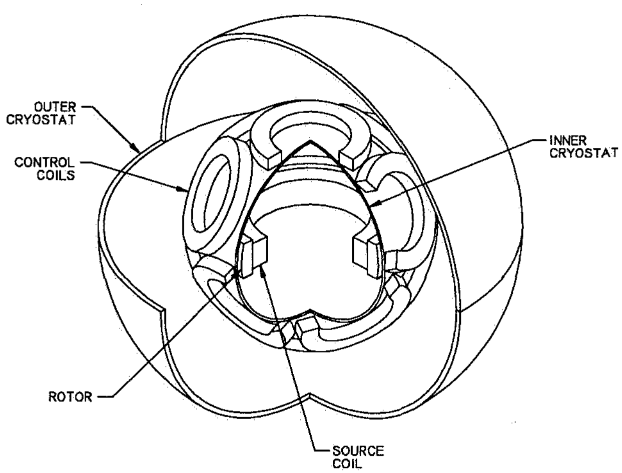
N92-27815

PERFORMANCE OF A SUPERCONDUCTING LARGE-ANGLE MAGNETIC SUSPENSION

James R. Downer
Dariusz A. Bushko
Vijay Gondhalekar
Richard P. Torti
SatCon Technology Corporation
12 Emily Street
Cambridge, MA 02139

SatCon Technology Corporation has been working toward the development of an advanced-concept Control Moment Gyro (CMG). The advanced-concept CMG is sized for use as a slewing actuator for large space-based payloads. The design features a magnetically suspended composite rotor which contains a persistent-mode superconducting solenoid magnet. The rotor is suspended and gimballed by the interaction of the fields produced by the superconductor and an array of cryoresistive ("hyperconducting") coils. The rotor spins in a liquid helium environment, while the control coils are liquid-hydrogen cooled. This design is only capable of meeting the requirements of many high-performance slewing applications (27,000 Nm). The use of the magnetic suspension as rotor bearings, gimbal bearings, and gimbal torquers also substantially reduces the mass of the CMG system.

MAGNETICALLY SUSPENDED CONTROL MOMENT GYROS (CMGs)



- **Dual Use of Magnetic Suspension**
  - **Rotor bearing**
  - **Gimbal system**
- **Advanced Magnetic Suspension**
  - **Superconducting magnet**
  - **"Hyperconducting" control coils**
- **Eliminates Mechanical Gimbal Assemblies**

PRECEDING PAGE BLANK NOT FILMED

In order to demonstrate this technology, SatCon has developed a demonstration for the required control system technology required for the advanced-concept CMG. The demonstration is called a superconducting Large-Angle Magnetic Suspension (LAMS). The demonstration hardware consists of a suspended body which consists of a persistent-mode superconducting magnet and its associated dewar. The control coils used for suspension are air-core normal (non-superconducting) copper coils. An innovative combination of sensors is used to sense the position of the suspended body in five degrees-of-freedom. The controller was implemented on a digital signal processor.

SUPERCONDUCTING LARGE-ANGLE MAGNETIC SUSPENSION (LAMS)

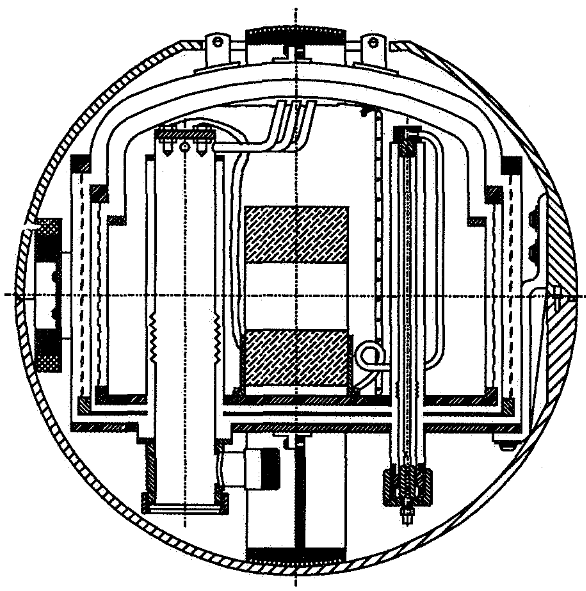
- **Control System Demonstration**
- **Suspended Body:** **Superconducting Magnet & Dewar**
- **Suspension Hardware:** **Air-core Normal Coils**
- **Sensor system:**
  - **Capacitive for translation**
  - **Mutual induction (variometer) for rotation**
- **Controller:** **Digital Signal Processor**

