Reaction Wheel and Drive Electronics For LeoStar Class Space Vehicles

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Abstract. *A new small low-cost reaction wheel and drive electronics are developed by Orbital Sciences Corporation for use on LeoStar class spacecraft. The LeoStar wheel produces a reaction torque of 140 mN-m with momentum storage capacity of 5.4 N-m-s. The wheel is unique in that it feature a relatively large, highly controllable reaction torque in a small package with low power and minimal induced vibrations. The design is an adaptation of an original NASA Goddard Space Flight center wheel using a brushless motor/flywheel combination. Two bearings support the shaft. To reduce size and mass, the drive electronics are incorporated directly in the wheel housing. The driver is based on a digital signal processor for accurate speed and torque control. An architecture was selected to allow for production of a radiation harden driver through simple pin for pin substitution of critical components.*

Description

In an effort to improve performance and reduce size of the first-generation reaction momentum wheel, Orbital Sciences is developing a new small low-cost reaction momentum wheel. This wheel (see Fig. 1 cross section) will be designed for extremely low vibration generation and ease in assembly. The outside dimensions of the wheel are 4.0 in high and 8.0 in diameter. A high efficiency brushless DC motor with integrated Hall effect sensors for commutation is mounted onto the base in the center, two deep groove bearings under precise preload support the shaft, and the flywheel is attached to the shaft's upper end.

A single wheel drive electronics board is mounted onto the base. The heat generated by the board is conducted into the base and used to improve the bearings' lubricant control. The optical tachometer on the flywheel is used to provide high-resolution speed information for the feedback loop.

