WHITE PAPER

EFFICIENCY FOR LIFE: ADVANCED MINIATURE MOTOR DESIGN FOR MEDICAL VENTILATION

by Bruno Fauvel

The roots of positive airways mechanical ventilation can be traced to WWII with the needs for pilots to breath at higher altitudes. Ventilation therapy then made accelerated progresses during the polio epidemic in the 50's.

Today, mechanical ventilation is indicated when a patient's spontaneous ventilation is inadequate to maintain life. It is also indicated as prevention for imminent collapse of other physiologic functions, or ineffective gas exchange in the lungs. Mechanical ventilation in hospitals and in the field have contributed to dramatically improve the life expectancy of patients during and after surgeries, or suffering from accidental disrupted lungs function or finally of patients suffering from acute chronic pulmonary diseases. More recently home care applications previously considered as comfort-improving therapies are showing premier medical interest in the race to extend people's life. For instance, lower end mechanical ventilators devices known as CPAP and used at night to treat sleep apnea, a disorder once considered a simple discomfort and which is now recognized as a source of major medical complications (increased blood pressure, diabetes,…) ; are increasingly popular and effective.

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Medical ventilation technology has been evolving from stationary units originally relying on oxygen and compressed air drawn from the hospital supply lines into autonomous portable devices, capable of providing their own controlled pressure and flow. This migration was accelerated with the increased need to allow patients to recover in the comfort of their own home after a pulmonary surgery when affected from acute Obstructive Sleep Apnoea (OSA) syndrome or even from more severe conditions such as acute respiratory failure or Chronic Obstructive Pulmonary Diseases (COPD), a growing leading cause of death globally.

Consequently former valves or piston driven solutions progressively gave way to high-speed micro-turbine blower driven ventilators, which can now be distinguished in 4 major categories: intensive care, home care, transport ventilators and neonatal ventilators.

Miniature Motors for High Efficiency Blower Systems

High efficiency blower systems which include a specific motor and a fan have been designed in such a way that inspiration pressure (IPAP) and expiration (EPAP) pressure can be generated and controlled by acting on the motor speed only (cf. fig. 1).

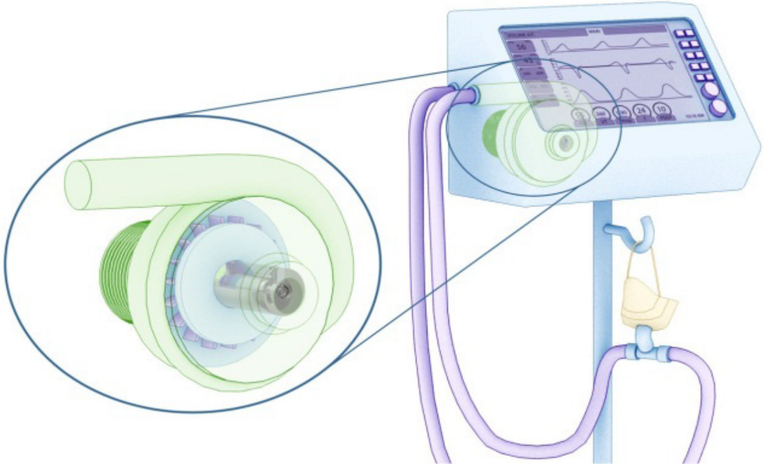

Figure 1: Typical Medical Ventilator Set-Up

By ramping up and down motor speed from 15,000 to 60,000 rpm in a matter of 100-120 milliseconds, the newest ventilators are capable of ventilating modes very close to a patient's natural breathing pattern, hence maximizing their therapy acceptance, and are also capable of invasive ventilation, once not possible with turbine blower designs. Pressure of 100 CmH2O and flow in excess of 200L/min are now common requirements which Portescap brushless-motor-equipped blowers can reliably support. Indeed, brushless technology offers the longer life span at such speed. Collaborative work with ball bearing manufacturers warrant the best solution for each application requirement (speed, load, oxygen content, noise level,..).

Because of the increased demand in ambulatory ventilation solutions mentioned above, longer battery life, and thus the need for a higher efficiency motor, is critical.

Miniature Motors for High Efficiency Blower Systems

To understand motor efficiency, let's review some of the losses that can be generated by a motor under load: Eddy current losses and Joules losses. Indeed both losses sources, if not minimized, contribute directly to poor battery life, as well to motor temperature raise which adversely affect bearing life and other ventilator internal components temperature. The later often leading to the use of cooling fans, vents which contribute to higher ventilator noise level and increased cost.

Hence, an efficient motor under constant load will consume little current to perform a task, while a less efficient motor will consume a lot of current to perform the same task and as a result will heat up more.

> { Portescap slotless brushless motors are particularly current frugal which allow to size down batteries and power supplies and further enhance the portability of ventilators }

Thanks to their specific coil design and optimized magnetic circuits, Portescap slotless brushless motors are particularly current frugal which allow to size down batteries and power supplies and further enhance the portability of ventilators.

Additionally, as explained previously, patient's therapy acceptance has driven motors to ever be more responsive to ventilators' command to ramp up and down in speed. This affects how motors draw current during these dynamic phases in relation with the inertias of the various components and the acceleration rate.

Let's consider:
Ji: inertia of the fan impeller.
Jm: inertia of the motor rotor.
a : the desired acceleration

The Torque T required to accelerate these inertias is: **T = (Ji+Jm).** (1)

Now let's consider:
K: motor torque constant (ability for a motor to create torque given a current)

I, the current drawn under acceleration becomes: **I=T/k**

Consequently, combined with equation (1), I current drawn under acceleration becomes:

I=(Ji+Jm). a/K

It then becomes obvious that optimizing the system inertia is critical for managing the thermal losses in acceleration phases since, as previously seen, these are proportional to the square of the current drawn (I^2.R). The ability to choose magnet grade, strength and dimension to optimize the final solutions is critical in that respect.

