20584-FR1 23 May 1969

# FINAL REPORT

# STERILIZABLE WIDE ANGLE GAS BEARING GYRO FGG334S

California Institute of Technology
Jet Propulsion Laboratory
Contract No. 951529



Honeywell Inc.
Aerospace Division
Minneapolis, Minnesota

20584-FR1

23 May 1969

# FINAL REPORT
# STERILIZABLE WIDE ANGLE GAS BEARING GYRO FGG334S

California Institute of Technology
Jet Propulsion Laboratory
Contract No. 951529




Honeywell Inc.
Aerospace Division
Minneapolis, Minnesota

20584-FR1 23 May 1969

JPL Contract 951529

PRELIMINARY FINAL REPORT

# STERILIZABLE WIDE ANGLE GAS BEARING GYRO FGG334S

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Agency under Contract NAS 7-100.

Prepared by: J. M. Bremer
J. M. Bremer
Senior Development Engineer

Approved by: R. G. Baldwin
R. G. Baldwin
Project Engineer

P. R. Hockert
P. R. Hockert
Program Administrator



Honey
Aerospac
Minneapolis, Minnesota

# NOTICE



Request for copies of this report should be referred to:

National Aeronautics and Space Administration
Office of Scientific and Technical Information
Washington 25, D. C.

Attention: AFSS-A

CONTENTS

## ILLUSTRATIONS

TABLES

# SECTION I
# SUMMARY AND CONCLUSIONS

This report is submitted in fulfillment of JPL Contract 951529. The program objective was to design and fabricate five gyroscopes which would incorporate the following major design goals:

- Heat sterilization capability
- High g-capability
- Single voltage start/run spinmotor
- Wide angle, pivot, and jewel suspension

The program was completed with the shipment of the fifth gyro, S/N A5 to JPL on April 3, 1969.

## SUMMARY

Despite the ground work on previous programs, much design effort, evaluation, and analysis was necessary on the present program. This is presented in Section IV of this report.

This program primarily generated test results -- a fairly extensive set of test results from which rather concrete conclusions can be drawn. Most of the report is devoted to this task as follows:

Section I -- Summary and Conclusions

This section summarizes the general results of all testing, draws the conclusions contained in these results, and makes the appropriate recommendations.

Section II -- Acceptance and General Testing

This section presents and summarizes all significant test results obtained on the five GG334S gyros tested at Honeywell, excepting environmental testing.

Section III -- Environmental Test Results

This section presents and summarizes the test results obtained on the two GG334S gyros which were subjected to environmental testing at the Honeywell facility.

## Historical Perspective

This program was the logical extension of previous contracts, which had developed the technology necessary to accomplish the objectives of this contract. These programs were historically accomplished as follows:

| Date | Technical Accomplishment | Work Performed Under |
|---|---|---|
| July 1964 | Study program to improve acceleration, vibration, and shock capability of the GG159C GBSM | JPL Contract 950604 |
| December 1964 | High rate torquer development study | JPL Contract 950604 (Mod. 3) |
| January 1965 | High-g gyro completed (GG159C7) | JPL Contract 950604 (Mod. 2) |
| April 1965 | High-frequency pump study | JPL Contract 950604 (Mod. 3) |
| June 1965 | Sterilizable gyro completed (GG159D1) | JPL Contract 950769 |
| December 1965 | Sterilizable High-g gyro completed (GG159D2) | JPL Contract 951139 |

| | | |
|---|---|---|
| April 1966 | High rate torquer fabricated | Honeywell funded |
| June 1966 | "GG334A style" spinmotor | Honeywell funded |
| July 1966 | Piezoelectric dither disks | Honeywell funded |
| September 1968 | Sterilizable, high-g, low-power gyro shipped (GG159E) | JPL Contract 951559 |
| April 1969 | Fifth sterilizable, high-g, single voltage start/run, wide angle gyro shipped (GG334S) | JPL Contract 951529 |

Initially, the GG334S program called for shipment of two gyros, utilizing essentially the GG159D2 style spinmotor modified for single voltage start/run operation. As the program progressed, the GG159E spinmotor, with the additional advantage of low power was undergoing development, and it was decided to incorporate this newer motor into the GG334S. The contract was modified to reflect this change, and at the same time the number of deliverable gyros was increased to five.

## CONCLUSIONS

Conclusions from the program results of the program are as follows:

1) The resultant gyro integrated the four basic design goals of the program:
   - Sterilization capability
   - High-g capability
   - Single voltage/run low power spinmotor
   - Wide angle pivot jewel suspension

2) The resultant gyro, in the present configuration, requires some improvement before it could be applied to a Mariner type mission. These improvements have been defined, are limited in scope, and can be achieved within the present state of technology. Primarily they are:

- Improved fixed torque stability
- Increased spinmotor starting torque margin

3) There is an incompatible relationship between the three requirements of low power, high-g capability, and single voltage start/run operation of the spinmotor. Any two may be simultaneously realized, but the three requirements together reduce starting torque to a marginal condition. For example, the stator could be wound to provide more starting margin to the present motor, but power would be higher. Alternatively, the stator could be readjusted for 36-volt start, 26-volt run operation providing both higher starting torque margin and lower power.

4) Detailed adjustments which are indicated to improve future units are limited in scope. These are:

- Reduction of spinmotor reaction torque, probably through incorporation of a hypernik shield of the H-ring.
- Increase starting torque of the spinmotor.
- Subject the completed assembly to sterilization temperature as part of the build process.
- Improvement of the balance pan.

5) Several minor difficulties were incurred in the course of this program because the units were under development rather than in production. For example, an intermittently "sticky" gimbal condition has been observed on some of the units. This kind of problem is naturally weeded out as the build process and inspection techniques are refined and tailored to particular designs, both because of "learning curve" effects and because of feedback of test results.

Sterilization

Four of the five gyros built on this program were subjected to extensive sterilization testing, two at Honeywell and two at JPL. Two of the five were subjected to shock and vibration testing, one at each facility. Testing on the fifth unit is continuing at JPL at this time. This rather extensive test program basically verified the ability of the unit to withstand both types of environments but also indicated that design adjustments were necessary to improve performance on future units.

Figures 1, 2, and 3 present the significant drift test results on all the GG334S gyros which have undergone sterilization testing. Mass unbalance data from the GG159E is included because of the gimbal similarity. First cycle shifts are removed from the data.

Fixed torque showed the single largest shift as the result of sterilization on S/N B3. It showed two consecutive, self-cancelling large shifts on S/N B2. The median shift was 0.25 deg/hour, average shift was 0.29 deg/hour and RSS shift was 0.38 deg/hour. It is unlikely that these shifts are caused by the flex leads -- spinmotor reaction torque is probably a major contributor. If so, as mentioned in the body of the report, shielding the H-ring with a hypernik shield should produce a marked improvement in future devices.

The mass unbalance data presented in Figures 2 and 3 indicates the ability of the gimbal to sustain the sterilization environment without serious damage. MUSRA seems marginally better than MUIA, but the difference is not conclusive. S/N B2 and S/N A5 each had one MUIA shift of approximately 0.9 deg/hr/g, but the remaining shifts seem to fall into a more reasonable statistical grouping.

Data may be summarized as follows, based on all twenty-four cycles:

| | MUIA | MUSRA |
|---|---|---|
| Median shift | 0.16 deg/hr/g | 0.08 deg/hr/g |
| Average shift | 0.19 deg/hr/g | 0.16 deg/hr/g |
| RSS shift | 0.34 deg/hr/g | 0.22 deg/hr/g |

A summary of the total sterilization temperature cycling on each unit is presented in the data listed below. The sterilization environment is 64 hours at +275°F per cycle at the gyro level; subassembly exposures were of shorter duration for test purposes. One spinmotor, that of S/N B3, became inoperable after five sterilization cycles at the gyro level (386 hours at sterilization temperature), but also after some post cycle test data had been obtained. Since the gyro operated for a short period of time after the last temperature exposure it experienced, the cause of the malfunction and any possible connection with sterilization cannot be conclusively established at this time.

Notwithstanding this data point, the operability of the set of five gyros over a considerable number of sterilization cycles and an extensive time at the sterilization temperatures demonstrates the ability to survive the sterilization environment with gas bearing gyros.

