MULTI PURPOSE ROTATING ACTUATOR FOR SATELLITES

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ABSTRACT

Having developed a two-axis periscope mechanism and two instrument scanning platforms for the SOHO and Cassini missions, VTT has gained experience on rotating spacecraft mechanisms. The purpose of this ESA funded study is to improve the performance and adaptability of direct drive pointing and scanning mechanisms in the performance range of 0.1 .. 0.01° pointing accuracy and 0 .. 30 RPM speed. As a result from the study a complete system, called 'Multi Purpose Rotating Actuator' or MPRA, equipped also with a control system and launch latch is developed, manufactured and tested.

For the MPRA VTT is developing a bearing assembly with long life, low friction and disturbance torque. In order to protect the rolling elements, the bearing assembly is caged and off-loaded for the duration of the launch with a special launch latch. The latching system and motor/bearing assembly are scalable for a wide range of payload sizes. Motor control electronics is studied to improve the scanning and pointing performance of a direct drive synchronous motor.

An engineering model of the MPRA is under production. The model payload, sizing and functional specifications were taken from a reference mission. The EM will undergo functional testing, where the pointing performance is characterised and the velocity stability is measured over the full speed range. Environmental testing consisting of thermal atmospheric cycling, vibration, thermal balance and thermal vacuum testing will be performed. In the end a life test followed by dismantling is carried out.

1. INTRODUCTION

As space technology develops it is expected that mundane tasks such as payload pointing and scanning should be provided by commercial components with optimum resource use. Such a need occurs when a mission consisting of several instruments with limited field of view demand independent articulation from the spacecraft. The requirements for such a multi purpose rotating actuator are very diverse ranging from unique scientific missions in harsh environments to more conventional communications and Earth observation missions. Also, the emergence of small satellites and the International Space Station should open many new needs for such devices. The desire is for a mechanism that uses optimum power and mass for payload pointing and scanning with little burden to the external control system. The device shall be able to withstand a wide range of environmental conditions because it is located on the spacecraft exterior surface. The reliability requirements favour use of space proven components and solutions for the subsystems. The fundamental problem is to create a generic system concept, which can be efficiently adapted to a more restricted set of individual mission requirements for cost savings.

Variations in the MPRA configuration can be driven by both the payload and the spacecraft. These include feedthrough requirements for signals, power, radio frequency, purge gas or optics. Another variation is the level of control autonomy of the MPRA, which could have a range from a simple motor drive circuit to programmable microprocessor control.

Sizing of the MPRA is strongly driven by the payload mass and inertial acceleration requirements. This leads to a product family approach built around a set of motor and launch latch sizes. The level of control versatility and autonomy affects the electronics volume and can also drive a range of sizes. The volume for the feedthrough is also dependent on the specific mission requirements.

2. SPECIFICATION

The MPRA must withstand a sequence of ground, launch and space environments. The most important environmental factors affecting the design have been assembled in Table 1.

Table 1. Environmental specification

FACTOR	SPECIFICATION
Operational temperature	-55 .. +80 °C
Non-operational temperature	-75 .. +100 °C
Space vacuum	10^{-12} .. 10^{-6} Pa
Cleanliness	< 10 000 during assembly < 100 000 for assembled unit
Sinusoidal vibration	Frequency level 5 - 20.5 Hz ±18 mm 20.5 - 60 Hz 30 g 60 – 100 Hz 12 g
Random vibration	Frequency level 20 – 80 Hz +6 dB/oct 80 – 500 Hz 0.35 g^2/Hz 500 – 2000 Hz -3 dB/oct
Acoustic	Overall sound pressure level < 146 dB
Quasistatic design load	Mission dependent, expected range 30-60 g
Structural materials	High stress corrosion cracking resistance, high corrosion resistance
Mechanical disturbances	As low as possible
EMC	The electronics design according to MIL-STD-461
Magnetic cleanliness	Minimise magnetics to < 5 nT at 1 m
Chemical cleanliness	Materials with low outgassing and low water absorption
Life time	2 years on ground, > 5 years in space, typically 1000 cycles in atmosphere and several million cycles in vacuum
Radiation	The design shall have potential for > 100 kRad total dose

