Portescap

WHITE PAPER

REDUCING SURGICAL HAND TOOL SIZE WITHOUT SACRIFICING PERFORMANCE

Figure 1: Surgical hand tools should be lightweight, with high density and reliability

Surgical hand tools require a minimum level of power for a given application, and higher power requirements generally necessitate larger motors. This in turn leads to a heavier and bulkier tool that reduces surgeon precision and increases fatigue. This paper explains how to minimize the size of the motor required for an application while balancing tradeoffs in other design parameters. As brushless DC motors (BLDC) are very popular for surgical tools due to high power density and high reliability, this paper is focused on BLDC motor technology. The concepts apply to both slotted and slotless designs.

Mechanical power is the product of torque and speed. All else being equal, the torque generated by a motor is roughly proportional to its volume. Torque is created by the presence of current carrying wires within a magnetic field, and it can be increased simply by adding more wires or more magnets. But relying on this brute force tactic alone will inevitably lead to increased size. Fortunately, more sophisticated motor design methods can be used to increase power output in smaller packages.

METHOD 1: OPTIMIZE THE WINDING TO SUPPLY VOLTAGE

The more voltage available to the motor, the faster it can turn at any given torque and therefore the more power it will produce (see Figure 2 below). This allows a smaller motor to be used to achieve the same output power. However, higher voltages generally dictate larger batteries which can negate the benefit at the tool level. Designers of battery powered tools often must choose from a limited variety of available battery cells and connect them in series to achieve a desired voltage. Obviously, this requires a whole number of cells and a discontinuous set of possible voltages. Therefore, even a small increase in voltage to increase motor power could dictate adding another cell and all the associate size and weight. A good motor design partner can tweak the diameter of the wire in the motor as well as the number of times the wire wraps around the stator (turn count) to maximize the power at convenient battery voltages.

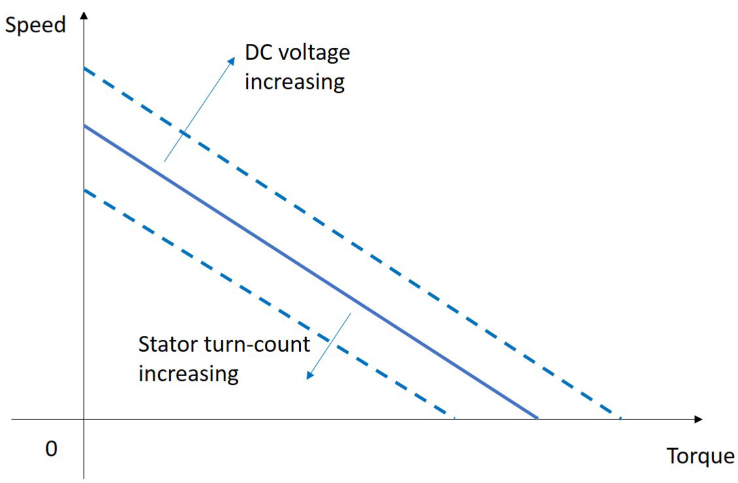

Figure 2: Effect of Voltage & Winding Adjustments on Speed-Torque Curve

METHOD 2: MATERIAL CHOICES

While power can be increased simply by including a higher volume of magnetic material, another option is to improve the grade of the magnetic material so that it can generate more magnetic flux for the same size and weight. High power density motors generally use magnets made of neodymium which is one of the highest-grade magnetic materials commercially available. The material of the wire used to construct the coils is also important. Lamination material also impacts power. High grade lamination steel will provide a more efficient path for the magnetic flux to travel, which amplifies the contribution of the magnet material. Finally, any material choice that reduces friction (such as in the bearings and gear teeth) will minimize the losses during conversion from electrical to mechanical power and get more out of a sleeker design.

METHOD 3: PRECISION MANUFACTURING

Obviously, the more tightly the various components of the motor are arranged the smaller the overall package will be. But positioning the magnets and coil as closely together as possible also increases power. Minimizing the distance between the magnet and the coil (called the airgap) strongly increases the airgap magnetic field strength and therefore the motor voltage constant and the performance of the motor (Figure 3). However, decreasing this distance is easier said than done because it requires very tight tolerances to avoid the rotor and stator rubbing during operation. A precision motor supplier can handle the machining and workmanship required to achieve this.

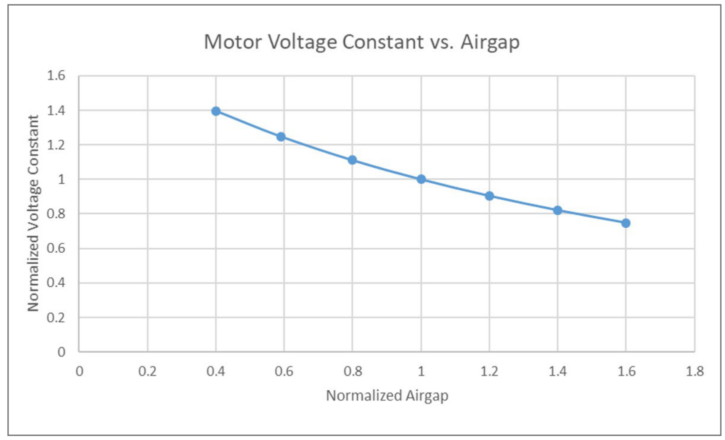

Figure 3: Impact of Minimizing the Airgap on the Voltage Constant

For slotted BLDC motors, precision assembly methods can also improve the amount of copper coil that can fit into the slots of the stator. Careful selection of the wire diameter and shape of the slot can maximize the slot fill factor and deliver the most power out of the smallest space.

