

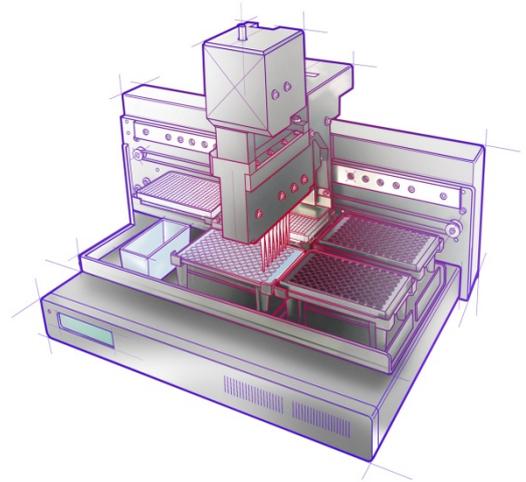
## Motion in Medical Analyzers

*Smaller, Faster, Stronger. How miniature motors are helping diagnostic equipment move forward.*

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Medical diagnostics are a part of everyday life, whether going to the doctor for a routine physical and blood work or heading to the emergency room. Doctors rely on the results from medical analyzers to inform us of changes in our body or administer life-saving medicine. The accuracy and speed of the analysis is critical for these machines and the responsibility for this falls on the motion control in the machine.

A medical diagnostic machine takes a sample and analyzes it for a variety of items or a specific item. The sample travels through various stages of the machine from preparation to final analysis, utilizing motion control in all of the functions. The test tube (or well) must move into position for the sample to be drawn. A needle is lowered down into the test tube (or well) to draw out the sample and reagents are then added to the sample. Motors control all of this motion and we will talk about the specifics of each of these applications.



### I Main Motion Functions in Medical Analyzer.

Samples reside in test tubes (or wells), placed in trays that can hold up to 96 tubes or wells up to 1,024. The tray is loaded into the sample preparation stage and the contents of each tube are loaded into the computer or identified by a bar code label on the test tube. Conveyors or linear stages move the pipette into position for the sample to be collected. Since the test tubes are small in diameter, the precision of the movement is critical for the sample to be taken quickly. The faster the sample is processed through the machine, the quicker the results can be provided to the doctor.

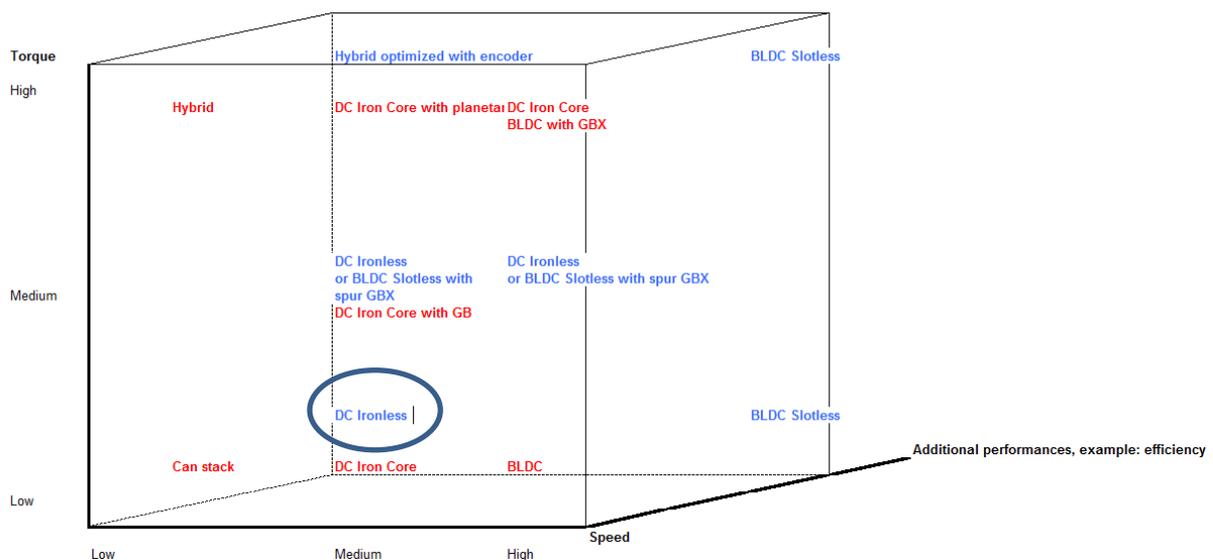
Once the pipette is in position for the sample to be drawn, it moves down into the test tube (or well) to draw the sample. In many machines, multiple pipettes operate at the same time. The movement required by the pipette is linear, driving the pipette downward and then pulling it back up to its starting position. Proper timing is required as the pipette must reach the proper depth in the sample to draw the required amount, plus wait in position for the sample draw to be completed.

