Motors and Mechanisms in the Ham Shack

Your shack contains many electromechanical devices that whir, rattle, clatter, and occasionally bang. Here's a brief guide to what they are and what they're for.

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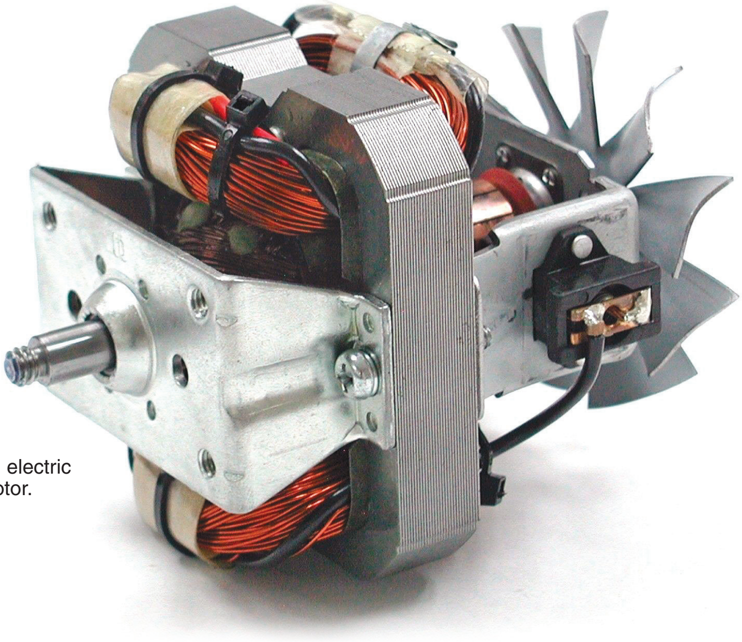
It's easy to overlook the less glamorous electromechanical technology of motors and actuators in the ham shack. Motors can be mystifying, solenoids — annoying, and steppers can be staggering. We totally ignore them, until they fail to work in the proper manner. This article will take some mystery out of these devices, and describe some of the wonderful new developments in electromechanical gadgets that will infiltrate the ham shack of the future.



An electric motor.

Electromagnets

More than any other device, the *electromagnet* is responsible for moving things around in your ham shack, whether it's the rotator that twirls the cubical quad atop your tower, or the diaphragm that wobbles air between your dynamic headset and your ears. We'd be hard pressed to get much hamming done without electromagnets. Despite developments in electrostatic, piezoelectric, and fluidic actuators, the electromagnet still reigns supreme among electromechanical devices.

Solenoids

Most mechanically meaningful electromagnets appear as some form of *solenoid*, which is a coil of copper wire wrapped around some form of core. The *core* is nearly always an iron-bearing (ferrous) material, which serves to increase the permeability of the solenoid. The core concentrates the field, making a more powerful electromagnet for a given amount of occupied space. The iron core is typically made of laminated soft iron to minimize hysteresis effects, which tend to make an electromagnet a permanent magnet. Although permanent magnets have an important role in electromechanical devices, you don't want unintentional permanent magnets.

A solenoid is often used in conjunction with an *armature*, a movable slug or lever of soft iron in proximity to the solenoid. An energized coil attracts the armature. The *relay*, or electromechanical switch, is one of the simplest applications of the solenoid.

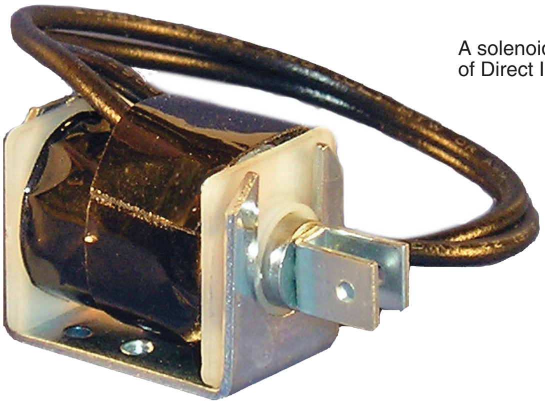
Relays range from nearly microscopic reed relays to monstrous contactors used in power substations. Solenoids can be extremely fast and powerful, but they are somewhat difficult to control in a linear fashion. Solenoids are generally either fully on or fully off. For a given coil current, the magnetic pull against the armature changes radically with distance. For this reason, straightforward solenoids are seldom used in robotic devices or with other electromechanical devices that need a smooth motion over a wide range. For robots, we need a more sophisticated actuator configuration of the electromagnet.

