MICRO-3 HIGH PRECISION LOW DISTURBANCE ROTARY ACTUATOR

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ABSTRACT

The purpose of this project has been to develop a rotary actuator technology achieving positioning performance superior to micro-stepping performance, to be used in highly accurate pointing and scanning mechanisms.
This paper summarizes the design and development of a new line of rotary actuators for use in spacecraft mechanisms requiring ultra-fine step resolution, low power consumption, high output torque, and, more importantly, low torque disturbance in operation.
Analysis of the latest missions, especially those for earth observation and imaging, show that performance requirements for rotary actuators used for antenna and instrument pointing are becoming more and more demanding. The ultra-fine resolution required of high precision continuous imaging satellites depends upon a low disturbance environment. The developed rotary actuator addresses those applications requiring small output step size, high precision pointing, and low disturbance, which challenge the use of conventional rotary actuators.

DESCRIPTION

The unit consists of a standard Moog Type 3 Rotary Incremental Actuator (RIA) output section coupled with a small harmonic drive actuator as its input, rather than the standard pancake configuration motor. The compounding of two harmonic drives results in a high overall gear ratio and a very fine output step angle-- as small as 8 micro-radians. The high torsional stiffness and freedom from backlash of the Type 3 actuator is retained. The unit is a drop-in replacement for standard Moog Type 3 actuators.

The concept was first demonstrated by combining two Moog rotary actuators; a small M8 actuator driving a Type 3 output stage. Testing of the development unit at ambient, and at hot and cold temperatures in vacuum, exhibited successful performance. This unit had an overall gear reduction ratio of 16,000:1, resulting in step sizes of less than 0.001 degrees. The unit performed with power consumption of less than 3 watts, exhibiting very quiet operation. Disturbance torque was more than 30 times less than that of the standard Type 3 actuator, illustrating the greatly reduced stepper motor dynamic effects as reflected to the Type 3 output.

Moog M8 size motors are available in 5 degree, 7.5 degree and 15 degree step size variations. To insure reliably meeting high cycle life requirements and maintaining fine resolution, a design utilizing a combination of two harmonic drives of lower than standard ratio and the smallest motor step size is required. This combination results in an overall gear reduction ratio of 2,500:1 and results in an output step size of 0.002 degrees.

In cases involving less challenging cycle life requirements, units with the highest possible gear ratio of 16,000:1 and a motor step angle of 15 degrees will result in an output step of less than 0.001 degrees.

The first production Micro3 actuator utilizes a three-phase stepper motor of 7.5 degree step angle, producing 48 full steps per motor revolution. Since micro-stepping is not used in the design, and un-powered holding torque is exhibited by the motor at every commanded step, the rotary actuator is capable of resisting applied torques and holding position with power off. The Micro3 actuator of ratio 5000:1 is capable of reacting torques as high as 40 Nm while holding position with power off. The angular interval between the stable step positions thus formed is only 0.0015 degrees, or 26 micro-radians.

By the time this paper is to be presented, the final Micro3 design will have undergone a comprehensive qualification and life testing program, the results of which will be presented.

The modular design of the multi-stage output transmission makes possible the addition of designs having different output parameters, such as lower torque and higher output speed capability, or higher torque/lower speed, in many different combinations. Some examples of additions to the Micro3 actuator family based on this growth capability will be presented in the paper.

Moog Rotary Incremental Actuators are based on a basic geometry and configuration evolved over the past three decades in response to the needs of the spaceflight community. Recent advances in real-time high definition mapping satellite imagery require high pointing accuracies and very quiet, i.e. jitter-free, operation. To address these requirements the actuators must have high resolutions (less than 0.003 degree step size) and very quiet operation. Instrument payloads driven and supported by the actuator would also require high stiffness, to eliminate unwanted low frequency vibrations.

The Micro3 design presented in this paper addresses the high stiffness, small step angle, and low disturbance requirements.

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The Micro3 actuator consists of a standard Moog Type 3 output section (harmonic drive and output bearings) and a Moog M8 input drive actuator (motor and harmonic drive). For the engineering development unit, the 15degree three-phase redundant stepper was chosen for the drive actuator. Advantages of the design include:
100:1 gear ratio in a single pass
0.15 degree output step
Power-off holding capability
No backlash

The configuration of the size M8 harmonic drive allows a clear bore of 3 mm on the centerline of the drive actuator, permitting accessories on the rear of the actuator to be driven at M8 output speed. The through-bore itself is a useful feature in many applications.

The Micro3 actuator components are lubricated with a space qualified lubricant to meet most spaceflight environmental requirements. The heritage M8 actuator and the output section of the Type 3 rotary actuator have been qualified on several spaceflight programs. The Type 3 actuator is the most widely used actuator for antenna pointing mechanisms. More than several hundred of these actuators have been launched and are in space currently.

