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Selecting Miniature Motors for your Medical Devices

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Selecting Miniature Motors for your Medical Device:

Recent advances increase portability, efficiency and reliability

The creation of small, portable infusion pumps opened a new chapter in medical care. A patient can receive carefully metered and timed doses of medicine, without requiring a visit to the medical practitioner, allowing life to be less restrictive. Ambulatory pumps have been developed to deliver insulin, nutritive supplements and anti-cancer drugs.

Medical equipment such as this demands extremely high reliability — any failure obviously being unacceptable — so during the design phase it's important to take into account the complete system: the pump itself, the motor, the driver, the feedback, etc. Miniaturization is crucial, for convenience to the user, especially with portable equipment. The patient should not be disturbed by the pump noise, either at rest or in social surroundings. For this reason, portable battery-powered pumps need a very efficient and quiet motor. When choosing a DC motor type, there are numerous advantages and disadvantages depending on which technology you choose, whether it be Brush DC, Brushless DC, or Stepper technologies.

In this paper, we will use a small syringe pump as an example. A typical design, illustrated below [Fig 1], is a piston moved by a lead screw, the screw or the nut driven with a micro-motor.

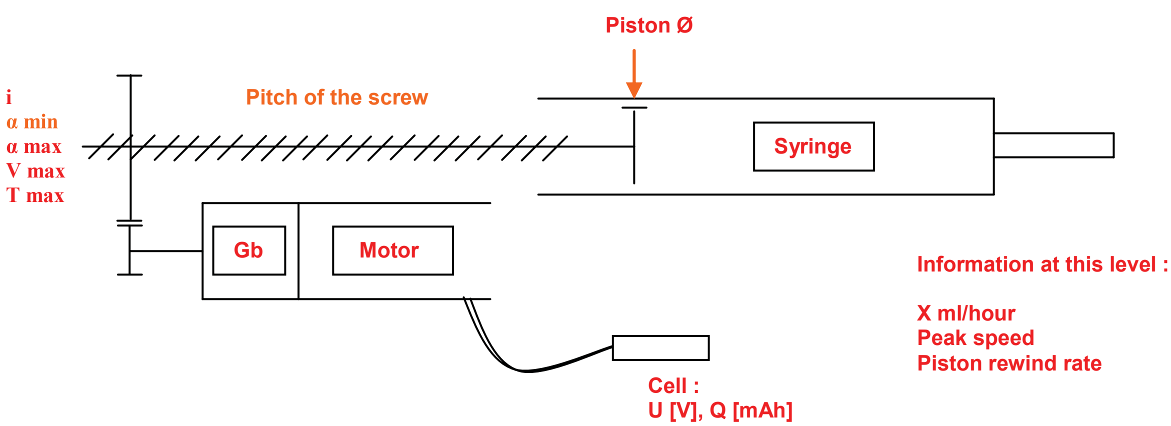

Figure 1- Typical Design of Syringe Pump

Miniature Motor Technologies

Miniature motors used in medical pumps have very specific requirements. To select the electrical motor the design engineer has the choice of different technologies; nevertheless, the primary motor function is to convert electrical power into mechanical power. The goals of the motor are to:

- Deliver a specified torque
- Move a specified angle in a given time
- Be very quiet
- Be as small as possible
- Be very efficient

Today's design engineers have the choice between three major technologies:

- DC ironless motor mounted on a gearbox and an encoder.

- Brushless motor with a gearbox and sometimes an encoder.

- Stepper motor, either direct drive or with a gearbox, and sometimes an encoder.

The designer will select the solution, mostly depending on his experience and background, as the three options can fulfil the same job in the pump. Each of these technologies presents some advantages and disadvantages, as described in the following table [Fig 2] and motor technology sections:

	Brushed DC Motor	Brushless DC Motor	Stepper Motor
Advantages	Best efficiency	Open loop at low speed. Closed loop at high speed	Electronics are simple because usually driven in open loop. One step, one basal increment
	Simple to use	Long life	Long life
	Needs gearbox + encoder	Needs gearbox + sensors	Needs gearbox + sensors
Disadvantages	Need an encoder	Lower efficiency	Complex electronics to manage both open and closed loop mode
	Close the position loop	In principle, bigger Ø than DC solution	
	Commutation wear		

Figure 2- Motor Technology Comparison

The Brush DC Motor

Brush-type motors fall into one of two sub-categories — the iron core and the ironless design [Fig 3]. The latter is usually selected for battery-operated portable pump applications because it has no iron losses. With a DC ironless motor, the majority of the losses are due to the copper losses, which are proportional to the coil resistance (copper volume) but also to the current squared in the motor. The current in the motor is proportional to the motor torque.