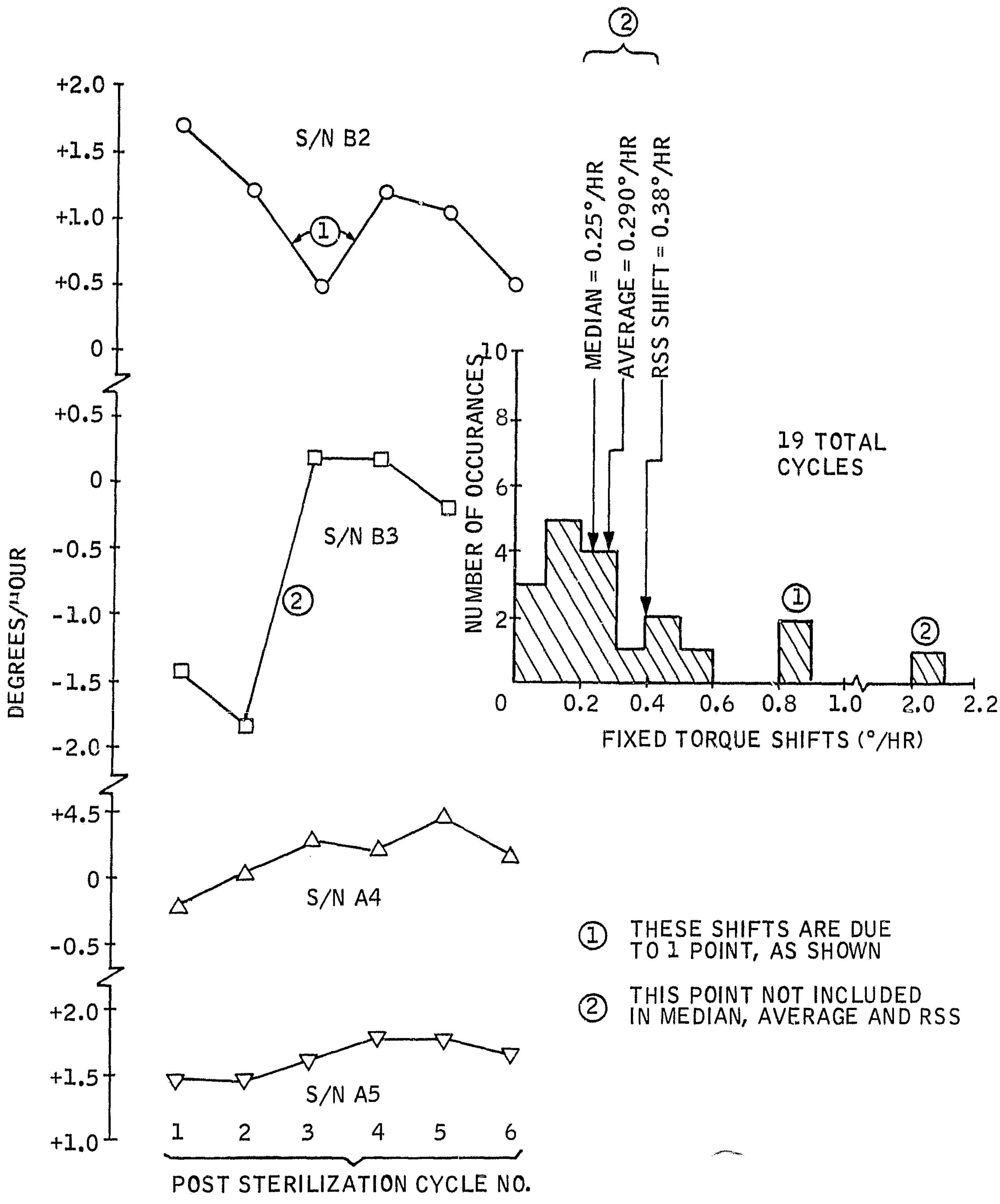



Figure 1. Fixed Torque Steril:zation Test History, First Cycle Excluded

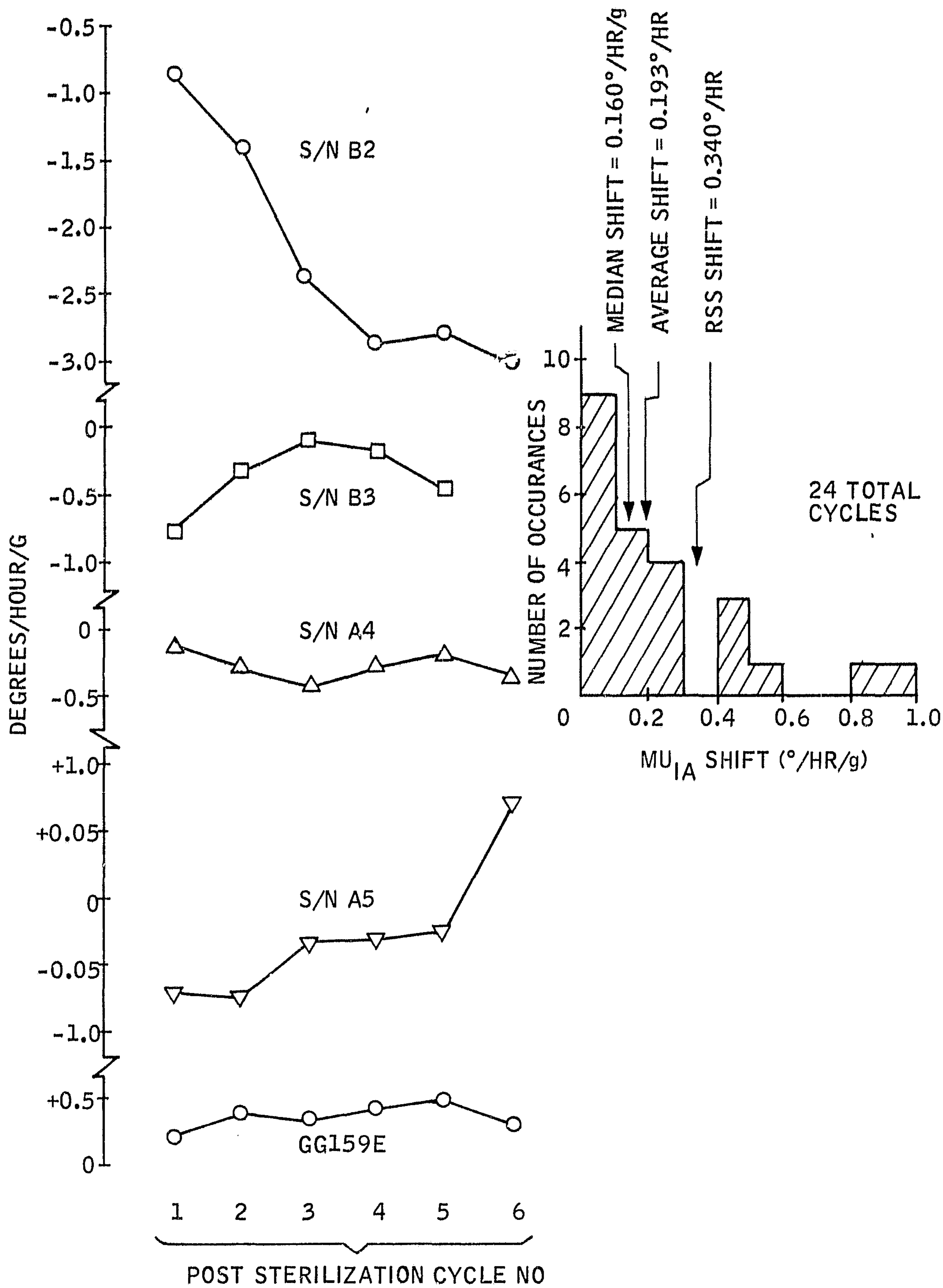



Figure 2. $MU_{IA}$ Sterilization Test History, First Cycle Excluded

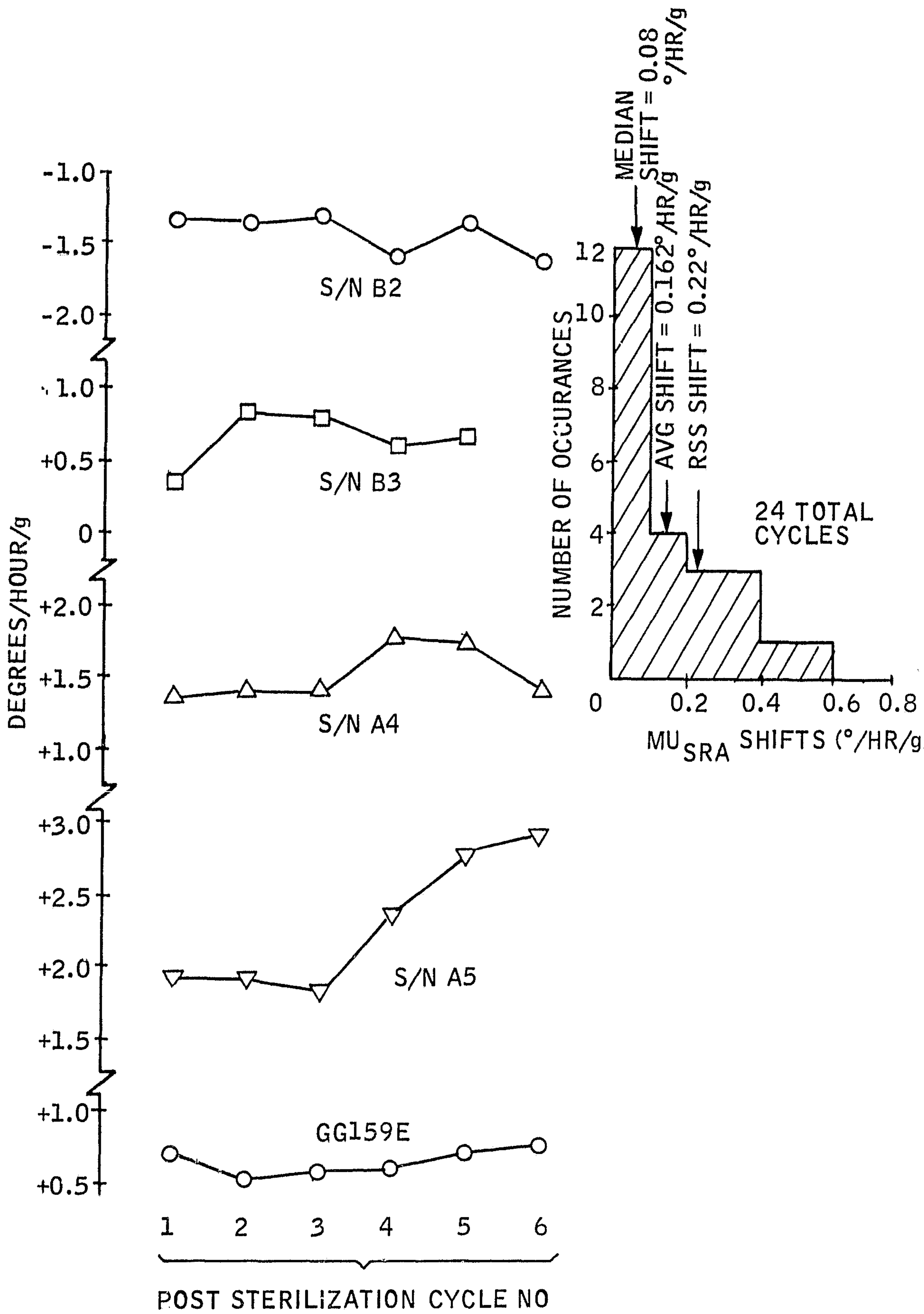



Figure 3. $MR_{SRA}$ Sterilization Test History, First Cycle Excluded

| Device | Subassembly | | Complete Gyro | | Total | |
|---|---|---|---|---|---|---|
| | Cycles | Hours | Cycles | Hours | Cycles | Hours |
| GG334S S/N B1 | 5 | 80 | 0 | 0 | 5 | 80 |
| B2 | 4 | 64 | 6 | 386 | 10 | 450 |
| B3 | 4 | 64 | 5 | 322 | 9 | 386 |
| A4 | 6 | 96 | 6 | 386 | 12 | 482 |
| A5 | 7 | 112 | 6 | 386 | 13 | 498 |
| GG159E S/N B1 | 6 | 96 | 7 | 450 | 13 | 546 |
| Total | 32 | 512 | 30 | 1930 | 62 | 2442 |

Vibration and Shock

The results of vibration and shock are summarized below. All values are in deg/hr(/g)

| Device | Shock | | | Vibration | | |
|---|---|---|---|---|---|---|
| | Δ FT | Δ MUIA | ΔMUSRA | ΔFT | Δ MUIA | ΔMUSRA |
| GG334S, S/N A4 Tested at Honeywell | 0.15 | 2.57 | 0.33 | 0.21 | 2.09 | 0.16 |
| GG334S, S/N B1 Tested at JPL | +0.10 | -0.72 | -0.22 | -0.03 | +0.04 | -0.04 |
| GG159E, S/N B1 Tested at Honeywell | - | +0.14 | -0.26 | - | -0.01 | +0.02 |

One gyro, S/N A4, showed large, but cancelling, MUIA shifts due to vibration and shock. The other two gyros did not evidence similar occurrence, indicating this will probably not be a major problem on future devices.

# SECTION II
# ACCEPTANCE AND GENERAL TESTING

## ACCEPTANCE TEST RESULTS

Table 1 presents significant acceptance test results from all five units built on this program. Each unit does show some individual differences, but the results have been generally consistent from unit to unit. The data presentation in Tables 2 and 3 emphasizes this.

Table 2 presents mechanical and performance characteristics (wherein either the range or the maximum value of test results is presented, whichever is more appropriate).

Table 3 lists acceptance test drift parameters (wherein the average and maximum values of the drift results are presented for comparison)

Closely examining the results presented in these tables will indicate that the unit is capable of performance consistent with gyros of similar size, weight, and power.

## SPINMOTOR REACTION TORQUE

Although spinmotor reaction torque (SMRT) was reduced to an acceptable level by use of the gimbal shield (discussed later in this report), it still remains the chief contributor to drift instability. It shows up especially in the measurements of both fixed torque stability and RMS drift stability and is the likely cause of large fixed-torque shifts during sterilization. Appropriate shielding of the H-ring is recommended to eliminate this problem on future GG334S gyros. This recommendation is made on the basis of a recent technical development on a Honeywell in-house program, the GG134M. This gyro incorporates a hypernik ring to shield the H-ring, which reduces the SMRT by an order of magnitude.

## Table 1. Acceptance Test Results

| Parameter | B1 | B2 | B3 | A4 | A5 | Units |
|---|---|---|---|---|---|---|
| Gyro Transfer Function | 10.22 | 8.88 | --- | 9.66 | 9.35 | volts/radians |
| Damping | $2.96 \times 10^5$ | $2.53 \times 10^5$ | $2.70 \times 10^5$ | $2.44 \times 10^5$ | $2.5 \times 10^5$ | dyne-cm-sec |
| Gimbal Freedom | +3.05<br>-3.10 | +3.15<br>-2.93 | +3.17<br>-3.42 | +3.12<br>- 97 | +2.64<br>-2.82 | deg |
| Operating Temperature | 181.2 | 180.0 | 178.14 | 180.9 | 179.7 | °F |
| Spinmotor | | | | | | |
| Start Power | 4.2 | 6.2 | 5.98 | 6.6 | 6.4 | watts |
| Run Power | 2.6 | 3.35 | 3.10 | 3.3 | 3.25 | watts |
| Runup Time | 26.0 | 16.1 | 17.6 | 14.4 | 14.4 | seconds |
| Rundown Time | 65.8 | 50.0 | 52.3 | 44.0 | 55 | seconds |
| Pickoff | | | | | | |
| Sensitivity | 24.38 | 23.47 | 24.63 | 24.3 | 25.3 | volts/radian |
| Null Voltage | 1.28 | ----- | 2.5 | 3.4 | 2.4 | mv |
| Torquer Scale Factor | 362.23 | 340.5 | 350.01 | 349.58 | 346.8 | deg/hr/ma |
| SMRD Output Signal | 6.8 | 9.8 | 9.1 | 8.0 | 8.0 | mv |
| Fixed Torque | +0.278 | -0.098 | -0.059 | +0.209 | +0.31 | deg/hr |
| MUIA | -0.344 | +0.075 | -0.214 | -0.214 | +0.015 | deg/hr/g |
| MUSRA | +0.096 | -0.003 | +0.254 | +0.078 | +0.214 | deg/hr/g |
| RMS Drift Stability | 0.55 | 0.042 | 0.037 | 0.096 | 0.040 | deg/hr |
| Drift Stability (Cooldown) | | | | | | |
| Fixed Torque (ΔRMS) | 0.078 | 0.080 | 0.033 | 0.10 | 0.054 | deg/hr |
| MUIA (ΔRMS) | 0.019 | 0.045 | 0.037 | 0.086 | 0.186 | deg/hr |
| MUSRA (ΔRMS) | 0.058 | 0.063 | 0.040 | 0.025 | 0.096 | deg/hr |
| Random Drift | | | | | | |
| OAV | 0.002 | 0.009 | 0.001 | 0.007 | 0.002 | deg/hr |
| IAV | 0.007 | 0.007 | 0.003 | 0.004 | 0.002 | deg/hr |
| Elastic Restraint | -0.596 | -0.077 | -0.070 | -0.099 | -0.065 | deg/hr/mr |
| Anisoelastic Coefficient | | | | | | |
| 100 Hz | +0.098 | +0.115 | +0.063 | +0.11 | +0.07 | $deg/hr/g^2$ |
| 500 Hz | +0.031 | +0.022 | +0.030 | 0.00 | +0.03 | $deg/hr/g^2$ |
| 1000 Hz | -0.022 | +0.004 | 0.00 | 0.00 | +0.02 | $deg/hr/g^2$ |
| 2000 Hz | -0.150 | +0.186 | +0.223 | -0.032 | -0.26 | $deg/hr/g^2$ |

