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Study of Parameters Affecting the Electrostatic Attractions Force

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***Abstract*—**This paper contains 2 main parts. In the first part of paper we simulated and studied three types of electrode patterns used in various industries for suspension and handling of the semiconductor and glass and we selected the best pattern by evaluating the electrostatic force, which was comb pattern electrode.

In the second part we investigated the parameters affecting the amount of electrostatic force such as the gap between surface and electrode (g), the electrode width (w), the gap between electrodes (t), the surface permittivity and electrode length and methods of improvement of adhesion force by changing these values.

***Keywords*—**Electrostatic force, electrostatic adhesion, electrostatic chuck, electrostatic application in industry, Electroadhesive grippers.

I. Introduction

ELECTROSTATIC force is used in printer toners in the printing industries, in painting and coating industries for the better adhesion of paint and coatings. Recently it's used in robotics industries for adhesion mechanism of wall climbing robots [1]. Also it's frequently used in the semiconductor industries for handling and moving the silicon wafers and display glass of LCDs [2], as well as the electrostatic suspension systems [3].

Handling of glass panels because of the small ratio of thickness to surface of them with mechanical methods creates several problems for manufacturers. In addition physical contact with the glass causes dirt and scratches on it. Because of this, the use of non-contact systems is essential. The best contactless functional system is electrostatic suspension and handling systems [4].

Electrostatic adhesive force affects all materials: glass to steel and it's practical on any surface quality: perfectly smooth to rough surfaces. In addition, it doesn't require a complicated system thus the systems can be extremely lightweight and portable.

The most common commercially available wall-climbing robots use suction cups [5] to create adhesion to some types of substrates [1]. Suction cups work only on smooth and nonporous surfaces, and need heavy pump system that usually has low energy efficiency. However, they can generate considerable adhesion force. Magnetic wheel robots work only on ferromagnetic walls. More recently, "dry adhesive" technologies that mimic gecko feet with tiny setae have been explored [6]-[8]. These "dry" adhesives work using Van der Waals forces of attachment and offer good clamping forces with no residue left behind on the climbing surface. However, both conventional as well as "dry" adhesives suffer from being "always on," which implies that they reduce their effectiveness over time by attracting dust, and require some power to overcome the adhesive forces in peeling away from the substrate during the robot motion [9], [10]. On the other hand, electrostatic forces are relatively small and very sensitive to the distance and it doesn't effect on some certain plastics.

This paper tries to 1. Simulate the geometry of the electrodes with different designs and choose appropriate design, 2. Investigate the parameters affecting the generated electrostatic force.

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II. Simulation of Patterns

"COMSOL Multiphysics 4.2" was used for simulation. This software has the ability to provide various analyzes of several physics. For this paper, the electrostatic physics and time-dependent module were used.

A. Model

Three different patterns Shown in Fig. 1 (the shown patterns in figure are schematic) was simulated, all patterns have the same area, and each has two electrodes.

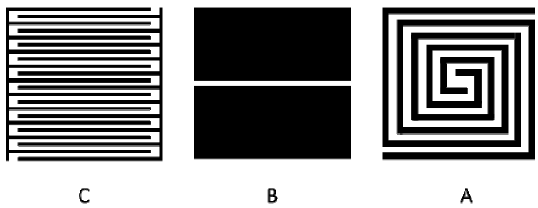

Fig. 1 Schematic layout of the proposed

Patterns modeled in three-dimensional space in dimensions of 100 mm * 100 mm. The width of electrodes was 1 mm in each of A and C models and the gap between the electrodes was 1 mm. In the Pattern B, each electrode's area was 49 mm* 100 mm and the gap between electrodes was 2 mm. The gap between the electrodes and the surface was selected 0.2 mm in all three patterns. Decreasing this gap caused an extremely increase in analysis time. And since the conditions are same for all patterns, this choice does not affect the comparative results.

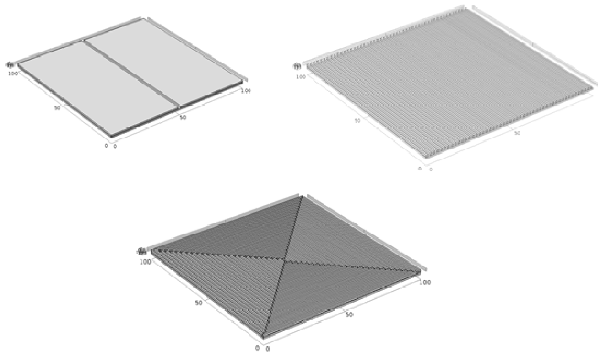

Fig. 2 The model of patterns

Free triangular mesh was performed. Electrodes material was selected as copper with a very low permittivity (0.01) and for the surroundings of the electrodes and between the electrodes and surface air was chosen with 1.005 permittivity and the permittivity of the surface was chosen 4.6 for glass.

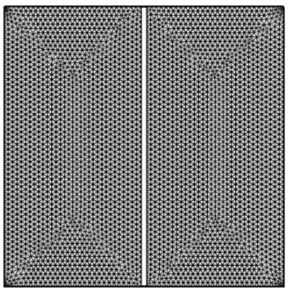

Fig. 3 Pattern B's mesh

B. Simulation

The increasing voltage was applied with a slope of 2000 V/s and the following results were obtained.