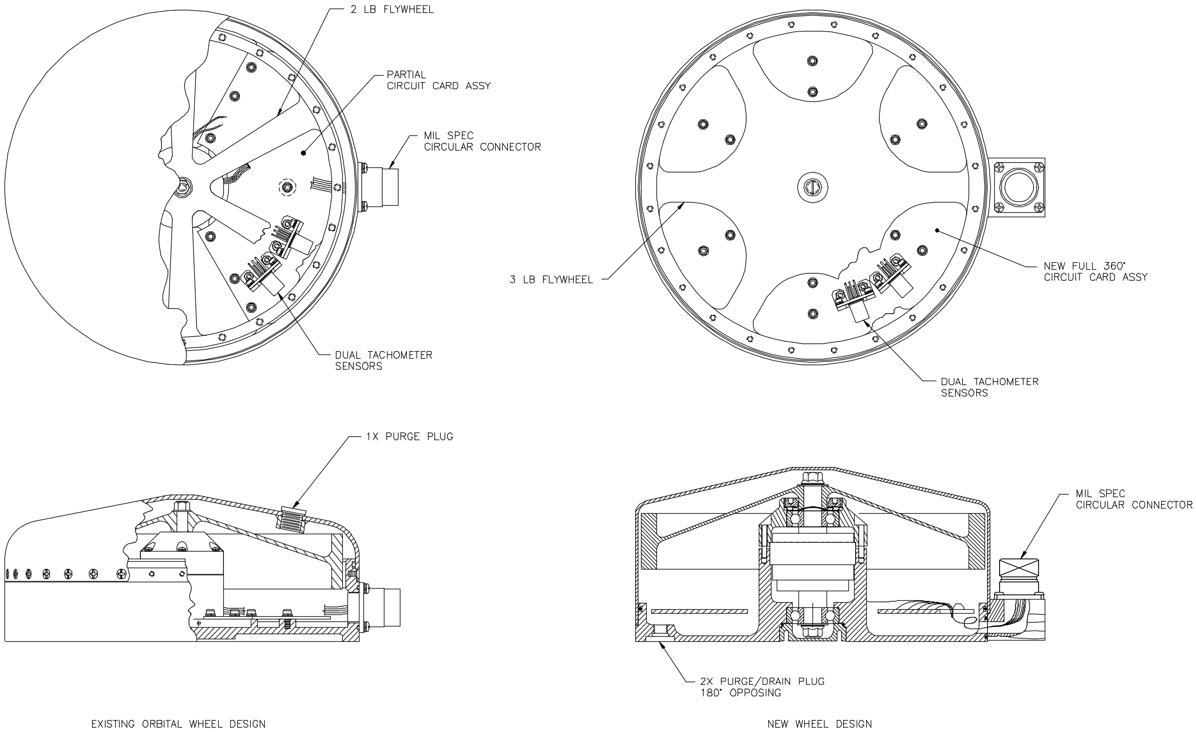

Figure 1: Wheel Assembly Drawing

Wheel Technical Specifications:

Lifetime:	>5 years
Torque Output:	0.14 n-m (20 oz. In)
Momentum storage:	4.7 n-m-s at 3740 rpm
- Max:	5.4 n-m-s at 4297 rpm
- Momentum Alignment:	5 arc-min
Total mass:	3.628 kg (8.0 lbs.)
- Flywheel	1.487 kg (3.28 lbs.)
Peak Power:	< 55 W (at 28 V)
Steady state power:	< 8 w
Bus Voltage	22V to 32V
Dimensions:	8.0 in. Dai. By 4.0 in. Height

Motor type:	8 Poles brushless dc motor	
Interface:	RS-422 serial interface	
- Connector	22 pin, Hermetically sealed	
- Mounting	12 Inserts #8-32	
Wheel internal pressure:	1/8 atm, Dry Nitrogen	
Environmental:		
- Static loading:	+/-16 g's in each axis	
- Random vibration:	14.1 grms in each axis for tow mints (1-sigma)	
Bearings Load Limit		
- Static:	Axial	515 lbf
	Radial	560 lbf
- Dynamic:		1000 lbf
Operating temperature:	-10ºc to 50ºc	
Radiation:	100k rads total dose	
Balancing:		
Per I.S.O 1940/1, grade G.4		
- Static	max. 0.085 grm-in	
- Dynamic	max. 0.042 grm-in²	
Minimum factor of safety:		
- Yield	1.4	
- Ultimate	2.0	

The wheel is purged with dry nitrogen at 1/8 atm and hermetically sealed to prevent oxidation and outgassing of the lubricant.

Housing

The wheel housing is made from two parts, the base and the cover. The base is a machined aluminum with 6 radial stiffeners on the inside to provide structural support for the motor and flywheel assembly. In addition these stiffeners are providing internal mounting surfaces and thermal path for the drive electronics board. A mounting provision is left in the base center for the motor and bearing mounting. This provision provides a good thermal heat sink and radiation shielding for the motor assembly.

The flywheel is a machined ring made from stainless steel supported by six spoked flexures. In addition the ring incorporated 24 tapped holes for balancing weights. The motor and the upper bearings are secure to the base by the motor cover and six screws.

The wheel cover is a machined aluminum that is mounted on to the base. An o-ring sealed between the cover and the base provides the sealing of the wheel. Two ports on the base are used for nitrogen purging and sealing of the wheel at 1/8 atmosphere.

Preload and Balancing

In an effort to reduce noise due to bearings axial and radial play, the bearings are axially preloaded. Using a wave spring washer and a retaining nut in the motor cover the bearings can be precisely preloaded and verified. Since the lower bearing is fixed to the base and the upper bearing is axially floating in the motor cover, any relative dimension changes in the housing and shaft bearing assembly due to thermal expansion will not induce any internal stress.

This open wheel design approach allows visual and mechanical access to the flywheel during balancing and therefore achieving extremely low static and dynamic imbalance. It also allows access to the drive electronics, verifies correct direction of rotation and visual inspection of the wheel for contamination prior to close-up.

Bearings

The bearings that where selected are chrome alloy steel ball bearings type with ribbon cage, deep groove races and cres steel shielding. The bearing are grade ABEC 7 and lubricated with Minapure Grease. This bearing design has high load capability and life prediction is 20 years at 99.9% reliability. The static radial load rating is 560 lbf and the axial is 515 lbf. The max dynamic load is 1000 lbf.

