MOMENTUM WHEEL WITH MAGNETIC BEARINGS

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In recent years, Goddard has undertaken development of practical magnetic bearings for space applications (References 1 and 2). The purpose of this talk is to present the results of one major effort of this work.

Figure 1 shows an engineering model of a momentum wheel which is suspended by magnetic bearings. It consists of a mechanical assembly on the right, and associated electronics on the left. The momentum wheel is mounted at the center of the rotor shaft and the magnetic bearings are on each end. The rotor is magnetically suspended so there is no physical contact between the rotor and the support structure. The system, therefore, can operate directly in the vacuum environment without lubrication; and it has virtually unlimited operating lifetime, independent of speed.

Figure 2 is a schematic diagram of one channel of the magnetic suspension system. It consists of a magnetic bearing at the upper right, the radial position sensor at the lower center, and suspension circuit electronics at the upper left. The magnetic bearing is con-

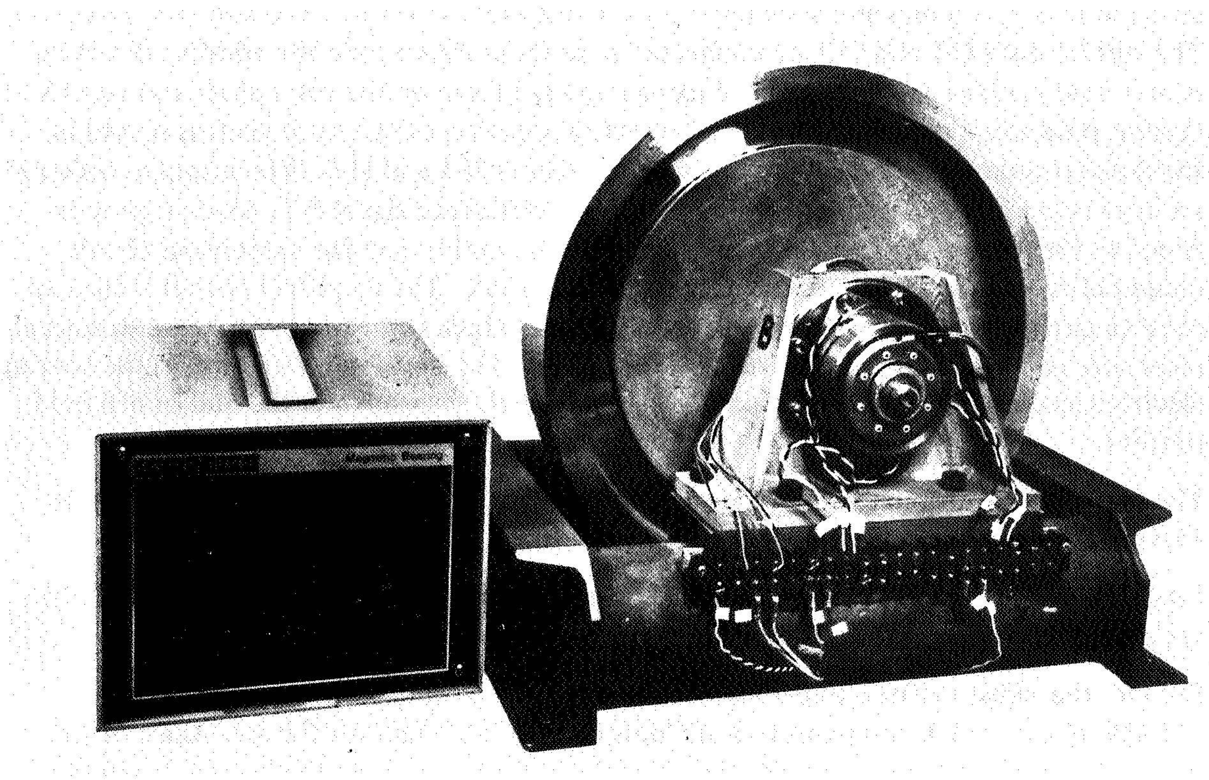

Figure 1. Engineering model of momentum wheel with magnetic bearings.