With the sample drawn, the next step is the analysis. Analyzing the sample involves introducing reagents via pumping or pipetting operations. The pumps used range from peristaltic to syringe, depending on the requirements of the sample. Once the analysis is completed, the sample and any additional waste must be removed from the system. Again this is achieved via a pumping or pipetting operation.

## II Technical Specifications for Each Axis

We will now take a look at the technical specifications for each of the functions. As mentioned above, different types of pumps are utilized throughout medical analyzers. The pumps are defined by their flow and volume capacity and are selected based on the needs for each function. A motor, typically Brush DC, Brushless DC or Stepper, provides the mechanical power to operate the pump. Motor selection is based on several criteria:

- Technical specifications – torque at speed, efficiency, noise
- Life required for the application
- Cost

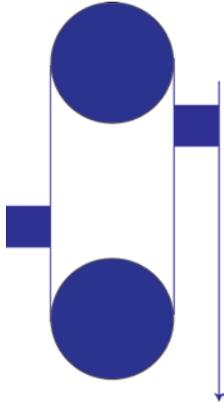


Pump OEMs can interchange the motor technology to tailor the pump to the specific axis requirement. Long life marries well to brushless technology and steppers. Since multiple pumps can be used in a medical analyzer, you can see all three motor technologies on pumps throughout the machine

The pipette motion, or Z axis, has to be fast and accurate. A high force can also be required either to perforate a cap on the sample or to clip a needle tip. Space is at a premium for this axis as multiple pipettes can be grouped together to gather samples simultaneously. Since the volume of the sample is critical for the analysis, the motion accuracy is confirmed via an encoder. The motion is accomplished using a belt system, rack and pinion or a leadscrew. Speed of the motor is important, so higher speed motors such as disc magnet steppers or brushless slotless dc motors are used.

If the space for the pipette drive is limited, the objective is to optimize the performance of the actuator. In this case, the design engineer will design the motor winding for high speed operation, maximizing the power even if a gearbox is required. The maximum continuous torque that a motor can deliver is related to the technology selected, but is also dependant on its size. So to have the smallest motor package size, it is better to create the mechanical power by using speed and not torque.

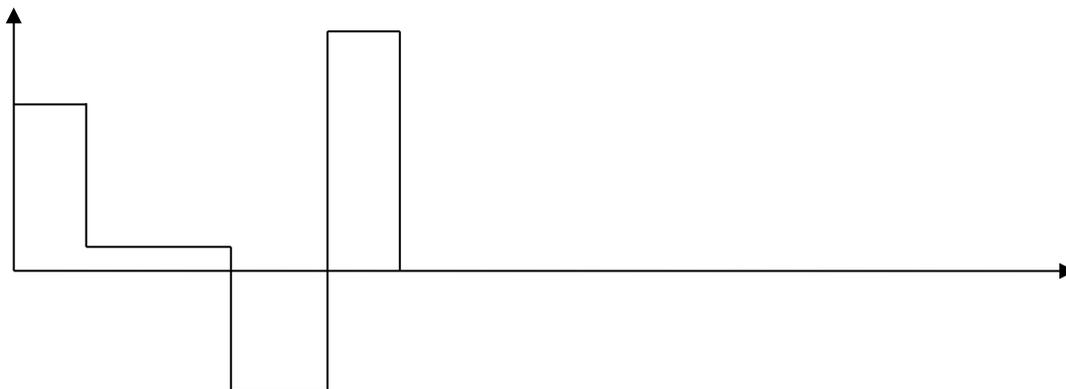
A typical example of a needle application for Z motion:



Typical characteristics:

- Displacement - 0.2 m
- Time to move up or down - 1 second
- Mass (By design the weight is balanced to eliminate the gravity effect) - 0.2 kg
- Force to hold when needle is down - 5N during 1 sec
- Radius of the pulley - 4 mm

Torque versus time



Such an application requires to hold a peak torque,  $15 \times 10^{-3}$  Nm at stall, and to be able to deliver torque for acceleration and deceleration (friction is low). If we consider the torque to hold the position equal to the torque to accelerate, then the acceleration will be  $50 \text{ m/s}^2$ . If the average speed is 0.2 m/s, the acceleration time is 4ms; therefore we can consider a trapezoidal motion profile.

