DEVELOPMENT OF A MODULAR TWO-AXIS GIMBAL MECHANISM FOR SPACECRAFT ANTENNA AND THRUSTER POINTING

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ABSTRACT

A changing satellite market, with an ever-increasing commercial presence, has driven industry to respond with minimal cost and high-volume production. This emergence fuels an increasing pressure on space component engineers to meet the high-volume, low-cost, short-cycle demand without compromising quality or performance. Honeywell is creatively meeting current commercial mechanism needs by providing the industry with modular actuation mechanisms. This class of modular mechanisms advances the state-of-the-art for large-volume, low-cost, high-producibility designs while preserving legendary Honeywell value in performance and expected on-orbit longevity.

INTRODUCTION

Commercial Communication Satellites demand Antenna and Thruster Pointing Mechanisms that provide high-precision performance at low total cost, and short production cycle times to support very aggressive spacecraft schedules. The Pancake Two-Axis Gimbal (PTAG) mechanism was developed to satisfy these parameters, and be modular enough to allow tailoring to a specific application with very little redesign.

The PTAG mechanism has numerous applications for deployment and pointing of spacecraft antenna systems and propulsion components, and is used as a drive train for Solar Array Drive (SAD) applications. Critical performance requirements include pointing accuracy, repeatability, torque margin, low weight, and long cycle life. Since the majority of applications are in commercial space, recurring cost and predictable production cycle times drive design.

Existing designs have difficulty achieving the necessary pointing accuracy and repeatability requirements due to stepper motor designs with low step accuracy and high tolerance couplings to the telemetry device. Conventional gimbal designs nest the actuator gearing inside the stepper motor, and utilize additional gearing and couplings to mate with telemetry devices. While this yields a rather short actuator package, the overall diameter can be large, compromising pointing accuracy . Additionally, assembly of this design type is serial in nature and; therefore, the risk of schedule slippage remains high until late in production.

1.0 MECHANISM DESIGN PHILOSOPHY

The design philosophy associated with the PTAG stems from the idea of minimizing assembly time by modularizing the design.

Testing time and support is minimized by employing automated test equipment capable of testing up to 8 actuators simultaneously. Test equipment is programmed to run through the different sequences (functional performance, thermal, etc) and stores trend data used to compare the performance of actuators against in or out of family data.

2.0 PTAG OVERVIEW

An isometric overall view of the PTAG is illustrated in Figure 1. The five main components comprising the PTAG mechanism are as follows:

- Motor/Fine potentiometer assembly
- Harmonic drive assembly
- Bearings and lubrication
- Coarse potentiometer assembly
- Mechanical limit stops

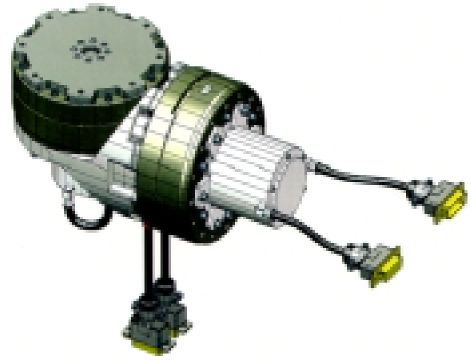

Figure 1: PTAG Two-axis Assembly Configuration

The two levels of the PTAG assembly are the actuator level and PTAG assembly level. Both actuators are identical and are integrated with the central bracket to create the PTAG assembly. Specified actuator mechanical limit stops are machined at the actuator level, and, if necessary, can be changed out and modified at the PTAG level, as the machined stop ring is a separate part that is pinned and fastened to the output.

PTAG components mentioned are fabricated in parallel by various vendors, then integrated and tested at Honeywell Inc., Satellite Systems Operation (SSO). This process enables individual components, such as the motor, harmonic drive, and potentiometer, to be fully tested at the vendors prior to final integration at SSO, reducing risk at the PTAG level. The assembly is modular by design, allowing for the application of different stepper motors, depending on drive electronics requirements. The design can easily be scaled up or down creating a reduction in non-recurring costs.