This photo shows the superconducting LAMS experiment. The hardware consists of the suspended body on its support stand, an array of twelve control coils mounted on two halves of a welded stainless steel support structure, and a crane-lift assembly which is used to move the parts of the system. A control console consists of the interface electronics for the sensors, power amplifiers for the control coils, control computer, and magnet power supply.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

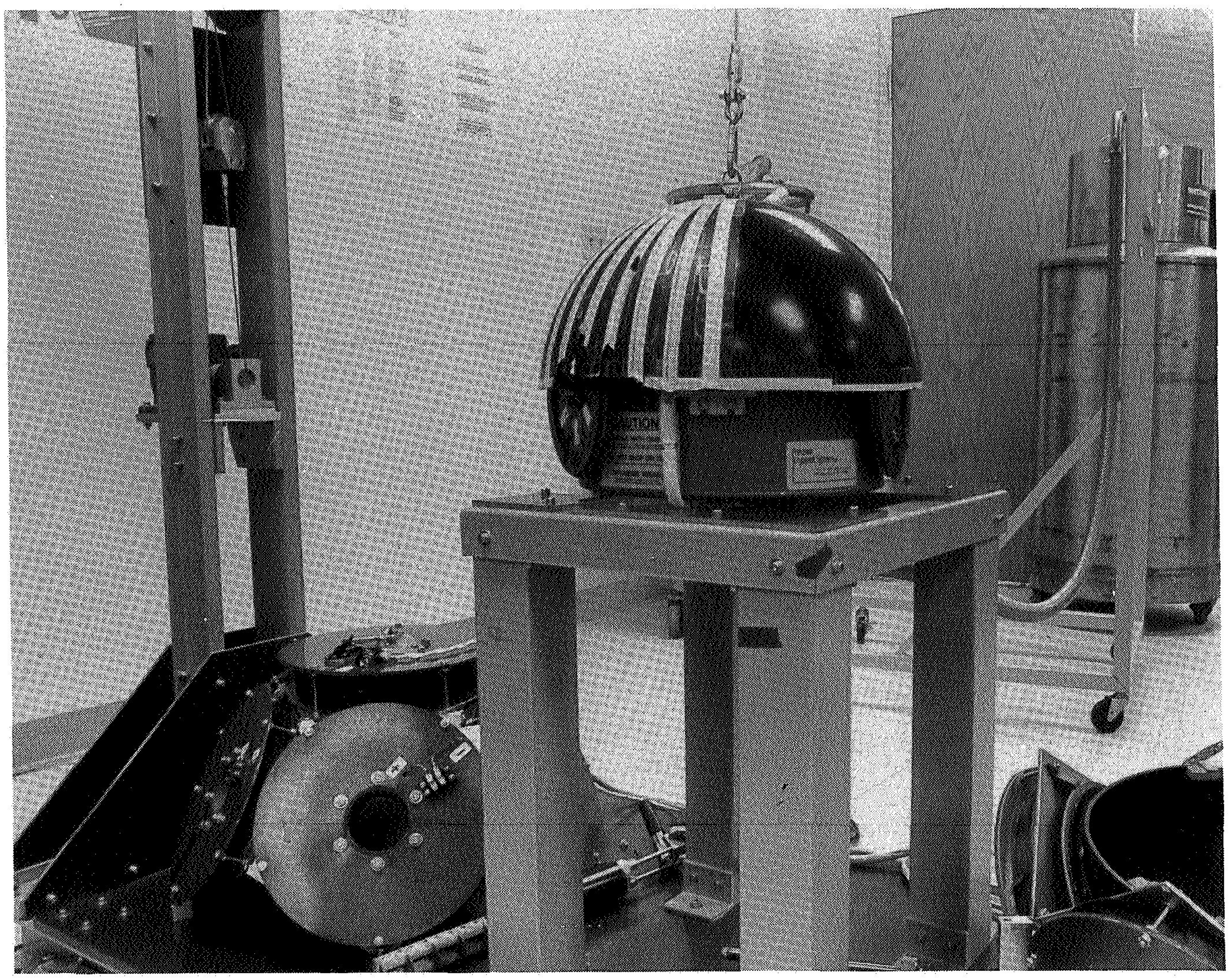
The drawing at the left is a cut-away view which shows the internal arrangement of the components on the suspended body. The central feature is the superconducting solenoid magnet. This is a commercially available magnet of niobium titanium wire which produces a maximum bore field of 8.2 Tesla and is capable of operation in a persistent mode. The temperature of the magnet is maintained at 4.2 °K by a vacuum-insulated dewar which holds approximately 7 liters of liquid helium. The dewar is surrounded by a spherical shell of conductive plastic which acts as a target for the capacitive sensors which provide the translational position of the suspended body.

