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FINAL REPORT ON

DESIGN, FABRICATION, AND OPERATION OF A TEST RIG FOR HIGH – SPEED TAPERED – ROLLER BEARINGS

by

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prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Contract NAS 3-16812
R. J. Parker, Project Manager

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Project Manager, Richard J. Parker, Fluid System Components Division, NASA Lewis Research Center, Cleveland, Ohio 44135

16. Abstract

A tapered-roller bearing test machine was designed, fabricated and successfully operated at speeds to 20,000 rpm. Infinitely variable radial loads to 26,690 N (6,000 lbs.) and thrust loads to 53,380 N (12,000 lbs.) can be applied to test bearings having a bore of 120.65 mm (4.750") and an outside diameter ranging from 174.62 to 206.38 mm (6.875" to 8.125") and a maximum width of 47.63 mm (1.875").

The machine instrumentation proved to have the accuracy and reliability required for parametric bearing performance testing and has the capability of monitoring all programmed test parameters at continuous operation during life testing. This system automatically shuts down a test if any important test parameter deviates from the programmed conditions, or if a bearing failure occurs.

A lubrication system was developed as an integral part of the machine, capable of lubricating test bearings by external jets and by means of passages feeding through the spindle and bearing rings into the critical internal bearing surfaces. In addition, provisions were made for controlled oil cooling of inner and outer rings to effect the type of bearing thermal management that is required when testing at high speeds.

All machine components and the lubrication system withstand maximum bearing ring temperatures to 505°K [450°F].

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1.0 SUMMARY & GENERAL MACHINE DESCRIPTION

The test machine L-197-1 accepts two tapered-roller test bearings of 120.65 mm [4.750 inch] bore with an outside diameter ranging from 174.62 to 206.38 mm [6.875 to 8.125 inch] and a maximum width of 47.63 mm [1.875 inch]. The machine is capable of operating from 6,000 to 20,000 rpm. Infinitely adjustable radial load from 0 to 26,690 N [6,000 lbs] and thrust load from 0 to 53,380 N [12,000 lbs] can be applied in any combination to each test bearing assembly.

The test machine has its own lubrication system and is fully instrumented to evaluate bearing performance over a wide range of test parameters. The instrumentation system will shut down the test machine in the event of a bearing failure, or when the operating conditions deviate from those programmed, permitting test machine operation on a continuous basis over 24 hours per day, 7 days per week.

All machine components and the lubrication system withstand bearing ring temperatures to 505°K [450°F].

The following general design objectives have been met:

(1) Simplicity and Reliability:

Simplicity of the basic machine design and the selection of proven and rugged components provide reliable and uninterrupted machine operation over the full range of specified loads, speeds and temperatures.

(2) Machine Versatility:

The machine accepts a variety of test bearing designs and mounting arrangements. It is anticipated that the majority of tests will be conducted with single-row bearings at each of the two test heads. However, the machine is capable of accepting bearing pairs as well as double row bearings (double cones or double cups) at each test head.

(3) Bearing Lubrication:

Provisions have been made to lubricate the test bearings with external jets or through annuli and holes at the spindle, feeding into the critical internal working surfaces of the bearings; or with a combination of these methods.

(4) Bearing Cooling:

Bearing inner ring and outer ring cooling was provided, which is essential for thermal management at high-speed operation of tapered-roller bearings. The rate of cooling oil flow to the inner and outer rings is independently adjustable so that low temperature gradiants across the test bearings can be achieved. The oil flow rates are individually measured without interrupting the machine operation.

(5) Machine Instrumentation:

The machine instrumentation system meets the accuracy required for parametric performance testing as well as the reliability to maintain all programmed test conditions for life testing. This system continuously monitors the performance of the test machine and shuts it down automatically if any of the important test

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parameters deviate from the programmed operating conditions.

(6) Bearing Installation:

Easy and reliable test bearing installation and removal is of particular importance for a bearing test machine. Applying pressure through the rolling elements to disassemble the bearings from the rig is not adviseable. Therefore, the test machine L-197-1 has, as an integral part of its design, a hydraulic push-off mechanism for removal of the test bearings from the shaft. The push-off force is applied by the thrust load actuators and acts directly against the test bearing inner race.

The completed machine was subjected to a demonstration test sequence which included a full range of loads and speeds of the design specification. Throughout these tests the machine operated satisfactorily. At 20,000 rpm some vibration was observed under a radial load condition. This is being further investigated.

Throughout the tests all operating parameters remained stable. All subsystems and instruments performed reliably and met all specified requirements.

2.0 INTRODUCTION

Industrial Tectonics, Inc. has designed fabricated and tested a machine which is capable of performance and fatigue testing high-speed tapered-roller bearings. This work was conducted under NASA Contract NAS 3-16812 and was concluded within a 15 month program duration.

Tapered-roller bearings are being considered for highly loaded helicopter transmissions such as the HLH currently being developed by the U.S. Army. To support the heavy loads imposed, ball and roller bearings can no longer be applied without incurring sizeable weight and load penalties. Because they have higher load carrying capabilities than ball and roller bearing combinations of equal size, tapered-roller bearings are now being used successfully in helicopter transmissions operating at moderate speeds up to 800,000 DN. (DN, a bearing speed parameter, is equal to the product of bearing bore in millimeters and the shaft speed in rpm).

Future generations of helicopter transmissions and similar high performance applications will require bearings which can operate reliably at speeds in the 2 million DN range in order to meet the size and weight limits imposed on aircraft transmissions. It will be necessary to conduct extensive research and test programs to arrive at tapered-roller bearing designs and lubrications schemes for sustained operation at these anticipated speeds, under heavy loads, and at elevated temperature conditions. The test machine described in this report has been developed to serve this purpose, and it will be an indispensible tool in such bearing research work.

Since 1966 Industrial Tectonics, Inc. has been actively engaged in the design, development and building of high-speed bearing test machines and has conducted extensive bearing performance and long life endurance test programs in its laboratories. The experience gained in these efforts has been an important contributing factor in the development of the tapered-roller bearing test machine. This experience has been valuable not only in developing the basic machine concept, but also in arriving at a design which is easy to service and trouble free in operation, and in developing the instrumentation which is critical in research and test efforts where the prime function is to accurately detect and interpret the data produced.

3.0 TEST RIG DESIGN

The machine, illustrated in figures 1 through 6, consists of the following major components:

- Machine frame
- Test head assembly
- Drive system
- Load system
- Lubrication system
- Instrumentation and controls

3.1 Machine Frame (Reference drawings, L-197-26,-33W)

Large section, rectangular tubes were chosen for all major beams of the welded frame structure. The cross beams were machined to accept precisely aligned, hardened and ground ways which in turn carry the test head assemblies. The frame layout allows easy access to all components of the lubrication and load systems. A separate frame component (L-197-32W) which serves as drive motor base is bolted to the main frame. The control panel frame is an independent weldement (L-197-27) connected to the main frame by shock absorbing mounts.

3.2 Test Head Assemblies (Reference drawings L-197-2,Figs. 1 and 2)

Each of the two test bearing heads accepts a single tapered-roller test bearing of 120.65 mm [4.750 inch] bore with an outside diameter ranging from 174.62 to 206.38 mm [6.875 to 8.125 inch] and a maximum width of 47.63 mm [1.875 inch]. By exchanging the outer ring adapters any bearing may be mounted within this size range, or bearing pairs which agree with the specified size ranges may be installed. Double row bearings having double cones or double cups may be used in place of single test bearings. The layout of the test heads permits full instrumentation of the test bearings and segregation of the individual lubricant flow paths. Test bearing removal from the shaft is assisted by a mechanism that utilizes the thrust load actuators to push off the test bearing inner raceways.

One end of the tubular test spindle (L-197-13) is open for fluid introduction for inner ring cooling and lubrication. The other end accepts a drive pulley for the high-speed belt drive. Contoured inserts with annular grooves or channels are fitted to the spindle bore. These channels lead to radial oil passages for test bearing and load bearing lubrication and/or inner ring cooling.

The outer ring adapter sleeves (L-197-108) are provided with passages for coolant flow to the test bearing outer rings.

Heat treated alloy steels were used for the test spindle and the outer race adapter rings. All bearing seats were hard chrome plated and ground. The test bearing housings and the frame structures are of carbon steel. The non-contacting shaft seals at the drive belt end and the center (load) housing were manufactured of an abradable aluminum alloy.

3.3 Drive System (Reference drawing L-197-1, -30)

A flat belt drive of proven reliability is used to drive the test spindle. The fixed speed 75 KW [100 HP] electric motor (3,600 rpm, 460 V, 3 phase) is controlled by a reduced voltage starter. The start-up voltages of 50,65,80 and 100% permit selection of the test spindle acceleration rate during start-up. A total of five drive pulleys are furnished to operate the test spindle at speeds of 6,000; 10,000; 12,500; 15,000 and 20,000 rpm. The above spindle speeds are chosen by exchanging the drive pulleys. The flat belt is guided by an idler pulley arrangement which maintains a controlled pre-load on the slack side of the drive belt. An eccentric device at the drive motor base enables belt alignment adjustment under dynamic conditions.

3.4 Load Systems (Reference drawings L-197-3,-2,-25)

Thrust load is applied to the test bearings by a set of hydraulic actuators which form an integral part with the flange of one test bearing housing, pushing against the flange of the opposite housing. This static load is adjustable from 0 to a maximum of 53,380 N [12,000 lbs].

Radial load is generated by a hydraulic actuator which is located beneath the center of the test spindle. This load is transmitted to the spindle through a set of high-performance, jet-engine main-shaft roller bearings. The radial load applied to the test spindle is adjustable from 0 to 53,380 N [12,000 lbs], thus, if one test bearing is used in each chamber the maximum radial load will be 26,690 N [6,000 lbs] per bearing.

The hydrualic system pressures are controlled by air pressure regulators and air to oil pressure boosters. The accumulators which are part of each oil pressure loop provide for stable pressures and easy control.

3.5 Lubrication System (Reference drawing L-197-3)

The lubrication system is compatible with advanced ester and synthetic hydrocarbon fluids for bearing operation up to 505°K [450°F]. Any practical scheme for test bearing lubrication and cooling can be adapted to this system.

Variable flow control valves are furnished for the lubricant loops supplying the outer ring adapters (jet lubrication and/or outer ring cooling). The previously described annular grooves in the spindle bore permit proportioning of the oil flow supplied to the bore, and various ratios of cooling to lubricant oil flow can be chosen by selecting the supply line orifices. The total lubricant flow to all loops is adjustable from 0 to 7.57×10^{-4} m^3/sec. [12 GPM] with manifold pressures up to 5.5×10^5 N/m^2 [80 psi]. The heat exchanger was dimensioned for test bearing operation at temperatures as low as 395°K [250°F], at maximum speed and load conditions. A high capacity 10 micron filter, flow and level switches, relief valves and pressure gages protect the hydraulic circuit. The oil return lines from the test chambers are dimensioned for gravity flow.

The controls for the pump drive include the standard safety features as well as a time delay which will automatically maintain pump operation during automatic machine shut down. In this case, the pump operates and supplies lubricant to the test bearings until the spindle has come to a complete stop.

Stainless steeltubings were used throughout the hydraulic system and the oil-to-water heat exchanger. The oil tank, fittings and bodies of the hydraulic instruments are of steel. Heat resistant fluorocarbon rubber was specified for the static high temperature lubricant oil seals.

