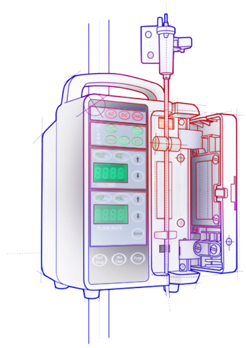
Portescap

WHITE PAPER

EVERY DROP COUNTS: DESIGNING MOTORS TO OPTIMIZE HOME AND AMBULATORY INFUSION PUMPS

by Brandon Steinberg



Hospital Infusion Pump

Ambulatory/Home Infusion Pump

To reduce total cost of care, healthcare providers are increasingly turning toward home and ambulatory infusion pumps to free the patient from the hospital setting. These small, battery powered pumps save thousands of dollars in hospital room and nursing care costs. They also allow the patient to continue therapy while leading a more normal life in the comfort of the home or on-the-go. Even within the hospital setting, patients and nurses benefit from the mobility that these smaller pumps provide.

The challenge for a home and ambulatory infusion pump designer is to create pumps that provide mobility and patient comfort while not sacrificing any quality of care. Furthermore, the industry faces strong cost pressure, especially in the home market due to lower or non-existent insurance reimbursement.

Design Challenges

MOBILITY

Traditional bedside hospital pumps remain stationary and often use large and inefficient hybrid stepper motors. Hybrid stepper motors are sufficient in this application because they offer a cost-effective option to achieve the high torque required, and their size and power requirements are not prohibitive because the pumps do not move and primarily remain connected to wall power. In contrast, home and ambulatory infusion pumps are carried on the patient or on a wheeled pole, and therefore often use higher power density and more efficient Coreless DC brushed motors. This allows for a smaller motor and battery to create a much lighter and more compact pump that operates longer between charges. Both are critical for providing freedom to patients that want to resume normal activities.

Figure 1: Miniature Motor Technology Size Comparison

Custom integration of the motor into the pump casing can also greatly reduce pump size. For example, if the motor is in-line with the pump axle, the motor shaft can be made long enough to double as the pump axle itself, eliminating the price and complexity of multiple mechanical components. Custom connectors and mountings can also help the motor more seamlessly fit the pump design and save valuable space.

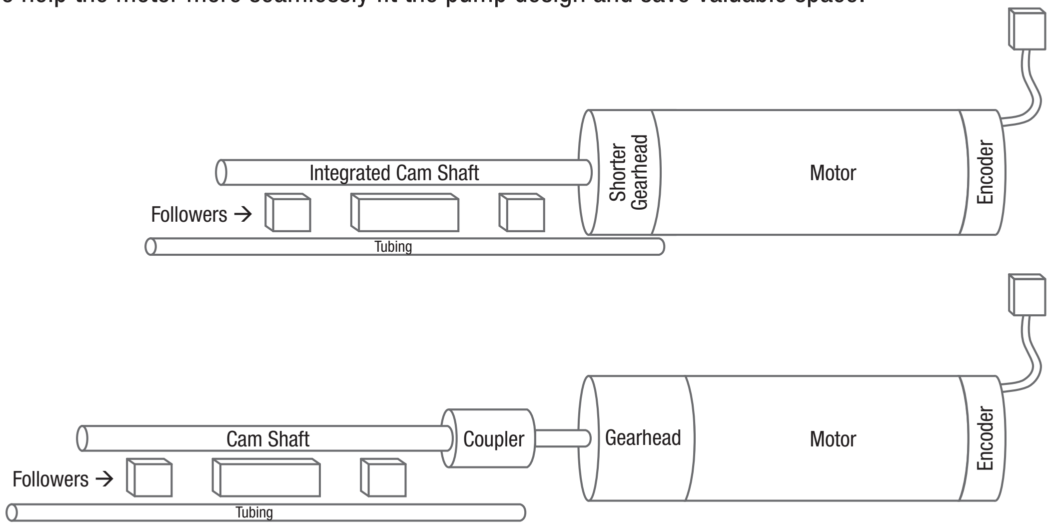


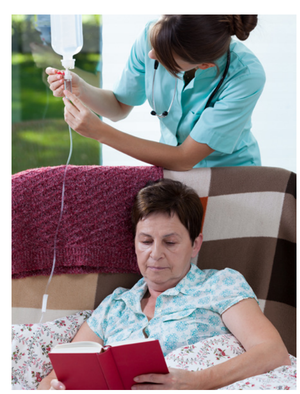
Figure 2: Example of a Custom Motor Integration

PATIENT COMFORT

The ability to receive therapy in the home environment instead of a hospital or clinic significantly improves quality of life. However, the much quieter home setting creates an additional challenge for pump designers in maintaining patient comfort. A gentle whirl that may have gone unnoticed among the chatter and alarms of a hospital may become quite disruptive in the quiet of the home, especially when a patient is sleeping. Additionally, low noise for the sake of discretion is key when administering drug therapy in a public setting.

