From the book "Near Zero: New Frontiers of Physics." Editors, J. D. Fairbank, B. S. Deaver. Jr, C. W. F. Everitt, P. F. Michelson, 1988



# The Stanford Relativity Gyroscope Experiment (E): Flight Gyro Suspension System

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## 1. INTRODUCTION

As has been explained in the previous papers in this series, the gyroscope for the relativity gyroscope experiment is electrically suspended by applying ac voltages to three mutually perpendicular sets of electrodes within the quartz gyro housing. In ground-based operation of the gyroscope the suspension system has to support the gyroscope against the 1 $g$ acceleration from the earth, but in the final operating conditions of space the suspension is switched down to a level of $10^{-6}$ $g$ or less. Design of conventional electrical suspensions for 1 $g$ operation is well understood through prior work at Honeywell, Rockwell and Stanford, but the task of developing a suspension system capable of operating at low $g$ raises many technical questions.

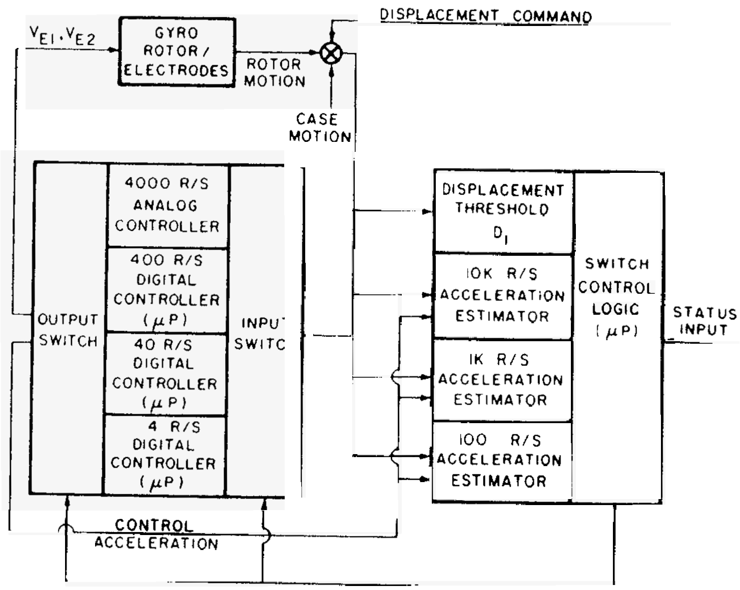
In this paper I describe work on the simulation of a suspension system for levitation and precision positioning of the niobium coated spherical quartz gyro rotor during orbital flight. The system employs multiple controllers and estimators with microprocessor (Z80) controlled range switching. The resulting system handles external accelerations up to 1 $g$ in the highest range, yet in the lowest range, below $10^{-6}$ $g$, the sensor noise power spectral density produces only $10^{-10}$ $g$ rms in the rotor. The system is capable of automatic emergency switch up within 100 $\mu$sec. Switch down is automatic to expected flight levels of $\pm 5 \times 10^{-8}$ $g$. Positioning accuracy in all ranges including emergency switch up is $\pm 5$ $\mu$in static and $\pm 50$ $\mu$in dynamic. The average acceleration during the mission should be $10^{-10}$ $g$ to attain the science data accuracy goal.

## 2. THE GYRO SUSPENSION SYSTEM

The electrical suspension system is mechanized by applying 20 kHz voltages to the electrodes consisting of a constant or "preload" component and a variable or "control" component which is added to the electrode in the direction the force is to be applied and subtracted from the opposite electrode. This approach linearizes the system, *i.e.*, the force is directly proportional to the control component rather than to the square of voltage. The rotor is maintained at zero voltage by using a three-phase system where each phase associates with one of the three orthogonal support axes. Position sensing is done with 1 MHz three-phase capacitance bridges using the same electrodes. The rotor electrode gap is 38 $\mu$m (1.5 mil). To support the ball on earth, a voltage of about 1 kV rms is needed with a control bandwidth of 4,000 rad/sec (640 Hz). In space, after spin up, the voltage needed to support against the residual acceleration of $\pm 0.5 \times 10^{7}$ $g$ is about 0.2 V rms with a control bandwidth of 4 rad/sec (0.64 Hz). The suspension system used in ground-based testing of the gyroscope was designed by the late J. R. Nikirk [1].

