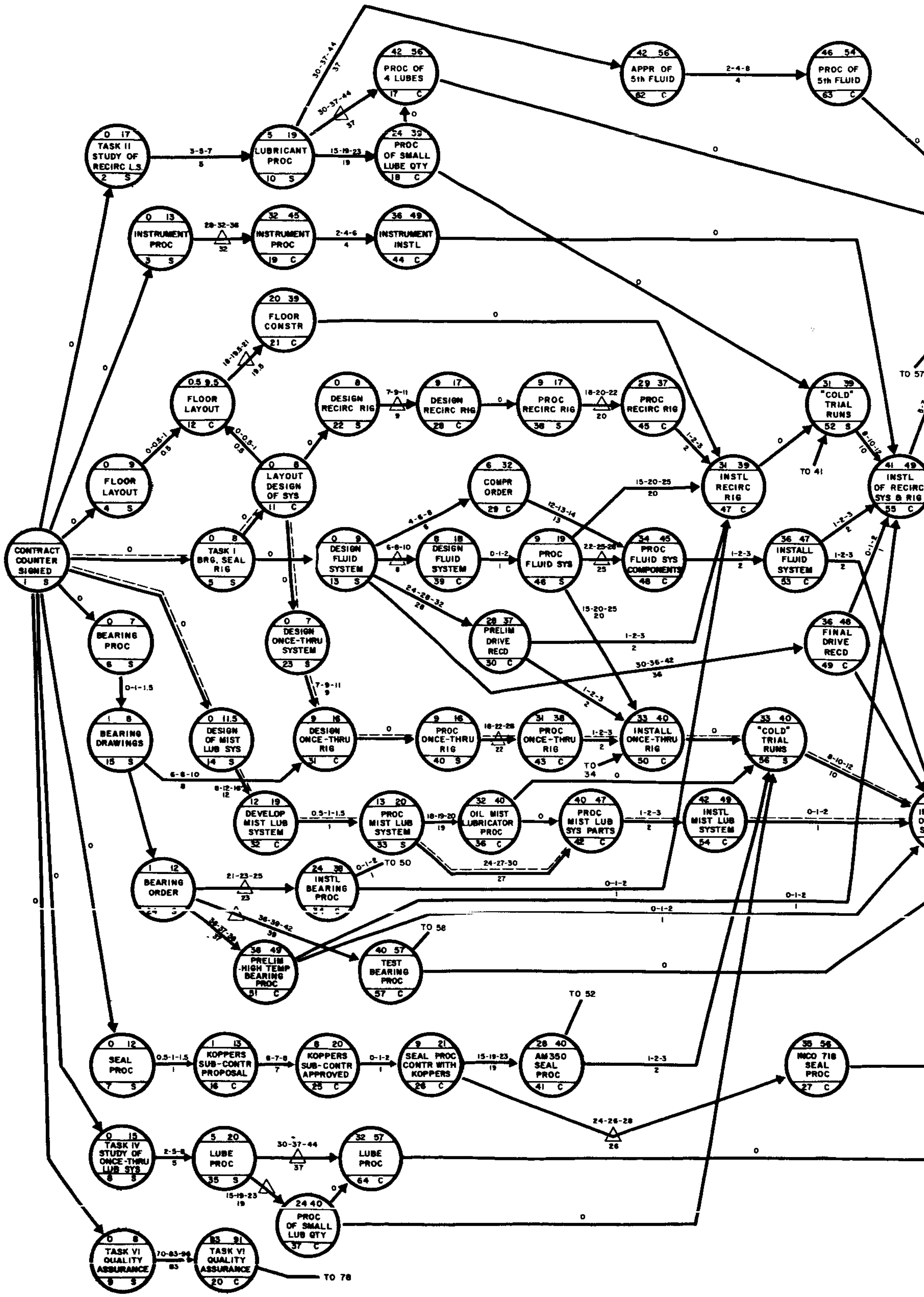
3. After final draining of the water, about 3 gallons of ethyl alcohol are added to the system, circulated and drained.

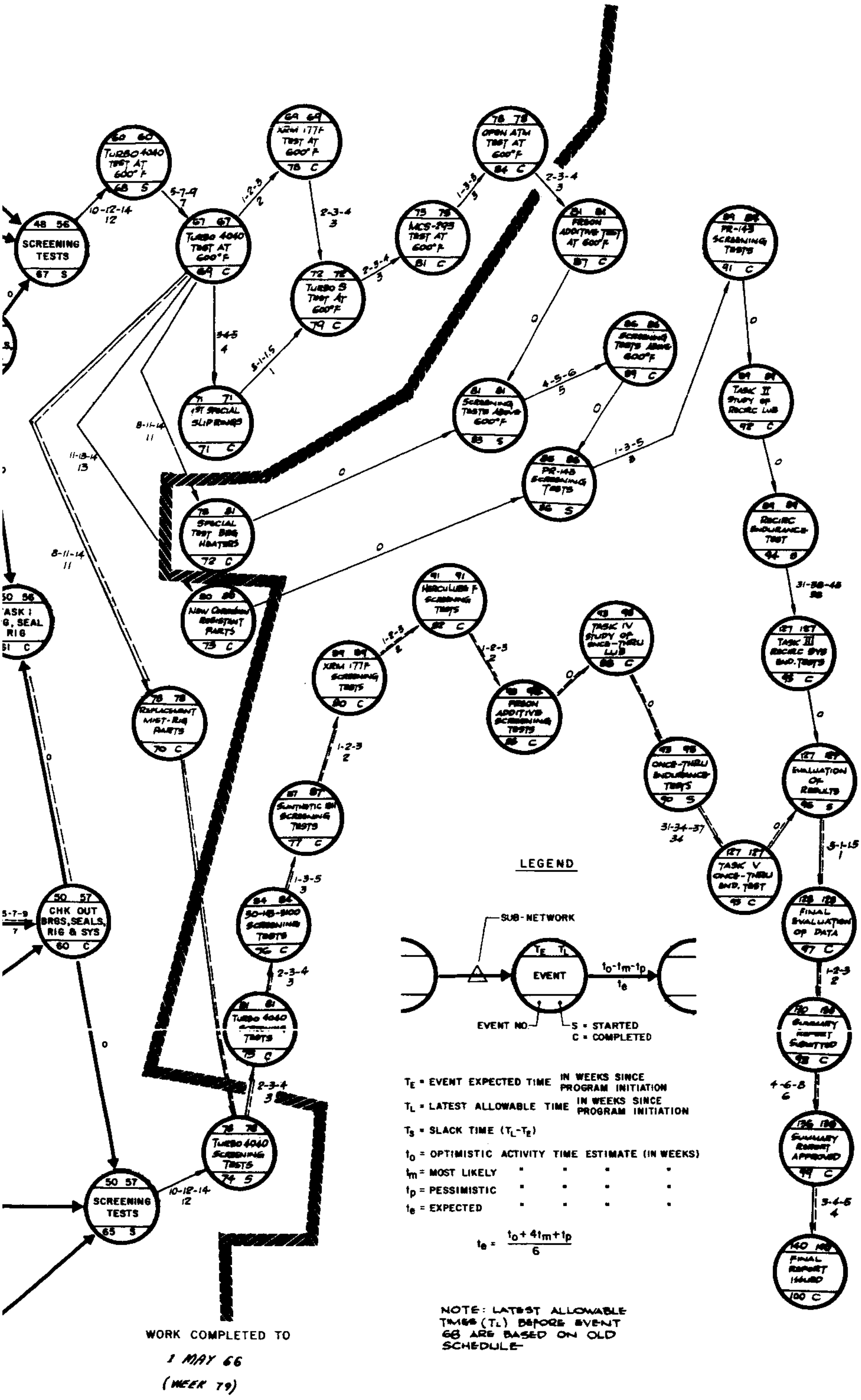
4. Dry nitrogen, heated to 300°F, is then circulated through the oil system until mass spectrometer analysis of the effluent nitrogen cannot detect any alcohol or water vapor.

The effectiveness of the above cleaning procedure was tested by disassembly of the lowest parts of the oil system and inspecting for residual fluids. Also, relatively static parts where the oil might coke were disassembled and inspected (i.e. the oil drain manifold bellows). No evidence of any puddles or deposits were found in any such inspections. In addition, infra-red analysis of the used Socony XRM-177F oil did not reveal any traces of the ester-type lubricants (Esso 4040 and Sinclair Turbo S) used previously in the system.

ENCLOSURE 1

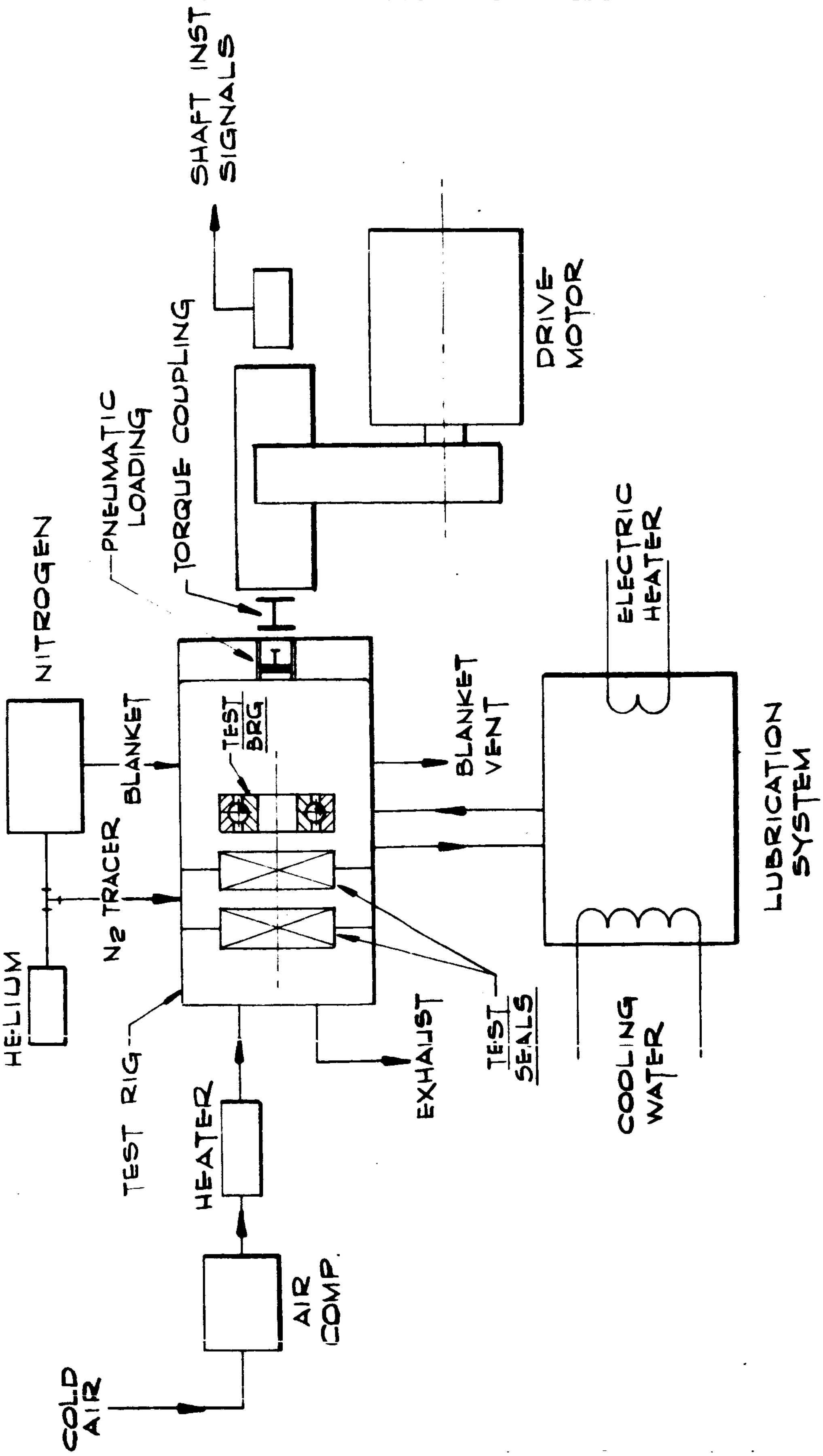
PERT NETWORK OF PROJECT TASKS




SCREENING TESTS
TURBO 4040 TEST AT 600°F
XRM 177F TEST AT 600°F
OPEN ATM TEST AT 600°F
MCS-293 TEST AT 600°F
TURBO S TEST AT 600°F
FREON ADDITIVE TEST AT 600°F
PR-143 SCREENING TESTS
SCREENING TESTS ABOVE 600°F
SCREENING TESTS ABOVE 600°F
1ST SPECIAL SLIP RINGS
TASK II STUDY OF RECIRC LUB
PR-143 SCREENING TESTS
SPECIAL TEST BRG HEATERS
RECIRC ENDURANCE TEST
NEW CARBON BRG STUNT PARTS
HERCULUBE F SCREENING TESTS
TASK IV STUDY OF ONCE-THRU LUB
TASK III RECIRC SYS END. TESTS
XRM 177F SCREENING TESTS
REPLACEMENT MIST-RIG PARTS
FREON ADDITIVE SCREENING TESTS
ONCE-THRU ENDURANCE TESTS
EVALUATION OF RESULTS
SYNTHETIC BN SCREENING TESTS
TASK V ONCE-THRU END. TEST
CHK OUT BRGS, SEALS, RIG & SYS
FINAL EVALUATION OF DATA
TURBO 4040 SCREENING TESTS
SUMMARY REPORT SUBMITTED
TURBO 4040 SCREENING TESTS
SUMMARY REPORT APPROVED
SCREENING TESTS
FINAL REPORT ISSUED
LEGEND
SUB-NETWORK
EVENT
EVENT NO.
S = STARTED
C = COMPLETED
T_E = EVENT EXPECTED TIME IN WEEKS SINCE PROGRAM INITIATION
T_L = LATEST ALLOWABLE TIME IN WEEKS SINCE PROGRAM INITIATION
T_S = SLACK TIME (T_L-T_E)
t_o = OPTIMISTIC ACTIVITY TIME ESTIMATE (IN WEEKS)
t_m = MOST LIKELY " " " "
t_p = PESSIMISTIC " " " "
t_e = EXPECTED " " " "
$t_e = \frac{t_o + 4t_m + t_p}{6}$
WORK COMPLETED TO
1 MAY 66
(WEEK 79)
NOTE: LATEST ALLOWABLE TIMES (T_L) BEFORE EVENT 68 ARE BASED ON OLD SCHEDULE

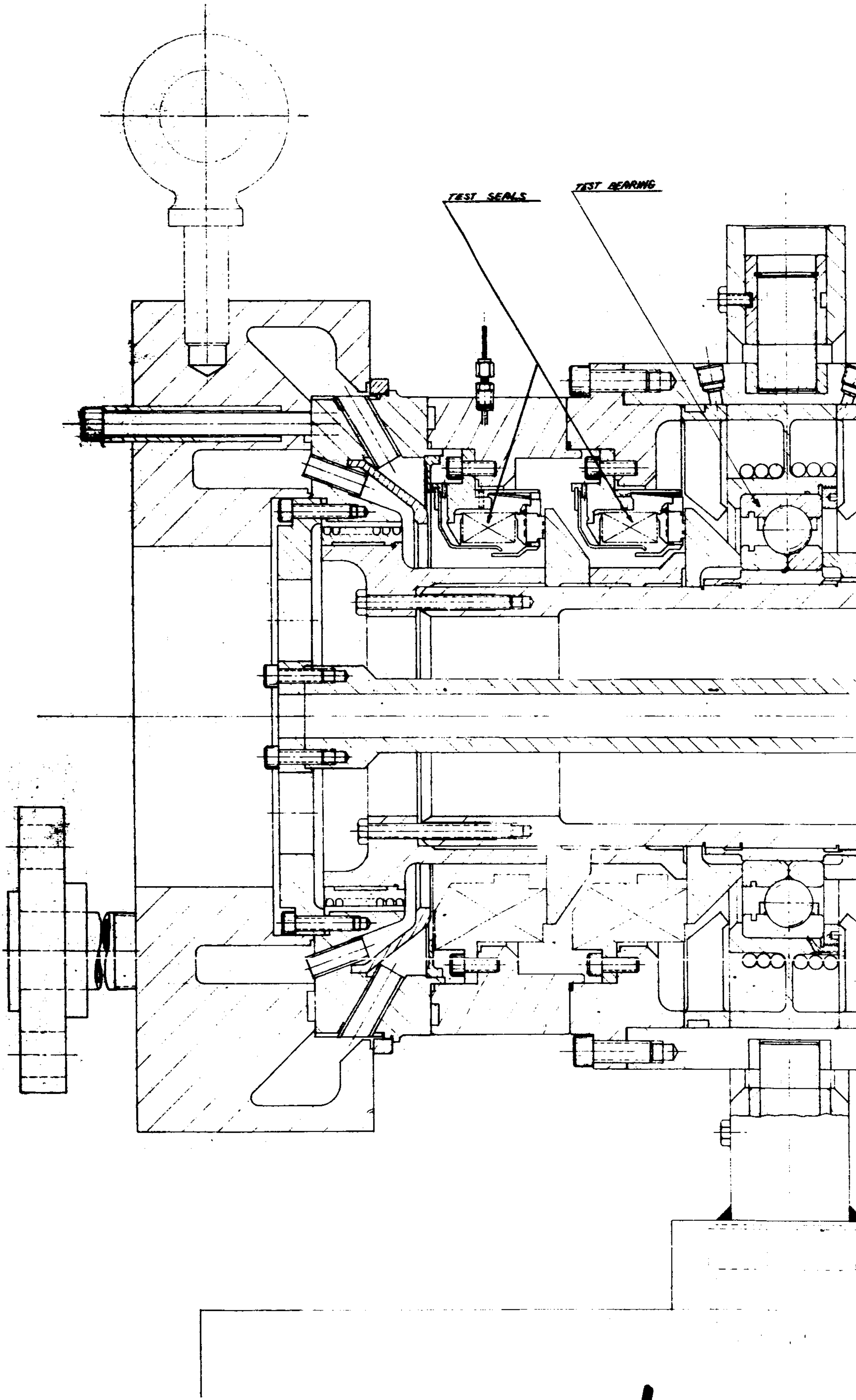
ENCLOSURE 2

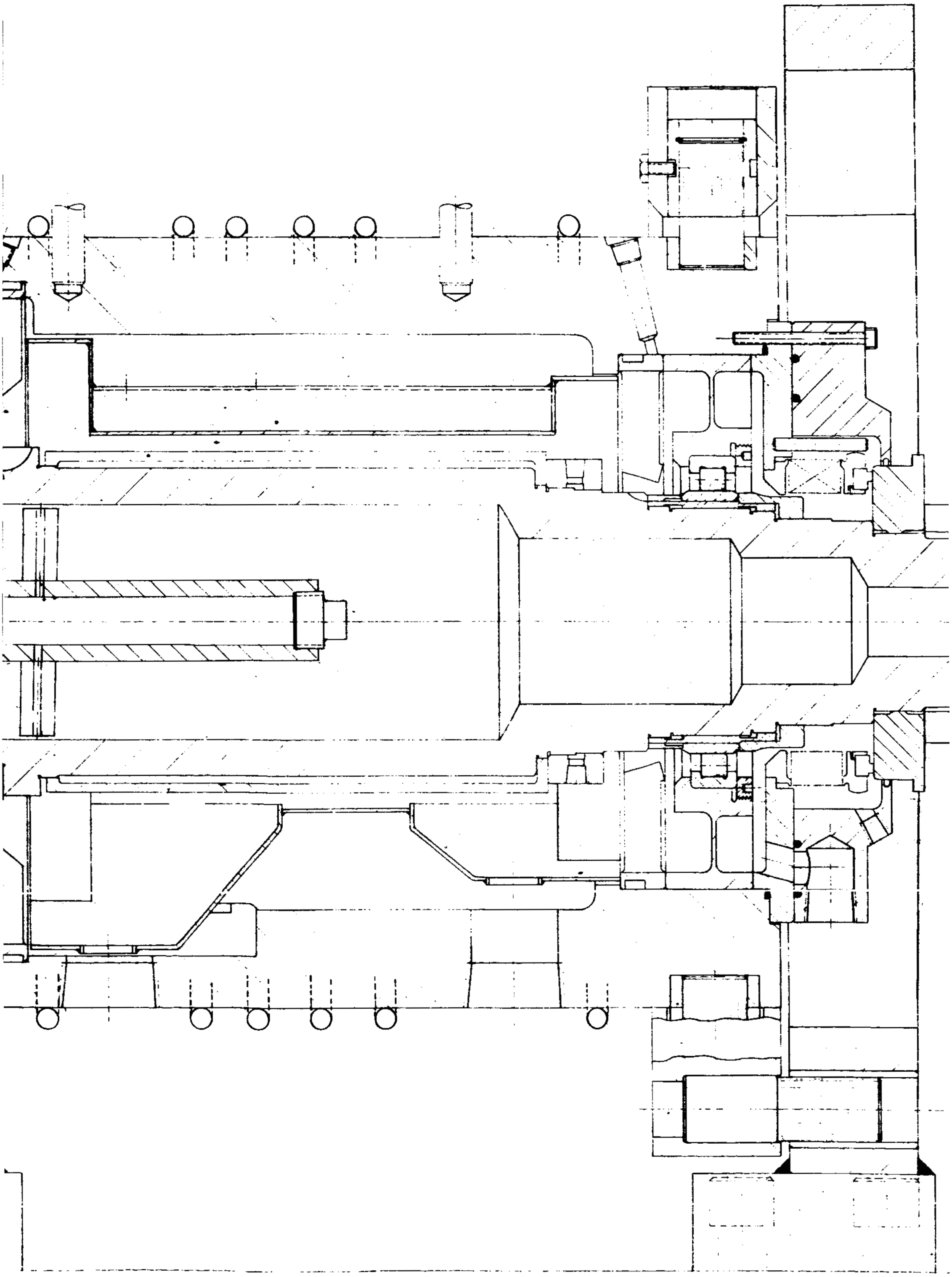
GENERAL TEST RIG LAYOUT SCHEMATIC



ENCLOSURE 3

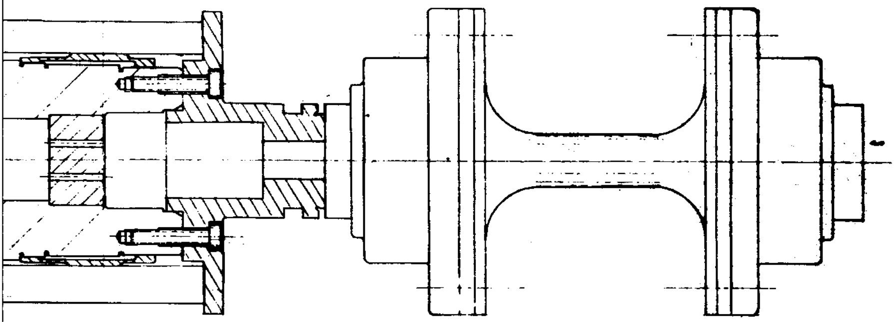
TEST RIG ASSEMBLY





SECTION "A-A"