The range of payload physical characteristics have been provisionally divided in three classes ranging from 0.05 kgm to 4 kgm based on the payload mass multiplied by the center of gravity distance from the MPRA interface. The payload inertia range is also divided in three categories in the range 0.05 kgm^2 to 1 kgm^2. Furthermore, all payloads must be statically and dynamically balanced. The payload configuration and task is highly variable. It can be a particle (charged, neutral, dust) detector, an optical or microwave instrument, an antenna, a materials processing experiment, a solar array, thermal radiator or robotic tool.

The main functions that the payload or spacecraft requires from the MPRA are described in Table 2.

Table 2. Functional specification

FUNCTION	DESCRIPTION
Support payload	Provide a stiff support for the payload during launch and parking
Scan payload	Scan the payload in a predefined profile, speed range 0..30 RPM
Position payload	Position the payload in a predefined location, accuracy 0.01..0.1°
Deploy launch latch	Transform the MPRA from a caged launch configuration to a freely rotating orbit configuration.
Reset launch latch on ground	Set the MPRA to a caged launch configuration manually.
Release launch latch manually on ground	Transform MPRA from a caged launch configuration to a freely rotating configuration manually
Park payload (option)	Park payload anywhere with minimum energy to sustain position
Electronics diagnostics (option)	Measure relevant electronics parameters for housekeeping and health check for digital electronics
Temperature diagnostics (option)	Measure relevant internal temperatures
Mechanism state diagnostics (option)	Measure launch and parking latch state Diagnose bearing health Measure latch preload for ground testing and latch operations
Thermal control (option)	Keep MPRA or payload in specified temperature range
Data feedthrough (option)	Electrical signals Radio frequencies Optical signals
Power feedthrough (option)	Electricity
Fluid feedthrough (option)	Purge gas Process gas or liquid for thermal system or materials research
Particles feedthrough (option)	Electrons, ions, neutrals, dust

3. BASIC DESIGN

3.1 Mechanics

The mechanical design shown in Figures 1 and 2 was conceived based on the requirements and in-house experience. The motor is a hollow-shaft synchronous motor from Sagem. Owing to the low torque and speed requirements direct drive power transmission with superior lifetime can be selected. The motor is available in different sizes and its magnetic geometry can be optimized for pointing or scanning applications. The encoder is mounted directly on the output shaft. The accuracy of the encoder is selected depending on the application. For low accuracy (0.1°) a resistive potentiometer is sufficient while for better accuracy (0.01°) a resolver is used. The bearings are a pair of thin section angular contact ball bearings from Kaydon with soft preloading and ion-plated lead lubrication (ESTL, England). The bearings are in back to back configuration. Soft preloading with about 50 N is required to maintain low bearing friction in a variable thermal environment. The preload is imposed with a flexible membrane, which is integrated to the shaft with electron beam welding. The preload is adjusted with a shim ring after characterization of the membrane stiffness. The bearing type, preload and lubrication were selected in order to minimize bearing torque (< 10 mNm) and maximize bearing life. The bearings were chosen of dissimilar size in order to be able to turn and grind the bearing seats all with one mounting to the lathe yielding higher precision. The goal for the geometric tolerances of the bearing assembly is