Motor

The motor is a brushless DC motor with 8 poles in delta configuration, using high efficiency laminates for the stator winding. Integrated Hall effect sensors are used for commutation. The rotor consists of high efficiency Samarium cobalt magnets bonded onto a stainless steel shaft. To insure good thermal control, the motor is encapsulated in Stycast and an integrated thermistor giving motor temperature status.

The following are the motor designed constants:

Kb – 0.0696 V/rad/sec
Kt – 0.0696 Nm/A
R – 1.8Ω
L- 0.9 mH

Drive Electronics

The reaction wheel contains an integrated controller and drive electronics. Advantages of an integrated controller are reduced mass and volume by the elimination of external control/drive boxes and external wiring. The reaction wheel controller architecture is based on the wheel developed for the ORBCOMM program. A digital signal processor (DSP) implements a precision motion control algorithm for control of speed and torque. The velocity of the flywheel is measured by dual optical reflective sensors and fed back to the DSP digitally. The advantages of digital implementation are elimination of time consuming analog trims, and unit to unit consistency. The output of the DSP directly drives a H bridge motor driver. The bridge implements three phase drive with true four quadrant operation. The design includes an adaptive gate dive feature that permits use of the controller with different bus voltages without requiring component changes.

One of the goals was to produce a design that could be tailored for the radiation environment by substitution of critical components. This was accomplished by analyzing the design to determine which components were most susceptible to radiation effects. Parts were then selected so that several different radiation hardness levels could be obtained in the same package type. The circuit board was then designed so that parts could be upgraded without layout changes.

Interface

A circular sealed 22-pin connector is attached to the side base used as an interface to the spacecraft ACS. Torque or speed is commanded by a full duplex RS 422 serial input. Status and telemetry are reported back to the ACS by serial output. The wheel is mounted to the spacecraft by 12 No. 8-32 threaded inserts on the base, 6 on 7.5 in bolt circle and 6 on 2.25 in bolt circle. This mechanical interface also provides the thermal interface to the spacecraft structure.

Heritage

Since 1990 Orbital Sciences Corp. built 14 wheels of the first generation that where based on a NASA Goddard Space Flight Center prototype wheel. Orbital Sciences Corporation used those wheels on the following programs:

Program	No. of Wheels	Status
COMET	2	Launch Failure
GEMNET	1	Launch Failure
REX 2	1	Is in-orbit 28 months
EarlyBird 1	2	Spacecraft Failure, operated 4 days
EarlyBird 1	2	In Storage
Life Test	1	Setup as life test, running more than 2 years
Prototype	1	-------
Inventory	2	-------

Currently there are two-life test wheel running for approximately four years. The new wheel design will be used on the following programs:

ORBVIEW-3	3 wheels
VCL	4 wheels
Life Test	1 wheel
Prototype	1 wheel

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Author Biographies

Eli Ahronovich is a principle engineer in the Mechanical Systems Group at Orbital Sciences Corporation. He is the lead engineer responsible for the design of the Integrated reaction Wheel under the IR&D program. In addition, he is supporting the development and testing of the new reaction wheel developed by NASA Goddard Space Flight Center to be used in the SMEX-LITE program. Previous assignments as lead mechanical engineer of EARLYBIRD 1 and COMET include development of deployment of solar arrays and antennae booms. Mr. Ahronovich holds a B.S. degree in Mechanical Engineering from Ben Gurion University, Israel.

Mike Balling received his BSEE from Virginia Polytecnic University and State University in 1978. He has held a number of positions in aerospace and aerospace related companies. While employed by National Semiconductor, he received the Field Engineer of the Year award in 1988. He worked on ACS components for the

SWAS, TRACE, and WIRE missions while employed by Lockheed Martin Special Payloads Division at the Goddard Space Flight Center. He joined Orbital Sciences Corporation in 1995, where he developed ACS components including the reaction wheel for the ORBCOMM Constellation.