3.6 Instrumentation

3.6.1 Temperature Measurements

Thermocouples are installed for temperature measurements of each test bearing cup, both load bearing outer rings, and the oil inlet and outlets of each test head. The thermocouples are connected to a strip chart recorder which provides a permanent thermal log for all test stations. An adjustable high and/or low temperature shut-off relay is wired so that a test is terminated if bearing ring temperature limits are exceeded.

Test bearing cone-rib temperature is measured with an infra-red pyrometer,looking through an air purged sight tube assembly. Strategically located baffles at the inside end of this tube keep the optical path free from contamination by the lubricant oil. Provisions to measure cone-rib temperatures were made at the test head located opposite to the drive pulley end. Measurements are possible only when a single test bearing or a double-row bearing with a double cup is installed. For most reliable temperature measurement the cone-rib outer face must be grooved or recessed and treated for maximum infra-red emittance.

3.6.2 Instrumentation for Lubrication System

Flow control valves, in conjunction with a series of selector valves and a flow rate indicator are used to meter and measure oil flow through each lubricant loop. Pressure gages are connected to the pump outlet and the lubricant manifold. A flow switch and oil level switch shut off the test machine drive in case of a pump malfunction.

3.6.3 Measurement of Machine Vibration

The machine vibration level is measured with a piezoelectric accelerometer. The output from this transducer is displayed at the control panel as general vibration level. This instrumentation will automatically shut down a test when the machine vibration exceeds a predetermined value. The set point for this shut off is adjustable to adapt to the wide variety of test conditions expected for this machine.

3.6.4 Miscellaneous Instrumentation

The test head design and the selection of machine components permits the adaptation and connection of additional instruments at a later date. Such instrumentation, not part of this effort, may include proximity probes capable of measuring shaft excursion in two planes as well as shaft speed and test bearing separator speed. Meters to determine drive motor line voltage and current can also be incorporated to determine spindle power requirements.

4.0 DEMONSTRATION TESTS

The objective of the demonstration test program was to evaluate the machine performance, accuracy, and the reliability of its sub-systems and instrumentation. The test procedure, given in Appendix A, was followed. Five test phases were conducted.

Phase I - was designed to evaluate and calibrate the load systems, the instrumentation for the temperature recording and the lubrication systems.

All components were found to operate in accordance with the equipment specification. The load calibration curves and the various systems check-out data sheets are given in Appendix B. The methods used to calibrate axial and radial loads are shown in figures 7 and 8.

Phase II - served to evaluate the safety equipment and shut-down devices by functional tests. The tests are described on the data sheet, Appendix C.

All safety and shut-down systems operated satisfactorily and within tolerance.

Phase III - demonstrated the machine operation at low speed and high loads. Commercially available tapered-roller bearings were used (Timken, type TS, Cone: 795 class 3; Cup: 792 class 2).

The original test plan, as detailed in Appendix A, specified a 24 hour run at 6,000 rpm with 35,586 N [8,000 lbs] thrust and 13,345 N [3,000 lbs] radial load per bearing. The loads were then to have been increased and the machine operated for one hour with 53,380 N [12,000 lbs] thrust load and 26,690 N [6,000 lbs] radial load, which represent maximum machine design loads. The test bearing inner and outer ring temperatures were to have been held below 436°K [325°F].

Several attempts were made to conduct the above test. It was found that the commercial tapered-roller bearings could not be operated at the intended speed without suffering severe distress to the cone-rib and large roller ends.

In view of these difficulties the operating speed was reduced to 3,000 rpm. At this speed the machine and bearings operated smoothly without sign of distress to any component. The loads and all operating parameters remained stable and all sub-systems and instruments performed reliably. The data of this test sequence are given in Appendix D.

Phase IV - objective was to check the machine performance at high speeds, including the maximum design speed of 20,000 rpm, and at bearing operating temperatures of 483°K ± 8° [420°F ± 15°F]. Loads of 26,690 N [6,000 lbs] thrust and 4,448 N [1,000 lbs] radial were specified for this 25 hour test, as shown in Appendix A.

Presently there are no tapered-roller bearings available that operate reliably at this speed. The tests were thus performed with a set of high performance split inner-ring ball bearings. The performance data of these bearings was known from earlier investigations, reported in NASA TMS-68264 "Parametric Study of the Lubrication of Thrust Loaded 120 mm Bore Ball Bearings to 3 Million DN".

The machine was run at 6,000, 10,000, 12,500 and 15,000 rpm before attempting the 20,000 rpm tests. At each speed all operating temperatures were stabilized and performance data collected before proceeding to the next higher speed. Some difficulties were encountered at 20,000 rpm where a high vibration level was measured as soon as radial load was applied. A future investigation should reveal whether the source of this characteristic lies in the performance of the radial roller load-bearings or is a natural frequency phenomenon of the test head assembly.

With NASA concurrance, the test requirements were slightly modified: The machine was operated for 15 hours at 15,000 rpm at 26,690 N [6,000 lbs] thrust and 4,448 N [1,000 lbs] radial load. Subsequently, the machine was run for 10 hours at 20,000 rpm under 27,690 N [6,000 lbs] thrust load and zero radial load. This test was run with the radial load bearings removed. During all high-speed tests an inner and outer race temperature of 490°K $\pm$ 8° [420°F $\pm$ 15°F] was achieved and maintained. Test data of this sequence are given in Appendix E.

Throughout the described tests the machine operated smoothly without any sign of distress to any of its components. The loads and all operating parameters remained stable. All sub-systems and instruments operated reliably.

Phase V - consisted of the machine disassembly for the purpose of inspection.

All machine components were in good condition and showed no sign of distress or operating malfunction.

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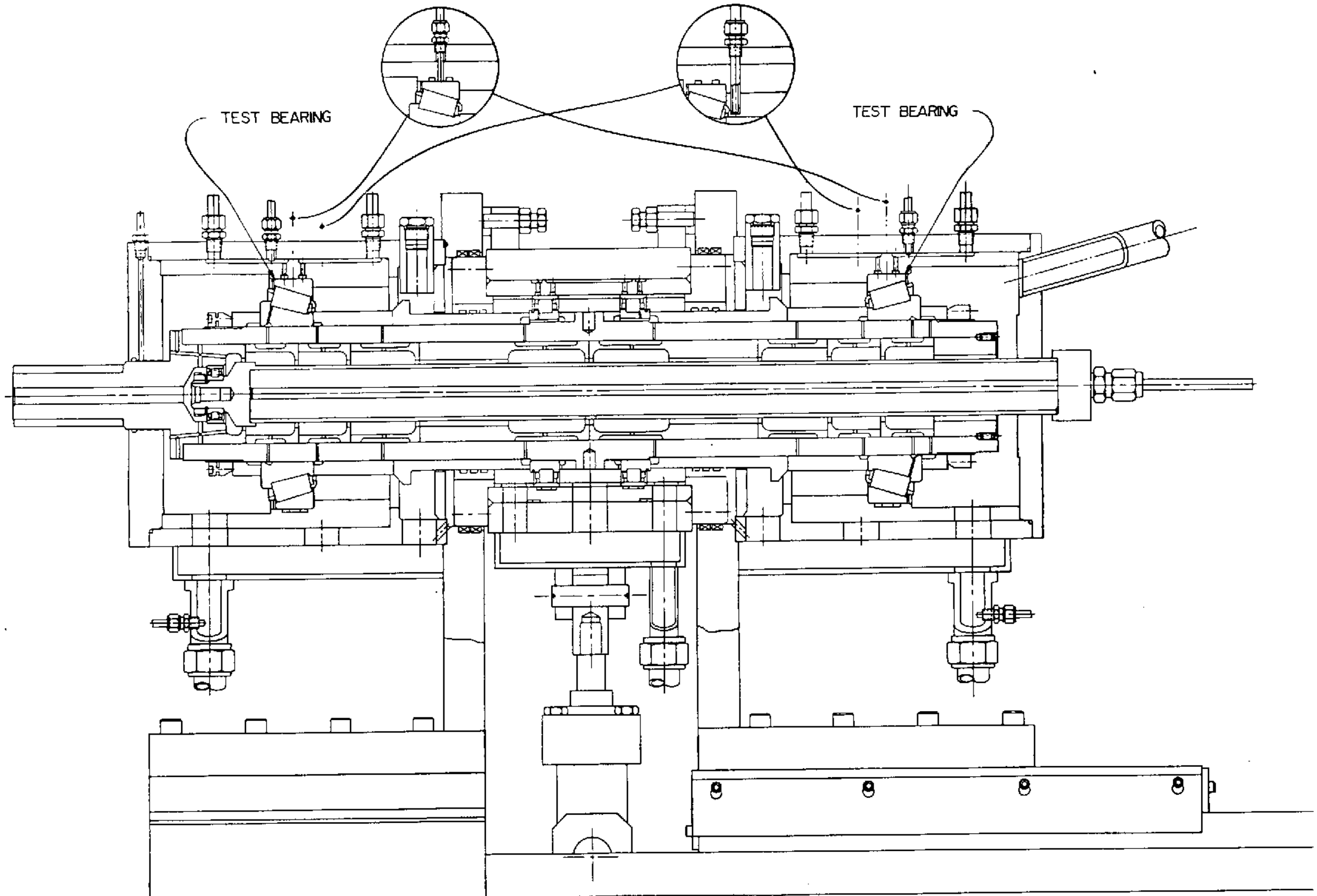