Selecting the proper motor and gearhead technology is the first step to ensuring a quiet pump. Spur gearheads are naturally quieter than planetary gearheads due to the fewer contact points between gear teeth. If further noise reduction is necessary, plastic or ceramic can be chosen for the gear material, or helical gears can be used. Finally, careful sizing of the motor and gear ratio will ensure the input speed to the gearhead is as low as possible, which has a significant impact on gearmotor noise.

Stationary Hospital Infusion Pump



Home Infusion Pump

COST PRESSURE

Due to the high performance required, the motor is often the most expensive component of a home infusion pump design. Fortunately, motor manufacturers have found ways to make high quality DC Coreless motors more cost effective without sacrificing quality through changes in material, processes, and manufacturing location. Additionally, a resourceful motor designer can devise ways to lower the overall cost of the pump, such as integration to remove redundant components, value-add features to reduce assembly time, and built-in low resolution feedback systems to replace expensive encoders. For successful implementation of these cost-saving strategies, it is critical to collaboratively engage with a motor designer early in the concept development when all options can be considered.

{ The ability to receive therapy in the home environment instead of a hospital or clinic significantly improves quality of life. }

Optimizing Mini Motors for a Home Infusion Pump

To illustrate the challenge that pump designers face in optimizing these many design criteria, consider a home infusion pump design which utilizes a linear peristaltic pump mechanism. Let's look at the motor selection, noise and feedback in closer detail.

Define Specifications:

Pump Specs		Peristaltic Mechanism Specs	
Max Flow Rate	1,200 mL/hr	Revolutions per mL	10 rev/mL
Feedback Resolution	100 pulses per mL	Torque at Max Flow	40 mNm
Efficiency	25%	Efficiency	50%
Maximum Noise Level	40 dB	Maximum Noise Level	30 dB
Dimensions	55 x 20 x 100 mm	Dimensions	30 x 16 x 25 mm

Table 1: Example Pump Requirements

Additional Details:

- The pump casing is plastic, is not sealed, and provides some noise dampening.
- The gearmotor is mounted by screws from its front face, but otherwise there is just a thin layer of air between the outside of the motor and the pump case.
- The pump is required to last for 4 years in the field, over which the pump will typically provide a 2-hour treatment an average of 4 times per week for 1,664 hours of total motor run-time.

Motor Selection:

Due to the required pump dimensions, there is not enough length available for an in-line solution and the motor must be positioned parallel to the linear peristaltic mechanism with a 180° transmission connecting the motor shaft to the pump axle. (The efficiency of a typical transmission such as this can vary, and the gear ratio can be adjusted as needed by the pump designer. For this example, we will assume 90% efficiency and a 1:1 gear ratio.)

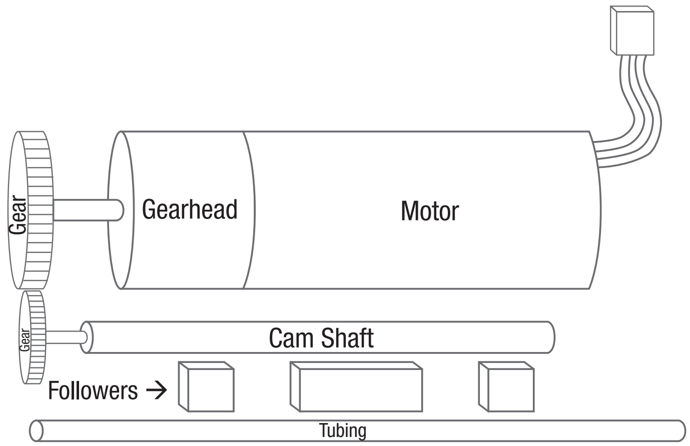


Figure 3: Suggested Motor/Pump Mechanism Layout Based on Pump Dimensions

To achieve 1,200 mL/hr max flow rate, the pump axle must be able to spin at 200 rpm:

- max pump flow rate × revolutions per mL ÷ 60 min/hr = max pump axle speed
- 1,200 mL/hr × 10 rev/mL ÷ 60 min/hr = 200 rpm

A reasonable operating speed for a DC coreless motor is 5,500 rpm, so using a 27:1 gear ratio would allow the gearmotor to achieve the desired maximum speed:

- motor speed ÷ gear ratio = gearmotor speed
- 5,500 rpm ÷ 27 = 203 rpm

To ensure brushed DC is the ideal technology, consider a brushless DC gearmotor as an alternative. However, brushless DC motors are most efficient at much higher speeds (10,000+ rpm), and require a much higher gear ratio to match the target speed of the application. The higher gear ratio creates more gear contact points, which increases noise and reduces efficiency.

