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**MAGNETICALLY SUSPENDED
REACTION WHEEL ASSEMBLY**

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INTRODUCTION

The Magnetically Suspended Reaction Wheel Assembly (MSRWA) is the product of a development effort funded by the Air Force Materials Laboratory (AFML) at Wright Patterson AFB. The specific objective of the project was to establish the manufacturing processes for samarium cobalt magnets and demonstrate their use in a space application. The development was successful on both counts.

This presentation emphasizes the application portion of the program, which involves the magnetically suspended reaction wheel assembly. The requirements for the reaction wheel were based on the bias wheel requirements of the DSP satellite.

The work was performed during the period of May 1976 through June 1980. The tasks included the design, fabrication, and test of the unit to the DSP program qualification requirements.

AFML PROGRAM SCOPE

- **Establish Manufacturing Processes For the Production of a Magnetically Suspended Reaction Wheel Assembly (MSRWA) Consisting of Two Subassemblies, Mechanical and Electrical.**
- **Work to be Completed Includes:**
 - **Electrical/Mechanical Design**
 - **Electrical/Mechanical Subassembly Production and Assembly**
 - **Engineering Model Assembly**
 - **Engineering Test and Evaluation**
 - **Quality Control and Test**

Figure 1

RADIATION FACTOR

One of these unique requirements is the radiation-hardened electronics factor. Under this type of requirement, designing involves additional analytical effort because of severe derating and the need to limit current. Once designed, however, the electronics proved to be the most reliable portion of the system.

AFML PROGRAM SCOPE (CONT'D)

- **Radiation Hardened Electronics**

- **Four Phase Program**
 - **Phase I Thru III Includes Design, Manufacturing Methods Development, Production and Test of Subassemblies, and Fabrication of an MSRWA**

 - **Phase IV Includes Testing and Evaluation of the Engineering Model**

Figure 2

PROGRAM REQUIREMENTS

The overall program goal was to demonstrate that magnetic suspension was a viable concept, capable of meeting realistic space program requirements.

PROGRAM GOALS

- **Elimination of Lubrication Requirements**
- **Increased Speed Capability**
- **Reduction of Temperature Sensitivity**
- **Reduction of Running and Noise Torques**
- **Reduction of Power Requirements**
- **Elimination of Single Point Failures**

Figure 3

MECHANICAL ASPECTS

ORIGINAL DESIGN
OF PCCR CONTROL

The mechanical portion of the system is patterned after our successful line of control moment gyros (CMGs), using a shell rotor and housing. Each end of the shaft assembly houses a magnetic bearing, a motor, a velocity sensor, and a position sensor. The normal mode of operation is to control the axial position from one end.

