MEETING HIGH-QUALITY RWA COMMERCIAL DEMAND THROUGH INNOVATIVE DESIGN

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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 Reaction Wheel Assembly (RWA) component challenges with an evolutionary RWA design, the HR14, as part of its Constellation Series family of RWAs. This series of RWAs 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.

1.0 INTRODUCTION

The successful advancement of technology for space applications, in general, demands careful execution of design principals that have been time proven with on-orbit success. A lesser approach ultimately realizes technical risk in meeting an application's performance targets, with a severe penalty for the program and its objectives. 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 of performance. The door is open for dramatic and revolutionary technical responses that offer an apparently economical technical response, only to fall short in fulfilling a space program's objectives.

Honeywell recognizes due diligence in space application designs and is meeting current commercial Reaction Wheel Assembly (RWA) component challenges with an evolutionary (as opposed to revolutionary) design, the HR14 RWA, of the Constellation Series, as illustrated in Figure 1. The HR14, a variable momentum (20 to 75 Nms), variable torque output (up to 0.2 Nm) RWA, reflects an advancement of high production RWA design, surpassing the design goals demonstrated by its predecessor, the HR0610 RWA.

Figure 1 HR14 Reaction Wheel Assembly

The HR0610 RWA design successfully supported a build, test, and delivery of 250+ wheels within a 20-month period and ahead of schedule for the Globalstar Satellite Communication System constellation. Like the HR0610, the new Constellation Series RWA advances the performance level for large-volume, low-cost, and high-producibility, while preserving heritage design principals to ensure legendary Honeywell value in performance and expected on-orbit longevity.

2.0 PRESERVING A SUCCESSFUL RECIPE

The commercial market provides the potential for compromising successful heritage design approaches in meeting the demand for cheaper and quicker to market products. However, products that are cheaper and quicker to market can be successfully achieved in design advancements through smart RWA design architecture involving producibility, modularity, fabrication techniques, process control, and forethought to maximizing design re-usage. This preserves the recipe of basic design principals for RWA elements involving successful application and design of mechanical, electrical, and bearing systems, and their components.

The Constellation Series RWA, illustrated in Figure 2, advances producibility through integration of design function and a reduction of subassemblies and overall parts count. Modularity of design provides the capability for efficient parallel manufacturing of subassemblies, and variability in output performance sizing and electrical interface interchangeability. Implementation of standardized design modules promotes maximum design re-usage of key components and materials, manufacturing processes and Special Test Equipment (STE), and data management systems. Smart design architecture enables effective up or down class sizing of the HR14 to support wide momentum range applications and continuation for reuse of key design modules.

