N83 24903 D22

A COMPACT MAGNETIC BEARING FOR GIMBALLED MOMENTUM WHEEL

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ABSTRACT

A three axis controlled magnetic bearing and its application to a momentum wheel are described. The four divided stators provide a momentum wheel with high reliability, low weight, large angular momentum storage capacity, and gimbal control. Those characteristics are desirable for spacecraft attitude control.

INTRODUCTION

Momentum wheels are widely employed for attitude control of satellites because the control system is simple and highly reliable. For example, according to the pitch attitude error sensed by certain attitude sensors, the wheel spin rate is changed so that the spacecraft may correct the attitude error around the pitch axis. At the same time, the large angular momentum stored in the wheel passively stabilizes the roll/yaw motions.

Although the system is simple and reliable, it does not meet the requirement of high roll attitude accuracy. For that purpose, precise active roll attitude control may be desired. The momentum wheel mounted on a gimbal mechanism might be one of the candidates (Ref.4). An example is seen in Fig.1 where the momentum wheel is supported by two pairs of bearings whose rotating axes are usually parallel with roll or yaw axis of the spacecraft. The two gimbal torquers provide the roll/yaw attitude control. However, the mechanically suspended gimballed momentum wheel has the disadvantages of its large size and mass, as well as of the disturbance torques at the gimbal bearings.

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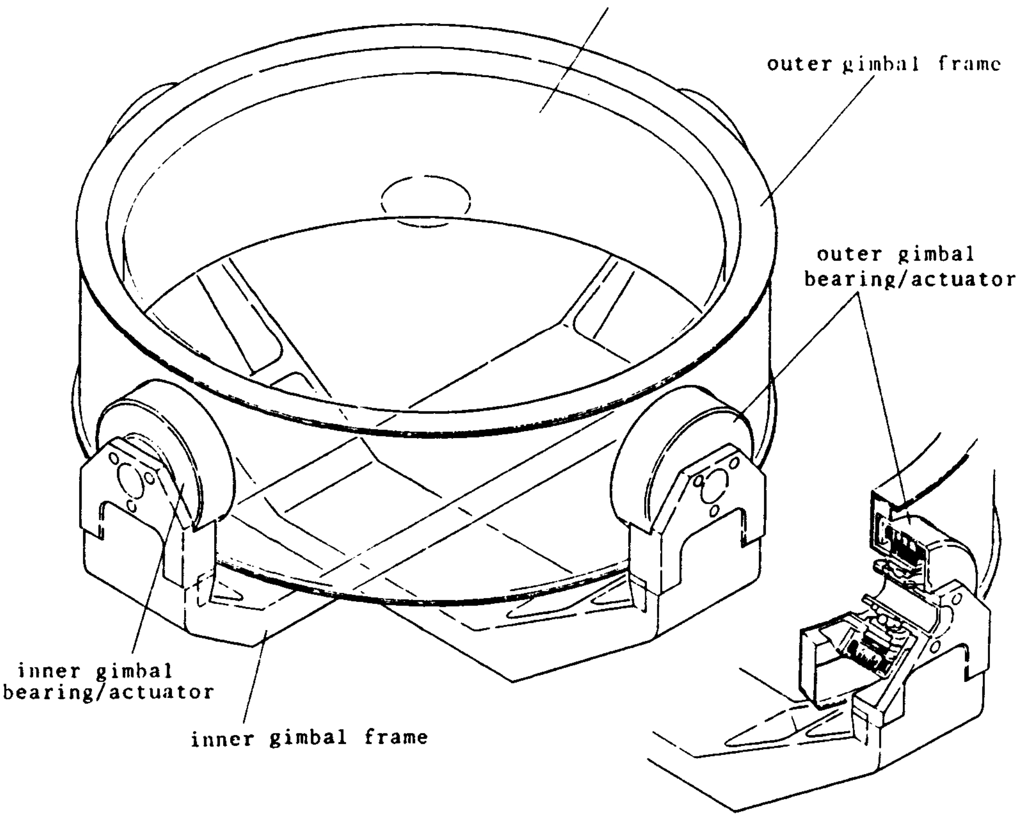


