Benefits of automatic linearity correction (ALC)

Ideal Pipette Linearity

Adjustable air-displacement pipettes are designed to deliver a known, user-defined, volume of liquid with a low percentage of error. For mechanical reasons, pipettes can only deliver samples accurately over a limited range of volumes for each particular pipette. For example, a typical 200 µL pipette has a recommended range of 20 to 200 µL. Ideally, the volume of liquid delivered in that range follows a precise linear relationship to the volume dialed on the micrometer. For example, it is expected that setting a 200 µL pipette at 20.0, 100.0 or 200.0 µL it will dispense 20.0, 100.0 or 200.0 µL, respectively.

Systematic Error Leads to Nonlinear Volume Dispensing

Manual pipettes and most electronic pipettes do not deliver liquid linearly across their volume range. This error does not mean that the pipette is not calibrated or unusable. To the contrary, the pipette may be calibrated and capable of delivering liquid within the manufacturer's specification for error. Figure 1 shows typical non-linear response and the percent error associated with a typical 200 µL pipette.

Automatic Linearity Correction Decreases Error

Rainin recognized that systematic error (nonlinear volume dispensing) occurs in most pipettes. It is associated with the physics involved in moving liquids, which is problematic. Systematic error emanates from tip internal diameter, orifice size, size of the air column, and other factors. These systematic errors can be reduced in electronic pipettes, like Rainin's EDP Plus™ and EDP3™ models, through corrective adjustments programmed into the circuitry that controls their stepper motors (see Rainin Technical Report TR-2001-5 on stepper motors for more detail). This feature, developed and patented by Rainin, is called Automatic Linearity Correction or ALC. The control circuitry is programmed with empirically determined correction factors for various volume settings throughout the pipette volume range. The correction factor adjusts the number of steps that the motor will move, which also moves the piston, drawing more or less liquid into the tip representative of the correction factor.

The pipette then delivers a corrected volume of liquid that better reflects the set volume (see Figure 2) and provides better linearity and accuracy as shown in Figure 1.

Conclusion

Rainin electronic pipettes with Automatic Linearity Correction provide improved accuracy when compared to manual or electronic pipettes without ALC.

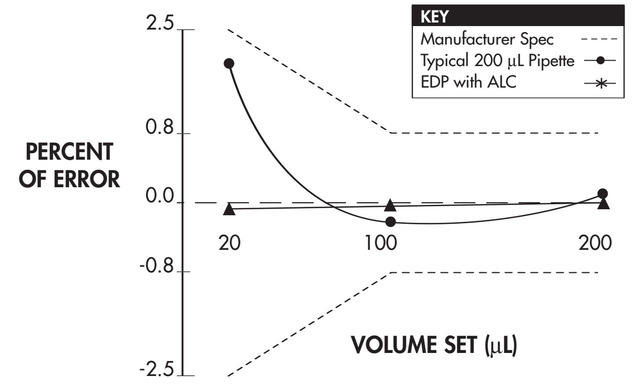

FIGURE 1

	VOLUME SETTINGS		
	20 µL	100 µL	200 µL
TYPICAL VOLUME DELIVERED **BEFORE** ALC	20.4 µL	99.6 µL	200.5 µL
NOMINAL # OF MOTOR STEPS BEFORE ALC (1 STEP= 0.5µL)	40	200	400
ALC CORRECTION FACTOR (IN STEPS)	-1	+1	-1
ACTUAL # OF MOTOR STEPS **AFTER** ALC	39	201	399
ACTUAL VOLUME DELIVERED **AFTER** ALC	19.9 µL	100.1 µL	200 µL

FIGURE 2- SIMPLIFIED THEORETICAL EXAMPLE

Comparison of Rechargeable Pipette Batteries

Anyone who has used a rechargeable flashlight, cell phone, or cordless drill is familiar with the frustration of a battery that is not fully charged. Fortunately, rechargeable battery technologies have greatly improved over the past few years, leading to batteries that hold charge longer and can be reliably recharged more times. Rechargeable batteries are not all alike. Several rechargeable battery technologies are commonly used in small hand-held devices such as electronic pipettes. Table 1 compares the properties of several rechargeable batteries.

Nickel Cadmium

One of the oldest and most well understood is the Nickel Cadmium (NiCd) battery used in Rainin's original EDP™ and EDP Plus™ electronic pipettes. NiCd batteries have a long life, when properly maintained, and are capable of delivering a high current. However, they are heavy, lose their charge over time while stored, and are susceptible to a charging-discharging phenomenon often referred to as "memory effect". If the battery is frequently left on a charger and not completely discharged regularly, the battery will not completely charge to capacity. This memory effect will continue to worsen over time requiring more frequent recharging. For many sporadic applications, such as pipetting, the memory effect creates problems because regular maintenance (complete discharge) is easily forgotten. While Table 1 shows NiCd as having the highest Theoretical Cycle Life (number of recharge cycles), this is rarely, if ever, achieved because of the maintenance issues.