Modularity enhances the testing phase of the assembly by characterizing unit performance, and identifying and quantifying torque loss contributors prior to final assembly. Interface brackets can be added to the PTAG, as necessary, to respond to customer requirements.

2.1 General Assembly

An expanded view of the PTAG actuator is illustrated in Figure 2. The modular design permits subassemblies to be generated within the actuator assembly. For a brief description of the major components of the unit, refer to para 2.1.1.

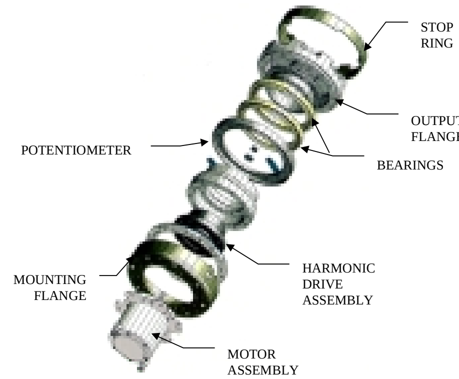

Figure 2: PTAG Actuator Assembly

2.1.1 Motor and Fine Potentiometer Assembly

The motor utilized is a 3-phase, 1.5 deg/step, redundant winding, hybrid stepper motor in a housed configuration. Motor performance, therefore, can be quantified at motor assembly level by the motor vendor, prior to assembled into the PTAG actuator. Integrated directly on the back end of the motor shaft is a redundant rotary potentiometer that serves as the fine telemetry output.

2.1.2 Harmonic Drive Assembly

A harmonic drive and oldham coupling are located in line with the motor and actuator output shaft. The harmonic drive gear used in the PTAG is a size 20, which uses a high-performance “S” tooth profile and a shortened flexspline design, as compared to conventional harmonic drives.

2.1.3 Bearings and Lubrication

The main output bearings are a back-to-back (DB) duplex pair that provide the main bending stiffness and structural path through the actuator. Like all other bearings in the PTAG, the main output bearings are 440C stainless steel lubricated with Bray oil grease.

2.1.4 Coarse Potentiometer Assembly

Mounted directly on the PTAG output shaft and bearing housing is the coarse potentiometer. The coarse potentiometer and fine potentiometer on the motor are different in size diameter, yet similar in construction and materials. The potentiometer provides positioning data over one-half of the circumference, and has a conductive track over the other half to provide an electrical conductive path around the bearings for Electrostatic Discharge (ESD) protection.

2.1.5 Mechanical Limit Stops

Both axes incorporate mechanical hard stops limiing actuator travel should the motor driver fail to stop the actuator at the theoretical end position. Each stop consists of a separate ring machined to the desired range of travel, and fastened to the rotating housing. The stop interfaces with a tab that is integral to the stationary flange.

2.2 Interface Design

The mechanical interface to the antenna or payload is through a close-toleranced pilot diameter and eight equally-spaced, #8-32 free running helicoil inserts. The spacecraft mounting flange provides eight equally-spaced, #8-32 free running helicoil inserts on the same base circle diameter as the antenna interface, and a pilot diameter. Both interfaces provide pilot holes for pinning the interfaces to the payload and/or spacecraft, if desired by the customer.

The standard electrical interface to the PTAG is through two, 15-pin Cannon D connectors at the end of pigtails for each axis of the PTAG, totaling 4 connectors per PTAG. Primary motor leads, primary fine potentiometer leads, and coarse potentiometer leads terminate in one connector on each axis. Backup motor leads, backup fine potentiometer leads, and any temperature telemetry leads terminate on another connector on each axis. This allows spare pins for customers with other telemetry requirements.

