H-1.

OPERATIONS INSTRUCTIONS MANUAL

# PRECISION TORQUE MEASURING SYSTEM

MODEL NO. TMS 68



MARCH, 1965

DYNAMICS RESEARCH CORPORATION
STONEHAM, MASS., 02180

H-1

# OPERATIONS INSTRUCTION MANUAL

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38 Montvale Avenue
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# I
# INTRODUCTION

The Precision Torque Measuring System is an electromechanical system used for measuring torques in the range of 0.1 to 50,000 dyne-cm where low threshold and high accuracy are required. The system, shown in Figure 1.1, consists of a gas bearing with enclosure, and a console. The bearing supports the test specimen, and together with the electronics in the console constitute a torque feedback system. The console also contains a strip chart recorder, gas controls, and a vacuum pump.

The system is divided into three functional groups:

> Gas Bearing - Supports the test specimen. Two microsyns provide signal output and torque feedback for closed loop operation.
>
> Electronics - Torque feedback amplifiers and torque readouts - Inductive product resolver and strip chart recorder.
>
> Vacuum System - Enclosure with pump provides for operating the bearing in a helium atmosphere.

Section II and III deal with the Physical and Theory of Operation description respectively. The theory of operation discusses the design approach of the several subsystems. System theory equations are derived along with the calibration procedure.

Sections IV, V, and VI contain Installation, Operation, and Maintenance instructions respectively.

# II
# GENERAL DISCUSSION

## 2.1 GENERAL

The Precision Torque Measuring System consists of three major assemblies: a Gas Bearing with fixtures, a Console, and a Vacuum Enclosure. The gas bearing supports the test specimen and acts as the torque summing device operating with the console electronics in a feedback system.

The console also contains a Gas Control Panel and a vacuum pump. This Panel controls the gas to the bearing, the vacuum chamber pressure, and the chamber helium atmosphere option. The vacuum chamber is a plastic enclosure in which the gas bearing operates.

The following paragraphs give a description of the system.

## 2.2 GAS BEARING WITH FIXTURES

The gas bearing is shown in Figure 2.1. The gas bearing journal supports an adaptor plate upon which a fixture mounts. Five fixtures are provided, one for each gyro wheel configuration. The fixture supports the wheel with its spin axis aligned with the bearing axis. The bearing housing is rotatable about the trunnion axis, allowing the test wheel to operate with its spin axis aligned with, or normal to, the gravity vector. A hand crank facilitates rotation of the housing.

## 2.3 CONSOLE

The console contains the electronic and gas control equipment. The console subsystems are:

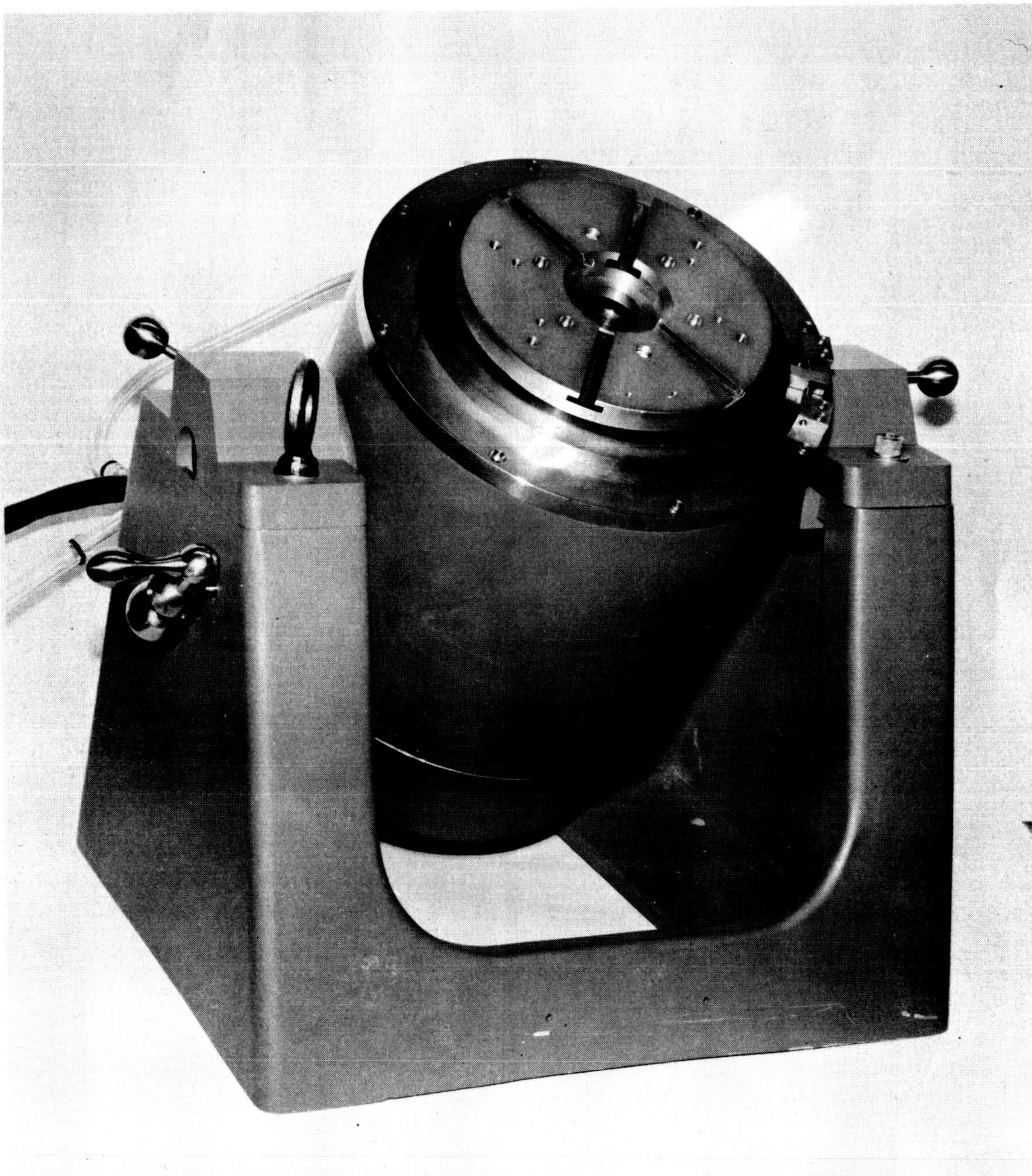

Figure 2.1 GAS BEARING

A. Electronics

1. Power Unit
2. Torque-to-Balance Unit
3. Monitor Unit
4. Recorder

B. Gas Control

1. Gas Control Panel
2. Vacuum pump

The interconnections among subsystems is shown in Figure 2.2. Subsystem functions are described in the following sections.

## 2.4 POWER UNIT

The Power Unit (see Figure 2.3) provides the main power control to the system. Switching and fusing are located on the front panel for the torque-to-balance (TTB) electronics and vacuum pump. This unit also contains the dc power supplies for the Torque-to-Balance Unit.