Table 2. Mechanical and Performance Characteristics of Five GG334S Gyros.

| Parameter | Results |
|---|---|
| Angular momentum | $1 \times 10^5$ g-cm$^2$/sec |
| Wheel speed | 24,000 rpm |
| Damping | $2.7 \times 10^5$ d-cm-sec ± 10% |
| Gyro transfer function | 9.5 volts/radian ± 10% |
| Gimbal freedom | ± 3.0 deg OA |
| Operating temperature | 180°F ± 2°F |
| Weight | 1.0 lb max. |
| Length | 3.0 in max. |
| Diameter (excluding flange) | 2.2 in max. |
| Flange diameter | 2.24 in max. |
| Spinmotor* | |
| Power, Start | 6.6 watts max. |
| Power, Run | 3.3 watts max. |
| Run Up Time | 17 sec max. |
| Run Down Time | 55 sec max. |
| Pickoff | |
| Sensitivity | 24.5 mv/mr ± 5% |
| Null Voltage | 4 mv max. |
| Torquer | |
| Scale Factor | 350°/hr/ma ± 5% |
| Linearity | 0.026% to 1°/sec |
| Stability | 0.018% |
| Slew Rate Capability | 11,000 deg/hour |
| SMRD Output Signal | 6 mv @ 400 Hz (min.) |

* Gyro B1 excluded because of low power spinmotor design

Table 3. Acceptance Test Drift Parameters of Five GG334S Gyros

| Parameter | Average Value* | Maximum Value* |
|---|---|---|
| Fixed Torque | 0.191 deg/hr | 0.310 deg/hr |
| MUIA | 0.185 deg/hr/g | 0.344 deg/hr/g |
| MUSRA | 0.129 deg/hr/g | 0.254 deg/hr/g |
| RMS Drift Stability | 0.054 deg/hr/rms | 0.096 deg/hr/rms |
| Drift Stability (Cooldown) | | |
| Fixed Torque (Δ RMS) | 0.069 deg/hr | 0.10 deg/hr |
| MUIA ( Δ RMS) | 0.075 deg/hr | 0.186 deg/hr/g |
| MUSRA (Δ RMS) | 0.057 deg/hr | 0.096 deg/hr/g |
| Random Drift | | |
| OAV (1 σ) | 0.004 deg/hr | 0.009 deg/hr |
| IAV (1 σ) | 0.005 deg/hr | 0.007 deg/hr |
| Elastic Restraint | -0.078 deg/hr/mr | -0.596 deg/hr/mr** |
| Anisoelastic Coefficient | | |

(See Figure 4 for typical result)

* Based upon absolute values rather than algebraic values.

** Not confirmed by JPL, hence not included in average.

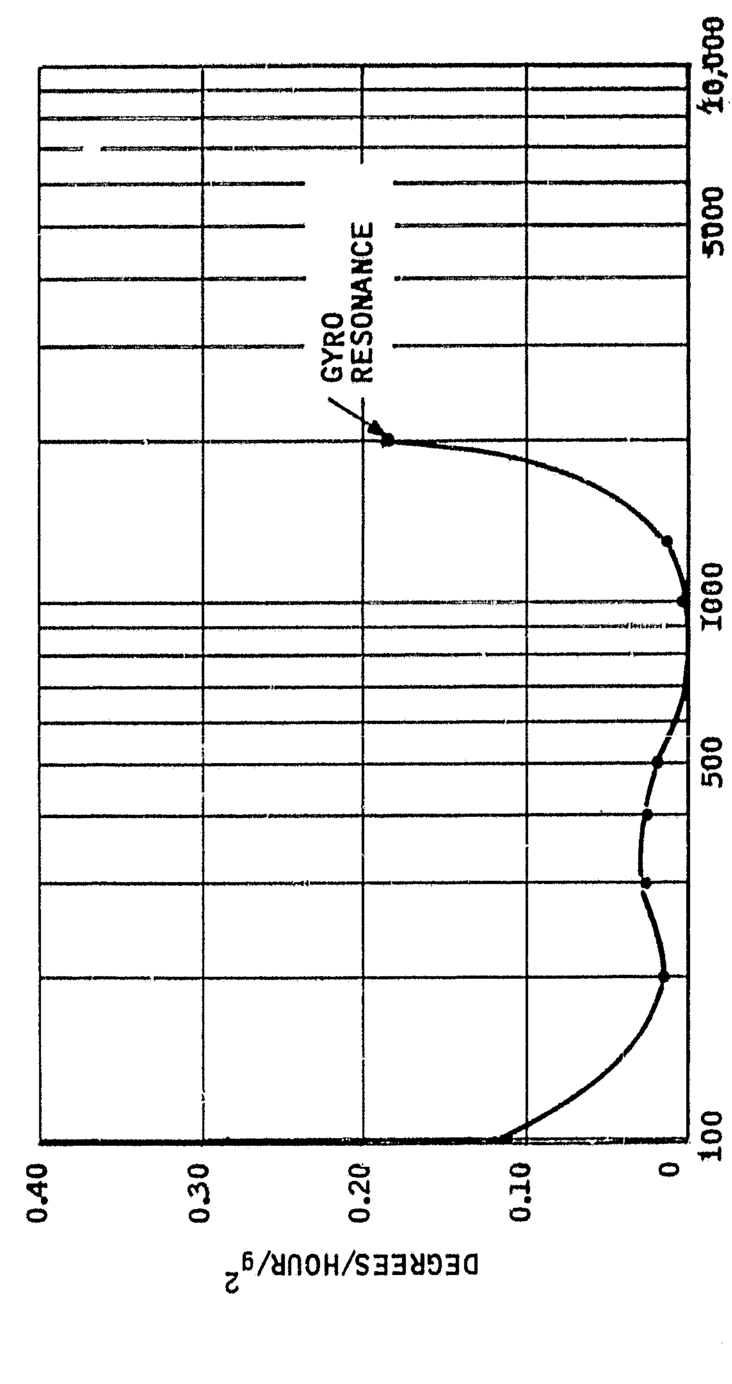



Figure 4. Ansioelastic Coefficient versus Frequency - Gyro 2

## Gyro Interface Details

Details of the gyro interface are presented in the following tables and figures:

Table 4 -- Excitations Required

Table 5 -- Circuit Resistances and Inductance

Figure 5 -- Installation Diagram

Figure 6 -- Schematic Diagram

## SPECIAL TESTS

Several special tests were run on single gyros throughout this program to obtain specific information. This information included:

- Spinmotor performance date on a specially wound stator used in gyro S/N A1 which resulted in a significant power reduction. Test results from this spinmotor, compared with typical data from the other motors, is presented in Table 6.

- DC resistance at operating temperature, obtained on gyro S/N B3. Table 7 presents this data.

- The effect of an elastic restraint compensating capacitor, obtained on gyro S/N B1. Table 8 presents the results of this test. The 0.047 μf capacitor increased the signal generator sensitivity to 28.16 volts/radian and reduced the secondary output phase angle from +28 degrees +4 degrees (leading).

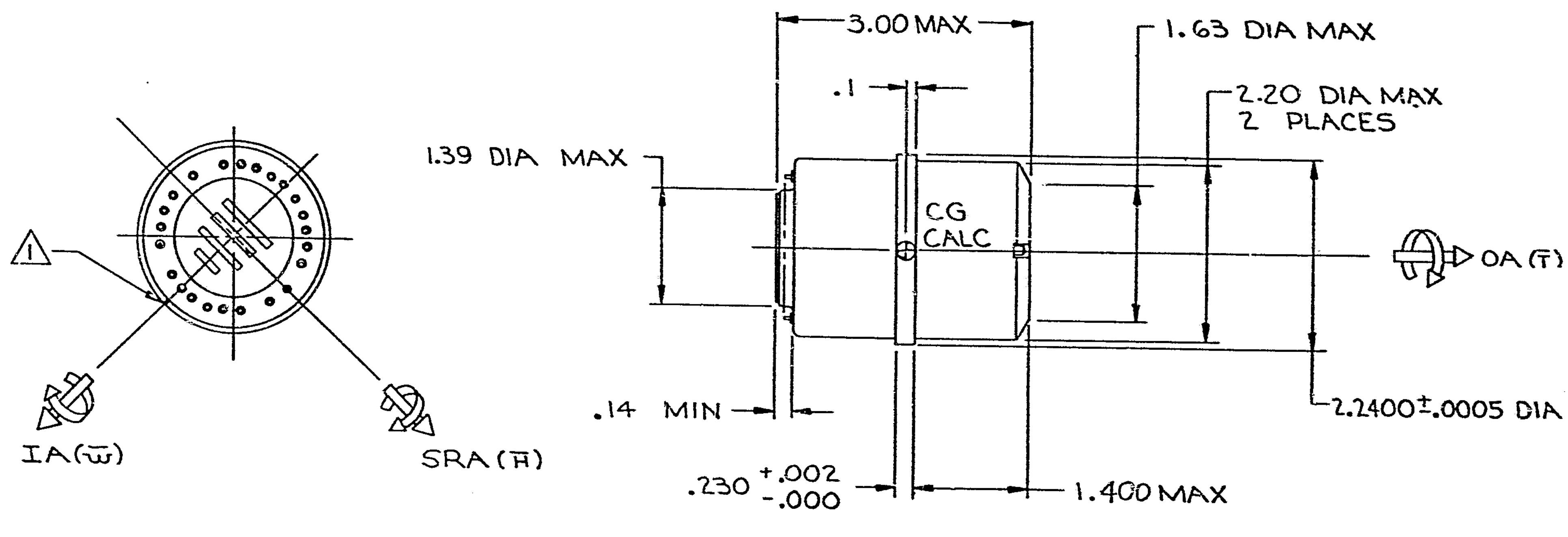
Table 4. Excitations Required

| Signal Generator | |
|---|---|
| Voltage | 10.5 volts rms |
| Frequency | 7200 Hz |
| Spinmotor (and piezoelectric dither | |
| Start Voltage | 26 volts rms - 2 phase |
| Run Voltage | 26 volts rms - 2 phase |
| Frequency | 800 Hz |
| Heaters | |
| Warmup ( 55 watts) | 120 volts max. (ac or dc) |
| Control (10 watts) | 40 volts max. (ac or dc) |
| Sensor | 10 ma max. (ac or dc) |
| Phasing | |
| Signal Generator Primary | Pin 22 high, pin 10 low |
| Signal Generator Secondary | Pin 19 high, pin 8 low |
| Torque Generator | Pin 14 high, pin 2 low |