TAPERED-ROLLER BEARING TEST MACHINE
L-197

Figure -1-

INDUSTRIAL TECTONICS, INC., RESEARCH AND DEVELOPMENT DIVISION

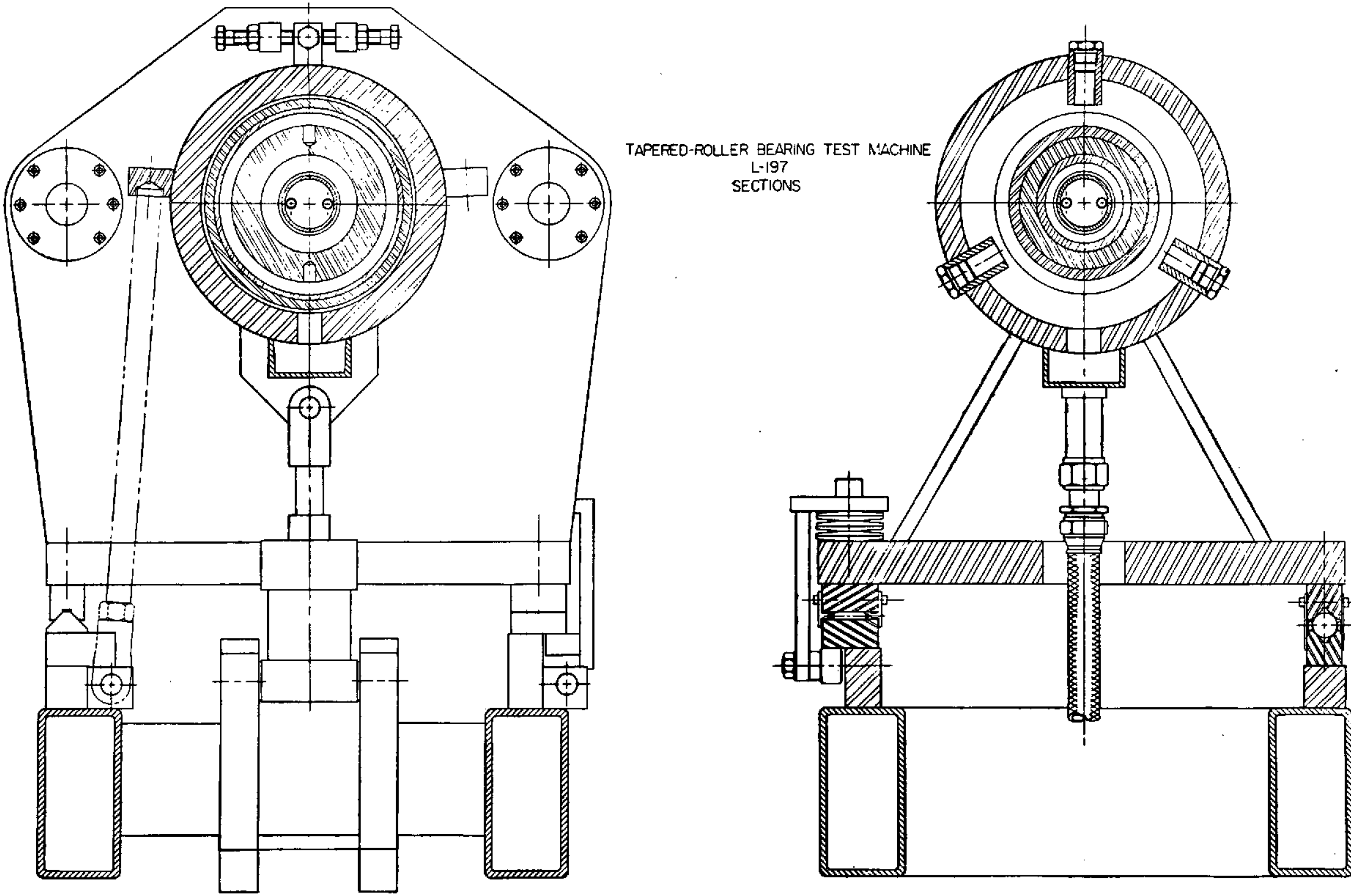
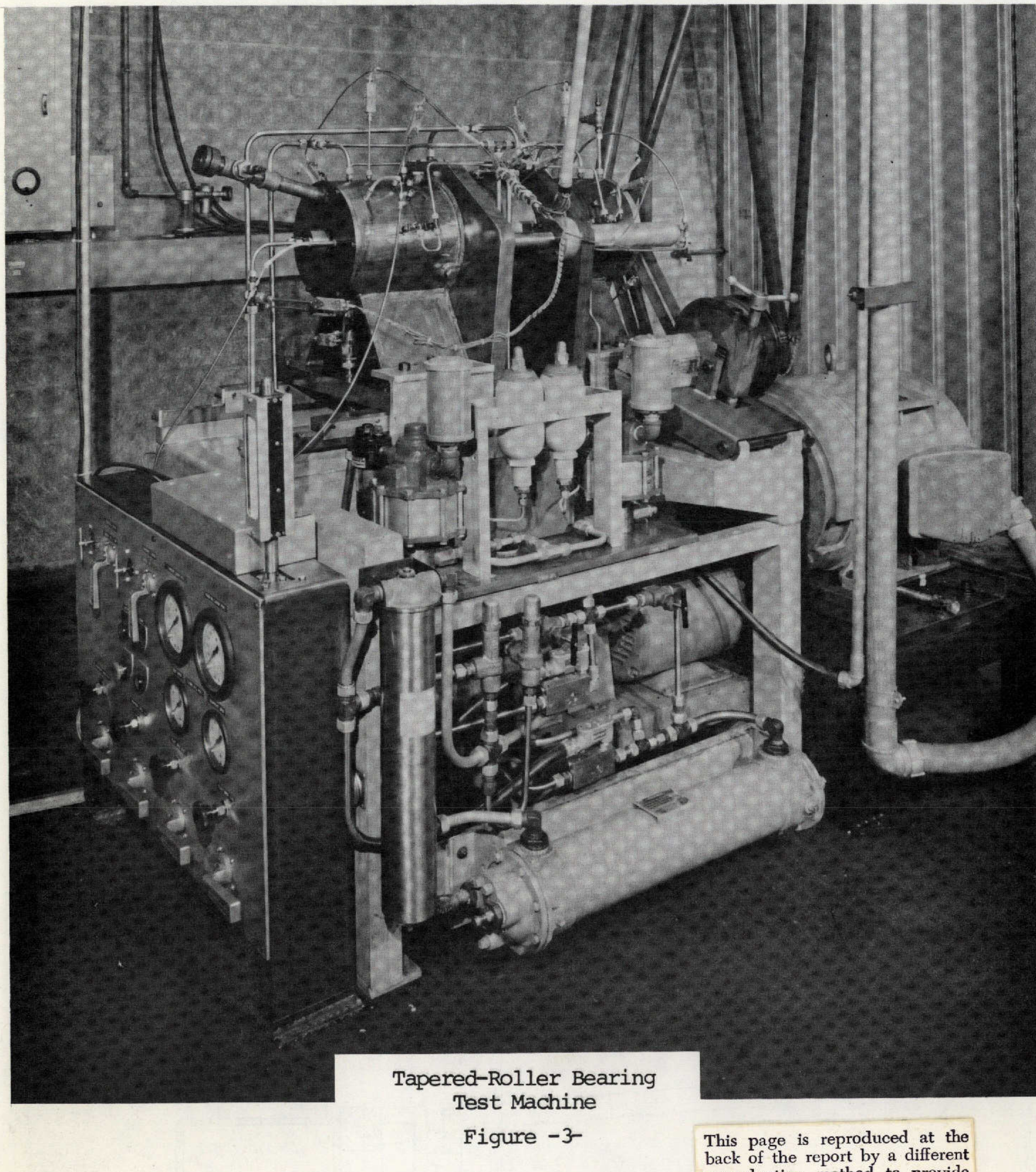


Figure -2-



Tapered-Roller Bearing
Test Machine

Figure -3-

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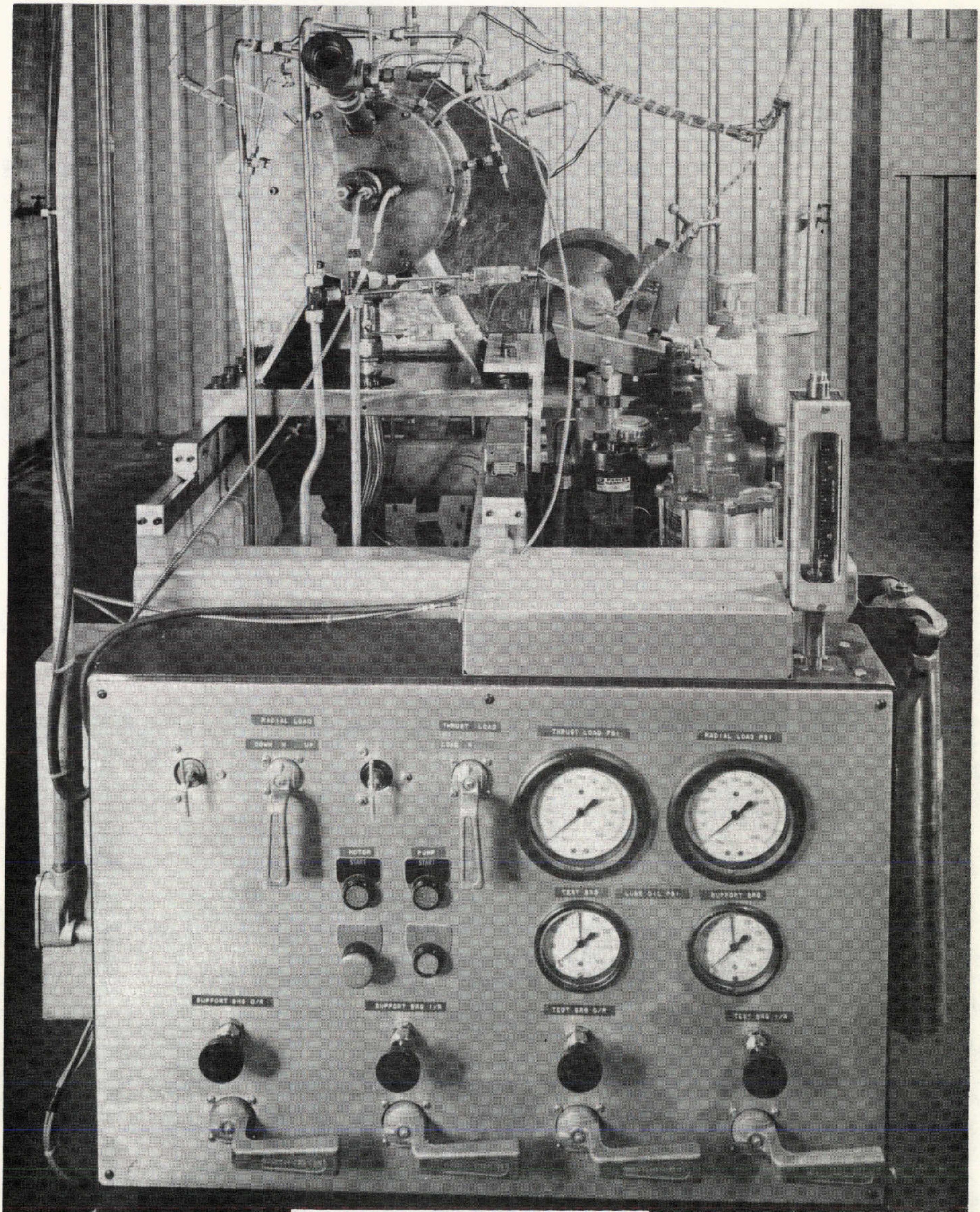