Before GPS, the 60 Hz power grid line frequency was by far the most accurate frequency standard available to the average ham.

Motors and Rotors

The next level of electromagnetic device complexity is the *motor*. There are countless varieties and configurations of motors; they all have some common elements. Motors can be broadly categorized as *dc* or *ac motors*. Commonly, dc motors often use permanent magnets. Generally, ac motors are synchronous, meaning their speed of rotation depends on the ac line frequency. Some motors, such as induction motors, are "semi-synchronous" in that their speed depends on both the line frequency and line voltage, as well as on the load.

Some form of commutation is needed with dc motors and generators. A *commutator* is a device for periodically reversing the polarity of the armature current. Commutators are generally troublesome



A solenoid. [Image courtesy of Direct Industry]

A servo motor.

and require maintenance, which is why most cars converted from dc generators to alternators in the late 1950s. Recently, *brushless dc motors* (where the commutator has been replaced with a solid state switch) have been appearing in ham radio and computer fans. The brushless dc motor is not a synchronous motor.

The surprisingly accurate old-fashioned ac wall clock uses a synchronous ac motor. This is because the 60 Hz line frequency of the US power grid is atomic clock accurate when averaged over long periods. In fact, before global positioning satellites (GPS), the 60 Hz power grid line frequency was by far the most accurate frequency standard available to the average ham. So, don't toss out your plug-in wall clock just yet.

Servo with a Smile

The *servomotor* or *servomechanical device* is a marvel of the last century. A servomotor has a feedback mechanism (loop) to reduce or compensate for mechanical errors somewhere in the system. The servo loop is analogous to the negative feedback amplifier. In fact, the math describing them is identical. Feedback theory became formalized after World War II.

There are several types of motor feedback loops that control speed, position, phase, or a combination of them. The nearly universal phase-locked loop (PLL) used in modern transmitters and receivers is actually derived from motor speed servo control. Any type of servo loop requires an independent reference, a comparator, and a controller. A typical antenna rotator, which uses a positional servo loop, employs all three items.

The *controller* is the bi-directional motor, which is often a split-phase ac motor. That is an ac semi-synchronous induction motor with two windings at 90-degree angles. Switching a proper capacitance into one of the windings creates a phase shift in the motor, causing the motor to run either clockwise or counterclockwise at a constant speed. You (or the controller) need some sort of feedback to tell you when the rotator is pointing where you want it. The simplest directional detector is a potentiometer attached to the rotator output. This is the independent reference. Finally, you need a *comparator*, which is another potentiometer in the control box that compares the voltage from the reference potentiometer in the rotator assembly with the position of the "big knob." When these two values are equal, the voltage to the motor shuts off. The motor may reverse briefly or it overshoots.

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Servo loops are also used in automatic antenna tuners, although the trend favors using stepper motors, which are easier to design than tricky feedback loops.

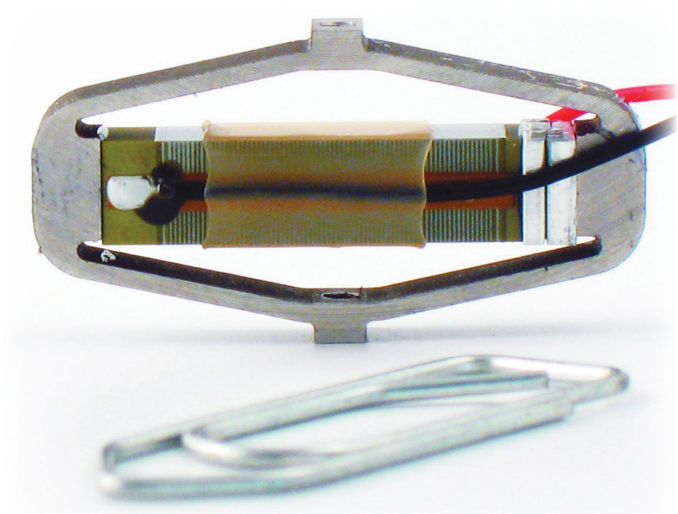
Selsyns and Synchros

The *synchro* or *selsyn* (for self-synchronizing motor), once very prevalent, is one of the coolest devices ever created. A selsyn set consists of two motor-like devices connected by five wires. Neither one of them rotates when you apply power. However, if you turn the shaft of one selsyn, the other one turns by the exact same amount. These were once used as rotational transducers on countless post-war ham antenna rotators. Earlier they were used extensively on radar systems or anywhere else you needed remote indication of a rotational value.