Table 5. Circuit Resistances and Inductances

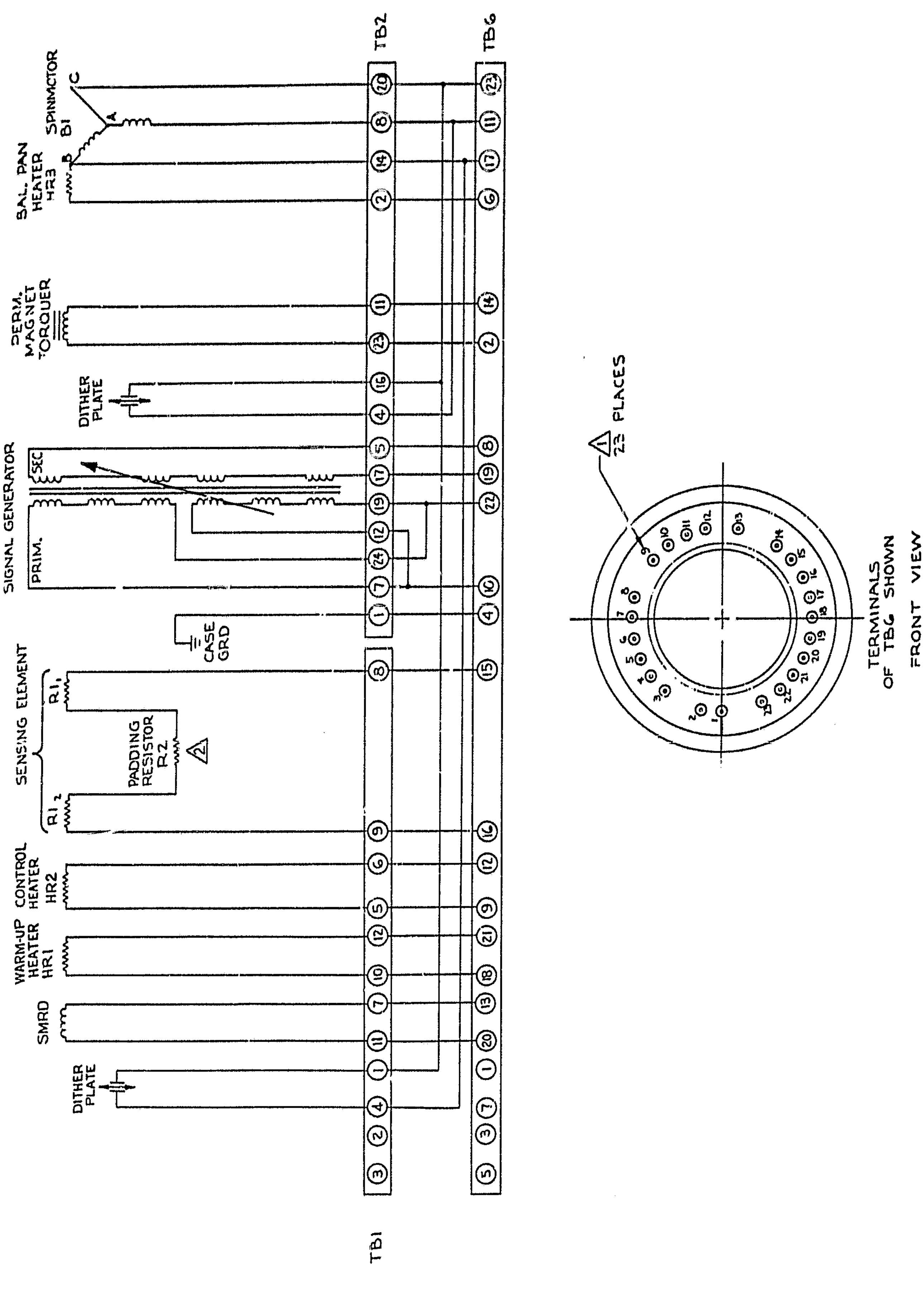
| Circuit | Average Resistance @ 72°F (ohms) | Average Inductance @ 72°F (mh) |
|---|---|---|
| Spinmotor* | | |
| ϕ A-C | 36.9 | ---- |
| ϕ B-C | 36.5 | ---- |
| Signal Generator | | |
| Primary | 32.3 | 1.67 |
| Secondary | 147.1 | 2.36 |
| Torquer | 158.0 | 1.92 |
| Sensor | 780.0 | ---- |
| Heaters | | |
| Warmup | 265.2 | ---- |
| Control | 139.0 | ---- |
| SMRD | 753.0 | ---- |
| Balance Pan | 54.0 | ---- |

* Excluding Gyro S/N B1 because of low power spinmotor design.




△1 SCRIBE MARK DESIGNATES POSITIVE IA LOCATION WITHIN ±1°

**Figure 5. Gyro Outline Dimensions, GG334S**




⚠2 RESISTANCE AS REQD

⚠1 NUMBERS ARE FOR REF ONLY AND DO NOT APPEAR ON PART

Figure 6. Schematic, GG334S

Table 6. Low Power Spinmotor Characteristics

| | Low Power Motor (Gyro S/N B1) | Typical GG334S Spinmotor (S/N B2-A5) |
|---|---|---|
| Start Power (watts) | 4.2 | 6.6 |
| Run Power (watts) | 2.6 | 3.3 |
| Min Start (volts) | 21.0 | 17.0 |
| Min Sync (volts) | 23.0 | 19.5 |
| Run Up Time (sec) | 26.0 | 17.0 |
| Run Down Time (sec) | 65.8 | 55.0 |
| ϕ A-C(ohms) | 47.3 | 36.9 |
| ϕ B-C(ohms) | 45.5 | 36.5 |

Table 7. DC Resistance versus Temperature, GG334S S/N B3

| Circuit | DC Resistance (ohms) @ 180°F (Motor Off) | DC Resistance (ohms) @ Room Temperature |
|---|---|---|
| Primary | 39.45 | 33.15 |
| Secondary | 170.4 | 138.8 |
| Torquer | 172.9 | 141.4 |
| Spinmotor | | |
| ϕA-C | 42.7 | 35.11 |
| ϕB-C | 41.6 | 34.26 |
| SMRD | 868.8 | 706.0 |
| Pan | 55.13 | 54.38 |
| Warm Up Heater | 270.3 | 267.3 |
| Control Heater | 140.0 | 139.7 |

Table 8. Elastic Restraint Compensation, Special Test, Gyro S/N B1

| Compensating Capacitor | Elastic Restraint |
|---|---|
| 0.060 μf | +0.050 deg/hr/mr |
| 0.055 μf | +0.025 deg/hr/mr |
| 0.050 μf | -0.030 deg/hr/mr |
| 0.047 μf | -0.042 deg/hr/mr |
| 0.045 μf | -0.055 deg/hr/mr |
| 0.040 μf | -0.125 deg/hr/mr |
| uncompensated | -0.620 deg/hr/mr |

# SECTION III
# ENVIRONMENTAL TEST RESULTS

Two of the five gyros were subjected to sterilization testing at Honeywell following acceptance testing. These were, S/N A4 and SN A5. One gyro, S/N A4, was subjected to the shock and vibration environments shown in Table 13 following the sterilization testing. The test results amply verify the ability of this gyro design to operate despite exposure to these environments. Drift results obtained over these environmental exposures are as follows:

STERILIZATION TEST RESULTS, S/N A4

| Parameter | Design Goal (Each Cycle) | Test Results |
|---|---|---|
| Change in TSF | ± 4.0 deg/hr/ma | 2.4 deg/hr (max. spread) |
| Change in RT | ± 0.08 deg/hr | 0.249 deg/hr (avg); 0.418 deg/hr (max) |
| Change in MUIA | ±0.14 deg/hr/g | 0.129 deg/hr/g (avg) 0.162 deg/hr/g (max) |
| Change in MUSRA | ±0.14 deg/hr/g | 0.152 deg/hr/g (avg); 0.346 deg/hr/g (max)[1] |
| Change in Elast. Restraint | ±0.015 deg/hr/mr | 0.006 deg/hr/mr Total |

STERILIZATION TEST RESULTS, S/N A5

| Parameter | Design Goal (Each Cycle) | Test Results |
|---|---|---|
| Change in TSF | ±4.0 deg/hr/ma | 3.1 deg/hr/ma (max. spread) |
| Change in RT | ±0.08 deg/hr | 0.088 deg/hr (avg); 0.17 deg/hr (max)[2] |
| Change in MUIA | ±0.14 deg/hr/g | 0.302 deg/hr/g (avg); 0.93 deg/hr/g(max)[2] |
| Change in MUSRA | ±0.14 deg/hr/g | 0.242 deg/hr/g (avg); 0.55 deg/hr/g (max)[2] |
| Change in Elast. Restraint | ±0.015 deg/hr/mr | 0.014 deg/hr/mr (max. spread) |

SHOCK AND VIBRATION TEST RESULTS, S/N A4

| Parameter | Design Goal (Shock/Vibration) | Test Results Shock | Vibration |
|---|---|---|---|
| Change in TSF | ±4.0 deg/hr/ma | 0.6 deg/hr/ma | 0.16 deg/hr/ma |
| Change in RT | ±0.04 deg/hr | 0.147 deg/hr | 0.210 deg/hr |
| Change in MUIA | ±0.15 deg/hr/g | 2.57 deg/hr/g | 2.09 deg/hr/g |
| Change in MUSRA | ±0.15 deg/hr/g | 0.327 deg/hr/g | 0.158 deg/hr/g |

[1]Excluding first point is not representative. Including the first point, the values would be 0.338 (avg); 1.268 (max).

[2]Excluding the first cycle shifts. Including these shifts, the results would be:

RT = 0.256 deg/hr (avg); 1.15 deg/hr (max)

MUIA = 0.376 deg/hr/g (avg); 0.93 deg/hr/g (max)

MUSRA = 0.668 deg/hr/g (avg); 2.13 deg/hr/g (max)

This data generally shows that moderate (albeit larger than the design goals) shifts can be consistantly realized with this design as the result of sterilization, once the first cycle has been passed.

Detailed results, from the complete test program are presented in the following tables and figures.

- Table 9, General Test Results

  Table 9 presents those parameters which were measured before sterilization testing and remeasured after completing six cycles. Gyro S/N A4 was also subjected to the shock and vibration environments before the parameters were remeasured. No significant change will be noted in these results except rundown time on gyro S/N A5. This is discussed in the following paragraph.

- Tables 10 and 11, Environmental Test Results

  Tables 10 and 11 present those items which were measured before and after each sterilization, shock, or vibration for S/N A4 and S/N A5, respectively. This data shows that relatively few parameters are affected by these environments and that the first cycle generally serves to stabilize those parameters that are affected by sterilization. This effect confirms similar findings on the GG159D1 program (see Final Report 250604-FR1), and the GG159E program (see Final Report 20660-FR1). In the course of this testing (assuming the first cycle shifts are normal), abnormally large shifts were produced only by the last sterilization cycle of gyro S/N A5 (MUIA) and by the shock test on S/N A4.

Another interesting result is the particularly consistent spinmoter performance of S/N A4 and the stabilizing of spinmotor run down time in gyro S/N A5 until it nearly reached the value consistently measured in S/N A4.

- Figures 7 and 8

  Figures 7 and 8 chronologically sequence the values of fixed torque, MUIA and MUSRA measured during the environmental testing of gyros S/N A4 and S/N A5 respectively. Both figures show that an abnormally large shift is likely to occur as the result of the first sterilization cycle, but that similar large shifts due to further sterilization cycles are rate (the one exception is MUIA on S/N A4).

The SMRD circuit opened during sterilization testing of the GG159E. No similar event occurred during testing of the GG334S, indicating that that particular failure mode would not be likely to be a significant problem on future devices.

Also during testing of the GG159E, the balance pan became erratic. This problem also evidenced itself on unit S/N B3, although not because of sterilization. This corroborates the conclusion reached at the end of the GG159E program that improvement of the balance pan would be in order for future devices.

The balance pan used in these units differs from the standard pan only in that the eutectic material was chosen for a melting temperature which greatly exceeded +300°F, the original sterilization temperature. With the reduction of the sterilization requirement to +275°F, it is now possible to use a lower temperature eutectic, thus the temperatures to which the pan must be subjected, and which evidently are high enough to deteriorate the surface of the pan can be reduced and the problem eliminated.