3-2



3.3

ENCLOSURE 4

TEST BEARING DESIGN DATA

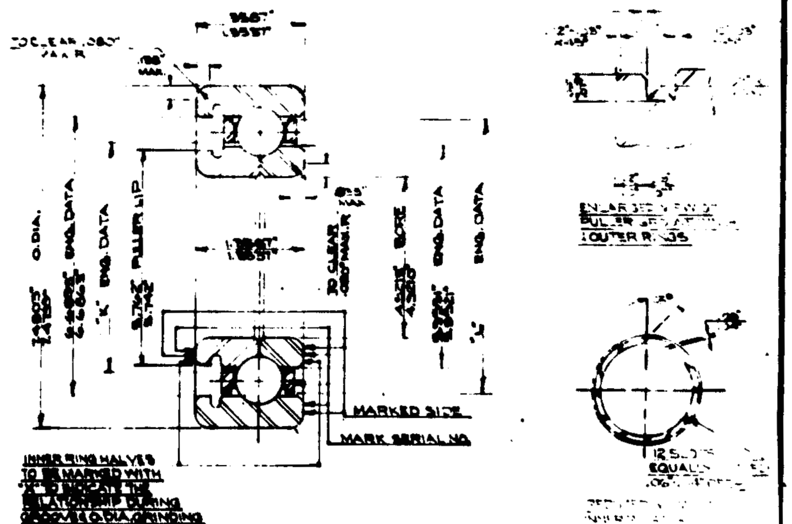
76272-2

	BEARING DATA			SKF			
1	VENDORS PART NO.	[illegible] H	[illegible] D	479980 J	479980 K	479981 E	479981 F
2	VENDORS DRAWING NO.	76272-2	76272-2	76272-2	76272-2	76272-2	76272-2
3	BEARING TOLERANCE	ABEC 7	ABEC 7	ABEC 7	ABEC 7	ABEC 7	ABEC 7
4	NO & SIZE OF BALLS	21-11/16" DIA.	21-11/16" DIA.	21-11/16" DIA.	21-11/16" DIA.	21-11/16" DIA.	21-11/16" DIA.
5	INTERNAL RADIAL LOOSENESS (UNMOUNTED)	.0087"-.0108"	.0078"-.0090"	.0085"-.0099"	.0087"-.0099"	.0068"-.0080"	.0068"-.0080"
6	MAX. END PLAY (UNMOUNTED)	.035"	.031"	.032"	.032"	.029"	.029"
7	DESIGN CONTACT ANGLE	31°30'-35°30'	28°30'-32°30'	32°30'-36°30'	32°30'-36°30'	29°30'-33°30'	29°30'-33°30'
8	OUTER GROOVE RADIUS AS PERCENT OF BALL DIA.	51.50-51.75	51.50-51.75	52.00-52.25	52.00-52.25	52.00-52.25	52.00-52.25
9	INNER GROOVE RADIUS AS PERCENT OF BALL DIA.	52.75-53.00	52.75-53.00	51.50-51.75	51.50-51.75	51.50-51.75	51.50-51.75
10	SHIM WIDTH	.015"	.015"	.009"	.009"	.009"	.009"
11	PITCH DIA.	6.280"	6.280"	6.280"	6.280"	6.280"	6.280"
12	CAGE WIDTH (MAX)	1.024"	1.024"	1.024"	1.024"	1.024"	1.024"
13	CAGE SPEC. (FOR OUT-OF-ROUNDNESS & SQUARENESS)	470939	470939	470939	470939	470939	470939
14	CAGE POCKET CLEARANCE	.009"-.017"	.009"-.017"	.014"-.022"	.009"-.017"	.014"-.022"	.009"-.017"
15	BALL GRADE (AFBMA)	15	15	15	15	15	15
16	INNER RING MATERIAL	WB49	M-50	WB 49	WB 49	M50	M50
17	OUTER RING MATERIAL	WB49	M-50	WB 49	WB 49	M50	M50
18	BALL MATERIAL	M-1	M-1	WB 49	M1	M50	M50
19	CAGE MATERIAL	M-1	M-1	M1	M1	M1	M1
20	CAGE TYPE	ONE PIECE MACHINED OUTER LAND RIDING	ONE PIECE MACHINED OUTER LAND RIDING	ONE PIECE MACHINED OUTER LAND RIDING	ONE PIECE MACHINED OUTER LAND RIDING	ONE PIECE MACHINED OUTER LAND RIDING	ONE PIECE MACHINED OUTER LAND RIDING
21	BEARING DESIGNED TO OPERATE AT (MAX.)	650°	650°	650°	650°	650°	650°
22	INNER RING HARDNESS	57 MIN	61 MIN	57 MIN.	57 MIN.	61 MIN.	61 MIN.
23	OUTER RING HARDNESS	57 MIN	61 MIN	57 MIN.	57 MIN.	61 MIN.	61 MIN.
24	BALL HARDNESS	62 MIN	62 MIN	62 MIN.	62 MIN.	62 MIN.	62 MIN.
25	CAGE HARDNESS	53 MIN	53 MIN	53 MIN.	53 MIN.	53 MIN.	53 MIN.
26	CAGE RUNNING CLEARANCE ON DIA.	.010"-.020"	.010"-.020"	.010"-.020"	.010"-.020"	.010"-.020"	.010"-.020"
27	CAGE O.DIA. "J"	6.681"-6.673"	6.681"-6.673"	6.681"-6.673	6.681"-6.673	6.681"-6.673	6.681"-6.673
28	CAGE I.DIA. "K"	6.111"-6.121"	6.111"-6.121"	6.111"-6.121	6.111"-6.121	6.111"-6.121	6.111"-6.121
29	CAGE PLATING — TYPE	SILVER AMS 2410	SILVER AMS 2410	SILVER AMS 2410	SILVER AMS 2410	SILVER AMS 2410	SILVER AMS 2410
	CAGE PLATING — THICKNESS	.001"-.002"	.001"-.002"	.001"-.002"	.001"-.002"	.001"-.002"	.001"-.002"

CAGE TO BE 100% FLUORESCENT PENETRANT INSPECTED (470908).
100% VISUAL INSPECTION (470683)
100% MAGNAFLUX INSPECTION (471682)
100% ETCH INSPECTION (471637)
MATERIAL AND IDENTIFICATION CONTROL AS PER SPEC. 471005
INNER RING, OUTER RING AND BALLS TO BE BLACK OXIDE TREATED AS PER AMS 2485
SURFACE FINISH REQUIREMENTS

INNER RING BORE	4	RMS	MAX.
INNER RING GROOVE	4	"	"
OUTER RING O.DIA.	10	"	"
OUTER RING GROOVE	4	"	"
CAGE SUPPORT SURFACE	20	"	"
BALL	1.2	"	"
OUTER RING BORE	4	"	"
INNER RING O.DIA.	4	"	"

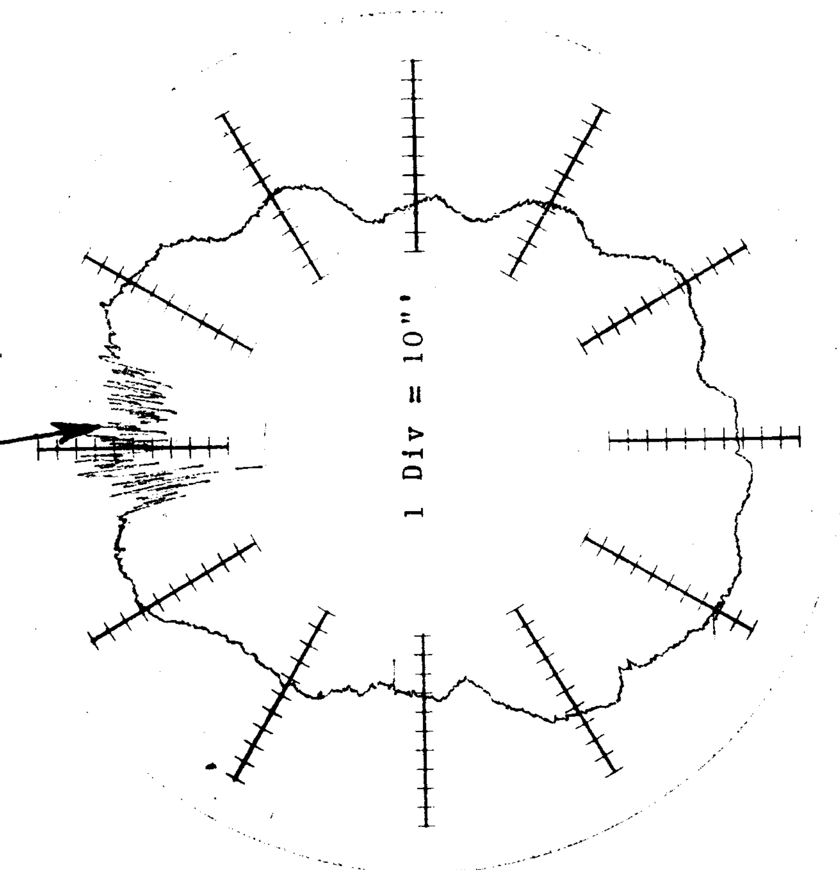
MAX. CAGE UNBALANCE 3GM-CM, BALANCE TO BE CHECKED AT 500 RPM (MIN)
INNER & OUTER RING LAND TOLERANCES
A. 3 POINT OUT-OF-ROUND WITHIN .0004" F.I.R.
B. ECCENTRICITY TO O.DIA. WITHIN .0004" F.I.R.
C. "K" ON HEIGHT OF LAND TO O.DIA. EQUAL WITHIN .0004" IN SAME AXIAL PLANE
D. 80% CONTACT WHEN ROLLED ON A BLUED SUPPORT
CAGE SUPPORT
A. 3 POINT OUT-OF-ROUND WITHIN .003" F.I.R.
B. 2 POINT DIAMETERS EQUAL WITHIN .002" IN SAME AXIAL PLANE
C. [illegible] TO COMMON MACHINING REF FACE WITHIN .002"
D. 80% CONTACT WHEN ROLLED ON BLUED FLAT PLATE



MRC
76272-2

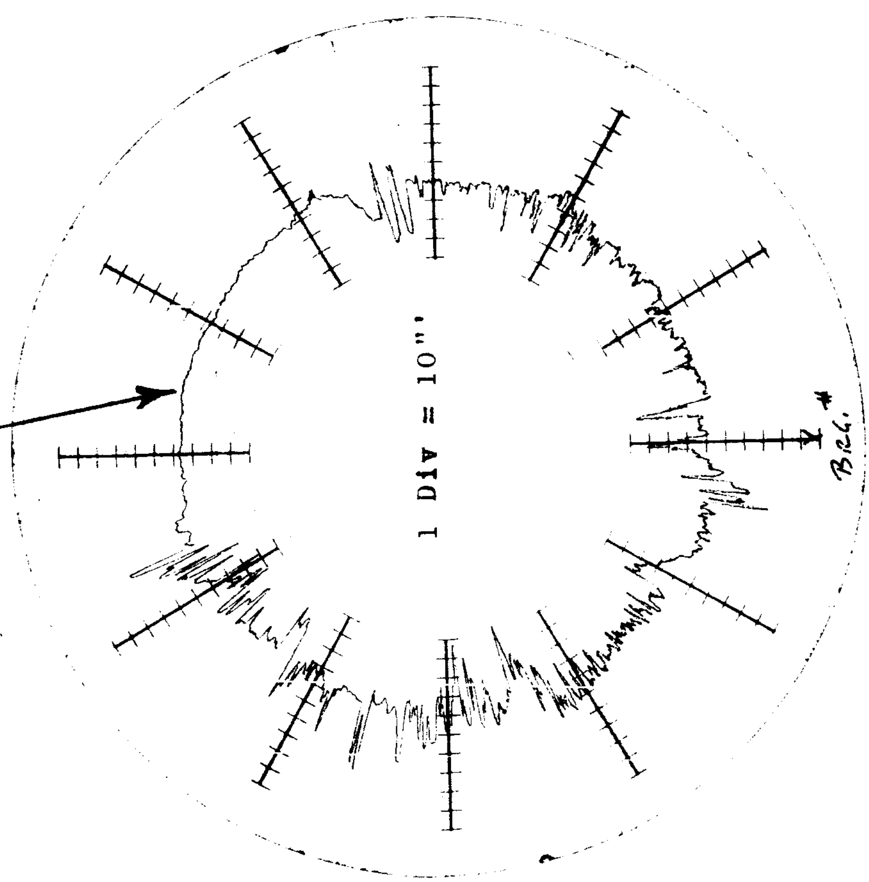
ENCLOSURE 5

SURFACE TRACES OF BLACK OXIDE COATED WB49 AND M-50 BEARING RINGS



Black Oxide Coating Scraped Off

Trace of WB49 Inner Ring 459980J



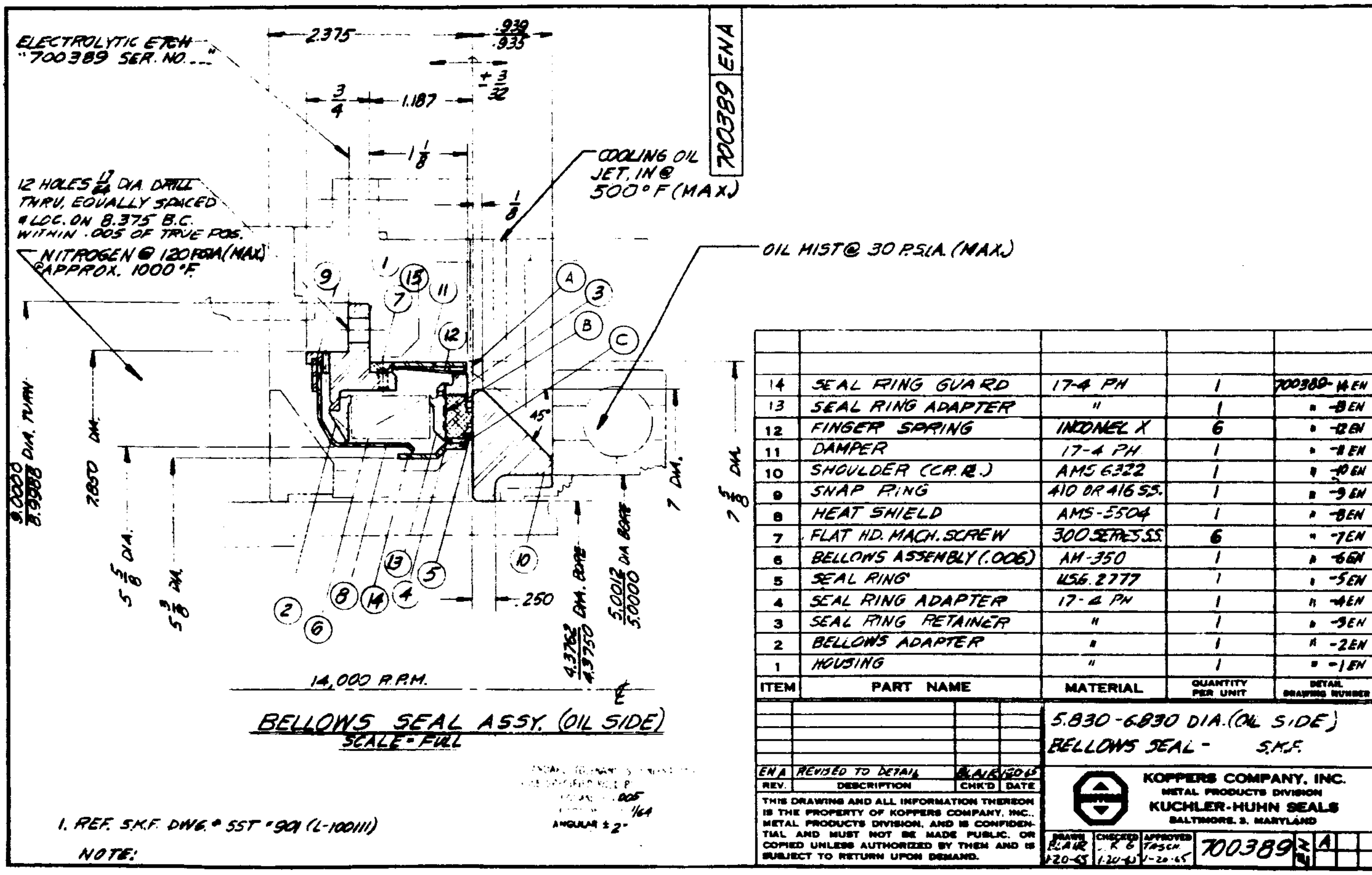
Black Oxide Coating Scraped Off

Trace of M-50 Inner Ring

ENCLOSURE 6

AM-350 BELLOWS TEST SEAL

(Oil Side)



ITEM	PART NAME	MATERIAL	QUANTITY PER UNIT	DETAIL DRAWING NUMBER
14	SEAL RING GUARD	17-4 PH	1	700389-14EN
13	SEAL RING ADAPTER	"	1	" -13EN
12	FINGER SPRING	INCONEL X	6	" -12EN
11	DAMPER	17-4 PH	1	" -11EN
10	SHOULDER (CR. PL.)	AMS 6322	1	" -10EN
9	SNAP RING	410 OR 416 SS.	1	" -9EN
8	HEAT SHIELD	AMS-5504	1	" -8EN
7	FLAT HD. MACH. SCREW	300 SERIES SS.	6	" -7EN
6	BELLOWS ASSEMBLY (.006)	AM-350	1	" -6EN
5	SEAL RING	USG. 2777	1	" -5EN
4	SEAL RING ADAPTER	17-4 PH	1	" -4EN
3	SEAL RING RETAINER	"	1	" -3EN
2	BELLOWS ADAPTER	"	1	" -2EN
1	HOUSING	"	1	" -1EN

REV.	DESCRIPTION	CHK'D	DATE
ENA	REVISED TO DETAIL	BLAIR	1-20-65

5.830-6.830 DIA. (OIL SIDE) BELLOWS SEAL - S.K.F.

