Prospective electric motors for high speed medical instrument

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Abstract. The article discusses promising designs of high-speed electric motors for autonomous medical instruments. These machines ensure the creation of an autonomous electromechanical tool with low energy consumption, which predetermines the possibility of its use in field conditions. On the other hand, higher ergonomic indicators contribute to better performance of operations.

1. Introduction

Modern medical power tools are an integral part of the technical equipment of operating rooms. This applies especially to the workplace of a surgeon, a dentist in particular. For example, the preparation of tooth tissues is made with tools that rotate at different speeds from 2000 to 450000 rpm (turbine tips). The presence of turbine tips determines the use of a sufficiently powerful compressor, as well as the sources of power supply for micromotors.

It is obvious that a significant drawback of the existing medical instrument is the presence of hoses and too high variety of micromotors. Modern technology allows you change the tool to operate wirelessly while getting rid of the compressor. Two micromotors with rotational speed control ranges from 2,000 to 40,000 rpm and from 40,000 to 400,000 rpm are sufficient. The creation of such machines requires reducing losses in the steel of the magnetic circuit, at best, their complete exclusion. Obviously, only the contactless DC motor can cope with the tasks.

Currently, cordless drills are a serious competitor to their wired and pneumatic counterparts. Cordless drills have an undeniable advantage over other types of this tool, which is the complete absence of any wires or hoses and, as a result, an exceptional ease of use. The modern level of technological development allows us to develop a high-speed (400,000 rpm) electric motor that can replace turbine tips in pneumatic drills [1].

Thus, the use of contactless DC motors allows you to get a machine with a wide range of speed control. For drills from 2000 to 40,000 rpm and from 40,000 to 400,000 rpm. On the other hand, the low power consumption of these machines makes it possible to create a wireless (autonomous) power tool. Figure 1 shows the design of the electric motor, and Figure 2 shows the magnetic system design.
Figure 1. Electric motor design.

Main dimensions of the machine

| Dimension                                      | Value (mm) |
|------------------------------------------------|------------|
| Diameter of the output end of the shaft       | 30         |
| External diameter of the cartridge            | 32         |
| Sleeve thickness inside the magnet            | 0.8        |
| Diameter of the sleeve inside the magnet      | 3.0        |
| Magnet height                                 | 2.0        |
| Diameter of the inductor (magnet)             | 8.0        |
| Gap between the anchor and the magnet         | 0.25       |
| Internal diameter of the armature winding     | 8.5        |
| Anchor Winding Thickness                      | 0.5        |
| Outer diameter of the armature winding        | 9.5        |
| Gap between the anchor and the magnetic core  | 0.25       |
| Internal diameter of the magnetic core        | 10.0       |
| Thickness of the magnetic armature            | 0.75       |
| Outer diameter of the armature magnetic circuit| 11.5      |
| Gap between a magnetic conductor and the case | 0.25       |
| Inner diameter                                | 12.0       |
| Shell thickness                               | 0.4        |
| Outer diameter                                | 12.8       |
| Active anchor length                          | 6.0        |
| Active magnet length                          | 6.5        |

Figure 2. Transverse electric motor geometry.
2. Features of the developed machine
In the design of the machine there are no threaded connections. The body of the machine and the front bearing shield are made as one piece. An anchor of the electric motor 2 is installed in the casing 8. The anchor of the electric motor 13 is a hollow frameless structure, the conductors of which are fastened with an epoxy compound. Thus, the winding is a monolithic unit that is installed inside the rotating magnetic circuit 7. It is fixed by means of the insulating sleeve 10 in the bearing shield 3. The ends of the winding are output through the sleeve in the housing 8. The bearing shield 3 is attached to the housing by means of adhesive bonding at the junction of the housing 8 and the bearing shield 3. The rotor or inductor 1 consists of a permanent magnet 5, non-magnetic sleeve 6, magnetic circuit 7, which are fixed to the steel sleeve 4 by means of adhesive bonding. Sleeve 4, in turn, is mounted on the chuck 11, which is intended for fastening the cutting tool [2, 3].

The rotor 1 is supported by two identical ball bearings 12. One bearing is installed in the casing on the drive side, and the other is installed in the bearing shield 3. The design of the electric motor allows operation at temperatures under 40 °C.

