Superconducting Bearings for Space Applications

RESEARCHERS HAVE DEMONSTRATED THAT SUPERCONDUCTING bearings for telescope mounting can be deployed on the lunar surface, which has a cold and dusty vacuum environment, that clogs conventional mechanical bearings. High pointing precision is required of the telescope for observations requisite to advance our knowledge of the cosmos. The superconducting bearing provides an ultra-smooth rotation capability without the expenditure of energy as in magnetic bearings. The properties of the superconducting magnet bearing also allow a construction with a wide tolerance to mitigate potential problems of clogging with dust.

The project went so far as to have the bearing characterized in terms of its drag torque. This drag torque was found to have spikes as the bearing slowly turns on its axis, on top of a larger sinusoidal variation due to imperfect alignment. These observed spikes were correlated with the number of discrete pieces of superconductors used around the circumference of the bearing. This phenomenon was an unexpected discovery, detailed in the following two manuscripts:

Lee, E., K. B. Ma, T. L. Wilson, and Wei-Kan Chu. "Characterization of Superconducting Bearings for Lunar Telescopes," IEEE *Trans. on Applied Superconductivity* 9 (1999): 911.

—. "Superconductor-Magnet Bearings with Inherent Stability and Velocity-Independent Drag Torque," *Proc.*, 1999 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM 99), Atlanta, GA, Sept. 19-23, 1999.

Vibration Isolation for Space Structures Using HTS-Magnet Interactions

A DETACHED BUT INTERACTING PAIR OF HIGH TEMPERATURE superconductor and permanent magnets behave like a very soft spring with a relatively high level of damping due to hysteresis. Vibrations originating from sources attached to one of these components would not be transmitted to sensitive equipment attached to the other end because there is no direct physical contact between the two parts, but these components remain tied together nevertheless through magnetic flux permeating both the magnet and the superconductor. These concepts have been validated through experiments, such as those published in the following manuscript.

Yu, J. H., Y. Postrekhin, K. B. Ma, T. L. Wilson, and W.-K. Chu. "Vibration Isolation for Space Structures Using HTS Magnet Interaction," IEEE *Trans. on Applied Superconductivity* 9 (1999): 908.

United States Patent No. US 6,231,011 B1
Chu et al. Date of Patent: May 15, 2001

Satellite Angular Momentum Control System Using Magnet-Superconductor Flywheels

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Abstract

A torque/reactive momentum wheel control system for use in satellites for dynamic attitude maintenance and alteration where the flywheel of each momentum wheel is levitated by a high-temperature superconducting element repulsively interacting with permanent magnets in the flywheel. The spin rate (rpm) of the flywheel being controlled by either an active magneto or electromagneto drive system. Each momentum wheel is cooled by a cryo-cooler and can have a total weight of about l0 Kg to a fraction of 1 Kg and delivering 3.5 Js with less than 1 W loss.

[Excerpted from U.S. Patent 6,231,011 B1, May 15, 2001]

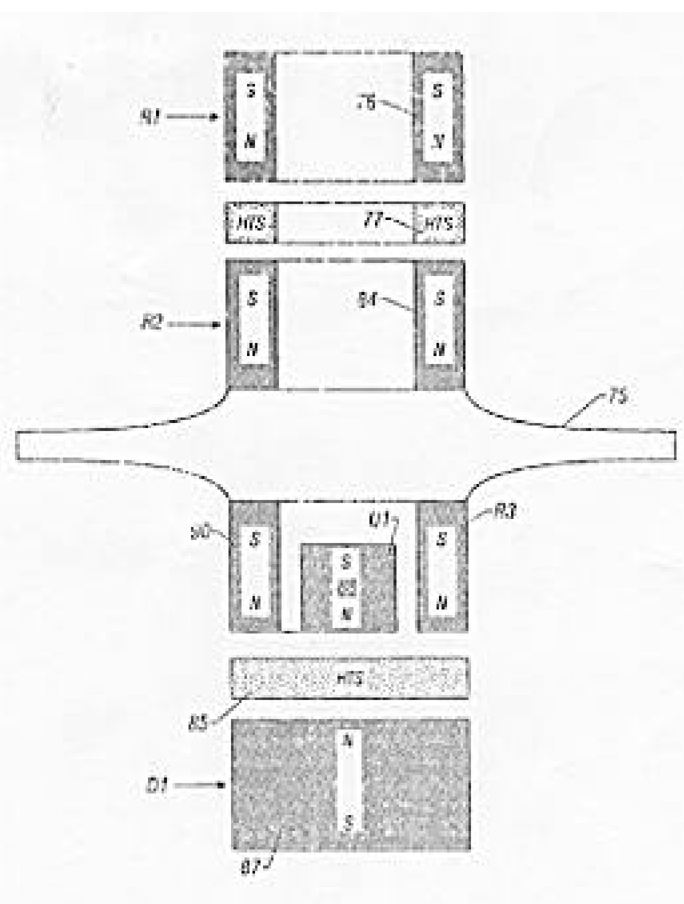
Background of the Invention

The present invention relates to satellite angular momentum control systems having at least one magnet-superconductor momentum storage device.