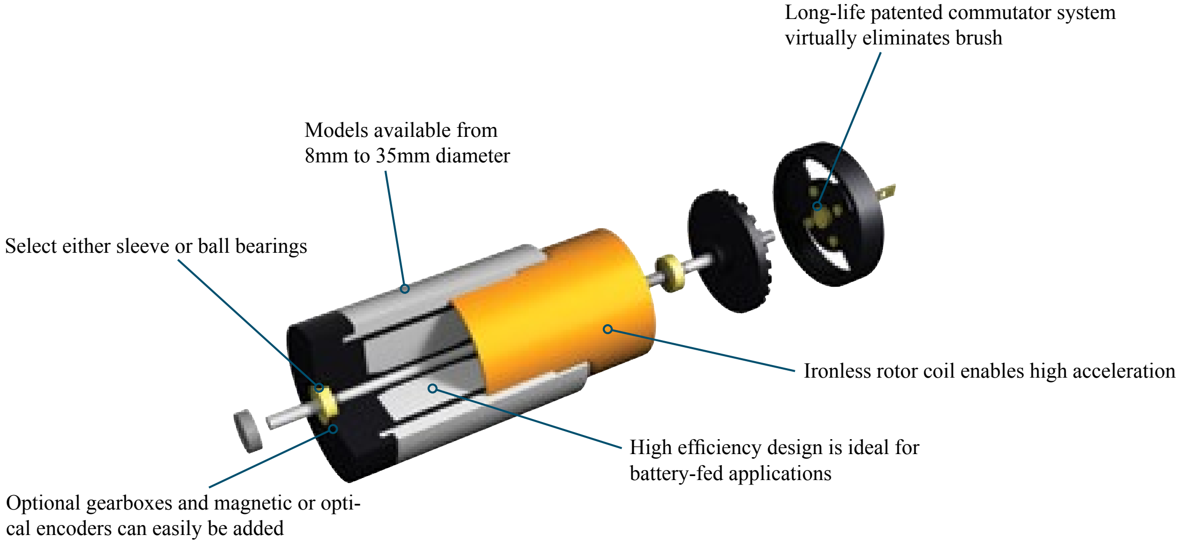

Figure 3- DC Ironless Core motor design and features

System efficiency must be optimized for a battery application. Precious metal commutation allows motor efficiencies up to 90%. Usually R/k2, which represents the power lost by joule effect in the winding, is an excellent figure of merit to compare a motor versus another. For a given size of motor, this figure is more or less constant — adjusting the winding to the battery doesn't change this parameter. However, if the choice arises, choose the motor having the smallest possible R/k2 ratio. It will offer a better efficiency. Additionally, while motor diameter is in principle defined by the customer and the application, the larger the motor is, the smaller the joule losses will be for a given torque.

The mechanical power is the torque multiplied by the speed. Intuitively, the best way to increase the efficiency of the motor is to get the power needed while running the motor at high speed. For the same mechanical power, the higher the speed is, the lower the necessary torque and the joule losses will be. New magnet technology has helped today's DC ironless motors achieve higher torque than ever before. [Fig 4]