Superconducting Magnet and Dewar



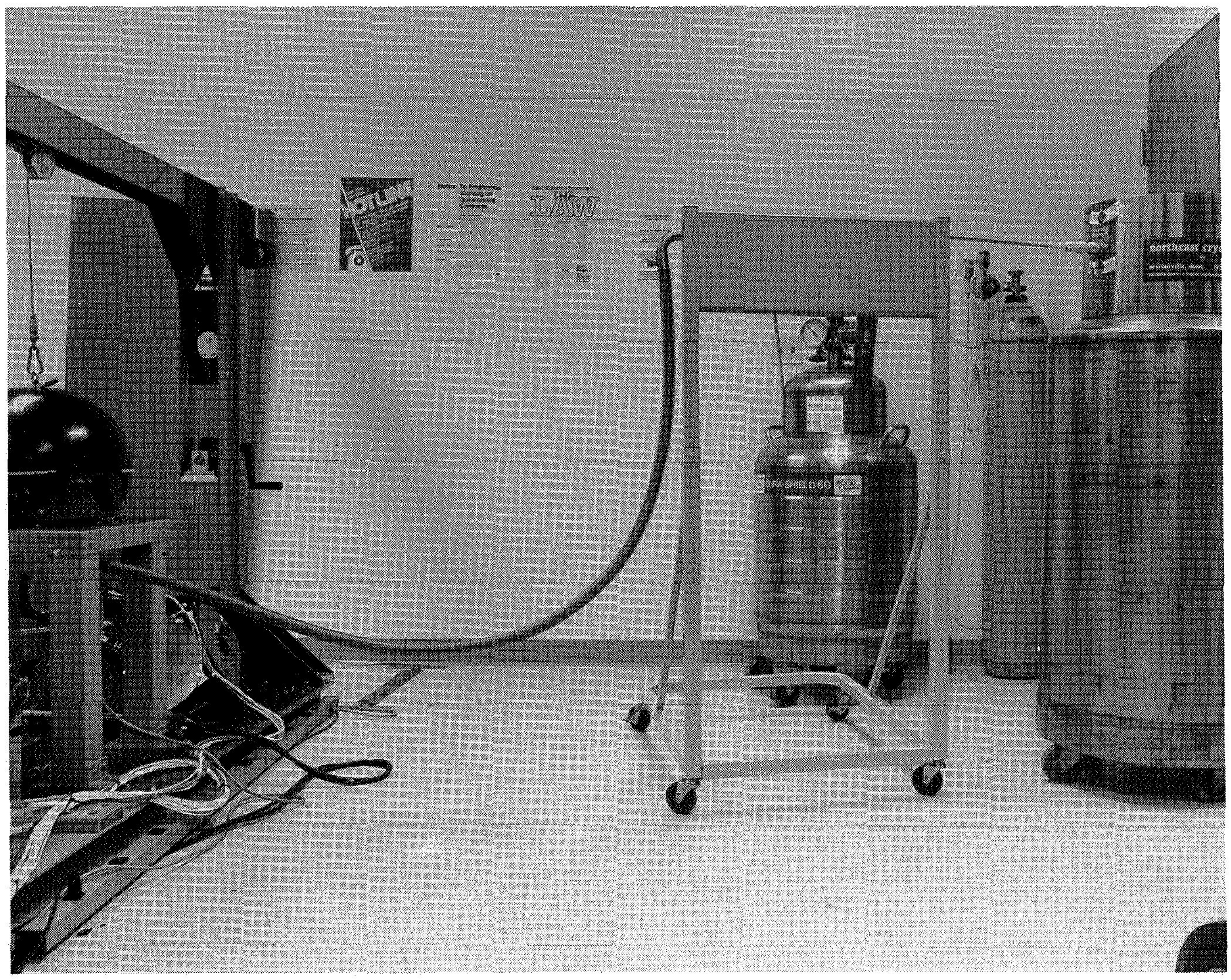
- o **Magnet:**
  - **Material: Niobium Titanium**
  - **Field: 8.2 Tesla**
  - **Persistent mode operation**
- o **Dewar:**
  - **Total weight: Approx. 48 lbs.**
  - **Helium capacity: 7 liters**

