

Automatic Remote Control and Data Acquisition for Experimental Study of EHD Lifters

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Abstract --

This paper presents the design of the automatic remote control and data acquisition for the EHD lifter experiment apparatus. The proposed setup is capable of automatically measuring the lifter thrust force, source current, corona current, and leakage current. Such strategy helps to prevent human reading error and provides better accuracy than manual data recording. In addition, certain statistic estimation on the measurement can be achieved readily but prove to be difficult and tedious for human manual reading, for example the thrust force standard deviation from the mean value for each applied voltage. Each component in the setup and its rationality is described in detail. Selected experiment results are presented to demonstrate the benefit of using such automation system. Unexpected finding of such results are discussed and further investigation is recommended.

Index Terms — corona discharge, electrohydrodynamic flow, lifter, automated data acquisition.

I. INTRODUCTION

An electrohydrodynamic (EHD) lifter utilizes only electrical energy and levitates without any mechanical moving parts. Typically, an EHD lifter consists of two mechanically connected but electrically separated electrodes, with one being a thin tungsten wire for corona generation and another being a much thicker ground electrode [1][2]. Fig.1 shows a typical triangular lifter configuration with a structural support made of balsa wood. The ground electrode made of thin aluminum foil mounted parallel to a thin corona wire. With a sufficiently high voltage applied between the two electrodes, the lifter is able to lift its own weight and a small payload [3].

The lifter has been investigated theoretically and

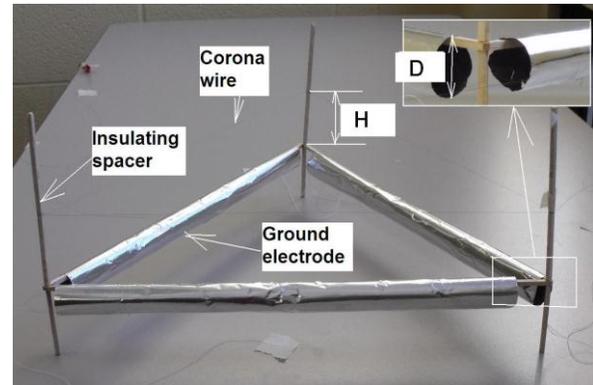


Fig. 1 A typical triangular lifter configuration [3]

numerically [4][5][6]. It is generally accepted that the lifter can be treated as a typical electric corona system. With the essential high applied voltage, the corona discharge takes place and the secondary EHD flow is created due to the momentum transfer between the drifting ions and the neutral air molecule.

The upward thrust of the lifter is originated from the reaction force to the one which drives the EHD secondary flow [3]. It is also experimentally verified that the thrust is mainly occurs on the ground electrode [3]. Due to the nature of the EHD lifter, the thrust is relatively small which is in the range of 0.1~0.2N/m based on the authors' experimental measurement [3][7]. The small thrust value along with unstable flight makes it very challenging to accurately measure the lifter performance characteristics. Although there are numerical simulation results available predicting the



Fig. 2 Overall apparatus setup for experimental study of the EHD lifter

optimum design for the best performance of the lifter as well theoretical assumptions of which type of configuration will be able to provide the most efficient lifter, precise and well-designed experimental measurement is still needed to verify the assumptions and provide crucial evidences. This paper presents a well designed setup to measure the thrust and the lifter current with remote/preset control of power supply and automatic data acquisition for currents and thrust measurements. Detailed design, data collection and sample results will be presented.

II. EXPERIMENTAL SETUP AND AUTOMATIC DATA ACQUISITION

The overall apparatus setup, as shown in Fig. 2, consists of one computer workstation, one high voltage DC power supply (capable of 40KV dual polarity), one digital weighing machine interfaced to workstation via RS232 communication, a specially designed lifter for thrust experiment, a custom made voltage-limiting circuit box connected to a digital multimeter which also interfaced to workstation via second RS232 port, one NI (National Instrument) PCI-M10-16E-4 DAQ card and a Multi-IO card are incorporated into workstation. The DAQ card is interface to others with an external NI DAQ break-out board. The goal of the setup is through using specially developed software program to automatically adjust the applied voltage, monitor the lifter flight, and collect data for thrust and currents without human interference and reading error. Therefore with a push of one button and few minutes later, the experimental data file and the curves are expected to be available on the workstation screen. The measurements are repeatable to achieve the most achievable accuracy. The overall system configuration schematic diagram is outlined in Fig. 3. The following sections are devoted to describe the detail information of each component of the setup.