KOPPERS COMPANY, INC.
METAL PRODUCTS DIVISION
KUCHLER-HUHN SEALS
BALTIMORE 3, MARYLAND

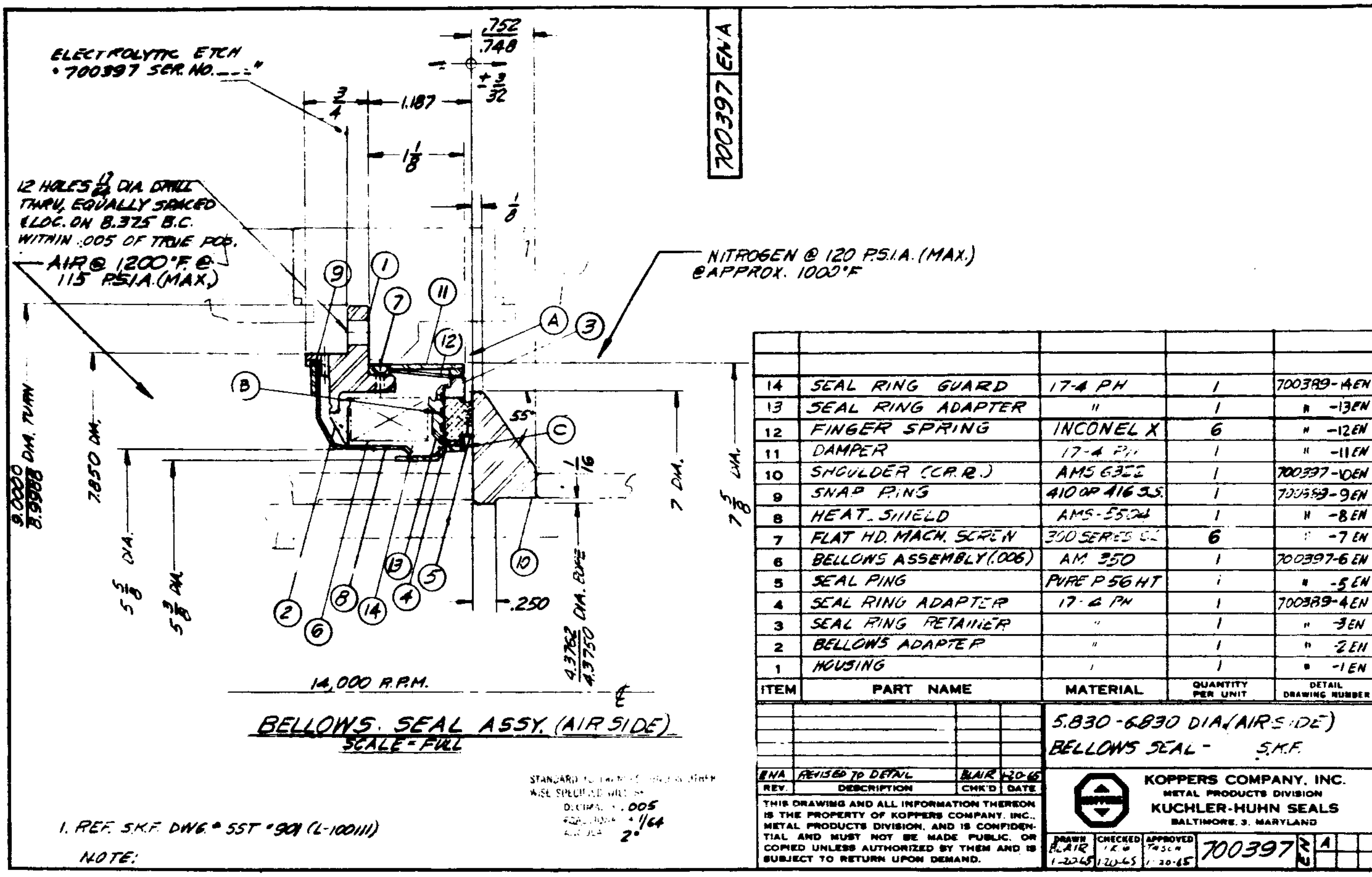
DRAWN	CHECKED	APPROVED	DRAWING NO.
BLAIR 1-20-65	K G 1-20-65	TASCH 1-20-65	700389 A

A. Improved damping device
B. Thermal barrier
C. Modified end fitting retention

ENCLOSURE 7

AM-350 BELLOWS TEST SEAL

(Air Side)



ITEM	PART NAME	MATERIAL	QUANTITY PER UNIT	DETAIL DRAWING NUMBER
14	SEAL RING GUARD	17-4 PH	1	700389-14EN
13	SEAL RING ADAPTER	"	1	" -13EN
12	FINGER SPRING	INCONEL X	6	" -12EN
11	DAMPER	17-4 PH	1	" -11EN
10	SHOULDER (CR.R.)	AMS 6322	1	700397-10EN
9	SNAP RING	410 OR 416 S.S.	1	700389-9EN
8	HEAT SHIELD	AMS 5504	1	" -8EN
7	FLAT HD. MACH. SCREW	300 SERIES S.S.	6	" -7EN
6	BELLOWS ASSEMBLY (.006)	AM 350	1	700397-6EN
5	SEAL RING	PURE P 56 HT	1	" -5EN
4	SEAL RING ADAPTER	17-4 PH	1	700389-4EN
3	SEAL RING RETAINER	"	1	" -3EN
2	BELLOWS ADAPTER	"	1	" -2EN
1	HOUSING	"	1	" -1EN

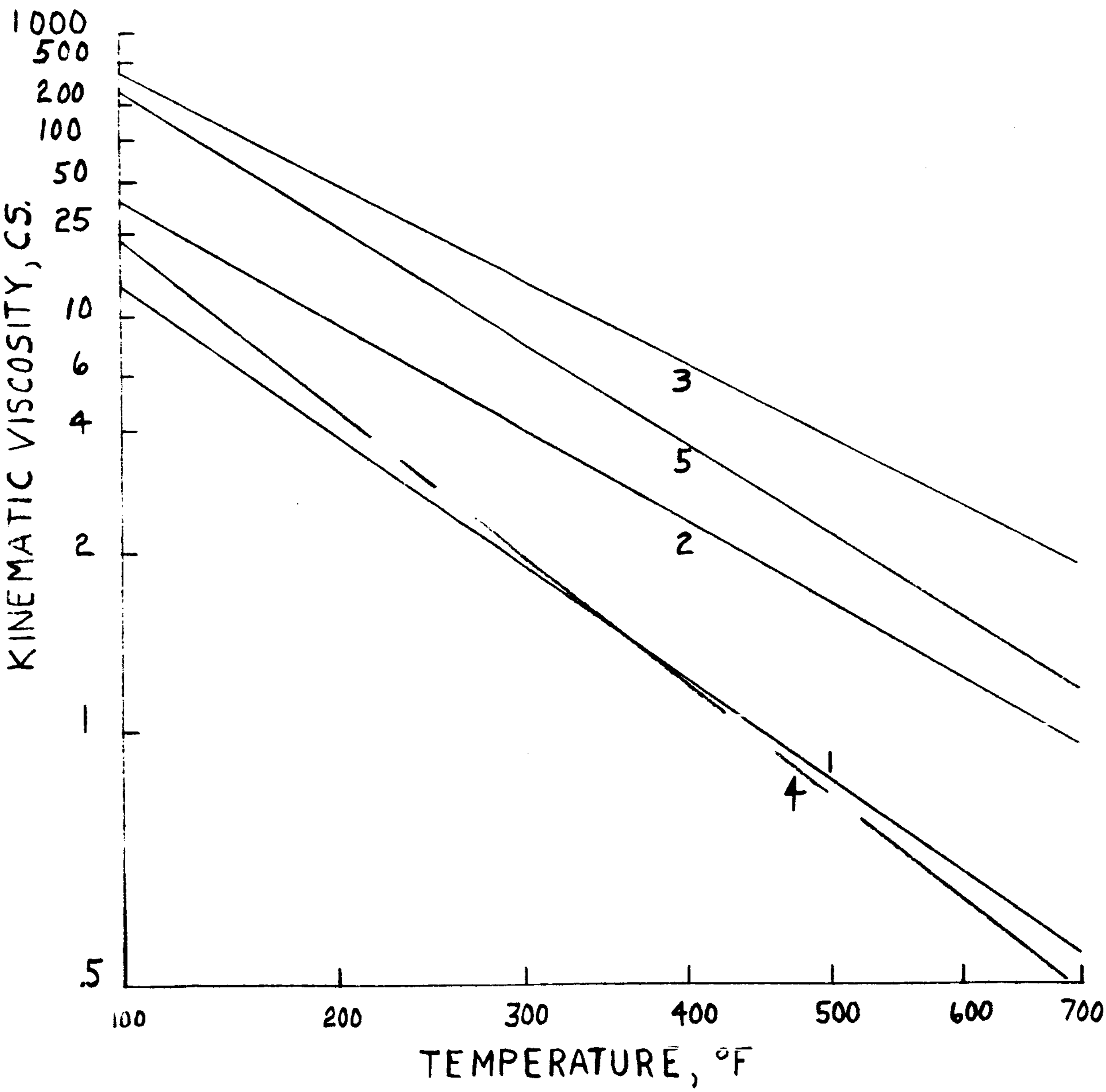
A. Improved damping device
B. Thermal barrier
C. Modified end fitting retention

T-924012

ENCLOSURE 8

VISCOSITY-TEMPERATURE RELATION FOR CIRCULATING OILS

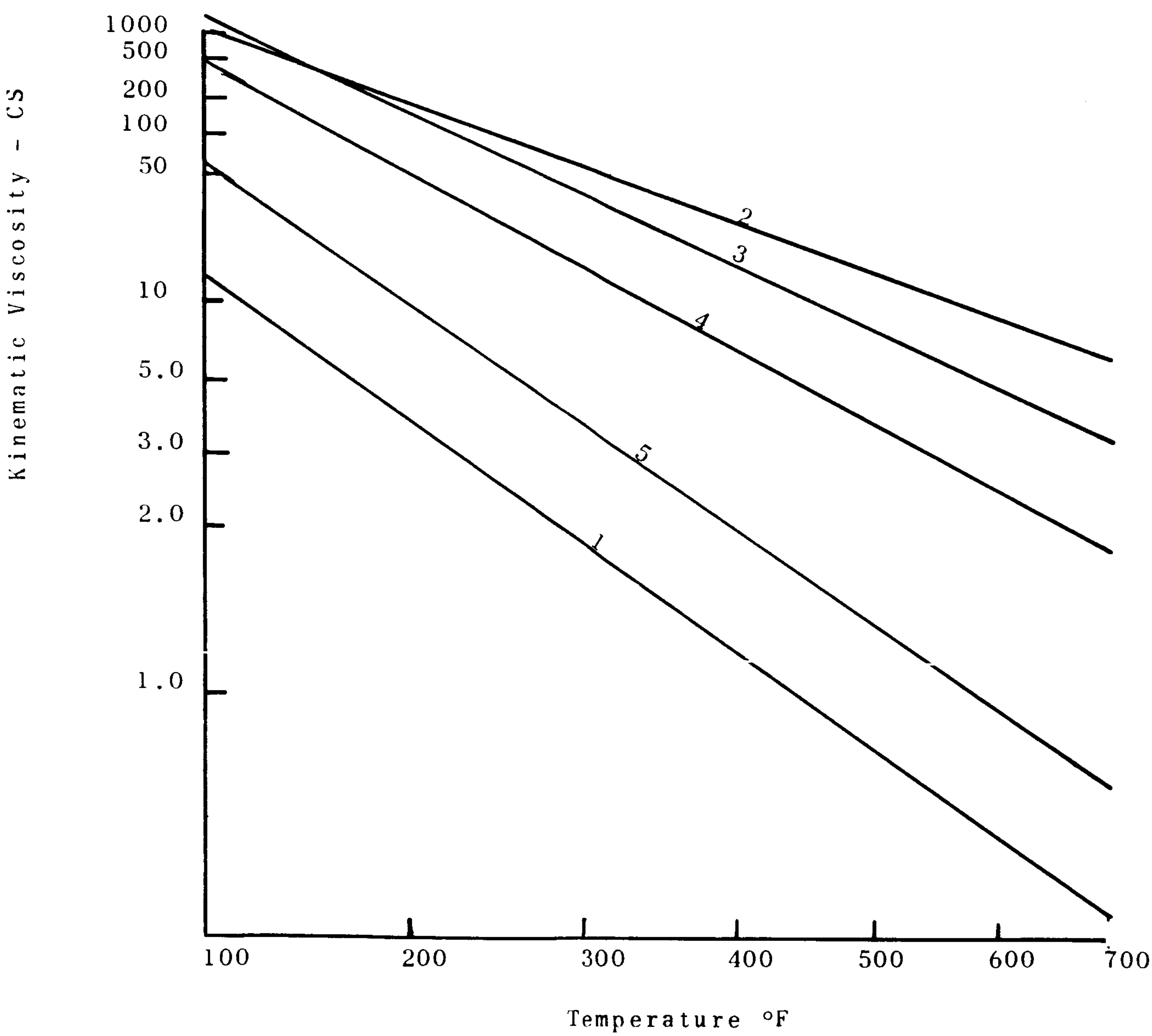
1. Esso 4040 MIL-L-7808E
2. Sinclair Turbo S 1048 Improved
3. Mobil XRM 177F
4. Monsanto MCS-293
5. DuPont PR 143



ENCLOSURE 9

Viscosity - Temperature Relation For Mist Lubricating Oils

1. Esso Turbo oil 4040 (MIL-L-7808E)
2. Union Carbide UCON 50-HB-5100
3. Sun Oil Sunthetic 18H
4. Socony Mobil XRM 177F
5. Hercules Hercolube F



ENCLOSURE 10

SUMMARY OF TEST OIL VISC. AND ACID NO. BEFORE AND AFTER TEST

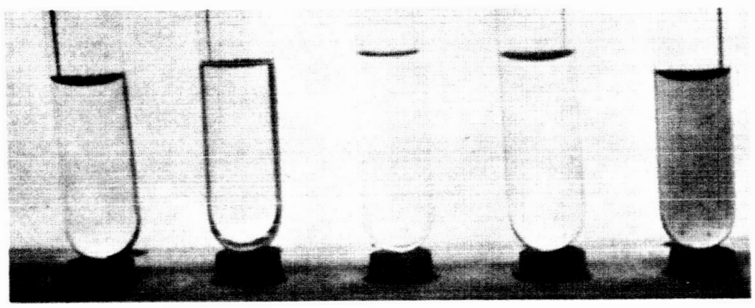
OIL		NEW DEGASSED	USED
Esso-4040	Visc. @100°F(Cs.)	12.05	12.3-12.8
	Acid No.	0.44	0.55-0.80
XRM-177F	Visc.@100°F(Cs.)	443.4	471.8
	Acid No.	0.055	0.055
Turbo-S	Visc. @100°F(Cs.)	38.9	37.4
	Acid No.	0.22	0.22
MCS 293	Visc. @100°F(Cs.)	24.8	24.9
N_2 Blanket	Acid No.	0.055	0.055
MCS 293	Visc. @100°F(Cs.)	24.8	26.5
Open Atmosphere	Acid No.	0.055	0.055

ENCLOSURE 11

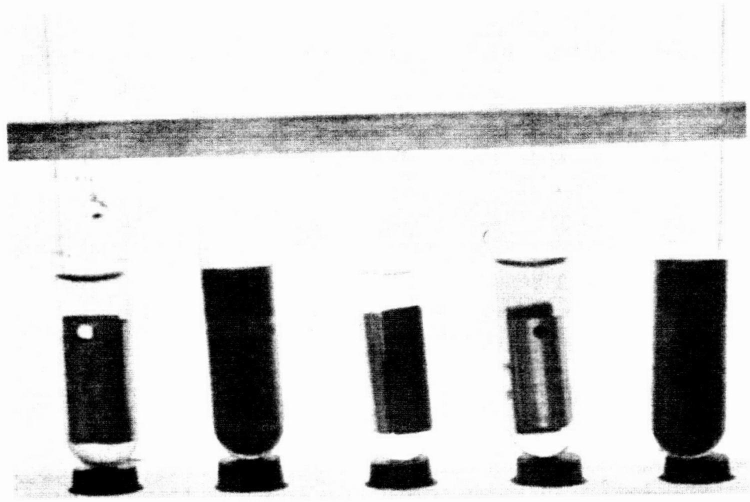
APPEARANCE OF OILS (A) ORIGINALLY, (B) AFTER 24 HOURS AT 500°F, AND (C) AFTER 24 HOURS AT 500°F CONTAINING 10 WT % "FREON-113" FLUOROCARBON

Oil Identification:
(1) Socony 177-F Synthetic Hydrocarbon
(2) Monsanto MCS 293 Polyphenyl Ether
(3) Du Pont PR 143 Fluorinated Ether
(4) Herculube F Polyester
(5) Turbo S-1048 Improved Synthetic Ester