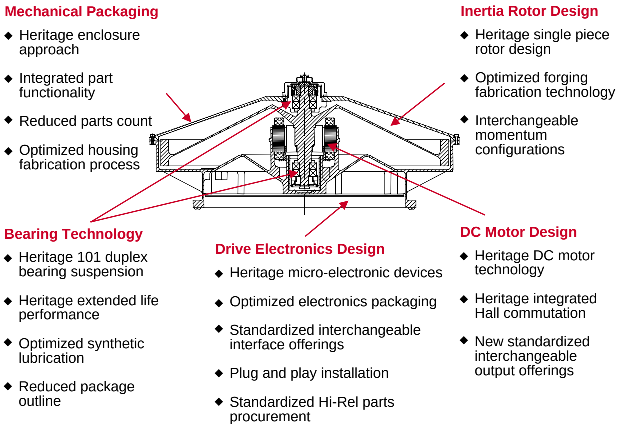

Figure 2 Constellation Series RWA Basic Design Elements

3.0 RWA DESIGN ARCHITECTURE

As with all successful architectures, the Constellation Series, which encompasses the HR14 RWA, is based upon a strong system engineering approach. A responsive RWA design architecture was developed as a result of market surveys indicating that product performance and price are major drivers. Bus applications were found to drive RWA design variations primarily involving torque, momentum, and electrical-interface flexibility to accommodate satellite sizing and a large range of bus voltages architectures. These elements drove the Constellation Series to respond with a design architecture flexible in performance and interface that allows for interchangeable momentum (inertia rotor), torque (motor), and electrical interface (drive electronics.) The RWA architectural design response addressed variability by providing a standard mechanical platform and matching single-piece modules of interchangeable design options offering variability in configurations of rotors, motors, and drive electronics. This approach provided the means for an expedient technical solution secured in basic design principals for various spacecraft bus requirements, which maintain heritage on-orbit performance and reliability.

3.1 Mechanical Design

The HR14 RWA mechanical architecture, similar to its predecessor, the HR0610, consists of a dual-chamber construction. The top chamber provides an evacuated enclosure containing the inertia rotor, motor assembly, and bearing assemblies. The bottom enclosure provides an unevacuated, isolated chamber that contains the drive control electronics separated from the spinning precision mechanical assembly. The chamber locates the spacecraft interface for electrical connections and physical mounting, as well as providing for direct electronics access without disrupting the mechanical spin assembly located above. Advances in producibility are addressed by this unique approach in mechanical architecture combined with a synergistic relationship involving design modularity, integrated part functionality, component fabrication techniques, and standardization of mechanical component interfaces.

The dual-enclosure architecture supports parallel manufacturing paths for both the mechanical and electrical subassemblies. This allows independent manufacturing paths without procurement or assembly schedule dependencies to support unconstrained, production-inventory accumulation. Advances in producibility were realized in the manufacturing of major design elements, housing, and inertia rotor. Housing elements consist of a top cover and bottom chassis. The housing design architecture was revised to locate the complexity of manufacture within the bottom chassis. Typically machined from aluminum-alloy raw material blank, the bottom chassis fabrication was revised to an aluminum-alloy casting; thereby, reducing extensive machining and leaving only precision-machined, interface surfaces. Therefore, the simplified aluminum-alloy top cover was relieved to support more economical manufacturing techniques. The inertia rotor, typically manufactured from a raw, stainless, forged-material blank, was revised to a near net forging. The near net forging process allowed significant material savings, and provided improved distribution and control of material properties.

Design modularity is supported through design architecture that allows performance sizing for both the inertia rotor and motor, as illustrated in Figure 3. The inertia rotor design allows variability in the outboard rim element. This simple approach, made possible by single-piece rotor construction, allows variability in rotor configurations that support momentum applications for the HR14 from 20 to 75 Nms, all interchangeable within the same housing design. The bottom chassis and rotor designs were configured to accept variability in motor sizing. Both the chassis and rotor provide a common mounting interface that supports interchangeable, low-to-high torque motor configurations.

Standardization was re-addressed through mechanical architecture. The housing design is configured as a common baseline mounting interface to support both electrical and mechanical subassembly configurations, now and in the foreseeable future. Similar to the housing, the inertia rotor was designed for a common mounting interface within the chassis, as well as common rotor cross-section configuration designed to support variability in its inertia element sizing previously mentioned. These architectural approaches implemented standardization throughout the component life cycle and support design reuse, minimizing repetition in analysis modeling, fabrication fixturization, procurement, subassembly, and end-item, STE.

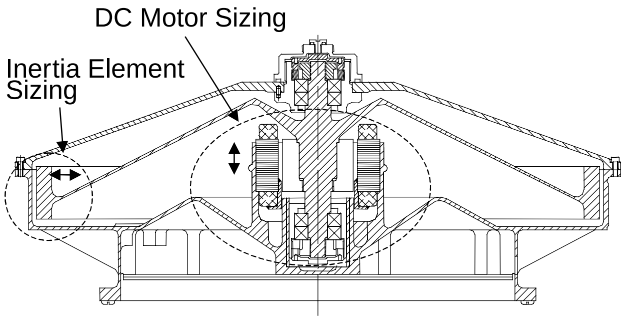

Figure 3 Variable Mechanical Sizing

3.2 Bearing System

The HR14 RWA design has implemented Honeywell's heritage bearing design and suspension architecture, previously proven successful, in more than 500 RWAs produced to date. The design principals involved support Honeywell's unblemished record of never failing to meet a program's mission objective.