It should be noted that, due to its very high gear reduction ratio, this actuator is intended for mechanisms requiring high torque with low duty cycles and/or low cycle life (e.g. 500 output revolutions). For applications requiring longer life (1000 output revolutions or more), the transmission ratio could be modified to the minimum possible of 2500:1, resulting in an output step of 0.002 degrees when installed with a 5 degree stepper.

The performance characteristics of the actuator are summarized in Table 1.

Table 1- Performance parameters for Micro3 actuator

Description	Units	Micro3 Configuration		
		-1-	-2-	-3-
Output Step Size	degree	0.000938	0.0015	0.003
Steps per revolution	-	384000	240000	120000
Gear Reduction Ratio	-	16000	5000	2500
Motor Step Angle	degree	15	7.5	7.5
Maximum Output Step rate	pps	640	600	600
Maximum Output Speed	deg/sec	0.6	0.9	1.8
Output Running Torque	N.m	90	28	14
Unpowered Holding Torque	N.m	120	38	20
Torsional Stiffness	Nm/Rad	17000		
Power Consumption	Watts	3 watts at ambient		
Load Capability				
Axial	N	9800		
Transverse	N	6670		
Moment	N.m	325		
Total Assembly Weight	grams	1600		
Environment:				
Temperature Range	-45C to +85C			
Vibration Level	26 Grms			

Figure 1 shows the fully assembled Micro3 actuator.

Figure 1: Micro3 Actuator

PERFORMANCE TESTS

The actuator was instrumented for torque measurements with a Kistler 92775A sensor. This non-rotating torque sensor is precise, highly sensitive, and has a high natural frequency. Its compact size and rugged construction makes it suitable for measurement of the reaction torques generated by small stepper motors.

Figure 2 depicts the test setup used to measure the reaction torque response of the Micro3 and the standard Moog Type 3 rotary actuator for comparison.

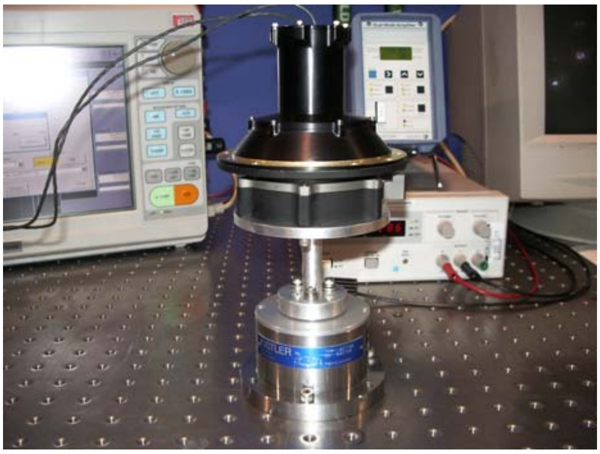

Figure 2: Kistler Sensor Test setup with Micro3

The actuator was commanded at rates of single step and 4, 40, and 400 pulses per second. The test was repeated with a standard Type 3 actuator at single step, 4, 40, and 400 pulses per second for comparison. The rates were chosen to account for the Micro3 and Type 3 step resolution differences.

The results of the tests are included in Figures 4, 5, 6 and 7. It is interesting to note that, with the internal frequency of the standard Type 3 very close to the test setup frequency of ~140 Hz, oscillations were damped very quickly, while the low amplitude oscillations at high frequency were not damped with the Micro3.

A new test fixture having a shorter length was fabricated. Subsequent testing with the new fixture clearly showed a pronounced improvement in reducting test setup oscillations. The tests were conducted with the new fixture (Figure 3).

Figures 4, 5, and 6 summarize the Micro3 response results in comparison with the standard Type 3 for 4, 40, and 400 pulses per second step rates, respectively.

The results clearly demonstrate the low disturbance characteristics of the Micro3 actuator.

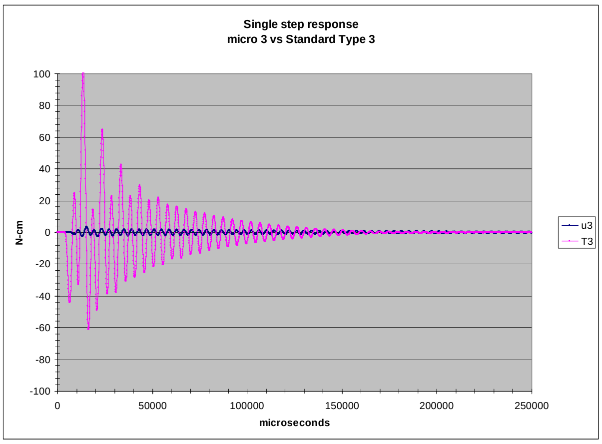

Figure 3: Comparison of Single-Step response

The results indicate attenuation for a single step response greater than 29:1, without filtering out effects of the test setup oscillations.