A feature of the armature of the electric motor is a smooth, non-skid construction, designed to apply a hollow winding, the conductors of which are fastened with an epoxy compound. Section sizes are shown in Figure 3, the layout of conductors is shown in Figure 4.

![Figure 3. Sizes of the winding section.](image1)

![Figure 4. Conductors layout scheme.](image2)

3. Modeling methods
When developing the design, the electromagnetic and thermal fields were simulated using the finite element method. The motor start-up dynamics were carried out in the MatLab Simulink environment.

The parameters of the machines for modeling the dynamics of motor start-up are presented in Table 1.

| Model Parameters | U, V | M, Nm | n, rpm | R, Ohm | L, mH | J, kg⋅m² | W, F, µW |
|------------------|------|-------|--------|--------|-------|----------|---------|
| U, V             | 24   | 0.00032 | 300000 | 0.328  | 1.25  | 5.71×10⁻⁸ | 225     |

We use the well-known mathematical model of a synchronous motor with permanent magnets (Figure 5) and consider the dynamics of motor start-up an electronic switch, which is controlled depending on the position of the rotor by a sensorless control system for zero-crossing EMF. The simulation results are presented in Figure 7 and 8.
\[
\begin{align*}
    u_d &= R \cdot i_d + L \frac{di_d}{dt} - p \omega L \cdot i_q \\
    u_q &= R \cdot i_q + L \frac{di_q}{dt} + p \omega L i_d + p \omega \Psi_m \\
    J \cdot \frac{d\omega}{dt} &= M_m - M_n \\
    M_m &= \frac{3}{2} p \cdot \Psi_m \cdot i_q
\end{align*}
\]

where \( u_d, u_q \) – voltage on the stator windings in d and q axes; \( i_d, i_q \) – currents in the stator windings along the d and q axes; \( R \) – active resistance of stator windings; \( L \) – stator winding inductance; \( \Psi_m \) – the flux linkage of the stator winding from the permanent magnet field; \( M_m \) – electromagnetic moment of the electric motor; \( p \) – the number of pairs of poles; \( J \) – moment of inertia of the rotor; \( \omega \) – rotor angular speed; \( M_n \) – load moment.

In case of discrepancy between the nominal values of the speed and the moment of the machine, obtained in the electromagnetic calculation, and the values obtained as a result of the simulation of the motor start, it is necessary to correct the winding data.

4. Results
The simulation results are presented in Figure 6 - 9. The linear view of the mechanical characteristic in Figure 6 shows that the inductance of the armature has no significant effect on the operation of the electric motor. Figure 7 shows the change in the speed of the electric motor during start-up and the time of its exit to the steady state, which corresponds to 1.2 seconds. Figure 8 shows the form of voltage in a quasi-steady state. The thermal state of the electric motor is characterized by the relationship between the temperature of the armature winding exceeding the ambient temperature (in Figure 9). The graph shows that during the time of 120 seconds, the temperature rise of the winding does not reach the steady-state value; however, the actual operating time of the tool does not exceed 20 seconds.
Figure 6. Mechanical characteristics of the motor (Baseline values: $P_b = 10.81$ W; $I_b = 0.477$ A; $M_b = 0.00032$ N·m, $n_b = 300000$ rpm).

Figure 7. Change of speed at start.
Figure 8. Linear voltage $U_{av}$ in a quasi-steady state.

Simulation of the temperature field of an electric motor in dynamics is shown in Figure 9.

Figure 9. Change in temperature rise of armature winding above ambient temperature.

5. Conclusions
Leading manufacturers such as BOSCH, BinAir, e.t.c. are engaged in the development of an autonomous medical instrument. However, there are still no autonomous power tools on the market.
with the characteristics discussed above. In the machines under consideration, high-coercive permanent magnets based on the Nd-Fe-B composition are used. In combination with a hollow anchor, you can get the most efficient use of magnetic material, as well as carry out the simultaneous rotation of the magnet and magnetic core, thus eliminating the magnetic reversal of the magnetic core and, as a consequence, the loss in steel, which significantly depends on the rotation frequency. In fact, the stamping production is excluded from the technological process of creating a machine. In addition, these machines are very technological.

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