Fig. 1 Conventional gimballed momentum wheel

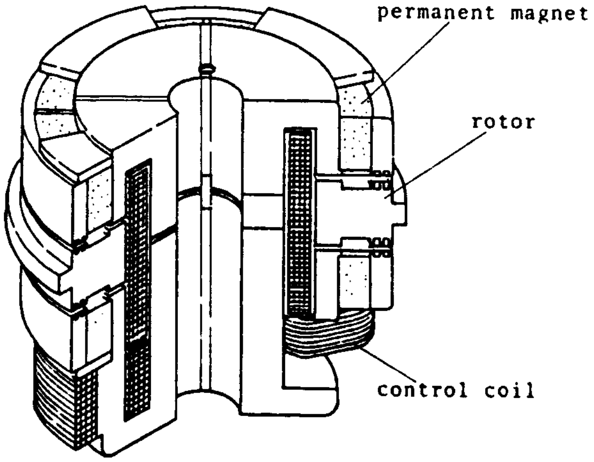


Fig. 2 Magnetic bearing with active axial/gimbal control

But the magnetically suspended momentum wheel is expected to be used as an attitude control device. As the magnetically suspended rotor has no contacts with stators, the difficult problems such as abrasion, frictional disturbances, lubrication in a vacuum environment, etc. have been eliminated, and long lifetime and high accuracy are achieved.

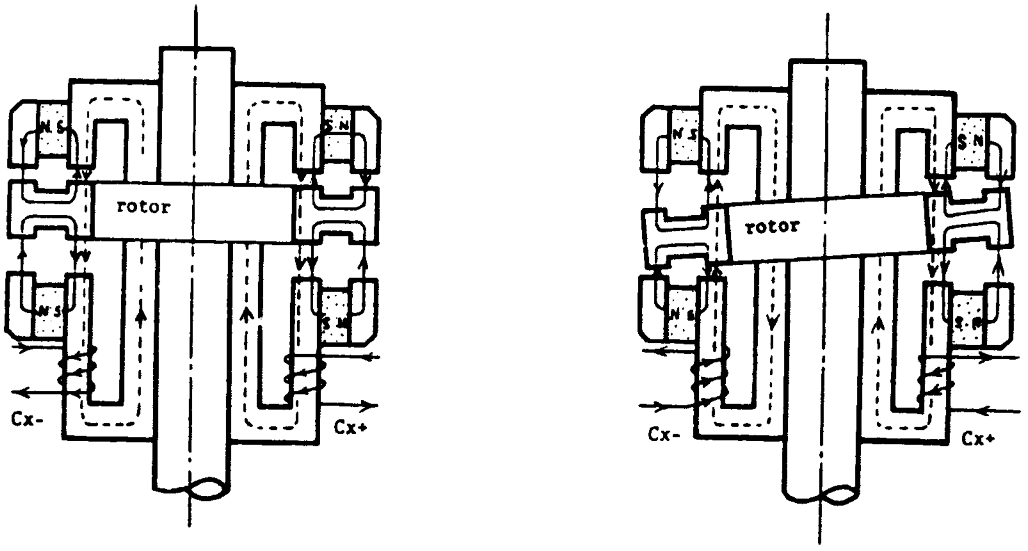
In addition, the rotor is able to tilt (gimballing) its spin axis within a clearance between the rotor and the stator. Though the gimbal angles might be rather small (1.0 degree at most), such vernier attitude error correction is sufficient if it is used with some other course attitude control devices such as thrusters or magnetic torquers (Ref. 1). Above all, the rotor gimballing without any contacts means that it does not require heavy mechanical gimbal frames seen in Fig. 1. and there are no frictional disturbances.

A magnetic bearing has to stabilize five degrees of freedom of the rotor: one axial, two gimbal and two radial motions. But the five active control mechanisms make the system complex and less reliable. The magnetic bearing to be described in detail has three active controllers, an axial and two gimbal ones. Two radial motions of the rotor are passively stabilized by the help of samarium cobalt permanent magnets (Ref. 1,2).

BEARING CONTROL MECHANISM

Figure 2 is a schematic illustration of the three axis controlled magnetic bearings. The stator is composed of four equivalent segments, each of which has the active axial position control and passive radial stability.

Figure 3 shows the magnetic flux flows in the bearing. In each segment, there are three flux loops: two of the permanent magnets and one of the control current. Consider the segment of right hand side of Fig. 3(a): The flux of the permanent magnets flows clockwise in the upper loop, while it flows counterclockwise in the lower loop. On the other hand, the flux of the control current may have alternating direction, so that the biased flux densities at the inner two gaps may be modulated by the control currents. When the control flux is counterclockwise, for example, the flux density in the upper inner gap become dense, while it becomes weaker in the lower inner gap, and vice versa. The unbalanced flux densities generate the control force to raise or lower the rotor.



