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THE DESIGN AND BUILD OF A GAS BEARING GYROSCOPE POSSESSING HIGH G AND STERILIZATION CAPABILITY AND UTILIZING A LOW POWER GAS BEARING SPINMOTOR AND HIGH FREQUENCY PUMP

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Fifth Quarterly Progress Report
for period
1 January 1968 - 31 March 1968

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California Institute of Technology

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Honeywell Inc.
Aerospace Division
Minneapolis, Minnesota

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This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Agency under Contract NAS7-100.

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ABSTRACT

The fifth quarter work on the design, build, and test of a gas bearing gyroscope possessing high g and sterilization capability and utilizing a low-power gas bearing spinmotor and high-frequency pump, has produced a gimbaled spinmotor, gyro assembly and first gyro test results. In parallel, a concentrated investigation into moisture, organic vapor, and particulate contamination is in process.

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SECTION I
SUMMARY

The purpose of this contract is to build a gas bearing gyroscope possessing high g- and sterilization capability utilizing a low-power gas bearing spinmotor and a high-frequency piezoelectric pump.

PROGRESS (FIFTH QUARTER)

- Coordination meeting at JPL and implementation of bi-weekly progress reports
- Test of moisture anti-lockup motor geometry
- Gimbal assembly
- Pretesting of high-frequency pump
- Preliminary gyro testing
- Detailed investigation of moisture, organic vapor, and particulate contamination

PROBLEMS (FIFTH QUARTER)

- The spinmotor starting voltage has increased to a marginal value

FUTURE WORK (SIXTH QUARTER)

- Continuing gyro test
- Gyro teardown and motor repair (high starting voltage)
- Gyro rebuild and start of final gyro testing
- Completion of contamination investigation

SECTION II
DISCUSSION

LOCKUP INVESTIGATION

The lockup problem is being investigated. This effort includes not only moisture-induced lockup but also organic vapor and particulate contamination-induced lockup.

Moisture Lockup

The moisture lockup problem was first discussed in the fourth quarterly progress report on contract 951529 (GG334S) which uses the same motor as the GG159E developed here under contract 951559. The problem is an inability to restart the motor when it has been stopped after continuous running for periods between 10 and 100 hours. Moisture in the gimbal parts evaporates into the gimbal atmosphere and then is pumped into the gas bearing where it condenses. This condensation allows the rotor to wring to the shaft when the motor slows down and the parts approach each other. The point of wringing in is indicated by an abrupt stopping of the rotor on rundown. The motor can be restarted if sufficient time (several days) is allowed for the water to evaporate; and the starting voltages quickly return to original values with a few quick starts and stops. Running the motor for a few hours will repeat the cycle.

Drying the gas with a molecular sieve-type drying agent, combined with piece part drying before assembly, extends the life of this motor but will not prevent the lockup from eventually occurring. It has been shown that revised bearing patterning is necessary to accomplish the required life.

Moisture lockup can be prevented by using patterns which pump gas through the bearing assembly as opposed to the usual configuration where each thrust bearing develops equal pressure at the ends of the journal bearing and creates a high-pressure, zero flow condition. By pumping gas through the assembly of thrust and journal bearings, the moisture can be carried away faster than it can condense.

Testing has shown the optimum pattern for preventing moisture lockup is the assymetrical journal pattern. In this approach, one of the two journal patterns is made longer than the other. This assymetry creates a pressure differential along the axial length of the journal bearing resulting in axial gas flow.

The assymetrical journal motor was tested under adverse moisture conditions with excellent results. After cleaning and assembly, the motor was mounted in a small air tight chamber and its performance monitored at the ambient relative humidity (RH) condition of 40 percent. Then, successive incremental amounts of water were added to bring the RH to 90 percent. No moisture lockup was observed. Table 1 summarizes the results.