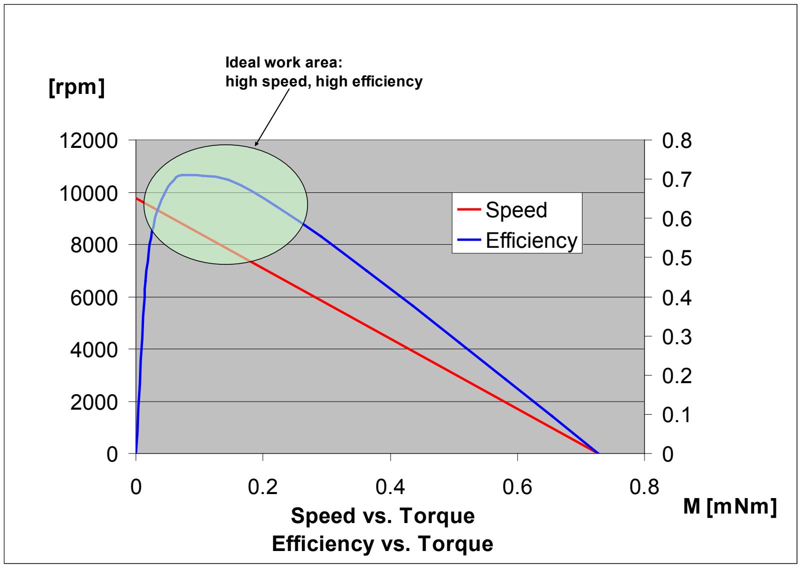

Figure 4- Example of Speed and Efficiency versus Torque for a 8mm DC motor, U=3V

Ironless motors also have a very low inductance and a commutation with small contact surface and pressure, resulting in a small electrical resistance and a very small friction.

Remember: A DC ironless motor with precious metal brushes will have a higher efficiency at high speed. For a given frame size, the torque versus speed and efficiency are roughly equivalent whatever the coil impedance is. A bigger motor has less iron loss than a smaller motor for the same torque output.

The Brushless DC Motor

A DC motor's life depends on its bearings and the brushes. With the introduction of the brushless motor, this dependency was reduced to the bearing life, which in some applications is a strong advantage. In a BLDC motor the coils are fixed and the magnet is part of the rotor. Commutation in the coils is done electronically. Usually the external tube closing the magnetic field of the magnet is fixed, generating iron losses while the magnet is rotating. In applications where inertia is not critical, the tube and the magnet can rotate together, removing iron losses. [Fig 5]

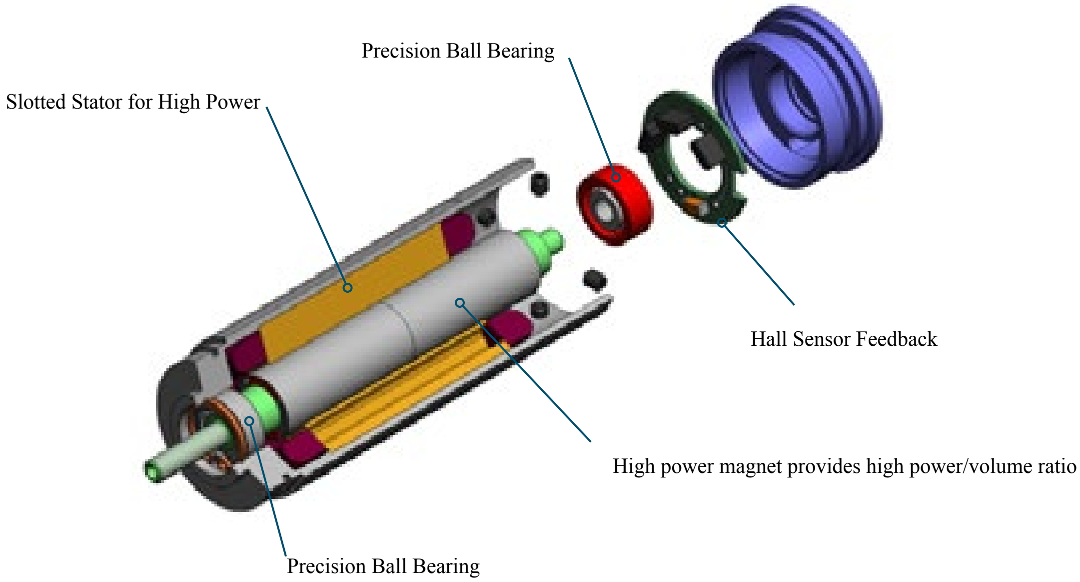

Figure 5- Brushless DC motor design and features

As with the brushed motor, The BLDC motor falls into one of two categories, the slotless and the slotted design. The slotless design has the advantage of no cogging or detent torque, and to have less iron loss than a slotted design. Slotted design motors are typically employed in tough environments, as when the product requires autoclave sterilization. New high energy magnets are making slotless design the preference in small motors.