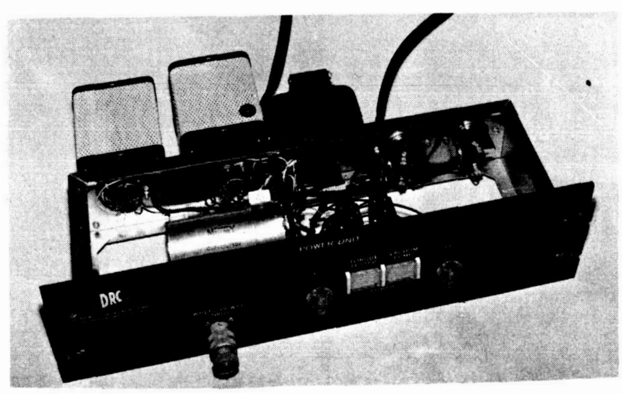


Figure 2.3 POWER UNIT

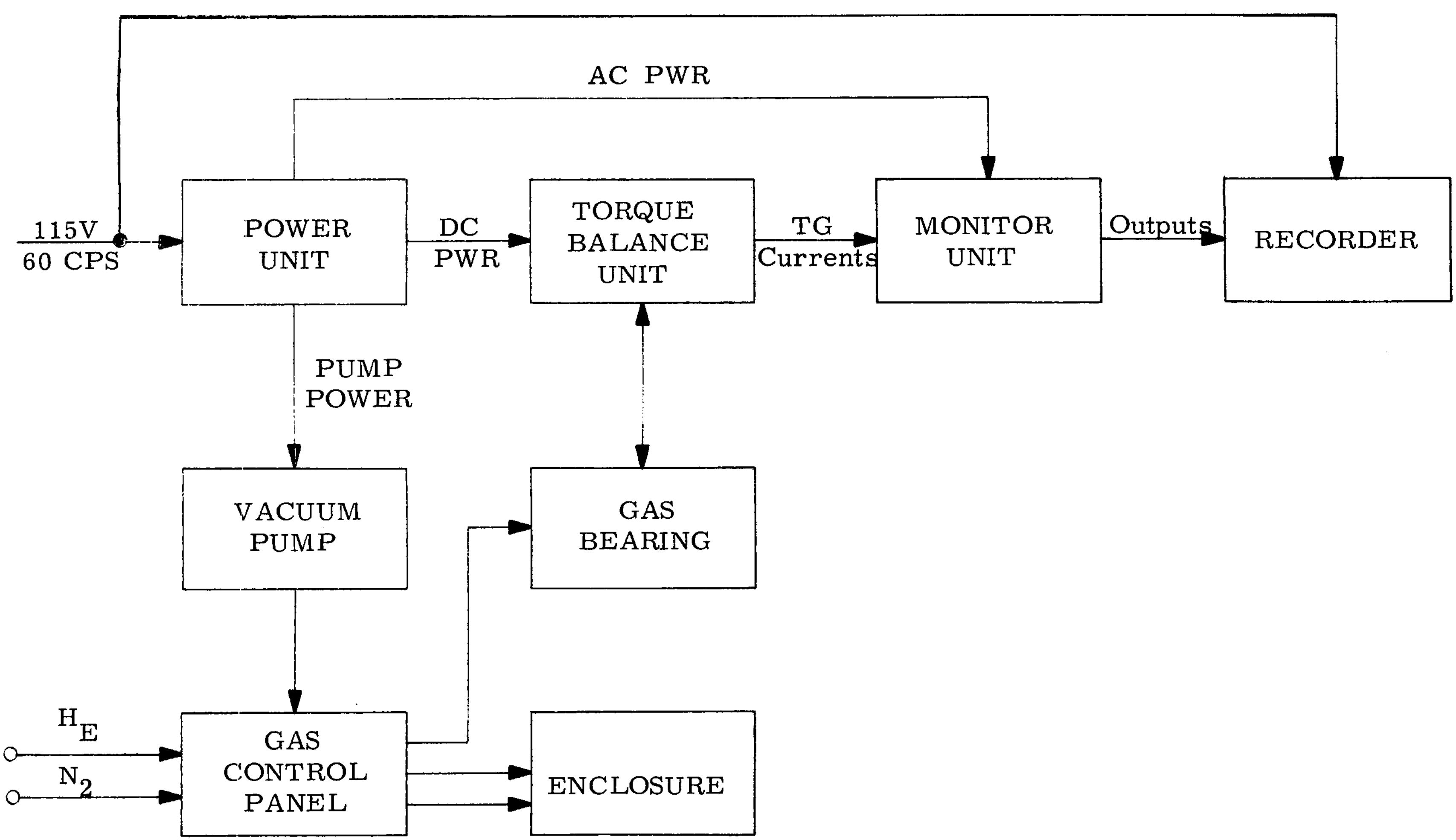


Figure 2.2 SYSTEM INTERCONNECTIONS

## 2.5 TORQUE-TO-BALANCE UNIT

This unit (shown in Figure 2.4) contains the electronics which provide the torque feedback around the gas bearing. It is powered by the Power Unit, and connects with the bearing by a single cable. Torque readout is provided by routing the microsyn torque generator currents through the Monitor Unit.

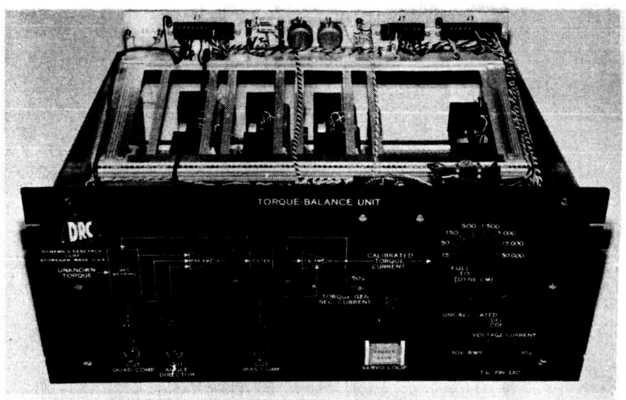


**Figure 2.4 TORQUE-TO-BALANCE UNIT**

## 2.6 MONITOR UNIT

The Monitor Unit (shown in Figure 2.5) contains the Product Resolver which is the torque readout device.
Its inputs are the torque generator currents; the output is a dc signal which is monitored at the front panel, as well as by the recorder. An expanded scale is also provided.

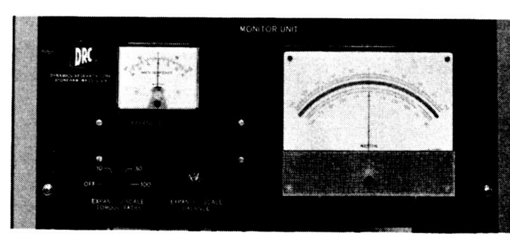


**Figure 2.5 MONITOR UNIT**

## 2.7 RECORDER

The recorder is a Sanborn two-channel unit. Both the direct torque scale and expanded scale are monitored.

## 2.8 GAS CONTROL PANEL

The Gas Control Panel (shown in Figure 2.6) is mounted in the console. It allows the operator to control the selection of bearing gas and to operate the enclosure vacuum pump.

**Figure 2.6 GAS CONTROL PANEL**

## 2.9 VACUUM PUMP

The vacuum pump operates with the enclosure and is used when the bearing is to be operated in helium. The pump with relief valve enables the chamber to be evacuated to 28 in. Hg. prior to filling the chamber with helium. A positive pressure relief valve maintains the enclosure pressure at one atmosphere when helium is admitted to the chamber and bearing.

## 2.10 VACUUM ENCLOSURE

The third major assembly is the vacuum enclosure (shown in Figure 1.1). The vacuum enclosure is a plastic box fabricated in two sections. The lower section, the base, holds the bearing with gas and electrical connectors. The upper section is a removable cover. The enclosure was designed to support 1.5 psi differential pressure.

## III
## THEORY OF OPERATION

### 3.1 SYSTEM THEORY

Figure 3.1 is a physical block diagram of the Torque Measurement System. The elements of the system are the gas bearing, electronic amplifiers, and product resolver. The transfer functions of these components are shown in the mathematical block diagram of Figure 3.2.

A torque, $T_M$, acting on the test motor is the quantity to be measured. This is accomplished indirectly by measuring the feedback torque, $T_F$, required to stabilize the bearing. The feedback loop is closed in the following manner.

The net torque on the gas bearing, $T_\epsilon$, is the difference between $T_F$ and $T_M$ as shown. $T_\epsilon$ acts on the bearing according to its transfer function. Bearing motion is sensed by the microsyn signal generator (SG) whose sensitivity is $S_{SG}$. The SG output voltage is amplified and converted to a current, $I_S$, which is fed back to the bearing torque generator (TG) secondary. The feedback torque is:

$$T_F = S_{TG} I_P I_S \qquad \text{Eq. 3-1}$$

where, $I_P$ is the TG primary current excitation, and $S_{TG}$ is the TG sensitivity.

The resulting closed loop transfer function of the system is:

$$\frac{T_F}{T_M} = \frac{K S_{SG} S_{TG} I_P}{J\left(p^2 + \frac{B}{J} p + \frac{K S_{SG} S_{TG} I_P}{J}\right)} \qquad \text{Eq. 3-2}$$

B and J are the bearing damping and inertia respectively.