Tapered-Roller Bearing
Test Machine
Panel, Hydraulic Controls

Figure -4-

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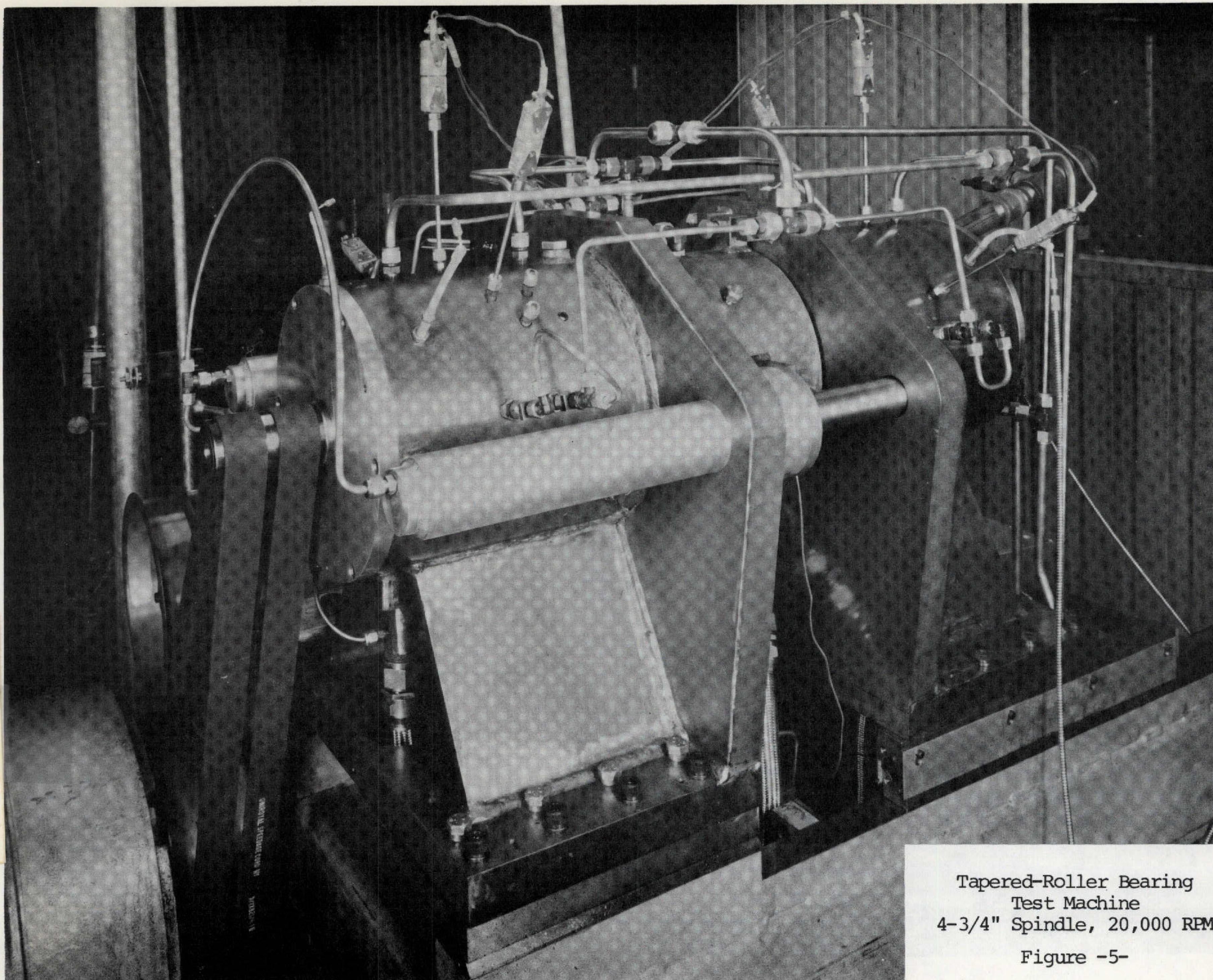
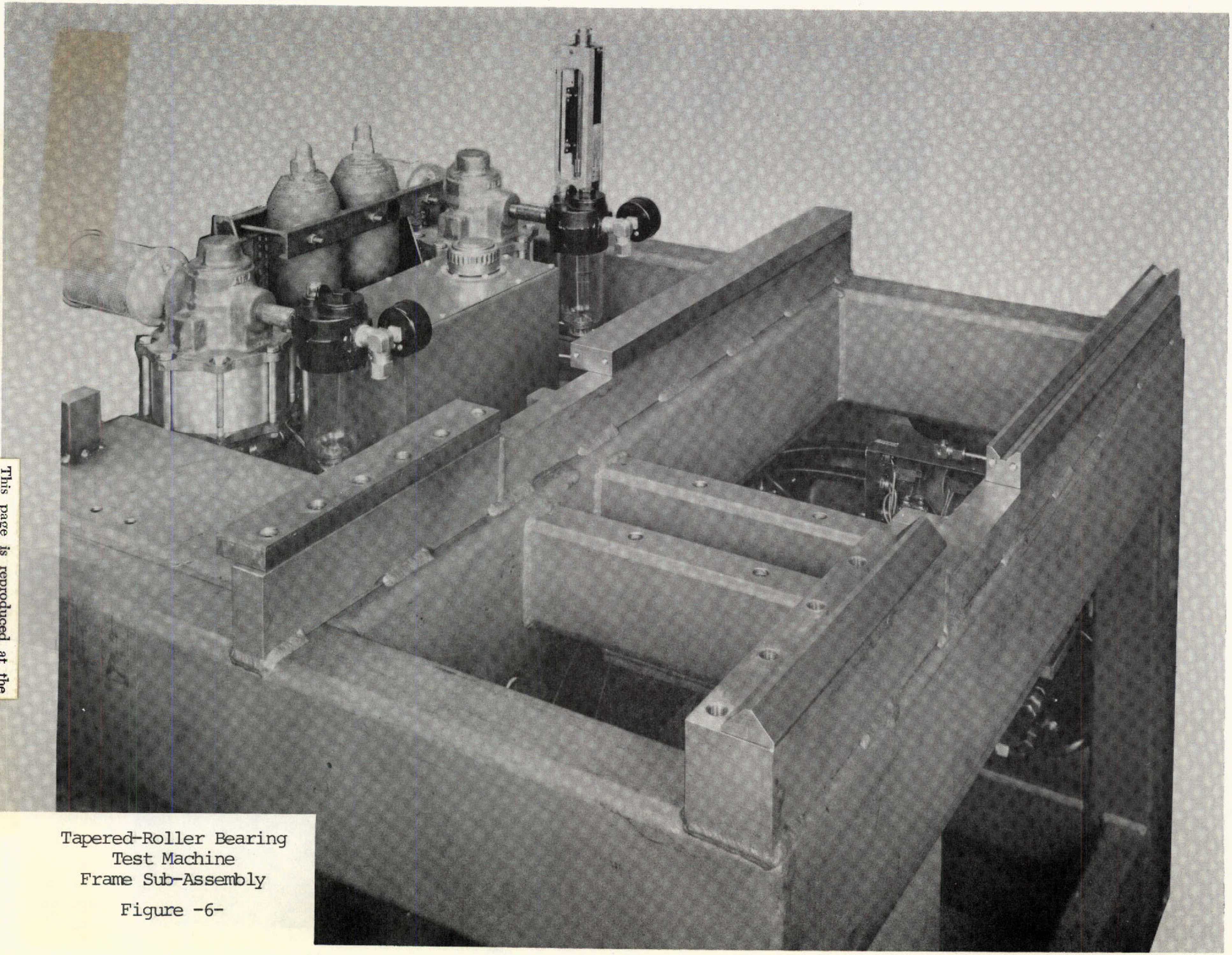


Tapered-Roller Bearing
Test Machine
4-3/4" Spindle, 20,000 RPM

Figure -5-



Tapered-Roller Bearing
Test Machine
Frame Sub-Assembly

Figure -6-

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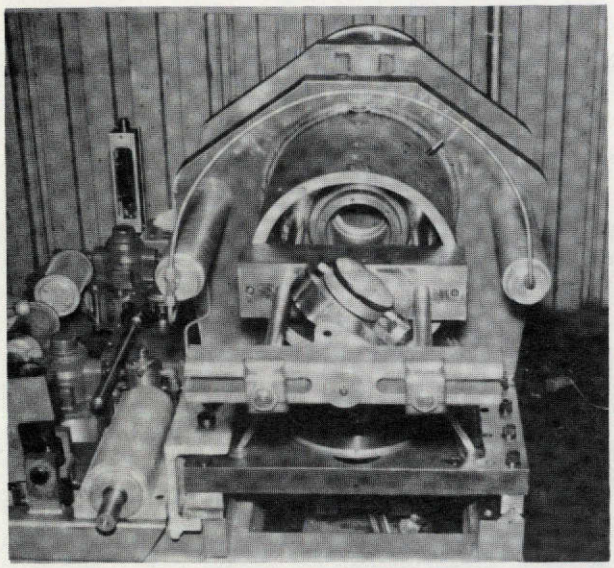

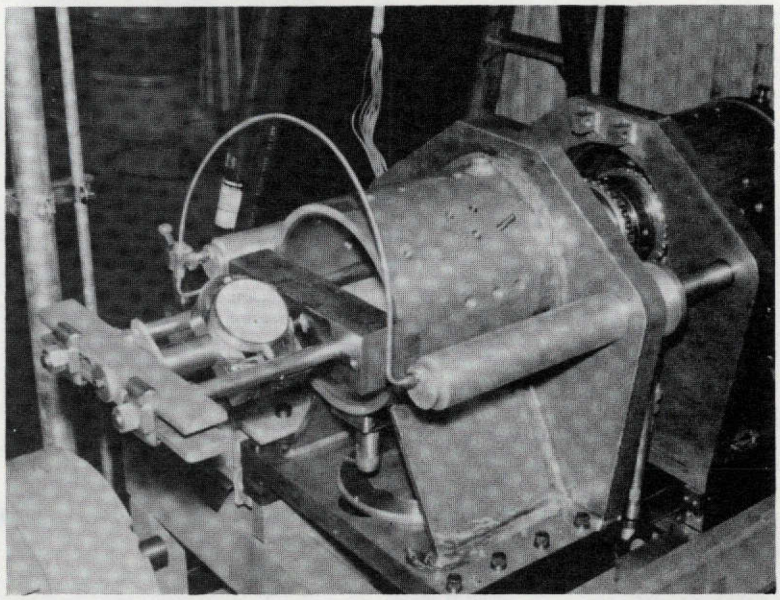

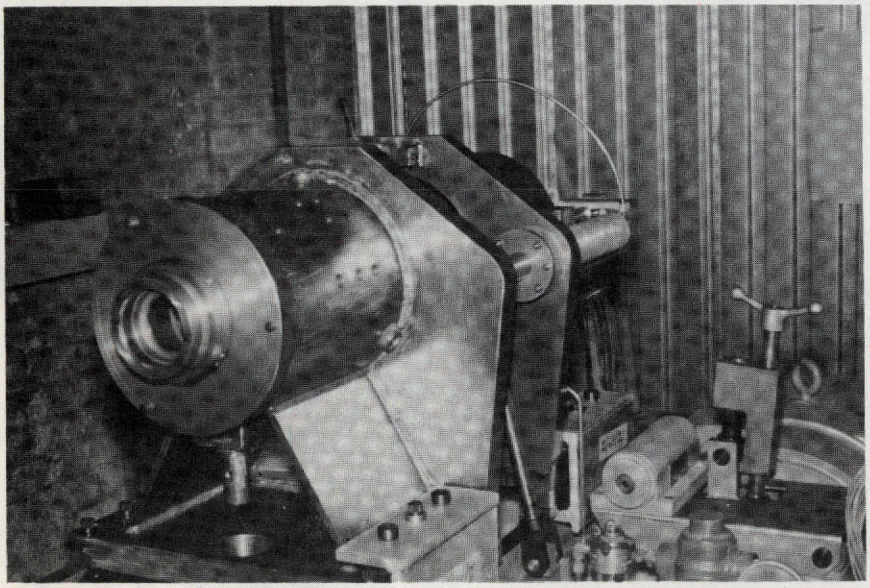

Tapered-Roller Bearing Test Machine
Thrust Load Calibration

Figure -7-

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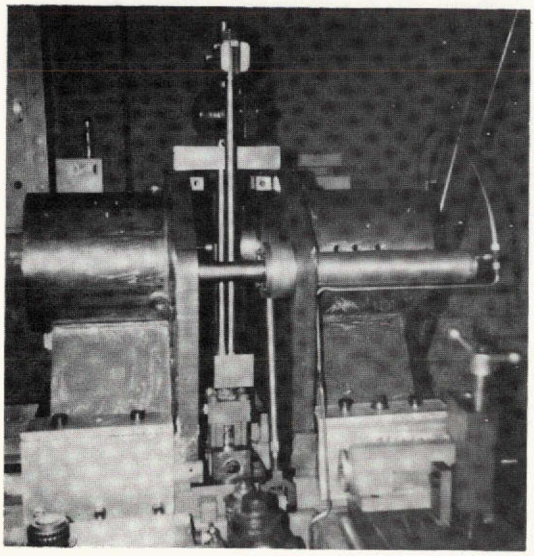