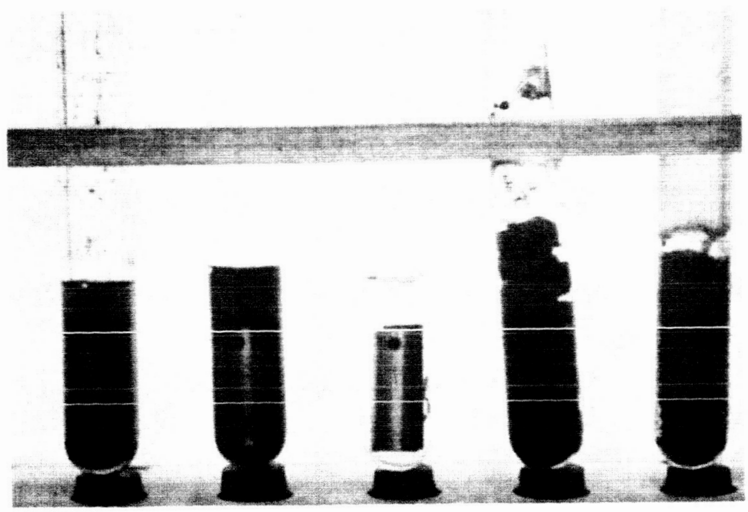
1 2 3 4 5



A



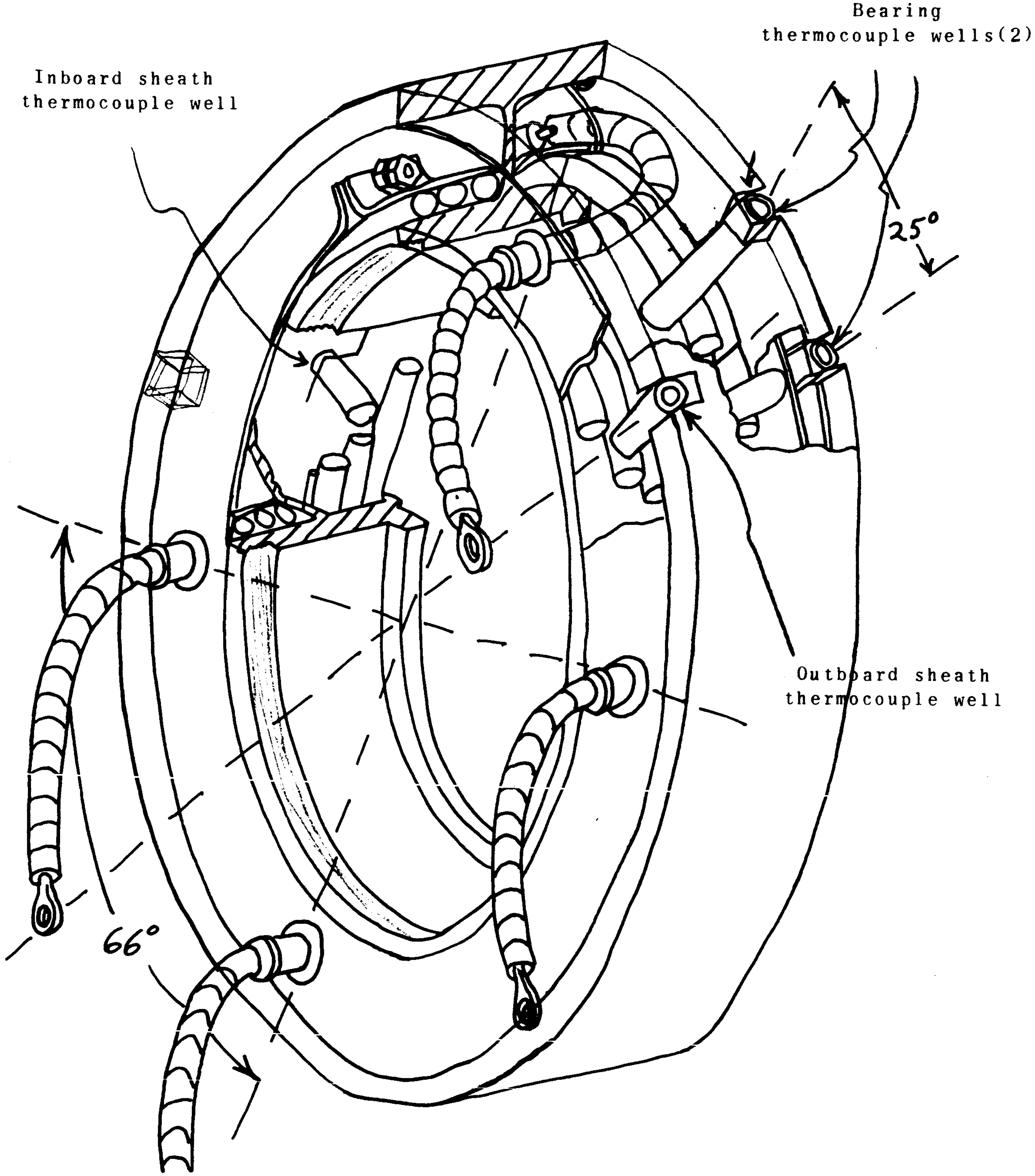
B



C

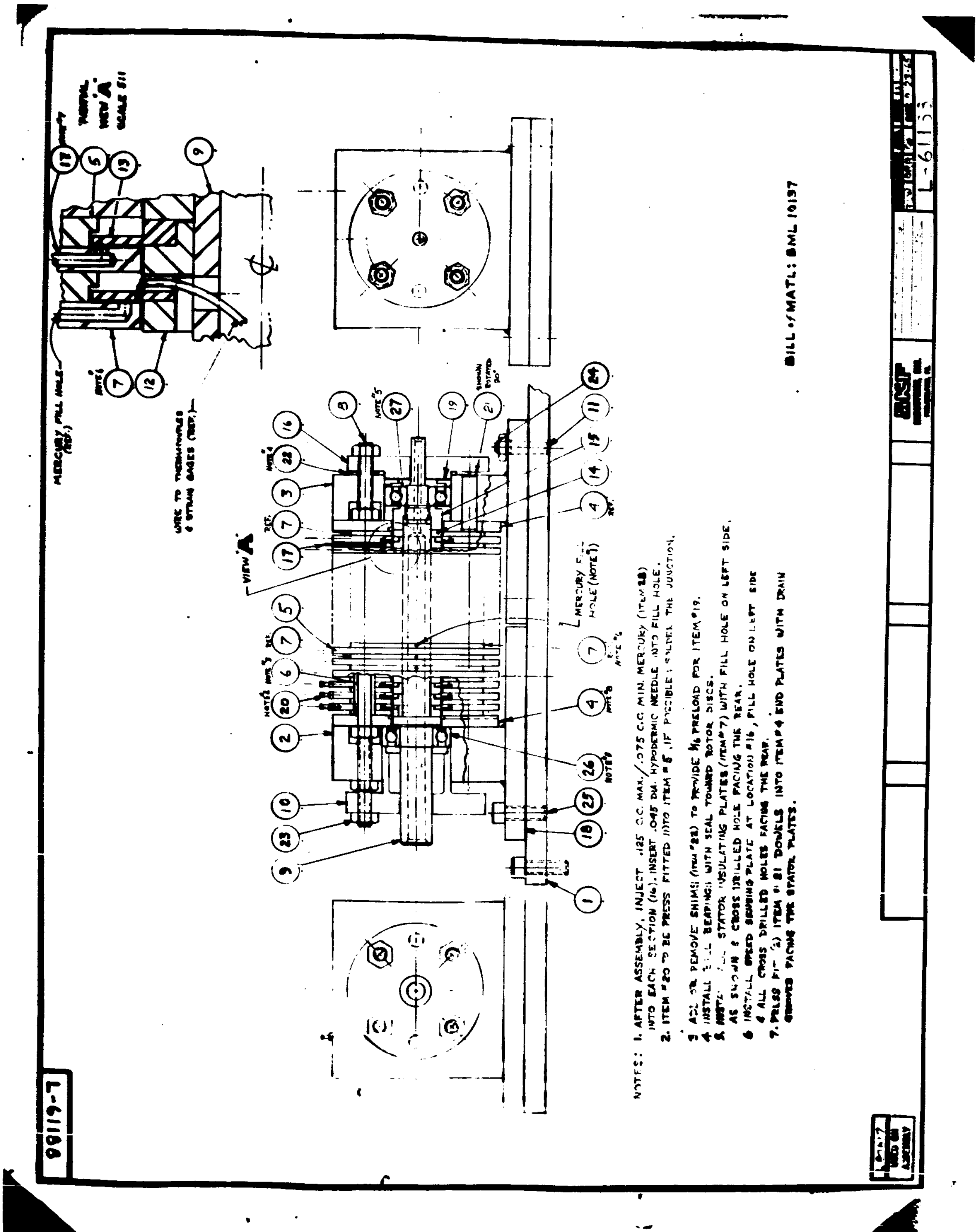
ENCLOSURE 12

SKETCH OF TWO 2 KW HEATERS
MOUNTED IN SST I-HOUSING



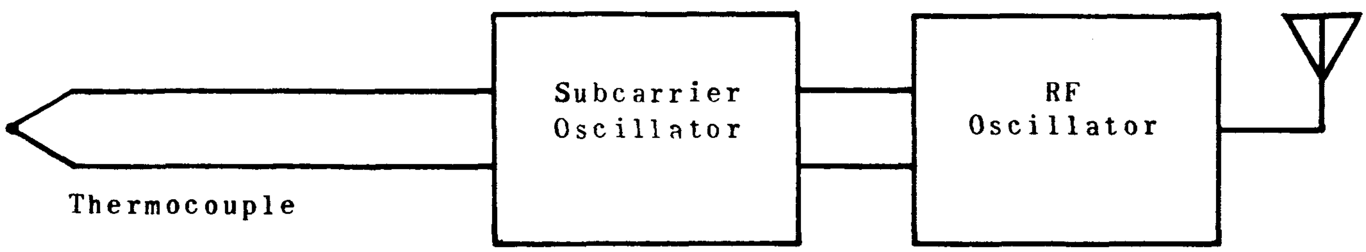
<u>ENCLOSURE 13</u>

SIXTEEN CHANNEL MERCURY WETTED SLIP RING - ASSEMBLY

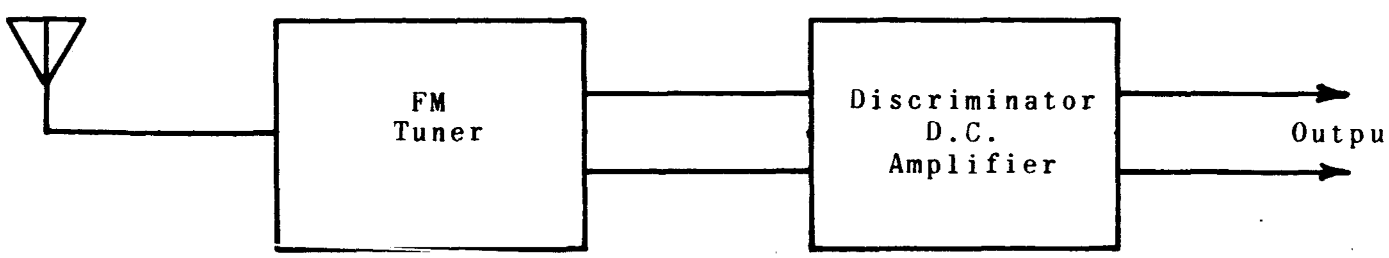


ENCLOSURE 14

BLOCK DIAGRAM OF THERMOCOUPLE TELEMETRY SYSTEM



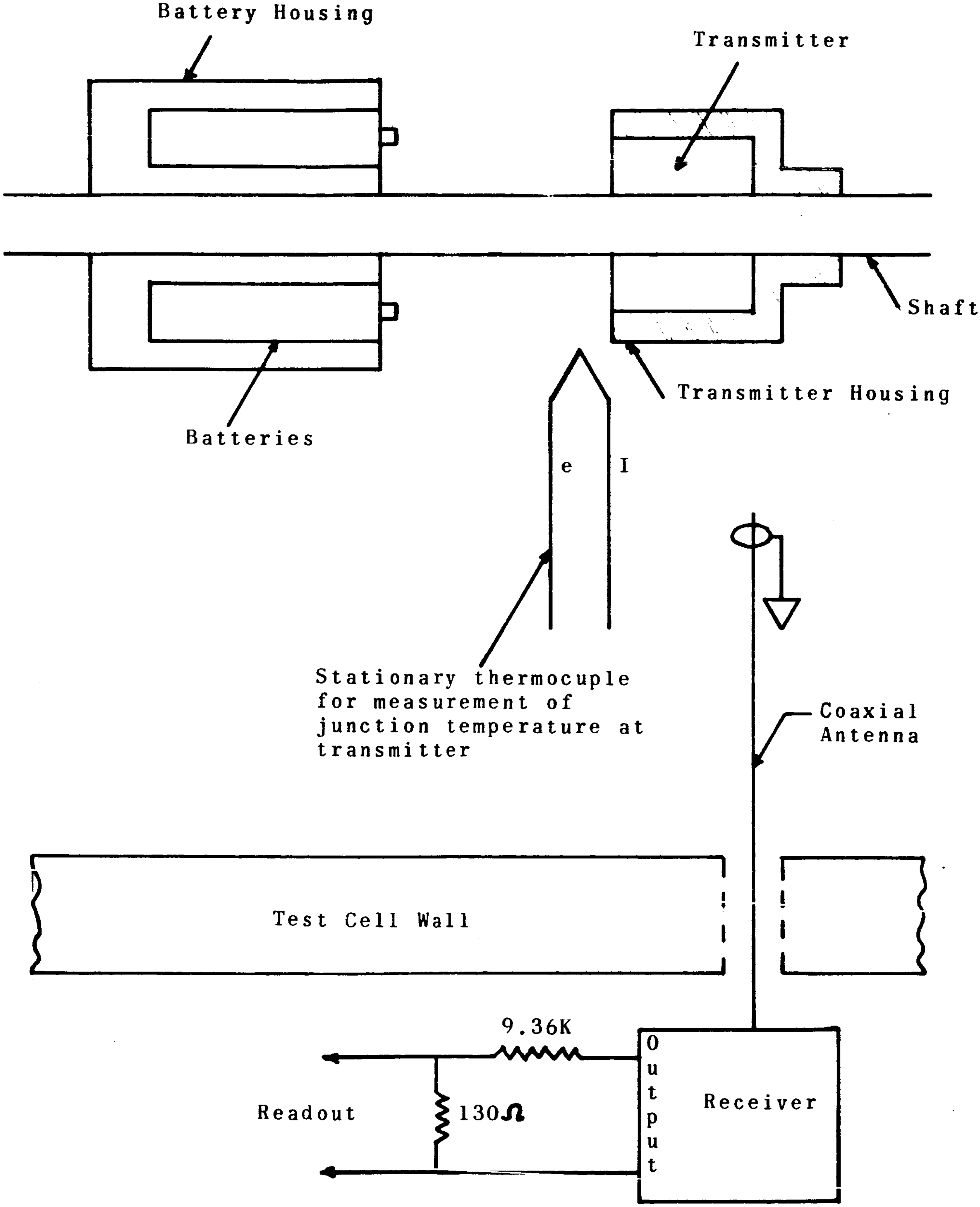
Transmitter



Receiver

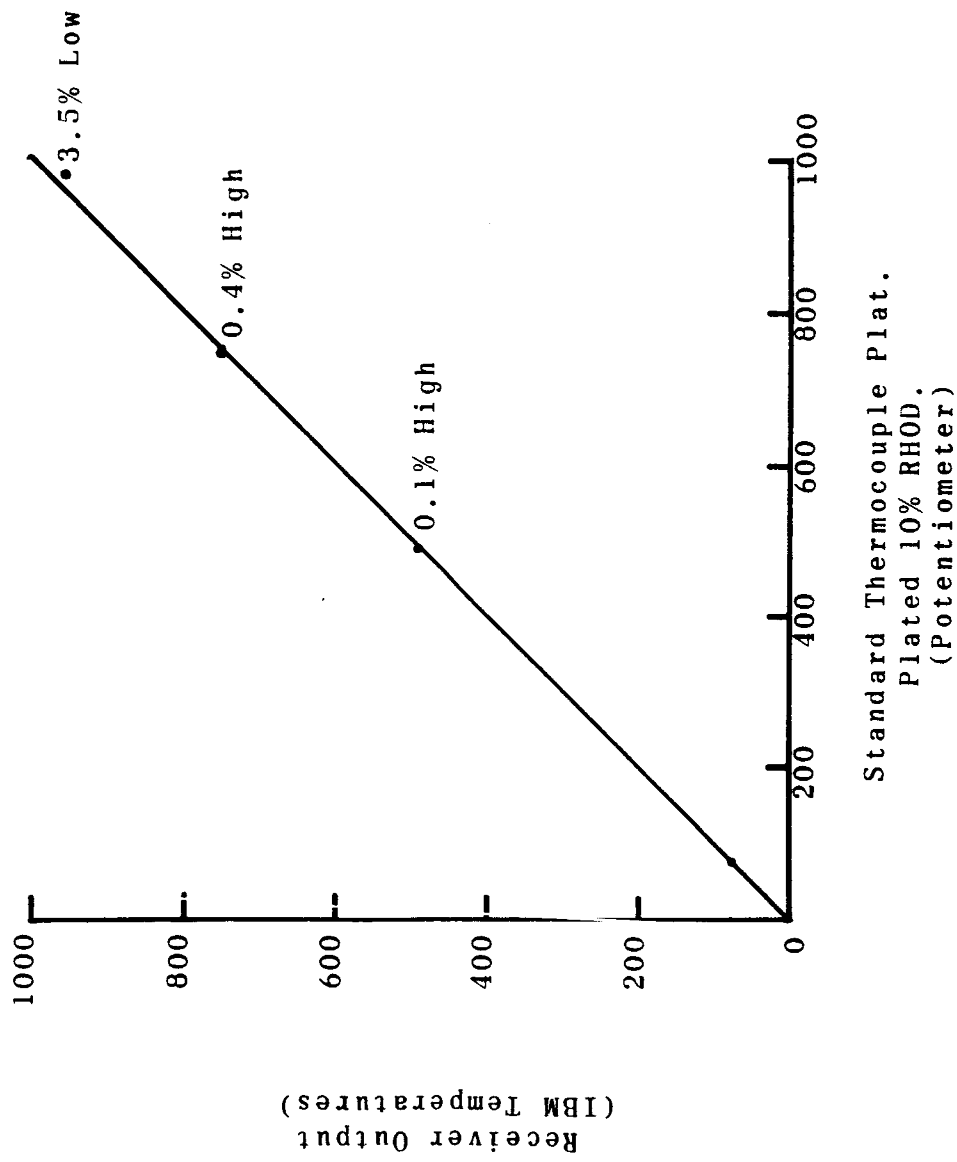
ENCLOSURE 15

THERMOCOUPLE TELEMETRY SYSTEM - MECHANICAL SETUP



ENCLOSURE 16

CALIBRATION OF TELEMETRY TEMPERATURE SYSTEM



Note: This test was conducted on mist rig using 4 Eveready #222 batteries as transmitter supply. All conditions were simulated except rotation.

ENCLOSURE 17

TEST RIG VIBRATION INFORMATION

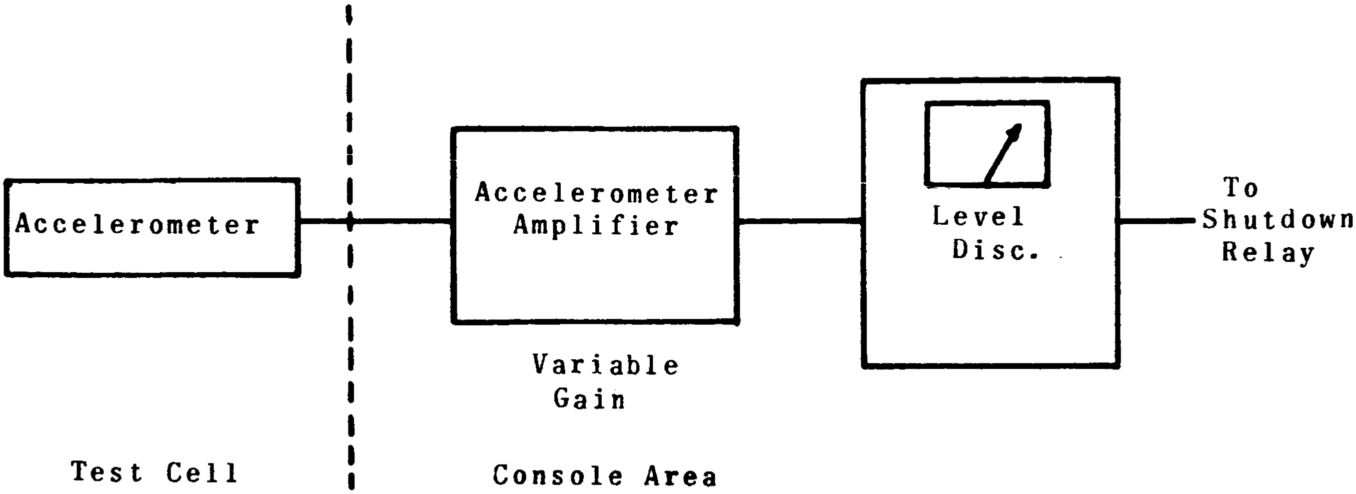


Figure 1

Vibration Measurement Block Diagram

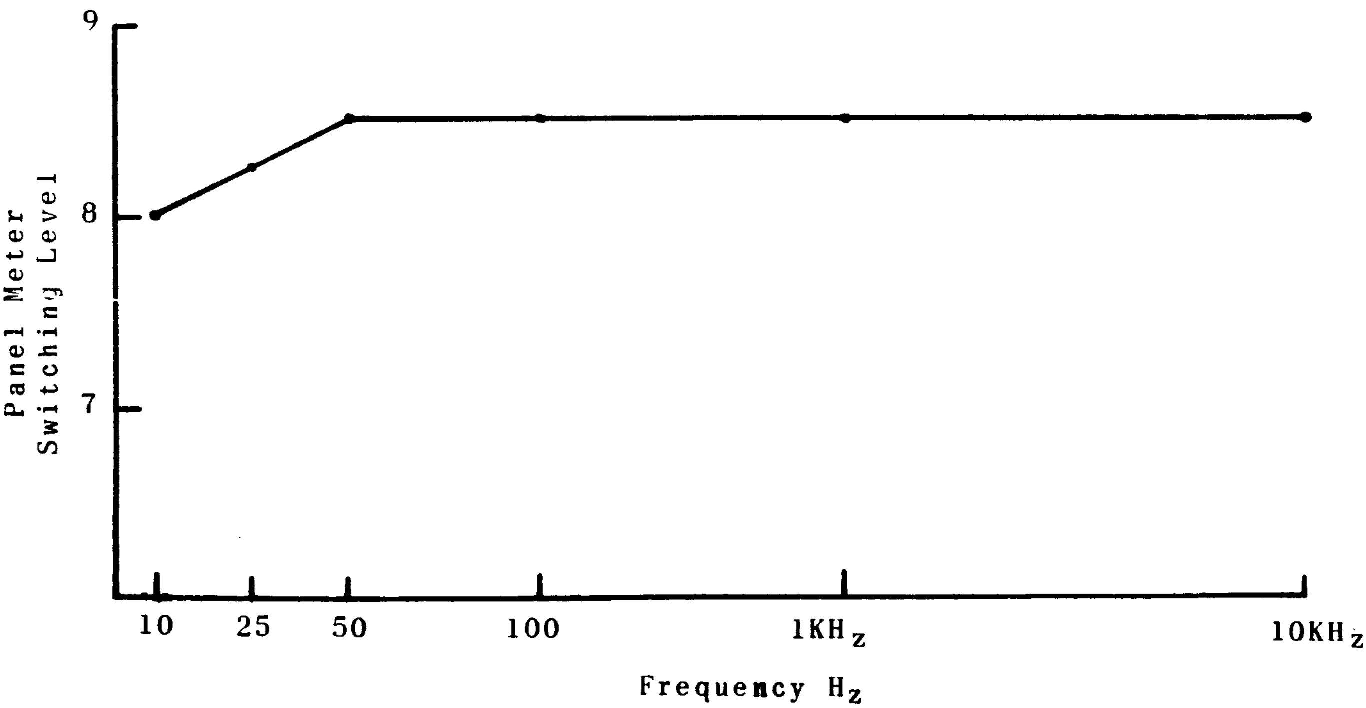


Figure 2

Frequency Response of Level Discriminator

ENCLOSURE 18

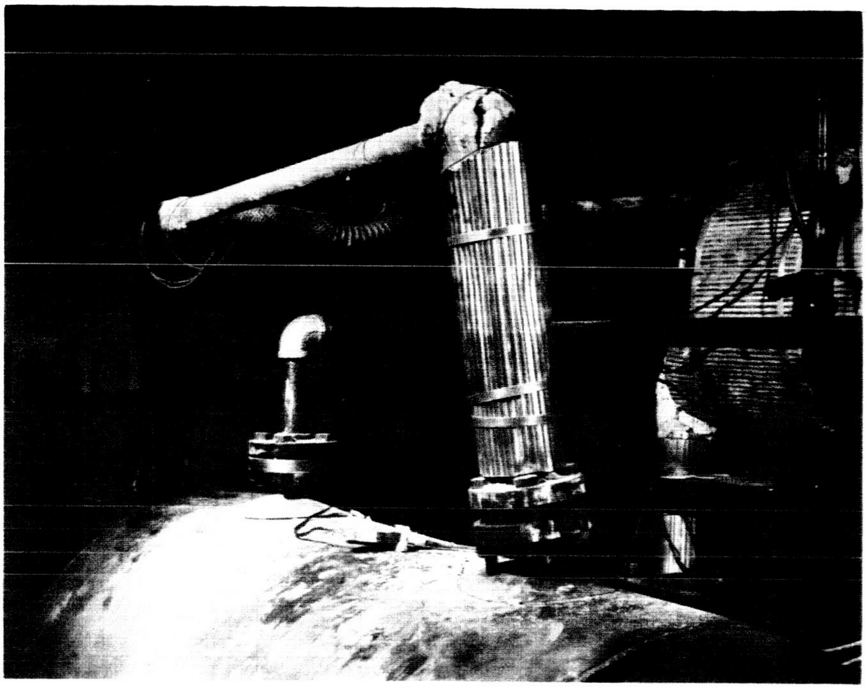
APPROXIMATE HEAT REJECTION FROM TEST BEARING THROUGH TEST OIL*
(Test bearing temperature approximately stabilized)