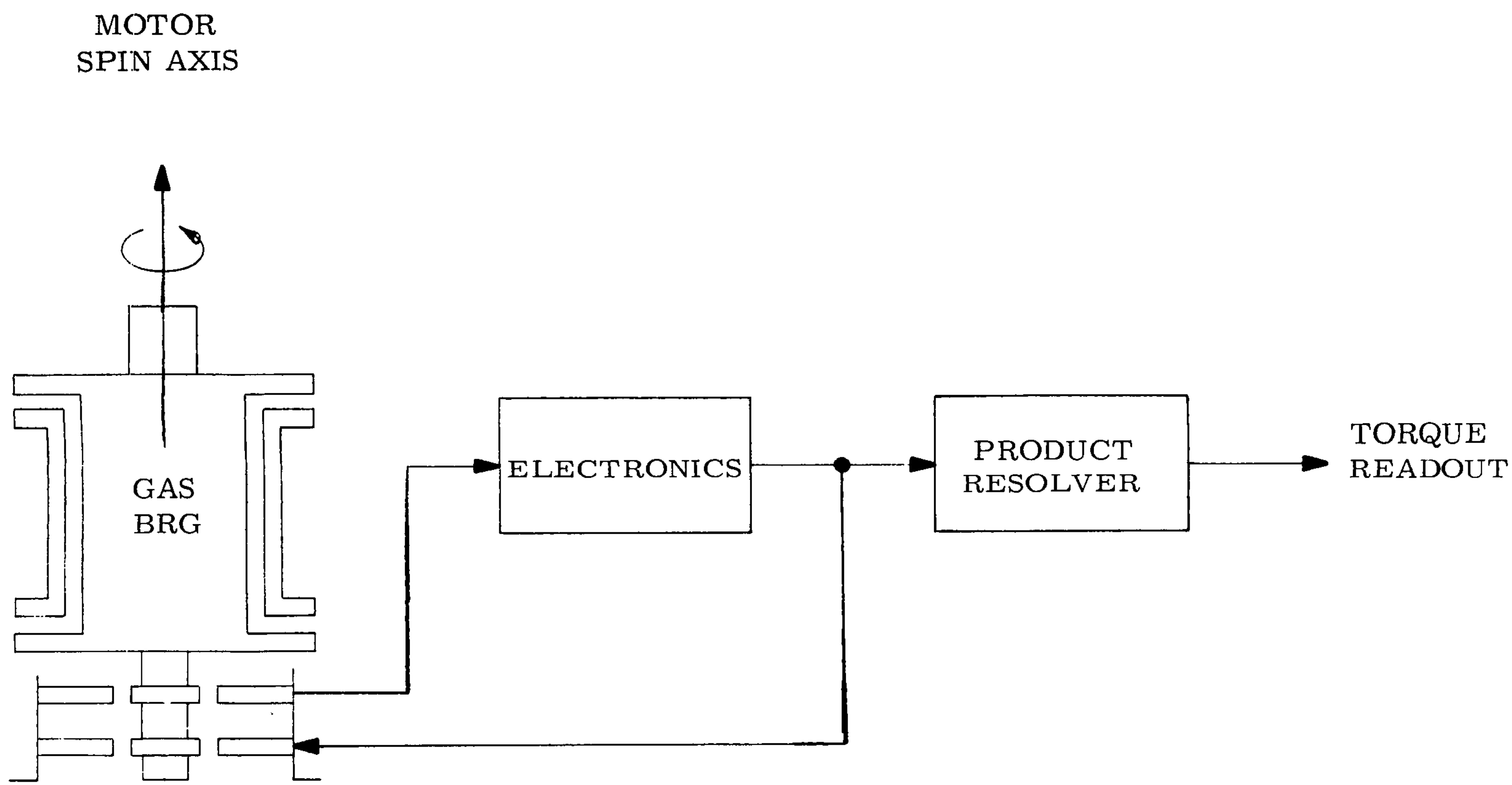


Figure 3.1 TORQUE MEASUREMENT SYSTEM, BLOCK DIAGRAM

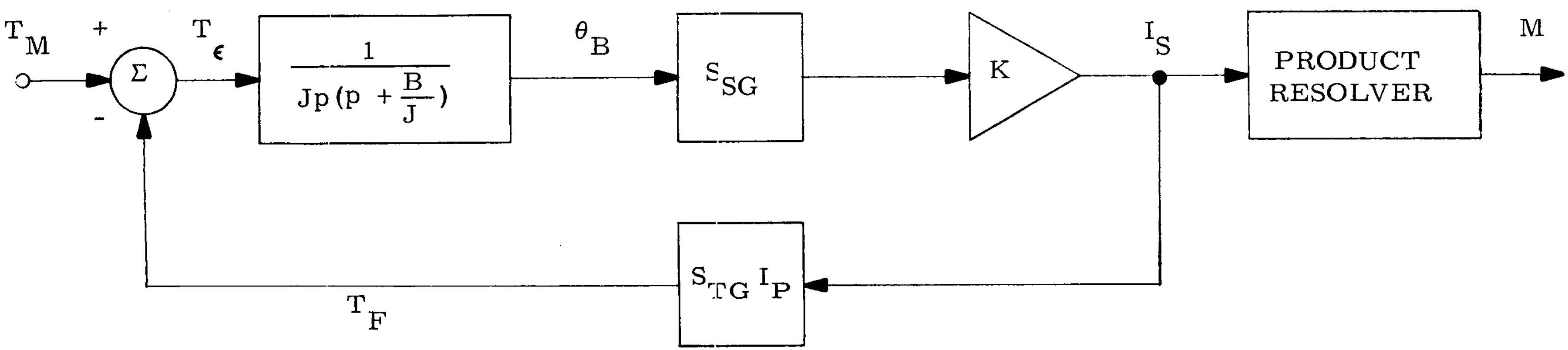


Figure 3.2 MATHEMATICAL BLOCK DIAGRAM

Torque is monitored by measuring the TG current product $I_P I_S$ in the following manner. The TG primary current also excites one winding of the product resolver; the other winding of the product resolver is excited by a current $I_r$, where;

$$I_r = K_S I_S \qquad \text{Eq. 3-3}$$

$K_S$ is a variable depending upon the selected output scale. The product resolver output, M, is proportional to the input current product:

$$M = K_r I_r I_P \qquad \text{Eq. 3-4}$$

where; $K_r$ is the product resolver sensitivity.

When Eq. 3-3 is substituted into Eq. 3-4, a relationship between the TG currents and resolver output is yielded:

$$M = K_r K_S I_P I_S \qquad \text{Eq. 3-5}$$

The torque equation, Eq. 3-1, is now inserted into Eq. 3-5:

$$M = \frac{K_r K_S}{S_{TG}} T_F \qquad \text{Eq. 3-6}$$

Eq. 3-6 is the final relationship between torque feedback and resolver output. The sensitivity is dependent upon the sensitivity of the TG, product resolver, and scale selector amplifier.

For a constant input, $T_M$, the steady-state torque relationship of Eq. 3-2 reduces to

$$\frac{T_F}{T_M} = 1 \qquad \text{Eq. 3-7}$$

and therefore

$$M = \frac{K_r K_S}{S_{TG}} T_M \qquad \text{Eq. 3-8}$$

## 3.2 GAS BEARING

The gas bearing assembly provides a friction-free means for measuring the motor torques. The bearing rotor acts as the torque summing member: input torques are applied directly by the test specimen fixed to the rotor, feedback torque is applied by a microsyn torque generator, and viscous damping is applied by an oil damper to stabilize the system.

The test specimen is mounted on the rotor by one of five adaptors supplied with the system. The adaptors are shown in Figure 3.3. There is an adaptor for each motor configuration. Motor power is applied through flex leads at the bottom of the bearing.

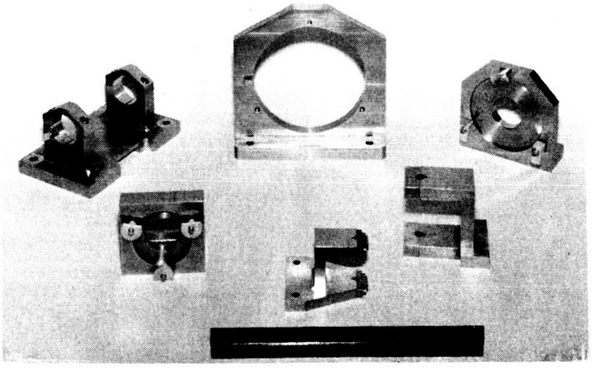

Figure 3.3 ADAPTORS

There are two identical microsyns in the Torque Tester. One is used as a torque generator as noted above; the second unit is a signal generator used to pick off bearing rotor motions. The microsyns are used with the electronics subsystem providing a feedback system to stabilize the bearing.

This bearing system was designed to minimize turbine torques subject to the requirements of load capacity, economy of gas flow, and stability. A fixed orifice design gives better control of the gas flow pattern than could be achieved with an inherent orifice design, and gives better load capacity per unit size and unit supply pressure than could be obtained by using a step bearing.

The bearings are designed to operate with either nitrogen or helium at 15 psig supply pressure.