This photo shows the suspended body on its support stand. The bottom half of the spherical shell has been removed for service (filling with liquid cryogen) and has been placed in the lower half of the control-coil support structure at the lower right corner of the photo. The upper half of the control-coil support structure and the current-lead assembly for the superconducting magnet are visible at the left-hand side of the photo.



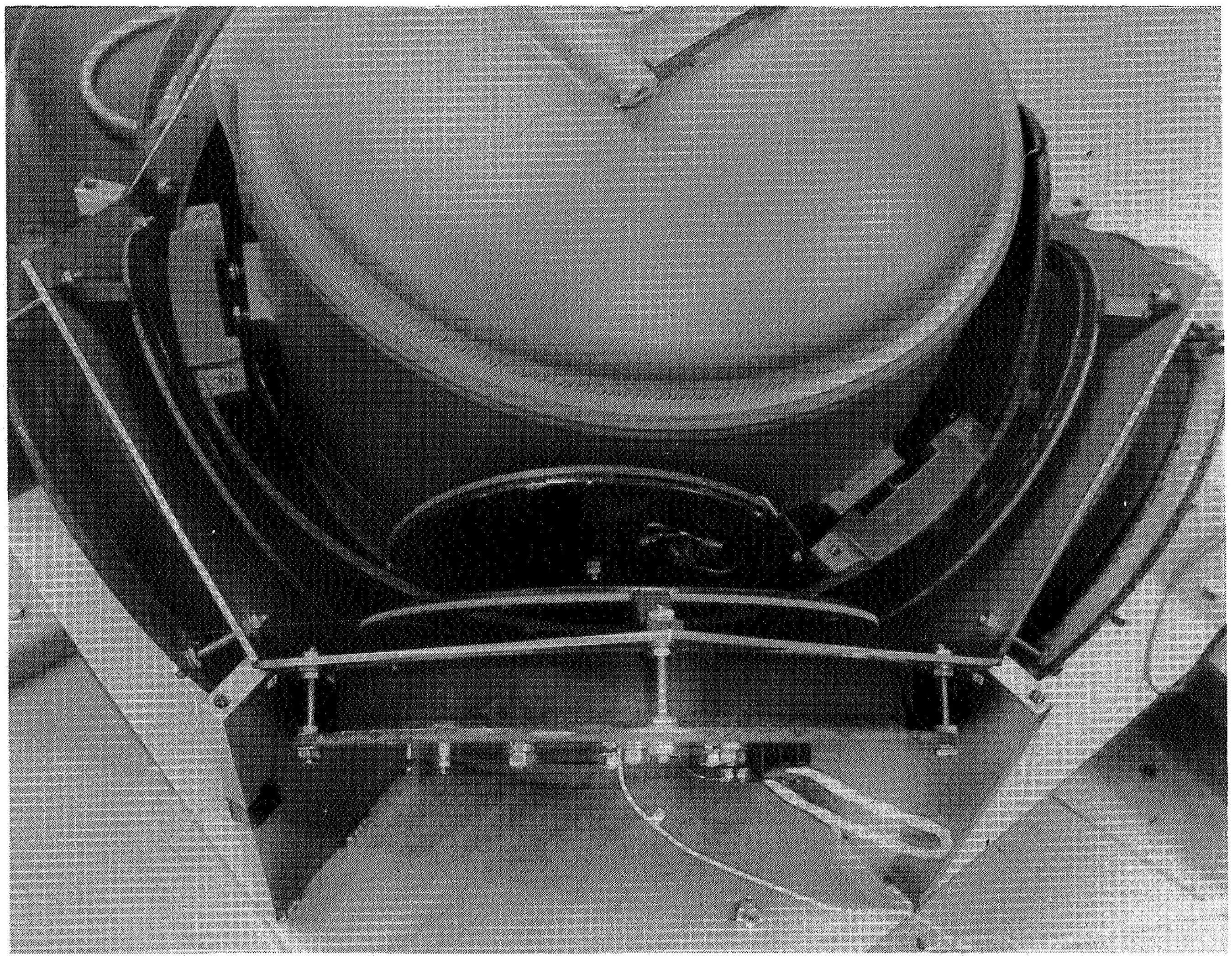
ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