Nickel Metal Hydride

Nickel Metal Hydride (NiMH) batteries have gained popularity during the last few years because they have a high energy density, are capable of delivering modest current and have an average life span. NiMH batteries are also heavy and are limited by a high self-discharge rate. While a mild memory effect exists, regular maintenance can be delayed much longer than with NiCd batteries. Theoretical Cycle Life as displayed in Table 1 is, like NiCd, difficult to achieve in actual use because battery maintenance (complete discharge), again, is a consideration.

Lithium Ion

Lithium Ion (Li-Ion) batteries, used in Rainin's EDP3™ electronic pipettes, are finding widespread utilization in many applications because they are light, provide high energy density, hold charge well over time, have a longer life and require little or no maintenance. This is the key reason they are found in most cell phones today as well as precision electronic pipettes. While very early Li-Ion batteries were susceptible to damage from over-charging, the past few generations of Li-Ion batteries, including the EDP3™ battery, have control circuitry built into them to eliminate that risk. Hence, the Theoretical Cycle Life for Li-Ion numbers listed in Table 1, while similar to the other types of batteries shown, are, unlike the others, very easily achieved by the end user. Therefore, in the absolute sense, Li-Ion batteries are vastly superior in actual use as also seen in Table 1.

Conclusion

Lithium Ion batteries are the best batteries to use for electronic pipettes when reliability, light weight and ease of maintenance are of paramount concern to the researcher or laboratory manager.

Table 1: A Comparison of Rechargeable Batteries

	NiCd	NiMH	Li-Ion
Energy Capacity/Weight (Watt-hours/Kilogram)	40-60	60-80	100
Theoretical Cycle Life (# of Recharges)	1000-1500	500-1000	500-1000
Cycle Life Typically Achieved in Actual Use	400-900	300-800	500-1000
Charging Issues Memory Effect	High	Low-Modest	Insignificant
Maintenance Frequency (Full Discharge) for Maximum Life	30 days	90 days	Not required
Self-Discharge per Month	20%	30%	10%

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Advantages of Stepper Motors in Electronic Pipettes

Electronic pipettes rely on two types of electromagnetic motors as their source for moving their pistons: direct current (DC) or stepper. While each of these motors follows the same electromagnetic properties, they operate in distinctly different ways. This paper explains the basic operating principle of each motor and the advantages and disadvantages of each with respect to electronic pipettes.

STEPPER VERSUS DC MOTOR TECHNOLOGIES

Stepper Motor Concepts

Stepper motors operate in a very simple manner: a central rotor with fixed magnetic poles is placed between electromagnetic end-pieces, known as stators. The stators (see Figure 1) are individually switched off and on with N or S bias in a defined order. The N and S polarization is dependent upon the direction that the current flows through the electromagnet. Properly sequenced switching of the stators' polarization precisely moves the rotor to the corresponding stator at a controlled speed. Hence, stepper motors have both positional and speed control built into their drive mechanism. In effect, the rotor takes a precise, defined "step" to the next position as needed. Simply put, finer control of the rotor is possible by increasing the number of stators as in Figure 2.

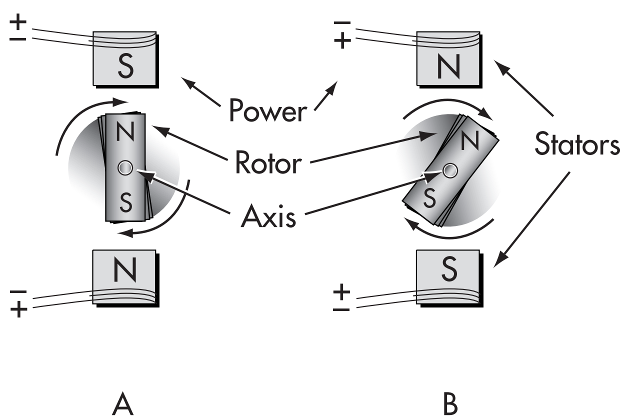

FIGURE 1- STEPPER MOTOR SEQUENCE

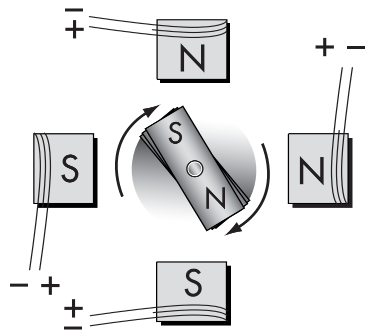

FIGURE 2- MULTIPLE STATORS

Stepper motors are simple devices. However, electronic circuitry is required to control and drive the stepper motor because each stator must be switched on and off with a set polarity in a very defined sequence if smooth motor motion is desired. Fortunately, many circuits, powerful batteries, and motors now exist to do this and have been "micro-sized" to fit within the confines of a pipette.

