Motion solution precision is key for surgical robots

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The patient outcome of surgery performed by a robot is contingent on the control precision of its end effectors. Central to this delivery is the motion performance achieved by the robot's miniature motor system. Innovation in motion control precision has the potential to expand the array of surgical procedures that can be performed by robots. Meanwhile, for current robotic surgical applications, enhancing control precision means improved patient recovery. What steps should surgical robot designers take when specifying a motion system?

Paul Schonhoff, Portescap's subject matter expert for surgical application motion control, explains.

Enhancing precision in surgical procedures not only amplifies surgical efficacy but unlocks new potential for procedures previously deemed high-risk, greatly reducing damage to vital organs and nearby tissues. This paradigm shift in precision, driven by motion systems employed in surgical robots, promises minimally invasive techniques and quicker recovery times for patients.

Central to this evolution is the motion system's core component: the electric motor. Its zero-cogging feature, achieved through a brushless DC design and slotless structure, sets the stage for unparalleled control and responsiveness critical in robotic surgery. When coupled with considerations of power density, encoder performance, autoclavable capabilities, and customization, the standards of precision and performance for robotic surgery are redefined.

Enhances the patient outcome

The breakthrough in surgical precision advances surgical outcomes for patients across all spectrums, from pediatric to adult. The leap in precision not only has the potential to increase the effectiveness of surgery, but it could also enable procedures that were previously considered too high risk. In the future, the improvement in tool control could minimise the prospect of damage to organs and arteries in close proximity to the location of surgery.

Similarly, a smaller incision also minimises the area of damage to healthy tissue. Even for robotic surgical procedures that are already considered ‘standard’, enhancing precision means improved patient recovery. The less invasive the surgery, the less time it can take to heal, and reduced scarring from a smaller incision can also minimise the potential for any future complications for the patient.

The central role of the motion system

The ongoing search for greater precision is the trend across all types of surgical robot development. This means that exacting control of the robot’s end effectors, holding and operating tools such as blades or grinders, is critical. Central to this capability is the motion system that drives and controls the end effectors.

The motion system’s key component is the electric motor, with its rotation controlling the position and speed of movement of the end effector. Smooth torque delivery is essential to ensure precision. To achieve this, the motor must overcome a phenomenon known as cogging, the periodic variation in torque that results in ripples during rotation.

While cogging can introduce relatively jerky motion, it can also reduce the responsiveness of the motor to control commands. Delays in achieving the desired position or trajectory of the end effector will inhibit haptic feedback and decrease surgical control where real-time responsiveness is essential. As a result, a motor that can deliver as close to zero cogging as possible is vital to optimise precision in robotic surgery.

Zero cogging

To achieve the smooth torque delivery, a brushless DC (BLDC) motor design is preferred. A BLDC motor uses electronics to achieve commutation, the process of switching the direction of current flow in the motor's coils to maintain continuous rotation of the rotor. Electronic commutation can also include integrated Hall sensors to optimise feedback and control of the electromagnetic circuit. This design is typically smoother than the mechanical method used by a brushed DC motor, where brushes make physical contact with a rotating commutator.

In combination, a slotless design minimises the cogging effect. Traditionally, the stator, responsible for generating the motor's electromagnetic field, is designed with slots that accommodate the copper windings and provide a path for the magnetic flux. Alternatively, in a slotless BLDC design, the windings are distributed evenly, allowing for a more symmetrical and continuous structure. This enhances uniformity of the magnetic force distribution and achieves smoother motor operation. By optimising this design, virtual zero-cogging can be reached.

Power density

The compact space envelope of an end effector on a surgical robot means that a small motion system is essential, but it still has to deliver the required torque for the operation. Optimising the torque-to-mass ratio also helps to ensure that the motor can provide sufficient rotational force to overcome the delaying effect caused by any residual cogging.

In combination, minimising a motor's inertia, or its resistance to changes in motion, can also improve speed of response. Optimising a motor's dynamism contributes to improved precision, and also helps achieve real-time control. Design and materials that can reduce the mass of the rotor are important considerations. Meanwhile, effective motor cooling techniques can minimise heat-induced resistance that would otherwise lead to an increase in inertia.

Combined with a BLDC design, the performance of an encoder is crucial to optimise control over the motor's position and speed. The encoder provides feedback to the controller on the motor's actual rotation characteristics to ensure precise control. This performance can be enhanced with a high-resolution capability.

The preferred feedback design for surgical robot applications is a magnetic encoder. Relying on sensing the motor's magnetic fields to identify position and speed, a magnetic encoder gives greater operational reliability in a surgical theatre compared to an optical design, where splashes and ingress of debris can obscure the sensor.

Autoclave

The robot's end effector might operate inside the incision, or in extremely close proximity. Hygiene is essential so the end effector, as well as the motion system that drives it, must be sterile for every procedure. While an autoclave unit eliminates bacteria and other micro-organisms by subjecting them to high-pressure saturated steam, the motion system must be able to withstand this process.

Portescap led the way in innovating autoclavable motion solutions, and this heritage in design continues today. Motors are guaranteed for a minimum of 1,000 autoclave procedures, and their controllers too, while Portescap's autoclavable encoders can be used for at least 2,000 autoclave cycles, and gearheads are tested to 3,000 cycles or more. The method of design and sealing with a high IP rating, as well as innovation in materials development, achieves this optimum resistance and durability.