Table 9. General Test Results

| Parameter | GG334 S/N A4 Before Environments Sterilization Vibration and Shock) | GG334 S/N A4 After Environments Sterilization, Vibration and Shock) | GG334S, S/N A5 Before Sterilization | GG334S, S/N A5 After Sterilization | Units |
|---|---|---|---|---|---|
| General Parameters | | | | | |
| Gyro Transfer Function | 9.6 | 9.88 | 9.35 | 9.85 | volts/rad |
| Damping | $2.44 \times 10^5$ | $2.44 \times 10^5$ | $2.54 \times 10^5$ | $2.50 \times 10^5$ | d-cm-sec |
| Gimbal Freedom | +3.1 | +3.12 | +2.64 | +2.67 | deg |
| | -2.97 | -2.97 | -2.82 | -2.79 | deg |
| Operating Temperature | 180.9 | 180.9 | 179.7 | 179.7 | °F |
| Spinmotor | | | | | |
| Start Power | 6.6 | 6.8 | 6.4 | 6.5 | watts |
| Run Power | 3.3 | 3.4 | 3.25 | 3.5 | watts |
| Run Up Time | 14.4 | 14.4 | 14.4 | 14.4 | seconds |
| Run Down Time | 44.0 | 44.0 | 55 | 41.7 | seconds |
| Pickoff | | | | | |
| Sensitivity | 24.3 | 24.4 | 25.3 | 26.33 | volts/rad |
| Null Voltage | 3.4 | 3.7 | 2.4 | 2.4 | mv |
| Torquer Scale Factor | 349.6 | 349.7 | 346.8 | 346.5 | °/hr/ma |
| SMRD Output Signal | 8 | 9.1 | 8 | 9.2 | mv @ 400 Hz |
| Drift Parameters | | | | | |
| RMS Drift Stability, IAV | 0.096 | 0.098 | 0.040 | 0.044 | °/hr |
| Random Drift | | | | | |
| OAV | 0.001 | 0.002 | 0.002 | 0.004 | °/hr |
| IAV | 0.004 | 0.002 | 0.002 | 0.004 | °/hr |
| Elastic Restraint | -0.099 | -0.105 | -0.065 | -0.069 | °/hr/mr |
| Resistances (@ 72°F) | | | | | |
| Spinmotor A-C | 39.5 | 39.6 | 38.9 | 39.6 | ohms |
| B-C | 38.5 | 38.4 | 39.9 | 40.5 | ohms |
| Signal Generator | | | | | |
| Primary | 33.4 | 32.3 | 33.0 | 33.3 | ohms |
| Secondary | 164.1 | 164.0 | 158.2 | 158.6 | ohms |
| Torquer | 166.4 | 166.3 | 186.7 | 186.7 | ohms |
| Sensors | 780 | 780 | 780 | 780 | ohms |
| Heaters | | | | | |
| Warm Up | 264.6 | 265.2 | 263.6 | 263.8 | ohms |
| Control | 137.0 | 137.0 | 137.0 | 137.0 | ohms |
| SMRD | 827 | 826 | 835 | 836 | ohms |
| Balance Pan | 53.4 | 53.4 | 53.5 | 54.9 | ohms |
| Inductances (@ 72°F) | | | | | |
| Signal Generator | | | | | |
| Primary | 1.82 | 1.85 | 1.86 | 1.88 | mh |
| Secondary | 2.22 | 2.20 | 2.25 | 2.24 | mh |
| Torquer | 1.90 | 1.80 | 1.86 | 1.84 | mh |

Table 10. Environmental Test Results

| | | Reaction Torque (°/hr) | MUIA (°/hr/g) | MUSRA (°/hr/g) | OAV Drift (°/hr RMS) | IAV Drift (°/hr RMS) | Torquer Scale Factor (°/hr/ma) | + Stop (deg OA) | - Stop (deg OA) | Spinmotor Start Power (Watts) | Spinmotor Run Power (Watts) | Spinmotor Run Up Time (Sec) | Spinmotor Run Down Time (Sec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial | | +0.209 | -0.214 | +0.078 | 0.001 | 0.004 | 349.58 | 3.10 | 2.97 | 6.6 | 3.3 | 14.4 | 44 |
| Post Sterilization Cycle | No. 1 | -0.209 | -0.109 | +1.346 | 0.005 | 0.015 | 349.55 | 3.07 | 2.88 | 6.8 | 3.3 | 14.2 | 46 |
| | No. 2 | +3.008 | -0.271 | +1.401 | 0.001 | 0.009 | 349.69 | 3.04 | 2.92 | 6.9 | 3.2 | 13.6 | 46 |
| | No. 3 | +0.0288 | -0.407 | +1.423 | 0.001 | 0.010 | 349.26 | 3.07 | 2.92 | 6.8 | 3.4 | 14.0 | 45 |
| | No. 4 | +0.236 | -0.281 | +1.769 | 0.003 | 0.002 | 349.40 | 3.16 | 2.99 | 6.8 | 3.4 | 14.0 | 45 |
| | No. 5 | +0.487 | -0.190 | +1.710 | 0.002 | 0.005 | 347.96 | 3.12 | 2.97 | 6.8 | 3.4 | 14.0 | 44 |
| | No. 6 | +0.192 | -0.346 | +1.432 | 0.002 | 0.006 | 350.40 | 3.12 | 2.97 | 6.8 | 3.4 | 14.5 | 44 |
| Post Shock | | +0.045 | -2.92 | +1.759 | 0.002 | 0.004 | 349.80 | 3.12 | 2.97 | 6.8 | 3.4 | 14.3 | 44 |
| Post Vibration | | +0.255 | -0.830 | +1.917 | 0.002 | 0.002 | 349.96 | 3.12 | 2.97 | 6.8 | 3.4 | 14.4 | 44 |

Table 11. Environmental Test Results S/N A5

| | | Reaction Torque (°/hr) | MUIA (°/hr/g) | MUSRA (°/hr/g) | OAV Drift (°/hr RMS) | IAV Drift (°/hr RMS) | Torquer Scale Factor (°/hr/ma) | + Stop (deg OA) | - Stop (deg OA) | Spinmotor Start Power (Watts) | Spinmotor Run Power (Watts) | Spinmotor Run Up Time (Sec) | Spinmotor Run Down Time (Sec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial | | +0.31 | +0.02 | -0.21 | 0.002 | 0.002 | 346.8 | 2.64 | 2.82 | 6.4 | 3.3 | 14.4 | 55 |
| Post Sterilization Cycle | No. 1 | +1.46 | -0.73 | +1.92 | 0.007 | 0.001 | 345.7 | 2.67 | 2.79 | 6.5 | 3.4 | 14.4 | 52 |
| | No. 2 | +1.45 | -0.78 | +1.91 | 0.003 | 0.010 | 347.2 | 2.67 | 2.79 | 6.5 | 3.5 | 14.5 | 48 |
| | No. 3 | +1.62 | -0.36 | +1.83 | 0.006 | 0.002 | 345.1 | 2.67 | 2.79 | 6.6 | 3.5 | 14.6 | 47 |
| | No. 4 | +1.76 | -0.33 | +2.38 | 0.009 | 0.006 | 347.2 | 2.67 | 2.79 | 6.3 | 3.4 | 15.2 | 43 |
| | No. 5 | +1.77 | -0.25 | +2.77 | 0.008 | 0.003 | 346.2 | 2.67 | 2.79 | 6.4 | 3.4 | 14.7 | 42 |
| | No. 6 | +1.66 | +0.68 | +2.93 | 0.004 | 0.004 | 346.5 | 2.67 | 2.79 | 6.5 | 3.5 | 14.4 | 42 |