METHOD 4: MANAGE TEMPERATURE RISE

To this point, we have not considered an extremely important aspect of motor sizing – temperature rise. A very tightly configured motor will naturally get hotter than one with its heat generating elements spaced farther apart. This problem gets even worse if voltage and current are increased to meet power requirements. To offset this effect, materials for the housing of the motor can be chosen to conduct heat away from the motor coils, which can become so hot during operation that the insulation melts and creates an electrical short. Extreme heat can even decrease the strength of permanent magnets. Additional heat sinking on the outside of the motor, or air or liquid cooling may be required to dissipate heat, which impact the overall size of the tool.

The following formula can be used to calculate the motor winding temperature to determine whether temperature rise will cause premature failure of the motor. A talented motor supply partner can help determine the value of the constants for each unique application. Note that this theoretical calculation can be used as guidance to select the prototypes, but only testing in the application can confirm when operating near the limits.

$$T_{coil} = R_{th} \times R_0 \times (1 + \alpha \times (T_{coil} - T_{amb})) \times I^2 + T_{amb}$$

Motor thermal resistance:------------------------- R_{th} (°C/W)

Terminal resistance at room temperature: ------------- R_0 (Ω)

Temperature coefficient of resistance for copper: ----- α (/°C)

Ambient temperature: ------------------------------ T_{amb} (°C)
(immediately surrounding the motor housing)

METHOD 5: UTILIZE GEAR REDUCTIONS

Brushless DC motors run most efficiently at relatively high speed, but many surgical tools need to operate much slower. In these cases, a gearhead is often employed which allows the motor to run at an efficient speed while increasing the torque output. While this allows for a smaller motor to do the job, the gearing itself takes up space, normally in the form of increased length as gearing is most commonly aligned axially to the motor. The decision to use a long but sleek gearmotor or a shorter but larger diameter motor depends on the required layout of the tool. One way to minimize the added length of a gearhead is to keep the gear ratio low enough that it can be handled with only one stage of gearing rather than multiple stages stacked on top of each other. Planetary gearheads are generally able to create higher gear ratios in a smaller space than spur gearheads.