Table 1. Moisture Lockup Sensitivity of Optimized Assymetrical Journal Design

Relative Humidity %	Running Hours	Motor Performance
40	1.0	No Lockup
50	3.0	No Lockup
60	2.0	No Lockup
70	2.0	No Lockup
80	2.0	No Lockup
90	2.0	No Lockup

This testing verifies that the assymetrical journal pattern will successfully solve the moisture lockup problem. However, experience on another gas bearing program shows there is also a possibility of organic vapor or particulate contamination causing lockup. Obviously, these mechanisms differ from the moisture mechanism, but the result is the same. Accordingly a parallel investigation program has been launched to pinpoint and remove any possible sources of contamination.

Organic Vapor and Particulate Contamination Lockup

A series of analytical tools have been and are being developed to aid in pinpointing sources of contamination. With the source identified, design changes can be implemented to prevent the possibility of contamination occurring. These analytical tools are discussed below.

Infrared Analysis -- A total of 14 organic materials are being used (or could be used) in the GG159E/GG334S gimbal assembly. These are listed below.

6020Q, $CaC0_3$ filled amine hardened

6020Q, fluorescent dye 7921

6293 F natural $CaCo_3$ filled amine hardened

6293 F black dye

6293 G unfilled, amine, with diisocyanate and tetrasulfide

6293 H, unfilled, amine

6293 J, anhydride, $Ti0_2$ filler

6293 N natural 7274 ceramic fill, amine hardened

6293 N black dye

7381 Bondmaster. Amine with isocyanate

7556 Eccobond aliphatic amine silver epoxy

7200 Heresite, phenolic

7553 Epoxolite 293-11. Anhydride

7997-01 DK-4. Anhydride

Infra red maps (see Figure 1 for sample) have been prepared for all 14 materials. With these maps, it should be a simple matter, should contamination occur, to compare appropriate finger prints and identify the contaminant.

Ultraviolet - Fluorescence Analysis -- Since gas bearing contamination is sometimes found in too small a quantity for infrared analysis, ultraviolet fluroescence samples were also prepared to form a standard for comparative checks. The previously mentioned 14 materials, plus "Sepko" cleaning powder, have been assembled into a compact visual aid comparison system. This system will permit visual correlation of the contaminant with the previously assembled standard. Table 2 lists the results.

Mass Spectrometer Analysis -- Mass spectrometer analysis will be used to sample gimbal fill gas for moisture content and organic vapor constituents. A fixture has been designed and built to permit direct gimbal gas sampling as shown in Figure 2. The gimbal is solidly clamped between the end nests with an "O" ring primary seal. A wheel puller device is used to extract the fill plug permitting the gimbal gas to enter the mass spectrometer chamber. The same fixture can also be used for gas chromatography cross checks.

Gas Chromatograph Analysis -- Five materials have been selected on the basis of quantity and proximity to the motors for outgassing and dewpoint tests. These materials are listed below.

MS6293F natural color, $CaCO_3$ filled, amine hardened (Stator Impregnant)

MS6293G unfilled amine hardened with Diisocyanate and tetrasulfide (Epoxy Adhesive)

MS6293N black dyed, ceramic filled, amine hardened (Stator Coating)

MS7381A Bondmaster, amine hardened epoxy (Stator Lamination Adhesive)

MS7556A Eccobond Aliphatic amine hardened silver filled epoxy (Electrically conductive adhesive)