We need a motor able to deliver a peak torque of 20 mNm and a peak speed of  $(0.2\text{m/s})/(4^{-3}\text{m}) = 50 \text{ rad/s}$  .

To find the smallest design, we will select a gear-motor as we will create the mechanical power with more speed than torque as the torque is linked to motor size.

*Gearbox selection:*

The gearbox ratio is selected by its highest input speed, for a small gearbox the peak speed ranges from 7,500 to 10,000 rpm.

Considering 7,500 rpm, the optimum gear ratio will be:  $785 \text{ rad/s} / 50 \text{ rad/s} = 16$

The efficiency of such a ratio, requiring probably 2 stacks, will be 85%.  
Therefore, the motor should deliver a torque of:  $20 \text{ mNm} / (16 * 0.85) = 1.5 \text{ mNm}$   
In this case we can use either a 8 mm DC brush motor or a 8 mm BLDC motor combined with a 8 mm planetary gearbox.

In case the motor size is not an issue, we could consider a stepper direct drive.  
In this case the torque is 20 mNm and peak speed  $50 \text{ rad/sec} = 477 \text{ rpm}$ .  
A NEMA 17 hybrid will easily do the work.

The movement of the sample to position for withdrawal is handled by a gantry system. Up to now, we have seen that the motors selected were according to the experiences of the engineering team. Typical selection includes hybrid step motors run in open loop (no feedback). But this solution has speed limitations, reaching only 1,000 RPM. For faster movement, a closed loop system using either a Brush DC or Brushless DC motor is applied. Brushless DC motors provide a longer lifetime, making them a better choice for long life requirements.

### III Medical Analyzer Trend

Medical analyzers target is to reduce the amount of time it takes to complete the analysis, without affecting the quality of the analysis. The objective is to increase the throughput, or number of samples analyzed per hour, by dealing with more samples simultaneously. The motion components of the analyzer have a direct impact on that capability and we will review the trends for each axis of motion.

For the pipette motion, the trend is to have more pipettes moving simultaneously. To accomplish this, the pipettes need to be closer to each other than in current designs. The requirements for moving the pipettes up and down are the same so the same motion must be accomplished using a smaller diameter motor. The motor speed therefore increases, as well as the accuracy.

Thanks to new magnet technology available today, the output of the motor can be maintained with a drastic reduction in diameter. Neodymium magnets can achieve a power of 50 MGoe, far exceeding the energy content previously available. A current application using a 16 mm Brushless motor can now be driven by an 8 mm diameter motor. Also, disc magnet technology has the advantage of low inertia, allowing the

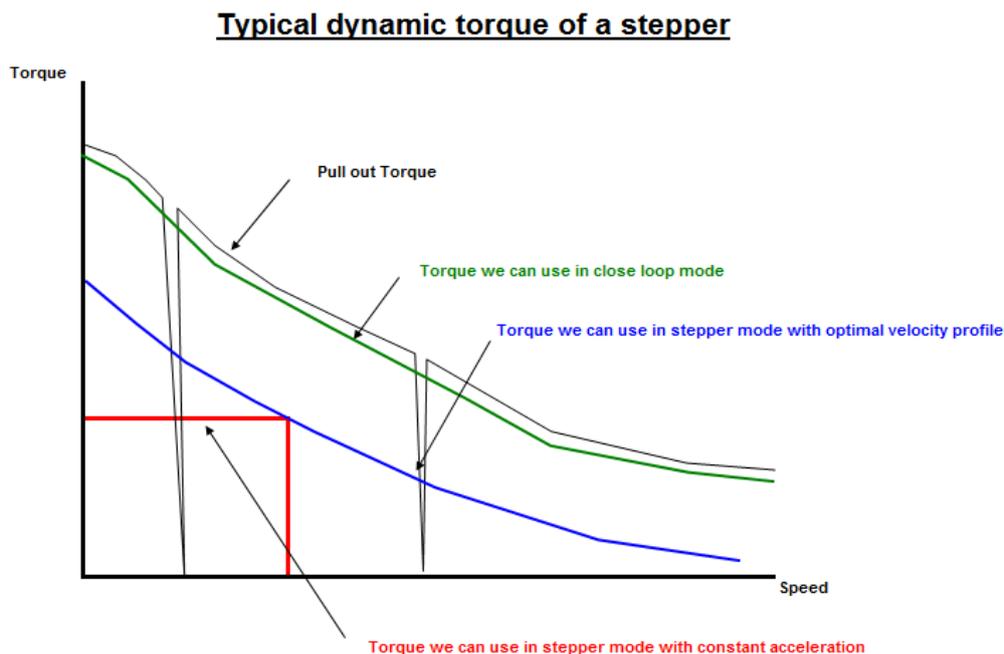
motor to stop quickly and avoid issues due to ringing. A direct drive solution can be achieved with the disc magnet stepper in this manner.