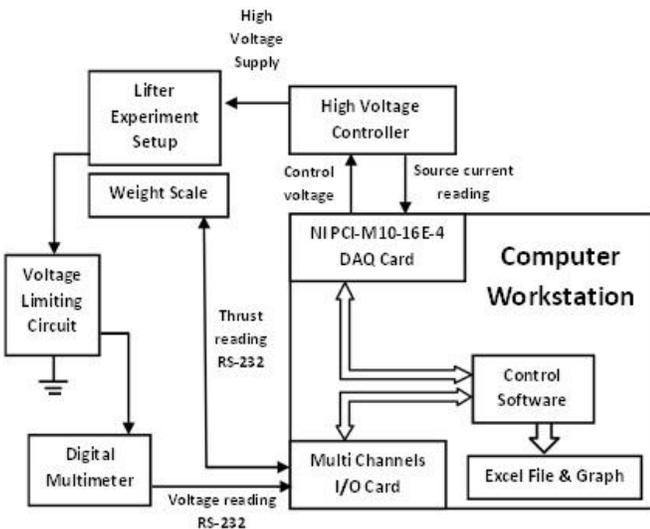


Fig. 3 Schematic of automatic data acquisition setup

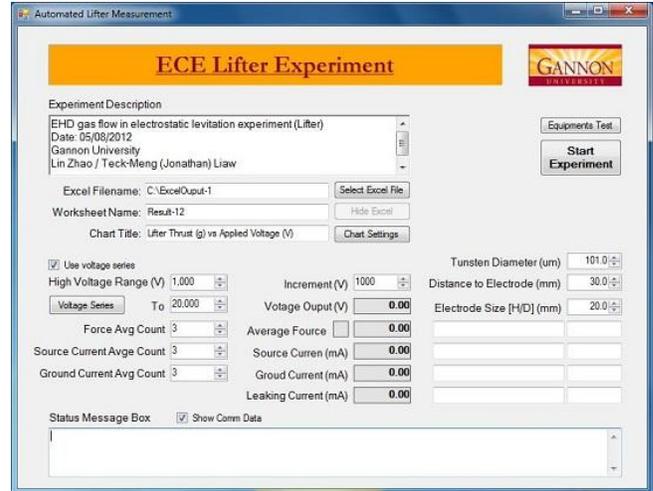


Fig. 4 GUI of the control software

A. Remote control the applied voltage

The high voltage controller (HVC) power supply, Spellman model SL40PN600 provides the necessary high voltage needed in the experiment. It is capable of produce voltage ranging from -40kV to 40kV. The value of the voltage can be controlled manually by the knob located on the front panel of the power supply. However, doing so the experimenter will introduce randomness of his/her choice with the applied voltage values and the experiment is not (theoretically speaking) repeatable. Another approach is achieved remotely by computer control via the NI DAQ card analog output. The NI DAQ analog output is capable of producing a digital to analog voltage with 12 bits resolution. It was found that with such resolution, the output voltage from the HVC can be adjusted to within 2 decimal point (kV scale) accuracy even without any calibration between the control software and the HVC. For ease of development, the Microsoft C# language is chosen to develop the control software. The software GUI screen shot is shown in Fig. 4.

Operator can control the applied voltage linearly between a specified voltage range or he/she can also setup the apply voltages individually. In general, any type of applied voltage pattern can be realized by this functionality. Fig. 5 shows an example of the applied voltage pattern. Basically, the control software reads this setup and outputs the appropriate control voltage between 0 and 10V through the NI DAQ analog output into the controlling ports of the HVC, which is located at the back panel of HVC. The connection between the external devices to the NI DAQ card

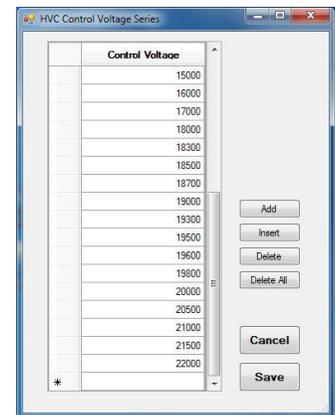


Fig. 5 Control voltage series setup

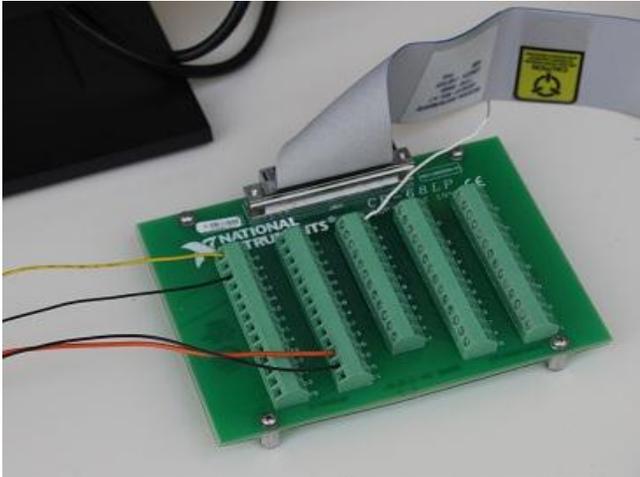


Fig. 6 NI DAQ card break-out board

is using a break-out board as shown in Fig.6.