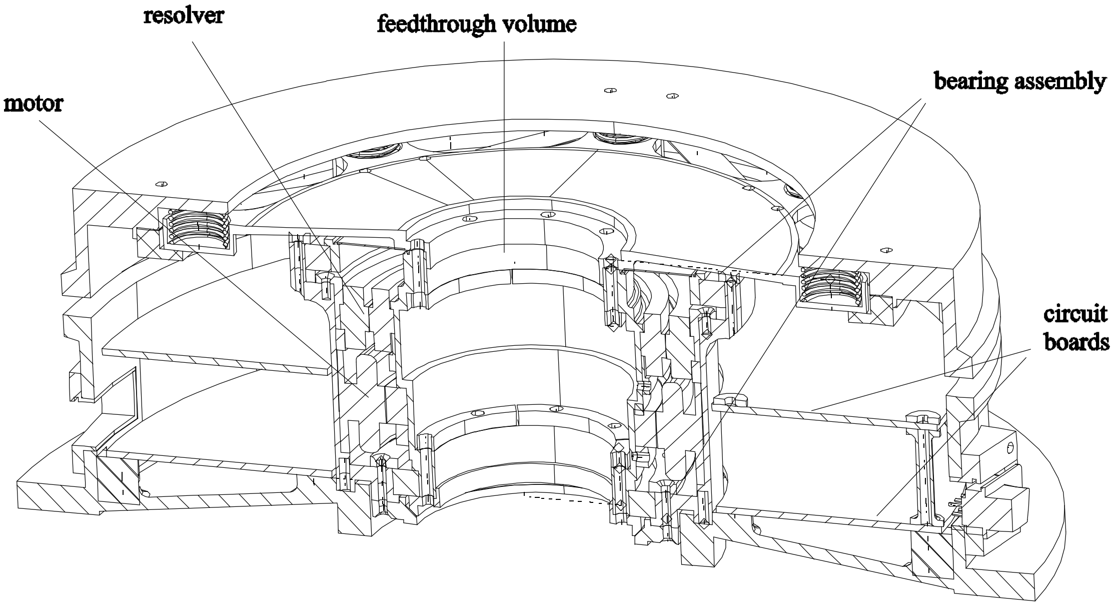

Figure 1. Mechanical configuration.

ABEC7. The volume inside the hollow shaft is reserved for feedthrough components. The bearing assembly is surrounded by ring shaped circuit boards. A cylindrical housing with ports for connectors contains the afore mentioned components. The bottom of the spacecraft side housing is conically shaped to increase its stiffness.

The launch latch (Fig. 2) is required to protect the payload and bearings from extremely heavy spacecraft induced vibrations during rocket lift off. The launch latch consists of a band and multiple clamps around the rotating payload platform circumference. The clamps compress and lock the payload platform to the static structure when the band is tightened. In the bearing assembly the shaft is locked with a contact between two conical surfaces and the smaller bearing is off-loaded while the larger bearing is preloaded for launch. Rotation is further prevented by a toothed profile in the two structures. The number of clamps, circumference and band tension is selected based on the payload characteristics and launcher vibration environment. The launch latch is deployed with a wax thermal actuator (WTA). Its limited load capacity requires the use of a force reduction mechanism for high latching loads. The force reduction mechanism, which is actually an over-center mechanism, is used to decrease the high 4000 N tension load in the latch band down to 50 N that can be handled by the wax thermal actuator. The basic idea with the over-center mechanism is to use a two-joint lever assembly to locate the high tension load so that its line of direction passes very close (a fraction of millimeter) to a rotating joint. In this way the holding force with the main lever can handle the high tension load. In an earlier project it was discovered that with such a mechanism including two rotating joints and high load forces, the friction of the joints became a significant disturbance for operation. A solution was to use low friction needle bearings, which however required much room for bearing seats and made the mechanism big and heavy. For the MPRA a new design to remove the bearings was developed. Both rotating joints were realized, instead of rotating bearings, with swinging joints. In the swing joint, as we call it, a sharp edge is swinging against a corner, thus the swing angle is limited but still enough for operation. An immediate drawback of the design is the high contact pressure that is present in the joint. However, the contact area is so small that even under plastic deformation, the release force is able to separate the surfaces even if the contact area is fully (cold) welded. Thus the joint is able to function under worst case conditions where lubrication (not actually needed) fails and the joint becomes completely cold welded. The swing joint is also a separable joint; after the sharp edge has rotated the line of force is directed so that the swinging part of the joint is able to rotate around the corner and thus completely sets the moving end of the latch free. In this way the travel of the latch free end is not limited by the locking mechanism. Additional means to direct the motion of the free end can be developed. An additional auxiliary lever is used to positively hold down the main lever. The WTA operates the auxiliary lever, acting only against friction, which sets the main lever free to open, and if necessary, pushes the main lever into the beginning of the opening. The latch self opens with the aid of the tension in the tightening band.

