Experimental Studies of EHD lifters

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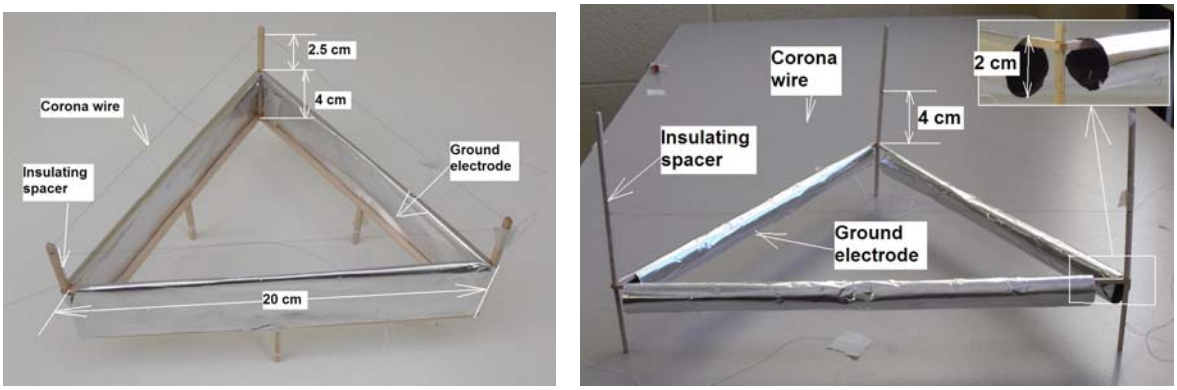
***Abstract*—This paper presents the experimental studies of the electrohydrodynamic (EHD) lifters. The detailed structures of two lifters were illustrated, followed by the presentation of the levitation experiment. The origin of the thrust force was proposed and confirmed by a special designed lifter and its levitation experiment.**

I. INTRODUCTION

In general, an EHD lifter consists of two mechanically connected electrodes, with one being a thin corona tungsten wire and another being a much thicker ground electrode [1][2]. Figure 1 shows two typical lifters investigated in this work.



(a) (b)

Figure 1 EHD lifters used in the levitation experiment

Both of the lifters have a triangular structure with a structural support made of balsa wood, which, along with the light material of the two electrodes, ensures the thruster has a small weight. The first lifter (a) has a ground electrode made of thin aluminum foil mounted parallel to the corona wire. This ground electrode is formed in the shape of close to an airfoil having a rounded leading edge with 0.75 mm radius. The balsa wood spacers supporting the corona wires are 1.5mm thick and have sufficient insulating property, so that a high voltage applied between both electrodes doesn't produce any measurable leakage current. The second lifter (b) has a same triangular structure as that of the first one.

The main difference is the new design of the ground electrode. From the enlarged image it can be seen that the ground electrode is a hollow cylinder (with a diameter of 2cm) made of thin aluminum foil. The hollow cylinder is not attached to the wood frame, rather hung over it. This special design will help to confirm the origin of the thrust force, which will be explained in detail in the following sections.