Figure 1 gives a single axis block diagram of the proposed multilevel flight suspension for which a hybrid simulation is operating. The system uses an array of four controllers with bandwidths of 4000, 400, 40 and 4 rad/sec, along with an array of three gyro cavity acceleration estimators with bandwidths of 10 k, 1 k and 100 rad/sec and a displacement threshold estimator. A Z80 microprocessor is used to determine which of the four controllers should be in use at all times, based on inputs from the four estimators, and to automatically switch accordingly.

The system must be able to operate with $10^{-7}$ $g$ preload and 4 rad/sec bandwidth during the experiment to avoid excessive suspension torques and sensor caused rotor noise acceleration. However, during ground test, spin up, and unexpected emergency, the system must switch up quickly to avoid dropping the ball and then switch down automatically when appropriate. Figures 2a and 2b show two oscilloscope photographs taken from the simulation, showing the reaction time after a period of operation at about $10^{-7}$ $g$ followed by an abrupt step in cavity position of 20 $\mu$in. The system has switched from the lowest to the highest range in the first 50 $\mu$sec. The



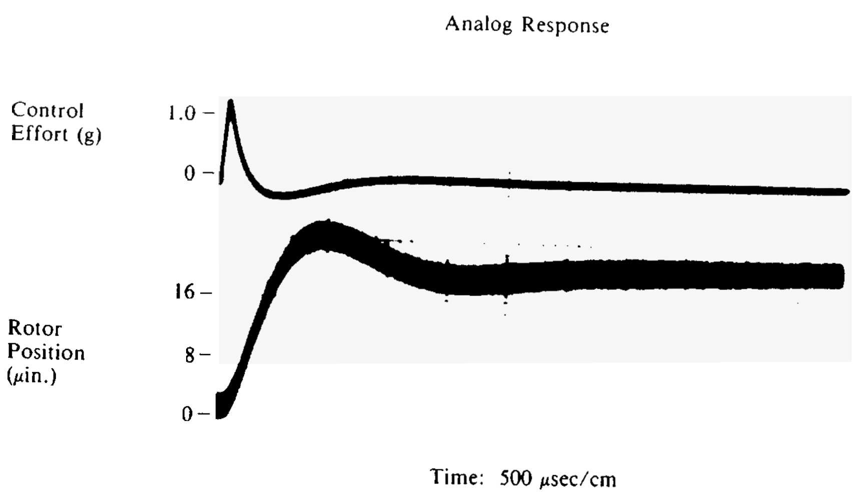




**FIGURE 2a**. Oscilloscope photograph of emergency switch up.

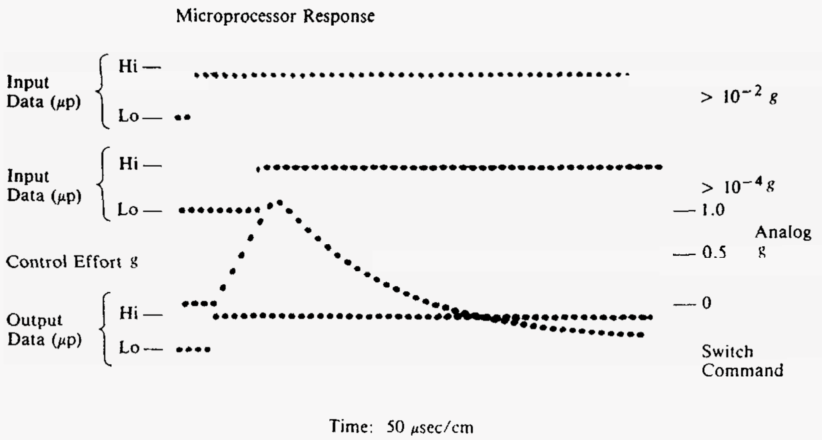



**FIGURE 2b**. Oscilloscope photograph of emergency switch up.

controller has applied 1 $g$ equivalent force within 150 $\mu$sec and removed it again at 300 $\mu$sec. The rotor has moved the 20 $\mu$in within 700 $\mu$sec with a 4 $\mu$in overshoot at 1000 $\mu$sec. The microprocessor has been given a change in the 10 k rad/sec estimator input (indicating $> 10^{-2}$ $g$), only 25 $\mu$sec after the emergency event. The microprocessor puts out the switching command (to jump from the 4 rad/sec range with $10^{-6}$ $g$ maximum to the 4000 rad/sec range with 1.0 $g$ maximum) only 50 $\mu$sec after the emergency event, and control effort begins to effectively solve the problem. Figures 3a and 3b show two oscilloscope photographs, the first of which is the switch

