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# Application of Magnetic Smart Materials to Aerospace Motion Control

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Energen, Inc. develops and manufactures actuators and linear stepper motors based on magnetic smart materials. Magnetic smart materials change their shape when exposed to a magnetic field. These materials can be classified into two categories – magnetostrictors and magnetic shape memory alloys.

Magnetostriction is a change in any dimension of a magnetic material caused by a reorientation of the atomic magnetic moments. When the magnetic moments are completely aligned, saturation occurs and no further magnetostriction can be produced by increasing the applied magnetic field. The amount of magnetostriction at saturation is the most fundamental measure of a magnetostrictive material. The modern era of magnetostriction began in 1963 when strains approaching 1% were discovered in the rare earth materials, terbium (Tb) and dysprosium (Dy), at cryogenic temperatures. Since then many materials have been shown to exhibit magnetostrictive behavior including several materials at room temperature but the highest magnetostriction is found in alloys with Curie temperatures below room temperatures making them ideal for cryogenic device applications.

Recently, shape memory materials have been discovered that undergo a phase transformation when exposed to a magnetic field. The behavior of these nickel-manganese-gallium alloys is similar to the Nitinol shape memory material except that the transition between the martenisitic and body-centered cubic structure can be induced by the application of a magnetic field. This behavior is reversible and repeatable. Several materials have been found to have an elongation of several percent near room temperature. These new materials will enable a broad range of devices for precision mechanisms and motion control.

## Actuators

A linear actuator consists of a rod of magnetic material surrounded by an electrical coil. Energizing the coil, with electrical current causes the magnetic material to elongate in relation to the current amplitude. Precision positioning can be achieved by precisely controlling the current. Such a simple actuator can be used for precise mechanical positioning, vibration control, or switch and valve operation. Energen, Inc. has built several sizes of linear actuators that can provide very high forces in a compact device. Figure 1 shows several actuators manufactured by Energen, Inc. (the largest of which weighs only 40 g) having strokes that range from 75 to 300 microns and force capabilities up to 1200 N (270 lbs.).

Larger actuators can be built by increasing the size of the magnetostrictor rod. Energen, Inc. has built an actuator with a 22.2 kN (5000 lbs.) force capability for use in superconducting particle accelerators. Typical response of our small actuators is shown in Figure 2.

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*Figure 1 - Energen's linear actuators*

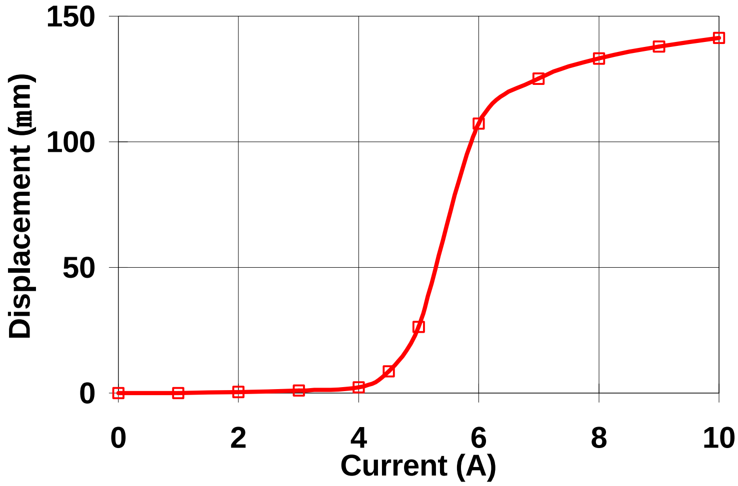


*Figure 2 - Typical response of an actuator*

## Linear Stepper Motor

Energen, Inc. has used the basic concept of a linear actuator to create a linear stepper motor. The linear stepper motor uses a set of three magnetostrictive actuators that enable it to move a rod forward or backward in a stepwise fashion. This motor can provide a large stroke of several millimeters. Variations on this design can yield an actuator with a stroke limited only by the length of the translating rod.

Figure 3 shows a photograph of a linear stepper motor designed for aerospace applications. The translating rod is comprised of three segments assembled end to end. The center section is a magnetostrictive rod surrounded by a superconducting coil. Clamps on each side of the actuator grab onto connecting rods. These clamps contain a magnetostrictor actuator that when energized will cause the clamp to release its hold on the rod.