Most selsyns are designed to use 440 Hz ac, so if you plan on using one you might want to build a small 440 Hz inverter. Internally, the selsyn is a modified three-phase motor with a three-phase stator, and a two-phase armature. Each of these legs is connected to the matching legs on the complementary device. Power is applied in parallel only to the armatures.

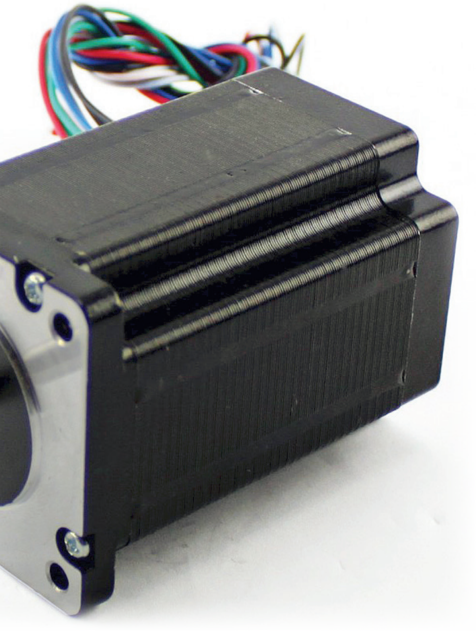
Stepper Motors

The stepper motor may be the greatest departure from conventional motor design, and was made possible by very powerful and relatively cheap rare earth magnets. With the proper drive electronics and programming, the stepper motor is capable of very rapidly and repeatedly returning to a precise position. They are the heart of most computer printers and many computerized machine tools. However, a stepper motor can lose count of steps occasionally, which means some sort of reset or reboot function is needed in the more critical applications.



A piezoelectric actuator. [Image courtesy of Direct Industry]

A stepper motor. [Image courtesy of Automation Technology]

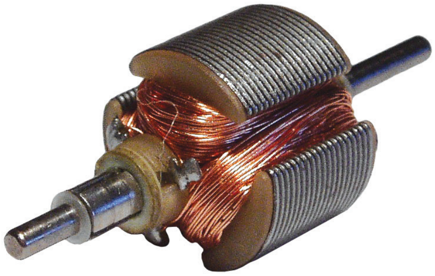


A servo-motor, on the other hand, won't lose its place.

The *linear actuator* is a useful variation of the stepper motor. It is basically a stepper motor driving a precision jackscrew. These are capable of tremendous amounts of pushing and pulling force and extremely high accuracy. Most micropositioners used in microsurgery and micro-manufacturing use some sort of stepper linear actuator. These require careful programming. Linear actuators are often used in robotic systems.

Small-scale Forces

There are electromechanical methods that do not rely on magnetism to move things. Most hams are familiar with piezoelectric properties of quartz crystals. When you apply an electric field to a hunk of quartz, it warps slightly. Until recently, this amount of warping was considered too minuscule to do any real work. However, *piezoelectric actuators* are now used for performing surgery on the cellular level. Only slightly less refined than the piezoelectric actuator is the magnetostrictive actuator. *Magnetostriction* is the distortion of a metal by an electric field, as used in the famous Collins mechanical filters. Magnetostrictive actuators are used in micro-manufacturing as well.



An electric motor armature.

Finally, we have *electrostatic actuators*. These have the least amount of force available, but are very cheap and are useful for many special applications. Electrostatic transducers have been used for a long time as components of loudspeakers and headphones.

Not all electromechanical devices are even solid. For example, spiders use hydraulic pressure to extend their limbs, as they lack extensor muscles. And in a similar fashion, tiny robots use tiny hydraulic systems. Special MHD (Magneto Hydro-Dynamic) fluids can be pumped directly with tiny electric currents instead of master cylinders, which can result in robots that are smaller — and creepier — than spiders. Now you know.

Back on Earth

It will probably be a while before armies of spider-droids are going to have much application in the typical ham shack. However, we need to realize that mechanical devices are not going to go away any time soon. There are certain things you just can't do with silicon and software.

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