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# Introduction to Actuators

## Primary Knowledge Participant Guide

### Description and Estimated Time to Complete

*This learning module is one of three SCME modules that discuss the types of components found in microelectromechanical systems (MEMS). This module covers “actuators” – what they are, how they work and how they are used in both macro and micro-sized systems. An activity provides further exploration into specific actuators and how they are used in everyday devices. Two related learning modules cover MEMS transducers and sensors.*

In this lesson you will learn about actuators, what they are, what they can do, and various applications. You will also be introduced to actuators in both the macro and micro scales. The understanding of this information is important to microelectromechanical (MEMS) or microsystems technology.

### Estimated Time to Complete

Allow approximately 45 minutes to an hour to complete this lesson. This lesson consists of this reading material and a short PowerPoint presentation. You may view the presentation before or after reading through this lesson.

### Introduction



*Types of actuators: electric motor, gear train, screw jack*

*[Image of microgears courtesy of Sandia National Laboratories, SUMMiT(TM) Technologies, [www.mems.sandia.gov](http://www.mems.sandia.gov)]*

An actuator is a device that actuates or moves something. An actuator uses some type of energy to provide motion or to apply a force. For example, an electric motor uses electrical energy to create a rotational movement or to turn on object, or to move an object. A tire jack or screw jack uses mechanical energy to provide enough force lift a car. In short, an actuator converts some type of energy into motion. Actuators include motors, gears, pumps, pistons, valves, and switches.

### **Objectives**

- Describe what an actuator does.
- Explain how two different types of actuators work.

### **Key Terms (These terms are defined in the glossary at the end of this unit.)**

actuator  
electromagnetic  
electromechanical  
electrostatic  
energy  
mechanical  
piezoelectric  
sensors  
transducer

## Basic Concepts of Actuators

An actuator is something that actuates or moves something. More specifically, an actuator is a device that converts an input energy into motion or mechanical energy. The input energy of actuators can be “manual” (e.g., levers and jacks), hydraulic or pneumatic (e.g., pistons and valves), thermal (e.g., bimetallic switches or levers), and electric (e.g., motors and resonators).

In the transducers unit, a transducer was defined as any device that converts one form of energy to another form of energy; therefore, by that definition, an actuator can be a specific type of a transducer. The motor is one such actuator. A motor converts electrical energy to mechanical energy; therefore, a motor is both an actuator and a transducer.

## Thermal Actuators

Thermal actuators are actuators that convert thermal energy into movement. One type of thermal actuator is a bimetallic strip, a strip made from two different metals such as steel and copper. The two metals have different temperature coefficients, which means, that when heated, they expand at two different rates. The graphic below illustrates this. When these two metals are heated, metal 2 expands more than metal 1; therefore, metal 2 has a higher temperature coefficient than metal 1.



Now let's join these two strips together.



Since they are joined, and each metal is expanding, but expanding at different rates, the strip bends. In this case, in which direction does the strip bend?

If you said “upward”, you are correct! This bending is due to thermal expansion.

Thermal expansion is the manifestation of a change in thermal energy in a material. When a material is heated, the average distance between atoms (or molecules) increases. The amount of distance differs for different types of material. This microscopic increase in distance is unperceivable to the human eye. However, because of the huge numbers of atoms (or molecules) in a piece of material, the material expands considerably and, at times, is noticeable to the human eye.

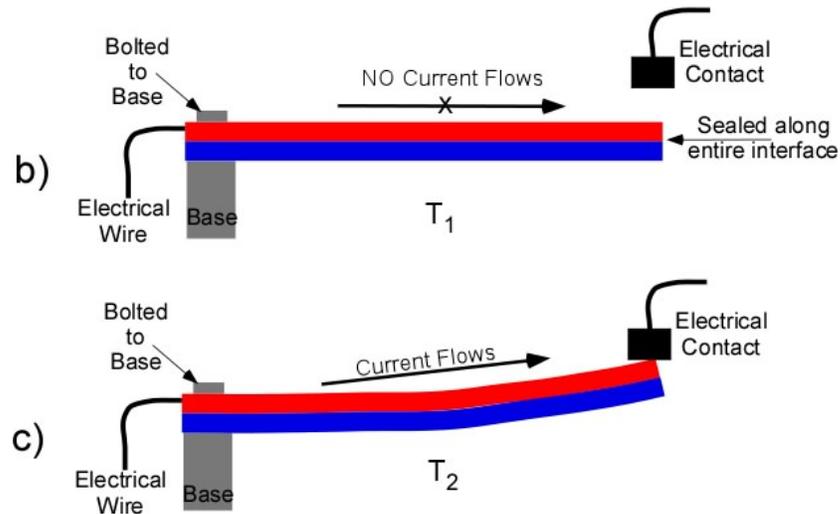
The opposite reaction occurs for a decrease in temperature when most materials contract. When exposed to the elements, a material constantly expands and contracts with ambient temperature changes. Consider a piece of steel 25 meters long. If the temperature of the steel increases by 36°C, (the difference between a cold winter day and a hot summer day), that piece of steel lengthens approximately 12 cm. This change in length is the thermal linear expansion. It is calculated by using the following formula:

$$\delta_L = aL_o\Delta T$$

Where  $\delta_L$  is the change in length,  $a$  is the coefficient of linear expansion,  $L_o$  is the original length, and  $\Delta T$  is the change in temperature in Celsius. If we are considering steel, the coefficient of linear expansion is  $1.3 \times 10^{-5}$ , the original length is 25 meters, and of course the change of temperature is 36°C. This results in an expansion of .12 m or 12 cm.

Now consider 40 pieces of steel 25 meters long laid end to end to make a 1 km long bridge. The bridge's length will change roughly 480 cm between the winter and summer! Fortunately, expansion joints are built into bridges allowing for this expansion, ensuring bridges are safe in all seasons.

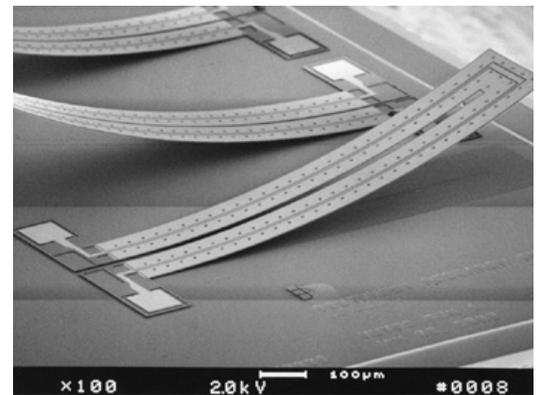
A bimetallic strip takes advantage of the thermal expansion effect to generate motion. Two dissimilar strips of metal are joined together along their entire lengths. When heat is applied, the bimetallic strip bends in the direction of the metal with the smaller coefficient of thermal expansion, (*see the figure below*). Bimetallic strips have many uses. One common use is in thermostats used to control the temperature in homes and offices. The diagram below shows how a bimetallic strip is used in a thermostat.



*Schematic showing how a bimetallic strip works.*

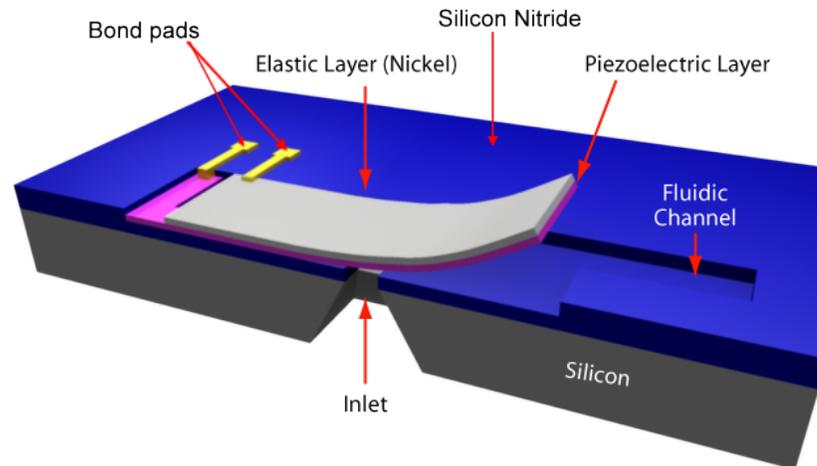
*This particular bimetallic strip is being used as a thermostat. a) Two dissimilar strips of metal are used that have different coefficients of thermal expansion, b) The two strips of metal are joined along their entire interface at some temperature ( $T_1$ ), c) When the temperature increases temperature,  $T_2$ , the bimetallic strips deflect enough to touch the upper contact and allow a current to flow in the bimetallic strip turning on the air conditioner.*

This SEM image shows actuated vertical thermal actuators developed by the Southwest Research Institute. These micro-actuators have two layers of dissimilar materials in each arm. The materials have different temperature coefficients. To obtain the initial upward curvature, the engineers took advantage of residual stresses in the film layers used to build the switch.