**AFML
MAGNETIC SUSPENSION
REACTION WHEEL
500-1000 RPM-SEC**

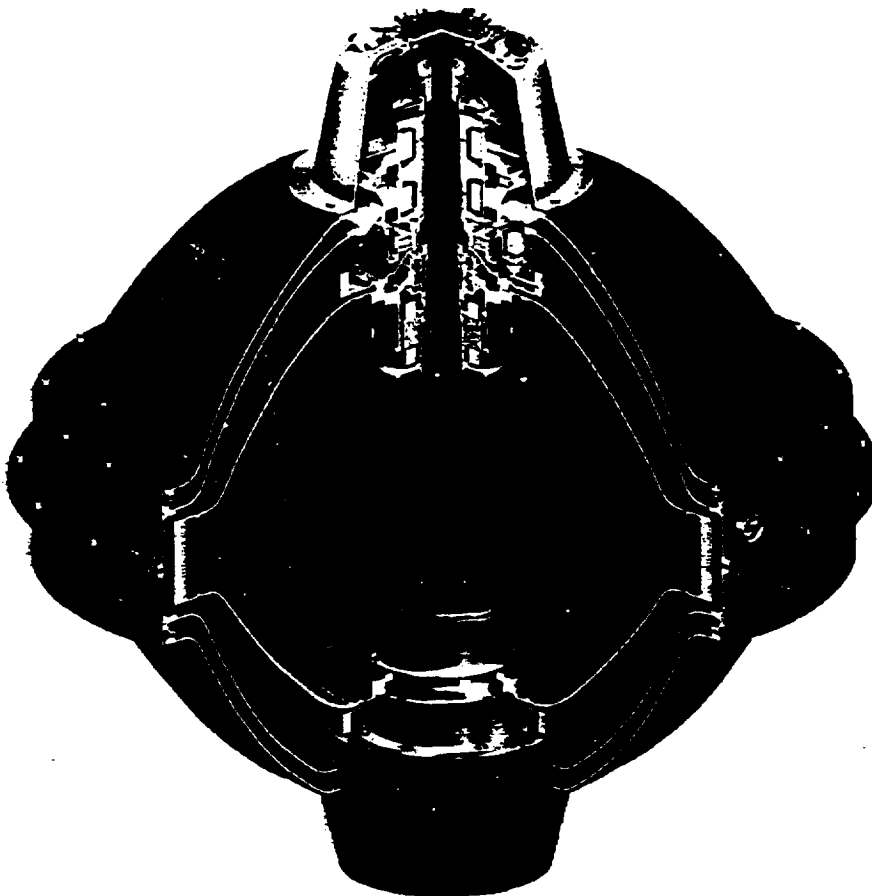


Figure 4

RELIABILITY

The high reliability and insensitivity to thermal conditions are the principal advantages of permanent magnetic suspension. Thus the limitations of permanent magnetic suspension do not present the serious threat to space-station type applications that they would present in high-rate and acceleration systems.

MAGNETIC SUSPENSION CHARACTERISTICS

ADVANTAGES

- High Reliability
 - No Wearout Mechanisms
 - No Lubrication
 - No Fatigue
- Low Torque— Starting, Drag and Ripple
- High Speed Capability
- Performance Independent of Time
- No Single Point Failures (With Redundant Electronics)
- Insensitive To Thermal Conditions
- High Momentum Capacity
- Low Induced Vibration

LIMITATIONS

- Lower Stiffness
- Low Cross Axis Torque Capacity
- Suspension Control Electronics Required
- Added Bearing Weight

Figure 5

HARDWARE

The hardware designed to meet the DSP requirements did not require any major developments. During the development phase we learned that a combined structural/vacuum shell was not practical, and the design was changed accordingly.

RESULTING HARDWARE FEATURES

- **Passive Radial, Active Axial, Attractive Mag Suspensions**
- **3 Loop Magnetic Circuit**
- **Titanium Shell Rotor**
- **AC Induction Motor**
- **Radiation Hardened Electronics**
- **Ball Bearing Backup or Touchdown System**
- **Samarium Cobalt Magnets**
- **Rate and Position Feedback**

Figure 6

MAJOR COMPONENTS

The cutaway (Fig. 7) shows the major components of the design. The rotor was designed for momentum efficiency, but it could just as easily be made to accommodate energy storage. A complete set of electromagnetic components is located at each end of the rotor shaft to provide the redundancy needed for long missions.

