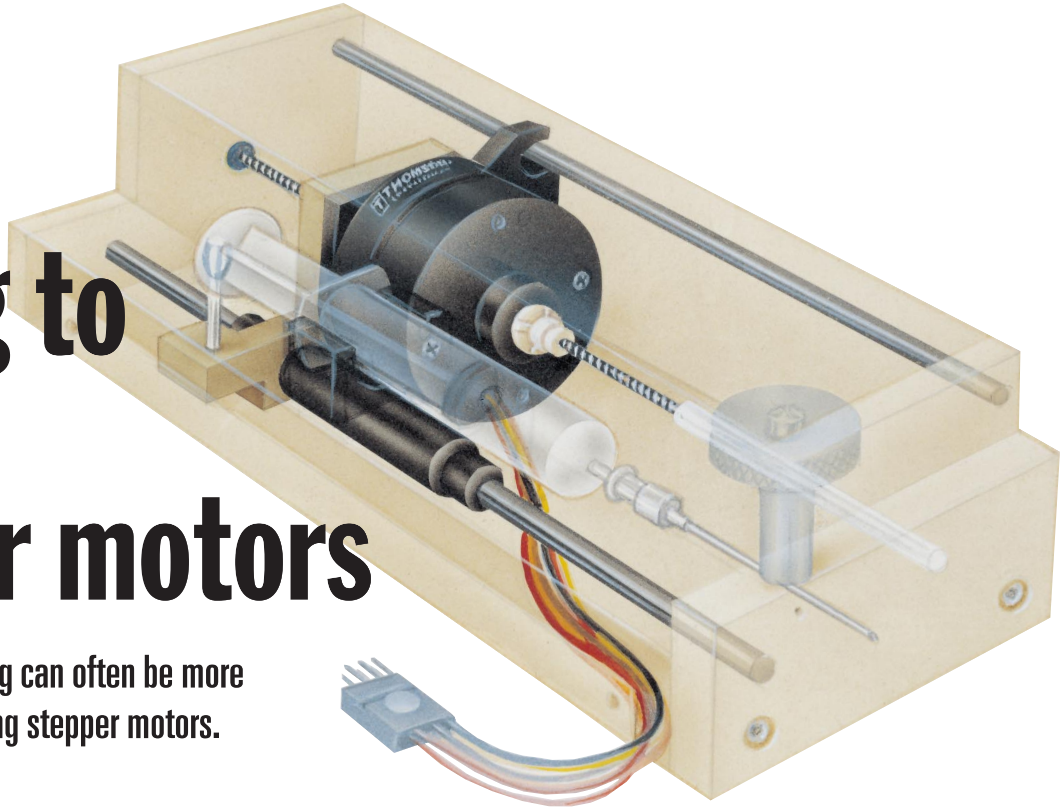
Getting to know stepper motors

Fluid control and metering can often be more precisely handled by using stepper motors.



Stepper-motor-based syringe pumps automatically dispense precisely controlled amounts of medications and solutions. Unlike an injection administered by a doctor that is quick and over in seconds, the microprocessor-controlled linear actuator can dispense medications over long periods of time at precise rates and volumes. And unlike an intravenous feeder that relies on gravity to dispense liquids, the syringe pump controls flow by using pressure. The two major factors, flow rate and amount, are controlled by stepper motors.

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From humble beginnings, the permanent-magnet stepper motor continues to complement a growing number of technologies by providing a cost-effective means of providing incremental motion. And with today's high-volume, low-cost ICs and computing power, it's easy for biomedical engineers to design stepper-motor-based solutions for medical equipment that must meter, dispense, or pump fluids. They can also use stepper motors to build analytical gear with motion control needs.

Stepper-motor systems provide precise speed, position, reliability, and efficiency — characteristics vital to the medical marketplace. When compared to alternatives like brush dc motors, stepper motors require no encoder or feedback loop and serviceable hours are measured in bearing life not brush life. Stepper motors don't create dirt or particulates that can lead to contamination. And as an added benefit, stepper motors generate low levels of EMI noise, which is a critical consideration in modern hospitals brimming with sensitive electronic equipment.

Electronic pipettes are linear-stroke devices that utilize digital linear actuators to precisely control the amount of fluid being dispensed. The shaft of the actuator is coupled to a pipette fitted with a piston. A microprocessor controls the step rate of the actuator and moves the shaft and piston in precise and repeatable linear increments. Many electronic pipettes are portable handheld devices with built-in batteries and microcomputers.