Test Oil	Oil Flow to test Brg.		Oil Inlet Temp. (°F)	Oil Outlet Temp. (°F)	Specific heat of test oil around (BTU/LBM/°F)	Test Brg. outer ring temp. (°F)	Housing temp. (°F)		Roller Brg. outer ring temp. (°F)	Heat removed by oil (BTU/min)
	GPM	LBS/min.					Test End	Roller End		
Esso 4040 (N_2 blanket)	Adequate oil outlet temperature data not available (Thermocouple placed against pipe-not in flow as in subsequent tests)									
Mobil 177F (N_2 blanket)	1.2	9.3	470 to 520	500 to 540	.66	550 to 600	925-470	370-415	560 to 570	125 to 185
Sinclair Turbo S (N_2 blanket)	.6	4.6	485 to 500	525 to 530	.65	590 to 620	480-610	360-470	500 to 510	100 to 135
Monsanto MCS-293 (N_2 blanket)	1 to 2	8.3 to 16.6	480 to 500	500 to 530	.50	580 to 600	520-590	480-510	490 to 510	150 to 200
Monsanto MCS-293 (Open Atm)	1	8.3	515 to 520	550 to 555	.50	590 to 605	650-690	500-560	560 to 570	150

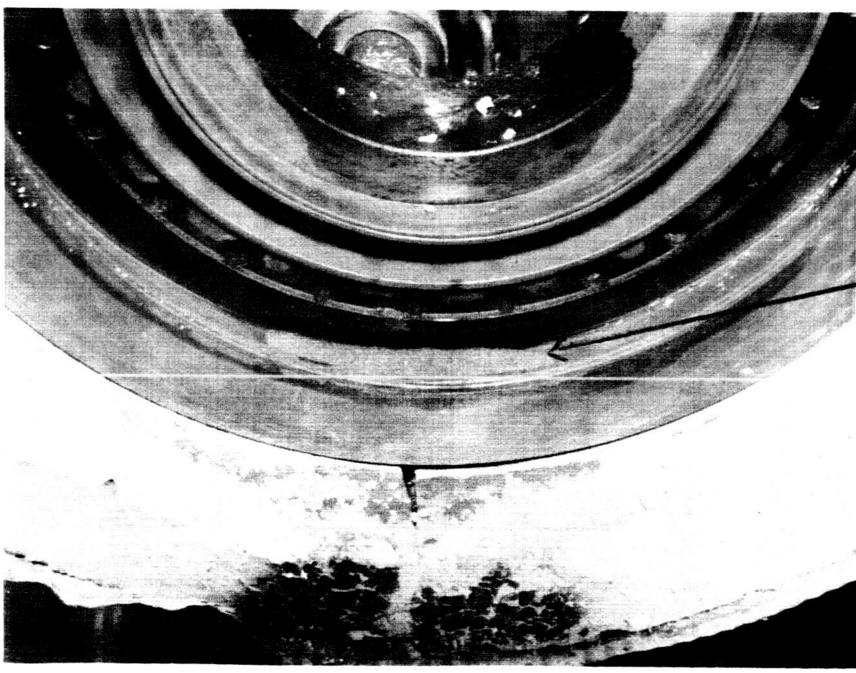
*This is approximate since the oil is exposed to the hot rig housing at some points and the oil outlet temperature includes oil that has gone through the roller bearing. However, since, about 80% of the total oil supplied goes to the test bearing (12-1/16"dia. nozzles supply test bearing, 3-1/16" dia nozzles supply roller bearing) since the oil is exposed to relatively little area of the housing, and since the oil temperature is measured some distance (several feet) from the rig and loses some heat, it is probably a reasonable estimate.

ENCLOSURE 19

DAMAGE TO HOT AIR SYSTEM AFTER ESSO 4040 RUN



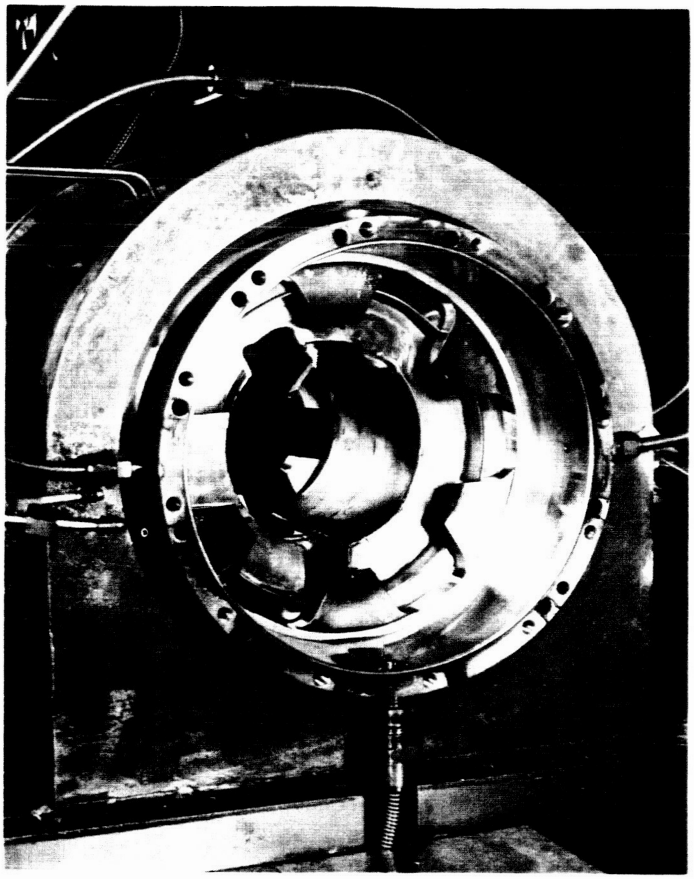
Damaged Hot Air Piping



Metallic Powder In Hot Air Manifold

ENCLOSURE 20

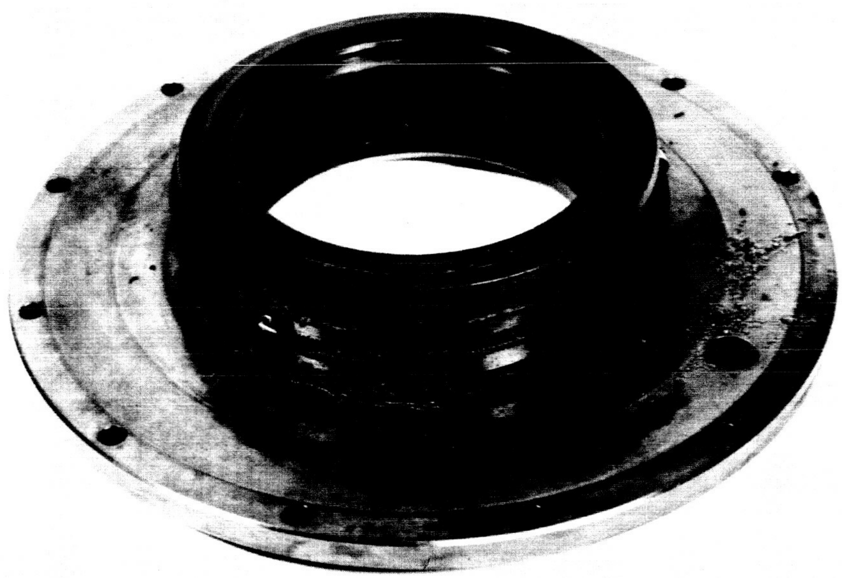
RECIRCULATING RIG-AFTER ESSO 4040 RUN

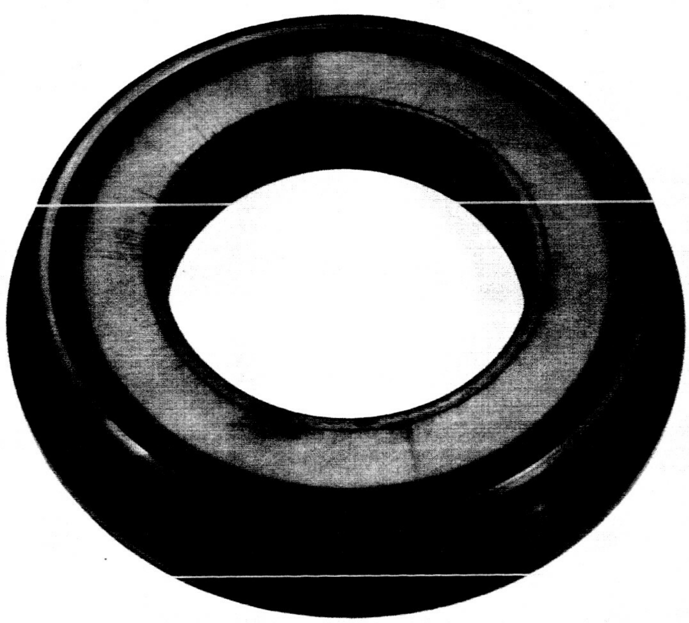


ENCLOSURE 21

RIG SEAL AND RUNNER AFTER 600°F ESSO 4040 RUN IN RECIRCULATING RIG

Note Deterioration of Silicone Rubber Damping Strip

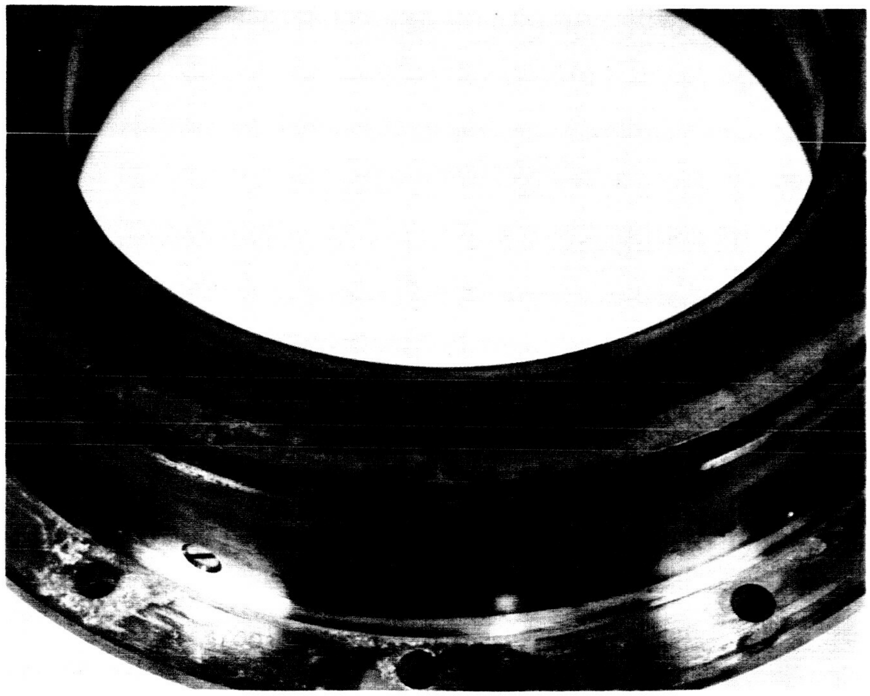


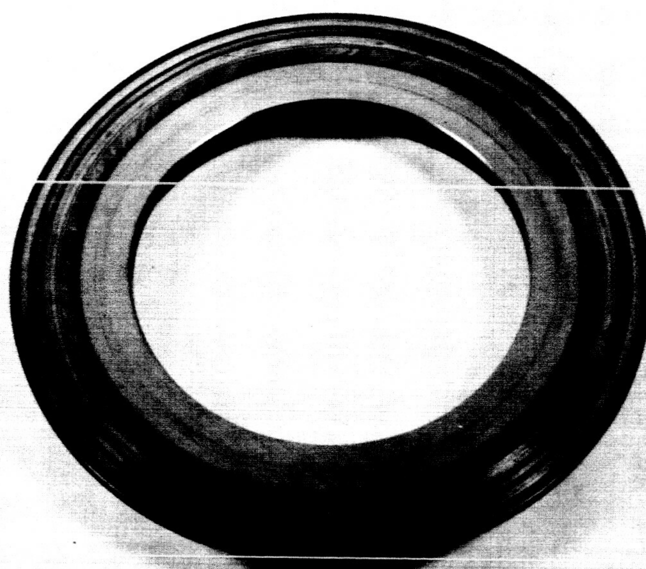


ENCLOSURE 22

AIR SEAL AND RUNNER AFTER 600°F ESSO 4040 RUN IN RECIRCULATING RIG

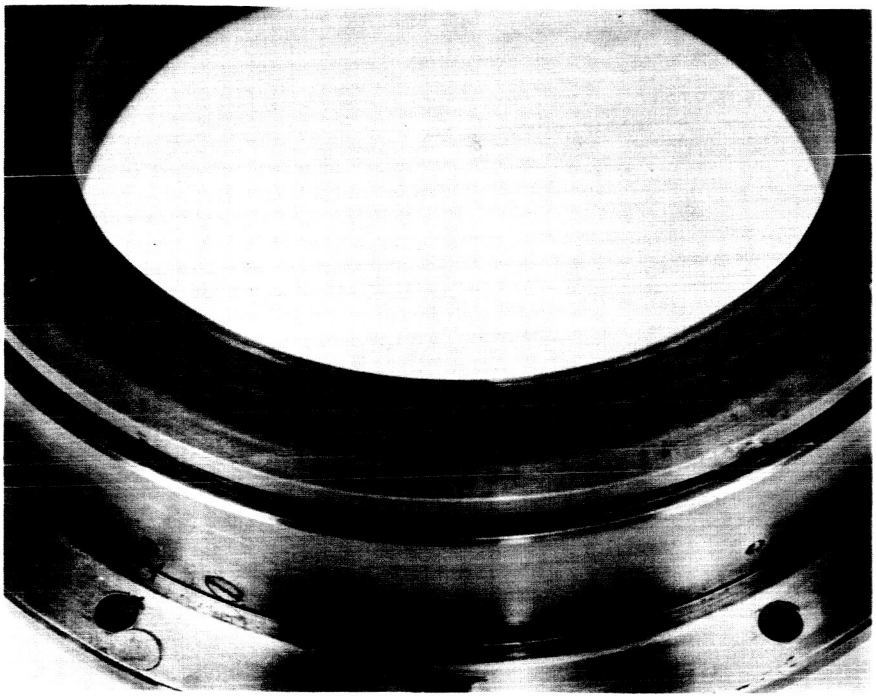
Note Damage to Carbon Caused By Metallic Oxide

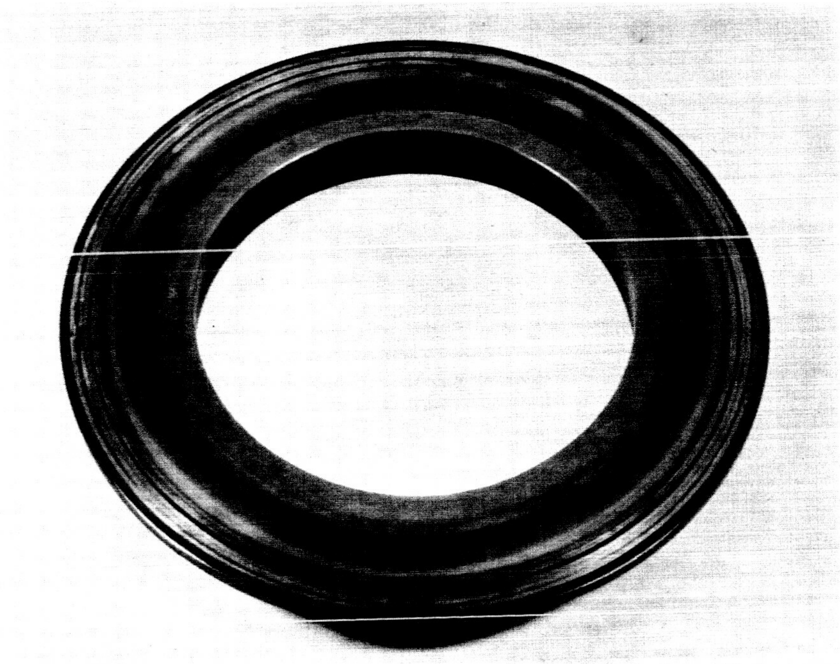




ENCLOSURE 23

OIL SEAL AND RUNNER AFTER 600°F ESSO 4040 RUN IN RECIRCULATING RIG

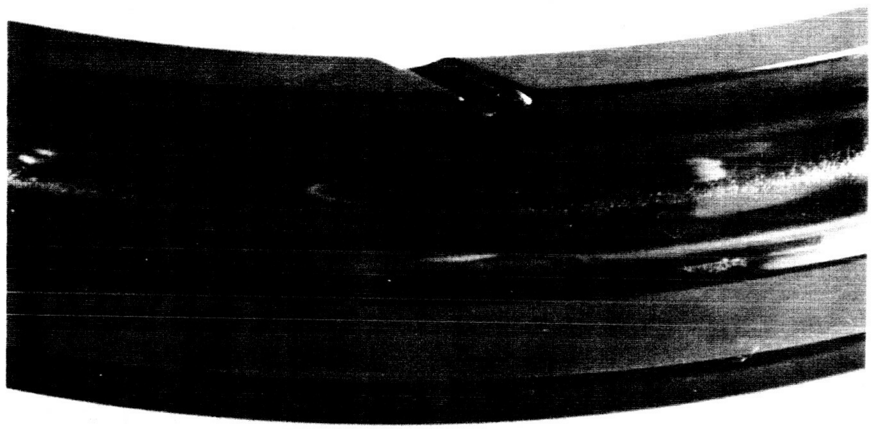




ENCLSOURE 24

TEST INNER AND OUTER RINGS OF FIRST 600°F ESSO 4040 FAILURE IN RECIRCULATING RIG

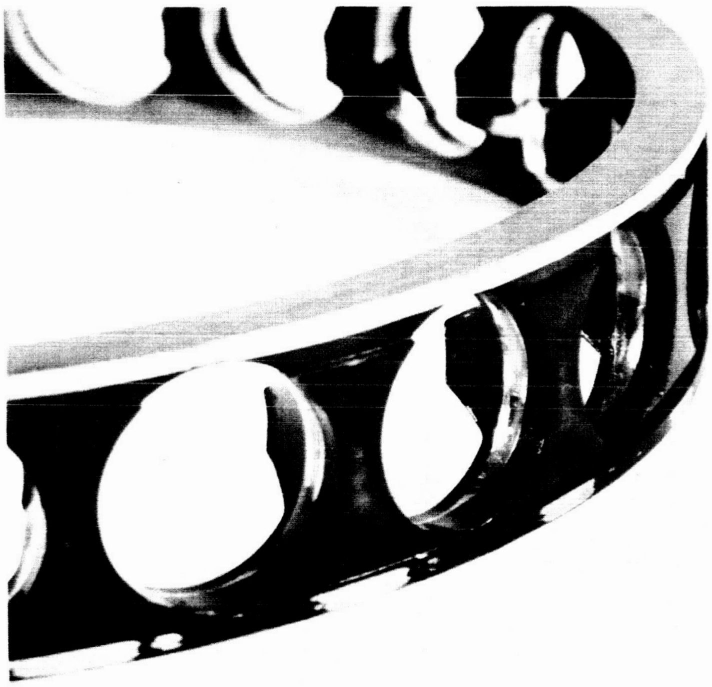
Note Beginning of Surface Distress on Inner Ring