*Figure 3 - Energen, Inc. uses three linear actuators to create a linear stepper motor*

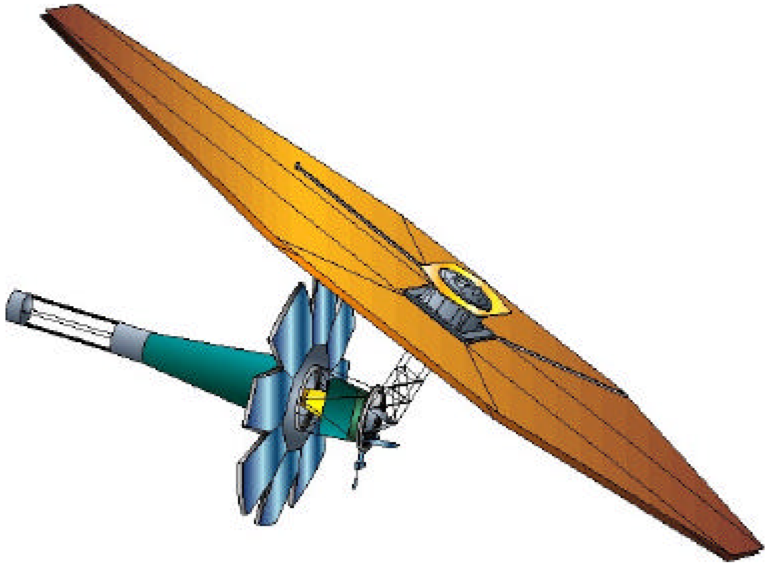

*Figure 4 - A conceptual design of the NGST showing the large sunshield with the telescope behind it. The segments of the 8-m primary mirror can be clearly seen.*

The linear stepper motor can be operated in one of two modes – stepper mode or fine tune mode. In stepper mode, the clamps and translating actuator are turned on and off in the proper sequence to cause the translating assembly to index forward or backward.

Fine tune mode operation provides high positioning resolution. In this mode, the forward actuator is energized to release and the current in the center actuator is modulated thereby moving the forward end of the shaft proportionally. Under this operating mode, the positioning resolution is limited by the current regulation. Thus, this motor is capable of providing a long stroke with high positioning resolution. It is capable of holding position with zero power dissipation since the clamps hold at zero current.

## Next Generation Space Telescope

Under contract to the National Aeronautics and Space Administration and aerospace companies, Energen has received several contracts to develop and demonstrate a series of compact actuators for use on the Next Generation Space Telescope (NGST). NGST is a $500 million project planned for launch some time in 2007 to replace the Hubble Space Telescope. It will have a large 6-8 meter diameter lightweight, segmented primary mirror that is launched in a folded configuration and then deployed in-orbit. The large aperture of the telescope and passive cooling technology employed by the telescope results in a high resolution visible and near infrared observatory that operates at 30-50 K.

Whereas on the Hubble the primary mirror was a ultra-low expansion glass structure similar to ground-based telescopes, the NGST will use lightweight, adaptive optics technology in the construction of the primary mirror system. The mirror will consist of several petals (or segments) that will unfold after launch. Each petal will consist of a rigid composite back structure onto which is mounted a lightweight reflective surface. An array of actuators connect the mirror surface to the rigid back structure and are used to align the mirror segments and to correct image aberrations resulting from thermal gradients and other external phenomena.

Energen’s magnetostrictive actuators are being used in the design of the Advanced Mirror System Demonstrator (AMSD) Project – a scale demonstration of mirror technology for the NGST. Successful completion of this demonstrator will lead to a flight demonstration to test the mirror characteristics in a zero gravity environment.

## Other Applications

Other applications of these magnetic actuators take advantage of their high force capability, large stroke and repeatability. Energen, Inc. is applying linear actuators to such diverse applications as

1. High conductance heat switches for cryogenic refrigerators.

Heat switches are a critical component of low temperature adiabatic demagnetization refrigerators. They provide higher thermal conductance than other technology at sub-kelvin temperatures enabling more efficient refrigerators for high sensitivity instrumentation and detectors. These refrigerators are being developed by Goddard Space Flight Center for future space missions such as STEPS and Constellation-X.

2. Resonant frequency control of RF cavities for particle accelerators.

Superconducting particle accelerators use a bellows shaped resonant cavity to impart energy to the particle with radio frequency waves. To achieve the particle energies for experiments, hundreds of cavities must work in tandem at the exact same frequency. Frequency matching is accomplished by squeezing the cavities axially. The high force capability combined with the sub-micron positioning capability of Energen’s actuators are well suited to this application. Energen has built a proof-of-principle demonstration actuator for cavity tuning and is presently developing a full scale prototype tuning system for Jefferson Laboratory in Newport News, VA.

3. Active vibration control.

Energen is applying its actuator technology to active control of vibration. With state-of-the-art accelerometers and control electronics, active vibration control systems are being developed for both cryogenic and room temperature applications. Magnetic vibration control is more efficient than the currently available piezoelectric systems for controlling low frequency high amplitude vibrations.