Ventilators requiring high Breadth Per Minute and lower delivered pressure & volume such as neonatal applications will most likely dictate the selection of smaller inertia motor to minimize losses during the acceleration phases and allow up to 90 BPM. In contrast, a full adult life-support ventilator with both higher delivered pressure and larger volume, but fewer BPM most likely will require a more powerful motor.

Joule losses: These are equal to $I^2.R$ where R is the motor resistance and I the current consumed.

Eddy current losses: are the other major generated losses in a running motor.

These losses occur while rotating a magnetic field in front of a piece of iron and generate heat. This phenomenon is exactly what happens inside a motor when its rotor magnet spins at high velocity in front of its stator laminations. Eddy current losses are proportional to the square of the frequency. With the increased requirement in pressure and flow of modern ventilators, thus in motor rotational speed, it is important to consider this while designing the best motor for each ventilation application. The number of rotor magnet pole-pairs is equally important as its rotational speed. As an example, Portescap brushless motors have been optimized with 1 pole pair, thus dividing by 4 the amount of Eddy current losses typically generated by 2 pole-pair motors.

{Lamination material and thickness selection is also an important step in the design of the best motor as they both dramatically affect losses and generated high speed.}

Lamination material and thickness selection is also an important step in the design of the best motor as they both dramatically affect losses generated at high speed. Low core-loss steel lamination material and thinner lamination can reduce operating temperature of motors, but they can rapidly affect its cost as well.

Brushless Motors – The Slotless Coil Technology

Slotless motor self-sustaining coil technology offers the added benefit of not requiring to be hosted by the lamination. Indeed, typical slotted brushless motors stator coils are wound around the laminations teeth created by their profile (cf. fig 2 below). The benefit of the slotless motor design is that it does not introduce iron in the air gap (area between magnet and copper wire) which further reduces iron losses. This design also yields a smoother rotation as the magnet is not attracted in any preferred position created by the stator teeth. Vibration and noise level are typically greatly reduced as a result.

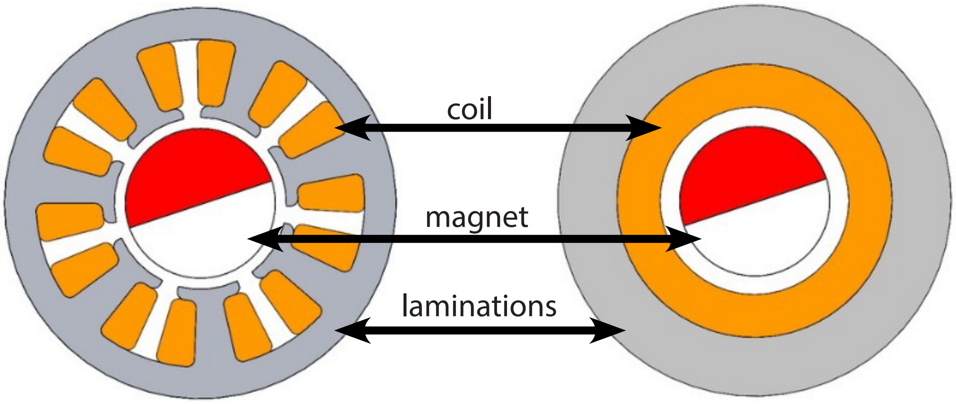

Fig. 2: Slotted versus Slotless brushless motor section

Consequently, both reduced these residual losses (Eddy & Joules) in some available miniature motors allow operating temperatures to decrease by as much as 25% under the same ventilation requirements (pressure, flow, BPM,..) than with previous generation motors.

Length is another factor to consider when selecting a motor. Indeed, a longer motor while increasing k (torque constant) thus reducing the current needed under a same load as for a shorter motor, also has the benefit of better dissipating the temperature generated by its losses. Although Eddy current losses also increase with the amount lamination material and inertia is also marginally negatively affected as motor length grows (as opposed to greatly affected when its diameter grows).

Miniature Motor Selection Considerations

In conclusion, the selection of the best ventilator motor comes down to a balancing act of application requirements. ICU ventilators, typically larger in size, can accommodate a full length 22mm slotless BLDC motor for its ability to continuously deliver full pressure and speed, maximize reliability with best thermal management, and where cost is not as sensitive as in home care solutions.

Home care and transport ventilators designers typically favour a medium length 22mm motor for its compactness, efficiency for longer battery life, reliability in ambulatory application, more modest cost and the flexibility it offers in providing temporary high pressure & flow or high dynamics.

Dedicated neonatal ventilators, usually running smaller fan impeller will best be designed with lower inertia motors such as Portescap 16 mm solution allowing for high speed and acceleration and repeated step function cycles.

> { Finally, motor and blower integration is key for the best overall flow generation function. }

Finally, motor and blower integration is key for the best overall flow generation function. Motor mechanical features such as shaft, front flange and more need to be customizable to accommodate for best union of components.

About Portescap

Interested in learning more about how Portescap can help optimize a motion solution for your medical application? Contact us today. Additionally, our expertise in assembled impeller balancing, laser and ultrasonic welding capabilities allows Portescap to deliver complete pressure and flow tested blower assemblies to OEMs.

Portescap offers miniature motor technologies to solve the motion needs of a spectrum of end markets, from medical devices to various industrial applications, that save, improve and enhance lives. We serve our customers through breadth of innovative product technologies encompassing Brushless DC, Brush DC, Can Stack motors, Disc Magnet motors and Stepper Linear actuators to optimize application performance. Our products deliver motion in a compact package with high efficiency and low power consumption.

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