ENCLOSURE 25

TEST CAGE AND BALL OF FIRST 600°F ESSO
4040 FAILURE IN RECIRCULATING RIG

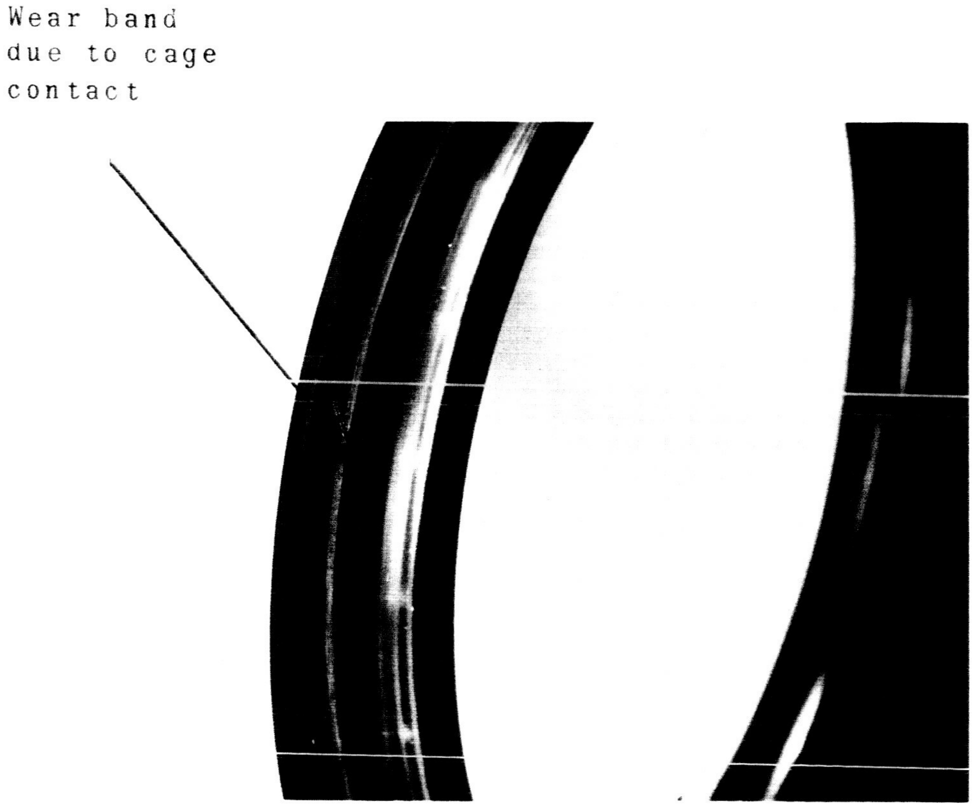
Note Wear in Cage Pockets and Lands



ENCLOSURE 26

TEST INNER AND OUTER RINGS OF SECOND 600°F ESSO 4040 FAILURE IN RECIRCULATING RIG

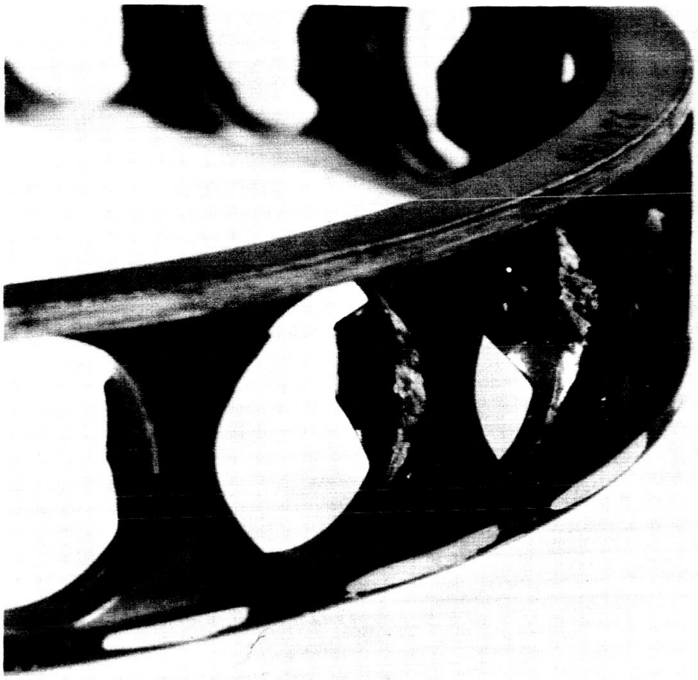
Note Distress and Wear Due to Cage Contact on Outer Ring

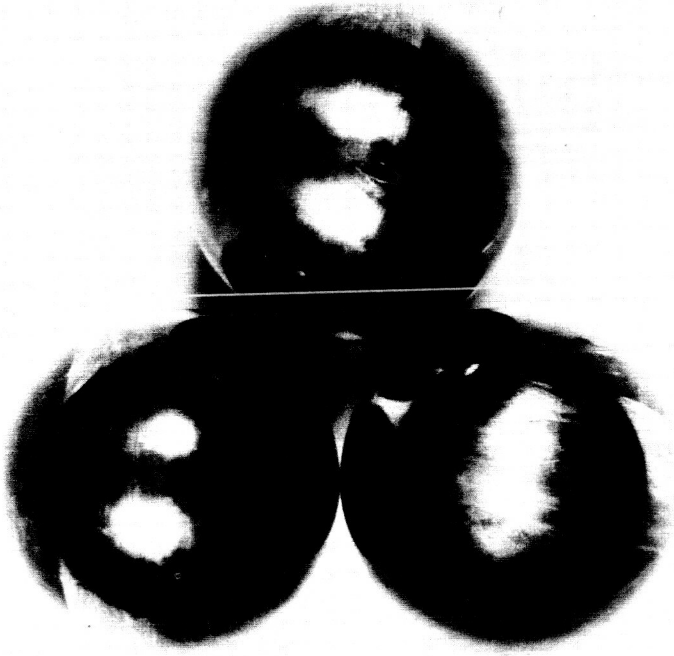


ENCLOSURE 27

TEST CAGE AND BALLS OF SECOND 600°F ESSO 4040 FAILURE IN RECIRCULATING RIG

Note Heavy Cage Wear and Wear on Balls





ENCLOSURE 28

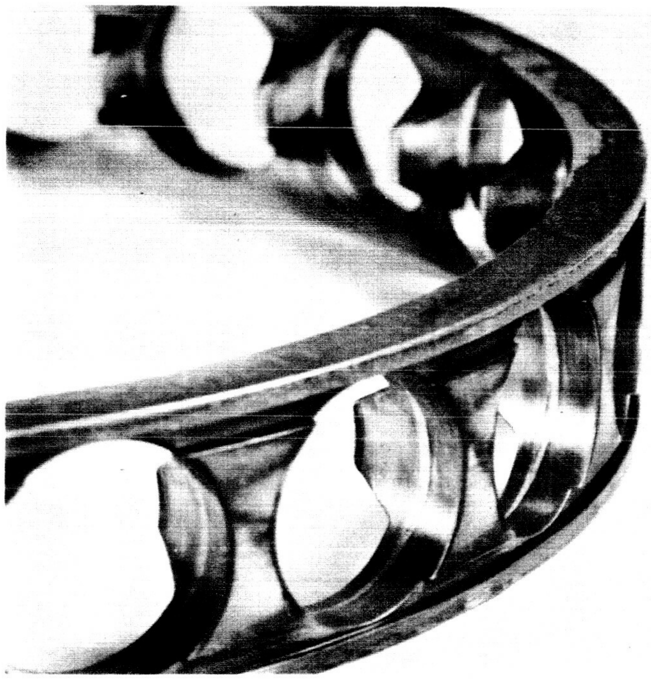
TEST INNER AND OUTER RINGS AFTER 600°F MOBIL XRM 177F SCREENING TEST IN RECIRCULATING RIG

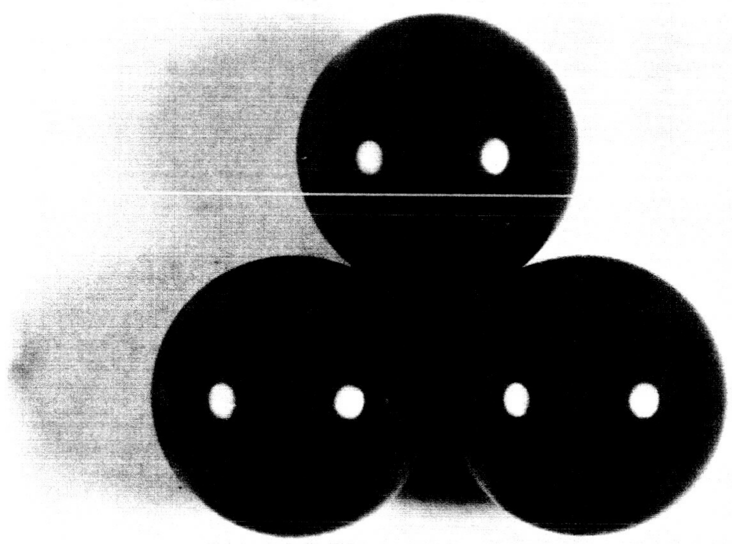
Note Good Condition With Slight Cage Land Wear On Outer Ring

ENCLOSURE 29

TEST CAGE AND BALLS AFTER 600°F MOBIL XRM 177F
SCREENING TEST IN RECIRCULATING RIG

Note Light Cage Wear and Balls With Duliting Intact

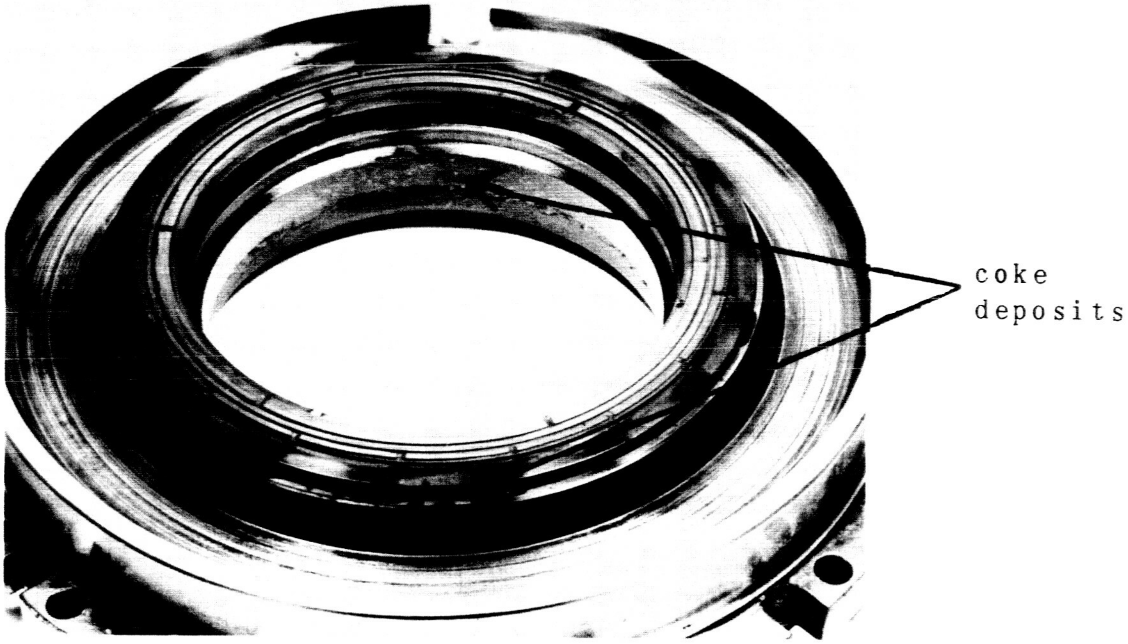


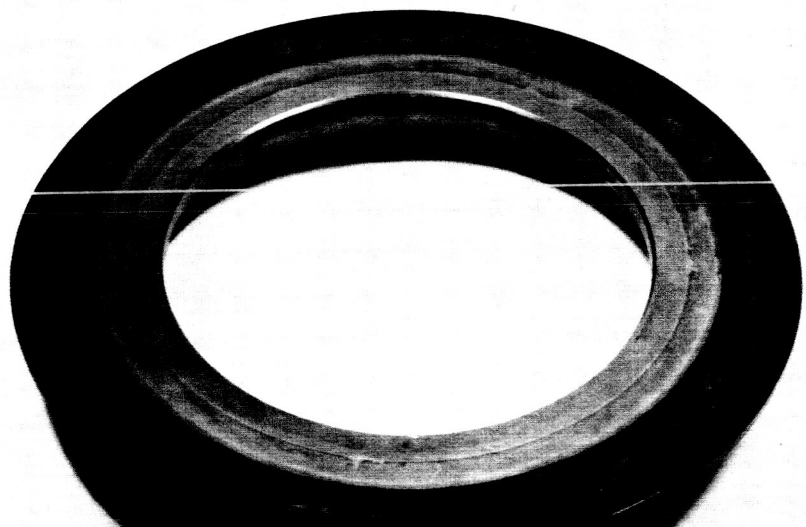


ENCLOSURE 30

OIL SEAL AND RUNNER AFTER 600°F MOBIL XRM 177F SCREENING TEST IN RECIRCULATING RIG

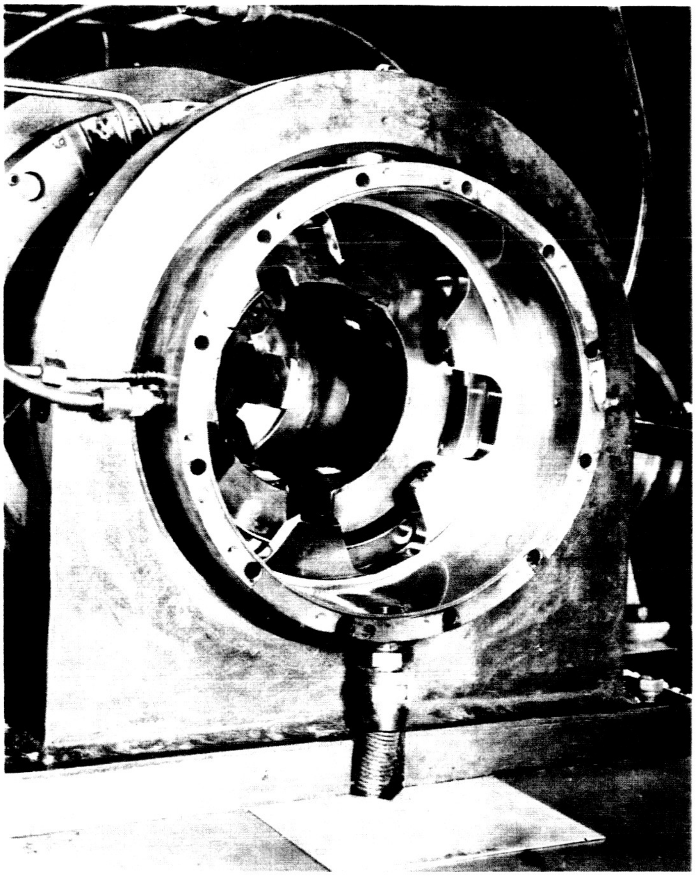
Note Evidence of Coking On Seal And Damage to Runner
(depth of damage about 0.001")





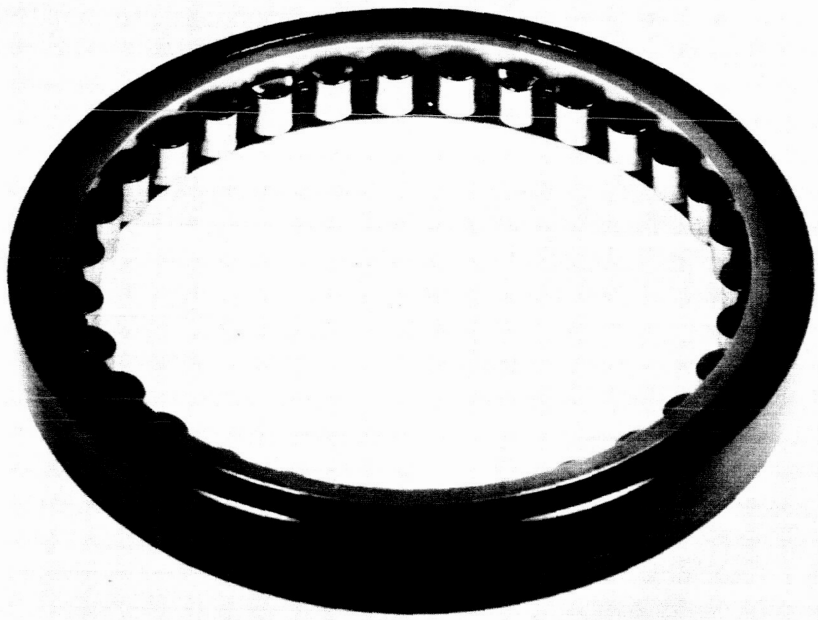
ENCLOSURE 31

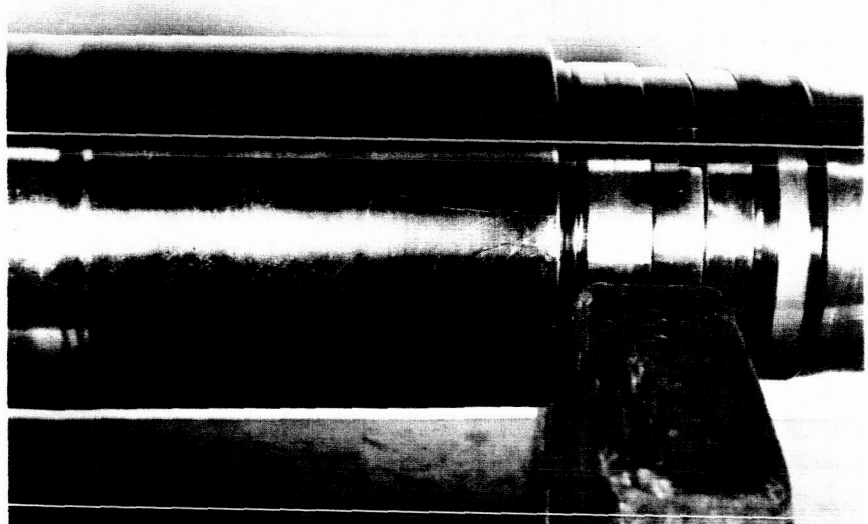
RECIRCULATING RIG AFTER 600°F SCREENING TEST WITH SINCLAIR TURBO S



ENCLOSURE 32

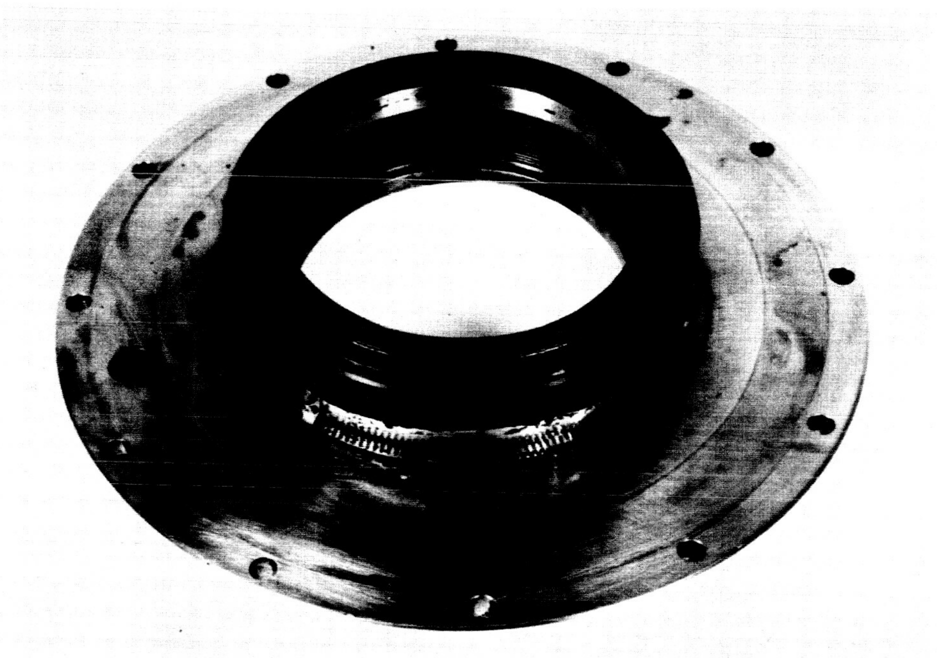
ROLLER BEARING AND SHAFT (WITH ROLLER BEARING INNER RING)
AFTER 600°F SINCLAIR TURBO S SCREENING TEST IN RECIRCULATING RIG