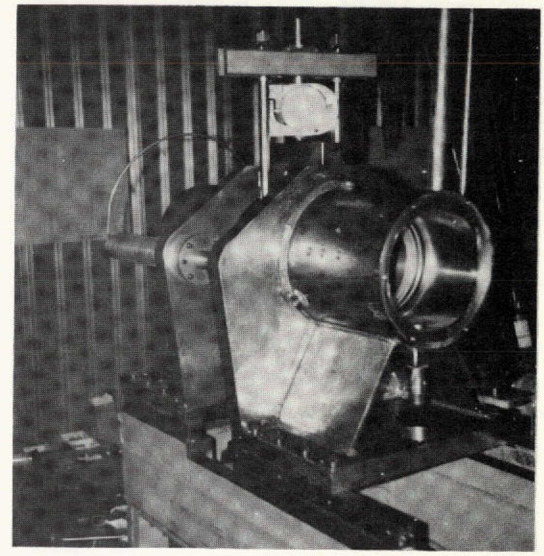

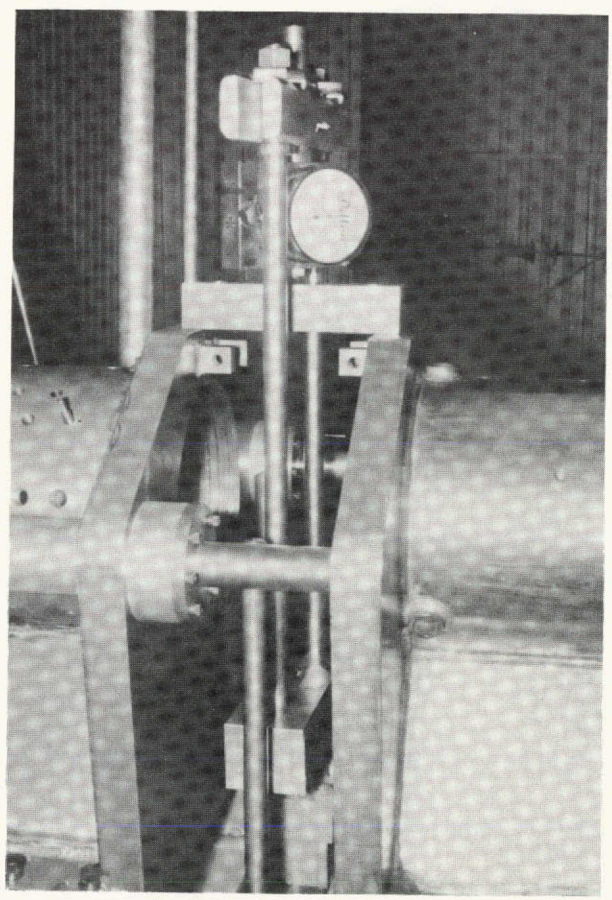

Tapered-Roller Bearing Test Machine
Radial Load Calibration

Figure -8-

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A P P E N D I X A

Demonstration Test Procedure

Demonstration Test Procedure of High-Speed Tapered-Roller Bearing Test Rig L-197

The qualification tests are divided into five parts:

I Instrumentation, evaluation and calibration in accordance with NAS 3-16812, Exhibit A, Task III. The completion of the evaluation and calibration of each item is indicated in Appendix B.

II System Component Tests

Functional tests are performed on the components of the safety and equipment shut-down devices.

The detail procedures are given in Appendix C.

III High-Load Low-Speed Tests

These tests shall be run with one commercial test tapered-roller bearing in each test chamber. The test conditions are:

Run Identification	IIIa	IIb
Speed, rpm	6,000	6,000
Thrust load on each brg., lbs.	8,000	12,000
Radial load on each brg., lbs.	3,000	6,000
Test brg. I.R. & O.R., temp.°F	<325	<325
Test period, hours	24	1

IV Low-Load High-Speed Tests

These tests are to be run with one high performance ball bearing in each test chamber. The tests and test conditions are:

Run identification	IVa	IVb	IVc	IVd	IVe
Speed, rpm	6,000	10,000	12,500	15,000	20,000
Thrust load on each brg., lbs.	← 6,000 →				
Radial load on each brg., lbs.	← 1,000 →				
Test brg. I.R. & O.R temperature	← 420°F ± 15° F →				
Test time	Until all parameters stabilize.				To total 25 hrs.

V Post Test Machine Inspection

The test rig is to be disassembled to remove the test bearings. All parts removed and/or visible will be visually examined. Any parts showning damage will be reported, the cause determined and corrected and, as required, replaced.

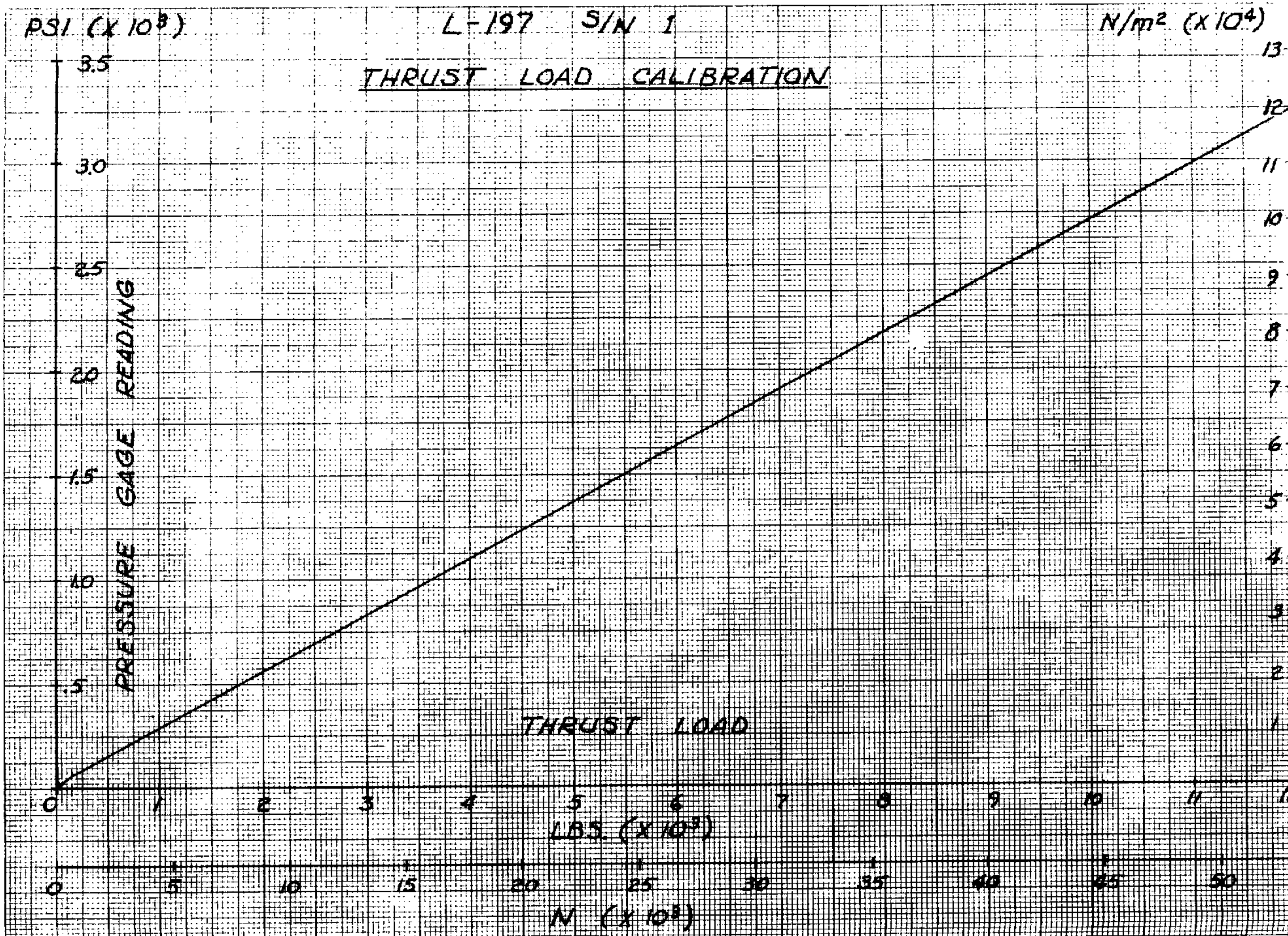
A P P E N D I X B

Instrumentation

Evaluation And Calibration

EQUIPMENT CHECK LIST

Equipment Description-Model No.& S/N	Evaluation	Calibration Date	Calibration By
Thermocouples 12 - Copper-Constantan 3/16"dia. x 6"long - with Bristol Dynamaster - 32 point recorder	Boiling water bath with thermometer at 212° F.	7-19-73	J. Gillen
	Room ambient temperature 78°F.	7-19-73	J. Gillen
Flowmeter	At ITI	7-19-73	J. Gillen
Pressure-gage - Radial load	Certified with purchase		
Pressure-gage - Thrust load	Certified with Purchase		
Load - Radial	See curve	7-19-73	J. Gillen
Load - Thrust	See curve	7-19-73	J. Gillen
Infra-Red Pyrometer	See curve	7-19-73	J. Gillen
Ammeter	Certified with Purchase		
Voltmeter	Certified with Purchase		