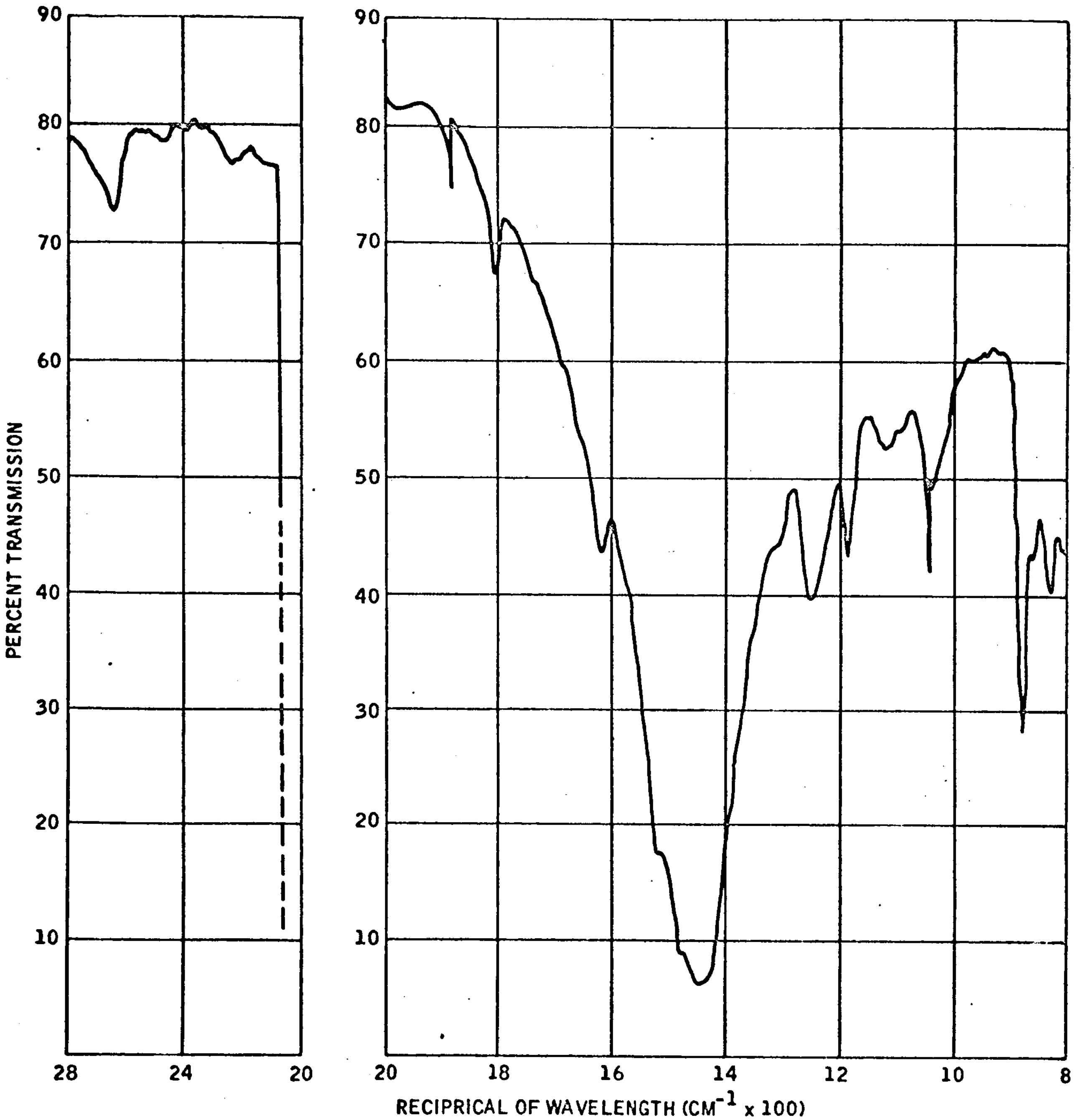

Figure 1. Sample Infrared Map

Table 2. Ultraviolet - Fluorescence of Materials Used in the GG159E/GG334S

Material	Samples in Solid or Bar Form	Samples Ground Into Powder
6020Q ($CACO_3$ Filled)	Mildly Fluorescent	Mildly Fluorescent
6020Q, Fluorsecent Dye	Fluorescent	Fluorescent
6243F Natural ($CACO_3$ Filled)	Mildly Fluorescent	Mildly Fluorescent
6293F Black Dye	Nonfluorescent	Nonfluorescent
6293G (Unfilled)	Mildly Fluorescent	Mildly Fluorescent
6293H (Unfilled)	Mildly Fluorescent	Mildly Fluorescent
6293J (TiO_2 Filled)	Nonfluorescent	Nonfluorescent
6293N Natural (Silicate Filled)	Mildly Fluorescent	Mildly Fluorescent
6293N Black Dye	Nonfluorescent	Nonfluorescent
7381 Bondmaster	Fluorescent	Fluorescent
7556 Eccobond	Nonfluorescent	Nonfluorescent
7200 Heresite	Nonfluorescent	Nonfluorescent
7553 Epoxilite 293-11	Nonfluorescent	Nonfluorescent
7997-01 DK 4	Nonfluorescent	Nonfluorescent
Sepko Powder	---	Mildly Fluorescent