AFML—MSRWA

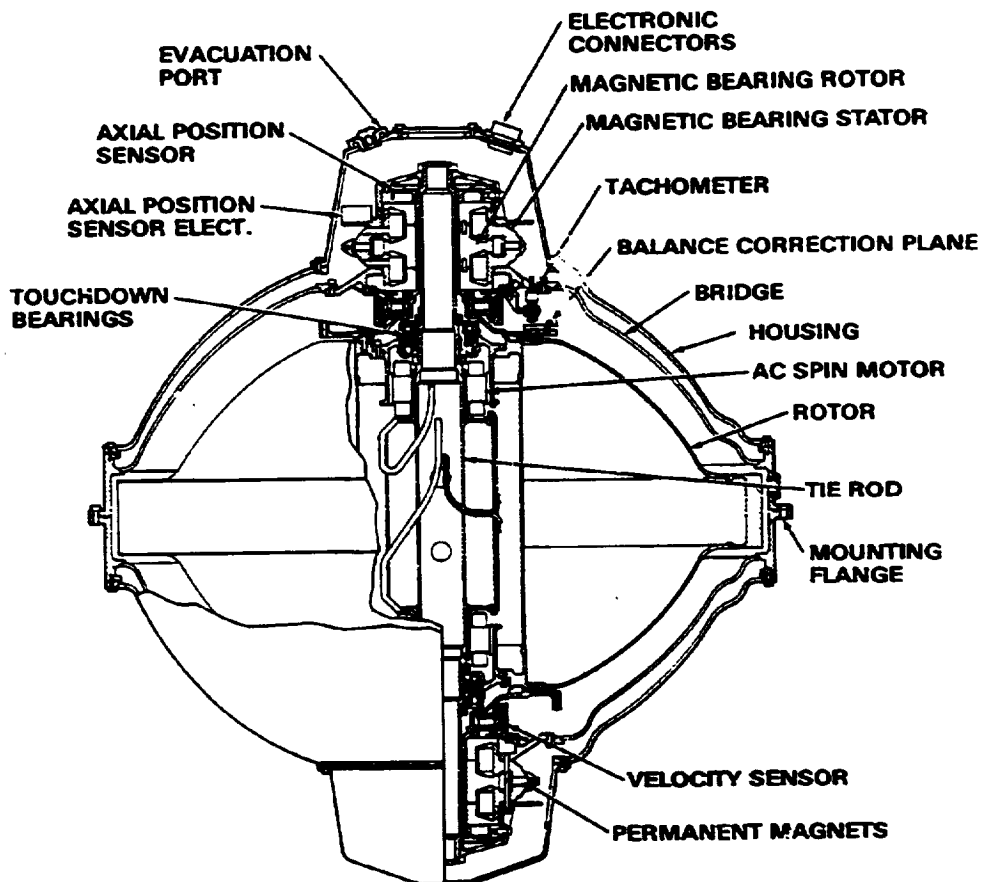


Figure 7

PERFORMANCE

The performance of the unit met all program requirements, with the exception of the cross-axis rate. A capability of 3 degrees per second was desired, but the weight impact precluded achieving this capability.

AFML MSRWA

PERFORMANCE CHARACTERISTICS

- **Momentum** 1000 FPS @ 10,000 RPM
 500 FPS @ 5,000 RPM

- **Cross-Axis Rate** 2°/Sec.

- **Spin System**
 - Motor Dual 6 Pole 2 ϕ Induction
 - Control Constant Power/Constant Slip
 - Torque 7 Oz-In @ 5000 RPM

- **Suspension System**
 - Control Axially Active with Position and Velocity Feedback

 - Stiffness
 - Radial 2000 Lb/In
 - Angular 4.3 X 10⁵ In-Lb/Rad.
 - Axial 32,000 Lb/In

- **Drag Torque** .05 Oz-In/1000 RPM

Figure 8

The system is capable of being run up with either one or two spin motors. Since weight was not a major design goal, there is approximately a 10 percent improvement available.

AFML MSRWA PERFORMANCE CHARACTERISTICS (CONT)

- **Power**
 - Steady State** **17 Watts @ 1000 FPS**
 - Run-Up** **110/220 Watts**
- **Weight** **145 Lb Mech (RWMS)**
 65 Lb Rotating Assy—Total
- **Envelope** **27 In. Dia X 30 In. High**
- **Life** **No Single Point Failure,
 Hardened Electronics**

Figure 9

TEST SEQUENCE

The conducted test sequence was based on program qualification requirements. No major problems were encountered during the environmental tests. However, it was discovered that motor heating was higher than predicted, which would be revised if the unit were prepared for flight.

