Development of a Miniature Actuator/Controller System

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Abstract

Development of new products is often hampered or prevented by the cost and resource commitments required by a traditional engineering approach. Schaeffer Magnetics, Inc. identified the potential need for a miniature incremental actuator with an integrated controller but did not want the development to be subject to the obstacles inherent in the traditional approach. In response a new approach - the Pathfinder Engineering Program (PEP) - was developed to streamline new product generation and improve product quality. The actuator/controller system resulting from implementation of this new procedure is an exceptionally compact and self-contained device with many applications.

Figure 1. Schaeffer Miniature Incremental Actuator

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Introduction

Schaeffer Magnetics, Inc. has for many years produced a line of rotary incremental actuators coupling small angle stepper motors with harmonic drive speed reducers in a coaxial arrangement. Controllers for the actuators have also been a staple Schaeffer product. Recently, a potential need was identified for miniature rotary and linear actuators with minimal control requirements. However, the application base was fairly narrow and did not necessarily warrant the cost of a traditional development program. In response, a new development scheme was utilized in an effort to achieve technical advance at minimum cost, yielding a substantially higher return on internal funding than with the traditional "mainstream" approach. The result of this effort, shown in Figure 1, was a small Schaeffer stepper motor coupled with a miniature size M8 harmonic drive from Harmonic Drive Systems, Inc., to produce a tiny 67.3 mm (2.65 in) long by 28.58 mm (1.125 in) square rotary incremental actuator. A self-contained electronics package was then developed complementing the compact size and low weight of the actuator.

Development Process Description

The challenge was to develop hardware faster, at less cost, with equal or improved quality. Due to the lack of a contracted development program and the need to optimally utilize internal funds, the traditional serial approach of design, analyze, review, fabricate, assemble, test, then iterate was rejected. Instead, a more informal yet still controlled development process - the PEP process - was developed and utilized which allowed early validation of designs with minimum cost. Conceptual drawings were generated with just enough detail to fabricate parts, then redlined as required for real-time improvements or corrections. Key members of the development team including both engineering and operations personnel were allowed to make changes which would enhance the performance or producibility of the unit, resulting in a design acceptable to all departments while minimizing bureaucratic delays and expenses. Only a single copy of each drawing was produced to maintain control of all redlined changes. This ease of modification enabled the initial fabricated design to be mature since inputs from all contributing departments were incorporated in a very rapid, inexpensive manner.

For the electronics, the engineer was provided only general goals of small size and ease of control. With inputs from other members of the PEP team, a compact workable design was breadboarded in just a few days.

Since hardware is available very early in the program, the PEP process allows validation of fabrication, assembly, and test techniques at the early stages of a program rather than at the end when little schedule (and perhaps budget) is available. The cycle of design/analyze/redesign/reanalyze is short-circuited, leading to economy and short fused deliveries. Redlines are incorporated after testing and data review with the assurance that the drawing revisions will be the last required and not just one iteration in a long series.

Actuator Description

The miniature actuator is a logical extension of the Schaeffer Magnetics rotary incremental actuator product line, but utilizes the miniature M8 harmonic drive in combination with a two-phase 90° stepper motor. A single cylindrical samarium-cobalt magnet is used and the rotor inertia is only 2.0 g•cm^2. The motor can be operated at any step rate between 0 and 80 steps per second. The rotor is supported on each end by annular contact ball bearings and drives the wave generator input of the harmonic drive via an Oldham coupling. The harmonic drive speed reducer is used because of its high ratio in a small package, torsional stiffness, accuracy, and lack of backlash. The 50:1 harmonic drive gear ratio results in an output step size of 1.8°. The M8 miniature harmonic drive is only 20.5 mm (0.807 in) long and the flexspline outside diameter only 20 mm (0.787 in). The motor stator is bonded in a 6061 aluminum housing to improve heat transfer. The output housing is fabricated from titanium 6Al-4V with 440C stainless steel output bearings for stiffness and load capacity. The bearings in the prototypes are wet lubricated, the specific lubricant selection being dependent on temperature range and load/life requirements. The unit is sealed against debris contamination and vented to outside pressure via labyrinth seals. The actuator is exceptionally light, weighing less than 0.23 kg (0.5 lbm). Since the actuator uses design, fabrication, and assembly practices borrowed or adapted from the Schaeffer heritage actuators, the M8 actuator system is fully flight capable with approved materials and processes. Figure 2 shows the dimensions of the actuator in mm (in).