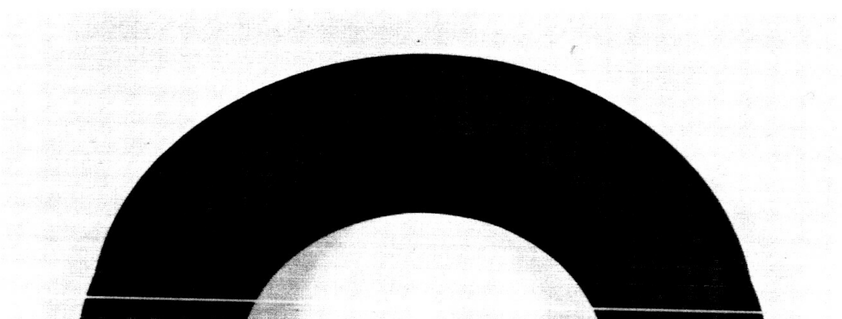




ENCLOSURE 33

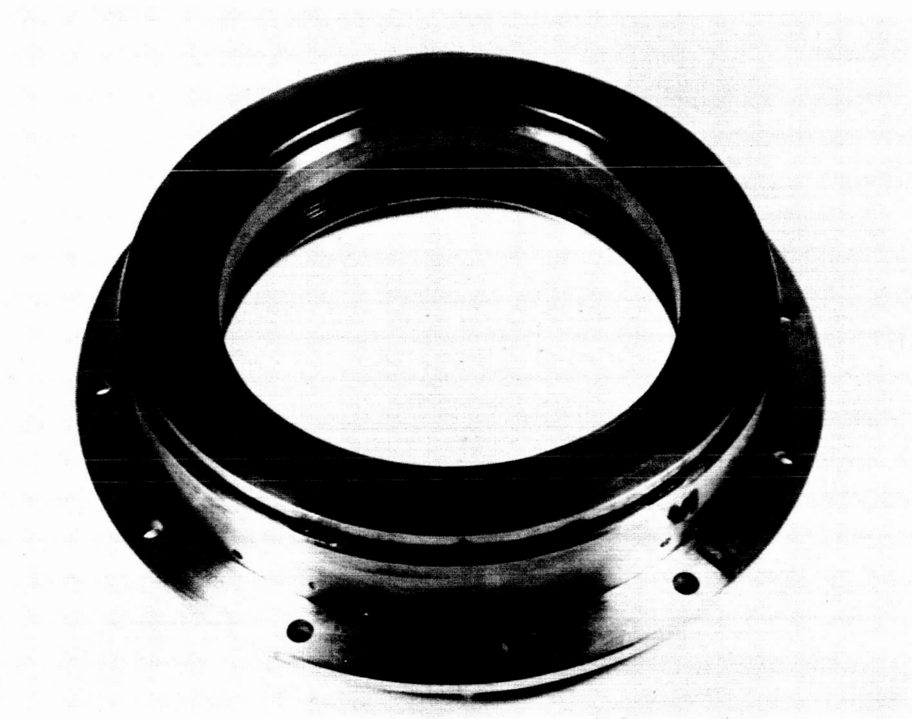
RIG SEAL AND RUNNER AFTER 600°F SINCLAIR TURBO S SCREENING TEST IN RECIRCULATING RIG

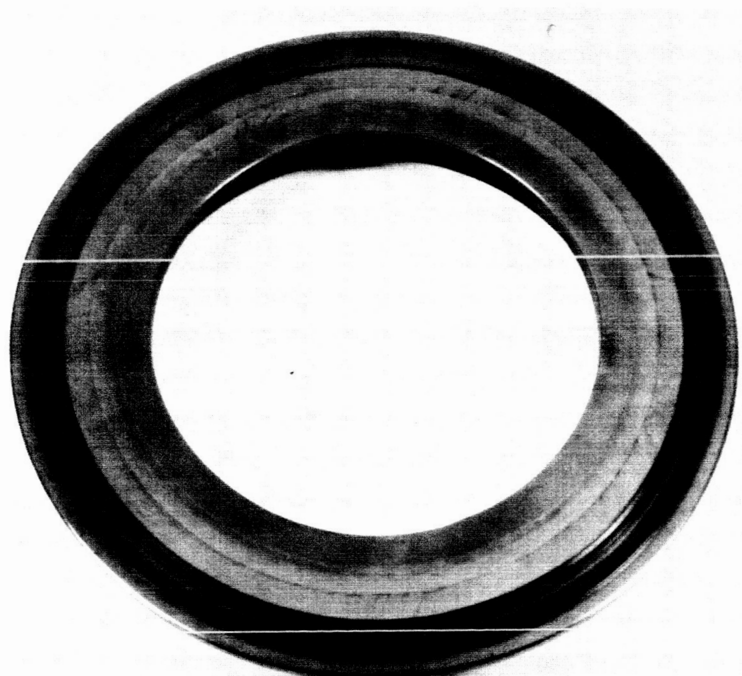




ENCLOSURE 34

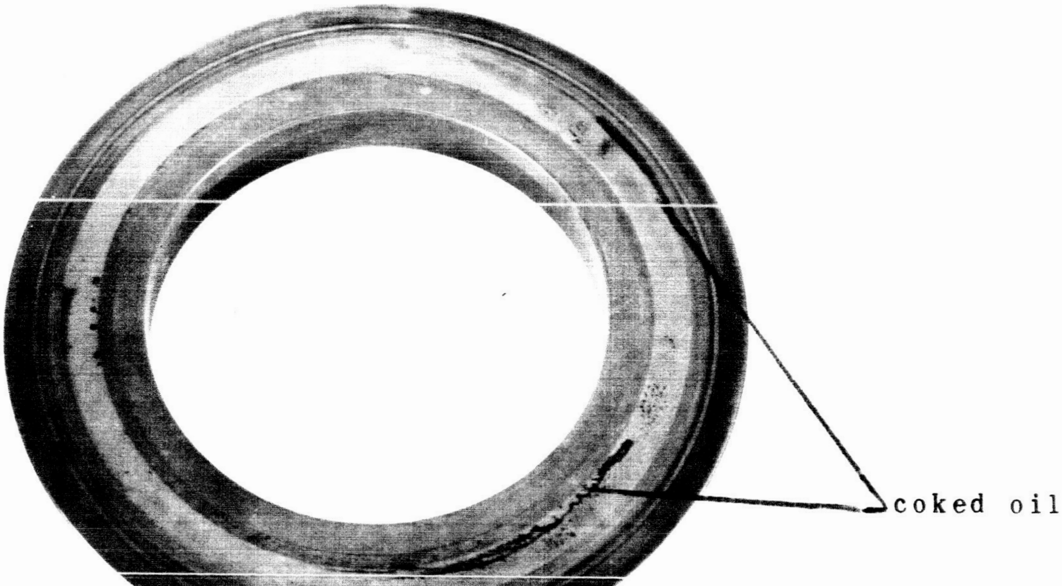
OIL SEAL AND RUNNER AFTER 600°F SINCLAIR TURBO S SCREENING TEST IN RECIRCULATING RIG





ENCLOSURE 35

AIR SEAL AND RUNNER AFTER 600°F SINCLAIR TURBO S SCREENING TEST IN RECIRCULATING RIG



ENCLOSURE 36

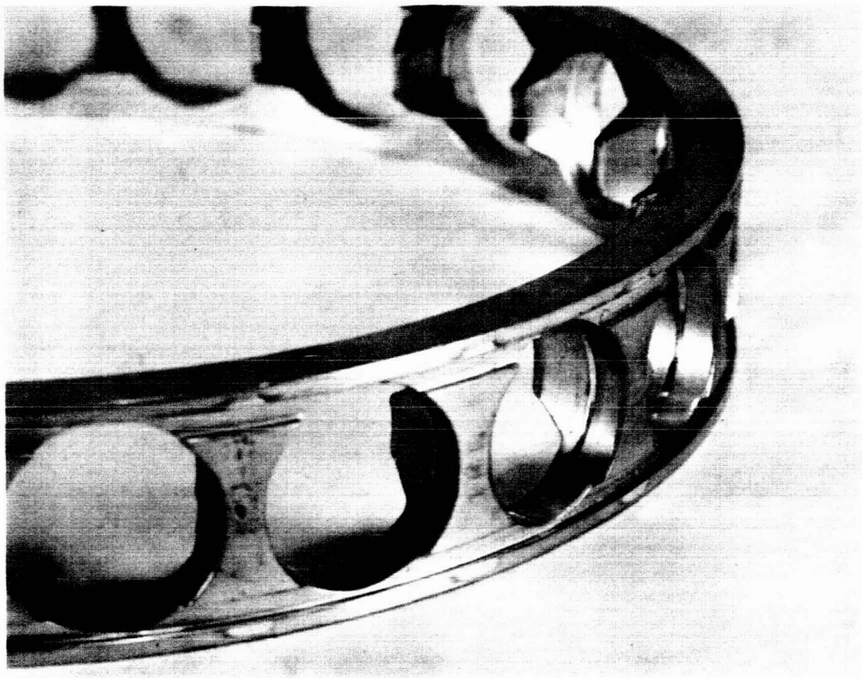
TEST INNER AND OUTER RINGS AFTER 600°F SINCLAIR TURBO S SCREENING TEST IN RECIRCULATING RIG

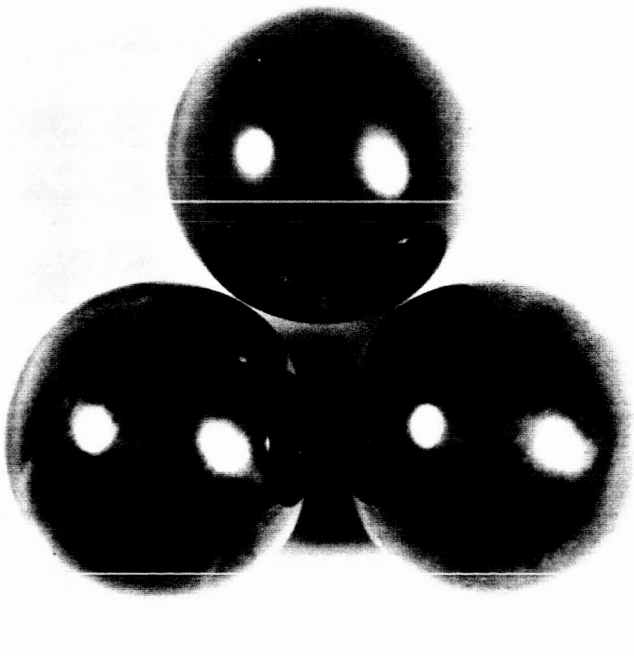
The Marks are Discolorations Most Likely Due to Oil Lying on the Hot Surface as the Rig Cooled After Shutdown

ENCLOSURE 37

TEST CAGE AND BALLS AFTER 600°F SINCLAIR TURBO S SCREENING TEST IN RECIRCULATING RIG

Note the Slight Cage Wear and Good Appearance of The Balls





ENCLOSURE 38

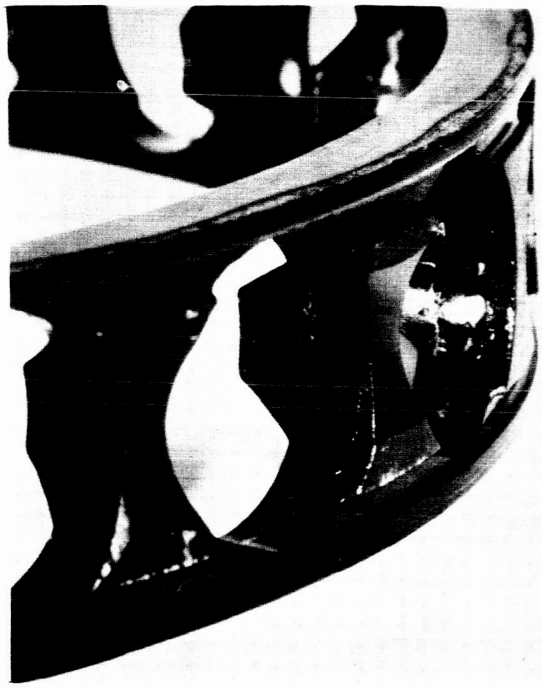
TEST INNER AND OUTER RINGS AFTER 600°F FAILURE
IN RECIRCULATING RIG USING MONSANTO MCS-293 UNDER A NITROGEN BLANKET

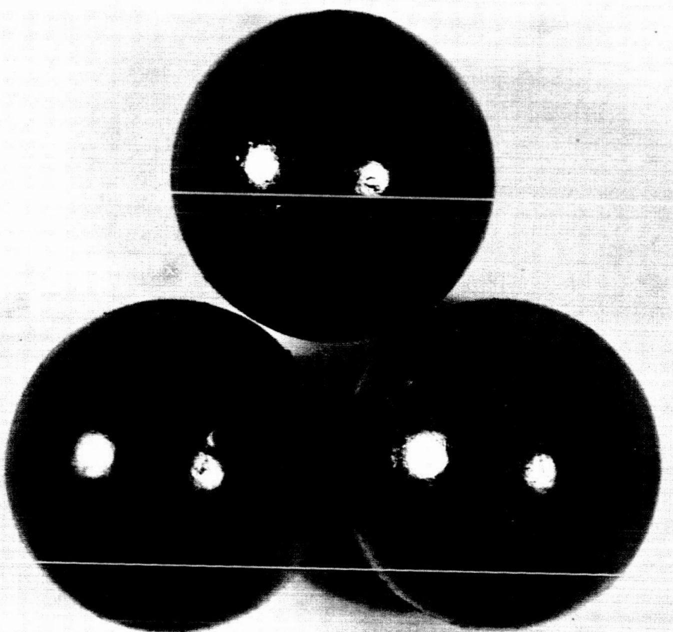
Note Severe Damage

ENCLOSURE 39

TEST CAGE AND BALLS AFTER 600°F FAILURE IN RECIRCULATING RIG USING MONSANTO MCS-293 UNDER A NITROGEN BLANKET

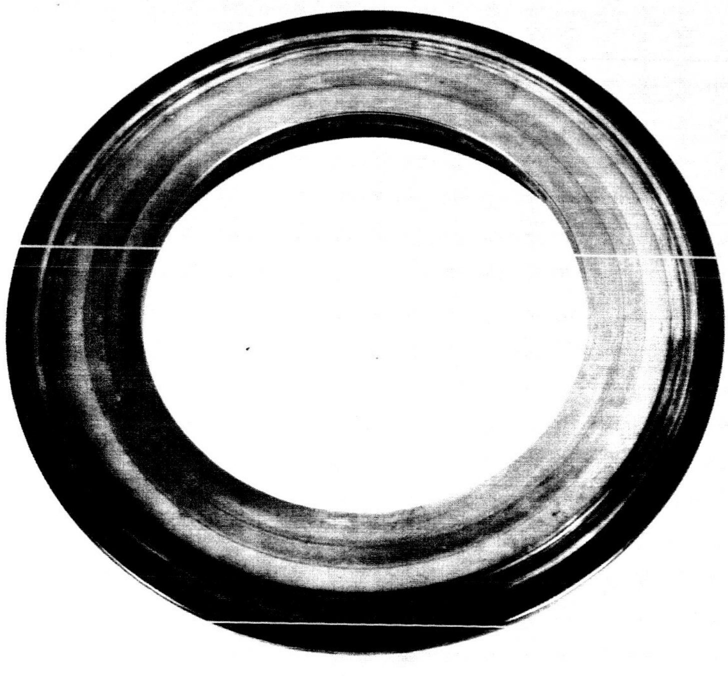
Note Severe Wear in Cage Pockets and Outer Land and **Poor** Ball Condition





ENCLOSURE 40

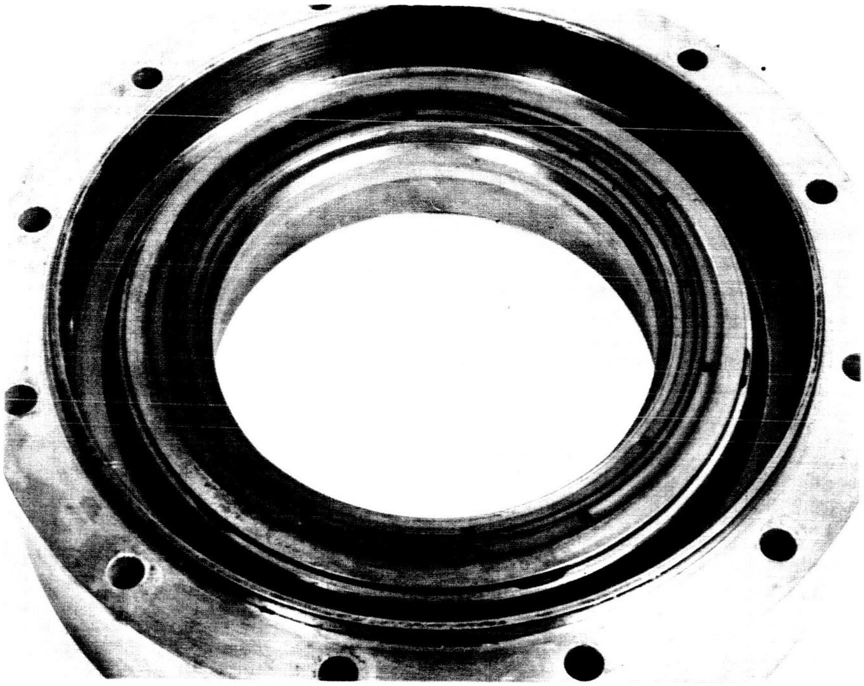
OIL SEAL AND RUNNER AFTER 600°F MONSANTO MCS-293 TEST UNDER NITROGEN BLANKET IN RECIRCULATING RIG

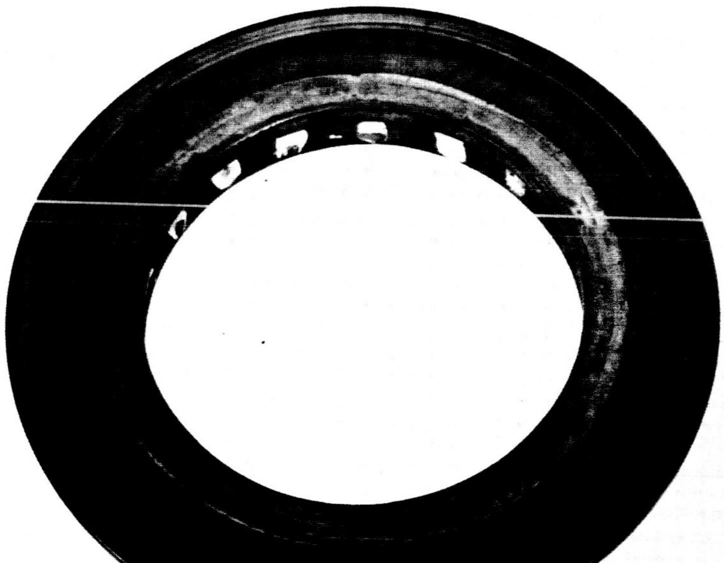


ENCLOSURE 41

AIR SEAL AND RUNNER AFTER 600°F MONSANTO MCS-293
TEST UNDER NITROGEN BLANKET IN RECIRCULATING RIG

Marks on ID of Runner Are Temperature Sensitive Paints





ENCLOSURE 42

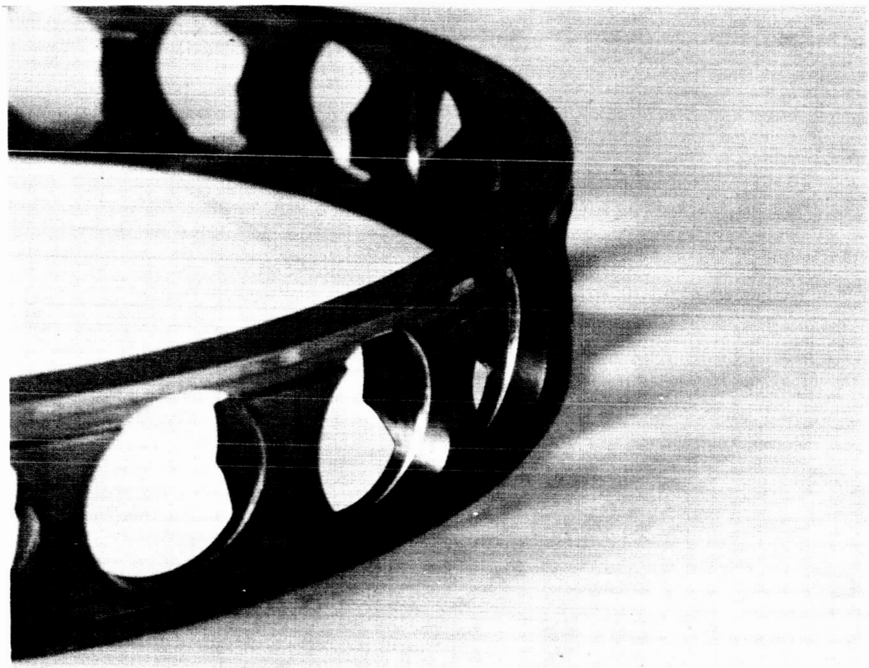
TEST INNER AND OUTER RINGS AFTER 600°F MONSANTO MCS-293 OPEN ATMOSPHERE SCREENING TEST IN RECIRCULATING RIG

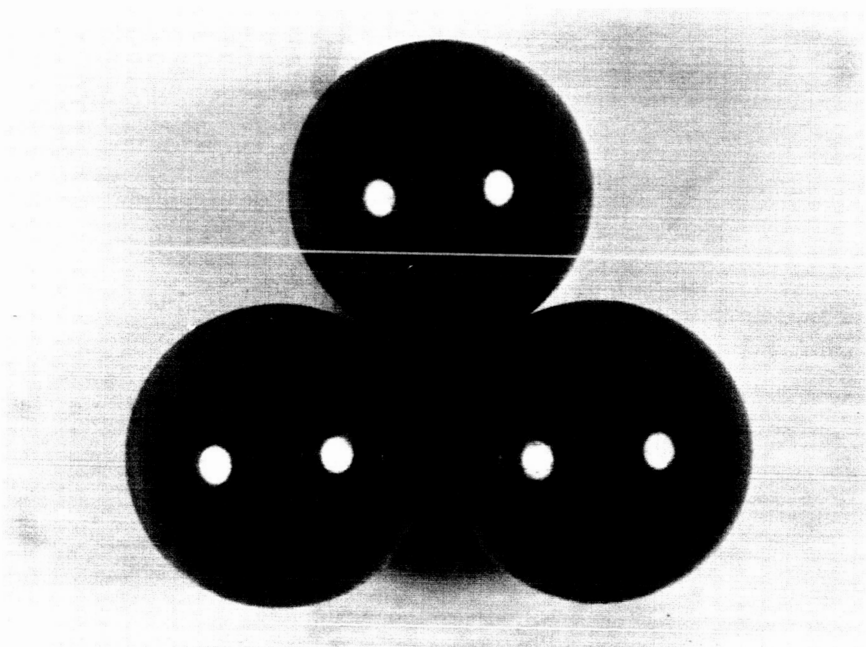
Marks are Discolorations and Not Surface Distress