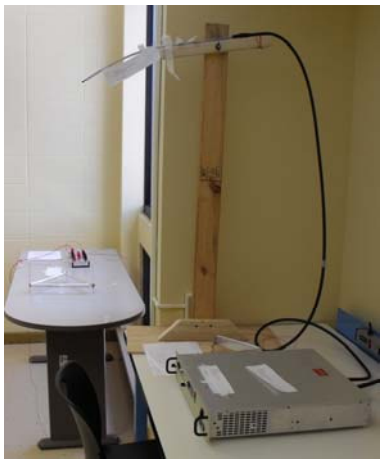
II. LEVITATION EXPERIMENT

A. Experiment apparatus

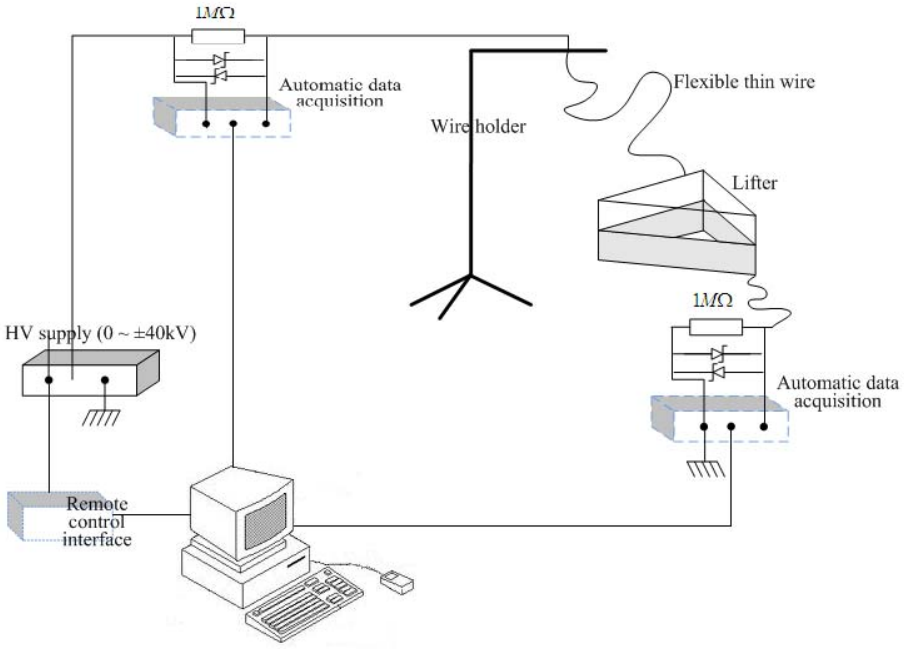
The lifting experiment was carried out using the setup shown in Figure 2. A Spellman high voltage power supply SL40PN600 is used as the main power source which can provide negative and positive high voltages both up to 40KV. The voltage is supplied to the corona wire and the foil base is grounded. Both connections were made using lightweight flexible wires. The corona current was measured by reading the voltage drop across a high power level resistor which connected directly to the ground. The power supply also provides the current and voltage readings during the experiment. An automatic computer data acquisition system is currently under design. The system consists of a computer workstation and a data acquisition application program developed using Visual C++, which drive a remote control interface board connected to the SL40PN600 power supply. The interface board provides digital linear control of the output voltage of SL40PN600 in predefined incremental values from several hundred volts to ten of thousand volt range. At each incremental setting, voltage measurements are taken across the power resistors between the ground and lifter and also between SL40PN600 and lifter (see figure (b) below). The voltage readings are done through the acquisition interfaces between the resistors and computer workstation. Upon completion, the performance characteristics of the lifter, including current, voltage, and thrust force, etc, will be obtained in real-time automatically. (It should be specially noted that the data and curves presented in this paper were gathered manually.)

B. Levitation experiment results

The levitation experiments were carried out with a slowly increasing voltage (negative polarity). For the first lifter, at 12 kV an initial movement was observed and corona sizzling was heard. At 19 kV the device was able to move freely and levitate on its own. Figure 3 shows the first lifter during a stable flight (a) and in total dark (b). Figure 3 (b) reveals clear evidence of corona glow around the thin corona wire. The corona glow along with the fact that there was an electric current flowing between the two electrodes confirms that the electric corona discharge takes place during the levitation. It is worth noting that a few glowing points were noticeable on the ground electrode, which suggests bipolar corona discharges were taking place. This can be avoided by creating a smooth surface of the ground electrode and avoiding any sharp points.