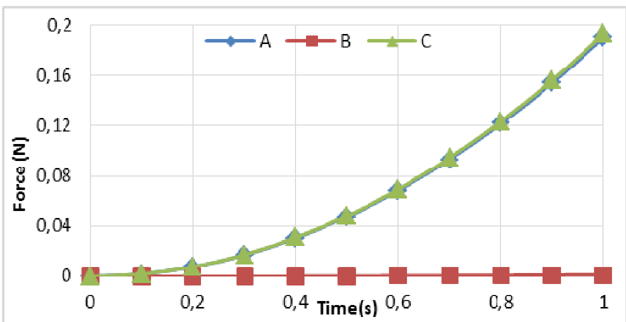

Fig. 4 Calculated force for three patterns

As seen figure the relation between Voltage and force is parabolic. Achieved force for Pattern B is much lower than that obtained for the two other cases.

Force calculated for the other two patterns were very close together, but the finer mesh shows that Pattern C (comb electrodes) can generate greater electrostatic force. Maximum force obtained for each pattern is shown in Table I.

TABLE I
MAXIMUM FORCE GENERATED FOR 2000V VOLTAGE IN VARIOUS PATTERNS

C	B	A
0.193118	0.00133	0.19048

III. EVALUATION OF AFFECTING FACTORS

Based on the results of the previous section comb electrode Pattern (C) provides more adhesion force than other patterns. So the other affecting parameters on adhesion force are evaluated on this pattern.

The pattern (C) was simulated in two dimensional space and the effect of voltage, gap between the electrode and the surface (g), the electrode width (w), the distance between electrodes (t), permittivity of surface and the electrode length (perpendicular to the figure) on the electrostatic adhesion force is analyzed (Fig. 5).

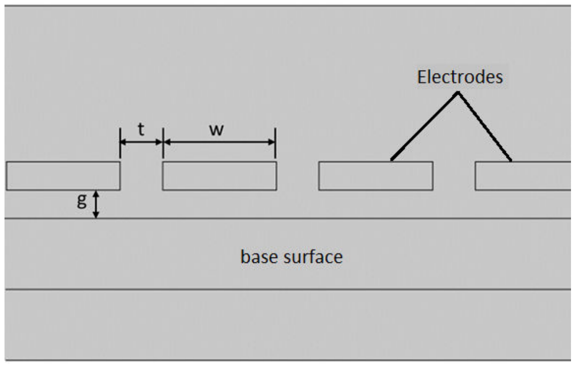

Fig. 5 Parameters in the Two-dimensional model

Fig. 6 implies the stress of the surface by applying voltage to the electrodes.

Stress is calculated by Maxwell stress tensor equations [11] and it is observed that the maximum stress occurs at the edge of electrodes. So it is natural to see that Pattern B has the least force.

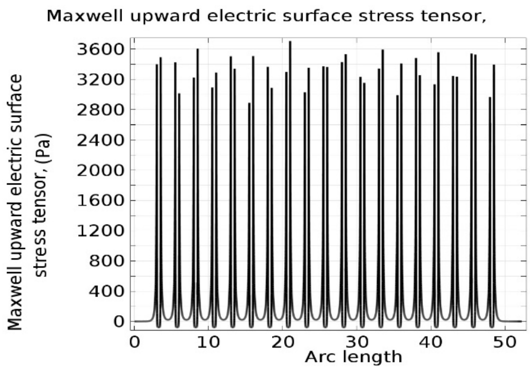

Fig. 6 Stress on the surface

Force increases parabolically compared to applied voltage (Fig. 7).

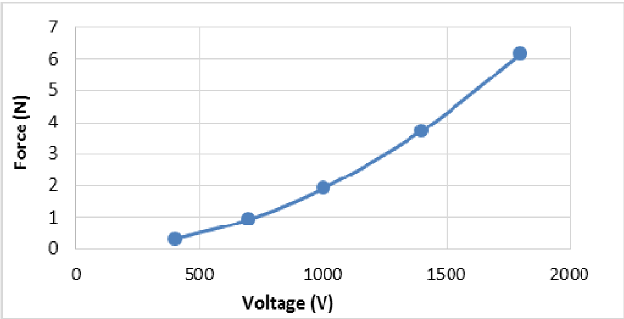

Fig. 7 Graph of adhesive force and voltage

In Fig. 8, the graph of adhesion force to the distance between electrodes is shown. By increasing the distance between electrodes the force decreases, so the less the distance between electrodes, the more the adhesive force is obtained. But there is a limit to the dielectric breakdown. In this model, the material of gap between the electrodes is air with 1.005 permittivity that's breakdown voltage is about 3000V/mm so the minimum gap to avoid dielectric breakdown must be considered.

