Motor architecture selection for surgical hand tools

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The use of motorized surgical hand tools has significantly enhanced precision, efficiency, and patient outcomes in operating rooms worldwide. From orthopaedic reconstruction to cranial procedures, powered drills, saws, and shavers allow surgeons to perform complex tasks with unprecedented speed and control.

However, as surgical techniques continue to evolve — particularly in minimally invasive and high-precision applications — the expectations placed on these tools are rising. To meet these demands, OEMs are placing greater emphasis on optimizing the motion system at the heart of each device. Motor architecture plays a central role in that effort, shaping fundamental factors such as torque delivery, vibration behavior, thermal management, sterilization durability, and overall tool lifespan.

Selecting the appropriate motor architecture is therefore one of the most critical decisions in surgical hand tool design. This paper examines the key considerations guiding that choice and explains how matching architecture to application ensures long-term clinical and commercial success.

Understanding the performance requirements

One of the key challenges in specifying motors for surgical hand tools is that they must operate across a remarkably broad range of use cases.

For example, large-bone orthopaedic procedures typically require high torque at controlled speeds to cut or ream dense material. These applications place sustained mechanical load on the motor and demand robust thermal performance. Efficiency and torque stability under load are therefore essential.

In contrast, cranial and neuro procedures often require extremely high rotational speeds — in some cases reaching 80,000 to 100,000 RPM. In these applications, smooth torque delivery and minimal vibration are paramount. Even small variations in torque ripple can affect precision in delicate anatomical areas.

Because torque and speed are inherently linked by physical constraints, no single motor architecture can optimize both at once – especially within the tight envelope of a handheld surgical tool. Clearly defining the application's torque, speed, and duty cycle requirements early in development allows engineers to select a motor architecture that aligns with clinical expectations rather than attempting to adapt performance late in the design cycle.

Comparing motor architecture options

Once the performance envelope is defined, attention turns to motor construction and commutation strategy.

Electromagnetic architecture plays a defining role here. Slotted motor designs concentrate magnetic flux through laminated stator teeth, enabling strong torque density and making them well suited to high-load applications. However, the interaction between rotor magnets and stator slots can introduce cogging torque – a small but unwanted torque ripple common in permanent magnet motors – which must be carefully managed in applications requiring smooth rotational behavior.

Slotless motor designs remove the stator teeth, reducing cogging torque and delivering smoother motion. This architecture is particularly advantageous in high-speed or precision-driven applications where vibration minimization is critical. The trade-off may involve differences in torque density or thermal characteristics depending on the specific implementation.

As such, selecting between slotted and slotless designs requires careful evaluation of the application's dominant requirement: torque robustness, motion smoothness and even heat dissipation.

Commutation strategy is equally important. Brushless DC (BLDC) motors provide electronic commutation, enabling precise speed and torque control with reduced mechanical wear. They are well suited to high-speed applications and designs requiring closed-loop control. Coreless brushed DC motors, by contrast, offer inherently smooth torque delivery in compact form factors and may simplify integration where electronic control complexity must be minimized.

Ultimately, there is no universal “best” motor type. The appropriate architecture depends on speed targets, torque demand, vibration sensitivity, lifetime expectations, and system integration requirements.

Thermal and mechanical stability

Although the design process for a surgical tool requires balancing many trade-offs, it’s crucial to remember that motor architecture in large part governs how the device behaves under real-world operating conditions.

For example, in high-torque orthopaedic applications, sustained load can generate significant heat. Elevated temperatures influence winding resistance and magnetic performance, significantly impacting torque output over time. Efficient magnetic circuit design and correct motor sizing are therefore essential to maintaining performance stability throughout a procedure.

High-speed applications introduce different stresses. Rotational balance, rotor design, and bearing selection must support stable operation at extreme RPMs. Vibration control and noise become a defining factor in perceived precision and surgeon confidence.