## 3.3 ELECTRONICS

The electronics provides the means of torque balancing and the capability to read out this torque. The balancing torque is provided by two amplifiers operating with the gas bearing to provide a feedback control system. One amplifier, the preamp, amplifies the bearing signal generator output; auxiliary preamp inputs facilitate quadrature compensation and angle directing. This function is shown in Figure 3.4.

The preamp output connects to the gain control potentiometer which in turn drives the TG drive amplifier. The second input to the TG drive amplifier is the fixed bias compensation which is a manually controlled input used to buck out any bias torques in the bearing. The output of the TG amplifier excites the torque generator secondary on the bearing.

Figure 3.5 shows the torque readout method. This function also requires two amplifiers: a preamp and the Inductronic drive amplifier. The preamp monitors the voltage across the current sensing resistor on the TG drive amplifier. The preamp output is connected to the input of the Inductronic drive amplifier which excites one winding of the Inductronic Product Resolver.

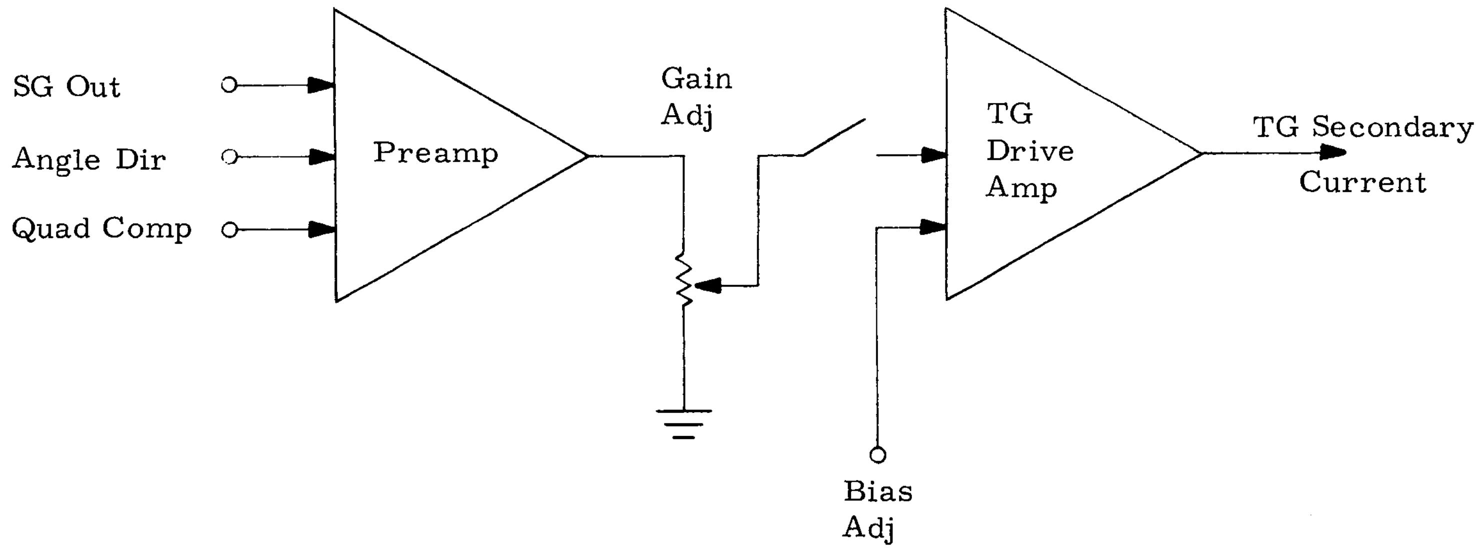


Figure 3.4 TORQUE FEEDBACK LOOP

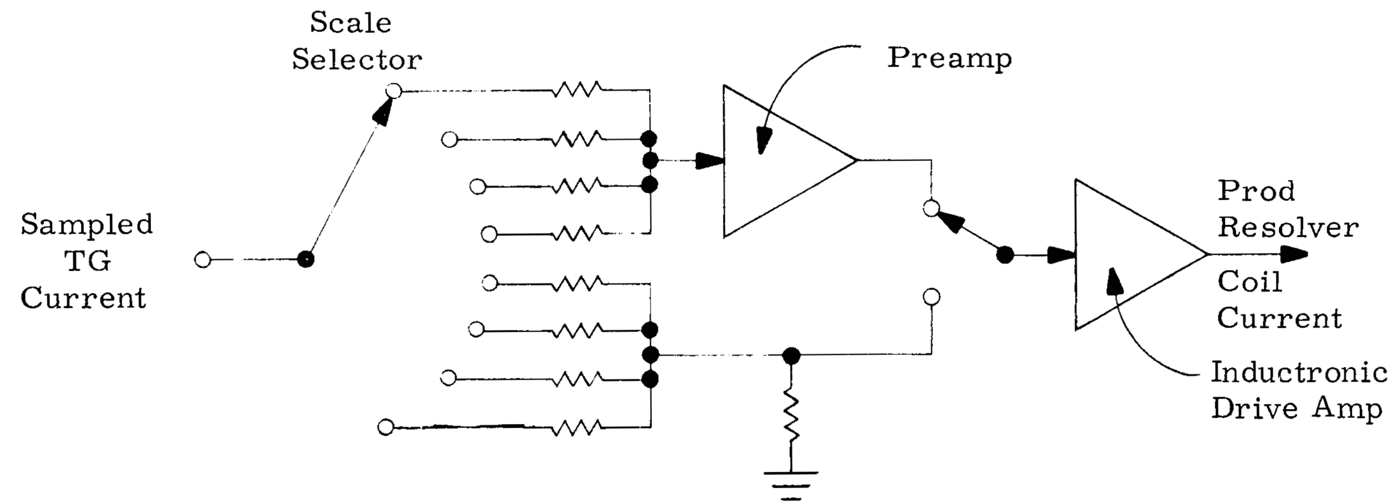


Figure 3-5 TORQUE READOUT SCHEMATIC

The other winding of the Inductronic is excited by the fixed TG primary current as noted in paragraph 3.2. Readout sensitivity is controlled by the selection of preamp gain.

An expanded scale is provided at the Inductronic output. This utilizes an operational amplifier which sums the Inductronic output and an adjustable buck out voltage. Both outputs, the full torque and expanded scale, are available on front panel meters, as well as on a strip chart recorder.

The electronics system operates from 115V 60 cps line power. It provides its own ac and dc excitation. The ac excitation is generated from a tuning fork oscillator and power amplifier. The dc power consists of a commercial supply for the low level circuits and a DRC designed circuit for the power amplifiers.

## 3.4 SYSTEM CALIBRATION

The Torque Tester is calibrated using both electrical and mechanical known torque inputs. The electrical technique uses the DRC microsyn standard to calibrate the 0-1000 dyne-cm range. Figure 3.6 is a schematic of the test setup.

The microsyn is excited by a 1kc power source with primary and secondary windings in series. Microsyn current is measured by monitoring the voltage across a 10Ω sampling resistor. Input torque is set by varying the current through the microsyn windings. With the windings in series, the torque is proportional to the square of the input current.

At the higher torque ranges the calibration torque is applied mechanically. Figure 3.7 shows this technique. The bearing axis is set to the horizontal