Though the housing/bearing suspension architecture at first appears dramatically different from previous Honeywell designs, closer inspection reveals that the basic design principals remain intact. The duplex ball bearing system's detailed component designs maintain previous heritage geometric precision control. The bearing suspension system remains consistent in design principals with its heritage fixed and floating cartridge suspension design, which uniquely provides insensitivity to housing deflections imposed by launch and operating temperature environments. The difference, however, rests in two significant advancements, as follows:

1) RWA bearing system lubrication
2) Application of statistical process control in aspects of the bearing manufacturing process

3.2.1 Bearing Lubrication

Honeywell has achieved noteworthy success in the industry concerning RWA on-orbit performance longevity. As important as it is to maintain critical principals of bearing geometrics and suspension design principals, so is the selection of the lubrication system.

In addition to RWAs, Honeywell is a recognized leader in Control Momentum Gyroscope (CMG) technology. CMG technology applies RWA principals supplemented by attaching a second and/or third axis of control via gimbal joint mechanisms and torque motor systems. This allows CMG systems to provide maneuverable satellite performance. Therefore, a CMG system presents more aggravated operating loads upon the momentum spin bearings resulting from gyroscopic force couples or moments. This cyclic-operating load condition, which surpasses typical RWA on orbit bearing loads, demands a robust lubrication system to ensure extended life capability.

The heritage system previously used in both RWAs and CMGs, though extremely successful, required extensive attention to operating temperature due to the highly evaporative characteristics of this mineral, oil-based system. This, in turn, required supplemental bearing lubrication reservoir systems to support the losses realized during life operation. The reservoir systems drove complexity in design, as well as the need for additional parts and space allocation.

Stringent CMG operating conditions required development of a unique formulation of synthetic oil and grease lubrication. This lubrication system has since proven, through extensive characteristic evaluations and CMG life testing, to extend operating life three to five times longer than that of its heritage predecessor.

The evaporative lubrication-loss concerns are now mitigated by this synthetic counterpart, which provides more than two magnitudes of reduced evaporative loss performance. Adaptation of this proven lubrication system from the CMG into the Constellation Series RWA product supported dispensing of the lubrication reservoir systems, a significant contribution in RWA simplification and downsizing, as illustrated in Figure 4. Savings were realized in overall mass, parts count, and supplemental manufacturing processes.

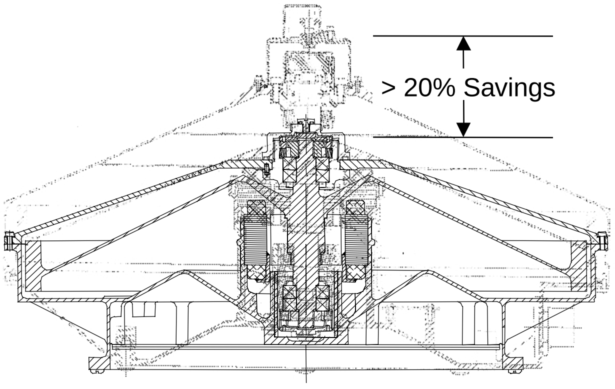

Figure 4 RWA Size Reduction

3.2.2 Bearing Manufacturing Processes

Additional savings opportunities were realized in the refinement of certain bearing manufacturing processes. These highly involved and detailed processes drove extensive component performance, data-recording practices. The substantial quantity of collected data was statistically analyzed and revealed certain controlled precision in performance, indicating good process repeatability. This insight allowed smart reduction in laborious measurement practices to be replaced by random process monitoring that ensured ongoing process control. This process monitoring approach resulted in notable cost-reduction improvement, while maintaining heritage precision and performance capability.

