Design and FEA of a Linear Electrostatic Motor

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ABSTRACT

A linear electrostatic motor was proposed and analyzed by using FEA method. The device consists of a single 3-phase electrode structure stator sheet which drives a nonconductive slider directly via electrostatic force. Stages of the operation respectively are (a) electrostatic charges are induced over the slider surface (b) stator polarity changes (c) a motive force is appeared between the stator electrodes and slider and consequently moves the slider. In this paper, we analyzed the magnitude of attraction and repulsive forces caused by applied voltage on stator and conversely, we calculated the least needed voltage to create motive force. This simple structure of device can be used in many fields such material handling, positioning system and separators. Because the electrostatic forces are distributed over entire surface of slider, it can drive both thin and delicate nonconductive material. Since performance is sensitive to humidity changes, this electrostatic technology needs a dry ambient to operate .Some experiments were conducted to verify the functionality of the proposed linear electrostatic motor, during the experiments many nonconductive material such as paper and cloth have been tested as moved material and could be propelled when the relative humidity condition was less than 30%.

INTRODUCTION

The electrostatic actuator has a good scaling law for miniaturization. In the past years, various micro sized motors were developed.

Most of the micro-motors developed so far are side-drive motors. The side-drive generates electrostatic force on the edge of a disk shaped rotor. it doesn't need layered construction of electrodes over the rotor, and the clamping force between the rotor surface and the substrate is small. However, most of the rotor surface area except its edge does not contribute to force production.

The cylinder harmonic or wobble motor drives its rotor on the surface, but, internal volume of the rotor is ineffective for field interaction. When a large force is demanded, an actuator based on these motors must contain many small rotors and add their forces.

We have developed one type of linear electrostatic motor*, film actuator*.

In a linear electrostatic, a thin slider slides on a planar stator equipped with electrodes. It can attain high force per area and produce a total force simply proportional to the overlapping area of its stator and slider.

In the previous work, T. Higuchi has developed several type of surface –drive motors, consisting of stator with three-phase and two phase electrodes and slider coated with slightly conductive material.

This paper describes a kind of film actuator recently developed. We have fabricated a new stator with three-phase electrodes. FEA is also described.

STRUCTURE

We have developed one type of linear electrostatic actuator. A three –phase motor, already reported in [2], this structure is useful for operation but three dimensional fabrications is needed to connect two power lines to each electrode. In [1] authors have described that the slider must have resistively in the range of 10^{13} to 10^{15} Ω. Otherwise, charges cannot be induced on the slider in appropriate time.

Figure 1 shows the basic structure and operating principle. This motor is driven as follows:

(1) Positive and negative voltage are applied on the two phases of electrodes.(2)charge are induced on the slider. The charging process takes a time defined by the resistively of the slider.

(3) The polarity of voltages is rotated between electrodes. This causes an instant change of charges on the electrodes, while charges in the slider are almost fixed since re-charging of the slider takes time. Charges on the stator and the slider produce a rightward motive force and an upward levitation

force.

(4) The slider moves about one pitch of electrode. This procedure can be repeated, shifting the voltage pattern applied to the electrodes.

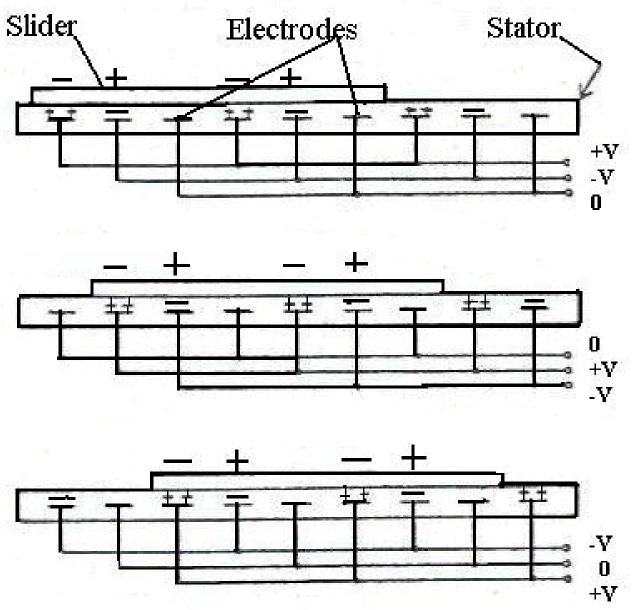

Figure1.principle of movement

ANALYSIS

The electrostatic force of the film actuator has been analyzed by the FEA method. In this type of electrostatic motor we are respectively encounter to (1) attraction force (2) repulsive force (3) motive force. We used ANSYS6.1 to analyze forces generated via electrical field. In this method, the surface of slider divided in to small parts and one of them was analyzed. Then obtained results were added together to get total force induced on the surface of slider. Figure 2 illustrates charge density on the surface of slider. We calculated charges induced on the slider, and then in next stage, we obtained forces. Produced force is given by balancing input, stored, and output energy in FEA method.
We analyzed electrostatic fields with various electrodes' pitch, and selected applied stator to move the slider (we selected paper as a slider).