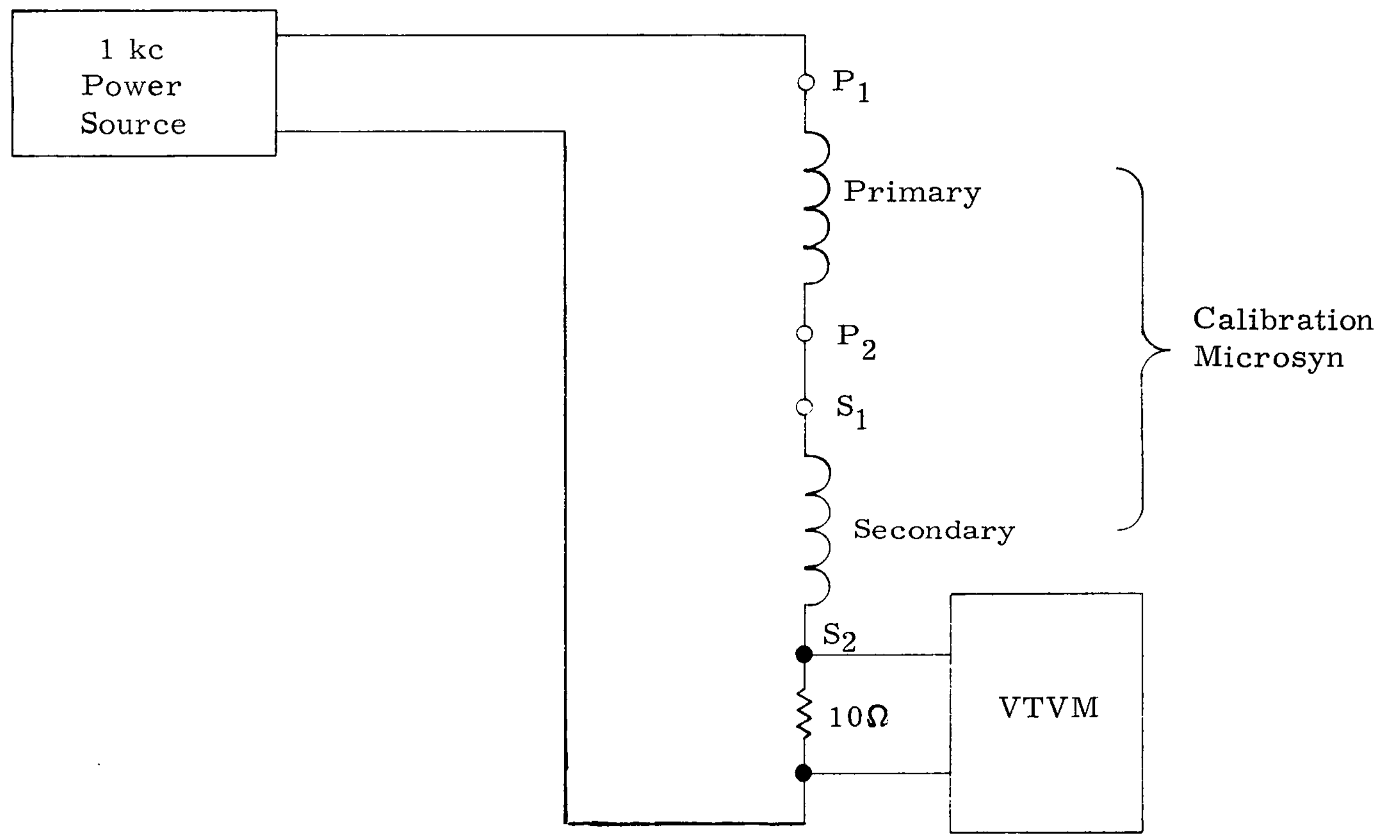


Figure 3.6 CALIBRATION SETUP - ELECTRICAL TORQUE INPUT

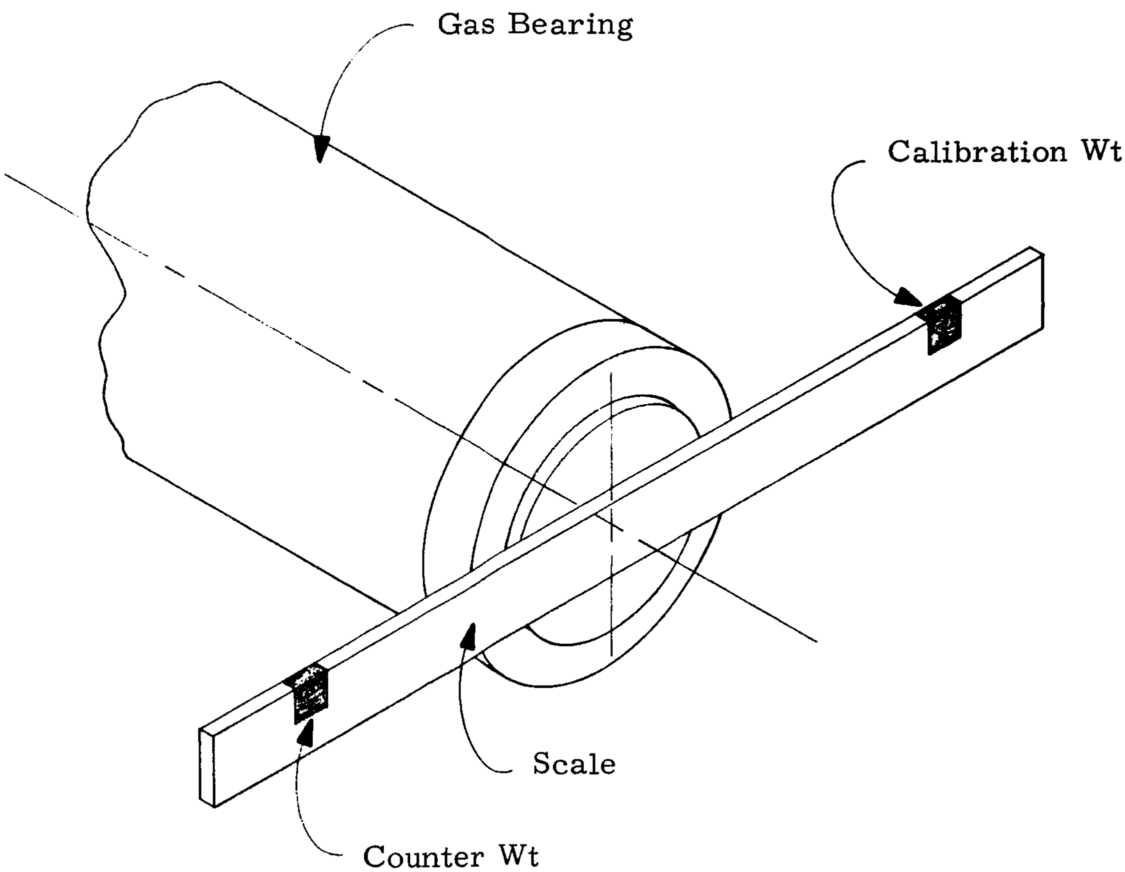


Figure 3.7 CALIBRATION SETUP - MECHANICAL TORQUE INPUT

position. A scale is fixed to the bearing as shown. Two weights are set on the scale; one, the calibration weight, is set at a convenient point on the scale; the second, a counterweight, is adjusted so that the output meter reads zero.

A known input is applied by sliding the calibration weight by a known increment. This technique is used to calibrate the 150 dyne-cm scale through 50,000 dyne-cm. The microsyn is used to calibrate the lower scale through 1500 dyne-cm. The overlapping of calibration ranges provides an additional check on the apparatus.

The mechanical method's accuracy depends on the accuracy of the increment by which the calibration weight is moved. This accuracy is 0.01 inch. Since the smallest increment is 1.0 inch, an accuracy of 1% is achieved.

# IV
# INSTALLATION

## 4.1 GENERAL

This section describes the installation procedure for the Precision Torque Measuring System. The following steps must be followed in order to insure proper installation.

## 4.2 PRIMARY POWER

Plug the console power cord into a 115V 60 cps outlet. The console is rated at 10 amps.

## 4.3 GAS SUPPLY

a. Insure gas lines are clean.
b. Connect 15 psig gas supplies to couplings on Gas Control Unit.
c. Connect the gas supplies and vacuum lines to the vacuum chamber.
d. Blow gas lines.

## 4.4 GAS BEARING

a. Place gas bearing into the vacuum chamber, and connect gas and electrical lines.
b. Apply gas pressure and verify that bearing operates.

## 4.5 ELECTRONICS

a. Apply power by depressing the Torque Tester power switch located on the Power Unit.

b. Depress the Servo switch to connect the Closed Loop Mode.

c. Rotate the TORQUE SCALE switch to a convenient scale.

d. The system is ready for use.

# V

# SYSTEM OPERATION

## 5.1 GENERAL

This section describes the operation and maintenance procedure for the Precision Torque Measuring System controls.

## 5.2 GAS BEARING CONTROLS

The Gas Bearing is operated by the Gas Control Panel located in the console. With the gases ($N_2$ and He) connected to their respective inlets, the operator may select the bearing gas by rotating the proper valve as indicated on the panel. The bearing should be pressurized whenever test specimens or fixtures are mounted on the adaptor plate.

## 5.3 ELECTRONICS CONTROLS

The electronics consist of the following subsystems:

Power Unit
Torque-to-Balance Unit
Monitor Unit
Recorder

The operation of the subsystems is discussed in the following paragraphs.

### 5.3.1 Power Unit

The Power Unit controls the AC power to the electronics and vacuum pump. The AC power is controlled by depressing the Electronics button and Pump button as required. (Ref. Figure 2.3) The receptacle provided on the front panel, which is supplied with a mating connector, is the wheel power input to the test motor.

### 5.3.2 Torque-to-Balance Unit

The Torque-to-Balance Unit contains the feedback electronics of the Torque Tester. The following controls are provided:

Quadrature Compensation: This control provides a variable quadrature signal that is used to cancel the quadrature component of the signal generator.

