Advanced Miniature Fluidic Modules Enhance Portability

Medical device demands require that component suppliers offer products that can be incorporated into portable solutions for patients and healthcare professionals alike. For makers of fluidic modules, the challenge to miniaturize is no different. This article looks at solutions available in pump and valve components that have addressed the miniaturization movement with the goal of portability in mind.

By Dan Schimelman
Dan Schimelman is the director of business development with Hargraves Technology Corp. He is responsible for developing new product technology strategies to best meet growing market applications requirements. Schimelman can be reached at 704-662-3500 or dschimelman@hargravesfluidics.com.

Portable medical treatments and therapies are driving the need for new generations of lightweight, reliable, and highly efficient miniature fluidic modules. System designers have been challenged to advance their product technology by specifying pumps, valves, and related components that can achieve increased performance capabilities while fitting in ever-smaller envelopes. Since most of these systems incorporate fluidic modules consisting of miniature diaphragm pumps and solenoid valves, these components need to be optimized to best achieve the market demand objectives. Fluidic systems developers benefit from understanding how these miniature diaphragm pumps and solenoid valves can be configured with advanced components to best meet their application specific requirements.

Miniature diaphragm pumps, compressors, vacuum pumps, and solenoid valves can be configured and optimized for specific portable medical device requirements

Miniature solenoid valves and diaphragm pumps have become popular with portable medical device system engineers to provide the pressure and vacuum transport of their fluid media in a cost efficient manner. Miniature diaphragm pumps and compressors exhibit excellent gas tightness and offer the advantage of the fluid chamber being totally sealed from the pumping mechanisms. An eccentric connecting rod mechanically flexes a diaphragm inside the closed chamber to create pressure or vacuum. Unlike piston pumps, miniature diaphragm pumps do not require lubricants in the pump's stroking mechanism. On a similar note, rotary vane pumps are prone to the vanes wearing and spewing debris in the flow path. Therefore, miniature diaphragm vacuum pumps and compressors ensure oil-less, contaminant-free fluid pathway.

Medical Devices Need Greater Portability

Portable hand held medical devices benefit from the very compact Hargraves CTS micro compressor that can obtain 2.5 LPM flow

Many healthcare procedures are increasingly being performed in diverse outpatient and ambulatory environments that were once performed only on an inpatient basis. Financial pressures from consumers and employers to reduce skyrocketing healthcare costs have contributed to this dramatic change to cost efficient outpatient procedures and therapies. The escalation of outpatient care is driven by medical technology advancements and the development of non-invasive and minimally invasive surgical procedures. In many cases, surgeries once requiring several days of postoperative observation and care have become same-day procedures. The trend for medical practitioners to have patients reduce hospital stays and continue treatments at home has required medical device companies to engineer systems to be more portable, easier to operate, quieter, more robust, and cost effective. Advanced diagnostic and therapy services such as wound therapy, compression therapy, kidney dialysis, transfusion therapy, oxygen therapy, and mechanical ventilation that required hospital supervision can now be in operation at one's home.

This paradigm shift in healthcare services is fueling the medical device field to experience explosive growth. The market will continue to accelerate as demographics and market drivers increase their pressure for new and innovative product offerings. To support this market demand for new generation outpatient therapy devices, medical device developers find that they need to incorporate smaller, high performance, and reliable fluidic modules to achieve similar capabilities of larger desktop units but in smaller, more portable enclosures.

Miniature diaphragm pumps and solenoid valves are typically the main source of providing the pressure and vacuum transport of air and gas in a cost efficient manner. By understanding the latest advancements in these key components and how they can be tailored for optimum system performance, portable medical device engineers can streamline their development process by identifying earlier exactly what they need.

Demand for Higher Performance Miniature Diaphragm Pumps

Current technology diaphragm pumps typically have been the first component to either fail or need service. Their expected life was found to be relatively low, with most pumps lasting less than 3,000 hours in real world operation. For many systems designers, this is unacceptable as their products need to operate in demanding environments for significantly longer. The cost for a medical device manufacturer to rebuild the pumps or replace them with new ones can be significant. The consequence of having dissatisfied customers because their product is plagued with downtime due to pump issues can be even more costly.

The Hargraves BTC-IIS achieves up to 11 LPM and can be configured with the high efficiency, long life slotless brushless DC motor

Innovative high efficiency designs and advanced materials have led to unprecedented improvements to miniature diaphragm pumps, compressors, and vacuum pump performance and operational life by incorporating elastomers capable of increased flex and stretch, optimized diaphragm geometry, and significantly enhanced brushless DC motor design technology. The ability for the components to endure much higher ambient temperatures along with a rugged design to withstand the demanding operation loads has enabled this pump technology to outlast most of the systems that it will be integrated into. The following technology drivers affect the design criteria for portable medical devices with regards to miniature diaphragm pumps and miniature solenoid valves.