B. Specially designed lifter for test

Fig. 7 depicts the specially designed lifter for thrust and current experiment. It attached onto the digital weighing machine with a custom fixture. The distance between the two electrodes is adjustable by sliding the ground electrode sub-assembly up and down along the markers on the wood poles (Fig. 8). The setup allows ground electrode readily detach from the wooden frame in order to test different types or shape of ground electrode. The entire setup is placed in a plastic enclosure to reduce the error caused by the surrounding draft.

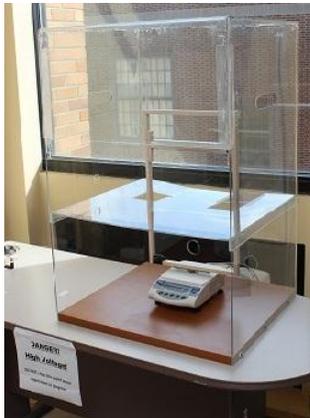


Fig. 7 Special design lifter for thrust measurement

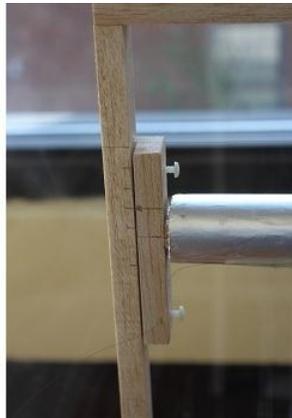


Fig. 8 Adjustable ground electrode

C. Thrust measurement

While the lifter is in flight, it is difficult to measure the thrust. An alternative way, which is adopted by this paper, is to fix the lifter on a weighing machine. When high voltage is applied to the lifter, the lifting thrust produces a negative

reading on the weighing scale. As seen in Fig. 9, the lifter was mounted to a solid wooden frame which was attached directly on a digital weighing machine (American Weight Scales, model PN-2100B). The lifter and the digital weighing machine assembly are enclosed inside an acrylic plastic enclosure. An additional dividing plate is inserted between the lifter and the weighing machine (Fig. 8) to reduce the EHD flow from blowing directly onto the weighing machine surface or wooden frame below, which might give rise to incorrect or fluctuating readings (It was observed that the weighing machine's reading was extremely unstable without the sliding plate). The entire enclosure is rested on the table and detached from the lifter and the weighing machine.



Fig. 9 Special design lifter attached to weighing scale

Before the experiment starts, the weighing machine is reset to zero by the control software. The thrust force then measured by the negative reading of the digital weighing machine connected to a computer workstation via RS232 communication port. The applied voltage is increased gradually based on the preset values through the remote control software. At each applied voltage, the weighing machine's reading was retrieved multiple number of times based on the operator setting. Each reading interval is delayed half a second or so to include the possible fluctuation in the experiment. Fig. 13 and Fig. 14 (see end of document below) give the screen shots of the software program data acquisition process sending the captured data to the Microsoft Excel spreadsheet with instant 2D chart plotting. For each applied voltage in the voltage series, the automatic data acquisition system also computed the maximum, minimum average, upper and lower standard deviation readings and saves them into an Excel file at the end of experiment.

D. Source current measurement

Source current measurement is achieved by reading a specific correlated voltage (or correlation voltage) output port located at the back panel of the HVC. The correlation voltage reading required calibration in order to compute the corresponding source current value correctly. To calibrate the correlation voltage, a series of applied voltages to the corona wire are selected. For each applied voltage, source current is measured using the similar method deployed for

reading the ground current, i.e. current flowing from the ground electrode to the circuit ground (see section E), at the same time, the correlation voltage from the output port of HVC is determined by the NI DAQ analog input. The correlation voltages against current values are plotted, which is shown in Fig. 10. The result is very close to the current reading from the HVC front panel as expected. With these data pairs, the software program can interpolate the current value from the voltage read from this output port. Any source current beyond the correlation voltage range is computed using the least square regression extrapolation.