This photo shows the filling process for the dewar. A flexible transfer line is used to supply liquid into the cryostat. The photo shows liquid nitrogen being transferred. The liquid nitrogen is used to pre-cool the dewar to 77 °K. Pressurized gaseous helium is then used to purge the liquid nitrogen. The dewar is then filled, further cooled and filled with liquid helium.

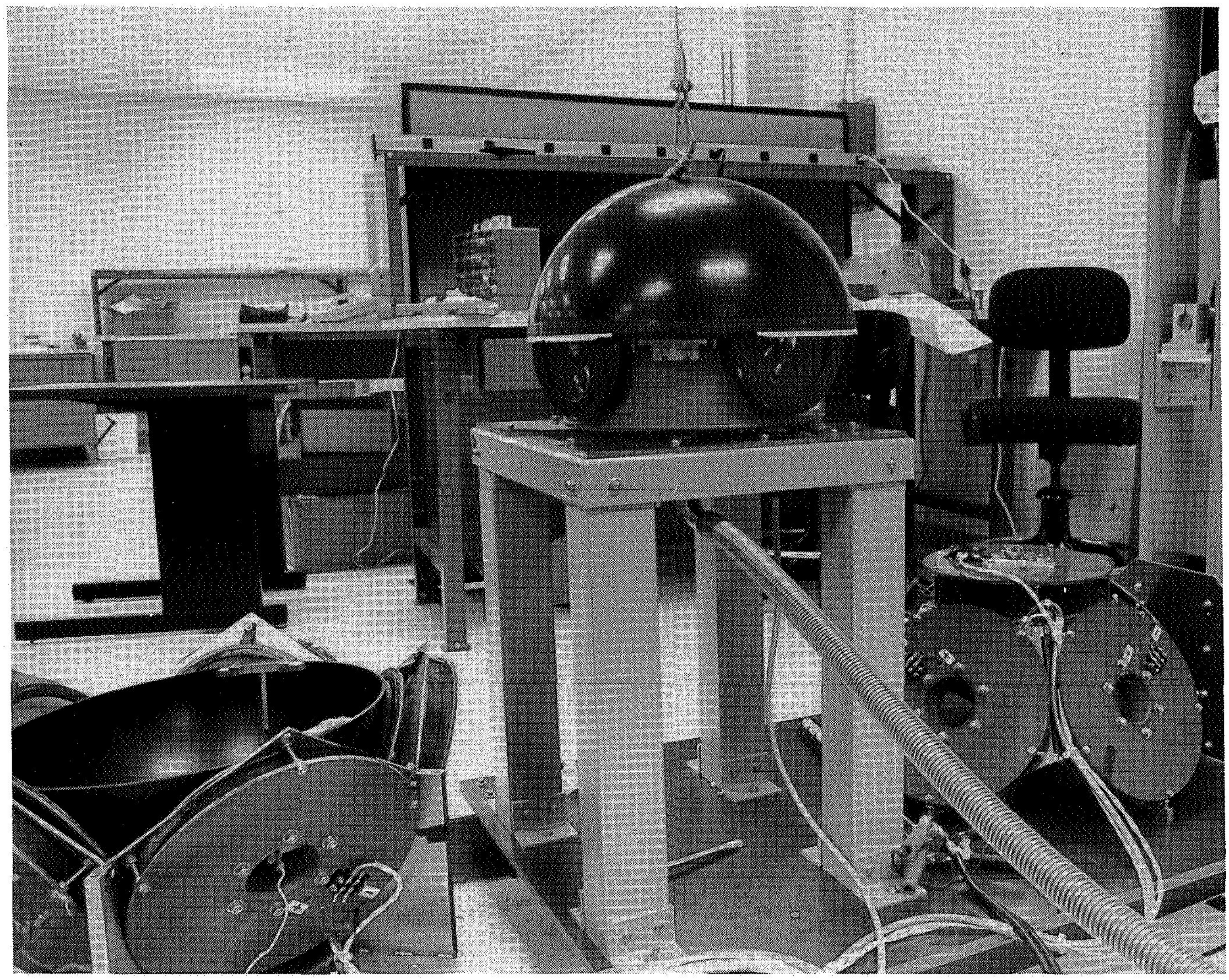


This photo shows the hardware for the position sensor systems. Leads for the capacitive translational sensor system are shown exiting from the bores of the control coils in the lower half of the control coil support structure.

The upper half of the spherical shell of the suspended body has been removed to show three coils which are attached to the dewar. An array of coils is also shown attached