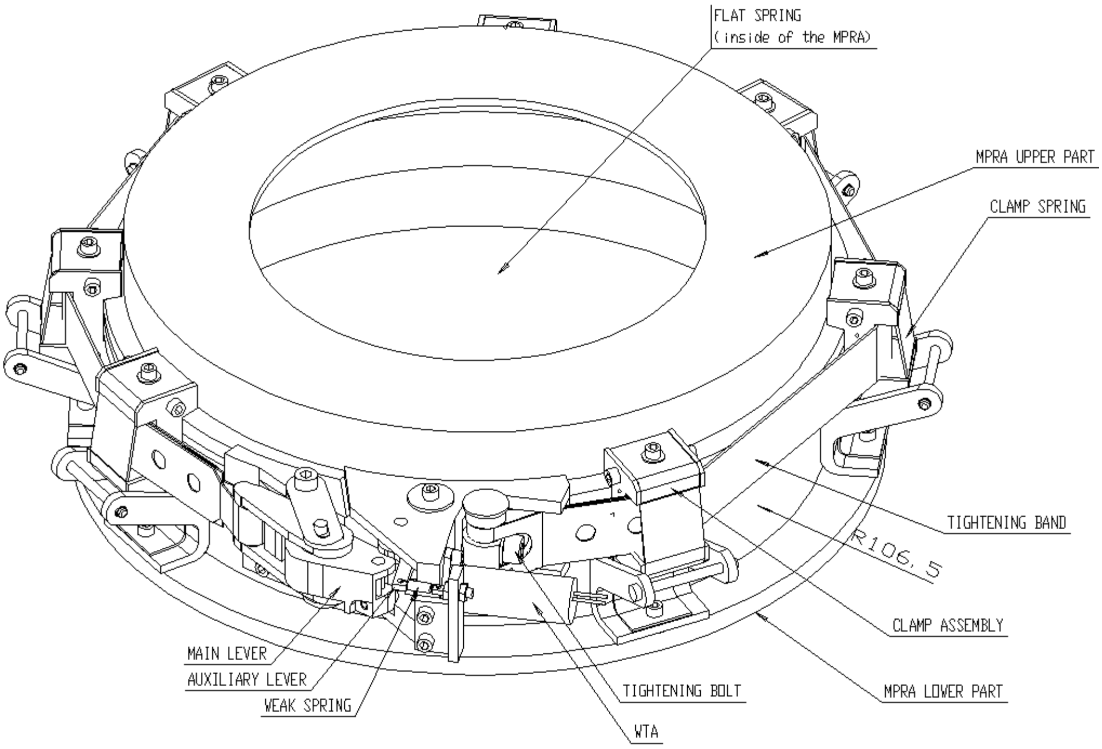

Figure 2. Launch latch.

The launch latch can also be outfitted with a more powerful actuator, such as a shape memory actuator, thereby eliminating the force reduction mechanism.

3.2 Electronics

The MPRA electronics unit controls the MPRA operation according to short high-level commands. The operation of the actuator is highly autonomous. The operational modes include the nominal functions of the realized hardware (positioner or scanner). The desired pointing/scanning modes are defined by the payload mission. The open loop pointing and scanning performance can be improved with feedback control algorithms. Different torque modes can be selected both in the pointing and scanning configuration in order to optimize the use of power. Acceleration/deceleration ramps will be used to decrease disturbations towards the platform.

The direct drive synchronous motor is controlled by supplying roughly sinusoidal currents to the two phase windings of the motor. In a constant speed scanning application, a good speed stability is one of the key performance measures to be optimized. In open-loop operation current waveforms, optimized on-ground for stable rotation and stored in PROM look-up tables, are used. In feedback control operation the position data read from a two-speed resolver is used to modulate the amplitude or the frequency of the controlling currents. The use of different input tables and different feedback algorithms are studied with dynamic simulations and with the engineering model.