L-197 S/N 1
THRUST LOAD CALIBRATION
PSI (X 10³)
N/m² (X 10⁴)
PRESSURE GAGE READING
THRUST LOAD
LBS. (X 10³)
N (X 10³)
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
1
2
3
4
5
6
7
8
9
10
11
12
13
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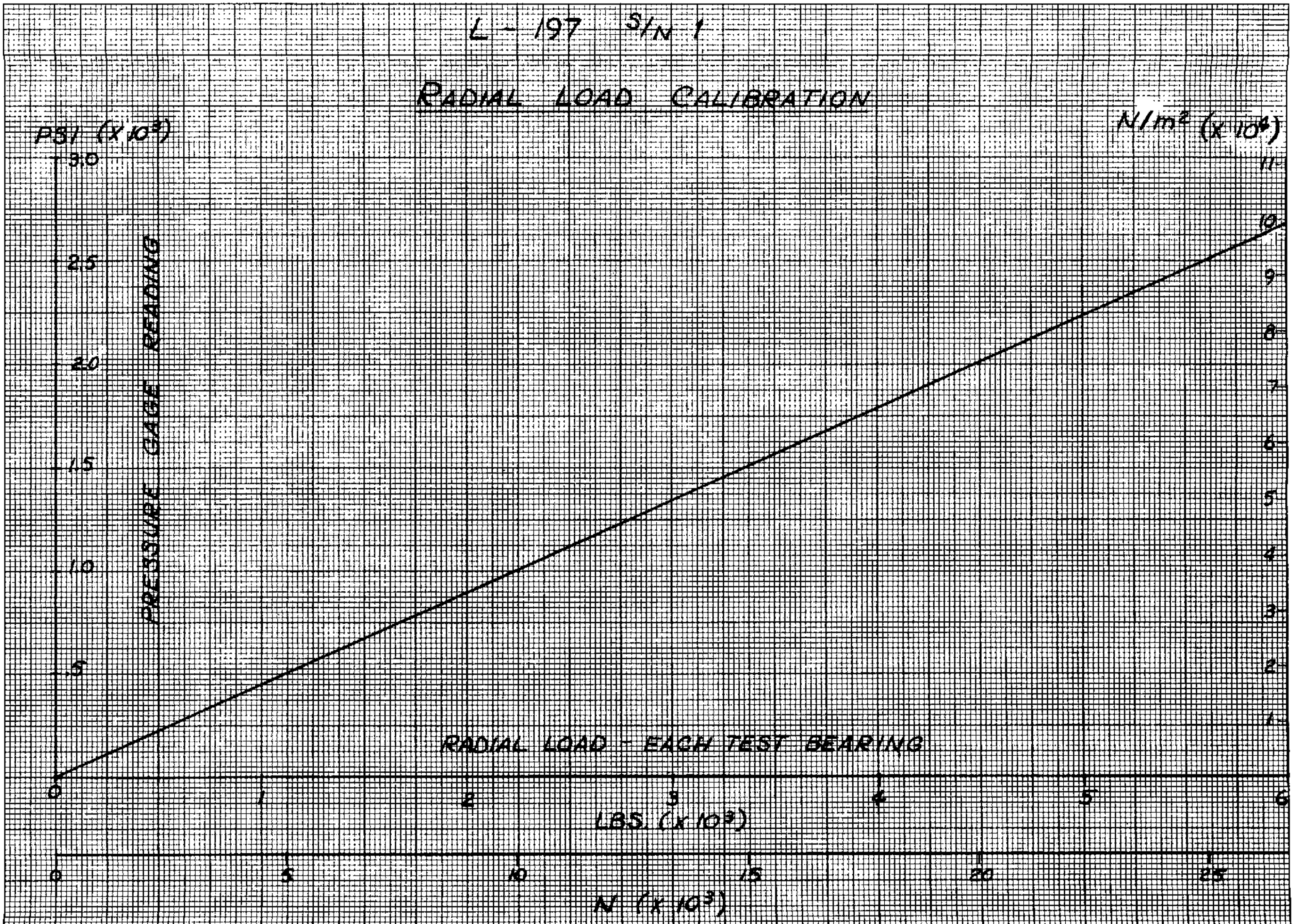
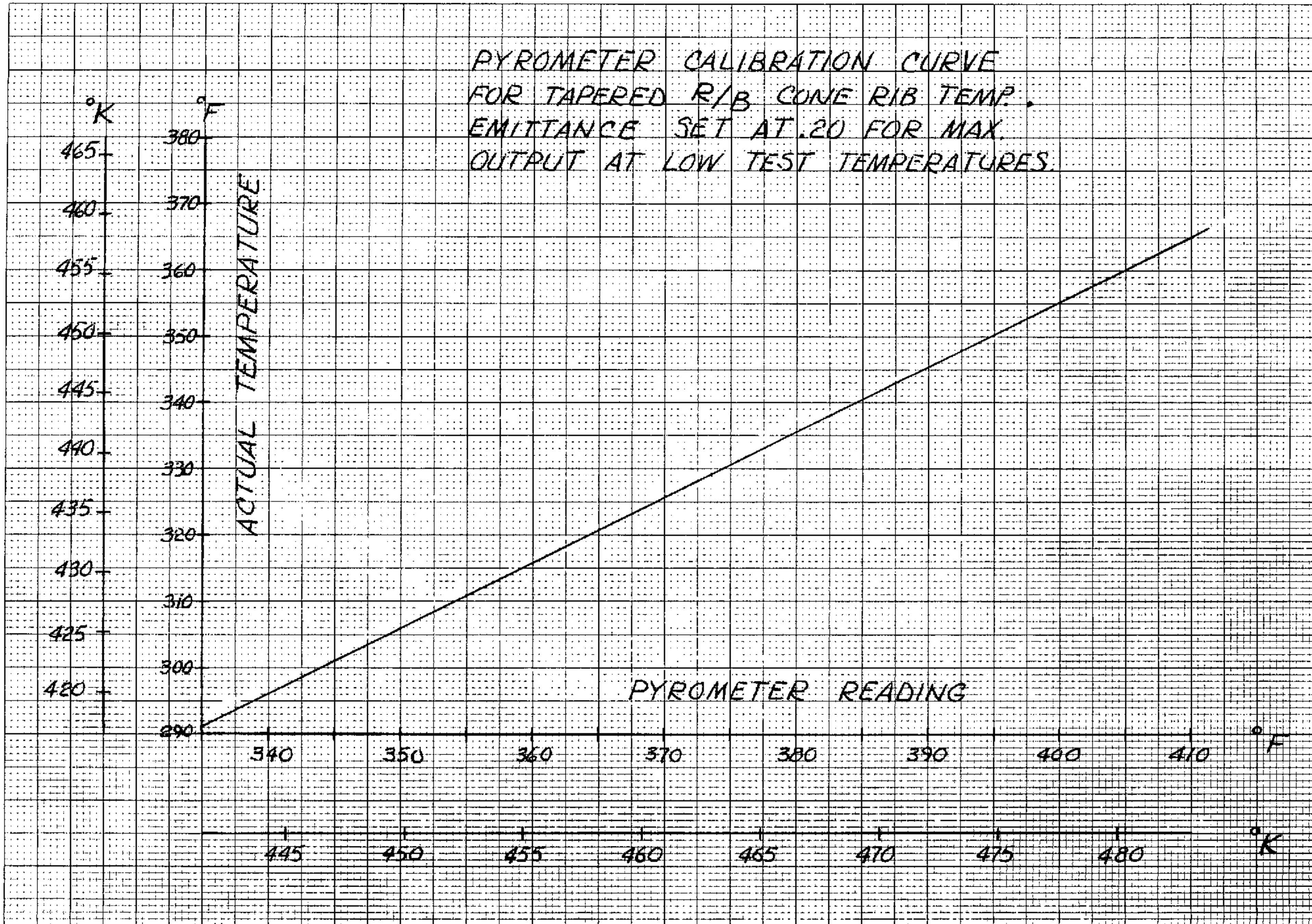
35
40
45
50


L - 197 S/N 1
RADIAL LOAD CALIBRATION
PSI (x 10³)
N/m² (x 10⁴)
3.0
2.5
2.0
1.5
1.0
.5
0
PRESSURE GAGE READING
11
10
9
8
7
6
5
4
3
2
1
RADIAL LOAD - EACH TEST BEARING
1
2
3
4
5
6
LBS. (x 10³)
5
10
15
20
25
N (x 10³)



PYROMETER CALIBRATION CURVE
FOR TAPERED R/B CONE RIB TEMP.
EMITTANCE SET AT .20 FOR MAX.
OUTPUT AT LOW TEST TEMPERATURES.
°K
°F
465
460
455
450
445
440
435
430
425
420
380
370
360
350
340
330
320
310
300
290
ACTUAL TEMPERATURE
PYROMETER READING
340
350
360
370
380
390
400
410
°F
445
450
455
460
465
470
475
480
°K

A P P E N D I X C

System Component Tests

SYSTEM COMPONENT TESTS DATA SHEET

Test & Para. No.	Test Description	Results
IIa Lubricating oil level switch	Remove oil from the reservoir until the float switch operates Measure height of oil in reservoir. The oil level is to be approx. 1/2 inch above the pump suction.	height of oil 7 inches. Oil volume 6.5 gallons. Height of oil above pump intake level 1/2 inches Date 7-18-73 By J. Gillan
IIb Lubricating oil pump time delay	Set the lubricating oil pump for 60 sec. Operate the lubricating oil pump and turn off the main motor. The pump shall continue to operate for 60 sec. ± 10 sec.	Time delay 70 sec. Date 7-18-73 By J. Gillan
IIc Vibration meter	Verify shut-off level relative to meter indication (to be within 5%)	Shut-off occurs at 5 sec. Date 7-18-73 By J. Gillan
IId Flow switches	Operate the lubricating oil pump and reduce the flow in: (1) Tapered R/B circuit (2) Radial R/B circuit Measure the range of flow at which the flow switches operate.	Max Min. 2.1 gpm 1.9 gpm 2.0 gpm 1.9 gpm Date 7-18-73 By J. Gillan
IIe	High temperature shut-off: verify set point by moving cam in temperature recorder.	Setting 430 °F Date 7-18-73 By J. Gillan

A P P E N D I X D

High-Load Low-Speed Tests

D-1

INDUSTRIAL TECTONICS, INC.

REF. BY J. Geller CHKD BY

TAPERED ROLLER BEARING
TEST MACHINE L-197
CHECKOUT PERFORMANCE
TESTS

DATE 9-5-73 PAGE 1 OF 1

CUSTOMER NASA

TEST NO. III a

TEST OBJECTIVES

Test Brgs	Speed RPM
TAPERED R/B	3,000

LOADS

Thrust	Radial
8,000	3,000

LUBRICATION

Type MIL-L-23699-A

DRIVE SYSTEM

Time to reach full speed

Cold	Hot
11 SEC	8 SEC

SETTINGS

Start-Up

Voltage	Time delay
65 %	30 SEC

Lube Flow Switches

Test Brg.	Slave Brg.
1.8 GPM	2.0 GPM

Time Delay Pump	Bearing Temp
70 SEC	<325 °F

Vibration 20 %

NOTES:

1) LUBE PUMP = 100 PSI

2) TEST BRG. LUBE THRU JETS ONLY

3) HE CONNECTED, "COLD" OIL VALVE TO TEST BRGS. CLOSED - "HOT" OIL VALVE FULL OPEN.

4) HEAT EXCHANGER DISCONNECTED

5) H.E. CONNECTED, "HOT" OIL VALVE TO TEST BRGS. OFF. "COLD" OIL VALVE FULL OPEN

TIME (HRS)			2.0	6.4	23.1	24.9
Load lbs.	Thrust		8,000	8,000	7,725	8,350
Load lbs.	Radial		3,000	3,000	2,800	3,000
SPINDLE SPEED (RPM)			3,130	3,130	3,130	3,130
TEMPERATURES °F	1. Brg. Outer Ring Test Front	#1	179	259	185	155
	2. Brg. Outer Ring Test Front	#2	183	261	189	160
	3. Brg. Outer Ring Test Rear	#1	171	251	176	147
	4. Brg. Outer Ring Test Rear	#2	173	254	179	151
	5. Brg. Outer Ring Slave	Front	121	242	130	123
	6. Brg. Outer Ring Slave	Rear	126	247	135	127
	7. Lube Oil Out	Front	183	262	187	158
	8. Lube Oil Out	Rear	170	252	174	144
	9. Cooling Oil Out	Front	169	250	164	128
	10. Cooling Oil Out	Rear	166	248	160	122
	11. Oil In	Test Brg.	151	246	154	110
	12. Oil In	Slave Brg.	110	244	119	110
INFRA - RED I.R.			—	—	—	—
FLOW GPM	Inner Ring Oil	Test Brg. (2)	2.9	2.8	2.5	2.5
	Inner Ring Oil	Slave Brg.	2.2	2.2	2.0	2.0
	Cooling Oil	Test Brg.	1.3	1.9	1.0	1.0
	Cooling Oil	Slave Brg.	1.1	1.9	1.3	1.2
MOTOR	VOLTAGE (VOLTS)		460	458	455	457
MOTOR	CURRENT (AMPS)		29	26	27	29
MOTOR	H.P. (CALCULATED)					
VIBRATION %			0	0	0	0
Shaft Excursion (inch-T.I.R.)	Front		.002	.002	.002	.002
Shaft Excursion (inch-T.I.R.)	Rear		.001	.001	.001	.001
			(3)	(4)	(3)	(5)

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INDUSTRIAL TECTONICS, INC.