(a) axial control mode (b) gimbal control mode

Fig.3 BEARING CONTROL MECHANISM

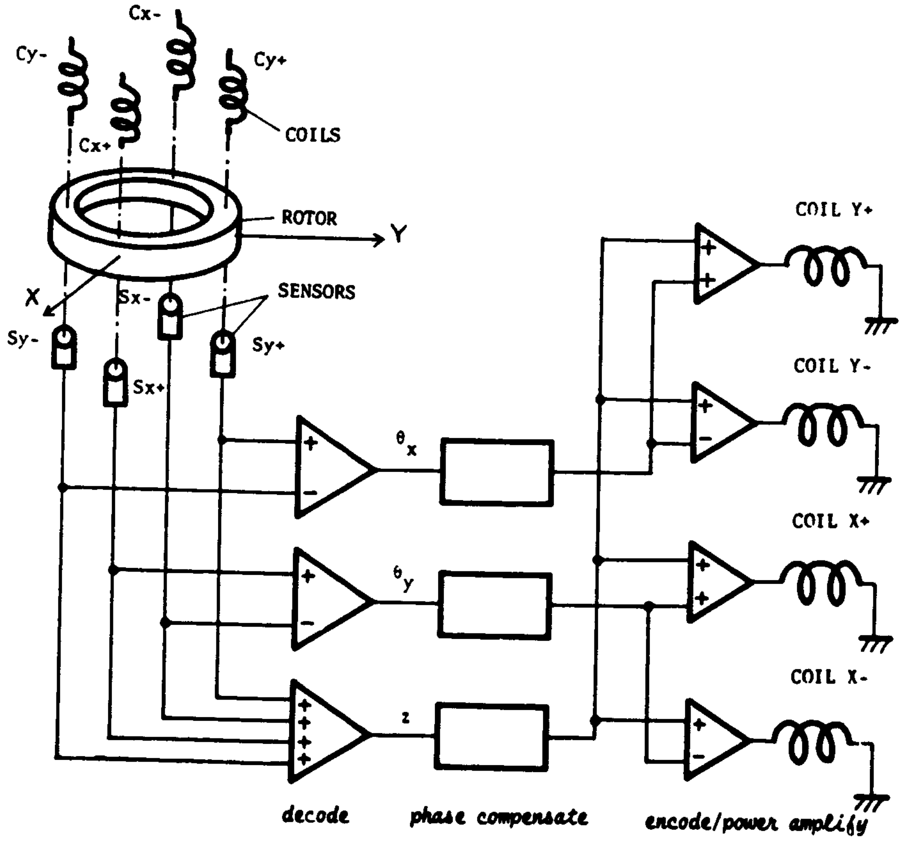


Fig.4 BEARING CONTROL ELECTRONICS

Figure 3(a) indicates the axial control mechanism of the magnetic bearing. The control currents in the control coils Cx+ and Cx- yield the coaxial flux flows. The two unbalanced axial forces drive the rotor in an axial direction. In the Fig. 3(b), however, each control flux has an opposite direction at the inner gaps so that the two unbalanced axial force become a gimbal control torque.

The active axial and gimbal control electronics is seen in Fig. 4. Four axial position sensors are located beneath the rotor. Summing up the four sensor outputs yields an average axial displacement of the rotor (z), and subtraction of the outputs between the opposite sides yield two tilting (gimbal) angles θx and θy. These three signals θx, θy and z are phase compensated then distributed to the four control coils in order to correct the position errors of the rotor.

MECHANICAL DESIGN OF THE MAGNETIC MOMENTUM WHEEL

In order to stabilize the attitude of a biased momentum spacecraft, a large amount of angular momentum storage capacity with a light weight is required. This requirement is fulfilled by a high spin rate and a flywheel with a large inertia-mass ratio. In addition, the wheel must have sufficient stiffness to endure the heavy acceleration during launch.

In the case of a mechanically supported wheel, careful lubrication design and assembly must be done in order to meet the severe requirement of reliability. The magnetic suspension has removed the burden. But the design of this type of magnetic bearing was not so easy since the stator was divided into four segments each of which had a complex configuration with various materials: samarium cobalt, soft iron, stainless iron and damping copper. To ensure the accurate machining and assembling, many jigs were prepared.