*[Image courtesy of Southwest Research Institute. Copyright SwRI.]*

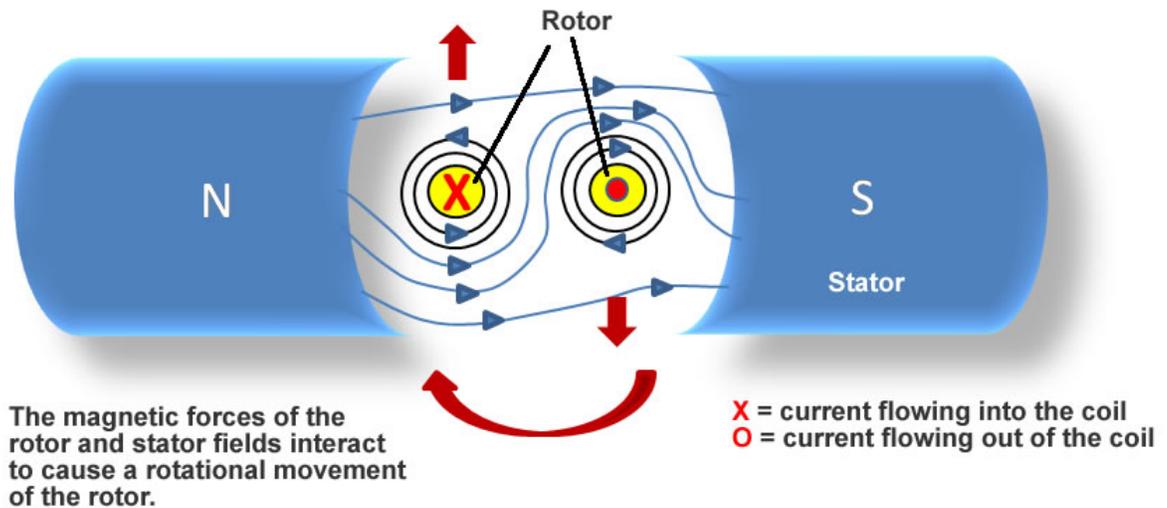
At the microscale, bimetallic actuators are made using both metallic and non-metallic materials. A variety of thin films with different thermal expansion characteristics are used to fabricate switches, electrodes, valves, strain gauges, and diaphragms. At such a small scale (less than 100 micrometers), the slightest expansion and contraction of a material can affect the operation of the device. In some micro-devices, the movement of the film due to temperature changes needs to be minimized or eliminated. However, for devices such as microswitches and microvalves, the temperature coefficient of the material becomes important to its operation. The graphic below illustrates a simple microvalve “switch”. The valve is made up of two different film materials – nickel and a piezoelectric film such as silicon dioxide ( $\text{SiO}_2$ ) and zinc oxide ( $\text{ZnO}$ ).



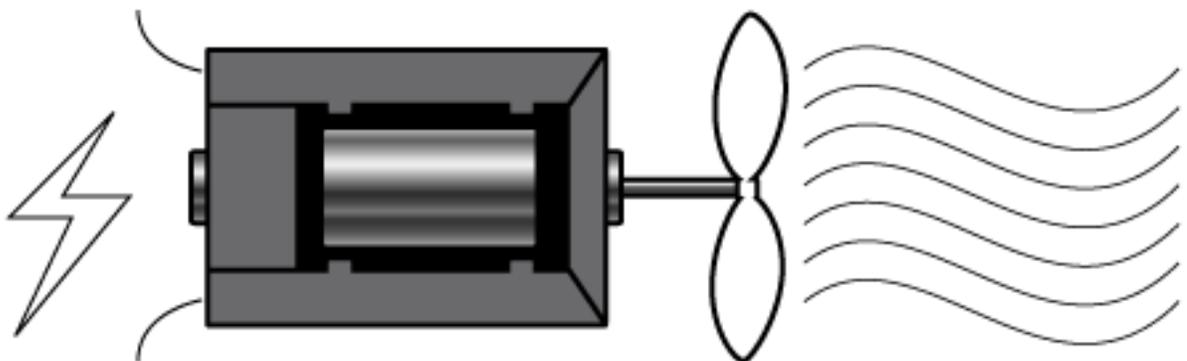
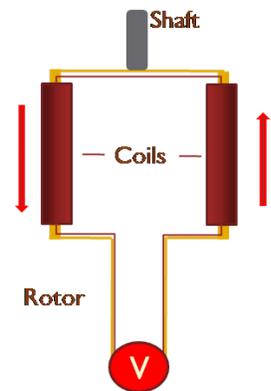
When a voltage is placed across the bond pads, the temperatures of the nickel layer and the piezoelectric layer increase. The nickel layer has the lower temperature coefficient; therefore, it “pulls” the valve upward since its expansion is less than that of the piezoelectric layer. This bending of the valve allows flow from the inlet into the fluidic channel.