STEPPER-MOTOR PRIMER

Stepper motors convert electrical signals into discrete mechanical rotational movements, and the most common can be divided into two types, hybrid and permanent magnet (PM). Hybrid stepper motors have laminated stators and permanent-magnet rotors. PM motors use stamped stators and radially magnetized permanent-magnet rotors. Modern materials and drivers have closed the performance gap between these two types, but there are differences.

Hybrid motors are typically chosen for applications needing a fine step angle output of 1.8°. They are also more efficient than permanent-magnet (PM) steppers but also carry a higher cost. PM steppers are normally available in step increments from 3.6 to 18° and are inherently more adaptable. They frequently yield a more cost competitive solution and have enjoyed broad acceptance in diverse applications for various medical equipment.

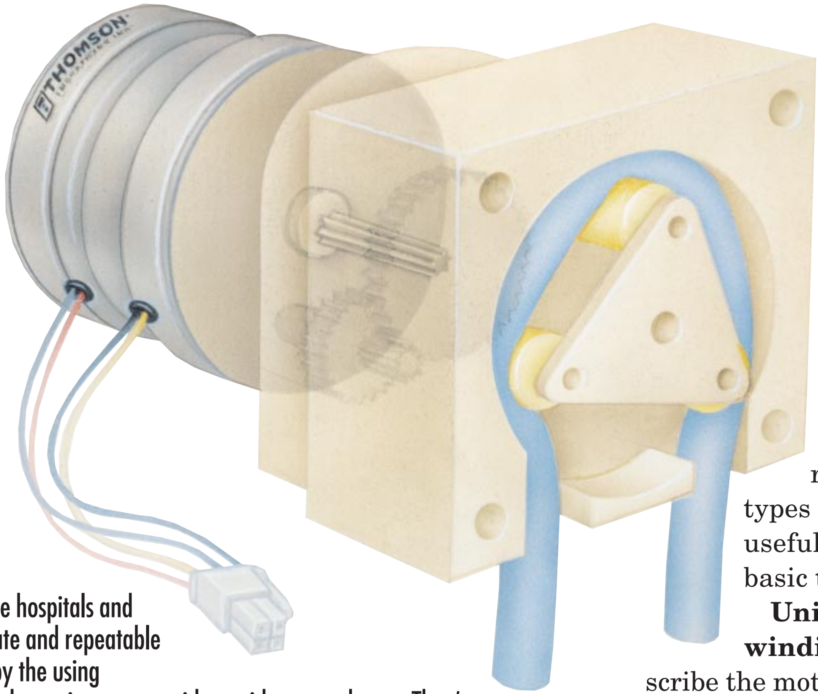
PM steppers typically range in size from 15 to 70 mm in diameter. With the certain gear reductions, the motors can generate output torques of 10 lb-ft or more.

Hybrid and PM steppers are bidirectional, and can be operated over a wide speed range, from incremental to speeds as high as 1,800 rpm, and speeds can be fixed or variable. Control is supplied in the form of programmable electronic inputs. Engineers can change a stepper-motor system's mechanical parameters — including shaft and mounting configurations, gear and pulley arrangements, and entire gearboxes — to meet an application's needs.

It's relatively easy to configure PM steppers for specific application requirements. Designers can tune the coil resistance and inductance to match the drive circuit and available voltage, for example. PM steppers also accept a variety of different types of magnets.

There are also complete libraries of standard and custom parts for designers to draw upon. Application parameters can be quickly analyzed with powerful CAD and engineering software. So with the properly sized frame motor, an optimized interface with the end product can be fitted. This equates to rapid turnaround and shorter development times.

Stepper motors use two basic types of coil windings — unipolar or bipolar — which determine the kind of driver that will be needed. Unipolar coils incorporate



Peristaltic pumps provide hospitals and medical labs with accurate and repeatable pumping performance by the using microprocessor-controlled stepping motors with or without gearboxes. They're used to pump blood for heart-lung machines and kidney dialysis units. By varying the diameter of the tubing or the step rate of the motor, the pump volume and rate can be easily changed and controlled. Various fluids can be processed using the same pump by simply changing the tubes and reprogramming the pump parameters. Nothing but the tube touches the fluid, thus eliminating the risk of cross contamination between the pump and the fluid.

bifilar windings with one center tap common to both coils. The center tap normally is tied to positive voltage. Unipolar circuitry is favored where high-volume programs demand the lowest cost. Bipolar coils contain just one winding each with about the same number of turns found in unipolar coils, but with a larger wire size. This gives bipolar coils about 30% more torque, especially at lower speeds. Because it has no center tap, bipolar coils require additional circuitry to switch direction of the current. This is accomplished cost effectively with modern one-chip drivers.