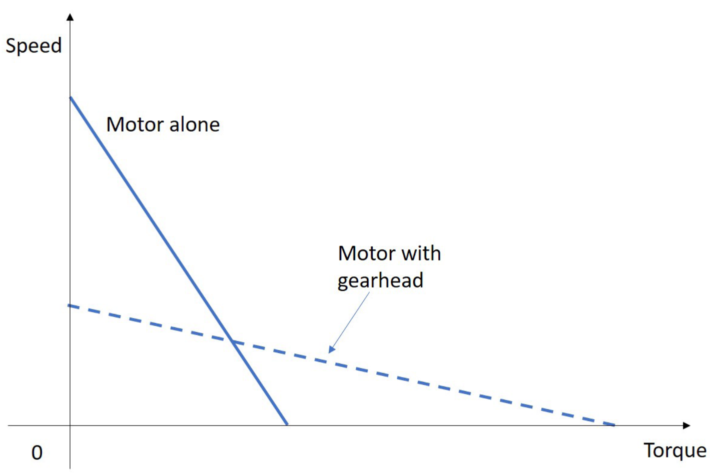

Figure 4: Using Gearing to Adjust the Speed-Torque Curve

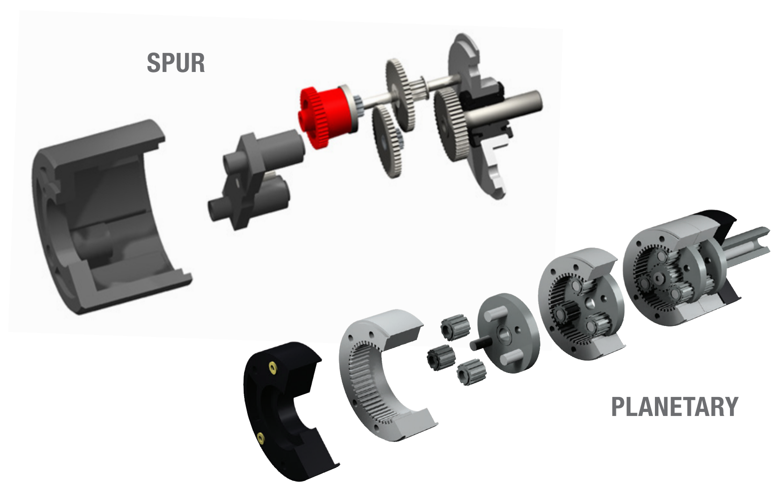

Figure 5: Spur vs Planetary Gear Construction

METHOD 6: MOTOR INTEGRATION

Finally, the best way to minimize surgical tool size may not only be to shrink the size of the individual components, but to optimize the way each component fits together. A motor is traditionally built within a metal housing that serves to encapsulate the components and allow it to be shipped in one piece and inserted into the hand tool. This motor housing is often immediately surrounded by the outer casing of the hand tool. Both components perform important functions, but these functions can often be accomplished with one combined component. A motor supplier experienced in the field of hand tool design can either provide a motor with a housing that can double as the outside of the hand tool or can coordinate with the tool manufacture to build the motor directly into the tool's outer casing (frameless design). Similarly, incorporation of other features such as tool drivers, seals, electrical connectors, and mounting hardware can be designed directly into the motor to eliminate redundancies and save space. Finally, selecting a sensorless motor can save space because the hall sensors of a sensored motor add a few millimeters to the length. However, sensorless motors require more complex controls so larger electronics boards could offset any gains.

In conclusion, creating high power density motors involves sophisticated design tactics, high quality materials, precision workmanship, and knowledge of how the motor fits into the greater architecture of the tool. A motor supplier comfortable with all these aspects will be best equipped to make the proper design choices for a sleek but powerful hand tool design. The ability for this supplier to incorporate the design methods discussed in this paper is drastically increased at the early stages of tool design. For best results, include an experienced motor partner at the concept or even ideation phase of development. **P**

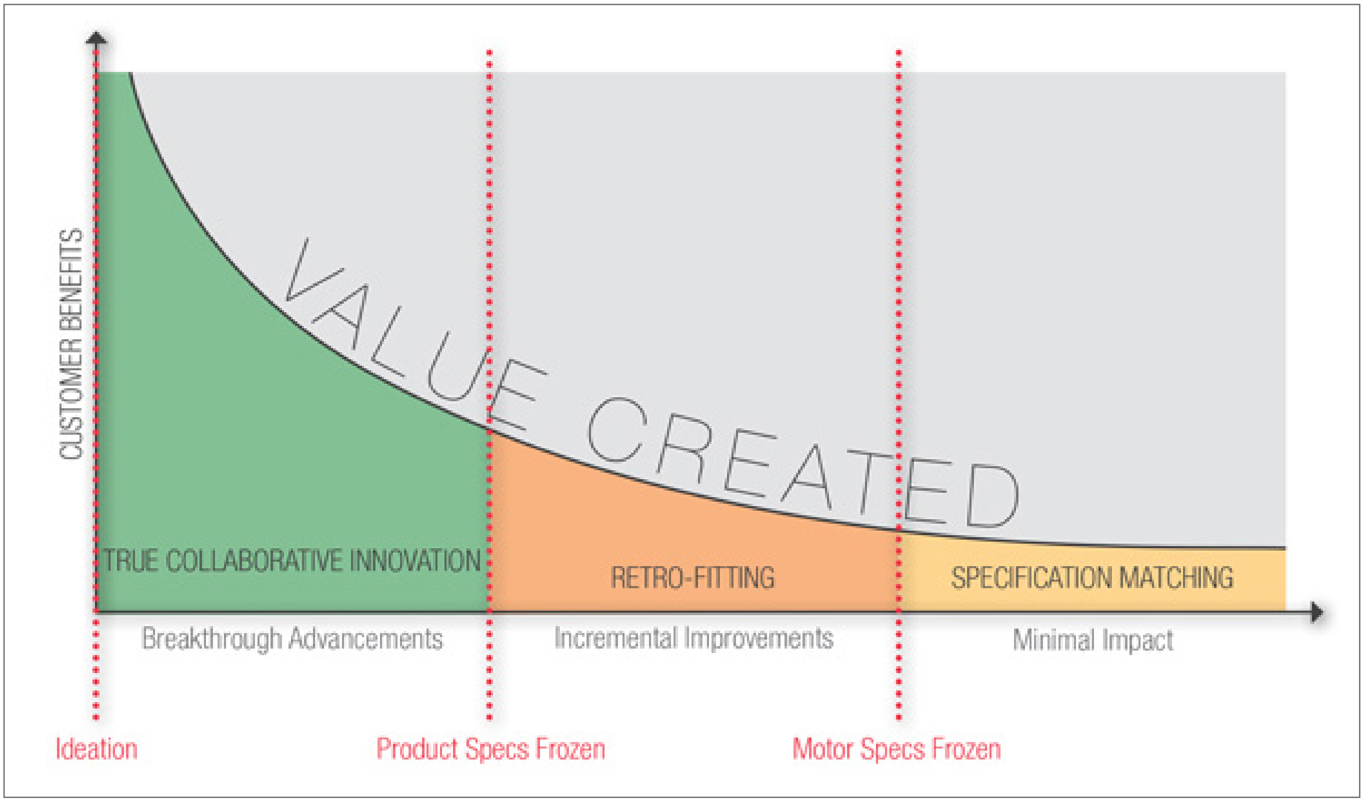

Figure 6: Benefits of Early Motor Supplier Engagement

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