

Research status and development trends of Electrostatic Motor

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Abstract. In recent years, because the capacitance variable type has a series of advantages such as simple structure, low cost, a slight loss, and is suitable for ultra-high temperature and strong magnetic field, researchers have been conducting continuous research on electrostatic motors. The authors are studying hardware neural networks (HNN) by the electrostatic motor that is the new actuator of the microrobot in previous research to control the microrobot's locomotion. In another article, they simulated the motion trajectories and motor output was analyzed for different operation speeds in different liquid viscosities and how they impact the output performance of a motor. In this article, the authors will introduce the current research status of the latest electrostatic motor in recent years and propose the development trend of capacitive variable electrostatic motor research.

Keywords: Electrostatic; motor; Electrostatic motor; HNN; microrobot

1. Introduction

An electrostatic motor is an energy conversion device that uses static electricity as an energy source [1]. It has the advantages of simple structure and high no-load rotating speed. With the further development of MEMS (Micro-Electro-Mechanical Systems), the development of electrostatic motor as a critical component of MEMS has attracted more and more attention. Currently, electrostatic motors have been used in some situations where no power output is required. The development of electrostatic motor as the critical component of MEMS has attracted more and more attention. An electrostatic motor is an energy conversion device that uses static electricity as an energy source[2][3]. It has the advantages of simple structure and high no-load rotating speed. However, there are also disadvantages such as low power and difficulty starting. The developed countries are competing to develop electrostatic motors and have made some progress. In consideration of the importance of MEMS in promoting the development of the national economy and military technology, China's Commission of Science, Technology, and Industry for National Defense have included MEMS in the ninth Five-Year National defense pre-research project. China have attempted to replace traditional electromagnetic motors in the field of aerospace satellites and medical devices.

2. New development of electrostatic motor

At present, electrostatic motors have been used in some situations where no power output is required, such as optical and magnetic fields. Electrostatic motors using surface micro-machining studied by the Toyota Central Research Institute in Japan are used to drive a micro-mechanical optical chopper. By applying a voltage of 100V between the motor electrodes, a corresponding pull force of 0.4 μN is generated shifts the grid by 2.5 μm . With the continuous development of Micro Electro Mechanical System (MEMS) and the continuous in-depth research of the basic theory in the micro motor, as the power of micro-machinery, will give full play to its advantages and have broad application prospects in various tiny and complex micro-environments.

For example, Nannan Zhao and Fei Lu conducted a 3-D finite element analysis (FEA) simulation and optimization process of electrostatic motors based on dielectric electrostatic motors. Losses including friction loss, windage loss, and dielectric loss are predicted. Thermal fields are analyzed using FEA, and the electrostatic motor presented can work stably at high ambient temperatures. To build a prototype machine to eliminate the process of mold manufacture and achieve a weight

reduction, use 3-D printing. The predicted capacitance of the machine is compared with the measured result, and good agreement is achieved.[4]

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At present, the research and development of electrostatic motor is still in the exploratory stage, which can be further carried out in the following aspects:

(1) As the size of electrostatic motor becomes smaller, friction has become the biggest factor restricting the life and performance of electrostatic motor (the life of electrostatic motor is generally calculated in hours). Meanwhile, the friction force also directly affects the efficiency of the electrostatic motor. For the super-micro electrostatic motor, the friction force is mainly caused by the interaction force on the surface, but not the load pressure. So the traditional macroscopic friction theory and research methods are no longer applicable. It is necessary to study the microscopic friction theory to get a boundary conditions in a small mass and little pressure with no friction, no wear to solve the above problems.

(2) The driving torque of the electrostatic motor is still relatively too small, which limits its scope of application. In order to realize the movement of long-distance heavy load of electrostatic motors, new manufacturing materials and new structures are needed. Also, the transmission mechanism between the electrostatic motor and the driven object should be studied[6].

(3) Because the external size of the electrostatic motor is relatively small, especially its structure is mostly flat (the radial diameter is greater than the axial length), a 3-D field analysis is required for the electrostatic motors. And generally, we should take finite element method (FEM) or boundary element method (BEM). Establish an analytical model (also called the aggregate parameter model) by the calculation of 3 D electrostatic field. And then the optimization of voltage excitation and shape size is combined to achieve the automation of electrostatic motor.[7]

3. The advantage of Electrostatic Motor

First, in terms of structure, the structure of electrostatic motor is simple. The electric field strength generated by the surface of electrode is independent of the thickness of electrode and the cross-sectional area of the electrode and wiring can be made to be very small.

Second, the field strength of electrostatic motor is only influenced by the performance of insulating material. Reducing the size does not affect the strength of the electric field and the force generated is proportional to the area of surface. Usually, the smaller the size of the insulation material, the stronger the performance is. According to the Panchen law[8], the smaller the gap, the electric field strength generated by the electric discharge in the air more sharply increases. For example, silicon oxide film is an insulating material and its insulation strength can reach several hundred kV / mm. Therefore, the electric field energy density generated by a miniaturized electrostatic motor can be comparable to that of an electromagnetic motor.