ENCLOSURE 43

TEST CAGE AND BALLS AFTER 600°F MONSANTO MCS-293
OPEN ATMOSPHERE SCREENING TEST IN RECIRCULATING RIG

Note Moderate Cage Pocket Wear and Good Condition of Balls

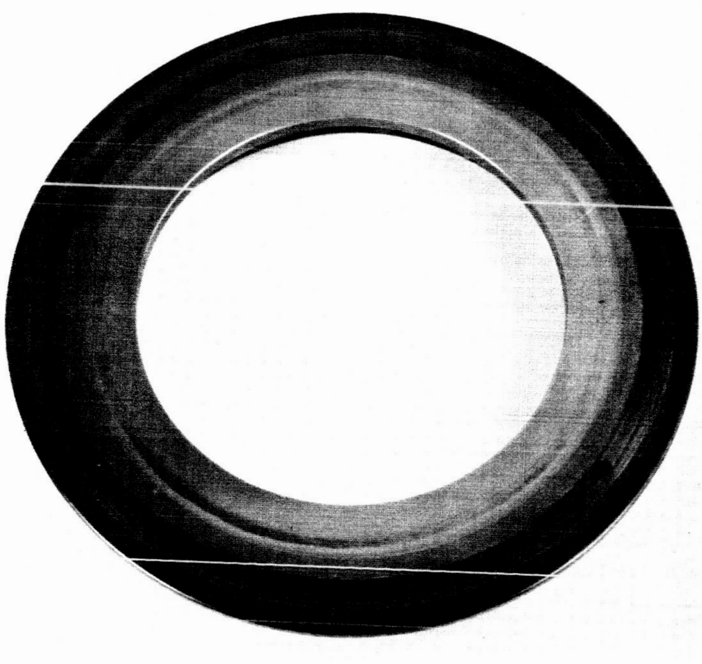




ENCLOSURE 44

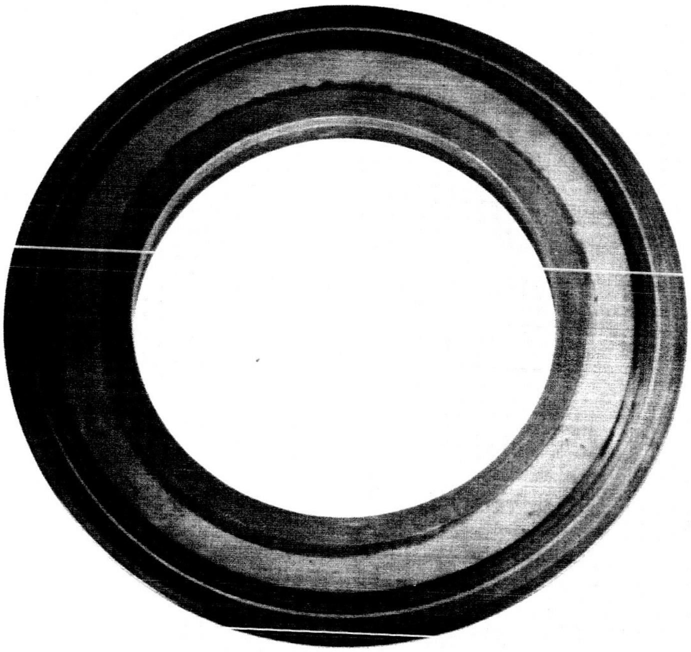
OIL SEAL AND RUNNER AFTER 600°F MONSANTO MCS-293
OPEN ATMOSPHERE SCREENING TEST IN RECIRCULATING RIG

Note Some Distress on Runner



ENCLOSURE 45

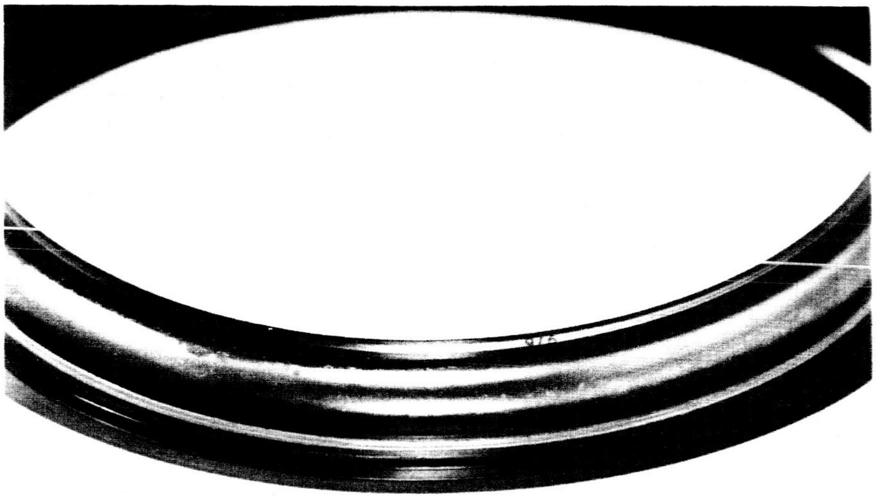
AIR SEAL AND RUNNER AFTER 600°F MONSANTO MCS-293
OPEN ATMOSPHERE SCREENING TEST IN RECIRCULATING RIG



ENCLOSURE 46

TEST INNER AND OUTER RINGS AFTER FAILURE IN MIST RIG USING ESSO 4040

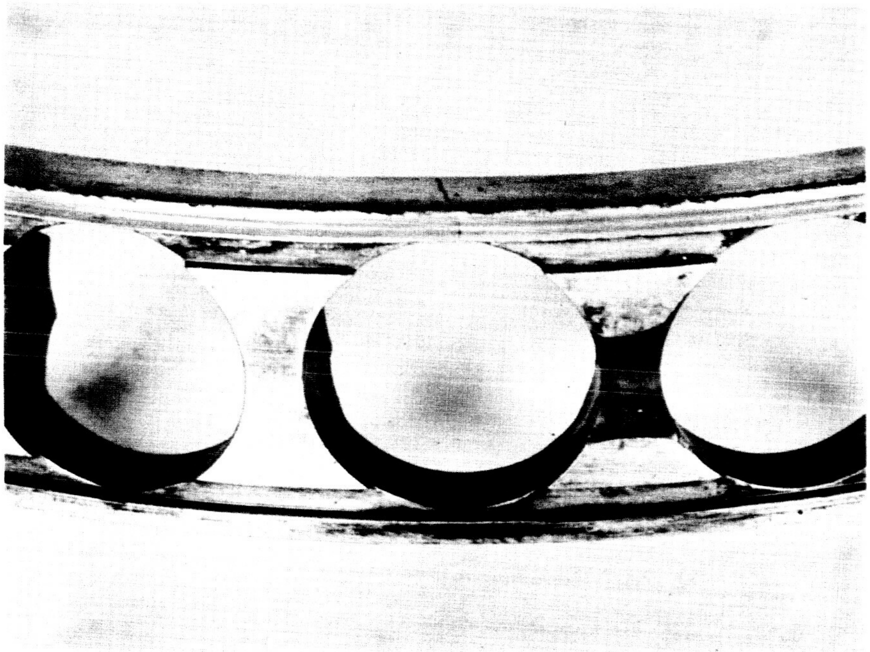
Note Severe Land Wear on Outer Ring

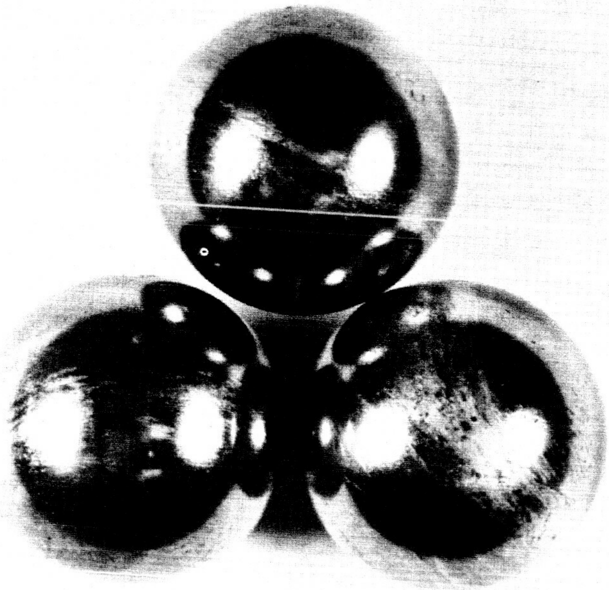


ENCLOSURE 47

TEST CAGE AND BALLS AFTER FAILURE IN THE MIST RIG USING ESSO 4040

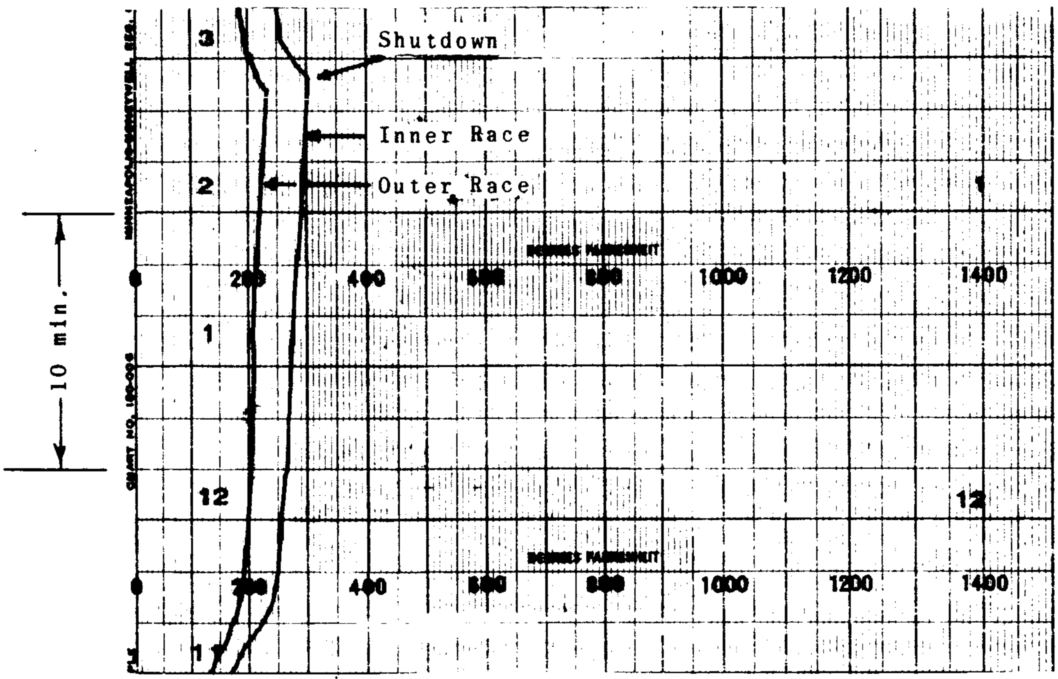
Note Severe Cage Land Wear and Crack in Rail

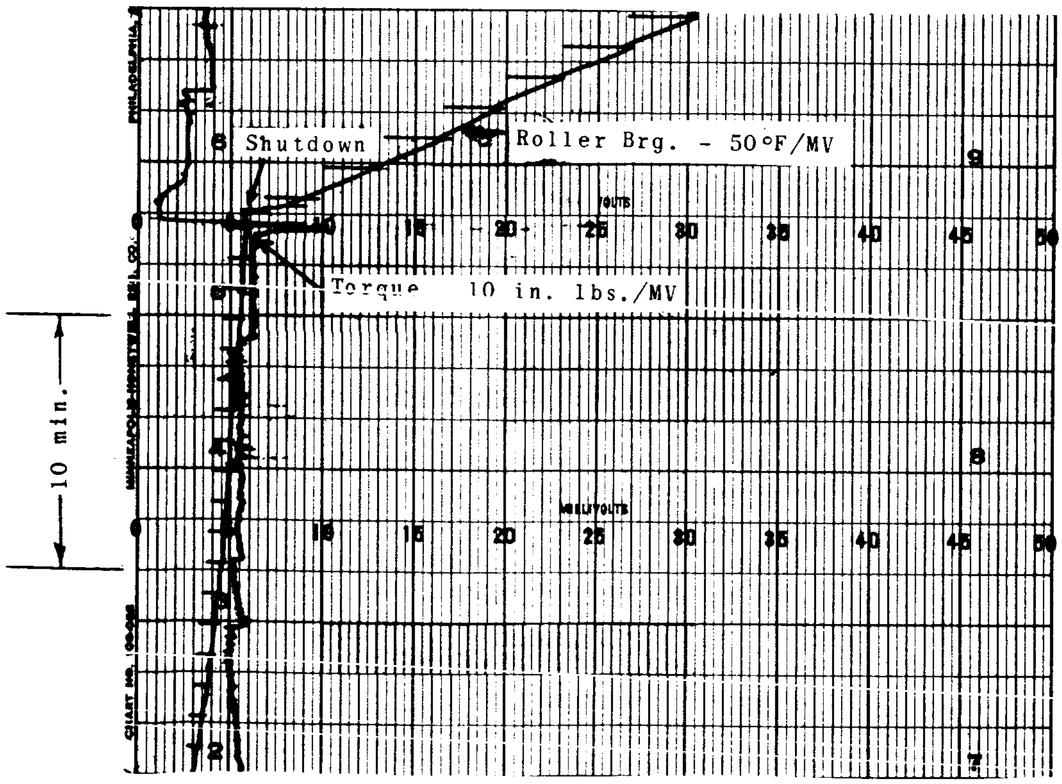




ENCLOSURE 48

PEN-CHART RECORD OF BEARING TEMPERATURES AND TORQUE IN OIL-MIST RIG TEST NO. 2 WITH ESSO 4040

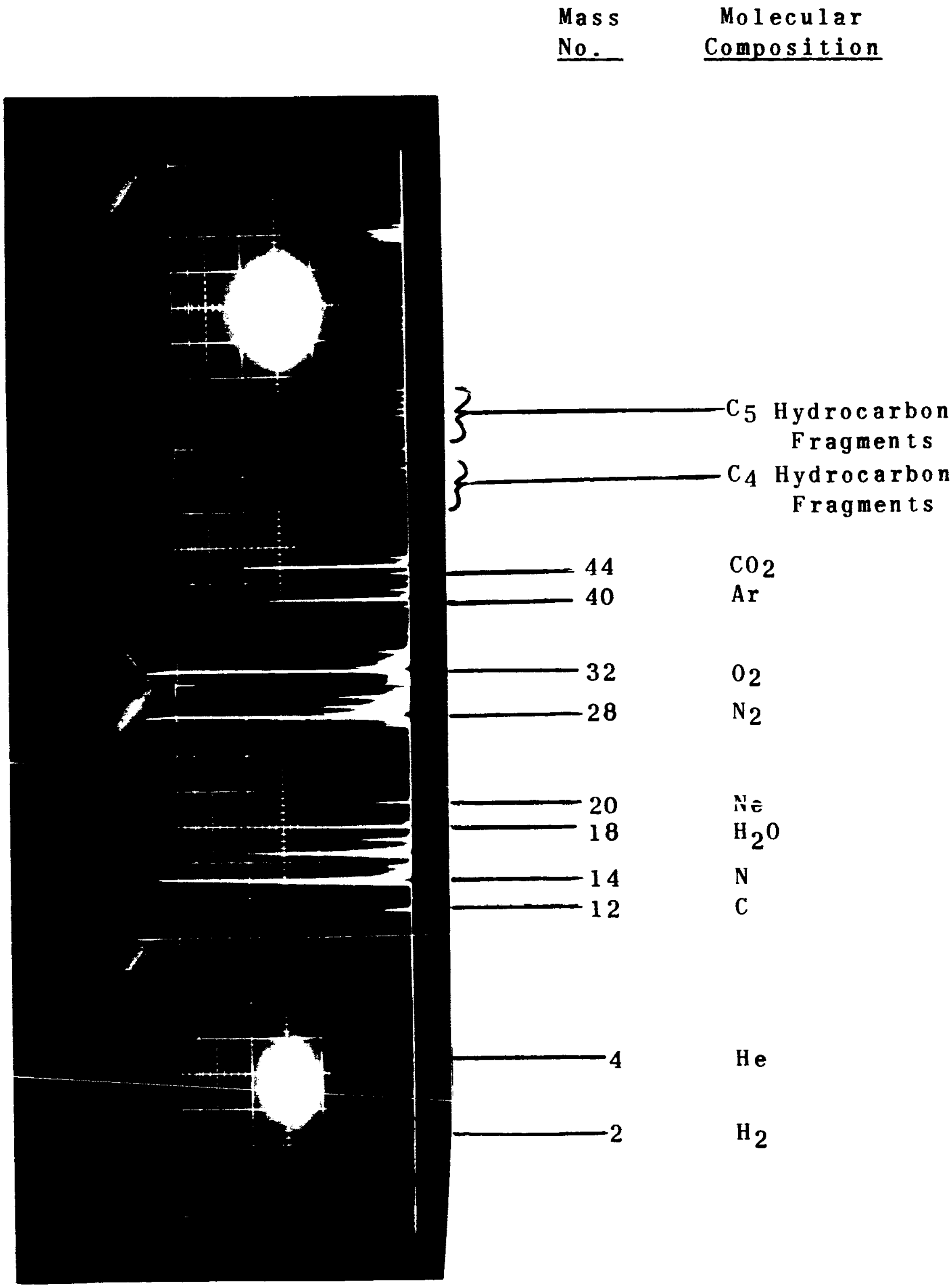




ENCLOSURE 49

OSCILLOSCOPE TRACE OF MASS SPECTROMETER ANALYSIS OF TEST BEARING CHAMBER ATMOSPHERE IN SCREENING TEST OF MCS-293 IN AIR

BENDIX MODEL 12-101A SPECTROMETER
FLIGHT TUBE PRESSURE AT SOURCE END, 5×10^{-5} TORR
IONIZATION VOLTAGE, 70 ELECTRON VOLTS
MULTIPLIER VOLTAGE SETTING NO. 4



ENCLOSURE 50

SUMMARY OF SCREENING TEST RESULTS

(FULL TEST CONDITIONS, EXCEPT WHERE NOTED)

System	Oil	Oil Flow Rate, gpm	Time at Test Conditions, hours	Oil Inlet Temp., °F	Test Bearing Outer Ring Temp., °F	Total Seal Leakage Rate, scfm	Conditions at End of Test Period			Reason for Test Termination	Test Conclusion and Recommendations
							Oil	Test Bearing	Test Seals		
Recirculating N_2 Blanket	Esso 4040	4 to 5	1.8*	500 to 555	590 to 600	1.5 to 10	Darkened, acid number very high	Considerable glazing, heavy cage pocket wear	Air seal scored by particles from heater; oil OK	Test brg. failure	Lubricant not suitable for 600°F brg. operation - do not test @ higher temp.
	Socony XRM-177F	1 to 4	3*	460 to 550	575 to 625	3 to 21	Acid number unchanged, viscosity increased somewhat	Excellent	Oil seal coked and worn from previous use; air seal OK	High seal leakage	Lubricant acceptable for 600°F bearing operation; test @ next higher temperature
	Sinclair Turbo S-1048	0.5 to 1	3.3*	480 to 500	590 to 625	6 to 8	Somewhat darker, acid number unchanged	Excellent	Oil seal leakage due to incorrect dam position in manufacture; air seal OK	Time-up*	Lubricant acceptable for 600°F bearing operation - test @ next higher temperature
	Monsanto MCS-293	0.5 to 1	1	480 to 500	580 to 600	<1	Dark particles; properties unchanged	Outer ring badly flaked cage pockets worn	Excellent	Test Brg. failure	Insufficient oil for adequate cooling flow; test @ next higher temperature with higher oil flow
Recirculating Open Atmosphere	Monsanto MCS-293	1	3.2	500 to 525	590 to 620	2 to 12	Dark particles; viscosity increased somewhat; acid No. unchanged	Excellent	Oil seal somewhat scored; air seal OK	Time-up	Suitable for testing @ next higher temperature
Mist N_2 Blanket	Esso 4040	Approx. 0.04 lbs. per.min.	None	-	260	5 to 10	-	Severe damage in cage land-outer ring contact	Air seal scored by particles from air heater	Test brg. failure	Modify lubricant delivery and re-test

*This denotes tests where there were minor deviations of temperatures other than the test bearing from full test conditions (i.e. test bearing housing, hot air, etc.). See Appendix II for additional details.

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