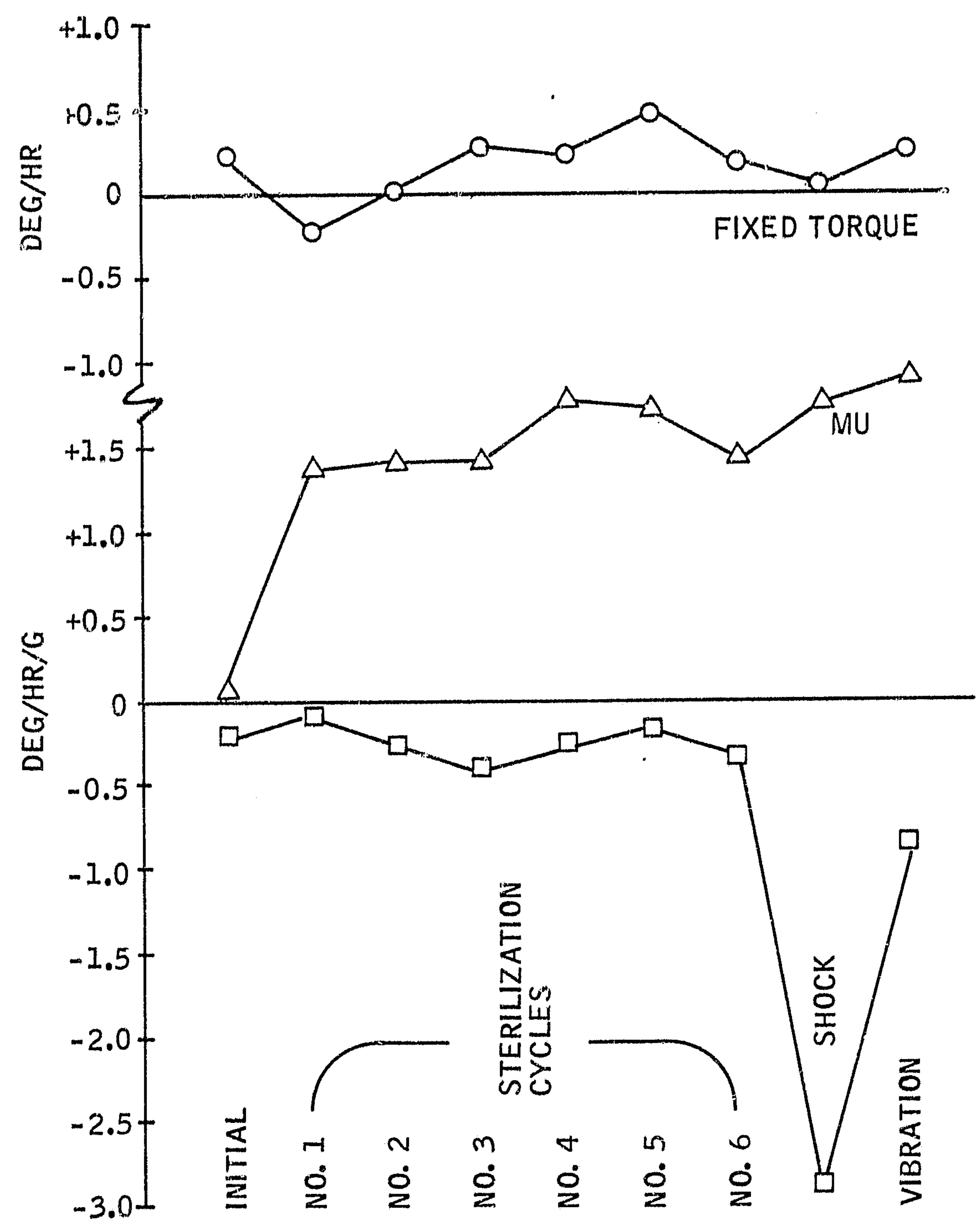



Figure 7. GG334S S/N A4 Environmental Test Torque History

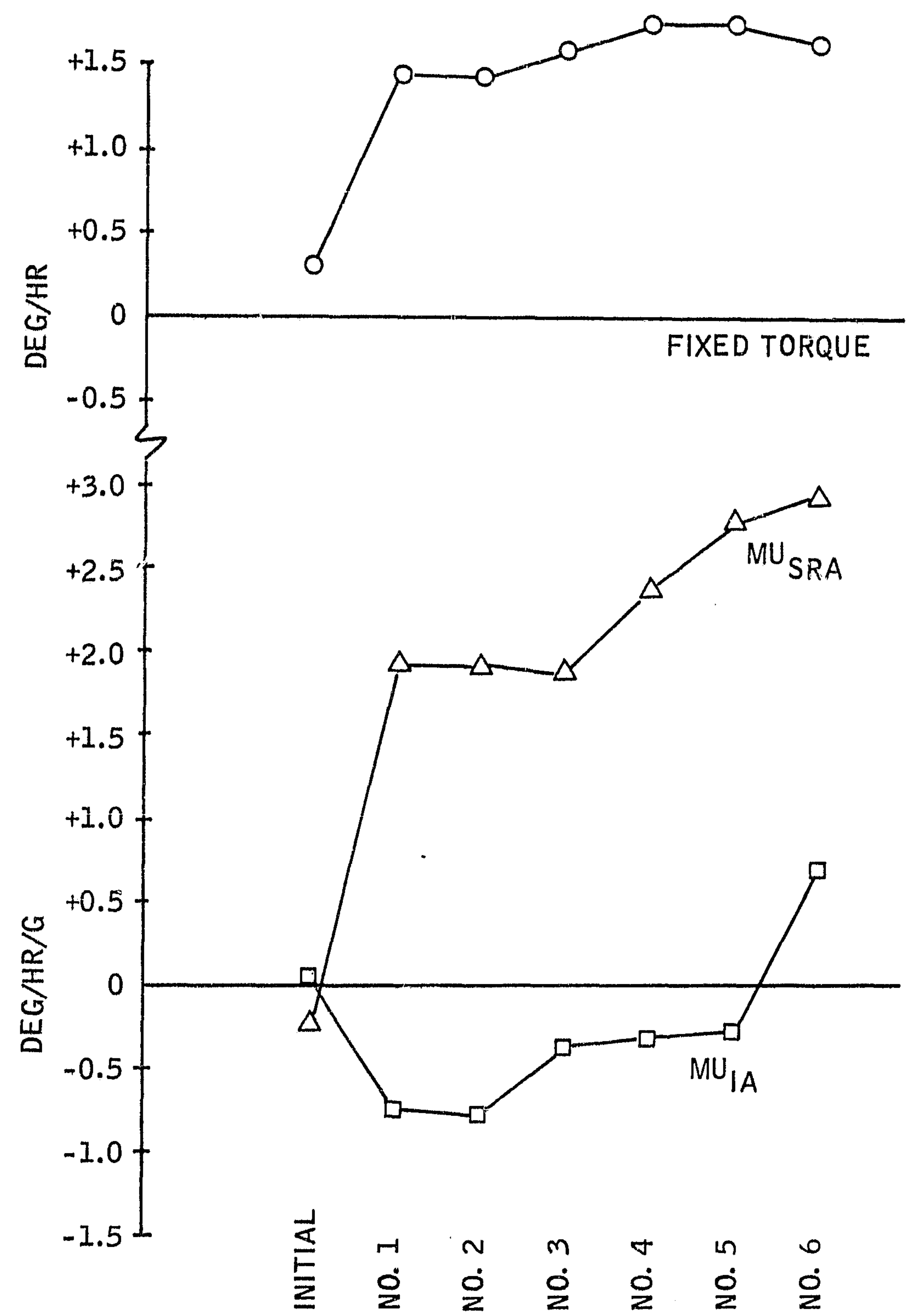



Figure 8. GG334S S/N A5 Environmental Test Torque History

# SECTION IV
# SUBASSEMBLY DEVELOPMENT AND TEST

Development of sterilization capability in a gyro began with JPL Contract 950769. This work included extensive design study and testing to determine which materials and subassemblies would withstand sterilization cycling to a temperature of +300°F. Potential problem areas such as corrosive properties of the damping fluid, epoxy strength, absorption rates of materials, creep and magnetic stability, were investigated and resolved. These efforts culminated in the GG159D1 gyro which successfully withstood exposure to sterilization and were readily transferred to the GG159D2 gyro which integrated sterilization and high-g capability.

This program was planned to extend the sterilization technology to a unit incorporating the following design features:

- The external configuration of the GG159D1, except header pins replace the connector cable.
- A gimbal assembly and case substantially the same as the GG159D2.
- With the exception of epoxy and solder changes to meet sterilization, a torquer/signal generator assembly identical to that developed for JPL and used on the GG159C11 gyro.
- Pivot/jewel dither
- A spinmotor capable of high-g environments except revised for single voltage start/run operation.

As this program progressed, work on the GG159E (JPL Contract 951559) was also progressing wherein a low power single voltage start/run spinmotor was being developed. Because the "D2" style spinmotor required considerably more power than the "E" motor under single volt start/run conditions, it was desirable to incorporate the new "E" motor into this design. Accordingly, the contract was renegotiated to exchange the motors.

Thus, although this gyro drew heavily upon the sterilization work which had preceeded this contract, further development effort was required to assure sterilization capability of several subassemblies. This work is detailed in the following paragraphs.

## PIEZOELECTRIC DITHER DISKS

The ring jewels are mounted in a piezoelectric ceramic assembly, which, when excited with an A. C. voltage vibrates the jewel axially. This axial motion provides "dynamic" rather than "static" friction, between the jewel and the pivot, approximately a factor of ten improvement.

### Piezoelectric Dither Disk Testing

The piezo dither discs were microscopically examined, and the deflection was measured with a capacitance probe at 36v 800 cycles. The disc assembly was then subjected to four 300°F sterilization cycles totaling 86 hours. Between each cycle the unit was again microscopically examined, and the deflection was measured (see Figure 9). These results are summarized as follows:

- No changes were observed in the surface finish.
- A slight change in deflection was noted after the first high temperature exposure, but subsequent cycles indicated the assembly had been thereby stabilized. The change itself was attributed to a minor shift in the mechanical mounting of the dither disk.

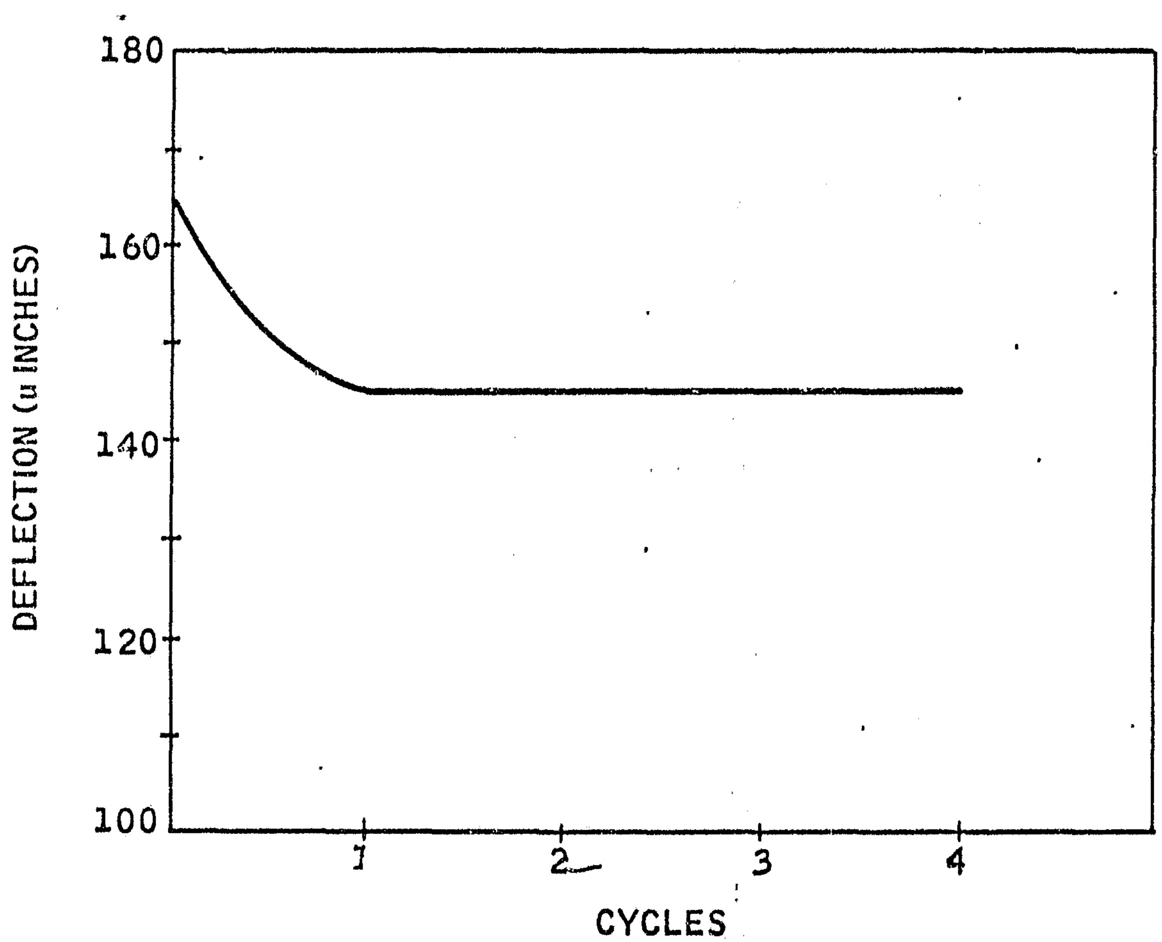



Figure 9. Dither Disc Displacement Versus Sterilization

Dither Plate Epoxy Bond Strength

A dither plate assembly was selected at random from those assembled for the GG334S build program. The plate assembly was then ground into four sections (see Figure 10). Sections 1 and 2 were not subjected to a sterilization cycle, while sections 3 and 4 were continuously cycled at 300°F for 150 hours. The test samples were then placed in a Tinuis Olsen tensile testing machine, and the tensile strength of the assembly tested to the failure point.

The results below show that the sterilization cycle did not degrade the bond strength, but rather increased it. This particular epoxy had also exhibited this characteristic on earlier bond strength testing for sterilization.

| | | |
|---|---|---|
| Sample No. 1 | 73 lbs | not sterilization cycled |
| No. 2 | 62 lbs | not sterilization cycled |
| No. 3 | 84 lbs | sterilization cycle 300°F 150 hours |
| No. 4 | 100 lbs | sterilization cycle 300°F 150 hours |

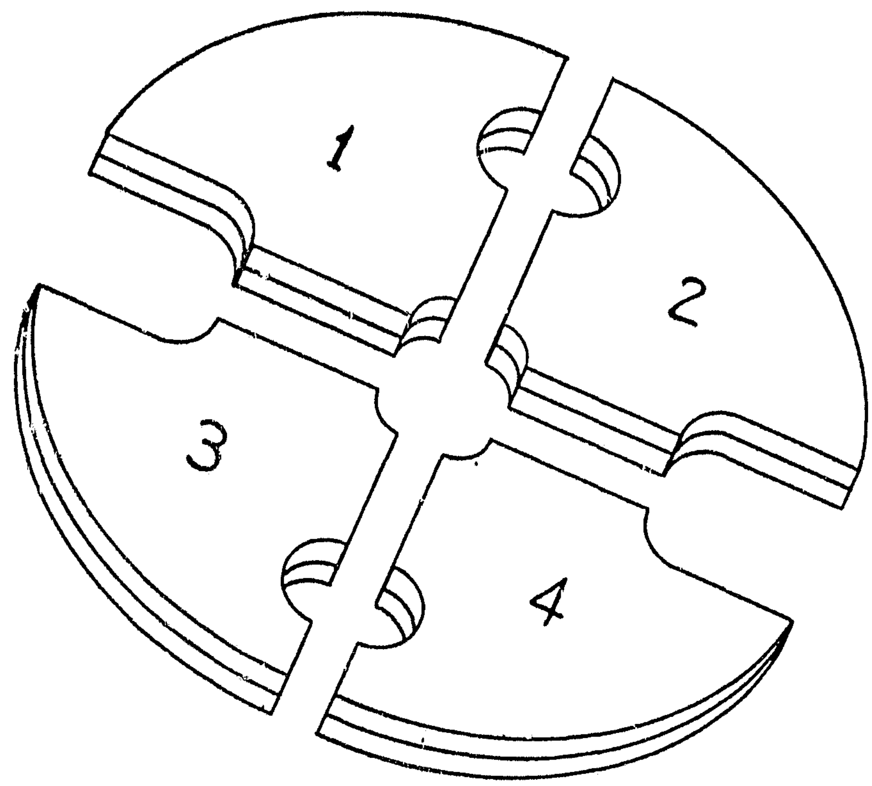



Figure 10. Piezo Dither Disc (Sectioned)

## HIGH VISCOSITY FILL FLUID

The program's high viscosity fill fluid was tested in Honeywell's materials laboratory. The fluid met the specification in all respects. The testing measured density, viscosity, stability up to 400°F, and corrosion up to 400°F.

This modified Kel-F Oil is as stable as the conventional oils such as MS7203 previously tested under the 300°F sterilization program for the Jet Propulsion Laboratories under Contract Number 950769.

COMPLIANT THRUST JEWEL MOUNTING

The gimbal "end shake" was limited to $0.0003^{+0.0001}_{-0.0001}$ at the gyro operating temperature of 180°F to provide optimum gyro performance. The difference in coefficient of thermal expansion between the ceramic gimbal and the aluminum case thus made a compliant thrust jewel mounting necessary in order to survive the low temperature environment required.

The compliant thrust jewel mounting scheme selected uses an alunimum disc (see Figure 11). The jewel holder assembly is free to move axially (along the OA) with the disc acting as a spring. When the gyro is at operating temperature, the jewel assembly is "loaded" against a fixed member. The geometry of the piece parts is such that the jewel holder protruces 0.0002 to 0,0006 above the adjacent surface. This provides a "pre-load", so that the jewel mount position is insensitive to small changes in the compliance of the aluminum disc.