Third, compared with the electromagnetic motor, the electrostatic motor has a high energy conversion efficiency.

Based on these characteristics of electrostatic motors, many countries have started the research on miniaturized electrostatic motors. With the rapid development of electronic technology, silicon processing technology gradually mature and processing size of integrated circuit can be achieved sub-meters level. In this context, Muller of the University of California, Berkeley proposed the concept of MEMS with intelligent structure based on silicon integrated process within the range of 1 μm ~1mm in 1987. By 1989, L. S. Fan and other students in that school had successfully made a

120 m-diameter electrostatic motor on a silicon wafer. Since then, the development of electrostatic motor mainly focuses on the super micro-structure[9].

Three technologies for making electrostatic motor in Japan, America and United States and Germany:

The first is the traditional machining means of using non-lithography methods (such as cutting and grinding of metal and plastic parts), that is the use of large machines to make small machines, and then using small machines to make micro machines. In Japan, the scientists believe that the future of producing electrostatic motors is not only limited to silicon and the silicon are one of the materials that people can use.

The second is the surface super-micro fabrication technology represented by the United States, which uses the combination of sacrificial layer technology and integrated circuit process technology to process silicon materials.

The third is the LIGA [10]technology represented by Germany, which uses X-ray lithography technology to electroforming and casting a deep micro-structure. This method allows for three-dimensional micro-processing of multiple metals and ceramics. The second method is compatible with the traditional IC process, which can realize the system integration of micro-machinery and microelectronics. And it is more suitable for mass production, which has become the mainstream of ultra-micro electrostatic motor production technology.

4. Operating Principle of the Electrostatic Motor

One is to use the principle of dielectric relaxation and the other is to use the principle of variable capacitance.

Electrostatic motors using the principle of dielectric relaxation are generally known as electrostatic induction motors or asynchronous dielectric induction motors [11]. The specific principle is as follows [12]: if a dielectric rotor is placed in a rotating electric field, then the charge will be induced on the surface of the rotor. Due to dielectric relaxation, these charges will lag behind the rotating electric field and the offset between these induced charges and the rotating electric field will create a torque acting on the rotor. If the rotor is composed of a variety of media, then different dielectric relaxation processes are superimposed to act at different frequencies. This motor is called "asynchronous" because the angular velocity of the rotor is smaller than the angular velocity of the rotating electric field. The torque and efficiency of the motor both depend on the ratio of the rotor angular velocity to the rotating electric field angular velocity.

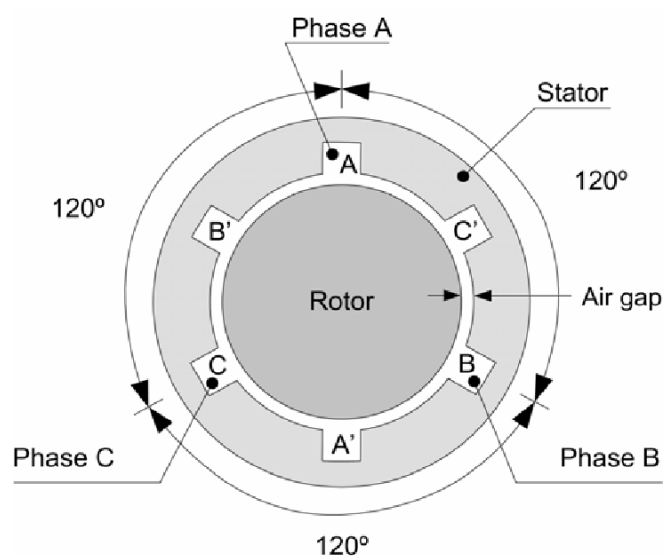


Figure 1. Induction motor [13]

Induction electrostatic motor has its own advantages: first, the induction motor relies on dielectric rotation to establish the charge distribution on the rotor, rather than relying on the convex pole structure of the rotor. So the rotor of the induction motor can be smooth and uniform, or even liquid. Therefore, in terms of the manufacturing process, the induction motor has advantages over the variable capacitance motor.

Second, the induction motor runs asynchronously, so it can obtain better operating performance without requiring feedback of the rotor position.