More particularly, the present invention relates to satellite angular momentum control systems for maintaining a satellite in a given attitude and spin orientation, for changing a satellite attitude and/or spin orientation, for measuring a satellite angular velocity vector, and for dynamic bias for orbital yaw steering where the momentum storage or gyro system incorporates at least one and preferably a plurality, magnet-superconductor momentum storage or flywheel devices. Moreover the present invention relates to an attitude control system.

Description of the Related Art

Satellites are aligned in orbit by two general methods. One method involves using attitude and spin jets to orient or change the orientation of a satellite in orbit. The second method, and the



Patent No.: US 6,231,011 B1; Date of Patent: May 15, 2001; appl. No. 09/184,914; filed, Nov. 2, 1998.

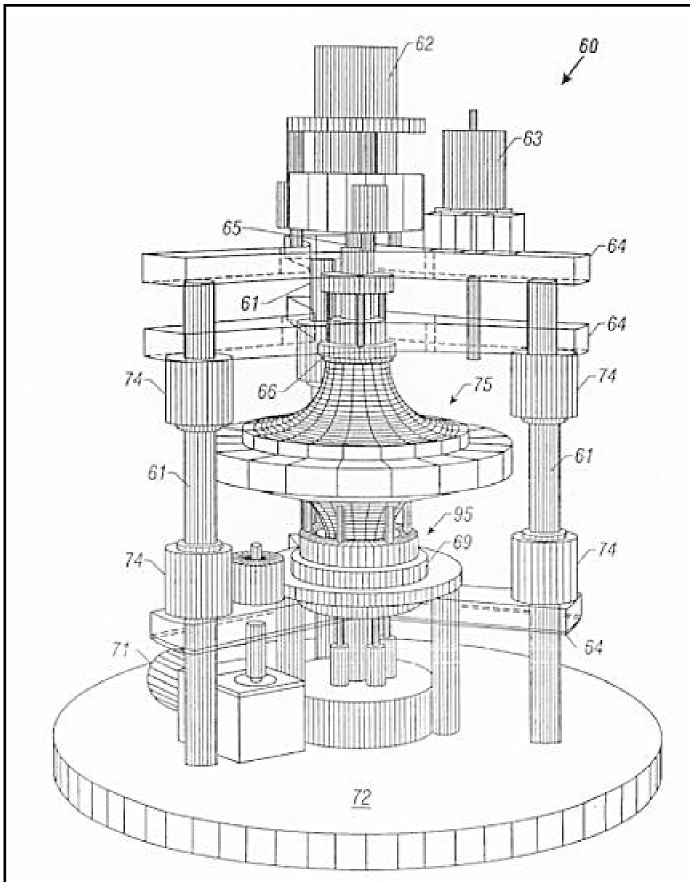


FIG. 5

ISOMETRIC DRAWING OF FLYWHEEL SYSTEM—Figure 5, in U.S. 6,231,011 B1—"Fig. 5 is a drawing of flywheel system 60 **showing flywheel** 75**, motor** 62**, steppermotor** 63 **forthe top chamfer, steppermotor** 71 **forthe bottom chamfer, rotorengaging switch** 65**, HTS cold stage** 66**, support posts** 61**, lateral supports** 64**, linear bearing** 74 **which allows movement of lateral supports** 64 **along with support posts** 61**, HTS cold stage** 69**, cold stage** 95**, and base support plate** 72**."**

method to which this invention pertains, involves the use of momentum storage devices the balance of which maintains the satellite in a given orientation with respect to the sun or the earth or any other fixed object. The amount of momentum stored in each device controls the exact orientation of the satellite as well as its spin axis. To change the orientation and spin of the satellite the momentum of one or all of the momentum storage devices is changed which, in turn, changes the angular momentum of the satellite resulting in its orientation change.

Flywheels have been well-known as one of the oldest ancient mechanical designs in human history. Historically, the first flywheel dates back to 3000 B.C. when the flywheel was recognized as the "potter's wheel." Essentially, a mechanical battery flywheel energy storage (FES) system many believe could be one of the most efficient means to solve two critical problems faced by modern society, the rapid increase in the use of energy and the consequent impact of energy consumption on the environment.

Of particular concern to a flywheel energy storage device is its overall efficiency which is dictated by four major factors: (1) motor/generator conversion efficiency; (2) power conditioning system efficiency; (3) windage drag; and (4) flywheel bearing efficiency.

Recent developments in new materials and magnetic bearings using electromagnetic levitation resurrect the interests of scientists and engineers in advancing the flywheel technology for energy storage applications.

Conventional mechanical bearings used in conjunction with high rotational speed devices are subject to metal wear noise vibration and friction heating problems. These problems can often lead to seizure or other failure of the bearing. In addition, mechanical bearings often require lubricants which fail in severe environments such as those commonly encountered in outer space. Failure of conventional liquid lubricants in outer space is usually due to the vacuum conditions that cause the lubricants to out gas, leaving bearing surfaces dry and resulting in the ultimate failure of the bearings. Additionally, in outer space, temperatures are very low, so most lubricants solidify and simply do not function as lubricants.

As a result of these and other shortcomings there has been considerable emphasis on the developments of alternatives to mechanical bearings. For example, work has been done to develop more efficient air bearings as well as magnetically suspended bearings. . . .

The present invention provides a practical design for a light weight momentum-bias attitude control system capable maintaining and altering satellite orientation in space including nadir pointing.