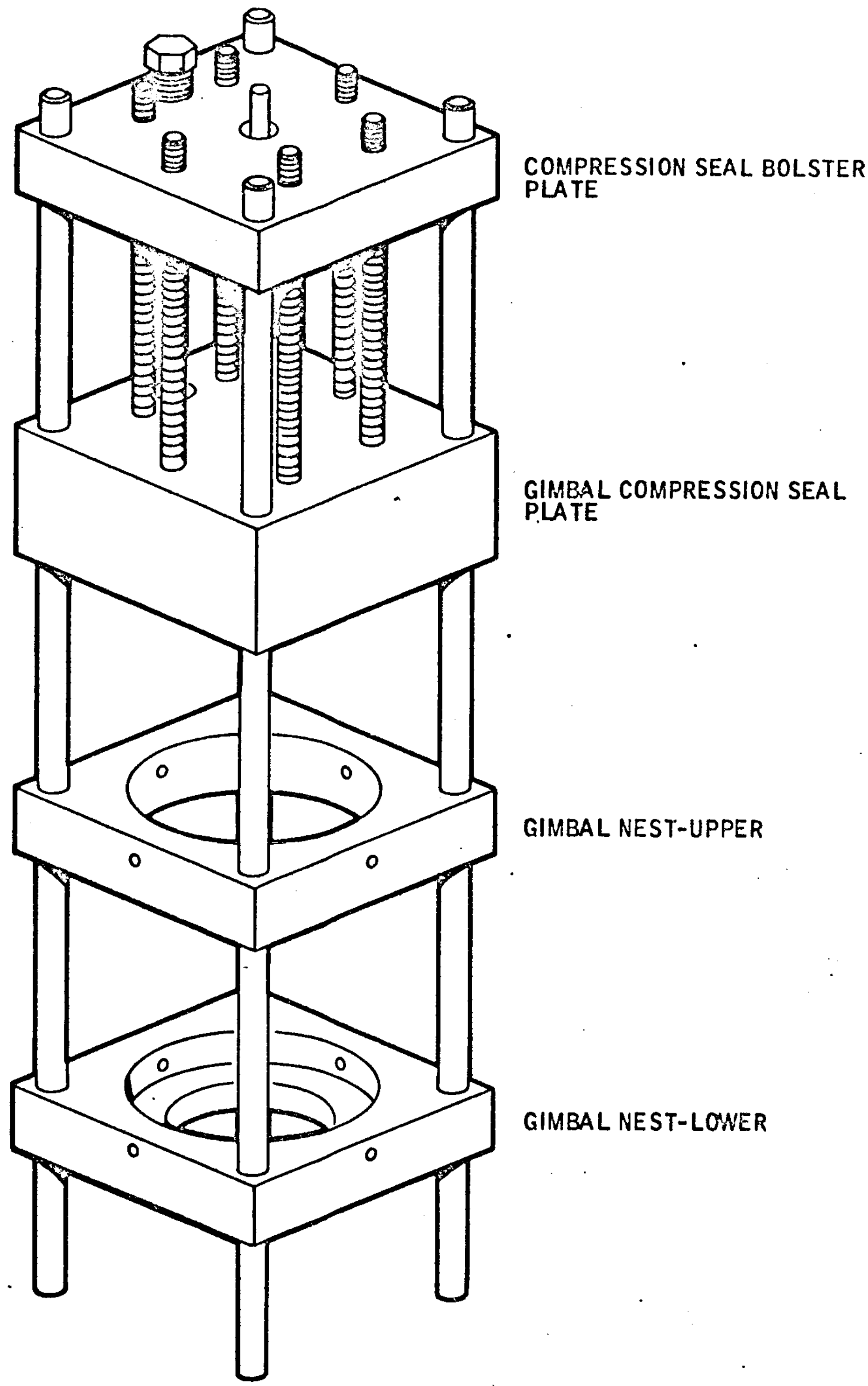

Figure 2. GG159E/GG334S Gimbal Gas Sampling Fixture

Thermal Analysis Tests -- Thermal behavior of the 14 organic materials used for the above UV-fluorescence tests will also be studied under a hot stage microscope capable of 350°C. Data from this analysis will enable more rapid future identification of contaminant materials.

