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WHITE PAPER

CONTROLLING BRUSHLESS DC MOTOR VIBRATION IN DENTAL HAND TOOLS

The adoption of electrically powered hand tools is reshaping the landscape of modern dentistry. Similar to their surgical counterparts, dental hand tools are transitioning to being electric in nature and are steadily gaining preference over air-driven alternatives due to their consistent speed and torque output. These high-speed electrical tools have become essential in a range of dental procedures, including cavity preparation, prosthodontic work and procedures, tooth restoration, crown and veneer preparation, and operative dentistry. This whitepaper will highlight the role that miniature brushless DC motors play in electrical dental hand tools, as well as different methods available to control the vibration of BLDC motors while the tool is in use.

HOW MINIATURE BLDC MOTORS ARE USED IN DENTAL HAND TOOLS

To accomplish the complex tasks required in dental procedures, electrical handpieces are outfitted with miniature brushless DC (BLDC) motors, specifically chosen for their exceptional efficiency, reliability, and precision control. These motors represent a significant advancement over traditional DC motors due to their electronic commutation, which minimizes maintenance needs and extends motor lifespan. Five key features of BLDC motors that makes them ideal for electric dental hand tools include:

- Efficiency. Brushless DC motors offer unparalleled efficiency, ensuring maximum utilization of input power while minimizing losses.
- Minimal Maintenance. BLDC motors utilize electronic commutation, leading to a longer lifespan than brush DC motors, which use brushes and commutators.
- Precise Control. The precise speed control capabilities of brushless DC motors enable dentists to maintain stable speeds even under varying loads, crucial for maintaining accuracy during various procedures.

- Variable Speed Control. The design of BLDC motors allows for easy implementation of variable speed control, enabling dentists to vary the speed of the hand tool based on specific dental procedure requirements.
- High Torque. BLDC motors offer high power density, providing increased output torque within a compact envelope.

Portescap's 16ECS36, 16ECP36, and 12ECP48 brushless DC motors are well-suited to meet the requirements of electric dental hand tools. These motors deliver speeds ranging from 30,000 RPM to 73,000 RPM at a rated voltage 24V, with close to 90% power efficiency, making them ideal for high-speed requirements. The 16ECS36 also gives high power density in a compact envelope. 22mm diameter motors, such as the 22ECS60 and 22ECS45 BLDC motors, are available in an autoclavable version, surviving up to 200 cycles, allowing the tool and the motor to be steam sterilized.

THE CHALLENGE OF AUTOCLAVE CYCLES AND VIBRATION IN ELECTRIC DENTAL HAND TOOLS

Electric dental hand tools undergo sterilization between patients, necessitating a design that is autoclavable and capable of withstanding a specified number of cycles. Autoclaving is the standard method employed to sterilize these tools, ensuring the removal of bacteria, viruses, and other pathogens prior to each patient's use. This process operates on the principle of exposing the instruments to high temperature and pressure steam. Autoclaves offer various cycle options, with the most common involving a 20-minute duration, reaching a steam temperature of 135°C, and applying pressure ranging from 0.5 bar vacuum to 2 bar.

Repeated autoclaving poses a challenge for dental hand tools, as not all materials can withstand the harsh environment. Consequently, modern electric instruments are typically constructed from materials specifically chosen for their resilience to multiple autoclave cycles. Given the critical role of the motor as the driving force behind these instruments, it must also be able to withstand the targeted number of autoclave cycles. This is especially critical in light of motor vibration, as the elevated temperature and pressure experienced during autoclaving can gradually lead to the degradation of certain materials; this can result in noise, vibrations, and damage to the motor and instrument itself.

VIBRATION CONTROL METHODS FOR BLDC MOTORS

Reducing vibration and noise levels is critical in the design of dental hand tools, particularly for professionals who utilize them for extended periods during sensitive procedures like cavity preparation. Excessive vibrations can not only impair the precise control required during the procedure, but also disturb the patient, leading to unnecessary discomfort. Moreover, continual exposure to vibration can accelerate wear and tear on components, compromising the longevity of the tool. However, with advancements in motor technology, high-quality brushless DC motors have been engineered to minimize vibration even after multiple autoclave cycles. Designers of BLDC motors can incorporate various techniques for vibration control, six of which are outlined below:

ROTOR BALANCING (FINE BALANCING)

The rotor stands as the major component within a BLDC motor that can generate vibration if not properly balanced. The balancing of the rotor is a crucial operation, with most of the unbalanced mass typically stemming from the magnet. To address this, separate balancing rings can be affixed to the shaft, as illustrated in Image 1, allowing for precision 2-plane balancing through material removal. With advanced balancing machines, the rotor unbalance can be reduced to almost zero, achieving a near perfectly balanced rotor. This effectively eliminates the primary source of vibration, ensuring the smooth operation of electric dental tools.

MAGNET TO SHAFT CLEARANCE

Magnets are usually affixed to the shaft using a gluing process. For sufficient gluing strength, there must be a minimum clearance (space) between the shaft and the magnet's inner diameter (ID). However, autoclave cycles can affect the glue distribution along the magnet, potentially resulting in the magnet becoming slightly eccentric on the shaft, leading to increased vibration. To mitigate this issue, motor designers may opt for a stepped shaft design to align and guide the magnet's inner diameter, providing a more uniform surface for glue distribution. Incorporating such design arrangements can help maintain the alignment of the magnet with the motor axis, thereby reducing unnecessary vibrations.