A brushless motor is capable of running at lower speeds. But at low speed the iron losses are much greater for a brushless than a brushed motor, and efficiency can be 20% to 40% lower. At low speeds, Brushless DC motors also require hall sensors and more complicated and higher cost controllers because their commutation system is electronic (not mechanical like the DC Brushed motor). However, brushless DC motors do have the advantage of longer life due to no brush wear. Because the life requirement for this application is not very high, the drawbacks of a brushless motor outweigh the benefits.

{ It is critical to collaboratively engage with a motor designer early in the concept development when all options can be considered. }

Another motor technology to consider is stepper. The speed of 200 rpm is achievable using full or half stepping and the torque is within the capability of a NEMA 11 hybrid stepper motor. The motor has enough torque that it does not require a gearbox. However, the efficiency of a hybrid step motor is around 40%, which is too low to allow the pump efficiency target of 25% given the efficiencies of the other pump components.

- motor efficiency × transmission efficiency × pump efficiency = overall efficiency
- 40% × 90% × 50% = 18%

The pump battery would have to be made larger to accommodate the lower efficiency motor, adding to size and weight. The hybrid motor itself is also bulkier and heavier than DC coreless, and can cause noisy resonance at certain frequencies. Therefore, it is not a good candidate for this mobile application.

	Coreless Brushed DC Gearmotor	Brushless DC Gearmotor	Stepper Direct Drive
Efficiency	+++	++	+
Compactness	+++	++	+
Lifetime	++	+++	+++
Quietness	++	+	++
Reliability	+++	+++	++

Table 2: Mini Motor Technology Comparison

In reviewing these considerations, the best solution would be the DC coreless gearmotor as it is the most efficient, is simple to control, and the life requirement is satisfied. A quick check confirms that a 16mm DC Brushed motor with a 27:1 gearhead can provide the required torque output, as the torque reflected on the motor is well below its maximum continuous torque of approximately 6 mNm.

- torque requirement ÷ gear ratio ÷ (gearhead eff. × transmission eff.) = torque on motor
- 40 mNm ÷ 27 ÷ (73% × 90%) = 2.25 mNm

The efficiency of this particular gearmotor can exceed 60%, which is more than enough to achieve the 25% efficiency requirement for the pump mechanism as a whole.

- gearmotor eff. × pump eff. × transmission eff. = overall efficiency
- 60% × 50% × 90% = 27%

An Athlonix™ 16DCT or 16DCP DC coreless motor from Portescap with a 27:1 B16 spur gearhead are two examples of gearmotors that meet the requirement for this particular example. The 16DCT provides a higher torque capability and therefore would require less current during operation, lengthening the time between charges for the pump. The 16DCP, using an Alnico magnet, offers a lower cost structure while still meeting the demands of the application. Both are well-suited for home infusion pump applications.

{ It is important to consider the motor used in detail at the earliest stages of concept development. }

Noise:

Total noise cannot be calculated effectively as it is not cumulative, depends heavily on how the motor and pump mechanism are mounted, and is affected by the insulation in the pump casing. The pump designer will take these factors into consideration, and testing in the pump during the design cycle will determine the noise level achieved.

Feedback:

The required feedback of 100 pulses/mL can be achieved by including a 10-line feedback system on the pump axle or at the output of the gearhead:

- 100 pulses/mL ÷ 10 gearmotor revolutions/mL = 10 pulses/gearmotor revolution

Alternatively, a single line encoder can be installed on the rear of the motor shaft. This takes advantage of the gear ratio to achieve 150 pulses/mL, which surpasses the requirement for even better flow control:

- 1 pulse/motor rev × 27 motor rev/gearhead rev × 10 gearhead rev/mL = 270 pulses/motor rev

The unsealed pump case means that dust from the home environment (not as clean as a hospital) can get into the feedback system, so an enclosed magnetic encoder is better than an open optical sensor. For additional safety, a redundant low resolution sensor on the gearbox shaft or pump axle can be used to provide confirmation that the axle is turning and that the drug is in fact being delivered to the patient.

Conclusion

As is clear from the sample situation we just reviewed, many design choices are highly codependent. For example, a decision as seemingly unrelated to motor design as the pump case material may ultimately limit the performance of the motor and in turn the final pump design. Therefore, it is important to consider the motor used in detail at the earliest stages of concept development. An experienced, capable, and cooperative motor supplier can play an outsized role in the product development process, expanding the limits of pump performance. **P**

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