The control of the MPRA operation is based on an 80C32 8-bit microcontroller. The program and look-up tables are stored in PROM memory (size up to 64 Kbytes). The data RAM will contain the execution time data and parameters that change during the operational lifetime. The properties of the microcontroller include modes for reduced power consumption. The host interface communication works through an RS-422 serial bus. In order to have savings in PC board area, electronics mass and power consumption, the necessary discrete logic is implemented with a field programmable gate array (FPGA) circuit.

The microcontroller writes the motor phase current data into two 8 bit digital-to-analog converters (DACs) followed by linear voltage to current converters. The benefits of a linear converter, in contrast to a switch mode converter, are low component count, high reliability and low development risk, and better EMC behavior. The efficiency of this solution is, however, poorer. Because modular design is utilized, the selection of the type of the converter depends on the final application. To allow full software programmability, and in order to have 8 bit resolution for all torque levels, another multiplying DAC is used to generate a reference setpoint for the motor phase current DACs.

The encoder unit includes a two-speed resolver (1x & 16x), its reference oscillator and a 16-bit RDC circuit. The absolute position information present in the resolver is not required continuously. Instead, the absolute position is checked after power down in the 1x speed mode, and the 16x output of the resolver is used for feedback and position measurement. The absolute position information is present in all orientations of the resolver, without the need to rotate it to an index mark.

4. ENGINEERING MODEL

In order to test the basic design described above an engineering model was built. The model payload, sizing and functional specifications were taken from a reference mission with a 15 kg payload. The EM diameter is 210 mm and height 80 mm. The motor assembly mass is 1.15 kg using titanium, launch latch 0.85 kg, electronics 0.35 kg and structure 1.5 kg with potential for optimization.

5. TEST PROGRAM

The EM is presently undergoing a series of functional and performance tests. Conclusive results are expected during the fall of 1999.

5.1 Pointing accuracy

The pointing performance of the EM will be measured with a laser interferometer. The EM is programmed to drive at 0.1° increments with a hold time at each position. The test is performed open loop and with different closed loop algorithms. The resolver position data is also recorded and the performance of the resolver is verified.

5.2 Velocity stability

In order to understand the various components affecting the velocity stability, several motor parameters will be measured. The motor assembly is rotated (using another motor) at various angular velocities and its opposing torque is measured for one revolution. The measured torque is a function of both angular velocity and angular position. The measured torque is divided into three parts: the offset part is the dynamic friction torque, the angular-velocity-dependent part is the viscous friction torque, and the angle-dependent part is the detent (cogging) torque. The holding torque of the motor is measured by feeding DC current to the motor phase windings and the motor is rotated slowly by an external motor. The necessary torque is measured as a function of the angular position. The back-EMF of the motor is measured by rotating the motor and recording the voltage it generates at various angular positions and speeds. The results of these three tests should characterize the motor completely. For velocity stability the EM is driven at various target speeds, and the position encoder data and reaction moments are recorded. The actual speed average and its standard deviation (1σ) will be calculated from the data. The test will be repeated without feedback, and with different feedback algorithms. To find out the performance for different load conditions, a variable inertia and a current controlled magnetic powder brake are used as a payload.

5.3 Launch latch deployment

The latch band is instrumented with strain gages at a few locations on the circumference. The tension in the band is measured as a function of the tightening torque. Repeatability and effects of knocking on the structure are studied. The tension during and after vibration testing will be monitored. The launch latch will be relatched and deployed several times without load and with the payload mass. Effects of making mistakes in the relatching will be tested.

5.4 Environmental testing

The subsystems will be subjected to atmospheric thermal cycling. The integrated EM will undergo vibration testing followed by thermal vacuum, life testing and strip down.

6. CONCLUSIONS

The initial tests have shown that the subsystems are operational. Time will tell if the MPRA concept as such is viable and whether the ideas employed in the subsystems will also find applications in other mechanisms.