2.3 Performance Summary

The major design goal was to maximize unit performance for a given envelope and weight. Figure 3 summarizes critical performance parameters and defines unit capability. Loading cases, thermal cases, and vibration environments to which the unit was designed demonstrate design capacity. As a variety of possibilities exist for loading and thermal cases, detailed models have been created such that particular scenarios can be easily analyzed on an application specific basis, as necessary.

3.0 PRODUCTION CAPABILITY

SSOs commercial product area is organized into two product-specific manufacturing cells; one cell to produce high-volume reaction wheel assemblies, and the other to produce high-volume actuator based commercial mechanisms. These cells are wholly contained and equipped with all required tooling and test equipment to produce their products. Cell functionality is duplicated within the main production facility and, as a result, immediate back up capability is available.

The current resources dedicated to the commercial mechanisms manufacturing cell supports production of 60 single-axis actuators per month. Design and development of a universal test console capable of testing multiple types of actuators is nearing completion. Test consoles will be dedicated to a program through production phase.

A new state-of-the-art assembly, integration, and testing area has been built to produce various types of mechanisms. The area can accommodate production of tilt platforms that incorporate linear actuators, single-axis SADs, rotary actuators, and actuator based multi-axis gimbals. (Refer to Figure 4, Factory Layout.)

This factory-within-a-factory is self-contained and separate from other product manufacturing cells. The factory is a FED-STD-209D class 100,000 controlled area, with multiple class 100 flow hoods and nitrogen purged storage cabinets. It has ultrasonic cleaning capability, and is configured in a U-shape to take full advantage of the cross-trained workforce. Inspection and measurement stations are centrally located in each cell providing efficient inline inspection. A semi-segregated testing area provides two thermal cycle chambers, and multiple other test stations.

The assembly and integration area is equipped with a paperless manufacturing documentation system that displays build operations and links to digital pictures, special process procedures, AutoCAD drawings, and other html programs. The documentation system can link build instructions to any build record data entry that may occur during build. A database captures needed build information as the operation is completed. The database is linked to the current configuration management system for quick and accurate configuration verification.

4.0 SUMMARY

Production of the PTAG in both single axis and gimbal configurations is underway. The units will be used to deploy and point antennas, and to actuate subreflector systems.

The paperless manufacturing documentation system proves to be a very effective tool in lowering costs and speeding up production. The next generation actuator in the family of modular gimbals is under development.

This smaller version of PTAG can be used as a replacement for reflector deployment hinges, or as a thruster pointing mechanism.

PERFORMANCE CHARACTERISTICS	CHARACTERISTIC VALUE
Nominal Output Step Angle	0.009375 deg
Actuator Pointing Accuracy from Nominal	±0.020 deg
Maximum Output Speed	9 deg/min
Output Rotation Range	±89 deg
Telemetry Type	Fine Redundant Potentiometer & Coarse Non-redundant Potentiometer
Motor Drive Type	3-Phase Stepper Motor, 1.5 deg/step
Motor Input Voltage	22 to 29 VDC
Size	see layout
Weight	12.0 lb
Stiffness: Torsional (about each rotation axis) Moment (entire PTAG)	 86,000 in.-lb/rad 120,000 in.-lb/rad
Output Torque Margin	> 200%
Unpowered Holding Torque	100 in.-lb minimum
Actuator Minimum Static Load Capacity (simultaneous loading at main output bearings): Axial Radial Moment	 700 lb 700 lb 2000 in.-lb
PTAG Minimum Static Load Capacity (simultaneous loading at antenna interface): Axial Radial Moment	 450 lb 450 lb 300 in.-lb
PTAG Level Quasistatic Minimum Load Capacity	40 g
Qualification Thermal Operating Range	-50 to +85 °C
Thermal Non-Operating Range	-60 to +90 °C
Operating Design Life	22.5 yr
Operating Cycles (±10°)	20,000

Figure 3: PTAG Performance Characteristics

Figure 4: Factory Layout