REF. BY

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TAPERED ROLLER BEARING TEST MACHINE L-197 CHECKOUT PERFORMANCE TESTS

DATE 9-6-73 PAGE 1 OF 1

CUSTOMER NASA

TEST NO. III b	
TEST OBJECTIVES	
Test Brgs	Speed RPM
TAPERED R/B	3,000
LOADS	
Thrust	Radial
12,000	6,000
LUBRICATION	
Type MIL-L-23699-A	
DRIVE SYSTEM	
Time to reach full speed	
Cold	Hot
— SEC	— SEC
SETTINGS	
Start-Up	
Voltage	Time delay
65 %	30 SEC
Lube Flow Switches	
Test Brg.	Slave Brg.
2.5 GPM	2.0 GPM
Time Delay Pump	Bearing Temp
70 SEC	< 325 °F
Vibration	PUMP R/V SET @ 90 PSI
20 %	

TIME (HRS)	.5	1.0		
Load lbs. Thrust	11,950	12,000		
Load lbs. Radial	6,000	6,000		
SPINDLE SPEED (RPM)	3,130	3,130		
TEMPERATURES °F 1. Brg. Outer Ring Test Front #1	161	189		
2. Brg. Outer Ring Test Front #2	165	193		
3. Brg. Outer Ring Test Rear #1	150	177		
4. Brg. Outer Ring Test Rear #2	154	180		
5. Brg. Outer Ring Slave Front	126	127		
6. Brg. Outer Ring Slave Rear	131	133		
7. Lube Oil Out Front	164	192		
8. Lube Oil Out Rear	158	176		
9. Cooling Oil Out Front	131	168		
10. Cooling Oil Out Rear	125	163		
11. Oil In Test Brg.	112	165		
12. Oil In Slave Brg.	112	114		
INFRA - RED I.R.				
FLOW GPM Inner Ring Oil (2) Test Brg.	2.5	2.5		
FLOW GPM Inner Ring Oil Slave Brg.	2.0	2.0		
FLOW GPM Cooling Oil Test Brg.	1.0	1.0		
FLOW GPM Cooling Oil Slave Brg.	1.2	1.2		
MOTOR VOLTAGE (VOLTS)	455	458		
MOTOR CURRENT (AMPS)	29	29		
MOTOR H.P. (CALCULATED)				
VIBRATION %	0	0		
Shaft Excursion (inch-T.I.R.) Front	.001	.001		
Shaft Excursion (inch-T.I.R.) Rear	.002	.002		
	(1)	(3)		

NOTES:

(1) H.E. CONNECTED "HOT" OIL VALVE TO TEST BRGS CLOSED - "COLD" OIL VALVE FULL OPEN

(2) TEST BRG. LUBE THRU JETS ONLY.

(3) H.E. CONNECTED "HOT" OIL VALVE TO TEST BRG FULL OPEN - "COLD" OIL VALVE CLOSED

A P P E N D I X E

Low-Load High-Speed Tests

E-1

INDUSTRIAL TECTONICS, INC.

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TAPERED ROLLER BEARING TEST MACHINE L-197 CHECKOUT PERFORMANCE TESTS

DATE 7-30-73 PAGE 1 OF 1

CUSTOMER NASA

TEST NO. IV a	
TEST OBJECTIVES	
Test Brgs BALL BRGS F-82 E-105	Speed RPM 6,000
LOADS	
Thrust 6,000	Radial 1,000
LUBRICATION	
Type MIL-L-23699A	
DRIVE SYSTEM	
Time to reach full speed	
Cold 5 SEC	Hot 4 SEC
SETTINGS	
Start-Up	
Voltage 65%	Time delay 15 SEC
Lube Flow Switches	
Test Brg. 2.0 GPM	Slave Brg. 2.0 GPM
Time Delay Pump 70 SEC	Bearing Temp 432 °F
Vibration 20 %	

NOTES:

TIME (HRS)			1.6
Load lbs.	Thrust		6,000
	Radial		1,000
SPINDLE SPEED (RPM)			6,090
TEMPERATURES °F	1. Brg. Outer Ring, Test, Front	#1	204
	2.	#2	
	3. Brg. Outer Ring, Test, Rear	#1	204
	4.	#2	
	5. Brg. Outer Ring, Slave, Front		201
	6. Brg. Outer Ring, Slave, Rear		201
	7. Lube Oil Out	Front	201
	8. Lube Oil Out	Rear	199
	9. Cooling Oil Out	Front	194
	10. Cooling Oil Out	Rear	191
	11. Oil In	Test Brg.	194
	12. Oil In	Slave Brg.	191
INFRA - RED I.R.			—
FLOW GPM	Inner Ring Oil	Test Brg.	2.5
		Slave Brg.	2.1
	Cooling Oil	Test Brg.	0
		Slave Brg.	0.5
MOTOR	VOLTAGE (VOLTS)		455
	CURRENT (AMPS)		27.0
	H.P. (CALCULATED)		6 HP
VIBRATION %			0
Shaft Excursion (inch-T.I.R.)		Front	—
		Rear	—

INDUSTRIAL TECTONICS, INC.

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TAPERED ROLLER BEARING TEST MACHINE L-197 CHECKOUT PERFORMANCE TESTS

DATE 7-30-73 PAGE 1 OF 1

CUSTOMER **NASA**

TEST NO.	IV b
TEST OBJECTIVES	
Test Brgs (BALL BRG'S) F-82 R-105	Speed RPM 10,000
LOADS	
Thrust 6,000	Radial 1,000
LUBRICATION	
Type MIL-L-23699A	
DRIVE SYSTEM	
Time to reach full speed	
Cold 10 SEC	Hot SEC
SETTINGS	
Start-Up	
Voltage 65 %	Time delay 15 SEC
Lube Flow Switches	
Test Brg. 2.0 GPM	Slave Brg. 2.0 GPM
Time Delay Pump 70 SEC	Bearing Temp 432 °F
Vibration 20 %	

NOTES:

TIME (HRS)			.6		
Load lbs.	Thrust		5,800		
Load lbs.	Radial		1125		
SPINDLE SPEED (RPM)			10,105		
TEMPERATURES °F	1. Brg. Outer Ring, Test, Front	#1	255		
	2. Brg. Outer Ring, Test, Front	#2			
	3. Brg. Outer Ring, Test, Rear	#1	249		
	4. Brg. Outer Ring, Test, Rear	#2			
	5. Brg. Outer Ring, Slave	Front	196		
	6. Brg. Outer Ring, Slave	Rear	194		
	7. Lube Oil Out	Front	241		
	8. Lube Oil Out	Rear	224		
	9. Cooling Oil Out	Front	241		
	10. Cooling Oil Out	Rear	231		
	11. Oil In	Test Brg.	205		
	12. Oil In	Slave Brg.	135		
INFRA - RED I.R.			—		
FLOW GPM	Inner Ring Oil	Test Brg.	2.5		
	Inner Ring Oil	Slave Brg.	2.2		
	Cooling Oil	Test Brg.	0		
	Cooling Oil	Slave Brg.	0.5		
MOTOR	VOLTAGE (VOLTS)		466		
	CURRENT (AMPS)		32		
	H.P. (CALCULATED)		16.5		
VIBRATION %			0		
Shaft Excursion (inch-T.I.R.)		Front	—		
		Rear	—		

INDUSTRIAL TECTONICS, INC.

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TAPERED ROLLER BEARING TEST MACHINE L-197 CHECKOUT PERFORMANCE TESTS

DATE 7-30-73 PAGE 1 OF 1

CUSTOMER NASA

TEST NO. IVc

TEST OBJECTIVES

Test Brgs #	Speed RPM
BALL BRG'S F-82 R-105	12,500

LOADS

Thrust	Radial
6,000	1,000

LUBRICATION

Type: MIL-L-23699A

DRIVE SYSTEM

Time to reach full speed

Cold	Hot
23 SEC	SEC

SETTINGS

Start-Up

Voltage	Time delay
65 %	28 SEC

Lube Flow Switches

Test Brg.	Slave Brg.
2.0 GPM	2.0 GPM

Time Delay Pump	Bearing Temp
70 SEC	432 °F

Vibration	
20 %	

N O T E S :

TIME (HRS)			.9
Load lbs.	Thrust		5,950
	Radial		1,400
SPINDLE SPEED (RPM)			12,550
TEMPERATURES °F	1. Brg. Outer Ring, Test, Front	#1	288
	2.	#2	
	3. Rear	#1	280
	4.	#2	
	5. Slave	Front	224
	6.	Rear	225
	7. Lube Oil Out	Front	283
	8.	Rear	260
	9. Cooling Oil Out	Front	252
	10.	Rear	249
	11. Oil In	Test Brg.	232
	12.	Slave Brg.	143
INFRA - RED I.R.			—
FLOW GPM	Inner Ring Oil	Test Brg.	2.5
		Slave Brg.	2.2
	Cooling Oil	Test Brg.	0.5
		Slave Brg.	0.5
MOTOR	VOLTAGE (VOLTS)		461
	CURRENT (AMPS)		40
	H.P. (CALCULATED)		28
VIBRATION %			0
Shaft Excursion (inch-T.I.R.)		Front	.0006
		Rear	.0016

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TAPERED ROLLER BEARING TEST MACHINE L-197 CHECKOUT PERFORMANCE TESTS

DATE 7-31-73 PAGE 1 OF 4

CUSTOMER NASA

TEST NO. IV-d

TEST OBJECTIVES

Test Brgs # (Ball Brgs)	Speed RPM
F-82 R-105	15,000

LOADS

Thrust	Radial
6,000	1,000

LUBRICATION

Type: MIL-L-23699A

DRIVE SYSTEM

Time to reach full speed

Cold	Hot
40 SEC	28 SEC

SETTINGS

Start-Up

Voltage	Time delay
65 %	30 SEC

Lube Flow Switches

Test Brg.	Slave Brg.
2.0 GPM	2.0 GPM

Time Delay Pump	Bearing Temp
70 SEC	432 °F

Vibration: 20 %

NOTES:

TIME (HRS)			.6
Load lbs.	Thrust		6,100
Load lbs.	Radial		1,100
SPINDLE SPEED (RPM)			15,050
TEMPERATURES °F	1. Brg. Outer Ring, Test, Front	#1	316
TEMPERATURES °F	2. Brg. Outer Ring, Test, Front	#2	—
TEMPERATURES °F	3. Brg. Outer Ring, Test, Rear	#1	308
TEMPERATURES °F	4. Brg. Outer Ring, Test, Rear	#2	—
TEMPERATURES °F	5. Brg. Outer Ring, Slave	Front	280
TEMPERATURES °F	6. Brg. Outer Ring, Slave	Rear	276
TEMPERATURES °F	7. Lube Oil Out	Front	302
TEMPERATURES °F	8. Lube Oil Out	Rear	280
TEMPERATURES °F	9. Cooling Oil Out	Front	269
TEMPERATURES °F	10. Cooling Oil Out	Rear	263
TEMPERATURES °F	11. Oil In	Test Brg.	238
TEMPERATURES °F	12. Oil In	Slave Brg.	138
INFRA - RED I.R.			—
FLOW GPM	Inner Ring Oil	Test Brg.	2.5
FLOW GPM	Inner Ring Oil	Slave Brg.	2.2
FLOW GPM	Cooling Oil	Test Brg.	.5
FLOW GPM	Cooling Oil	Slave Brg.	1.0
MOTOR	VOLTAGE (VOLTS)		455
MOTOR	CURRENT (AMPS)		51
MOTOR	H.P. (CALCULATED)		40
VIBRATION %			10%
Shaft Excursion (inch-T.I.R.)		Front	.0008
Shaft Excursion (inch-T.I.R.)		Rear	.0017

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TAPERED ROLLER BEARING TEST MACHINE L-197 CHECKOUT PERFORMANCE TESTS

CUSTOMER NASA

TEST NO IVd cont.	
TEST OBJECTIVES	
Test Brgs BALL BRGS 83-F 106 R	Speed RPM 15,000
LOADS	
Thrust 6,000	Radial 1,000
LUBRICATION	
Type MIL-L-23699-A	
DRIVE SYSTEM	
Time to reach full speed	
Cold 71 SEC	Hot 15 SEC
SETTINGS	
Start-Up	
Voltage 85 %	Time delay 30 SEC
Lube Flow Switches	
Test Brg. 1.9 GPM	Slave Brg. 1.9 GPM
Time Delay Pump 70 SEC	Bearing Temp 425 °F
Vibration 30 %	

TIME (HRS)				1.2
Load lbs.	Thrust			6,100
Load lbs.	Radial			1,000
SPINDLE SPEED (RPM)				15,410
TEMPERATURES °F	1. Brg. Outer Ring	Test	Front #1	250
	2.		Front #2	—
	3.		Rear #1	—
	4.		Rear #2	241
	5.	Slave	Front	230
	6.		Rear	216
	7. Lube Oil Out		Front	249
	8.		Rear	235
	9. Cooling Oil Out		Front	189
	10.		Rear	188
	11. Oil In		Test Brg.	155
	12.		Slave Brg.	132
INFRA - RED I.R.				
FLOW GPM	Inner Ring Oil		Test Brg.	2.6
			Slave Brg.	2.6
	Cooling Oil		Test Brg.	1.3
			Slave Brg.	1.4
MOTOR	VOLTAGE (VOLTS)			455
	CURRENT (AMPS)			54
	H.P. (CALCULATED)			
VIBRATION %				14
Shaft Excursion (inch-T.I.R.)			Front	.0012
			Rear	.0010
				①

NOTES:

① H.E. CONNECTED - "COLD" OIL VALVE FULL OPEN - "HOT" OIL VALVE 1/4 OPEN

NEW TEST BRG AND NEW RADIAL LOAD BRG'S

INDUSTRIAL TECTONICS, INC.

REF. BY

CHKD BY

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TAPERED ROLLER BEARING TEST MACHINE L-197 CHECKOUT PERFORMANCE TESTS

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CUSTOMER NASA

TEST NO. IV d (Cont)

TEST OBJECTIVES

Test Brgs	Speed RPM
BALL BRG [illegible] L-156	15,000

LOADS

Thrust	Radial
6,000	1,000

LUBRICATION

Type: MIL-L-23699-A

DRIVE SYSTEM

Time to reach full speed

Cold	Hot
21 SEC	15 SEC

SETTINGS

Start-Up

Voltage	Time delay
85 %	30 SEC

Lube Flow Switches

Test Brg.	Slave Brg.
2.5 GPM	2.5 GPM

Time Delay Pump	Bearing Temp
70 SEC	425 °F

Vibration: 40 %

			9-17	9-17	9-18	9-19
TIME (HRS)			1.5	2.9	4.0	7.7
Load lbs.	Thrust		6,000	6,000	6,000	6,200
Load lbs.	Radial		1,000	1,000	1,000	1,100
SPINDLE SPEED (RPM)			15,445	15,460	15,460	15,470
TEMPERATURES °F — Brg. Outer Ring — Test	1. Front	#1	300	408	422	419
	2. Front	#2	—	—	—	—
	3. Rear	#1	—	—	—	—
	4. Rear	#2	296	406	420	420
Brg. Outer Ring — Slave	5. Front		228	358	372	368
	6. Rear		219	354	368	364
7. Lube Oil Out	Front		294	396	410	407
8. Lube Oil Out	Rear		280	380	396	398
9. Cooling Oil Out	Front		248	370	387	384
10. Cooling Oil Out	Rear		246	368	384	383
11. Oil In	Test Brg.		225	345	360	359
12. Oil In	Slave Brg.		138	301	317	309
INFRA - RED I.R.					429	428
FLOW GPM — Inner Ring Oil	Test Brg.		2.5	2.5	2.5	2.5
	Slave Brg.		2.4	2.5	2.5	2.5
Cooling Oil	Test Brg.		1.4	0.5	0.5	0.5
	Slave Brg.		1.6	1.5	1.5	1.5
MOTOR	VOLTAGE (VOLTS)		461	458	458	459
	CURRENT (AMPS)		53	43	42	42
	H.P. (CALCULATED)					
VIBRATION %			20	20	22	23
Shaft Excursion (inch-T.I.R.)	Front		.0009	.0008	.0009	.0008
	Rear		.001	.0008	.0009	.0008
			1	2	2	2

NOTES:

1 H.E. ON-"COLD" OIL TO TEST BRG'S OFF. "HOT" OIL FULL ON.

2 H.E. ON ORIGINAL "COLD & HOT" OIL VALVES FULL OPEN "NEW COLD" OIL VALVE 1/4 TURN OPEN

INDUSTRIAL TECTONICS, INC.

REF. BY

CHKD BY

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TAPERED ROLLER BEARING TEST MACHINE L-197 CHECKOUT PERFORMANCE TESTS

CUSTOMER NASA

TEST NO. IV d (cont)	
TEST OBJECTIVES	
Test Brgs: BALL BRGS [illegible]	Speed RPM: 15,000
LOADS	
Thrust: 6000	Radial: 1000
LUBRICATION	
Type: MIL-L-23699-A	
DRIVE SYSTEM	
Time to reach full speed	
Cold: 21 SEC	Hot: 15 SEC
SETTINGS	
Start-Up	
Voltage: 85 %	Time delay: 30 SEC
Lube Flow Switches	
Test Brg.: 1.8 GPM	Slave Brg.: 1.8 GPM
Time Delay Pump: 70 SEC	Bearing Temp: 430 °F
Vibration: 40% %	

NOTES:

TIME (HRS)				11.5
Load lbs.	Thrust			6,000
Load lbs.	Radial			1,000
SPINDLE SPEED (RPM)				
TEMPERATURES °F	1. Brg. Outer Ring, Test	Front	#1	425
	2. Brg. Outer Ring, Test	Front	#2	
	3. Brg. Outer Ring, Test	Rear	#1	
	4. Brg. Outer Ring, Test	Rear	#2	425
	5. Brg. Outer Ring, Slave	Front		382
	6. Brg. Outer Ring, Slave	Rear		377
	7. Lube Oil Out	Front		416
	8. Lube Oil Out	Rear		404
	9. Cooling Oil Out	Front		390
	10. Cooling Oil Out	Rear		390
	11. Oil In	Test Brg.		368
	12. Oil In	Slave Brg.		327
	INFRA - RED I.R.			437
FLOW GPM	Inner Ring Oil	Test Brg.		2.5
	Inner Ring Oil	Slave Brg.		2.5
	Cooling Oil	Test Brg.		0.5
	Cooling Oil	Slave Brg.		1.4
MOTOR	VOLTAGE (VOLTS)			460
	CURRENT (AMPS)			42
	H.P. (CALCULATED)			
VIBRATION %				24
Shaft Excursion (inch-T.I.R.)	Front			.0008
	Rear			.0008

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PAGE #3

INDUSTRIAL TECTONICS, INC.

REF. BY CHKD BY J. Gille

E-8
TAPERED ROLLER BEARING TEST MACHINE L-197 CHECKOUT PERFORMANCE TESTS

DATE 9-25-73 PAGE 1 OF 1

CUSTOMER NASA

TEST NO. IV e	
TEST OBJECTIVES	
Test Brgs BALL BRG'S 82 F 83 R	Speed RPM 20,000
LOADS	
Thrust 6,000	Radial -0-
LUBRICATION	
Type MIL-L-23699-A	
DRIVE SYSTEM	
Time to reach full speed	
Cold 28 SEC	Hot 20 SEC
SETTINGS	
Start-Up	
Voltage 85 %	Time delay 30 SEC
Lube Flow Switches	
Test Brg. 1.8 GPM	Slave Brg. — GPM
Time Delay Pump 70 SEC	Bearing Temp 430 °F
Vibration 20 %	

TIME	2.0	5.6	9.3
Load lbs. Thrust	6,000	6,000	6,000
Load lbs. Radial	-0-	-0-	-0-
SPINDLE SPEED (RPM)	20,280	20,275	20,280
TEMPERATURES °F 1. Brg. Outer Ring Test Front #1	415	414	416
2. Front #2	—	—	—
3. Rear #1	—	—	—
4. Rear #2	410	410	412
5. Slave Front	—	—	—
6. Slave Rear	—	—	—
7. Lube Oil Out Front	403	403	404
8. Lube Oil Out Rear	380	383	385
9. Cooling Oil Out Front	353	356	357
10. Cooling Oil Out Rear	349	353	354
11. Oil In Test Brg.	300	300	300
12. Oil In Slave Brg.	120	125	125
INFRA - RED I.R.	431	435	434
FLOW GPM Inner Ring Oil Test Brg.	2.5	2.5	2.5
Inner Ring Oil Slave Brg.	.4	.4	.4
Cooling Oil Test Brg.	1.1	1.2	1.1
Cooling Oil Slave Brg.	-0-	-0-	-0-
MOTOR VOLTAGE (VOLTS)	460	460	459
CURRENT (AMPS)	45	45	45
H.P. (CALCULATED)			
VIBRATION %	<10	<10	<10
Shaft Excursion (inch-T.I.R.) Front	.0017	.0017	.0017
Shaft Excursion (inch-T.I.R.) Rear	.0019	.0018	.0019
	①	①	①

NOTES:

① H.E. CONNECTED ORIGINAL "HOT & COLD" OIL VALVES FULL OPEN "NEW" COLD OIL VALVE 1/2 TURN OPEN

THE FOLLOWING PAGES ARE DUPLICATES OF ILLUSTRATIONS APPEARING ELSEWHERE IN THIS REPORT. THEY HAVE BEEN REPRODUCED HERE BY A DIFFERENT METHOD TO PROVIDE BETTER DETAIL