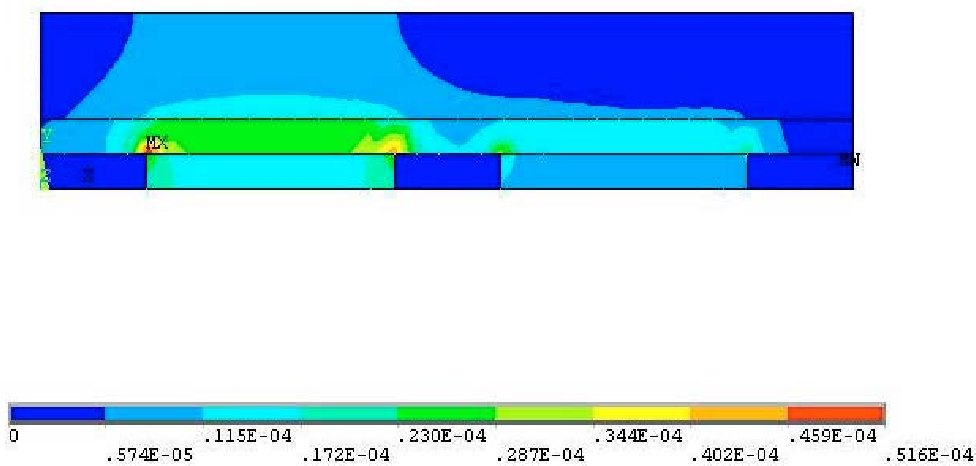

Figure2.charge density (c/m^2) on the surface of slider for a 1mm pitch stator (Applied voltage is 600 v)

We expect the maximum of net charges appear close to the gap between two electrodes, where the fringe field is most. FEA method reveals that the surface charge density is effective significantly higher in the mentioned region, as shown in figure.3.

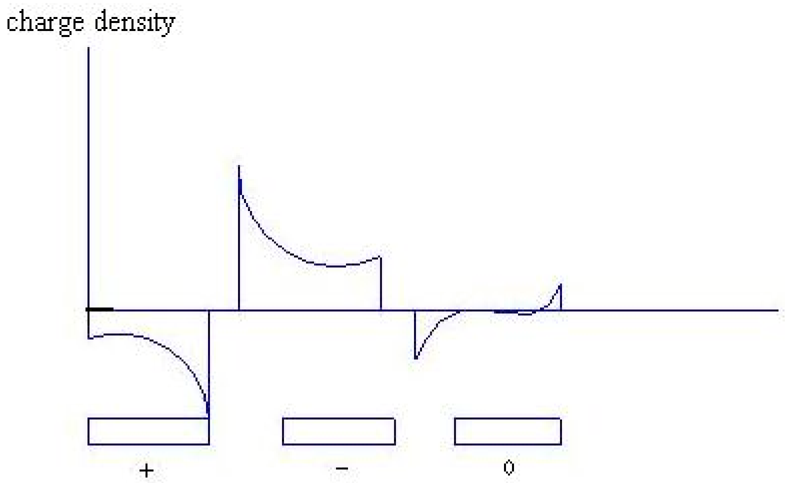

Figure3.schematic plot of the charge density distribution on a three-phase electrode

FABRICATION

Stators with (0.7mm and 1 mm)-pitched electrodes has been fabricated. The overall area of electrodes is 50×50 mm and copper electrodes with 0.3 mm width were etched on the electrical board. Two of the three common lines supply voltages to corresponding phases of electrodes on the upper side of the board. The third common line is placed on the back side and connected to electrodes by vertical conductors formed through the board. Figure 4 shows a manufactured device.