AFML—MSRWA TEST ENVIRONMENTS

Test	Level
● Thermal-VAC	Ambient, -35°C, +71°C
● Sine Vibration	±1.0 g, 20-2000 Hz, 1 Oct/Min, 2 Axes
● Random Vibration	
— Acceptance	8.5 g-rms, 0.08 g ² /Hz pk, 1 Min/Axis, 3 Axes
— Qualification	17.0 g-rms, 0.32 g ² /Hz pk, 3 Min/Axis, 3 Axes

Figure 10

MAGNETIC BEARINGS

The magnetic bearing characteristics that were measured were very close to the design goals established early in the program. Especially encouraging was the drag torque, which makes this type of suspension attractive for energy storage. Ball bearings for this application would produce 10 oz-in drag torque.

MAGNETIC BEARING CHARACTERISTICS

- **Stiffness**
 - Radial 2000 Lb/Inch Per End
 - Angular 430,000 In-Lb/Rad
 - Axial 32,000 Lb/In
- **Capacities**
 - Radial 50 Lb
 - Angular 450 In-Lb
 - Axial >65 Lb
- **Weight**
 - Stators (2) 10 Lb
 - Rotors (2) 22 Lb
- **Current**
 - Lift-Off 8 Amp
 - Steady State .07 Amp
- **Drag Torque** < 0.5 Oz-In
@ 10 K Rpm

Figure 11

MODEL CORRELATION

This figure shows the open-loop axial characteristic from an analytical model. The structural modes of the system are phase-stabilized.