on the interior wall of the control-coil support structure. The ten stationary coils are driven with a high-frequency sinusoidal current and the voltage of each is monitored. The voltage is a measure of the mutual inductance of the rotating and stationary coils and therefore, also of their angular separation.

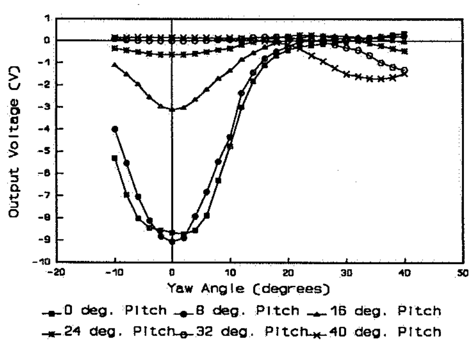


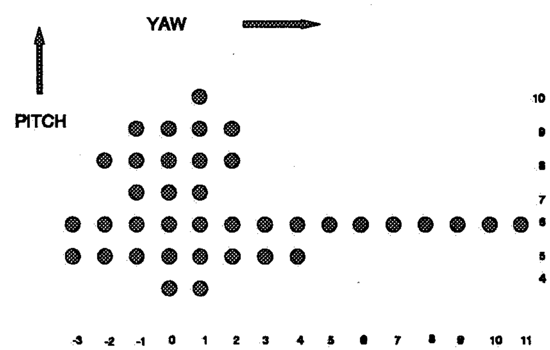
This photo shows more detail for the suspended-body portion of the rotation sensing system. There are three coils attached to the dewar on the suspended body. The terminals of these coils are shorted through capacitors to create a passive tuned inductor-capacitor system at the resonant frequency of the stationary transmitting coils. The stationary transmitting coils are similarly tuned to the excitation frequency.