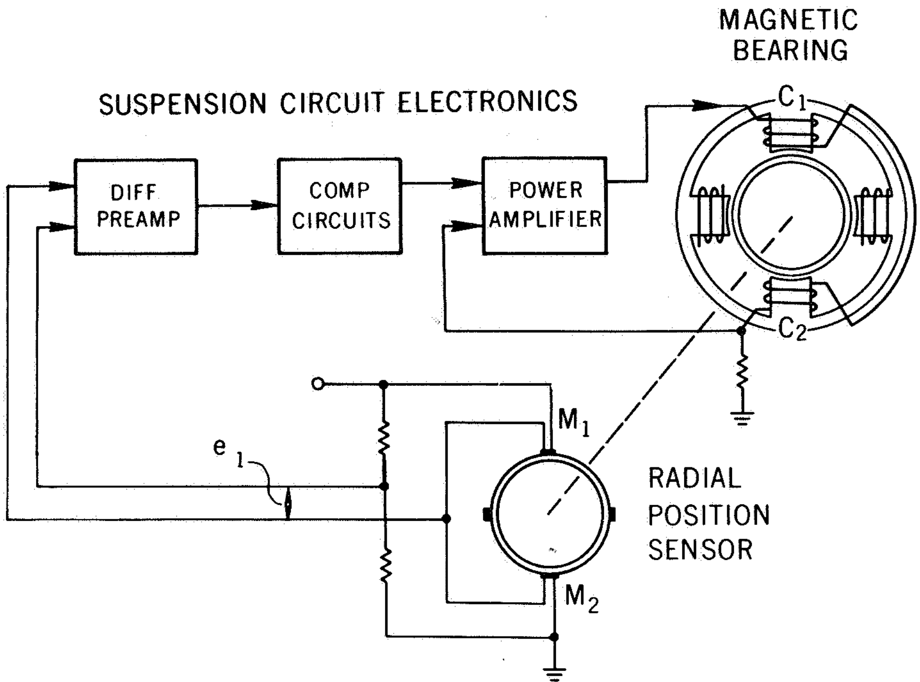

Figure 2. Schematic diagram of magnetic suspension system.

structed with four poles and associated coils, two along the vertical axis and two horizontal. The vertical coils C-1 and C-2 are connected in series as shown; and the winding direction is such that positive coil current produces an upward force on the rotor shaft and negative current produces a downward force. The vertical position of the rotor shaft is sensed in the radial position sensor, using two magneto resistors M-1 and M-2. The magneto resistors are connected in a bridge circuit which provides a difference signal E-1, which is proportional to the rotor shaft displacement. Signal E-1 is amplified in the suspension circuit preamplifier to a level of approximately one volt per mil. The amplified output is then applied to circuits which provide system damping, and which compensate for rotor structural resonance and saturation of the power output stage. The power amplifier drives the bearing electromagnet in a direction to maintain the rotor shaft suspended at the null or centered position.

The performance characteristics of the engineering model momentum wheel are listed in Figure 3, and may be summarized as follows:

First, the design value of momentum is 100 N·m s, corresponding to 6000 rpm. So far the system has been operated to 5200 rpm.

Second, the radial stiffness under static conditions has been measured as greater than 350,000 N/cm, which compares to a stiffness of 110,250 N/cm for the steel shaft of the rotor. This means that under load, the rotor shaft displacement in the bearing magnetic

(1) MOMENTUM = 100 N·m s

(2) RADIAL STIFFNESS

STATIC > 350,000 N/cm

DYNAMIC = 15,750 N/cm

(3) MAX. LOAD CAPACITY = 350 N

(4) SIZE

ROTOR DIAMETER = 36 cm

BEARING DIAMETER = 9 cm

(5) WEIGHT

ROTOR = 67 N

BEARING = 28 N/bearing

(6) POWER

ELECTRONICS = 6 watts

BEARING (FULL-POWER) = 19 watts

(7) ROTATIONAL LOSSES $\Rightarrow$ 0.0033 N·m/rad/s

Figure 3. Characteristics of momentum wheel with magnetic bearings.

field is less than one-third the displacement at the center of the shaft due to bending. Also, the radial stiffness under dynamic conditions is 15,750 N/cm, out to a frequency of about 80 hertz.

Third, the maximum load capacity of the system has been measured as 350 N. The design load capacity is limited by the onset of instability caused by magnetic bearing and suspension circuit nonlinearities.

Four, five and six in Figure 3 are the size, weight, and power consumption, and these are self-explanatory. Seventh, the measured rotational losses correspond to 0.0033 N·m/rad/s. This is about one-quarter the rotational loss in ball bearings which are suitable for this application.

Now, the results in this figure show that magnetic bearings are feasible for use on momentum wheels, despun antennas, scanning mirrors, and other spacecraft applications. The results also show that magnetic bearings offer entirely new suspension characteristics not previously available. Present indications are that magnetic suspension systems can be tailored to meet accurate pointing and isolation requirements for space shuttle missions.

REFERENCES

1. "Final Report, Design and Development of a Motor with a Magnetically Suspended Rotor, 5 July 1968 to 31 July 1970." NASA/GSFC Contract NAS5-11585. Cambion Thermionic Corp., Cambridge, Mass.
2. Philip A. Studer. "Magnetic Bearings for Spacecraft." NASA/GSFC X-721-72-56. January 1972.