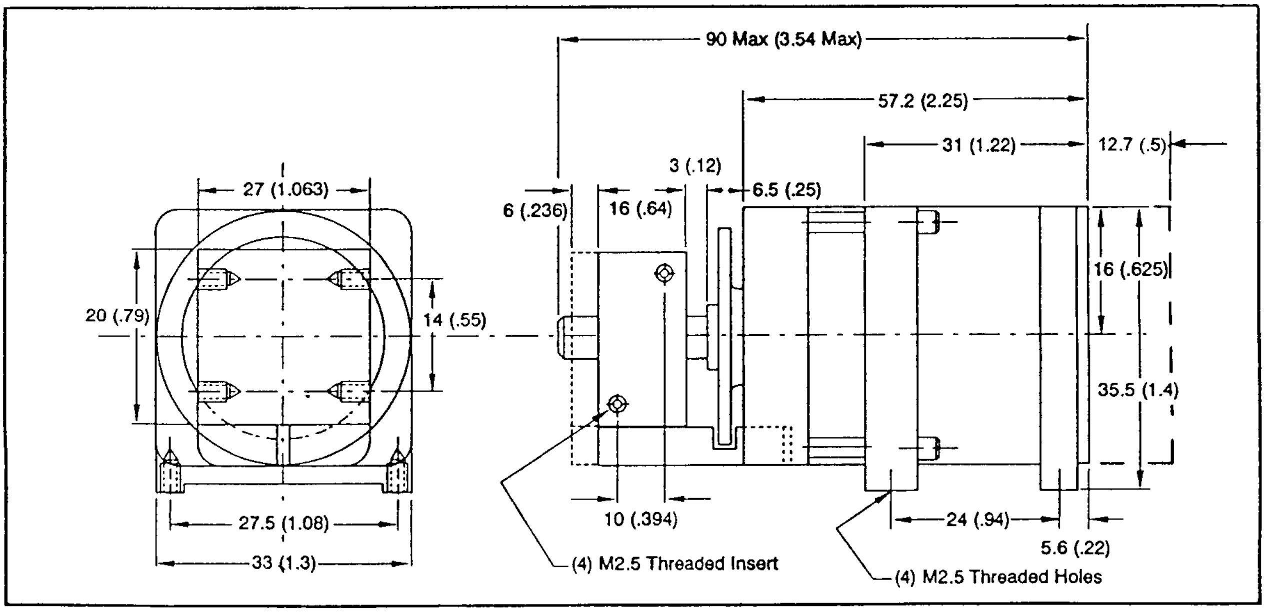

Figure 2. Miniature Type M8 Linear Actuator

Two prototypes have been developed, one rotary and one linear. The rotary actuator is capable of delivering 0.45 N•m (4 in•lb) of torque with a 12 volt input at a maximum output speed of 2.513 $^{rad}/_{s}$ (24 rpm). The linear model of the actuator is identical to the rotary but is equipped with a lead screw and nut on the output resulting in high linear force for the package size and fine resolution. The prototype has an output step of 0.010 mm (0.0004 in) with a total stroke of 35.1 mm (1.38 in), with other step sizes and strokes easily accommodated. Maximum speed is 0.30 mm (0.012 in) per second. Output force is a substantial 111 N (25 lbf). Non-jamming stops have been included so that the actuator can be driven through the full range of motion without damage.

Electronics Description

The miniature and self-contained electronic control unit mounts to the back or side of the actuator, following the unit contour with an envelope of 28.6 mm (1.125 in) square by 12.7 mm (0.500 in) deep. The module has been developed to adhere to strict high-reliability spaceflight standards with regards to design, manufacture, and test. All components are Grade 1 per MIL-STD-975 with one exception covered by a source control drawing. With simplicity of design and operation an important goal, the device requires only power and a direction command.

The electronics can be configured for two or three-wire operation. In the two-wire configuration, reversing the power polarity to the leads reverses the actuator motion in a manner similar to a DC brush motor but the unit operates at a pre-selected fixed rate. This arrangement also simplifies the driver since the controller only requires on/off power switching and not a linear drive circuit. In the three-wire configuration, the easiest to control, two leads are for power while the third controls direction. The prototype unit is configured for 13 volts maximum input which results in approximately an 11 volt output to the actuator. Total power dissipation is approximately 4 watts at 12 volts nominal input. Due to the power steering diodes and their associated voltage drops, the two-wire configuration is slightly less efficient than the three-wire system. The electronics can be easily modified to accommodate far higher input voltages depending on the required performance of the actuator. An optoisolator can also be incorporated to isolate direction command power return from actuator power with the addition of a fourth wire.

An internal regulator provides 5 volt power for the logic circuits enabling operation from a single voltage source. The unregulated bus voltage goes directly to the drive circuits. The unit can also operate directly from batteries which offers intriguing advantages for remote applications, including minimal power and control requirements and excellent EMI resistance. The linear regulator circuit offers high reliability without EMI generation or custom magnetics, and comparable power consumption to other types of converters.

An oscillator circuit generates the step rate. The rate can also be externally provided at the cost of additional control complexity. The design incorporates a precision timer integrated circuit and a temperature compensated capacitor to limit temperature and end of life rate variation. A crystal oscillator can be easily incorporated for enhanced step rate accuracy.

The motor state sequence generator converts the step and direction inputs into a sequential series of four repeating states required by the two-phase motor. A change in direction command reverses the sequence to the motor. The system always powers

up in a legal state and if a transient condition is encountered the unit would immediately recover to a legal state after conclusion of the event.
Level shifting and bipolar switching are functions performed by the motor drive circuits which receive the low voltage, low current motor phase commands from the state sequence generator and amplify the voltage and current to the levels necessary to drive the motor. The output section is a two-phase, four-leg, H-bridge inverter which drives the two motor windings in bipolar mode. Two diodes are provided across each leg of the inverter to suppress the back electromotive force generated by switching current to an inductive load.

Applications and Optional Configurations

Since the actuator/controller system can be controlled with respect to direction, position, and speed, there are numerous potential applications in either its linear or rotary form. The design was originally conceived as a cage mechanism or pin puller for deployment mechanisms offering controlled reversible motion and synchronous operation of multiple actuators, replacing one-shot pyrotechnic devices or other slow reacting linear motors. Due to its small size, the unit can also be utilized in focusing applications within cameras or other optical instruments. Other possibilities include use as door openers or small antenna pointing mechanisms.

For a biaxial configuration, the actuator housing is designed to bolt directly to the output flange of another actuator without an intermediate bracket for maximum weight savings. The design easily adapts to incorporate position feedback devices, including encoders, potentiometers, and resolvers. The stepper motor winding can be modified to match system power parameters and redundant motors can also be provided. A brushless DC motor can also be easily substituted for the stepper.

Conclusion

Improvements can and have been made in the traditional serial approach of engineering development programs. Using the Pathfinder Engineering Program (PEP) enabled Schaeffer Magnetics to develop a new product - a miniature incremental actuator/controller system with a promising market niche - at an investment of resources significantly less than typically associated with new product development.

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