A top-face-sway electromagnetic micromotor

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In this paper, the structure of a top-face-sway electromagnetic micromotor and its principle, fabrication and performance are introduced. A combination of the electromagnetic actuating and the planetary reducing provides this micromotor an advantage of low rotational speed and high torque. In addition, since a flexible coupling absorbs the sway and only outputs rotation, it gives this micromotor a balanced output. The dimension of the micromotor is 5 mm. Its rotation speed has a range of 20 – 860 rpm, and its driving current is 300 mA. The output torque of the micromotor is measured to be 13.0 μNm.

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As a microactuator, the micromotor plays an important role in the micro optical electro mechanical system (MOEMS). So many researchers have been working on it[1]. The electrostatic micromotor[2−4], the piezoelectronic micromotor [5,6] and the electromagnetic micromotor[7−13] have been successively developed since then. Among which, the electromagnetic micromotor is thought as an ideal one because it has larger output torque and higher efficiency, etc. Many results on the electromagnetic micromotors were reported during the last decade, the details can be found in the references[7−13].

Some electromagnetic micromotors used currently had higher rotational speed and lower torque. In that situation, a decelerator was needed both to reduce the rotation speed for connecting and matching other mechanical parts and to increase the output torque of the micromotor for driving the mechanical parts connected with it. However, it was not easy to fabricate such a decelerator in a microelectromechanical system, especially a decelerator with a big decelerating ratio. Moreover the micromotor with a decelerator generally had bigger dimension. We introduced a novel electromagnetic micromotor entitled a top-face-sway electromagnetic micromotor, which used a flexible coupling in its structure. The flexible coupling absorbed the sway and only output rotation, so the micromotor was measured to have a higher torque with same or lower rotation speed. Furthermore we used a structure, which combined the electromagnetic actuating and the planetary reducing, in the micromotor, so it had a smaller dimension with the same performance. In the rest of the paper, we will introduce the structure and the working principle of the top-face-sway electromagnetic micromotor, describe its fabricating process and show some measured results.

Figure 1 briefly shows the working principle of the micromotor. The motor's stator was a cylinder with a conical inner surface, and the conical surface was its working surface. The rotor was a cone and its outer conical surface was the working surface. The stator's inner surface and the rotor's outer surface shared a common conic node but there was a different angle α between their cone apex angles (we called this angle α as the swaying angle of the rotor). Inside of the stator, there were well-distributed coils. The top-face-sway electromagnetic micromotor worked in such a way: When the coils were driven sequentially by the driving current, a rotation magnetic field came into being in the stator, and the rotor started a pure circumference rolling along the stator's inner surface under that rotation magnetic field. There were two kinds of motions included in the rotor motion. One was the rotation of the rotor around its instantaneous axis, and the other was the sway of the rotor to the conic node. In order to output the rotation but absorb the sway of the rotor, a flexible coupling was put between the rotor and the axis of the micromotor.

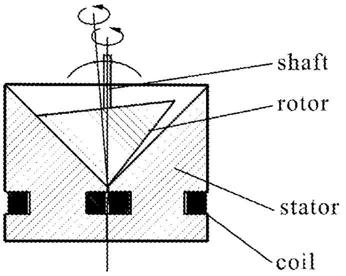

Fig. 1. The working principle of the top-face-sway electromagnetic micromotor.

In order to decide the parameters of the top-face-sway electromagnetic micromotor, the conic apex angle 2β of the stator and the swaying angle of the rotor α should be decided firstly (see Fig. 2). And then the dimension of the micromotor, the parameters of all the mechanics parts of the micromotor can be easily decided. From Fig. 2, the motion of the rotor can be regarded as the fixed-point rotation around its conic node. Axis OZ is coincidence with the center line of the stator. The swaying angle α is the angle between the center line of the stator and the center line of the rotor. The angle β is the half of the conic apex angle of the stator. According to

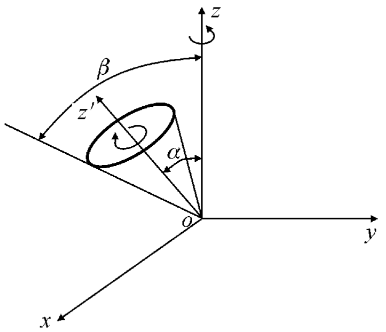

Fig. 2. The motion of the rotor of the top-face-sway electromagnetic micromotor.

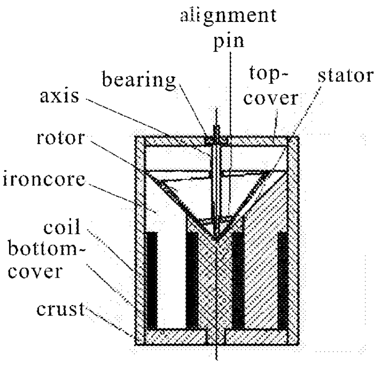

Fig. 3. The mechanical structure of the top-face-sway electromagnetic micromotor.

the principle of kinematics analysis and some mathematical derivation, we got the equation for calculating the output rotation speed of the rotor[14]

$$\frac{\omega}{\omega_f} = \frac{\sin\alpha}{\sin(\beta - \alpha)}, \tag{1}$$

where ω is the angular velocity of the rotor, ω_f is the angular velocity of the rotation magnetic field.