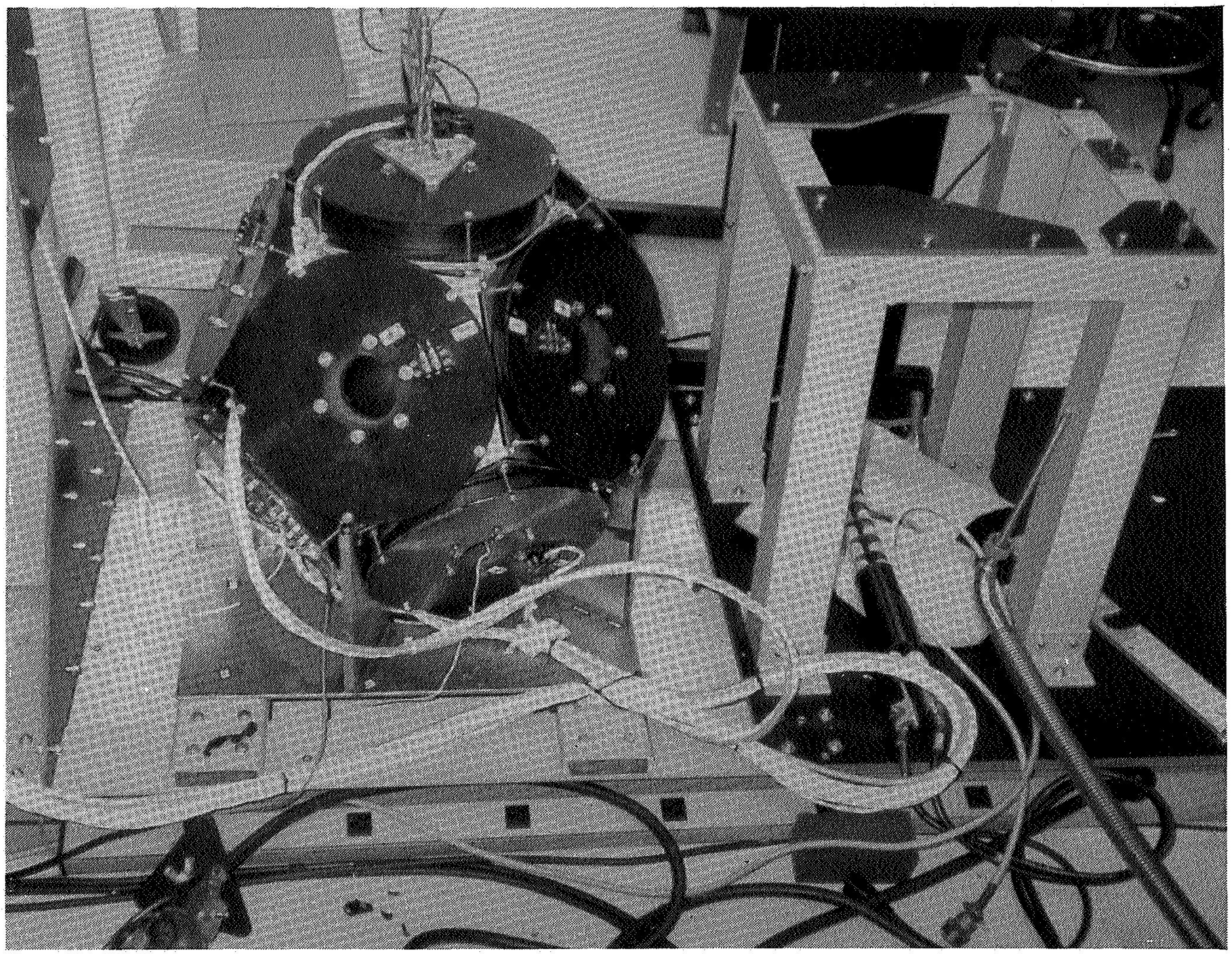
This figure shows the output of the rotating sensor system and the resulting angular range. The figure at the left-hand-side is the voltage of one transmitting coil as a function of the relative yaw and pitch of a passive coil. The outputs of three transmitting coils were sampled and the pitch and yaw angles were inferred by an iterative algorithm implemented in the digital signal processor. The figure at the right-hand side shows the range over which the algorithm was stable. This indicates the allowable gimballing range of the superconducting LAMS.

SENSOR SYSTEM OPERATION





This photo shows the assembled superconducting LAMS ready for test. The upper half of the control coil support structure has just been lowered via the crane and attached to the lower half. The dewar has sufficient helium storage capacity for a one hour experimental run.