When the gyro temperature is reduced, the compliant member allows the jewel to be displaced preventing excessive loading at the pivot/thrust jewel interface. Figure 12 shows end shake versus temperature. The "minus end shake" is the amount, in inches, that the compliant member must accommodate. The amount of loading generated by the compliant member at +50°F will be 1.01 pounds maximum.

Tests, using gyro hardware, were run to establish repeatability of position of the thrust jewel and to establish that no degradation of the compliance of the mount would occur.

Two units were tested. The test was set up on an Instron Tester with an automatic load cycling accessory. In each case, the jewel mount was loaded between limits of zero to four pounds. Unit number one was cycled 102 cycles and unit number two was cycled 97 cycles. The change in compliance were less than one percent in both cases.

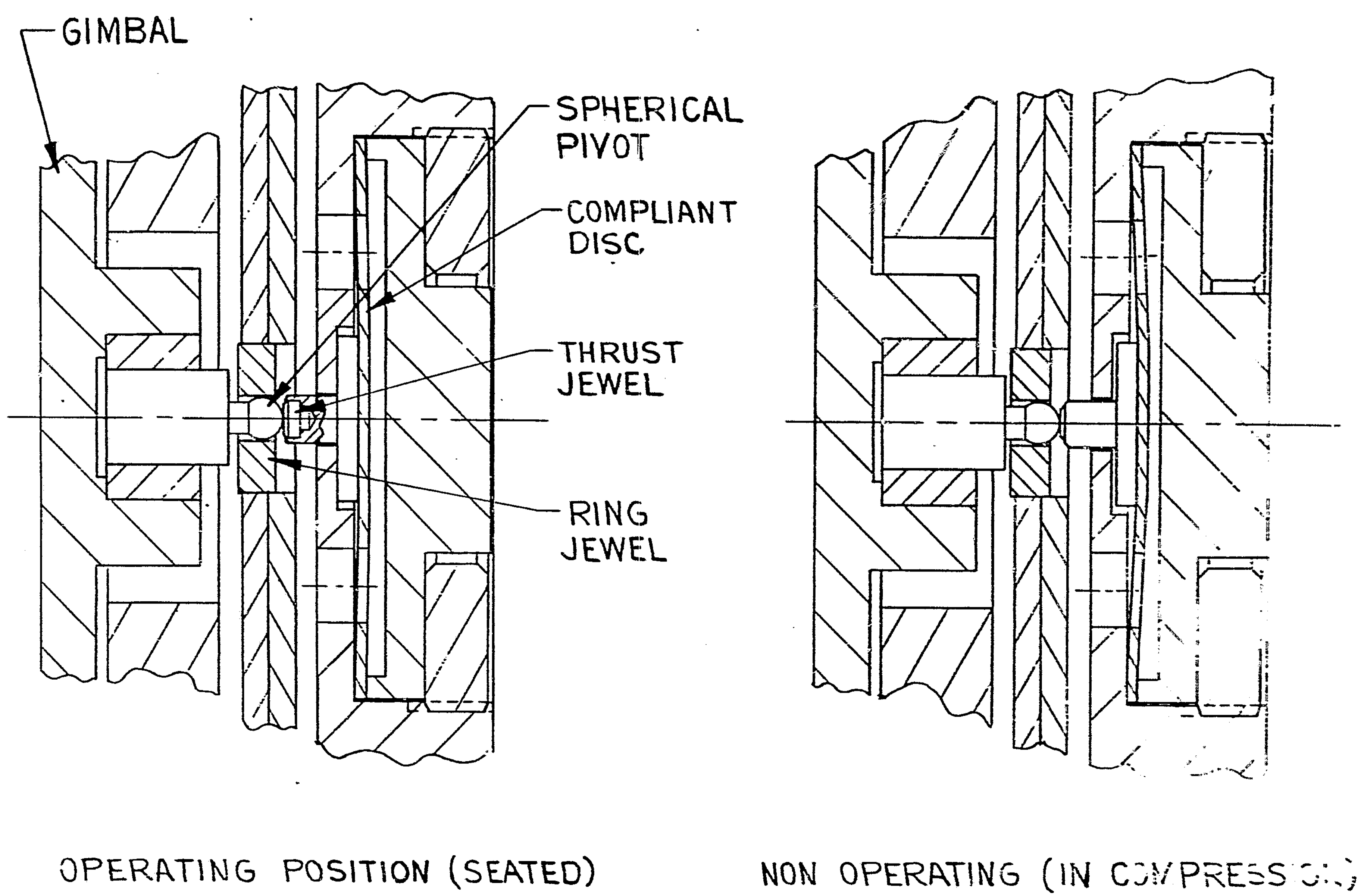



Figure 11. Thrust Jewel Compliant Mount Detail

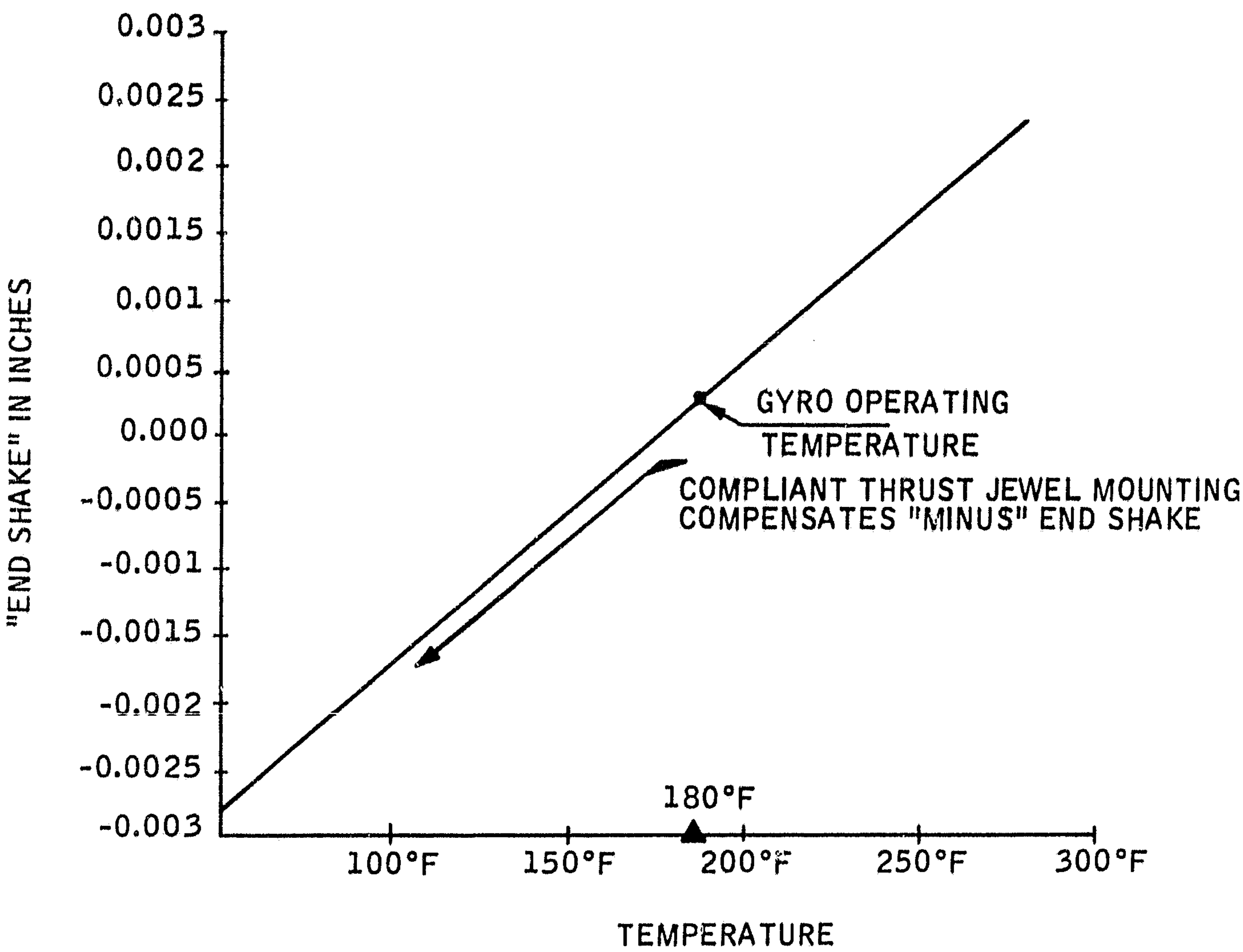



Figure 12. "End Shake" vs. Temperature with Compliant Thrust Jewel Mounting

The repeatability of jewel position from first cycle to last cycle was less than 20 micro-inches.

Since both the loading and displacement were nearly four times as great as expected in the GG334S gyro, the test indicated no problems with this concept in this application.

TORQUE GENERATOR

The torque generator used in the GG334S gyro is a four-pole torquer utilizing platinum/cobalt magnets. The torquer was subjected to individual cycles of 8, 16, and 48 hours, all at 300°F. Indi-ron checks of the geometry taken before and after each cycle showed no movement of the magnets after an initial shift of 0.00007 inches. (see Figure 13).

SPINMOTOR STERILIZATION

The spinmotor used in the GG334S gyro is identical to the motor originally developed for the GG159E (JPL Contract 951559). This motor was designed to combine high-g capability with low power and single voltage start/run operation plus the ability to be sterilized. For a detailed account of the development of this motor, see GG159E Final Report 20660-FR1, 31 October 1969.

During the build process, the spinmotor was subjected to extensive high temperature exposures both for stabilization and sorting purposes. This exposure to temperature is presented in Table 12. The results of this testing at the subassembly level revealed no significant spinmotor malfunction, although on two occasions at the gimbal level the spinmotor required approximately 28 volts to start after the first sterilization cycle. This condition disappeared once the unit had been started and did not repeat itself upon recycling the gimbal.

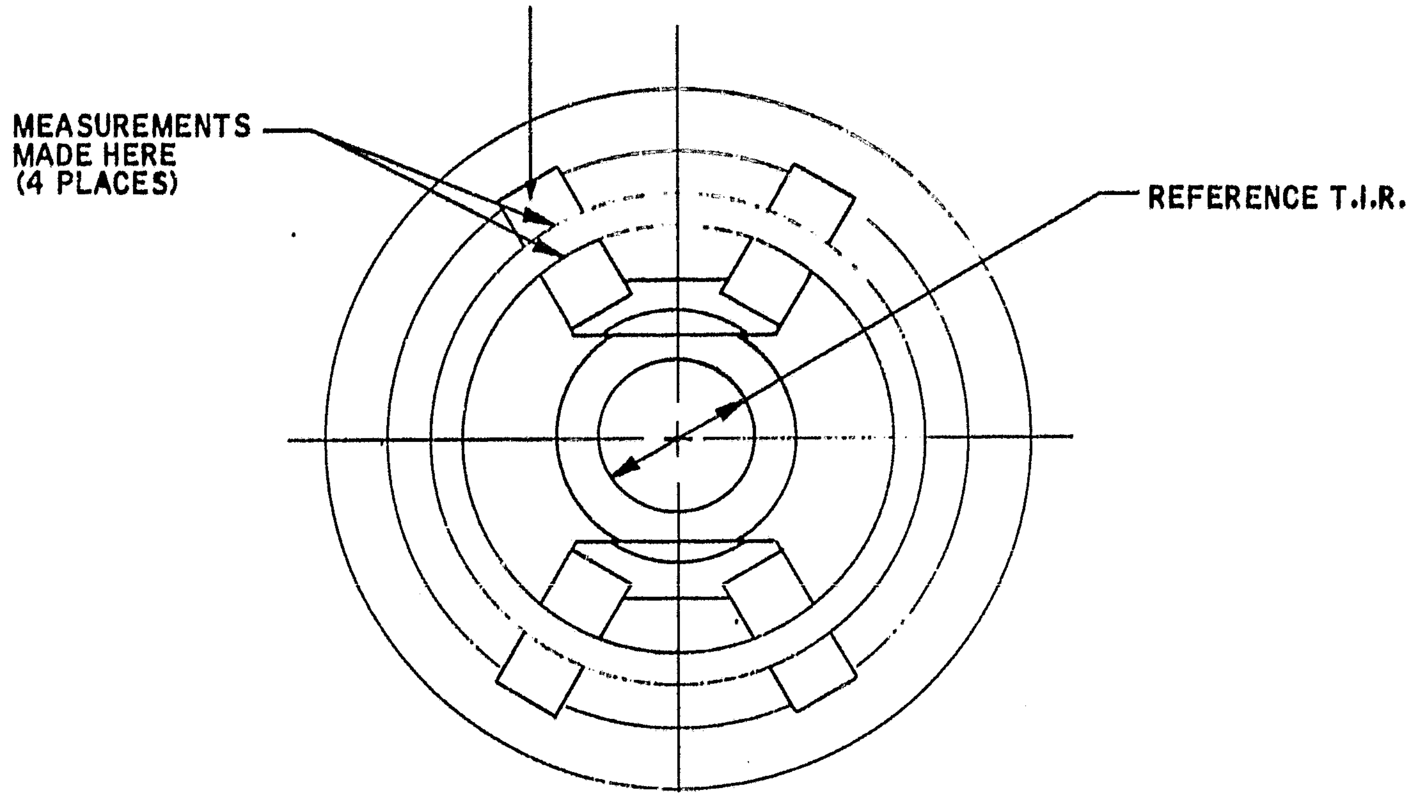



Figure 13. GG334S Torquer

Table 12. Spinmotor Subassembly Sterilization Tests (at 275°F Sterilization Temperature)