STATOR CANNING

Design layout work on the canned stator was completed and experimental units built and tested. Figure 3 shows the basic concept. Two end cans are formed to the exact contour of the stator end turns. These cans are then bonded to the slot bridge and stator hub to totally enclose the stator in metal except for the bondlines. This approach should minimize organic vapor or moisture contamination exuding from the stator. Also, consideration was given to a solid liner for the laminated P-6 hysteresis ring as also shown in Figure 3. A series of magnetics tests were conducted with various combinations as shown below.

1. Canned stator - standard H-ring rotor

air gap = 0.002"	Power	3.0 watts
	Sync Margin	7.0 volts
	Start Margin	6.0 volts
air gap = 0.004"	Power	4.2 watts
	Sync Margin	6.0 volts
	Start Margin	6.0 volts

2. Canned stator and lined H-ring

air gap = 0.001"	Power	3.6 watts
	Sync Margin	2.0 volts
	Start Margin	4.5 volts
air gap = 0.002"	Power	3.9 watts
	Sync Margin	3.0 volts
	Start Margin	5.0 volts
air gap = 0.004"	Power	4.0 watts
	Sync Margin	4.0 volts
	Start Margin	6.0 volts

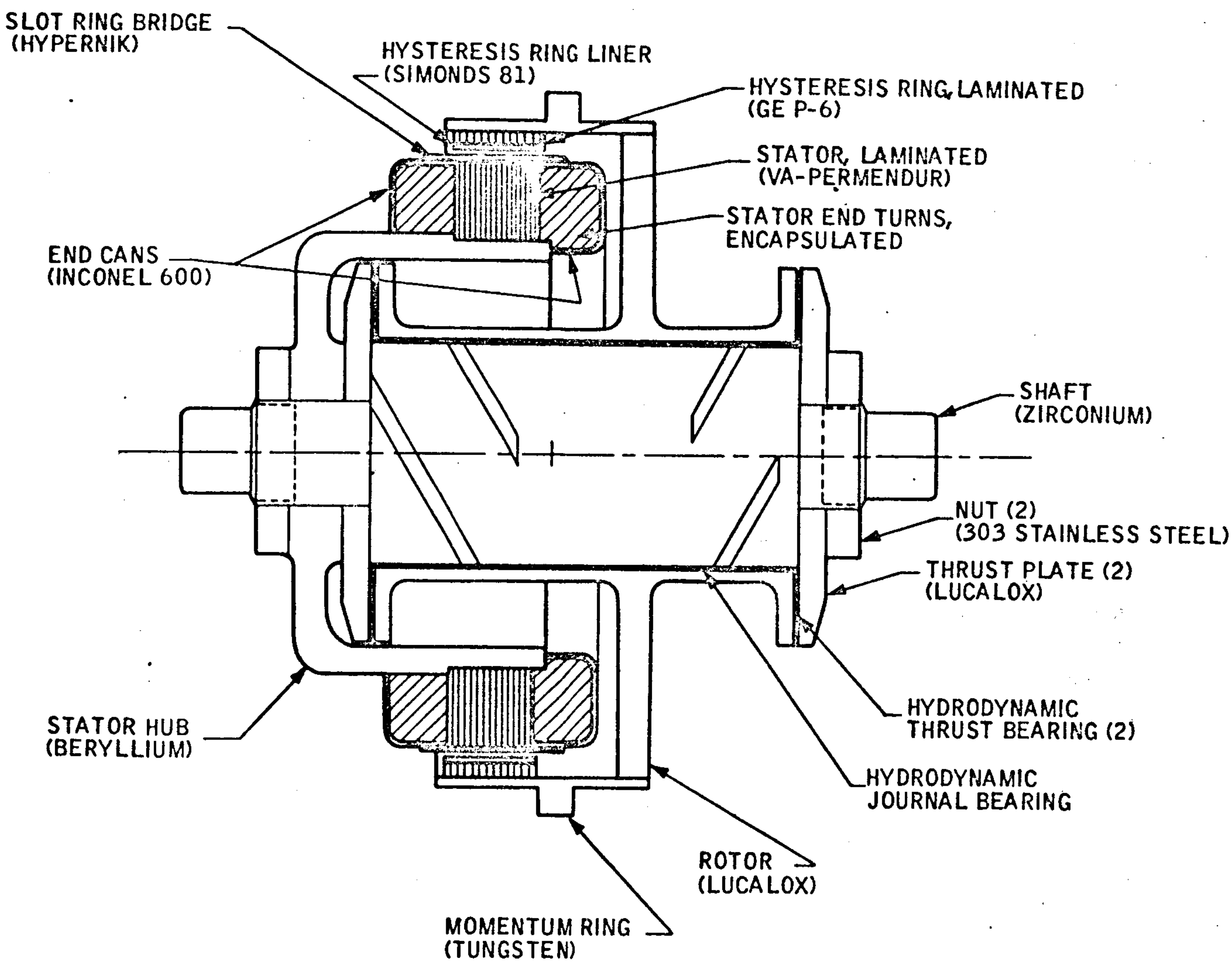

Figure 3. GG159E Gas Bearing Spinmotor

It is evident from these tests that adding the slot bridge and stator cans and reducing the air gap to 0.002 inch produces a motor with reasonable sync and start margins with acceptable power consumption. Lining the hysteresis ring is not desirable from a power standpoint. The GG159E spinmotor will be fabricated with a slot bridge and stator cans.

SPINMOTOR SHOCK AND VIBRATION TESTING

Shock testing of the unsymmetrical journal pattern motor was successfully completed with the application of five 200 g, 1.5 millisecond shocks in each axis. The three-pattern thrust plates increased the thrust capability to greater than 200 g's.

Successful vibration testing was also accomplished with the motor withstanding the random noise and random noise plus sine wave per JPL spec N 30250B amendment 2.

GYRO BUILD AND TEST