Mechanical durability must also be considered in conjunction with architecture selection. Integration with gearheads, shaft assemblies, and sealing systems must be evaluated holistically to ensure long-term reliability.

A motor architecture that performs well in isolation may behave differently once integrated into the complete tool assembly.

Architecture and Integration

Modern surgical hand tools are rarely built around standard, catalogue motors without modification. Rather, envelope constraints, ergonomic considerations, sterilization cycles, and regional electrical requirements frequently necessitate customization.

Motor architecture selection therefore cannot occur independently of system-level design. Shaft interfaces, housing materials, sealing strategies, and control electronics all influence how the chosen architecture will perform once integrated. Early collaboration between the OEM design team and the motion supplier allows architecture decisions to be validated against real integration constraints. This early-stage alignment helps teams to:

- Accurately size the motor for the intended torque and speed profile
- Evaluate slotted versus slotless technologies in context
- Assess thermal behavior under expected duty cycles
- Integrate sealing and protection strategies from the outset

This structured, collaborative approach reduces development risk and increases the likelihood that performance targets will be met without costly redesign.

Conclusion

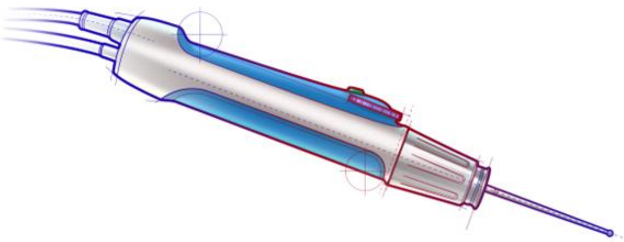
Surgical hand tools operate in demanding clinical environments where precision, reliability, and durability are essential. Motor architecture is what shapes how effectively a tool can meet these requirements.

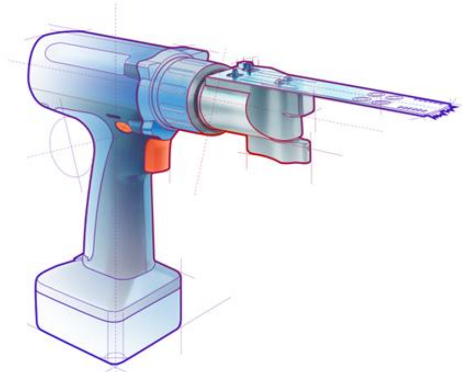
Slotted or slotless construction, brushless or coreless commutation, direct drive or geared configuration — each choice influences torque behavior, vibration, thermal stability, and lifespan. Matching the motor architecture to clearly defined application requirements ensures that the tool performs as intended, whether delivering sustained torque in orthopaedic surgery or smooth, high-speed motion in cranial procedures where every second has an impact on patient outcomes.

For decades, Portescap has partnered with surgical device OEMs to develop application-specific motor solutions tailored to their performance and integration needs. By combining architectural expertise with early design collaboration and a robust product portfolio, OEMs can optimize motion systems that support both clinical excellence and long-term reliability.

Selecting the right motor architecture is not simply a component decision. It is the foundation of surgical tool performance.

Images:





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At Regal Rexnord, we create a better tomorrow with sustainable solutions that power, transmit, and control motion. Focused on customer needs and committed to sustainability, we harness innovation to transform industries and create a brighter future. From high-performance, precision motion control systems that power surgical robots, humanoids, satellites, and unmanned aerial vehicles, to advanced automation systems that optimize motion across factory floors, to precision-engineered power transmission components and innovative air moving solutions that drive efficiency, our technologies fuel progress.

Utilizing our deep knowledge of the unique motion needs of the industries we serve — robotics, aerospace, space, defense, medical, data centers, factory automation, renewable energy, agriculture, construction, and more — we collaborate with our customers and serve as trusted advisors to deliver optimized solutions. Customer-focused innovation drives us, and our global network of design and manufacturing centers enables us to effectively engineer and reliably produce the complex solutions required to drive progress all around the world.

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