Technology Performance Drivers

The diaphragm in diaphragm pumps stretch and flex under load. In many applications, the material can fatigue or eventually tear due to the number of cycles under elevated temperature and prolonged pressure loads. Advanced fluidic engineers have determined that standard EPDM (ethylene propylene rubber) used in many existing miniature diaphragm pump designs continues to be a major limiting factor in the life of the pumps. Due to these limitations, many current technology miniature diaphragm pumps and compressors are only rated up to 40°C and have limited elastic properties to endure the rigorous cyclic stretching required for higher output applications. Pumps configured with EPDM and operating at higher ambient environments typically will endure ripped diaphragms before they achieve 3,000 hours. To extend diaphragm life past the 10,000 hours under operating conditions that new generation portable medical devices require, innovative research was conducted to develop an advanced performance elastomer that could withstand 70°C with improved mechanical capabilities. A research project conducted by Hargraves Technology resulted in the development of an advanced EPDM (or AEPDM)—an elastomer material configuration that lasts up to ten times longer than standard EPDM. Depending on the fluidic loads and ambient operating temperatures that the miniature diaphragm pump will be operating at, AEPDM diaphragms have been found to exceed 20,000 hours of operational life.

High flow, high efficiency valves that can be easily mounted to printed circuit boards or customized manifolds enhance space utilization

The cross sectional geometry of the diaphragm itself has also been evaluated and optimized to improve flow, pressure, and vacuum performance. Typical flat diaphragms are performance limited by the amount that it can be stretched. To achieve increased performance in the smaller package size that portable medical devices require, air and gas diaphragm pumps require increased stroke beyond the stretch limits of the flat diaphragm. Increased flow or increased pressure and/or vacuum performance can be achieved with a larger flat diaphragm but this would require a larger pump head design. An increase in diaphragm surface area can accomplish more efficiently by using a shaped diaphragm. This will enable the pump stroke to increase up to 80%. As a result, a miniature diaphragm pump or compressor can increase its capacity in a much smaller, compact envelope size by optimizing the diaphragm shape.

DC Motor Selection

The motor is the biggest driver affecting the overall performance, efficiency, expected operational life, and cost of the miniature diaphragm compressor or vacuum pump. Since the motor is the highest cost component of a diaphragm pump, it is a major cost driver impacting the overall cost of a fluidic module. There are several motor design technologies that can achieve the same fluidic performance but vary significantly regarding overall efficiency, noise, life, and cost.

Two major motor technology designs—DC brush and DC brushless—can be configured on the pump with their respective advantages and disadvantages. Portable devices focused on low cost products where operation life is relatively low will typically incorporate DC brush motors with the diaphragm pressure and vacuum. Iron core brush motors typically use carbon brushes to conduct the electrical input from the lead wires to the motor's commutator. The constant rubbing of the brushes on the commutator causes the brushes to wear down like the lead in a pencil. Brush motors are designed to last from 500 to 5,000 hours, depending on the quality of the motor and how it is used.

A good quality brush motor can be expected to last no more than 3,000 hours with frequent on/off cycles. The motor brushes experience an electrical arcing upon each start up. Frequent arcing will heat up the carbon brushes, causing them to wear out more rapidly. Therefore, brush motors that experience frequent on/off cycles per day wear out more quickly. Brush motors used in high duty applications with more continuous operation can last longer. Very few medical therapy applications allow a pump to run continuously. Frequent starts and stops are the norm. Occasional cycling may lead to the brush motor to stall due to carbon dust build up between the brush base and commutator. Clearing these deposits from the brush tips by tapping the outer housing can usually restart the motor. Another possible negative characteristic of brush motors is that they can introduce unwanted electrical or RFI noise into a system's circuitry.

A higher efficiency variation of brush motors is a coreless motor design. It differs from the standard brush motor in that the winding is wound onto itself on the rotor. The precious metal brushes are highly conductive and efficient. No iron is on the rotor, making the lighter, coreless rotor spin at a given performance level with less required input energy. This results in lower current draw required to power the respective diaphragm pump. Coreless motors come with a price premium due to the precious metal brushes and the complexity to manufacture the wound rotor. As a result, coreless motors are commonly used in portable, battery-operated systems requiring exceptional efficiencies to achieve longer battery operation.

Long Life, High Efficiency Brushless DC Motors

Electronically commutated brushless DC motors remove the issues inherently experienced with mechanically commutated brush motors. Instead of carbon brushes engaging on a commutator bar, the windings are switched on and off sequentially by solid-state electronics. In a brushless motor, the magnets are on the rotor, and the windings are wrapped around poles on the stator. As a result, brushless motors require less maintenance and are smaller, lighter, and more efficient than brush motors with comparable outputs. With a brushless DC motor design that focuses on performance, reliability, and endurance, operational life can be expected to exceed 10,000 hours with a high precision bearing cage design to take out any play that causes bearing fretting. This precision design can also produce a quieter motor as the mechanical noise common with brushless motors is significantly reduced.