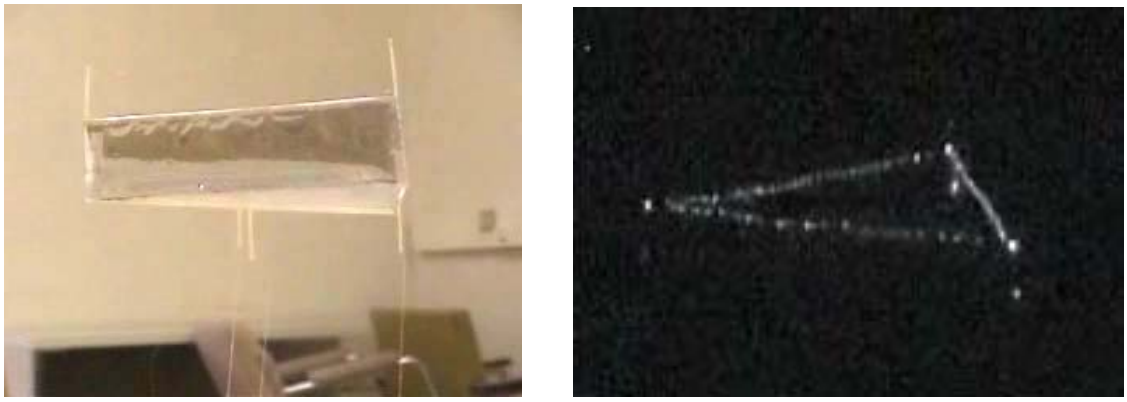


(a)



(b)

Figure 2 Setup for the levitation experiment



(a) (b)

Figure 3 The thruster during the levitation experiment.

For the second lifter, at 17 kV an initial movement was observed and corona sizzling

was heard. At 24kV the stable flight was achieved. Figure 4 shows the relationship between the applied voltage and the measured corona current. There is no surprise that the curve assembled the perfect corona discharge I-V characteristics. More experiments will be conducted to investigate the factors which influence the performance of the lifter. These factors may include the polarity of the applied voltage, the distance between electrodes, the structure of the lifter, the thickness of the corona wire, the shape of the ground electrode, etc.

III. THRUST FORCE ORIGIN ANALYSIS AND VERIFICATION

A. Force analysis

As suggested in previous section, the lifter forms a typical corona discharge system with a high electric field in the vicinity of the corona wire. The high electric field causes local gas ionization, and as a result, ions drift to the ground electrode, a space charge is formed, and an electric current flows between both electrodes. The drifting ions collide with neutral air molecules on their way to the ground electrode and transfer their momentum to the surrounding bulk air to create the EHD flow. Figure 5 shows a schematic model of the problem with the main forces identified. The corona wire, supplied with a negative voltage, experiences repulsive force F1i due to negative space charge and attractive force –Fe due to the ground electrode. Similarly, force F1i+F2i acts on the negative space charge and F2i+Fe on the ground electrode. During the process of generating the EHD flow the ionic space charge transfers its momentum to the air bulk. So if we treat both electrodes and the space charge as a system, the net force acting on the system, as shown in Figure 5, is F1i+F2i and it is the reaction force to the one that drives the EHD flow. This net force is the thrust force causing the device levitation[3][4].

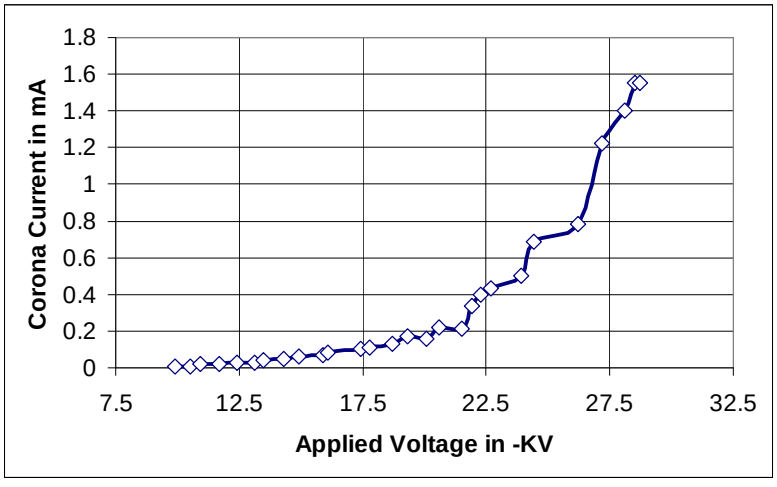


Figure 4 The I-V characteristics of the lifter during levitation experiment.