Figure 3 shows the mechanical structure and some main mechanical parts of the top-face-sway electromagnetic micromotor. The overall profile of the micromotor was a cylinder. The stator was a cylinder with a conical inner surface that was matched with the conical outer surface of the rotor when the micromotor was driven. The material of the stator was polysulfone. Inside of the stator there were several coil cores for coils. The rotor was a cone with the wall-thickness of 0.5 – 1.0 mm and it was made of the permanent magnetic materials, such as permalloy. Within the rotor there was an alignment pin with a square hole. The bottom end of the output axis was connected with the inner conic node of the rotor. A diamond axle bearing was placed in the top cover, and the output axis came out through the diamond axle bearing.

We fabricated the top-face-sway electromagnetic micromotor by means of microprocess technique in the micromechanics. Firstly we fabricated special micro-tools such as micro-cutters and micro-clamps, by using them we fabricated and placed the stator, the rotor and the coils. We also got a special kind of method for aligning and fixing all the mechanical parts together to be the micromotor. Figure 4 is a photograph of the top-face-sway electromagnetic micromotor together with a coin of one Chinese Yuan.

The rotation speeds of a top-face-sway electromagnetic micromotor under different magnetic field frequencies were measured. The main parameters of the top-face-sway electromagnetic micromotor were that the diameter of the micromotor 5 mm, the angle β was 45 degrees, and the angle α was 5 degrees. The rotation speed of the rotor could be expressed as $\omega = 0.136\,\omega_f$ according to Eq. (1). Table 1 shows the measured results of the output rotation speed of the rotor. Figure 5 shows the characteristic curve of the output rotation speed of the micromotor, in which the straight line describes the theoretical results and the line with dots show the measured results. We can see from this figure that the bigger the magnetic field frequencies became, the higher the output rotation speeds were. The measured results matched better with the theoretical values when the values of the magnetic field frequencies were lower. But the measured output rotation speed of the micromotor was getting much higher than the theoretical results. That was because that the motion of the rotor within the stator varied from pure rolling to the combination of the rolling and sliding when the rotation speed of the micromotor became higher. In this situation, the motion of the rotor became much like the motion of a stepping motor, so the theoretical equation we used was not valid any more.

Besides we developed a testing equipment with the testing range of 0.25 – 300 μNm for the measurement of the output torque. The main part of the testing equipment is a plate-shaped torsional-spring, the output torque was measured by testing the change of the angle of the torsional-spring. The output torque of the top-face-sway electromagnetic micromotor was measured to be 13.0 μNm.

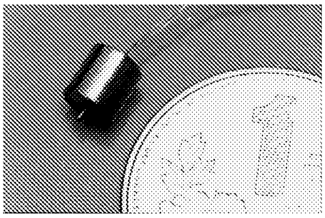

Fig. 4. The outlook of the prototype of the top-face-sway electromagnetic micromotor.

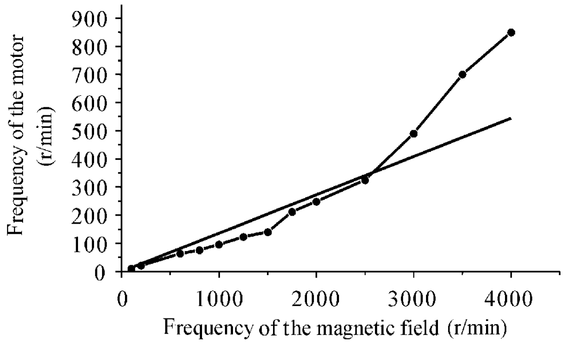

Fig. 5. Characteristic curve of the output rotation speed of the top-face-sway electromagnetic micromotor.

Table 1. Measured Results of the Output Rotation Speed Along with the Magnetic Field Frequencies

Frequency of the Magnetic Field (r/min)	100	200	600	800	1000	1250	1500	1750	2000	2500	3000	3500	4000
Frequency of the Rotor (r/min)	10	21	63	76	96	123	140	212	248	325	490	700	850

A top-face-sway electromagnetic micromotor was described in this paper. The dimension of the micromotor was 5 mm, and the driving current for it was 300 mA. The rotation speed of the micromotor had the range of 20 – 860 rpm and could be rotated in two-direction. The output torque was 13.0 μNm. The top-face-sway electromagnetic micromotor had larger output torque with lower rotation speed, lighter weight and smaller dimension. As one of the key units in the microelectromechanical systems, it can be applied in the fields of the microoptics, the robots, the space detectors, the medical devices, and the miniaturization of the medical equipments.

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