There are many integrated-circuit driver options for low to mid-volume applications. Engineers can choose between a variety of one or two-chip solutions with advanced features such as PWM (pulse-width-modulation) current limiting, chopper, half-stepping and microstepping.

BASIC TERMINOLOGY

Before engineers select the proper stepper system, they typically determine what work needs to be done, the space constraints, the voltage and current, and the driver types available. But it is also useful to understand some basic terminology.

Unipolar and bipolar windings. These terms describe the motor's coil configuration. It helps determine the appropriate driver to be used. Varying the coil resistance can optimize torque response to best match the driver, voltage and current to be used. A lower resistance can improve performance, but heat generation and duty cycle must be considered to avoid damage to wire insulation.

Torque. Torque, a key parameter in stepper-motor systems, depends on several factors including the step rate, the drive current supplied to the windings, and the driver's design. It can be expressed as detent (or residual), holding, pull-in, or pull-out torque.

Detent or residual torque is the nonenergized torque due to the effects of the permanent-magnet rotor and friction in the bearing system. This is an advantage in many medical applications since it lets a motor hold a load in position even when there's no power to the motor.

Holding torque is that needed to deflect the rotor one full step, and is measured with the motor energized in a standstill condition.

Pull-in torque is produced by a stepper motor started at a fixed step or pulse rate.

It is also called the start-without-error torque, and is typically included on most performance charts. It is often used at the beginning and end of a motor routine to overcome load inertia.

Pull-out torque is produced by a stepper motor after it has reached the operating or running speed. In performance charts this may be referred to as the slew curve, and since it is the actual dynamic torque produced by the motor during operation, it is key to selecting the proper motor for an application.

Magnets. Major torque improvements can be made with the stronger magnets. Upgrading ceramic magnets (of either anisotropic or isotropic forms) to rare-earth materials such as neodymium increases motor performance. And the strength of rare-earth magnets can be adjusted by varying the percentage of fillers used, typically boron, cobalt, or iron. Greater availability of rare-earth materials has recently driven rare-earth magnet prices to competitive levels. However, rare-earth magnets are more susceptible to damage from heat than ceramic magnets.

Step angle. While hybrid motors typically come in step increments of 0.9 to 3.6°, PM steppers range from 3.6 to 18° in a full-step mode. The greater the angle, the fewer steps are needed for the motor shaft to make one revolution. Steppers are most accurate when energized in even numbers of steps. Being noncumulative, step error zeros out every fourth step, or 360 electrical degrees. Half-stepping and microstepping are effective for finer incremental positioning and smooth operation. (Microstepping can let a motor operate in an area of resonance, minimizing or alleviating the need for mechanical damping through added friction or inertia.)

Gearboxes. Gear reductions are available for most PM motor sizes. They let engineers match inertia between motors and applications, increase torque, and create finer step increments than possible with a directly-coupled motor. They can also save space and money by using common drive electronics in multifunction designs. Standard reductions are quickly available, and custom ratios can be developed for volume requirements.

Digital linear actuator. DLAs provide accurate, repeatable incremental linear travel down to 0.0005 in. (full step) with forces up to 30 lb. Travel can be from a few thousandths of an inch to several feet. DLAs have a permanent-magnet rotor, so they can hold position without being energized against loads up to 16 lb. They are a good choice for managing precise amounts of liquid or gas as in syringe pumps and electronic pipettes. They are available in two or four-phase configuration and a voltage range from 5 to 12 Vdc. Package sizes for DLAs range from 26 to 75 mm in diameter. DLAs also feature built in thrust bearings.

Despite the proliferation of solid-state devices and equipment, advancements in technology continue to open new opportunities for incremental motion with stepper motors. Besides medical applications, industries as diverse as office automation, automotive, HVAC, telecommunications, and defense utilize the durable, reliable, and cost-effective steppers in their latest products. ■

Getting up to speed

For those wishing to get up to speed quickly on designing medical products with stepper motors, Thomson Airpax has simplified the process and shortened the learning curve with a preengineered motor/driver kit. It features a microstepping controller IC developed by Allegro Microsystems. The motor-driver board can be used in low-volume designs, while higher volumes might call for the IC to be used in a custom PCB. The kit also contains the necessary interface cable and software. A Windows-friendly program helps engineers select the proper direction, ramp, run, and operation time which can be modified for specific applications. Aside from a PC, laptop, or programmable controller, all that's required is a small power supply.