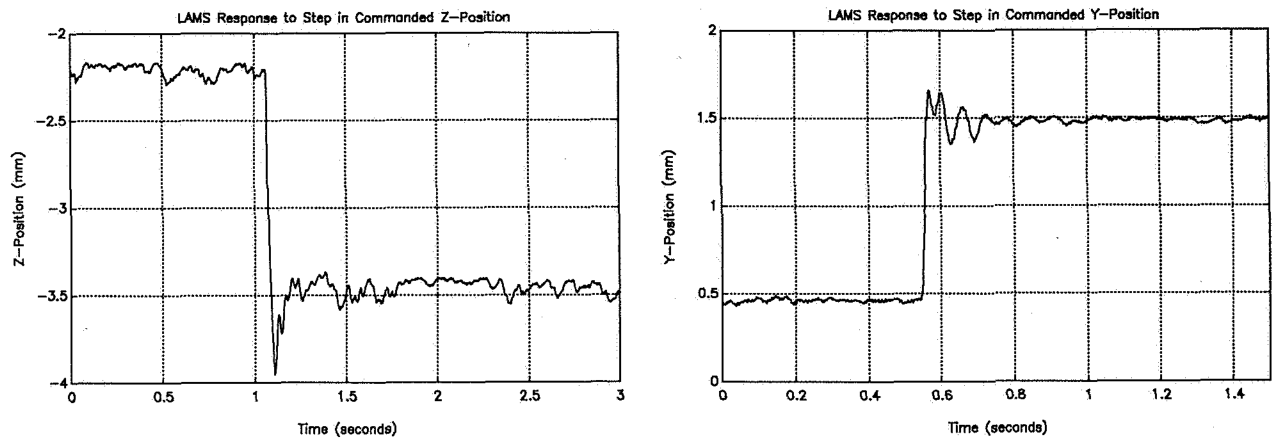
The control for the superconducting LAMS was done in a reference frame which was fixed with respect to the solenoid. This allowed the controller to be implemented as five single-input-single-output lead-lag compensators. The controller acted as a regulator for the translational position of the suspended body. Two of the three available analog inputs were used to provide command signals for the rotational control loops. There were four analog outputs available for troubleshooting of the controller during development. The vertical position of the suspended body was regulated to a reference position which was provided by the user via the keyboard.

Five Degree-Of-Freedom Suspension

- Simple Lead Lag Controller
- Regulation around nominal center position
- 3 Auxillary Analog inputs
- 4 Auxillary Analog outputs
- Vertical reference input via keyboard

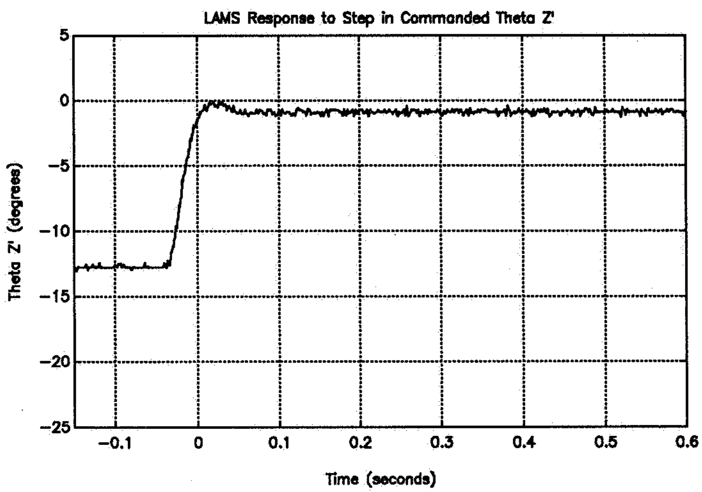
These figures show the transient responses of the translational controllers. The figure at the left shows the result of a commanded downward step in the vertical position (height) of the suspended body. The figure at the right is the response to a commanded step along one of the horizontal axes.

Performance of Superconducting LAMS Translational Controllers



This figure shows the response of the superconducting LAMS to a commanded step change in one of the rotational degrees-of-freedom. This particular angle is the yaw angle. This demonstrates the capability of using the superconducting LAMS as a replacement for a mechanical gimbal system.

Performance of Superconducting LAMS Rotational Controllers



The superconducting LAMS demonstration experiment was performed for the NASA Langley Research Center under Small Business Innovation Research (SBIR) funding. The first phase was an analytical study during which SatCon developed the analytical tools necessary to design the full-scale CMG system and finalize the design requirements. The performance of the full-scale system was also estimated. The demonstration experiment was identified during Phase I and carried out during Phase II. This experiment, which was described in this paper demonstrated the control system technology necessary to simultaneously suspend and gimbal a persistent-mode superconducting magnet and its associated dewar.

SATCON SUPERCONDUCTING LAMS SBIR PROGRAM

- **Phase I:**
  - **Developed analytical tools**
  - **Developed CMG design**
  - **Estimated performance**
  - **Identified technology demonstration experiment**
- **Phase II:**
  - **Demonstrated LAMS control system for suspension and gimballing**
  - **Suspended and gimballed commercially-available superconducting magnet and associated dewar**