By monitoring the preamp output Lissajous pattern with the excitation voltage (test points located on the front panel), the operator can cancel the quadrature component by rotating the Quadrature Compensation. This control may be disconnected from the circuit by placing the toggle switch in the OFF position.

Angle Director: This control provides an in-phase signal used to operate the torque feedback loop away from the microsyn null. It is useful in checking microsyn elastic restraint. It is not normally used in torque measurement; therefore, the toggle switch should be in the OUT position.

Servo Gain: This control varies the loop gain of the feedback system. The operator may set the gain for optimum response by recording the transient response on the recorder and making appropriate gain adjustments. An increased gain lowers system damping while raising the natural frequency. Correspondingly, a decreased gain lowers the natural frequency and results in a slow response.

Servo Loop: The servo loop may be opened or closed by depressing the switch. The control is used in making transient response checks or in trouble shooting the system where the open loop condition eases fault finding.

Bias Adjust: A residual torque on the gas bearing may be electrically compensated by this control so that the product resolver output reads zero at the start of a test.

Degauss Control: This control varies the amplitude of the excitation. It is used to demagnetize the microsyns. In normal system operation the excitation voltage is applied and removed suddenly upon turn-on and turn-off of power. To demagnetize the microsyns, the control is rotated counter-clockwise to the stop and then clockwise to the calibrated position as indicated by the lamp. The result introduced a slow variation in the amplitude of the excitation which removes any residual magnetization by allowing the microsyn material to demagnetize its B-H curve.

Full Scale Torque: This control sets the full scale torque of the system. The following monitor points are provided on the front panel.

> Torque Generator Secondary Current: The Torque Generator Secondary Current is measured at the front panel by monitoring the voltage across the torque generator drive amplifier current feedback resistor.
>
> Torque Generator Primary Excitation: The excitation voltage and torque generator primary current are also available on the front panel. The excitation voltage TP is used for checking system performance. The torque generator primary current is sampled by a 10 $\Omega$ resistor.

### 5.3.3 Monitor Unit

The Monitor Unit contains the product resolver and associated readout circuits. Two meters are located on the front panel. The larger is the system torque readout; the smaller is the expanded scale readout. The following controls are located on this panel.

Expanded Scale Torque Ratio: This control sets the gain of the expanded scale provision by a four-position switch. Gains of 10, 30, and 100 times the Full Scale Torque setting are provided.

Expanded Scale Balance: The expanded scale is balanced by rotating this control until the expanded scale meter reads near zero. This provision provides the facility to read variations about a large torque level.

5.3.4 Recorder

Refer to the manufacturers handbook for operation of the recorder (Model No. 320).

## 5.4 VACUUM SYSTEM

The vacuum pump is turned on by depressing the pump power switch on the Power Unit; the relief valve automatically regulates the chamber pressure at 28 in. Hg.

## 5.5 MAINTENANCE

The following paragraphs describe the maintenance and safety procedures of the Gas Bearing, Electronics, and Commercial Equipment.

### 5.5.1 Gas Bearing

a. When not in use, keep a dust cover over the complete bearing fixture.
b. Keep fixture in a reasonably clean area.
c. Do not drill, file, or rework any test fixture while it is mounted on or near the bearing fixture.
d. Keep air pressure on bearing whenever working with unit.
e. Never pour any liquids over the top of the bearing fixture.

f. When transporting bearing from one work area to another, keep the bearing under air pressure, if possible. If not, carry bearing, do not roll on a cart.

g. Inspect and change, if necessary, millipore filter every time air line coupling at fixture is disconnected.

h. DO NOT rotate bearing rotor whenever air pressure is not present on the bearing fixture.

I. When changing air supplies, always blow air line before installation.

### 5.5.2 Electronics

The following adjustments are located at the rear of the electronics chassis.

Power Supply Adjustment: The -43 VDC adjustment is located on the power supply board (A10).

Power Amp Bias Adjustment: The power amplifier located in positions A3, A5, A7 have a bias adjust potentiometer. This potentiometer is set so that the amplifier output clips symmetrically. See Figure 5.1 for the location of this control.

Torque Generator Drive Amp Gain: This is a noncritical adjustment available for conveniently setting the gain of this amplifier. Refer to Figure 5.1 for its location.

Excitation Adjustment: The excitation amplifier gain adjust is set for a 10 VRMS output as measured on the front panel test points. Refer to Figure 5.1 for its location.

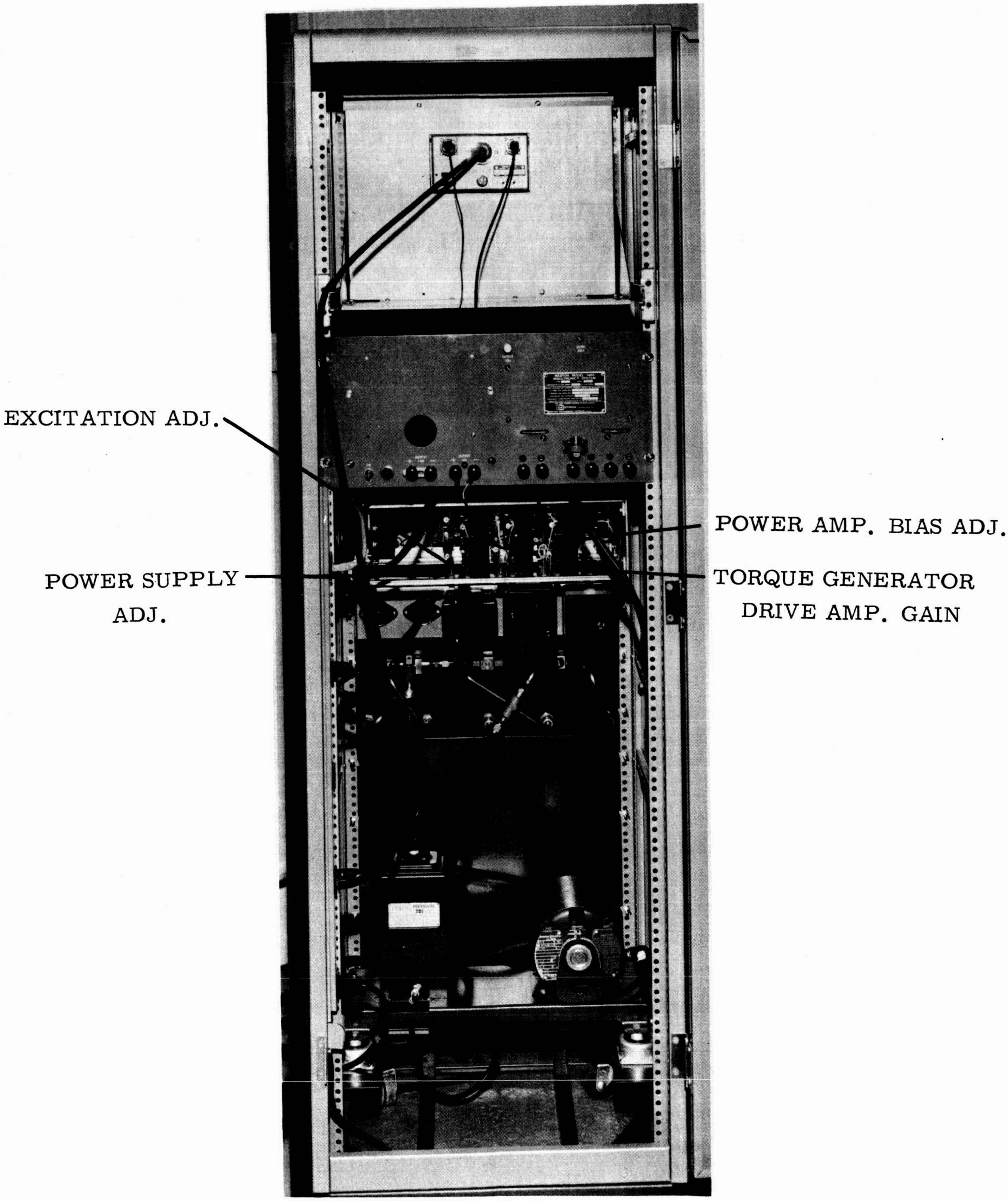


Figure 5.1 ELECTRONICS CONSOLE REAR VIEW

Inductronic Drive Amp Gain: This gain is set during calibration.

Microsyn Current Pots: Two potentiometers are located on the connector bracket. R8 sets the torque generator current at 100 ma rms. R7 sets the signal generator current at 100 ma rms. Torque generator current is monitored at the front panel; signal generator current is monitored by measuring the voltage across the 10 $\Omega$ resistor (R6) located between V1 and R7.