A cross section, a photograph and an assembly drawing of the magnetic gimballed momentum wheel are shown in Figs. 5 to 7. A spoked flywheel design provided a high inertia-mass ratio. Five pairs of spokes connected the wheel ring and the center hub. The wheel ring, the spokes and the center hub were machined out of one super duralumin block so that the number of wheel parts was decreased. That also made the wheel easy to assemble and highly reliable and reduced the weight. But the machining became more difficult and it took much more time.

Even as the centrifugal force became a hoop stress in the thick wheel ring, those thin spokes would well sustain the load at a high spin rate. In order to bear the large axial acceleration during launch and the gimbal reaction torques, the spokes had the form of thin blades and the two spokes are connected in the middle as was seen in the figures to increase the resonance frequency.

The baseplate is not only a mechanical interface between the wheel and the spacecraft but also a reference of the angular momentum vector since the four position sensors placed on the plate detects the tilting (gimbal) angles of the spin axis. As the base plate is fixed to the spacecraft directly, the alignment of the momentum vector is accurate.

A brushless DC motor whose stator coils were composed of thin copper films, insulated and formed by fiber reinforced plastics is seen in Fig. 7. Three coils were laminated around a cylinder for each three phases. The total nine coils had 1.8 mm in thickness. The thin stator coil and small permanent magnets, which yield sufficient magnetic field to generate drive torques, made the motor considerably compact. The motor phase angle was identified by the three commutation sensors, which also played a role of tachometer whose output was 24 pulses/rev.

The performances of the momentum wheel are as follows.

Maximum Angular Momentum		70 Nms
Maximum Speed		10,000 rpm
Maximum Gimbal Angle		0.5 deg.
Maximum Motor Drive Torque		0.02 Nm
Maximum Gimbal Reaction Torque		5.0 Nm
Weight (without electronics)		5.5 kg
Bearing Power consumption (zero gimbal position)		8 W
Motor Power consumption (maximum torque)		50 W
Supply Voltage	Bearing	18 V, -18 V
	Motor	15 V