AFML ANALYTICAL AXIAL MODEL

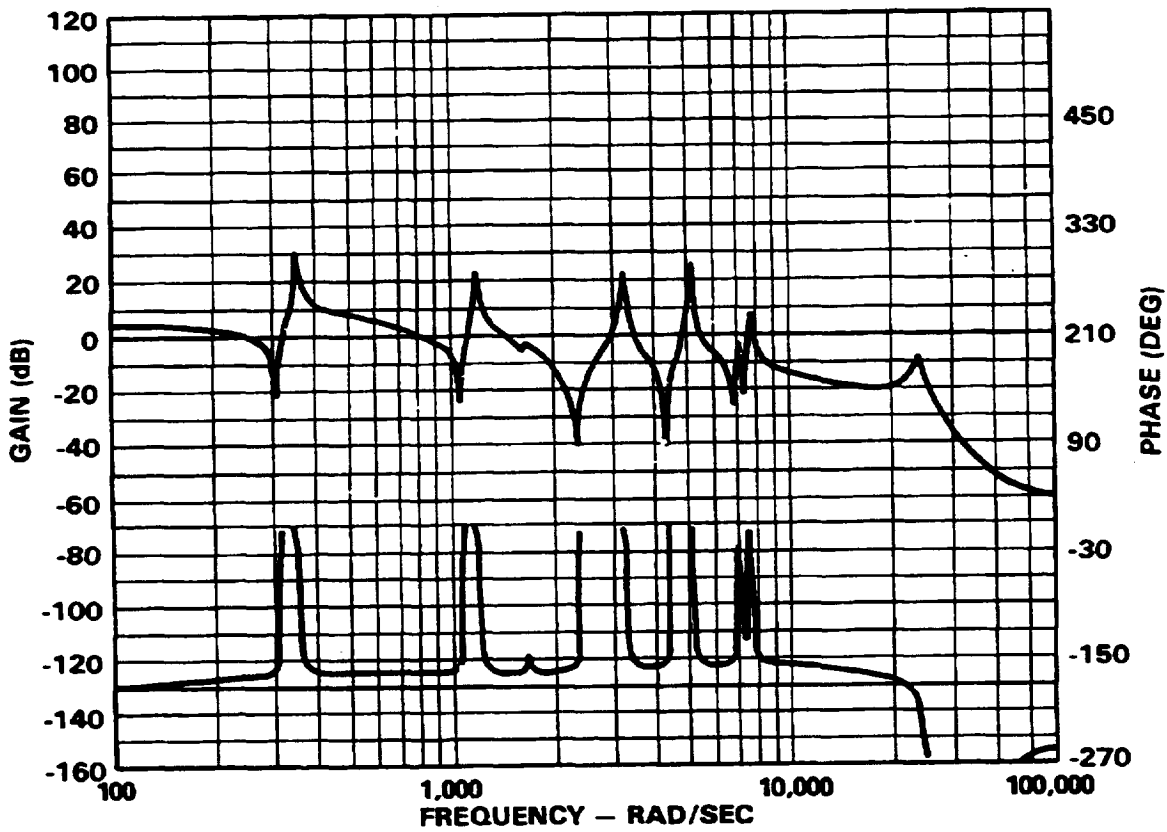


Figure 12

RESULTS

Fig. 13 shows the results obtained by measuring the open-loop characteristic of the hardware. The correlation with the analytical model was quite good.

AFML AXIAL CONTROL SYSTEM RESPONSE

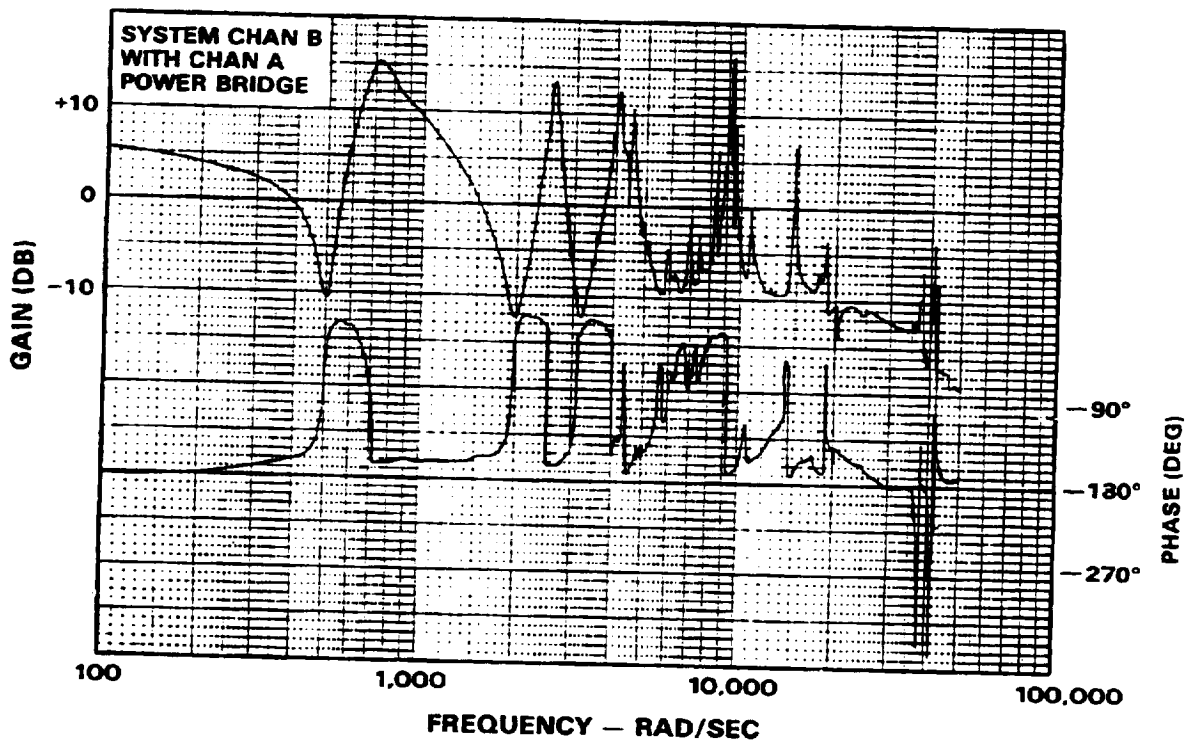


Figure 13

SUMMARY

The unit demonstrated that permanent magnetic suspension of this type provides a definite advantage over ball bearings for energy storage efficiency. The low radial stiffness would have to be evaluated for each application.