3.3 Electrical Design

Similar to the mechanical architecture, the Constellation Series electrical architecture is based upon heritage design concepts. The implementation was simplified and modularized to allow customization with low, nonrecurring effort. The electronics design is implemented via current loop control. A torque command is converted into a current command and presented to the forward control path. This current command is converted to average current, through pulse-width modulation, and presented to the motor. The motor current is continuously sampled and used as the feedback to the control loop. Other elements of the electronics include the Input/Output (I/O) interface, Electromagnetic Interference (EMI) filter, and secondary power supply.

In order to architect a low-cost electronics implementation, the basic loop function was studied and categorized into functional blocks. The optimized architecture was established for each of the blocks along with a target hardware implementation. Completed trade studies, at both the block and system level, resulted in the control architecture. (Refer to Figure 5.) The physical architecture is implemented using three custom hybrids, one gate array, optional interface drive components, and an assortment of standard resistors and capacitors.

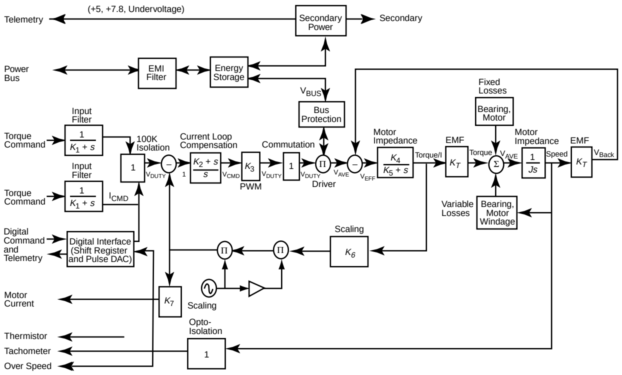

Figure 5 Control Block Diagram

Trade studies completed within the system flowdown revealed that a hybrid electronics implementation costs approximately one-half of an equivalent discrete implementation. This is primarily driven by the procurement costs of high-reliability parts, their lot charges, and procurement labor for the many components required in a discrete design. A microelectronics design based upon hybrid and gate array implementation requires far fewer parts than a discrete design. The discrete RWA electronics designs completed in the early 1970s required seven Printed Wiring Boards (PWB) populated with 850 parts (of 250 part types.) The first introduction of microelectronics reduced the design to 2 PWBs and 300 components (97 types.) The Constellation Series RWA takes this reduction one step further by utilizing only 1 PWB populated with 250 components (55 types.) The electronics layout is illustrated in Figure 6. In addition to parts reductions, the smart functional partitioning is used, which provides reduced nonrecurring effort to implement customer requested scaling changes.

The smart partitioning results in flexible functional blocks, as follows:

- EMI filter
- Secondary power system
- Control system
- Motor drive
- Bus protection
- Command interface

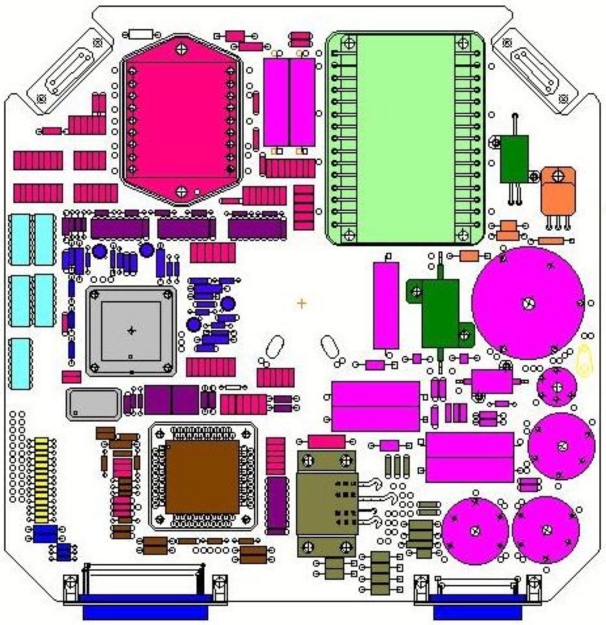

Figure 6 Electronics Layout

Each block is grouped in an area on the single board PWB that allows a minimum amount of unwanted interaction between functional blocks. This physical implementation prevents reconfiguration in one area from affecting another functional block. Figure 6 and Figure 7 illustrate the interrelationship of the functional blocks.