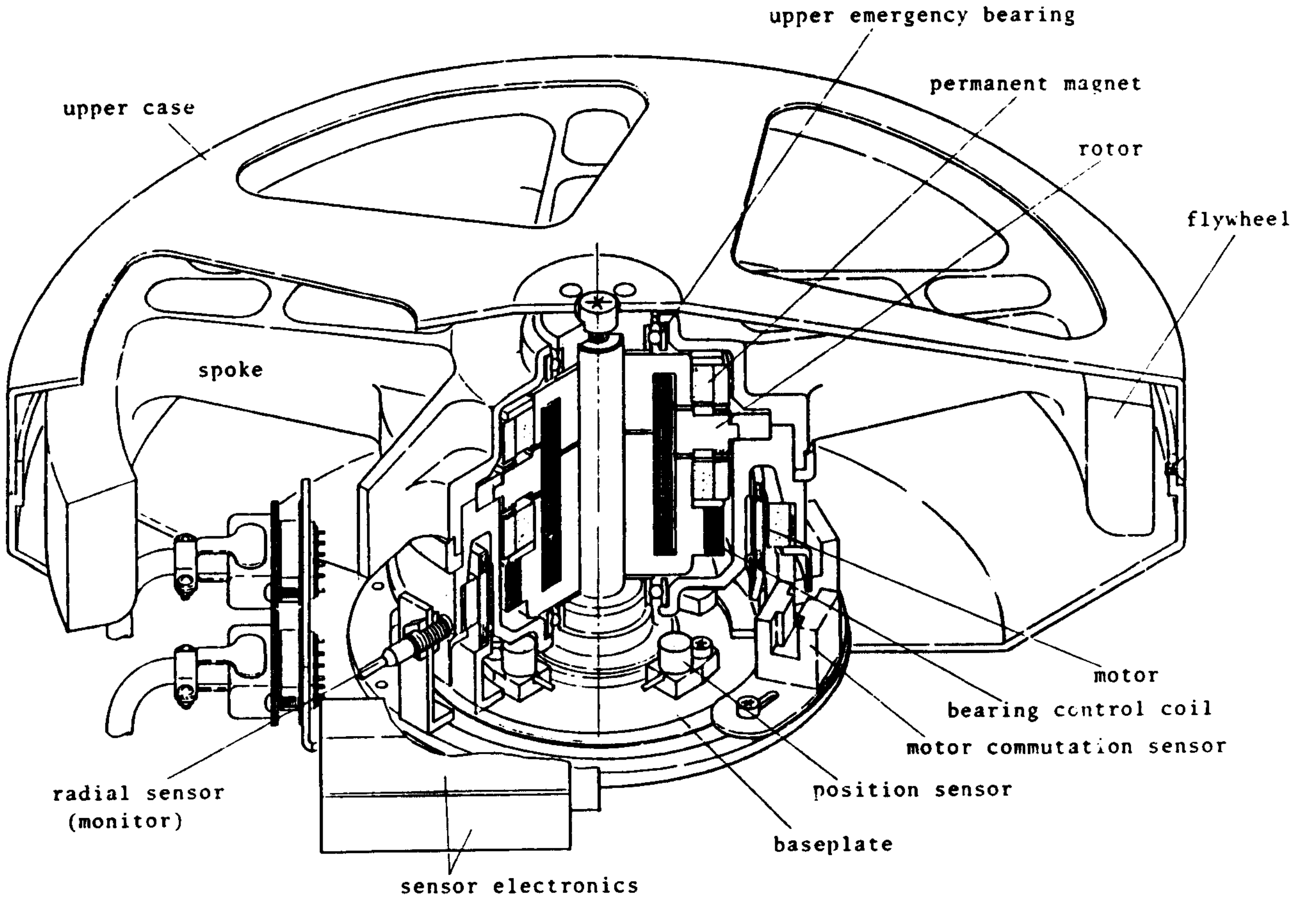


Fig. 5 Cross section of the magnetic wheel

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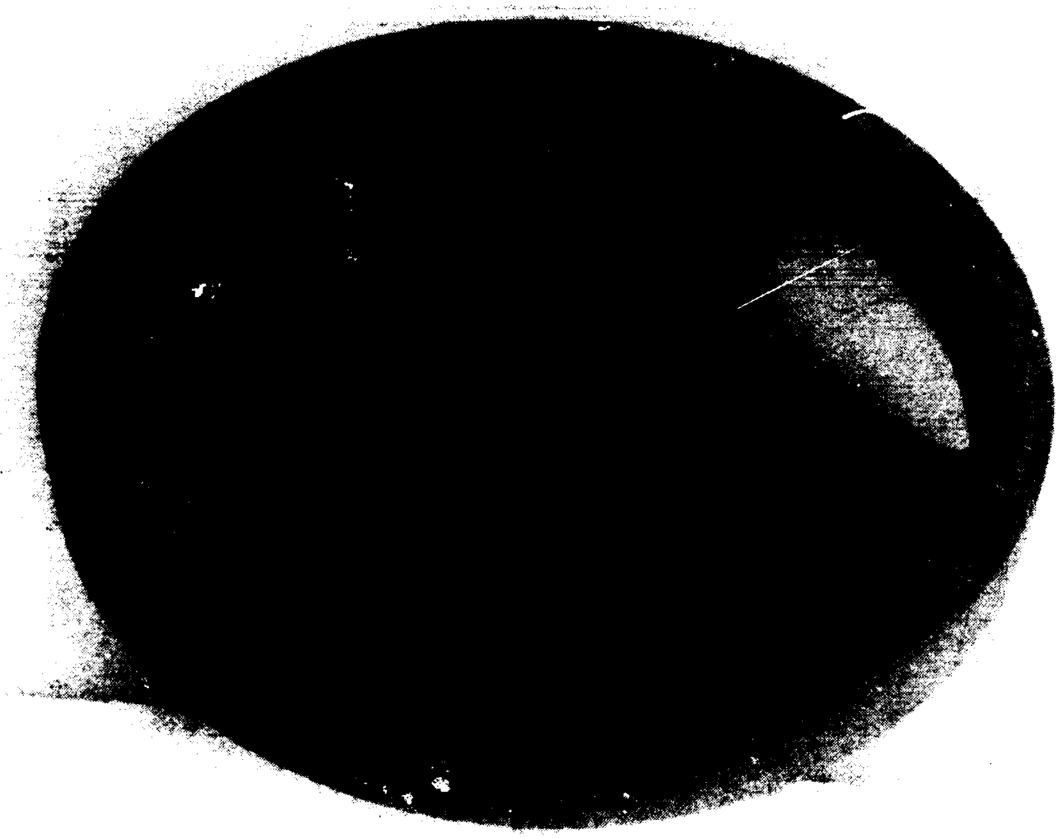