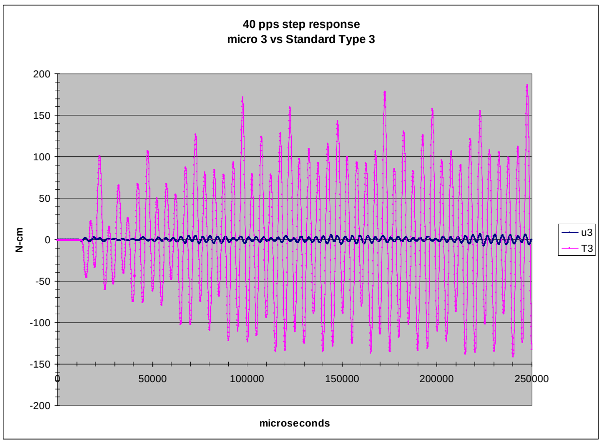

Figure 5: Comparison of 40 pps step response

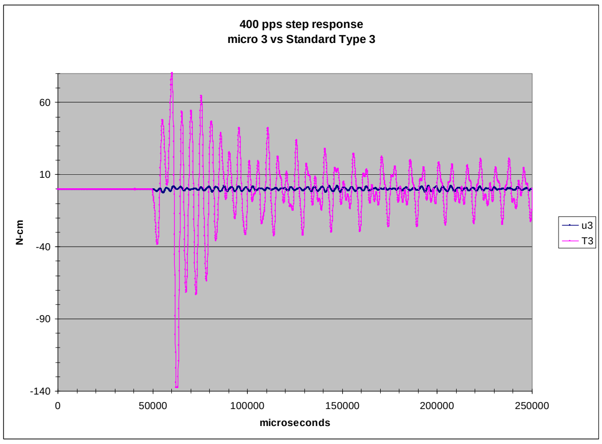

Figure 6: Comparison of 400 pps step response

Figure 7 summarizes the attenuation of reaction torques as a function of excitation frequency. The curve is based on results without any filtering.

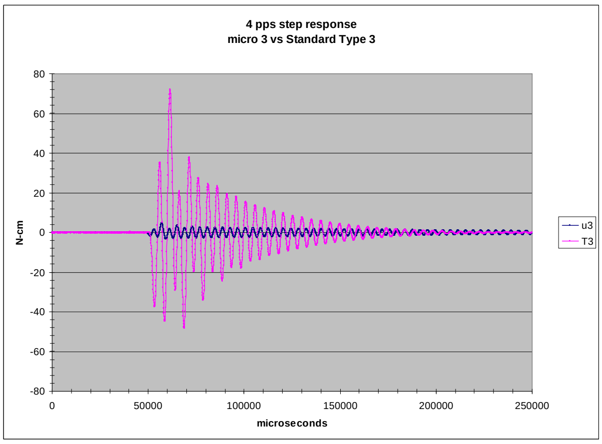

Figure 4: Comparison of 4pps step response

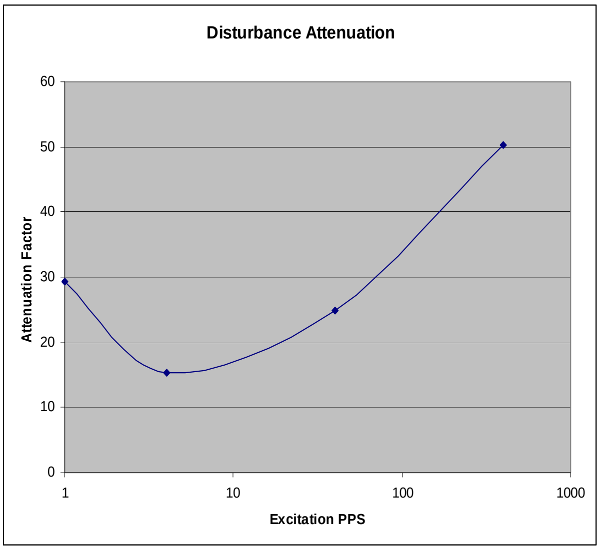

Figure 7: Disturbance attenuation vs. pulse rate

LESSONS LEARNED

When measuring very low disturbance torques, special attention must be given to tooling and test setup natural frequencies. The initial tests exhibited responses greatly influenced by test fixture resonant frequency.

CONCLUSIONS

The actuator presented in this paper has met the requirements for disturbance torque attenuation.

The design is based on heritage hardware components integrated into a compact package. It achieves a very fine step angle, while retaining the advantage of unpowered holding torque at every commanded step.

Modularity of the design, and the possibility of selecting different motor step angles and harmonic drive gear ratios, allows variations optimized for different applications.

Finally, the design was tested for performance at ambient and at extreme hot and cold vacuum environments to assess its capabilities. It was determined that the unit has achieved performance superior to that of micro-stepped units, with acceptable margins.