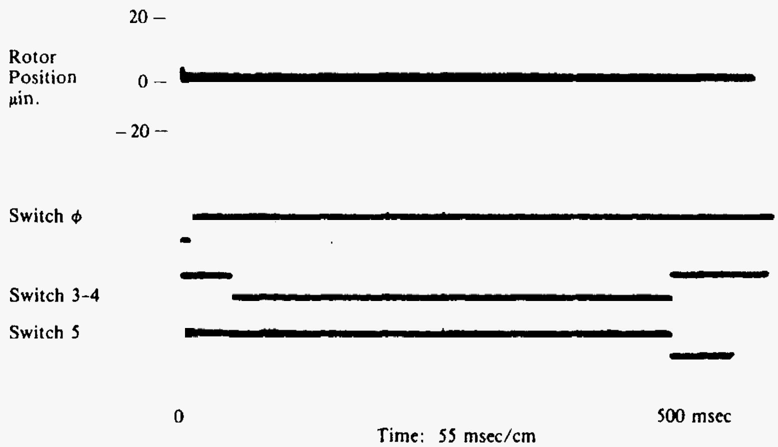



**FIGURE 3a**. Automatic switch down.

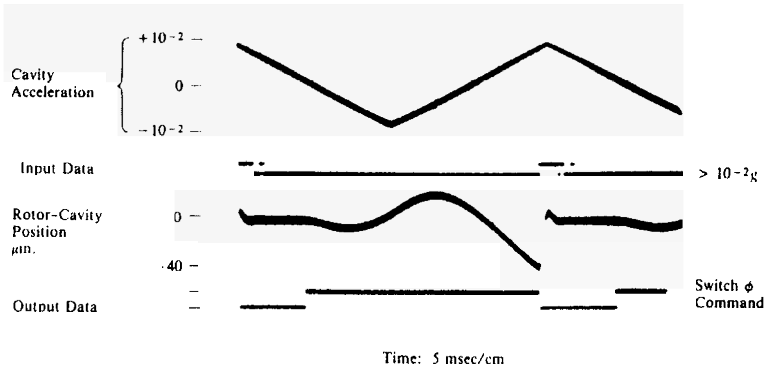



**FIGURE 3b.** Switch up/down at $10^{-2}$ $g$

down activity following the event of figure 2. The switch down events occur at about 5 msec (4000 to 400 rad/sec), 50 msec (400 to 40 rad/sec), and 500 msec (40 to 4 rad/sec). The final photo shows switching activity under a different condition where the external acceleration (cavity acceleration) shown in the upper trace has a triangle wave form going from slightly less than $|10^{-2}\ g|$ in the negative direction to slightly above $|10^{-2}\ g\ |$ in the positive direction. The system switches from the 400 rad/sec ($10^{-2}$ $g$) mode to the 4000 rad/sec (1 $g$) mode when $|10^{-2}\ g\ |$ is exceeded and back again after the level and time-out conditions have been met under microprocessor control.

Table 1 gives the key parameters used in the design of the suspension system simulation. These parameters include control authority, noise, switching thresholds and bandwidth for the controllers and cavity acceleration estimators.

**TABLE 1. MULTILEVEL FLIGHT SUSPENSION OPERATING RANGES.**

| Maximum Control Authority, $g$ | Switching Threshold, $g$ | Estimator Noise, $g$ and Bandwidth | Control System Noise, $g$ and Bandwidth |
|---|---|---|---|
| 1 | ↓ $10^{-2}$ | | $2 \times 10^{-3}$ at 640 Hz |
| $10^{-2}$ | ↑ $10^{-2}$, ↓ $10^{-4}$ | $1.3 \times 10^{-3}$ at 1600 Hz | $4 \times 10^{-6}$ at 64 Hz |
| $10^{-4}$ | ↑ $10^{-4}$, ↓ $10^{-6}$ | $4.0 \times 10^{-6}$ at 160 Hz | $2 \times 10^{-8}$ at 6.4 Hz |
| $10^{-6}$ | ↑ $10^{-6}$ | $1.3 \times 10^{-8}$ at 16 Hz | $7 \times 10^{-11}$ at 0.64 Hz |

## 3. CONCLUSION

The simulation results to date, although very preliminary, demonstrate the feasibility of the multilevel flight suspension system as well as the great advantage of operation under dedicated microprocessor control.

## References

[1] J. R. Nikirk, "Fabrication of an Electronic Suspension Subsystem for a Cryogenic Electrostatically Suspended Gyroscope for the Relativity Experiment," Final Report on NASA Contract NAS 8-27333, submitted by Dept. of Aeronautics and Astronautics, Guidance & Control Laboratory, Stanford, CA, Jan., 1973.