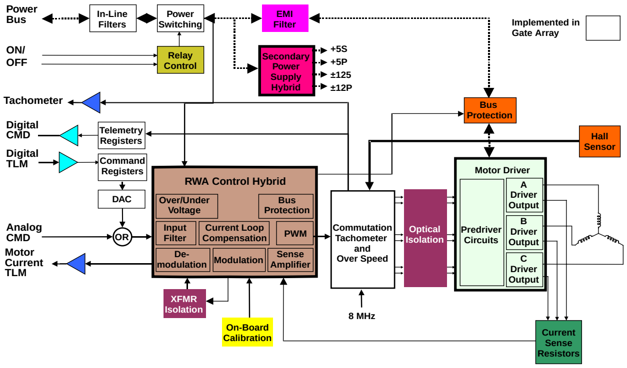

Figure 7 Electronics Physical Block Diagram

The EMI architecture is based upon a three-stage LC filter. It is designed so that a reduction in overall RWA power results in a reduction in the number of capacitors required to support electronics noise rejection to the spacecraft. The secondary power system is based around a DC-to-DC converter that supports all potential bus voltages and eliminates the need for reconfiguration.

The control law implementation is completed utilizing a custom hybrid device and a gate array. These devices were designed to be flexible with respect to I/O and scaling to allow ease of reconfiguration. The control system provides for simple reconfiguration of the motor torque and voltage range. The hybrid and gate array combination supports both unipolar and bipolar analog commands, in addition to a 32-bit digital interface. Both digital and analog telemetry is provided. Motor current is supplied to the motor through a custom driver hybrid capable of switching up to 10 A.

Custom hybrids were used due to reduced procurement cost, compared to Off-The-Shelf (OTS) common devices. Equally important, they meet the rigorous analysis and radiation requirements needed for space flight applications. The size reduction afforded by the microelectronics implementation allowed for integration into a single PWB. The PWB design incorporates power and signal spacecraft interface connectors as an integral part of the board. This combination eliminates internal harnessing and provides for interchangeable electronics assembly configurations that interface directly with the mechanical assembly, supporting plug and play operation.

These concepts provide for a low-cost, single-board electronics that is flexible in the ability to migrate from one design to another. The low number of components results in both lower procurement costs and high reliability implementation. The simplicity of implementation promotes reduced assembly time at board level and end-item integration, and standardization in tooling and test support.

4.0 MAXIMIZING DESIGN REUSE

The Constellation Series, HR14 RWA design was configured with forethought in satellite application sizing, which typically drives RWA momentum sizing. Needed was an RWA platform that could simply provide momentum variability, while avoiding the nonrecurring expense of complex redesign and verification. The Constellation Series RWA architecture was, therefore, configured to provide independence from momentum sizing. Figure 8 illustrates the HR14 RWA with momentum class sizing options, the HR12, and HR16. Each class represents an optimized momentum to mass configuration.