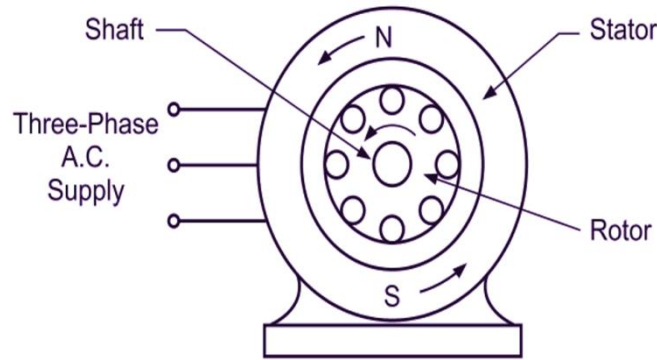


Figure 2. Induction motor

Third, the characteristics of bearing friction and wear can be improved in a specific operating state of the induction motor. However, because the electric performance of the dielectric induction motor material has a great impact on the operation of the motor, so for the induction motor, the control of the material conductive performance becomes difficult in the design and production.

Electrostatic motor using the principle of variable electric capacitance refers to the mechanical displacement based on the electrostatic energy trends between charged plates, which makes the two electrodes close to each other and reach a stable position with a minimum energy. The stator of the motor is a stationary electrode and the rotor is a mobile electrode. By limiting the degree of freedom of the rotor to the stator direction, the rotor can obtain a single direction of displacement. Capacitive variable electrostatic motor is simple in structure and it is composed of good performance insulator and conductor. And a simple open-ring voltage pulse is enough to activate it.

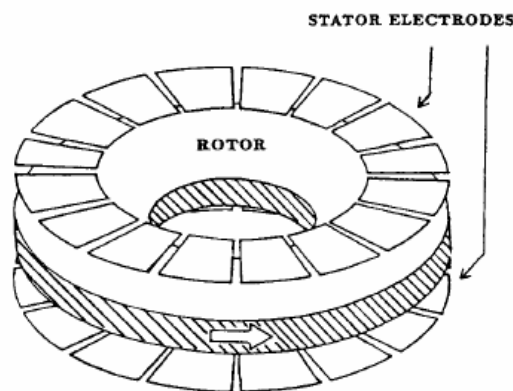


Figure 3. variable electric motor

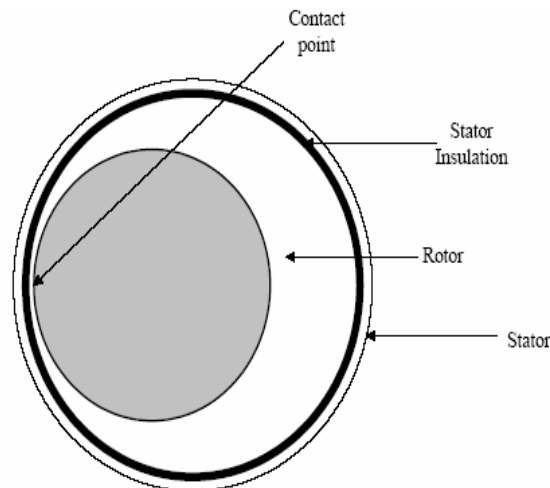


Figure 4. variable electric motor

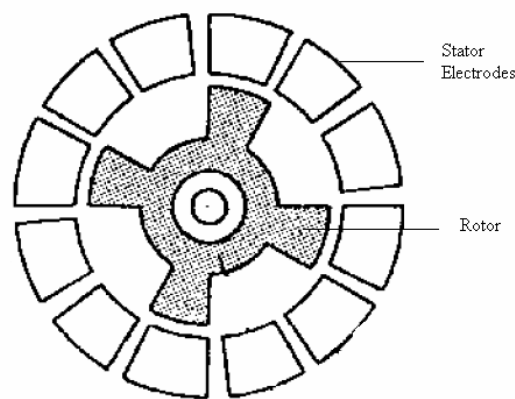


Figure 5. micro variable capacitance electromechanical energy converter [14]

Variable capacitance electrostatic motor also has some disadvantages: first, in order to operate, we must ensure that the capacitor between the fixed rotors is variable. Therefore, the rotor of top drive and side drive motor must be a convex pole structure. Making such a structure into flat surface requires complex process. Second, in order to obtain large capacitance variance to improve the drive torque, the air gap between the fixed rotors needs to be reduced, which increases the difficulty of processing. Third, the variable capacitance electrostatic motor is a synchronous motor, so even minimal operation requires feedback of the rotor position, which can be a very serious disadvantage. Finally, the rotor is susceptible to transverse electric field forces, which cause friction and wear of the bearing.

5. Conclusion

From my point of view, electrostatic motors will be used in a broader range of places. Such as artificial intelligence, neural networks, chips, micro-robots, and other fields. It also expands into various production methods. For example, it is already possible to make electrostatic motors using 3D-print, which have the same effect as predicted. And researchers continue to make progress towards simple structure, low cost, lightweight, and high efficiency. I expect that electrostatic motors will stand on a broader platform with the constant maturity of artificial intelligence technology and neural network technology and will be an essential part of the human-brain connection.

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