Piezoelectric thin films are used throughout MEMS because the characteristics of piezoelectric are that movement occurs when a voltage is applied and vice versa – movement in the film can generate a voltage. Sounds like an actuator, doesn't it? In actuators, piezoelectric films can be found in MEMS motors, switches and valves. In sensors and transducers, such films can be found in MEMS cantilevers, strain gauges, membranes, hydrophones and microphones.

## Electric Actuators



Electric actuators use electricity or electrical energy to create motion. An electric motor is a type of an electric actuator. Most direct current (DC) motors operate by current flowing through a coil of wire (the rotor) and creating a magnetic field around the coil. The coil is wrapped around the motor's rotor, creating a loop, and is positioned between the poles of a permanent magnet or electromagnet. The interaction of the two magnetic fields causes the rotor to rotate on its axis, rotating the motor's shaft (*see figure above*). Reverse the direction of the current flowing through the rotor and the rotor will rotate in the opposite direction. Thus, an electric motor is a transducer AND an actuator because it converts electrical energy to magnetic energy to mechanical energy or motion.



*An electric motor is an actuator that transforms electrical energy into mechanical energy or motion.*

## Mechanical Actuators

Mechanical actuators convert a mechanical input into linear or rotary motion. A common example of a mechanical actuator is a screw jack. The picture shows a screw jack in operation. Rotation of the screw causes the legs of the jack to move apart or move together. Inspecting the motion of the top point of the jack, this mechanical rotational input is converted into linear mechanical motion.

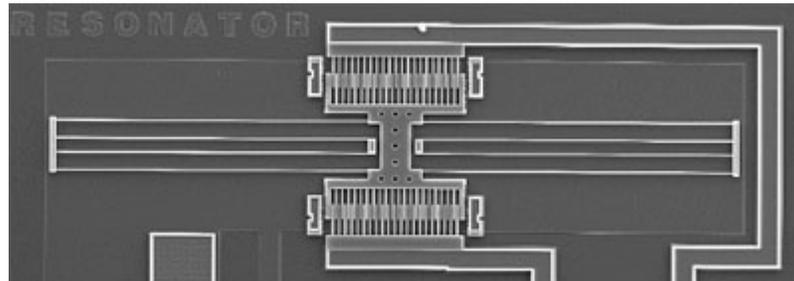
Mechanical actuators can produce a rotational output as well with the proper gearing mechanism.



*A screw jack converting rotational energy into linear motion (to lift a car possibly)*

## MEMS Actuators

An example of a microactuator (or MEMS) is the electrostatic comb drive. Comb drives are used in many MEMS applications such as resonators, microengines, and gyroscopes.