Brushless motor designs can further be differentiated to those that incorporate either slotted or slotless stators. “Slotted” stators consist of slotted iron laminations that are fused to form a solid, uniform stack. The slots form rows that extend the length of the stack, and the windings are inserted into each row. As the rotor turns, the magnets are more attracted to the stator’s teeth than the gaps between them. This uneven magnetic pull—called cogging—reduces the motor’s efficiency and makes it difficult to produce smooth motion at low speeds. With typical operating pressure and vacuum loads, current technology brushless motors today can see efficiencies in the 50% to 60% range.

A new and innovative brushless motor design incorporates a slotless stator that doesn’t have slots to keep the windings in place. The windings are instead attached to the inside surface of the stator with adhesive. Cogging is eliminated since there are no teeth to attract the magnets. The result is a motor that produces a smooth, quiet rotation. The absence of teeth also provides room for larger magnets in the rotor and more wire in the windings. This design benefit allows the slotless configuration to generate more torque without a corresponding increase in size. The slotless design has the added benefit of significantly reducing damping losses. In both slotted and slotless motors, eddy currents are induced as the magnets pass the stator. However, these currents are weaker in slotless motors, because the distance between the stack and the magnets is greater than in slotted motors. This makes slotless, brushless motors more efficient than slotted motors. Compared to slotted brushless motors, miniature diaphragm pressure and vacuum pumps can expect to see improved efficiencies up to 70% coupled with the exceptional life that the brushless design produces.

Greater Fluidic Efficiency With High Flow Solenoid Valves

Many portable medical devices utilize miniature solenoid valves to direct and control the flow generated by the miniature diaphragm pumps or micro compressors. The new design trend has challenged component manufacturers to produce smaller, lighter components, specifically miniature solenoid valves, to fit these new products. To fit in these new generation enclosures, the valves typically cannot exceed a 10-mm package size. Since most of these smaller valves are based on past solenoid designs, smaller orifices were inherent with restricted throughput. This had the negative effect of reducing flow at the expense of a smaller package. The typical 10-mm solenoid valve has up to 1/6th the throughput area when compared to the pump output capacity. Due to the restrictions of these small, ineffective valve orifices, the pumps in a fluidic system have been required to overcome significantly large pressure differentials. A common practice of fluidic systems engineers to overcome this reduction in throughput has been to incorporate a pump with two to three times more capacity than necessary. Even with the higher output pumps, minimal performance gains were achieved while adding unnecessary weight, noise, and size, as well as increased power consumption and heat. Additionally, as portable medical device designers develop smaller instruments with more functions, more solenoid valves are required, compounding the increased heat, noise, and power consumption problems.

New and innovative advances in solenoid valve designs and manufacturing processes have focused this miniature valve technology to be small in overall size with a much larger orifice. By using finite element analysis to analyze the fluid flow throughput and the flux efficiency of the magnetic field created by the solenoid, flow of up to two times the current capabilities may be achieved. Power consumption and heat generation have been able to be significantly reduced due to much higher efficiencies achieved in the solenoid design. In addition, advanced manufacturing processes can lock in exact, optimized orifices that will enable fluidic tailoring for application specific flow. This has resulted in breakthrough improvements in solenoid valve performance. In addition, the new generation miniature solenoid valves can be mounted individually, on a manifold, or soldered directly to a printed circuit board (PCB), giving fluidic module design engineers the most flexibility available.

The weak link in a fluidic module for many portable medical devices has been the miniature solenoid valve with its small, restrictive orifice. Instead of specifying oversized and higher output diaphragm pumps, fluidic designers are working with advanced fluidic solution suppliers to provide a tailored solution optimizing the solenoid valve orifice with an optimized and advanced miniature diaphragm pump to best meet their system criteria. These advanced fluidic solutions provide benefits of smaller, lighter pumps; less noise; and greater pump life since the differential load pressures significantly decrease, and overall size and weight are also decreased.

Technology Innovations Drive Smaller Fluidic Modules

Portable medical devices that seek to achieve higher flow, longer battery operation, and longer device life while in a smaller but cost-effective fluidic module are benefiting from tailored configurations of advanced miniature diaphragm pumps and solenoid valves. Recent technology innovations in high efficiency slotless brushless motors, advanced elastomers exhibiting increased stretch and flex at elevated ambient temperatures, and larger effective solenoid valve orifices exhibiting higher flow capabilities are facilitating new generations of ever smaller portable devices. Understanding how the diaphragm pumps and solenoid valves can be tailored to best meet the portable system criteria will help ensure the project success with quicker time to market.

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