The disadvantages of the traditional BLDC motor versus a DC ironless motor lie in its lower efficiency due to iron losses, and lower torque for the same size unit. One way to compensate for the losses is to use the BLDC motor at higher speeds, taking into account this parameter when selecting a gearbox.

A BLDC's driver and controller are critical to the efficiency of the system. There are several ways to drive the BLDC motor:

- Drive the motor as a stepper with an open loop, wherein the current in the phase is linked not to the real rotor position but rather to a theoretical rotor position.
- Drive the motor sensor less by using the EMF of each phase as information to commutate current in the phases. Such a technique offers the advantage of working with no position feedback, but the disadvantage of working only when the rotor is moving, such that it doesn't function well at low speed.
- Drive the motor as a servo motor by using a position sensor to commutate the phases.

For a small medical pump, one can drive such a stepper at low speed and a BLDC at higher speed.

The Stepper Motor

By definition, a stepper motor is a BLDC with many poles; thus, the current in each phase will have to be commuted many times per revolution. For instance, a 2-phase stepper having 100 steps/revolution will need 25 current reversions in each phase to make one full revolution. This design has the strong advantage of having many stable positions (steps) per revolution, providing a high torque for a given size (versus regular BLDC or DC motor). The disadvantage of a stepper is that it is not able to run at high speed, due to the inductance combined with the commutation frequency, and due to iron losses (current reversed so many times).

Different technologies of stepper motors are available:

- Variable reluctance
- Permanent magnet (Can Stack)
- Hybrid
- Disc magnet technology (TurboDisc)

For battery applications, the Disc Magnet technology [Fig 6] is best, as it carries lower inertia and iron losses than other steppers, resulting in higher efficiency.

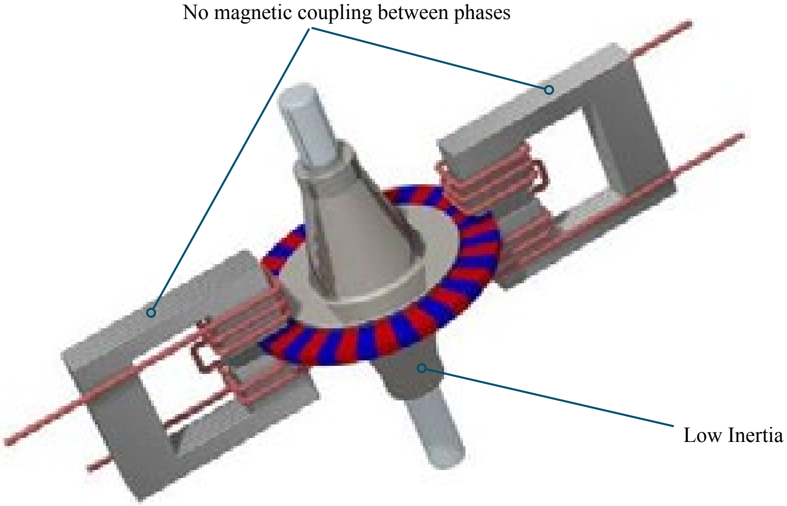

Figure 6- Disc Magnet Technology

As with the BLDC motor, stepper motors can be driven in different ways:

- Open loop in full step, half step or micro stepping mode. In this case, no position information is needed — the rotor follows the magnetic flux generated by the coils. A linear combination of current in each phase allows micro-stepping. A big disadvantage is that with no position feedback, the security is ensured only by providing more torque or current than needed.
- Closed commutation loop like a servo motor. The advantage here is high torque at low speed, while the disadvantage is higher losses and non-linear behavior at high speed (i.e. torque versus speed).

For small portable pumps, stepper motors are the primary selection, if at low speed, they can be used in full step mode, and the detent torque is sufficient to hold the load. In this case, they are driven like a watch motor — the right quantity of energy is delivered to move one step to the next, while at stall position no current is applied in the phase. At high speeds, there are two options: either the motor has to run at high speed intermittently (syringe change) then driven as a regular stepper; or the motor needs to operate many times at high speed, increasing efficiency by closing the commutation loop like a regular servo motor (thereby adding position feedback).