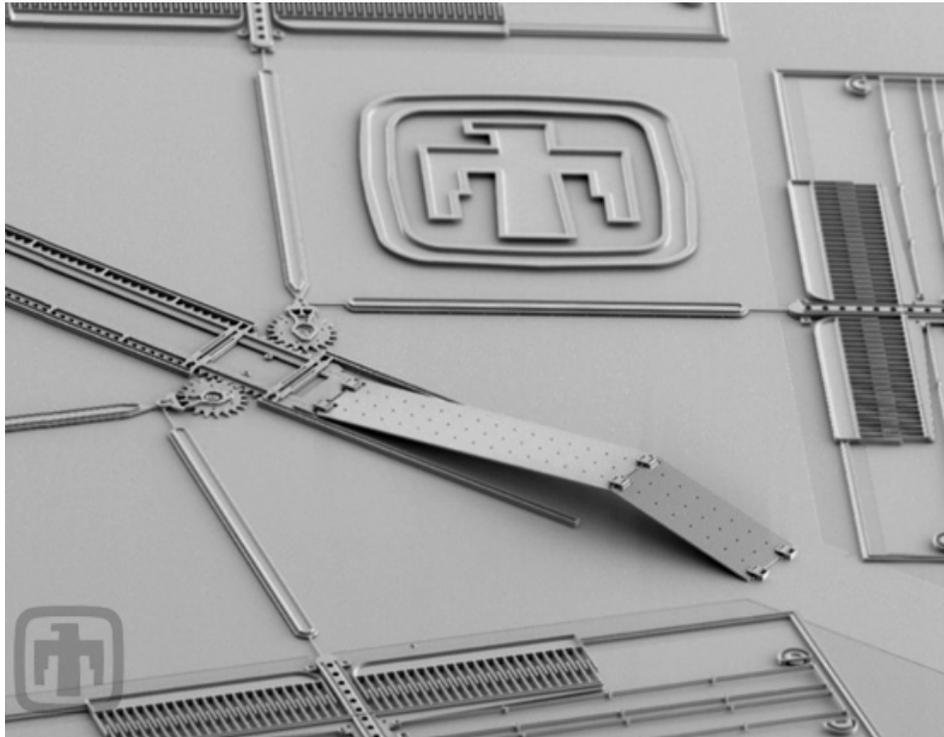


*SEM of a typical comb-drive resonator [Courtesy of Sandia National Laboratories]*

The image above is an example of a MEMS electrostatic comb drive resonator, a common MEMS actuator. A resonator is a device that naturally oscillates at its resonant frequency. The oscillations in a resonator can either be electrostatic or mechanical. As an actuator, this comb drive resonator can move another object at the rate of the comb drive's oscillations. The force generated is low, usually less than  $50\mu\text{N}$ . However, these devices are predictable and reliable making them popular as MEMS actuators.<sup>1</sup>

Let's take a look at a MEMS actuator that is used to precisely position an optical mirror. This system was developed by Sandia National Laboratories

Below is a scanning electron microscope (SEM) image of a micro-sized polysilicon mirror and its drive motors.<sup>2</sup> Each drive motor consists of a gear connected to two comb drives by bars or pins. The gears are actually part of a rack and pinion system with a linear rack for each gear. Take a minute and make sure you can identify each of these components – the comb drives, gears, linear racks and mirror.



[Courtesy of Sandia National Laboratories, SUMMiT(TM) Technologies, [www.mems.sandia.gov](http://www.mems.sandia.gov)]

As the comb drives oscillate, the bars move back and forth causing the gears to rotate. As the gears rotate, they move the linear rack. The movement of the rack causes the hinged mirror to raise and lower. By changing the position of the optical mirror, one can change the angle of reflection of light hitting the mirror from a source such as a fiber optic cable or laser.

The rack and pinion is a common actuator that can be found in both the macro and now the micro-scales. Such actuators use rotary motion to produce linear motion. Like all actuators the rack and pinion uses an energy on its input (in this case, mechanical energy) to make something move.

### **Coaching Question**

When was the last time that you “actuated” something?  
What did you do?  
What was the actuator?  
What was moved?

## Key Terms

Actuator – a specific type of transducer that converts energy into motion

Electromagnetic: Objects made magnetic by an electric current.

Electromechanical: A mechanical device that is controlled by an electronic device.

Electrostatic: Of or related to electric charges at rest or static charges.

Energy: The sources of energy encompass electrical, mechanical, hydraulic, pneumatic, chemical, thermal, gravity, and radiation energy. There are two types of energy---kinetic and potential. Kinetic energy is the force caused by the motion of an object for example a spinning flywheel. Potential energy is the force stored in an object when it isn't moving.

Mechanical: Pertaining to or concerned with machinery or tools.

Piezoelectric: The ability of a material to create movement or produce a mechanical force when a voltage is applied; or, the ability to generate a voltage when a mechanical force is applied.

Sensors: A device that responds to a stimulus, such as heat, light, or pressure, and generates a signal that can be measured or interpreted.

Transducer: A substance or device that converts input energy of one form into output energy of another.

## References

1. MicroElectroMechanical Systems (MEMS). Sandia National Laboratories. 2017.  
<http://www.sandia.gov/mstc/mems/>
2. Khalil Najafi, University of Michigan, Sensors Presentation
3. "Thermal Expansion – Linear". The Engineering Toolbox.  
[http://www.engineeringtoolbox.com/linear-thermal-expansion-d\\_1379.html](http://www.engineeringtoolbox.com/linear-thermal-expansion-d_1379.html)
4. Table of the "Coefficients of Linear of Expansion" for many different materials.  
<http://www.farm.net/~mason/materials/expansion-coefficient.html>
5. E. J. Garcia and J. J. Sniegowski, "Surface Micromachined Microengine," *Sensors and Actuators A*, Vol. 48 (1995) 203-214.

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