New encoder technology, such as the magneto-resistive encoder, offers high resolution in a small package. You can achieve up to 512 lines in an 8 mm diameter package. This allows the loop to be closed for position feedback and accuracy.

Another trend is for faster movements with higher accuracy. We do see a big trend to use stepper motors driven in closed loop mode. For applications where high torque is needed up to 2,000 – 3,000 rpm, closed loop steppers are a cost effective solution. For instance, any existing design using open loop steppers could increase the performances by 30% by adding an encoder.

The graph below demonstrates the dynamic torque we can use during the motion when:

- 1) The motor is driven as a stepper with an optimum velocity profile
- 2) The motor is driven as a stepper with standard profile using constant acceleration
- 3) The motor is driven in close loop

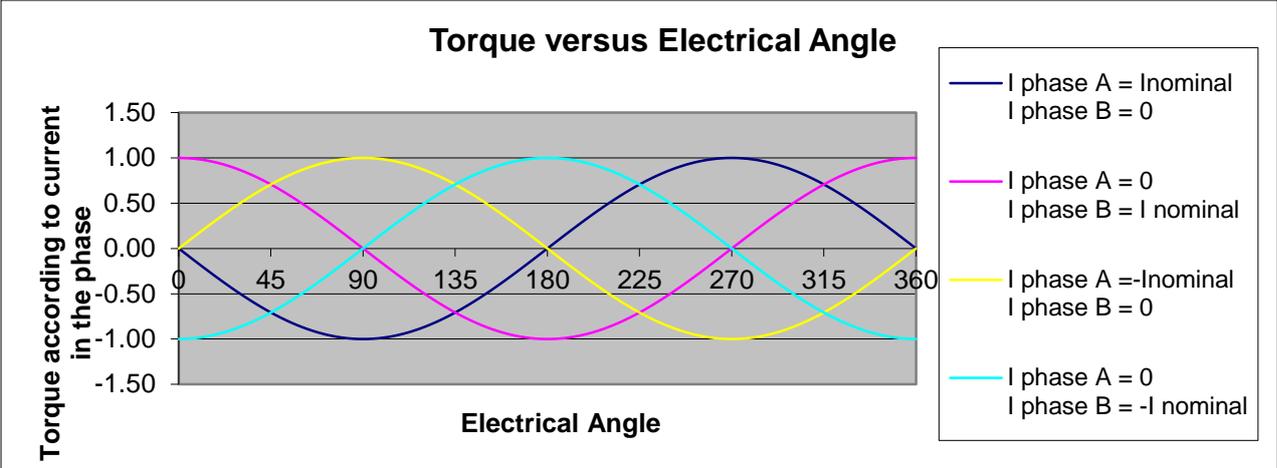


We can immediately see the benefit to drive the stepper as a servo – increased torque over the entire speed range

When holding a position after motion, the position is kept by either closing the loop or going back to stepper mode. The stepping mode has big advantage at position - it provides high stiffness which would be difficult to have by driving the motor in closed loop.

The figure below shows the static torque you can get with a stepper. For instance, a stepper motor having a holding torque of 1 Nm and 200 steps/revolution (meaning a torque constant having a periodicity of 50 per revolution) will present a stiffness

around zero torque of: Holding torque X Number of period per rev = 50 Nm / rad. To get the same stiffness in a BLDC closed loop system will require a high gain which could make the design unstable.



IV **Conclusion**

The trend in medical analyzers is to go smaller and faster with higher accuracy. Motor technologies help machine designers move in that direction. New magnets allow motor designs to be smaller and stronger. Advances in electronic component technology increase the resolution while reducing the package size. New materials such as MIM and CIM increases the torque output of gearboxes in a smaller package. Micro controllers allow driving a stepper like a servomotor, allowing increased torque over their speed range. As we saw, there is no universal motor technology. There are a several motor technologies, each with their own benefits, allowing machine designers the flexibility to make their machines smaller and faster.

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Dr. Norbert Veignat, Ph.D.  
 Dave Beckstoffer  
 Portescap  
[www.portescap.com](http://www.portescap.com)