In some applications, a stepper solution with a gearbox may be the most economical design, since no encoder is required. In addition, at stall position no energy will be needed if the detent torque is strong enough to maintain the position.

Gearboxes and encoders

As mentioned earlier, a DC motor operating at high speed often requires a gearbox between the motor and the application. Different styles of gearboxes are available, including types with planetary or spur gears, and units

with belt drives. Gearboxes are defined (for a given frame size) by the output torque needed, the gear ratio and efficiency desired. A spur gearbox has a better efficiency than a planetary gearbox for a given size and gear ratio, but a planetary system will be able to handle a stronger torque.

During the optimization phase, it's very important to take into account the system efficiency. The motor itself will present the highest efficiency at high speed, but higher speeds require a gearbox with a larger gear ratio. The higher the gear ratio, lower the gearbox efficiency. The designer will have to select the best compromise between them.

An encoder, important for closing the position loop, is defined by its resolution and its efficiency. Different options exist, such as optical, magnetic with hall sensor and magnetic with magneto-resistance. Today the trend is to use the latter, with the advantage of providing an extremely high resolution in a tiny package. Dedicated ASICs used in such encoders are able to interpolate two sine-shaped signals in quadrature. Again, the design engineer will have to make sure the resolution and efficiency are correct.

Summary

No universal technology solves all applications, but for each situation, there are some solutions with various advantages and disadvantages. To optimize a solution with specific criteria requires much expertise and access to different technologies. Thus, during the design phase, project engineers should work closely with mechanical specialists, motor experts and electronic designers in order to take into account the entire system and not just a part of it.

Portescap Solutions and Expertise When Selecting A Motor for Medical Pumps

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Available Portescap solutions:

For the DC products, we can suggest our new DC motor family using the high energy neodymium magnet technology and outstanding brush commutation. Our newest technologies, the 16N88(16mm frame size) and 22N88(22mm frame size) products delivering 40% more efficiency, 20% more torque, and 100% longer life time versus the previous motor generation, in the same working conditions would be good choices.

For applications such as portable infusion pumps that are constrained for space, our recommendation would be the 08G (8mm frame size) brush DC series. They are noiseless, highly efficient, thus give long life for battery run applications. Portescap continues the innovation for such applications through its dedicated product development effort in platform projects such as high power density coreless brush DC motors in the size range of 12 thru 22 mm and improved commutation longer life motors in the 8mm frame size.

Portescap,

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For the Brushless DC technology, Portescap suggests our new nuvoDisc motor family. This revolutionary flat brushless DC motor has a very high efficiency and is ideal for space limited applications such as pumps and respirators.

Portescap can also offer a third solution: The TurboDisc technology. This motor family represents an enhanced stepper motor owning the unique disc magnet technology initiated by Portescap in the 1980's. The first strength of this technology is the quick acceleration in open loop thanks to the high torque constant and low rotor inertia. The second advantage of this family is the high step resolution, compared to other stepper technologies. The TurboDisc is well suited for microstepping, allowing further increases in step resolution. The third advantage lies in the high speed capability, able to reach speeds up to 10,000 RPM. Considering medical pumps, Portescap recommends the P010 and P110, 10 and 16 mm size.

For high torque applications, Portescap has developed a special gearbox family that can be adapted to its entire product panel. At that point, we would suggest the new R08, the R16 planetary gearboxes and the B16 spur gearbox dedicated for medical solutions.

In addition to that, for incremental positioning applications, those motors can be driven in close loop with the new Portescap MR Encoder available in size 12 through 22 mm for coreless Brush DC motors and can reach 512 lines per revolution. The new Portescap MR2 encoders provide better accuracy and higher line counts than standard encoders available in the market place. Due to the ease of integration these encoders aid in reducing the size of the motor-encoder package while rendering high resolution and accuracy. They can be integrated across our product line offerings of Brush DC, BLDC and steppers.

Portescap products, specifications & contact information can be found by visiting our website at www.portescap.com.