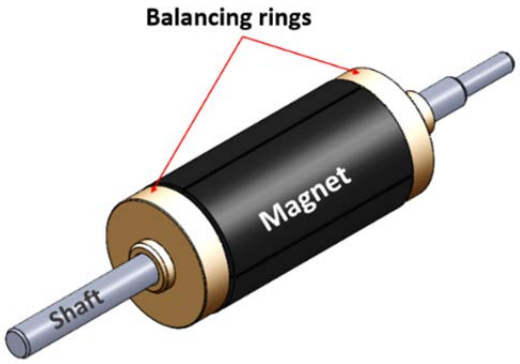

Image 1- Rotor balancing with balancing rings

BALL BEARING GREASE

Ball bearing grease often evaporates or loses its properties under the high temperatures and pressures of steam. When the grease diminishes, the ball bearing experiences heightened noise and friction, adversely affecting the smooth and quiet operation of dental hand tools. Designers must take special care in choosing the proper ball bearing grease, taking guidance from the manufacturer to ensure optimal performance during a targeted number of autoclave cycles.

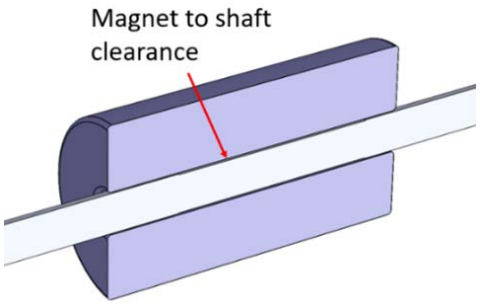

Image 2 – Example of a magnet and shaft assembly

BALL BEARING RADIAL CLEARANCES AND PRELOADING

The stator supports the rotor shaft using bearings, commonly employing deep groove ball bearings in BLDC motors to accommodate high speeds and radial/axial loads. However, ball bearings inherently possess radial play, a characteristic specified by manufacturers across all bearing sizes. Despite appearing minor, this radial play can significantly influence motor vibrations. As the unbalanced mass will be the same as the whole rotor mass which rotates eccentrically within the radial play of the bearing, large vibrations can ensue. To mitigate this issue, ball bearings undergo preloading with an optimal preloading force. Preloading diminishes free radial play and brings added benefits such as noise reduction and increased bearing longevity. Designers incorporate methods to maintain preloading integrity post-autoclave cycles.

DAMPING MATERIALS

Motors in dental hand tools operate at high speeds, which require additional vibration reduction techniques. Designers can add vibration damping components such as rubber O-rings or washers to improve bearing support. The selection of materials for damping components is crucial due to the targeted number of autoclave cycles. Under high temperature steam and pressure, many rubber materials lose their elastic properties and tend to plastically deform, impacting their damping effectiveness. However, due to technological advancements, design engineers now have access to synthetic rubber materials like silicon and Fluoro carbon rubbers that can maintain their properties within the autoclave environment.

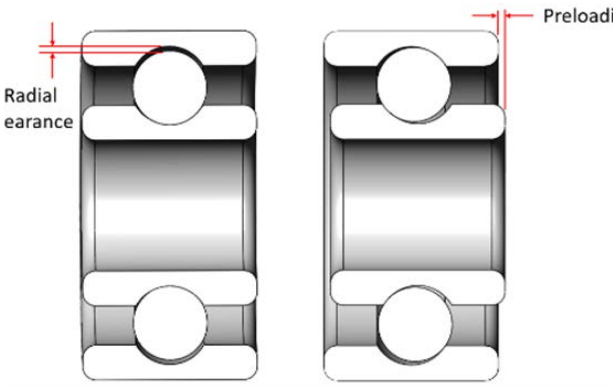

Image 3 - Ball Bearing radial play and preloading illustration

MAGNET PROTECTION AGAINST CORROSION (PLATINGS, COATINGS, SLEEVES)

Magnets tend to rust when exposed to steam due to their material composition. Rusting may cause small particles to chip off the magnet surface; this increases rotor imbalance, which in turn increases vibrations. Designers have several options to prevent magnet rusting, including employing various types of plating or coating. A metallic sleeve can also be designed to enclose the magnet and protect it from steam exposure.

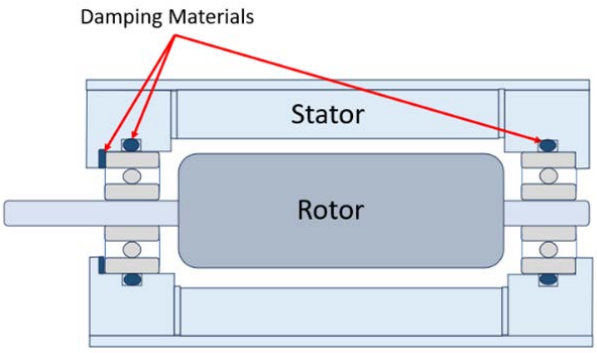

Image 4 - Vibration damping illustration

OTHER VIBRATION CONTROL METHODS

BLDC motor manufacturers must also carefully consider critical design elements. These include implementing effective sealing mechanisms to prevent steam infiltration, choosing materials capable of enduring high temperatures, pressures and humidity, ensuring proper electrical insulation, employing resilient electronics, and facilitating efficient heat dissipation. By addressing these aspects, BLDC motors can fulfill the exacting demands of sterilizable applications, delivering dependable and enduring performance in dental hand tools.

CONCLUSION

Motor vibration plays a crucial role in electric dental hand tools, influencing operator and patient comfort, tool longevity, and the types of procedures that can be performed. As the primary source of vibrations, the motor's characteristics significantly impact the tool's performance; this means design engineers must carefully evaluate the motor's design and technology type to mitigate vibrations. Tools that are subjected to autoclave cycles will also tend to increase vibrations and affect tool longevity. It is essential to address vibration control at the motor design stage using the methods outlined earlier. Consulting with a trusted motion solutions provider like Portescap can offer valuable expertise in managing vibrations of brushless DC motors effectively within dental hand tools.

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