| Unit | Spinmotor Piece Parts | | Spinmotor Assembly | | Gimbal Assembly | | Total | |
|---|---|---|---|---|---|---|---|---|
| | Cycles | Hours | Cycles | Hours | Cycles | Hours | Cycles | Hours |
| GG334S | | | | | | | | |
| S/N B1 | 3 | 48 | 1 | 16 | 1 | 16 | 5 | 80 |
| B2 | 3 | 48 | 1 | 16 | | | 4 | 64 |
| B3 | 3 | 48 | 1 | 16 | | | 4 | 64 |
| A4 | 3 | 48 | 1 | 16 | 2 | 32 | 6 | 96 |
| A5 | 3 | 48 | 1 | 16 | 3 | 48 | 7 | 112 |
| GG159E | | | | | | | | |
| S/N B1 | 3 | 48 | 1 | 16 | 2 | 32 | 6 | 96 |

## SPINMOTOR SHOCK AND VIBRATION TESTING

All GG334S spinmotors were qualified to the vibration and shock specification prior to installation into the gimbal. Table 13 lists vibration and shock specifications.

Table 13. Vibration and Shock Specifications

- Random Vibration

Test Envelope:

| | |
|---|---|
| 0.2 $g^2$/cps (16.4 g rms) | 300-1000 cps |
| -6 db per octave | 1000-2000 cps |
| -24 db per octave | above 2000 cps |
| -3 db per octave | 20-300 cps |
| -24 db per octave | below 20 cps |

Test Duration:

3 minutes each axis.

- Random Vibration (with superimposed sine vibration)

  Test Envelope:

  | | |
  |---|---|
  | 5.0 g rms Gaussian | 15-2000 cps |
  | 2.0 g rms sine | 15-40 cps |
  | 9.0 g rms sine | 40-2000 cps |

  Test Duration:

  Sweep 15 to 2000 cps and back in 10 minutes each axis.

- Shock

  200 g peak
  1.5 ms (half sine)
  5 times each axis

Gimbal Shield

Initial test results obtained from both the GG159E and GG334S indicated very large spinmotor reaction torque (SMRT ~ 0.3 deg/hr RMS). As the result, a mu-metal shield has been incorporated into the gimbal at the coil cup end to reduce the interaction between the motor and torque generator magnetics. This shield serves to improve the runup-to-runup stability which had proved to be unacceptable in the test results on the preliminary gyro build.

The 800-cycle flux density, at the outside surface of the gimbal in the plane of the spin axis, was measured for three different stator configurations:

1) A stator without end cans
2) A stator with inconel end cans
3) A stator with mu-metal end cans

Figure 14 shows the result of these measurements. Note that the greatest flux density occurs in the plane of the rotor hysteresis ring due to leakage through the ring. Since the H-ring is a permanent magnet material, its permeability is low. Note also that the mu-metal end cans reduce the end turn flux but do not affect the flux leakage through the H-ring.

Flux density measurements were made on the torquer end of the gimbal (see Figure 15. Configurations were also mapped in three ways:

1) Without either the external or internal shield
2) With the regular external shield in place
3) With both the external shield and the 0.005-inch-thick internal shield

Since the external shield has a large center hole to clear the gimbal snout, it is not effective in shielding the flux leakage from the spinmotor. The internal shield attenuated the leakage flux by a factor of 5.5. Subsequent gyro test results indicated approximately the same attenuation in SMRT, to approximately 0.05 deg/hr RMS.

The nonsymmetry apparent in both Figures 14 and 15 was due to the stator being slightly off center with respect to the center line of the gimbal.

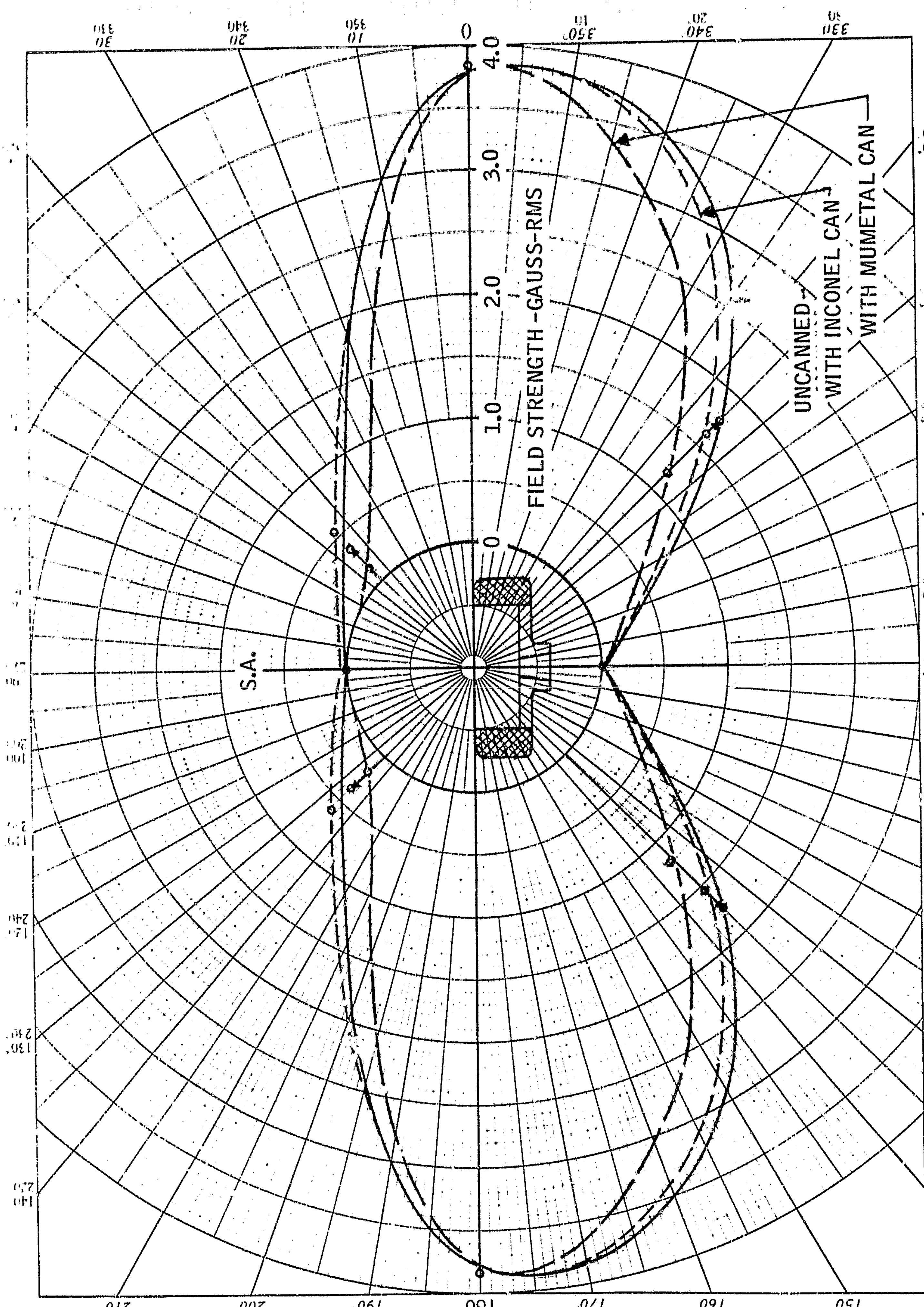



Figure 14. Field Strength Around Gimbal

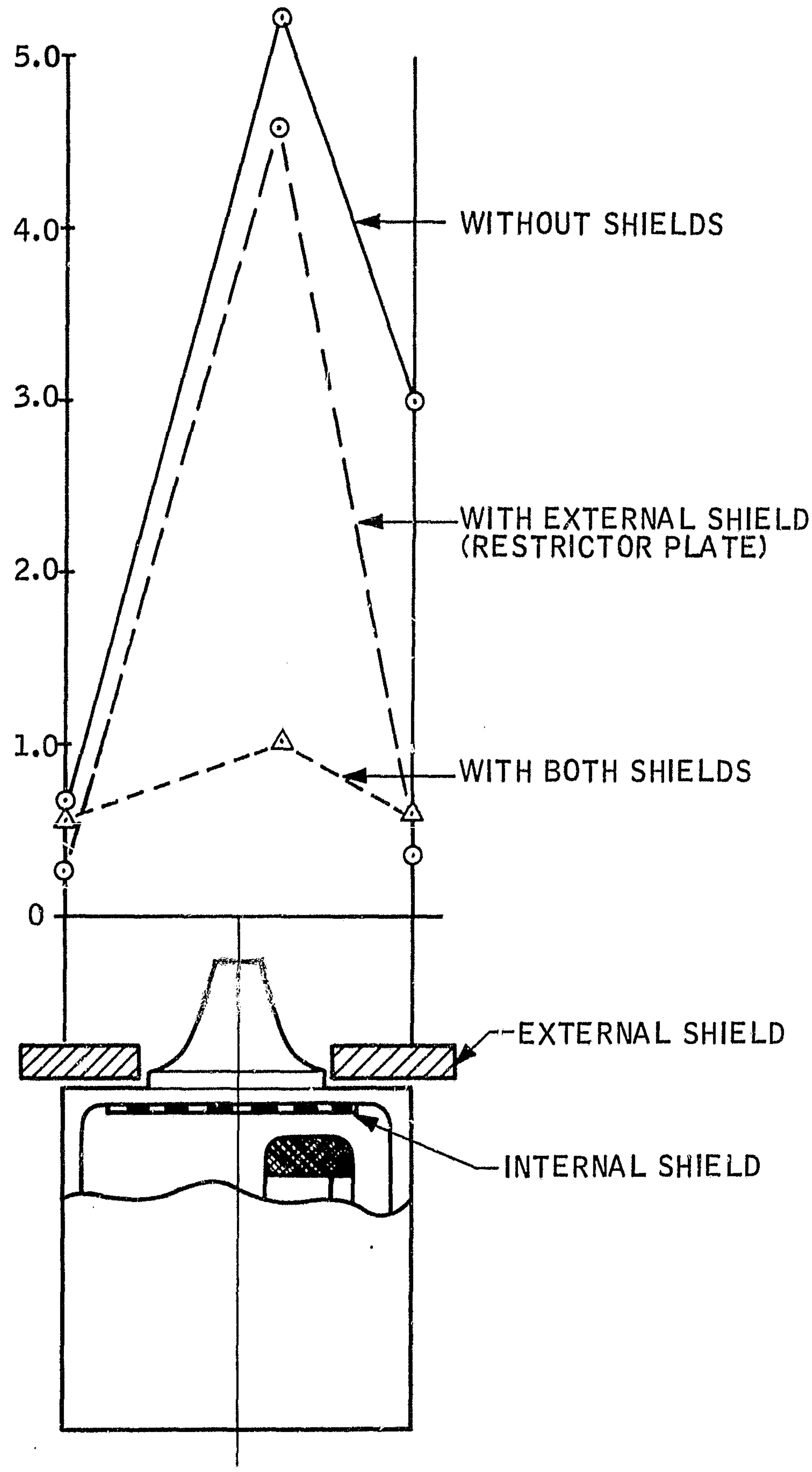



Figure 15. Field Strength in Gyro Spin Axis-Output Axis Plane