Scale Calibration Adjustment: Five scale calibration potentiometers are located on the scale selector switch on the front panel. Refer to Section 3.5 (Calibration Procedure) for operation.

Frequency Adjustment: The oscillator is provided with a fine frequency adjustment potentiometer. The amplitude regulator output is monitored and set to 1 kc $\pm$ 10 cps.

### 5.5.3 Commercial Equipment

Refer to the manufacturers handbook for maintenance of the Weston Product Resolver, Cenco Vacuum Pump, and the Sanborn Recorder.

DYNAMICS RESEARCH CORPORATION

29 March 1965

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Cat 15

N65-27829

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama

Attention: Purchasing Office, PR-RC

Gentlemen:

SUBJECT: Final Progress Report
Covering Period 24 June 1964 through 17 March 1965
Contract NAS 8-11724 - DRC Job No. 1043

The following is a final report submitted in compliance with the subject contract. Included in this report are DRC's recommendations for further investigation, as well as a detailed discussion of the Electronics, Gas Bearing, Microsyn, Damper, and Calibration appearing in Attachment A.

Also attached as part of the final report is an Operations Instruction Manual. The manual contains photographs, schematics, sketches, and calibration data for the Precision Torque Measuring System. A detailed discussion on Installation and Operation also appears in the manual.

RECOMMENDATIONS

Recommendations for further investigation are threefold:

Lower Torque Ranges

The present torque measuring system has a capability of measuring down to 0.1 dyne-cm. With proper modifications to the electronics, it is felt that the system range could be extended down to 0.01 dyne-cm. This would be advantageous for measuring extremely low motor noise and for evaluating microsyns and flex leads of gyros. At the lower ranges, some system response time may be sacrificed in order to utilize the filtering

TELEPHONE 438-3900
38 MONTVALE AVENUE, STONEHAM, MASSACHUSETTS

properties of the torque-to-balance loop. Since fast response time is not an important system parameter for measurement of microsyn reaction torques, the trade-off would not adversely affect the measurements.

Viscous Damping

The present system was designed to provide radial and rotational damping. In testing the bearing, it was found that radial damping was not necessary. In view of our finding, it is recommended that a simpler mechanical viscous damper or an electrical viscous damper be investigated. In so doing, the fabrication costs would be reduced.

All Solid State System

At present, all of the electronics are solid state with the exception of the Product Resolver. Investigation into the use of a Hall multiplier, which has no moving parts, is recommended. An all solid state system would result in greater reliability, longer life, minimum maintenance, and lower cost.

If you have any questions regarding the information contained herein, please do not hesitate to contact the undersigned.

Very truly yours,

DYNAMICS RESEARCH CORPORATION

Harry B Silverman

Harry B. Silverman
Contract Administrator

HBS/js

Enc. Attachment A, Design Information
Attachment B, List of Reproducible Prints*
Operations Instructions Manual, H-1

*Reproducible prints are being forwarded under separate cover.

D Y N A M I C S R E S E A R C H C O R P O R A T I O N

DESIGN INFORMATION

The major areas are as follows:

1. Electronics
2. Gas Bearing
3. Microsyn
4. Damper
5. Calibration

## ELECTRONICS

The electronics are completely transistorized with the exception of the product resolver. The transistorized circuitry is low on power consumption, high in reliability, and easy to fabricate. The philosophy was to minimize design effort by making use of a single circuit design in as many applications as possible. Therefore, one power amplifier design is used in three system functions: TG drive amplifier, system excitation amplifier, and product resolver amplifier. One preamp design is used in the torque-to-balance loop and in the calibration circuit.

A special DC supply was designed to work with the power amplifiers. The requirement of several bias voltages and low noise levels made it more practical to design a special unit for this function. Commercial supplies were used for the other circuits.

## GAS BEARING

The gas bearing is discussed in the following paragraphs.

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Design Basis

This bearing system was designed to minimize turbine torques subject to the requirements of load capacity, economy of gas flow, and stability. A fixed orifice design was chosen to give better control of the gas flow pattern than could be achieved with an inherent orifice design. The fixed orifice also gives better load capacity per unit size and unit supply pressure than could be obtained by using a step bearing.

The bearings are design to operate with either nitrogen or helium at 15 psig, supply pressure.

Performance

The calculated performance characteristics for the thrust and journal bearings are listed in Tables 1 and 2, respectively.

Table 1 THRUST BEARING PERFORMANCE CHARACTERISTICS

| Gas | Stiffness lb/in | Max. Load lb. | Gas Flow cfm. | Resonant Freq., cps | Damping Ratio |
|---|---|---|---|---|---|
| $N_2$ | $18.3 \times 10^4$ | 53 | 0.131 | 326 | 1.0 |
| $H_e$ | $13.8 \times 10^4$ | 44 | 0.258 | 308 | 1.17 |

Table 2 JOURNAL BEARING PERFORMANCE CHARACTERISTICS

| Gas | Stiffness lb/in | Gas Flow cfm. | Resonant Freq., cps | | Minimum Damping Ratio* |
|---|---|---|---|---|---|
| $N_2$ | $15.6 \times 10^4$ | 0.53 | 488 | 248 | 0.15 |
| $H_e$ | $15.6 \times 10^4$ | 1.2 | 488 | 248 | 0.26 |

*Not including external damping.

Bearing Parameters

Thrust Bearings: Supply pressure = 15 psig., clearance 6.4 x $10^{-4}$ inch. Feeding orifice diameter = 0.008 inch.

Journal Bearings: Supply pressure = 15 psig., radial clearance = 1.2 x $10^{-3}$ inch. Feeding orifice diameter = 0.008 inch.

Fabrication

The performance of the bearing is very sensitive to deviations of clearance, both local and gross, from nominal values. The turbine torques will be a direct function of assymmetry introduced in manufacture.

The stator is final machined after installation of the feeding orifice plugs. Both stator and rotor were completely inspected for roundness, parallelism and flatness of thrust faces, and for clearance dimensions.

Extreme care was taken to flush all dirt and machining chips from the unit before assembly, and a $5\mu$ filter is used before the gas manifold.

MICROSYN

The microsyn used for the signal generator and torque generator was designed by DRC to meet the 50,000 dyne-cm full scale torque requirement. Both rotor and stator laminations were stamped from Carpenter 49. This material has a sufficiently high permeability and saturation flux density, and is easier to machine than such similar materials as Hypernik. Stamping, bonding, and grinding were performed by vendors to DRC specifications. Coil winding and final assembly was performed by DRC personnel.

## DAMPER

Damping is required for two reasons: First to stabilize the torque-to-balance loop and second to stabilize the gas bearing.

The damper was designed to provide rotational damping for the servo loop and radial damping for the bearing itself. When the bearing was built, it was found that the bearing was sufficiently stable without additional damping. Therefore, only rotational damping was utilized in the final system.

## CALIBRATION

The system was calibrated by the methods of Paragraph 3.4 of the attached manual. The results are shown in the following table (Table 3).

Table 3 CALIBRATION DATA

| Scale Calibration Technique | Input Torque | Indicated Torque |
|---|---|---|
| 50,000 Mechanical | 49,000 | 49,000 |
| 50,000 " | 14,700 | 15,000 |
| 15,000 " | 14,700 | 14,900 |
| 15,000 " | 4,900 | 5,000 |
| 5,000 " | 4,900 | 5,100 |
| 5,000 " | 1,470 | 1,520 |
| 1,500 " | 1,470 | 1,480 |
| 1,500 " | 490 | 490 |
| 500 " | 490 | 495 |
| 500 " | 147 | 145 |
| 150 " | 147 | 150 |
| 1,500 Electrical | 1,000 | 1,000 |
| 1,500 " | 500 | 490 |
| 500 " | 500 | 490 |
| 500 " | 100 | 100 |

Table 3 CALIBRATION DATA (Cont'd.)

| Scale Calibration Technique | Input Torque | Indicated Torque |
|---|---|---|
| 150 Electrical | 100 | 100 |
| 150 " | 50 | 48 |
| 50 " | 50 | 48 |
| 50 " | 10 | 9.7 |
| 15 " | 10 | 9.5 |