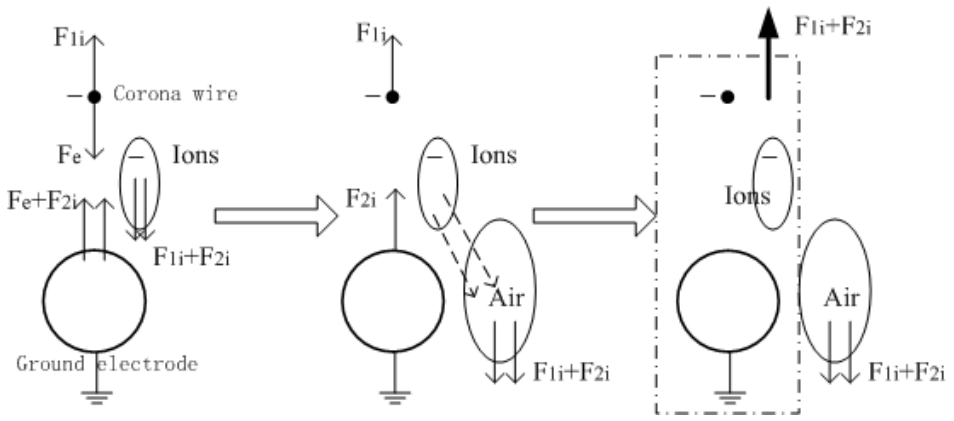
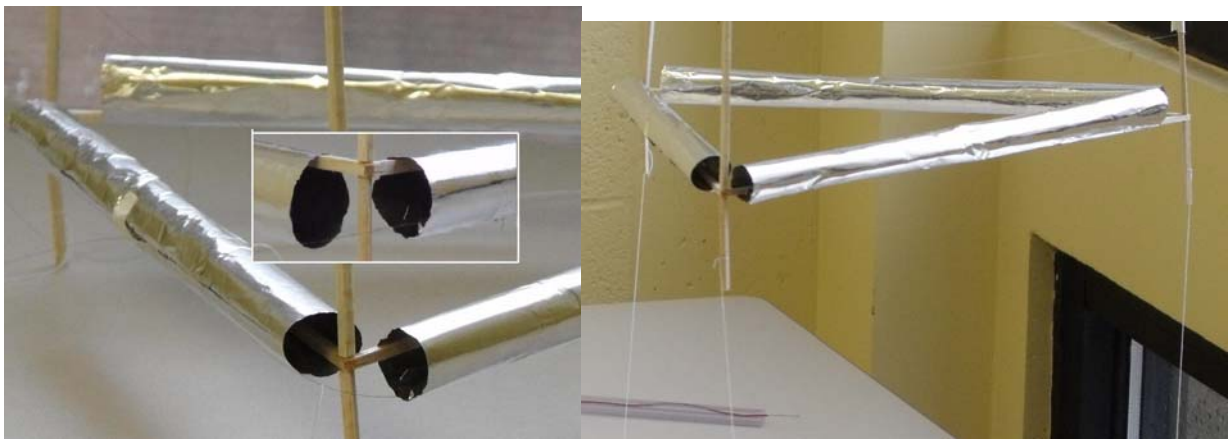


Figure 5 Forces presented during levitation experiment.

B. Force origin verification

The objective of the force origin experiment is to confirm the conclusion from above analysis that the thrust originates from both the ground electrode and the corona wire.



(a) (b)

Figure 6 Cylinder ground electrode (a) before and during and (b) after levitation

The second lifter shown in Figure 1 (b) was specially designed with this goal in mind. Since the hollow cylinder ground electrode is not attached to the wood frame, it can move freely. During the levitation experiment, while increasing the applied voltage slowly, it was first observed that, as shown in Figure 6 (a), the cylinder was levitated before the initial movement of the entire lifter and the lifter was still rested on the table. There was a short moment when the cylinder was floating in the air with no touch of the rest of the lifter as shown in Figure 6 (a). With the increase of the applied voltage, the bottom of the cylinder touches the wood frame and pulls the lifter up to the air, as seen in Figure 6 (b).

This experiment successfully confirmed the force F_{2i} on ground electrode qualitatively. Further quantitatively experimental evidence is needed to confirm the value of the force. Additional experiments will be carried out to confirm the part of the thrust force F_{1i} acting on the corona wire (Detailed information will be available in June 2011).

IV. CONCLUSIONS AND DISCUSSIONS

This paper presented current available experiment results of research of the EHD lifters,

the analysis of the thrust origin and its preliminary verifications. A few research projects are undergoing, including the remote control and automatic data acquisition unit, new lifter structures design, levitation experiments with positive applied voltage, and the experimental verification of the thrust acting on the corona wire. More results will be available during the conference.

ACKNOWLEDGMENTS

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