Fig. 6 Magnetically suspended gimballed momentum wheel

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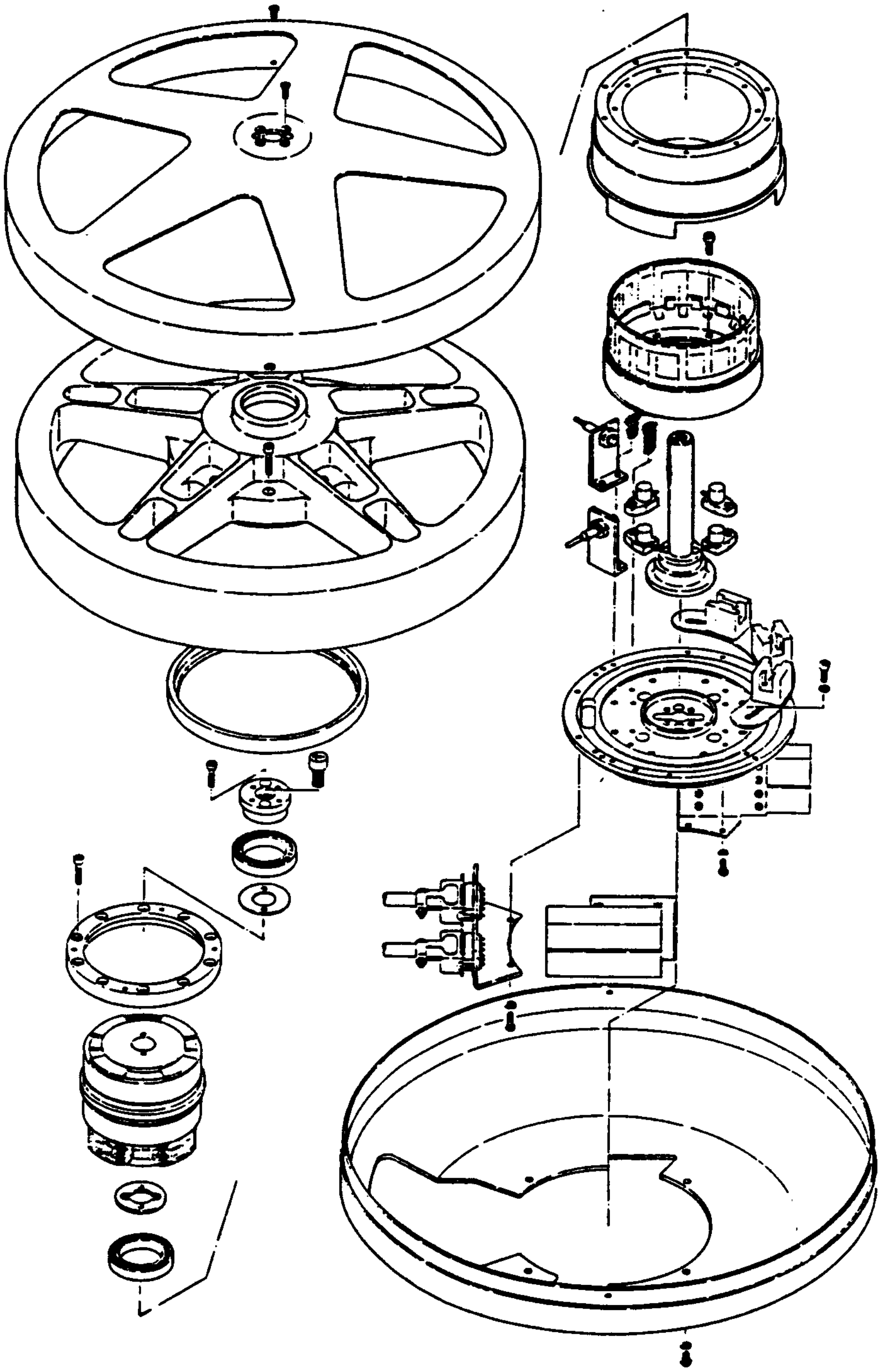

Fig. 7 Assembly drawing of the magnetic wheel

CONCLUSION

A magnetic bearing with a new mechanism, active axial/gimbal control and passive radial centering, was proposed. The magnetic bearing had suitable characteristics for attitude control of biased momentum spacecraft since it had **light weight and gimbal control.**

In applying the magnetic bearing to the momentum wheel, some philosophy about the mechanical design was described. The magnetically suspended gimballed momentum wheel **displayed small size, large angular momentum** storage capacity and high reliability.

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