DYNAMICS RESEARCH CORPORATION

## LIST OF REPRODUCIBLE PRINTS

| Print Number | Title |
|---|---|
| D-100000 | Panel Assembly Drawing Monitor Unit |
| C-100001 | Front Panel Labeling Monitor |
| D-100002 | Panel Machining Monitor Unit |
| C-100003 | Connector Mounting Bar for Torque Balance Unit |
| D-100004 | Torque Balance Unit Hanger Bracket |
| D-100005 | Torque Balance Unit Chassis Assembly |
| D-100006 | Assembly Front Panel Torque Balance Unit |
| C-100007 | Labeling Torque Balance Unit |
| C-100008 | Panel Machining Torque Balance Unit |
| D-100009 | Precision Torque Tester Block Diagram |
| D-100010 | Power Unit Assembly |
| C-100011 | Power Unit Schematic |
| C-100012 | Power Unit Chassis Machining |
| C-100013 | Power Unit Panel Machining |
| C-100014 | Power Unit Labeling Drawing |
| C-100015 | Power Unit Rectifier Board Machining & Assembly |
| A-100017 | Schematic - Preamplifier |
| C-100018 | Assembly - Preamplifier P.C. Board |
| C-100019 | Assembly - DC Power Supply P.C. Board |
| B-100020 | Schematic - DC Power Supply |
| C-100021 | Master - Preamp. P.C. Board |
| C-100022 | Machining - Preamp. P.C. Board |

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| Print Number | Title |
|---|---|
| B-100023 | Schematic - Phase Splitter |
| C-100024 | Master - Phase Splitter P.C. Board |
| C-100025 | Machining - Phase Splitter P.C. Board |
| C-100026 | Assembly - Phase Splitter P.C. Board |
| C-100027 | Assembly - Power Amplifier P.C. Board |
| B-100028 | Schematic - Power Amplifier |
| C-100029 | Master Power Amplifier P.C. Board |
| C-100030 | Machining Power Amplifier P.C. Board |
| B-100031 | Machining Heat Sink Power Amplifier |
| C-100032 | Master D.C. Power Supply P.C. Board |
| C-100033 | Machining D.C. Power Supply P.C. Board |
| C-100034 | Machining Connector Bracket Torque Balance Unit |
| C-100035 | Assembly Connector Bracket Torque Balance Unit |
| C-100036 | Precision Torque Tester Assembly |
| D-100037 | Schematic Torque Balance Unit |
| C-100038 | Front Panel Labeling Gas Control Panel |
| C-100039 | Machining Gas Control Panel |
| D-100040 | Vacuum Enclosure |
| D-100041 | Assembly Gas Control Panel |
| B-100042 | Schematic Scale Selector Switch |
| B-100043 | Machining & Assembly of Scale Selector Switch Component Board |
| C-100044 | Wiring Diagram A.C. Power Circuit Power Unit |
| C-100045 | Wiring Diagram D.C. Power Circuit Power Unit |
| C-100055 | Master Oscillator & Filter Printed Circuit Board |
| C-100056 | Machining Oscillator & Filter Printed Circuit Board |
| C-100057 | Assembly Oscillator & Filter Printed Circuit Board |
| C-100058 | Schematic Oscillator and Filter |
| C-100059 | Cable Diagram Torque Balance Unit |
| B-100060 | Machining Component Board Monitor Unit |
| C-100061 | Assembly Component Board Monitor Unit |

| Print Number | Title |
|---|---|
| C-100062 | Machining & Assembly Vacuum Pump Isolation Mount |
| A-100063 | Master Microsyn Printed Circuit Terminal Board |
| A-100064 | Machining Microsyn Printed Circuit Terminal Board |
| A-100065 | Machining Microsyn Spacing Ring |
| A-100066 | Microsyn Insulator Ring |
| A-100067 | Microsyn Shield |
| C-100068 | Schematic Monitor Unit |
| B-100069 | Microsyn Rotor Assembly |
| B-100070 | Schematic 3.25 Microsyn |
| C-100071 | Wiring Diagram 3.25" Microsyn |
| A-100072 | Air Intake Gas Relief Valve |
| A-100073 | Chamber Atmosphere Connect Pipe |
| A-100074 | Chamber Evacuation Connect Pipe |
| A-100075 | Helium Supply Connect Pipe |
| A-100076 | Nitrogen Supply Connect Pipe |
| A-100077 | Air Bearing Connect Pipe |
| A-100080 | Microsyn Retaining Ring Torque Tester |
| B-100081 | Cable - Torque to Balance Unit to Vacuum Chamber |
| C-100082 | Assembly and Machining Filter Board |
| B-100086 | Gas Chamber and Air Bearing Wiring Diagram |
| C-100087 | Machine & Assembly Filter Board Torque to Balance Chassis |
| A-100088 | Emcor Enclosure Assembly for Precision Torque Tester Assembly |
| A-100089 | Coil, 50,000 Dyne-cm Microsyn |
| A-100090 | Stator, Torque Generator |
| A-100091 | Rotor, Torque Generator |
| A-100092 | 'O' Ring for Precision Torque Tester Vacuum Enclosure |
| B-100095 | Internal Cable Vacuum Chamber |

| Print Number | Title |
|---|---|
| A-1654 | Torque Tester Spring Bushing |
| A-1655 | Torque Tester Shaft Bushing |
| A-1656 | Torque Tester Stop Shaft |
| A-1657 | Torque Tester Shaft Coller |
| A-1658 | Torque Tester Brake Stud |
| A-1664 | Wire Tube Retainer Torque Tester |
| A-1665 | Wire Tube Support Torque Tester |
| A-1666 | Wire Support Tube Torque Tester |
| A-1667 | Retaining Pad Torque Tester |
| A-1668 | Stop Block Torque Tester |
| A-1670 | Filler Plug Torque Tester |
| | |
| B-1305 | Torque Tester Microsyn Shaft |
| B-1306 | Torque Tester Worm Gear |
| B-1310 | Torque Tester Brake Block |
| B-1311 | Torque Tester Brake Block |
| B-1313 | Torque Tester Orifice Carrier-Long |
| B-1314 | Torque Tester Orifice Plug |
| B-1315 | Torque Tester Worm & Bevel Gear Shaft |
| B-1316 | Torque Tester Terminal |
| B-1317 | Torque Tester Terminal |
| B-1318 | Torque Tester T-Slot Nut |
| B-1319 | Torque Tester Terminal Insulator |
| B-1320 | Torque Tester Bevel Gear Shaft |
| B-1321 | Torque Tester Level Bracket |
| B-1322 | Torque Tester Level Bracket |
| B-1323 | Torque Tester Orifice Carrier-Short |
| B-1324 | Torque Tester Orifice Carrier Assembly |
| B-1333 | Torque Tester Terminal Block |

| Print Number | Title |
|---|---|
| B-1334 | Torque Tester Terminal Board Assembly |
| B-1335 | Torque Tester Counter-Weight |
| B-1336 | Torque Tester Counter-Weight |
| | |
| C-1139 | Torque Tester Bottom Thrust Plate |
| C-1140 | Torque Tester Top Thrust Plate |
| C-1141 | Torque Tester Bearing Journal |
| C-1142 | Torque Tester Rotor Bearing Machining Assembly |
| C-1143 | Torque Tester Adapter Plate |
| C-1144 | Torque Tester Damper Rotor |
| C-1145 | Torque Tester Damper Stator |
| C-1147 | Torque Tester Trunnion Mount (R.H.) |
| C-1148 | Torque Tester Trunnion Mount (L.H.) |
| C-1149 | Fixture for Gyro AB-5 |
| C-1150 | Fixture for Stabilizing Gyroscope |
| C-1151 | Fixture for Gyro Motor AB-3 used on Torque Tester |
| C-1152 | Fixture for Gyro Motor in Float AB-3 Used on Torque Tester |
| C-1155 | Torque Tester Cover |
| C-1156 | Torque Tester Terminal Board |
| C-1157 | Torque Tester Damper Mounting Plate |
| C-1158 | Torque Tester Worm & Bevel Gear Mounting Block |
| C-1159 | Torque Tester Worm & Bevel Gear Assembly |
| C-1162 | Torque Tester Damper Rotor Assembly |
| C-1164 | Torque Tester Damper Stator Assembly |
| | |
| D-852 | Torque Tester Microsyn Housing |
| D-853 | Torque Tester Base |
| D-854 | Torque Tester Outer Housing |
| D-855 | Torque Tester Stator With Orifice Plug |

| Print Number | Title |
|---|---|
| D-587 | Fixture for Gyro in Float Assembly AB-5 |
| D-858 | Fixture for Gyro in Float AB-5 |
| D-859 | Torque Tester Bearing Assembly |
| D-860 | Torque Tester Complete Assembly |
| D-869 | Torque Tester Microsyn Assembly |