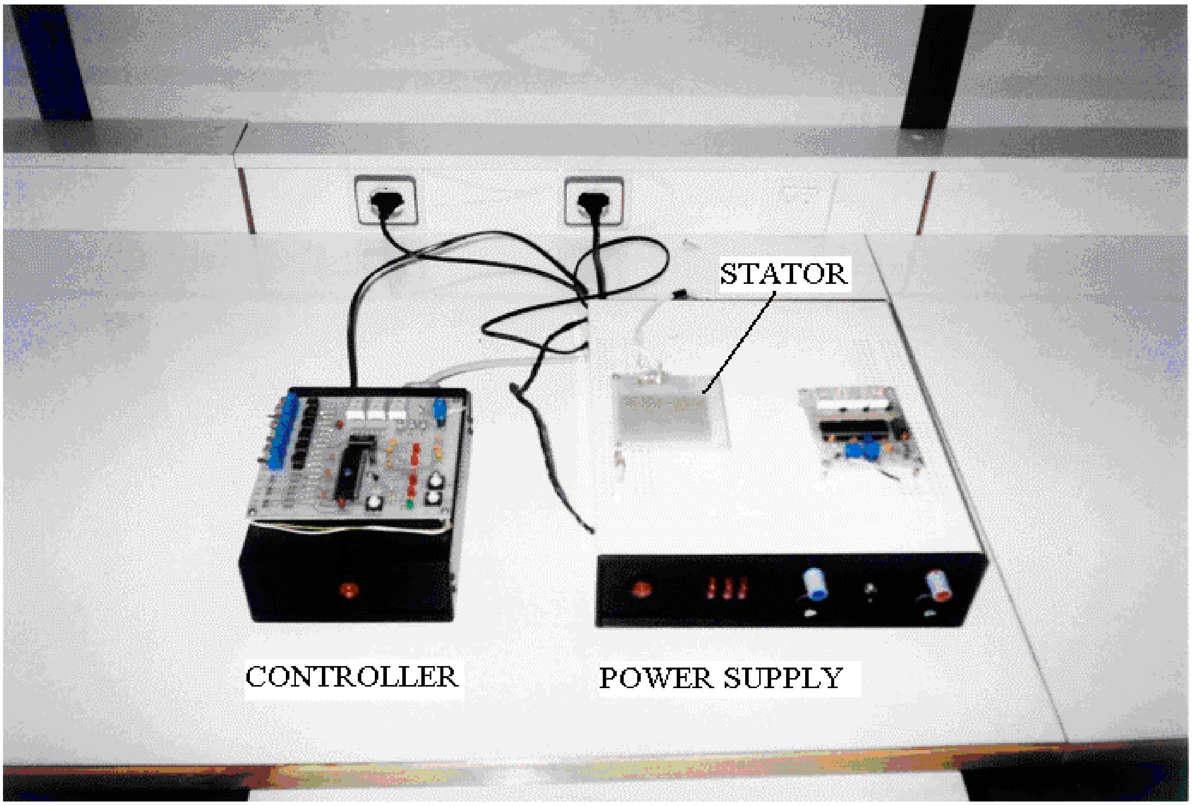

Figure4. Photo of experimental setup (the thickness of the electrodes is 0.3 mm)

The stator was driven by a high voltage amplifier. We applied maximum $\pm 600\,v$ on the upper

electrodes. It required a few seconds to induce initial charges on the slider. The minimum cycle time was 100 ms, that is, the velocity was 1 mm/s.
In the experiment above, friction between the slider and the stator is a limiting factor for performance. Friction in the film actuator is reduced by the electrostatic levitation force, but it still remains.
Resistively of the slider (paper) in the room atmosphere is 10^9 -10^{13} Ω. This electrostatic motor can move thin material with resistively over $10^{13}\Omega$. We have tested driving many kinds of paper in various conditions. Many papers can move if they are dried by heat, and some highly resistive paper can be driven with no special treatment. This electrostatic motor can be applicable to paper feeder in small printers or copiers. [3]

RESULT
Table 1 summarizes the experimental results reported in this paper. As the pitch of electrodes become finer, force per area increases even though voltage is decreased. This is because the field strength, which can be roughly evaluated by voltage/pitch, is increased. The force per volume increases more rapidly as the pitch is reduced since the height becomes lower.
Our experiments showed that electrostatic forces in linear electrostatic motors limit us to use it in miniaturized usages and handing thin materials.

Table 1.maximum performance of fabricated motor

Type	3phase	3phase
Electrode pitch [mm]	0.7	1
Driving voltage[v]	500	600
Max. driving Freq.[ms]	100	100
Velocity[mm/s]	2	1
Force/Area[N/m^2]	5	1.8

REFRENCES:
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