Customisation

Although the need for control precision and durability for sterilisation is common across motion systems specified for surgical robots, each OEM usually has specific design requirements. This often involves specific torque and speed profiles, as well as control characteristics. The form of the host robot may also need specific mechanical integration, that could include a customised footprint, or even a frameless motor design. As a result of these specific needs, around 80% of Portescap's motion system development is for custom applications.

To maximise the benefits of the customisation approach, it's advantageous to involve the motion team early in robot design. Sharing full visibility of the requirements from the outset can speed up development and minimise the need for rework or adaptions at a later project phase. This also challenges the perception that an off-the-shelf motor design can reduce time to market. Although a catalogue-selected motor can save time initially, the design adaptions required can extend the project length beyond that of the custom approach.

Instead, a motion system tailored to the surgical robot's specific operational parameters, removes the need to compromise. A custom approach will achieve the optimum balance of motion performance, combined with ease and speed of design integration.

Image captions:

Image 1: For current robotic surgical applications, enhancing control precision means improved patient recovery.

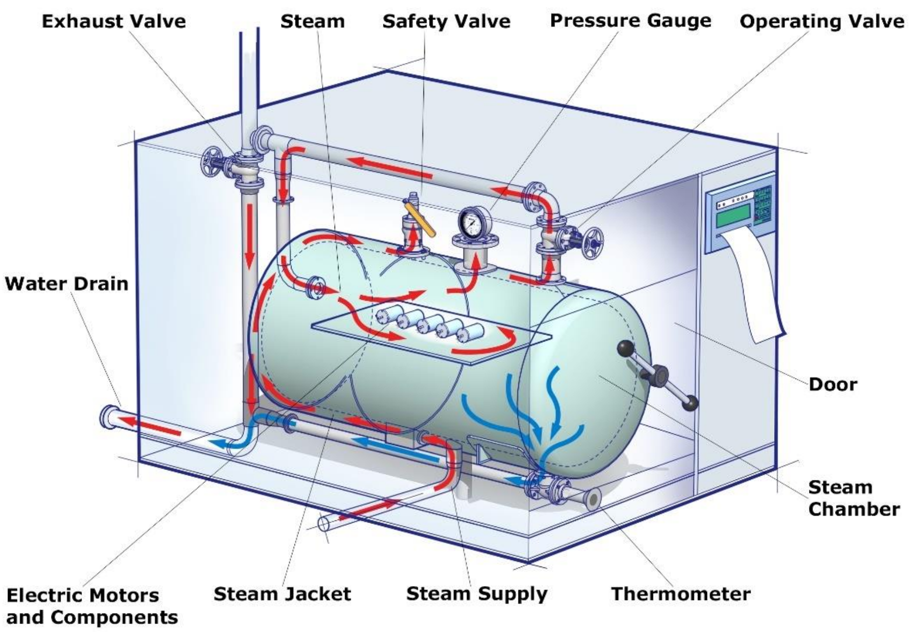

Image 2: Portescap’s autoclavable encoders can be used for at least 2,000 autoclave cycles.

Image 3: Central to this evolution is the motion system's core component: the electric motor.

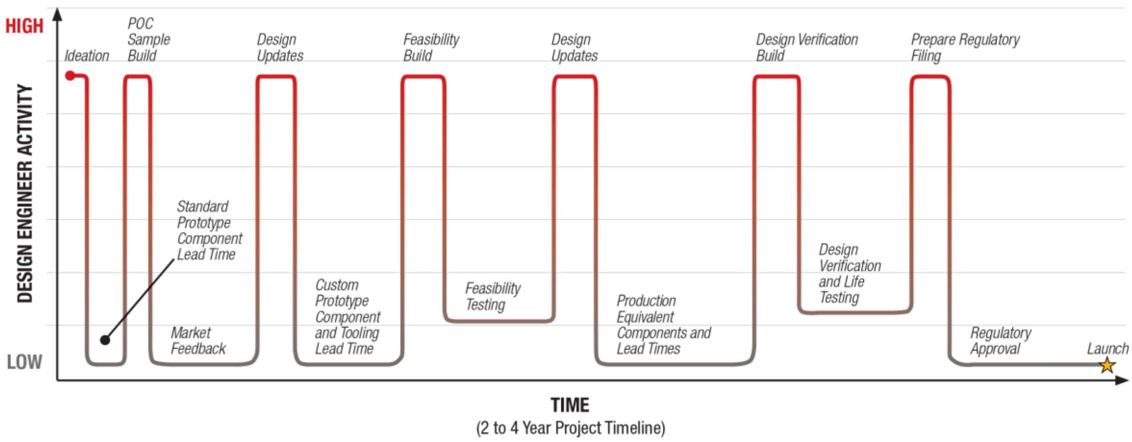

Image 4: Project timeline.

About Portescap

Portescap offers the broadest miniature and specialty motor products in the industry, encompassing coreless brush DC, brushless DC, stepper can stack, gearheads, digital linear actuators, and disc magnet technologies. Portescap products have been serving diverse motion control needs in wide spectrum of medical and industrial applications, lifescience, instrumentation, automation, aerospace and commercial applications, for more than 70 years.

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