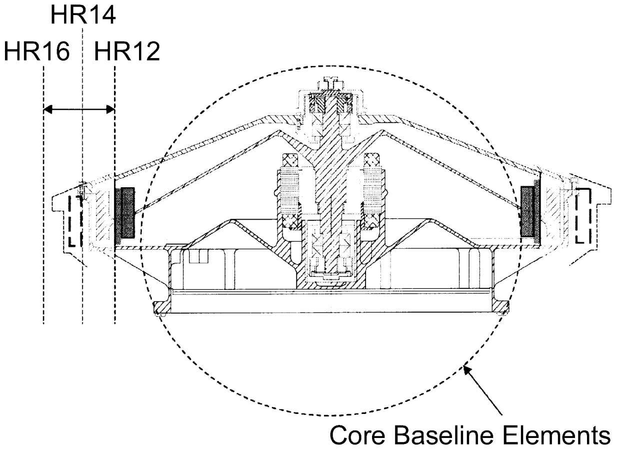

Figure 8 Constellation Series RWA Momentum Sizing

Core design elements involving bearing suspension, motor interface, and drive electronics and its packaging are preserved. Affected design elements were restricted to the case and cover housing components. Within these elements, the form factor and interface approach was maintained. Core baseline design elements and their complexity are preserved. Drive electronics remains interchangeable with each class of RWA. Design reusage was maximized throughout, allowing opportunity for economical high quantity purchasing of the core elements and significantly reducing the potential for nonrecurring design activity, given new satellite applications. Figures 9 and 10 present the resulting individual momentum range applications and a performance overview for the three classes of RWAs: the HR12, HR14, and HR16

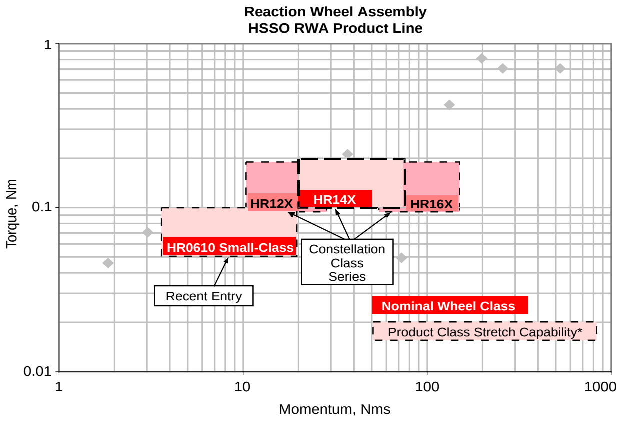

Figure 9 Constellation Series RWA Momentum Ranges

5.0 SUMMARY

The Constellation Series RWA has introduced an evolutionary, rather than a revolutionary, solution to the high production, minimal cost, commercial market. Through innovative RWA design involving architecture, modularity, interchangeability, manufacturing processes refinement, and maximum design reuse, the Constellation Series RWA provides an effective, high-quality method of meeting the market demand. By maintaining proven heritage design principals, the Constellation Series RWA supports the customer's expectation and investment for continued and legendary on-orbit performance in total support of the program's mission objective.

Constellation Series
Reaction/Momentem Wheel Performance Overview

Performance Item	**Units**	**Class Capabilities**		
Product Number		HR12X	HR14X	HR16X
H, momentum @ 6000 rpm, Mass optimized (	Nms	12 to 50 (25)	20 to 75 (50)	75 to 150 (100)
Reaction torque @ 6000 rpm	Nm	up to 0.2		
Power consumption				
Peak torque @3000, 6000 rpm:	W	< 105, 170 @ 0.2Nm (50V Bus)		
Steady state @3000, 6000 rpm:	W	< 15, 22		
Quiescent	W	< 7		
Bus voltage	Vdc	50 reg or 23 to 50 unreg		
Interface	-	Analog or Serial Digital		
Wheel speed range	rpm	± 6000		
Mass, (H optimized), bus dependent	kg	6 to 9.5 (7.0)	7 to 10.6 (8.5)	10.6 to 14 (12)
Life requirement:				
On ground and Storage	yrs	> 5		
On-orbit	yrs	> 15		
Integrated electronics	-	Yes		
Radiation hardness (Si)	kRad	> 300		
Motor type	-	DC Brushless		

Figure 10 Constellation Series RWA Performance Overview