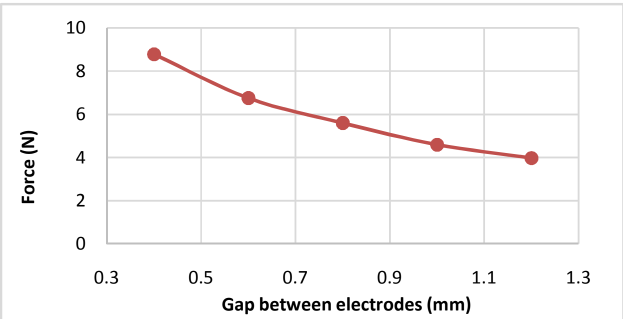

Fig. 8 Adhesive force compared to gap between two electrodes

Fig. 9 shows the relationship between adhesion force and width of electrodes. It seems that the electrode width doesn't have any effect on the adhesive force directly. But it should be noted that by increasing the width of electrodes, the number of electrodes per unit area decreases and as shown in Fig. 6 the Maxwell stress is created at the beginning and end of the electrodes. Therefore force is result of potential gradient between the electrodes, so as a result it's better to choose the width of electrode lower as much as possible to obtain more adhesion force. Fig. 9 shows the effect of electrode width on electrostatic force by ignoring its effect on electrodes number.

The relative permittivity of surface has a direct relationship with the electrostatic force and this is shown in Fig. 10.

Fig. 11 shows the inverse relationship of the electrodes and the surface gap between adhesion forces. It is seen that for a small increase in the gap the force dramatically decreases.

In Fig. 12 the effect of electrode length on electrostatic force is shown.

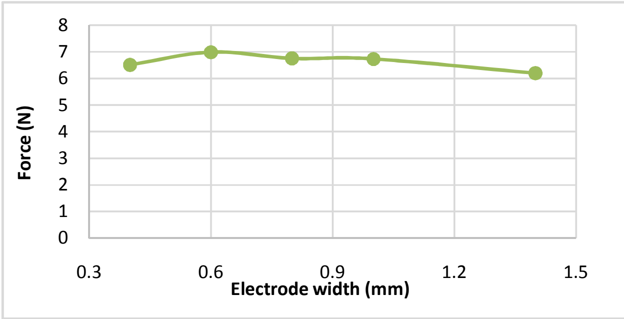

Fig. 9 The adhesive force compared to width of the electrodes

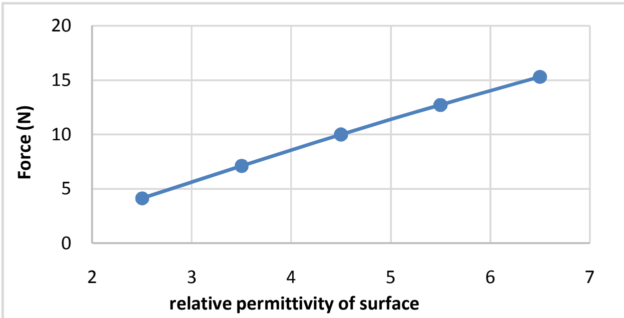

Fig. 10 Adhesion force compared to the surface Relative permittivity

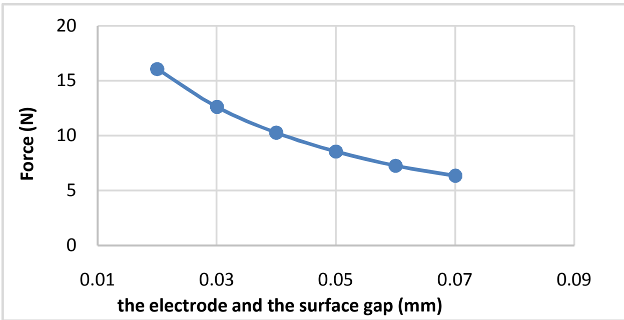

Fig. 11 Attraction force compared to the gap between electrodes and surface

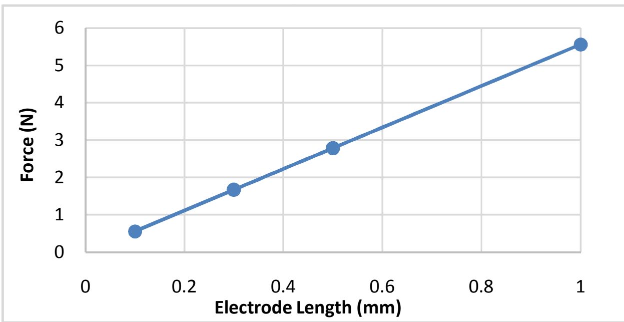

Fig. 12 Attraction force compared to the electrodes length

IV. Conclusion

In this paper we proposed three different electrode patterns and simulate them in finite element method. The generated electrostatic force evaluated by applying the voltage to each pattern. It was observed that pattern B with two electrodes and the maximum area of the electrodes generated the minimal force. The force generated by pattern A and C were very close together, however after using finer mesh, the most adhesion force obtained from pattern A.

In the second section we proceeded to analyze the effect of various parameters such voltage, gap of electrodes and surface (g), the electrode width (w), the distance between the electrodes (t), permittivity of the surface and the electrode's length, on the electrostatic adhesion force. This data would be useful in designing of the electrodes of such grippers, chucks and other thing that use electrostatic adhesion.

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