As the circuit that controls the stepper motor has two very convenient advantages – outstanding position and speed control – the motor can be directly attached to a linear actuator to drive a piston in precise increments. Thus, the control circuitry can be programmed to compensate for a number of additional properties encountered in any given use. An excellent application of this capability accounts for the accuracy of an EDP3™ Rainin electronic pipette with Automatic Linearity Correction (see Rainin Technical Report TR-2001-3 on ALC for more detail). ALC is a control circuit program that compensates for non-linear dispensing across a wide range of volumes.

DC Motor Concepts

Direct current (DC) motors predate stepper motors in widespread applications because they are simple to operate and do not rely upon a control circuit. Simply attach a DC power supply to the DC motor and it will run. However, precisely controlling the motion, speed and position of DC motors is difficult. DC motors do not make finite steps and need additional components to control speed. Instead of controlling the rotor's movement from stator to stator in finite steps, the DC motor spins or doesn't spin. It lacks the inherent position and speed control of the stepper motor.

Like a stepper motor, DC motors have stators and rotors. Unlike a stepper motor however, the rotor motion does not follow stators that are sequentially magnetized. Instead, the stators are fixed magnets. When current is supplied to wire coils that are wrapped around the ends of the rotor, a magnetic field is created, causing the rotor to move. Figure 3 shows the basic parts of a simple DC motor.

Disadvantages of DC Motors

As mentioned above, DC motors do not have inherent positional control. Hence, optical sensors are often added on to determine the position of the rotor. Optical sensors may malfunction because of dust or wear particles created by the mechanical braking system. This can have a negative effect on achieving the accuracy and precision of piston movement required in an application like pipetting.

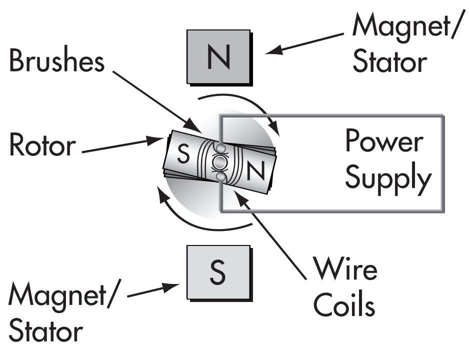

FIGURE 3- DC MOTOR

DC motors also lack the braking control of stepper motors. A stepper motor can be stopped rapidly and held firmly when the switching pulse stops and allows the rotor to orient itself in a set position. DC motors however, must incorporate additional mechanisms, such as gearing, clutches, and a solenoid brake to control speed and stop the rotor in desired positions (see Figure 4). These additional components increase the mechanical complexity of the system and are susceptible to wear and tear. Thus, the reliability of the DC motor system is frequently an issue.

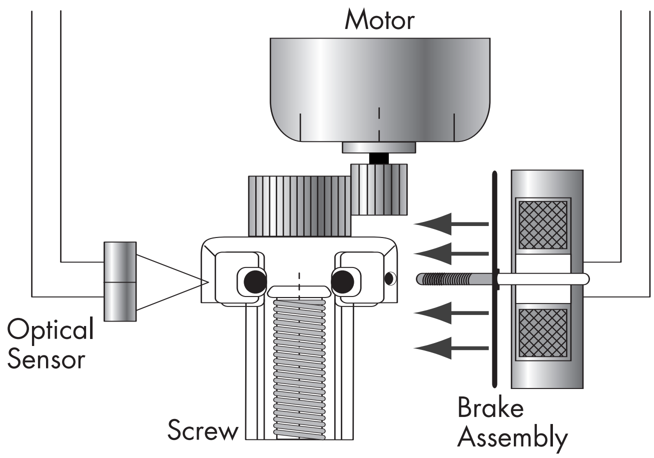

FIGURE 4- MECHANISMS OF A DC MOTOR SYSTEM

Conclusion

DC Motor System:

A DC motor system requires a DC motor, optical sensor, and mechanical braking components. The mechanical braking system is subject to wear, and the optical sensor can malfunction from dust or wear particles. This can reduce reliability, accuracy, and precision.

Stepper Motor System:

A modern stepper motor system consists of the motor itself and the electronic circuitry required to automatically brake motor rotation and control position. Therefore, stepper motors are better suited for use in electronic pipettes than DC motors particularly when accuracy, precision and reliability are required.