Gimbal Assembly

After the successful shock and vibration testing, the spinmotor was sealed into a gimbal and placed on extended runin. Some variability in starting voltage was noted and some out of spec starting voltage readings were obtained. However, the motor was still operable after 480 hours and no indication of the classic moisture lockup was evident. Starting voltage variability is attributed to organic vapor or particulate contamination. It was decided to proceed with the gyro build to determine whether any problems would result from the integration of the piezo pump to the gyro.

Gyro Build*

High-frequency pump operation was pre-tested prior to final sealoff. Torque levels due to pump on - pump off were less than the threshold of the test of 0.1°/hr.

Gyro Test

After functional tests on the unsealed version were completed, the gyro was sealed and preliminary tests were performed. Initial tests verify the piezo pump reaction torques to be less than 0.1°/hr as was suggested by the unsealed unit testing. Random drift was good. Proper suspension operation has been verified by good null repeatability performance (less than 0.01°/hr). Preliminary testing on the bellows capacity indicates a larger bellows will be required. Additional data is required to put this in perspective. Table 3 summarizes gyro test data to date. Vibration, shock, and sterilization tests tests are planned for the near future. A complete rebuild of the gyro is anticipated to correct the marginal spinmotor starting voltage and incorporate the canned stator.

Table 3. Summary of Gyro Test Results

Item	Value	Contract Req.
High freq. pump reaction torque	< 0.1°/hr	0.25°/hr
Random drift	OAV < 0.008°/hr	0.008°/hr
	IAV < 0.015°/hr	0.015°/hr
Null Repeatability	< 0.01°/hr	-

*Gyro build proceeded with no difficulty.

SECTION III
SCHEDULE

The present gyro test will continue until mid April. Teardown and rebuild will be accomplished by early June. The gyro will be tested and shipped by 9 September 1968.