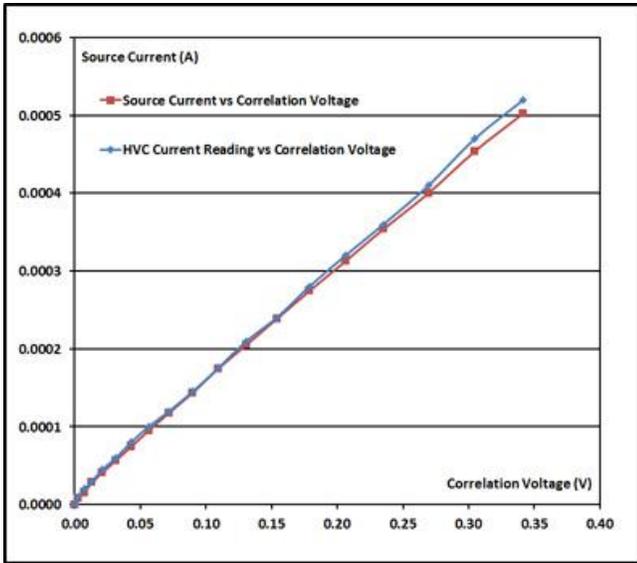


Fig. 10 Calibration of correlation voltage to source current value

E. Ground current measurement with voltage limiting circuit

The current flowing between the two electrodes is the crucial parameter determining the value of the thrust [3], therefore accurate current measurement plays an important role when investigating the optimum lifter design. The HVC provides milliamp (mA) current reading from the front panel with two decimal point accuracy. It should be pointed out that, this current is the total current provided by the power supply, which is not necessary the current flowing between the two electrodes due to the inevitable present of the leakage current.

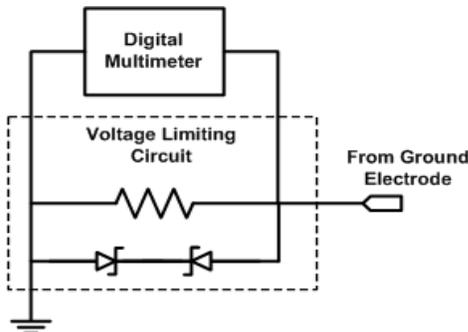


Fig. 11 Voltage limiting circuit

Leakage current can be well estimated by the difference between the source current and ground current measurements. To measure the ground current, an indirect method is devised: instead of measure the ground current directly, the voltage across a carefully selected resistor (403K ohm in our setup) is used to calculate the current flowing through it, note that the calculation also take into account the multimeter input impedance. Since arcing may occurs during experiment, a pair of Zener diodes is deployed to limit the voltage across the resistor, thus prevent the multimeter from damage due to voltage overloading. The schematic diagram of the voltage limiting circuit is shown in Fig. 11.



Fig. 12 Voltage limiting circuit

Fig. 12 shows the external and internal close up view of the actual circuitry implemented.

III. SELECTED EXPERIMENTAL RESULTS

The above presentation shows the apparatus is capable of provide reliable measurements with just a push of a button. This section will discuss a few selected experimental results that demonstrate the advantage of using automated acquisition over human manual data recording. The length of the lifters used throughout all the experiments is equal to 1 foot. The ground electrode is in cylindrical shape with 20mm in diameter. The diameter of corona wire used is 0.004".

Fig. 13 illustrate the objectives achieved in this work, not only the system computed the mean value of the thrust force measured, it also able to calculate the upper and lower

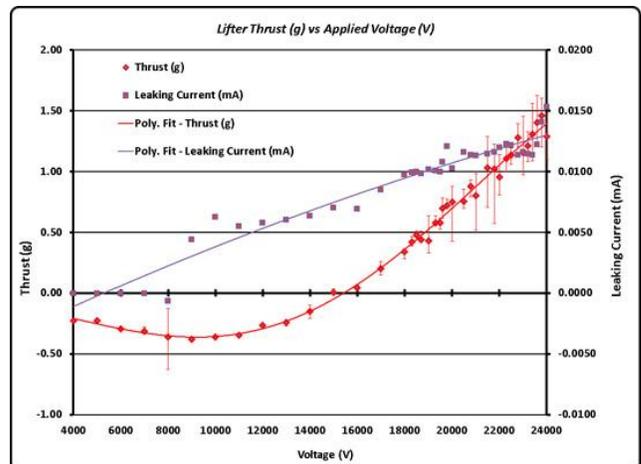


Fig. 13 Excel charting output from data captured from experiment

standard deviation from the mean value instantly, which gives certain indication of the error spread. The figure also shows that the leaking current is in trend within the applied voltage used (4kV – 24kV), which is expected. One surprising result consistently observed is there appears to exhibits negative thrust force in the low voltage region (4kV – 15kV). We have no analytical explanation on this phenomenon, but can only speculate that this could be due to the turbulent drag underneath the cylindrical ground electrode. Further work need to be carried out to investigate the nature of these behaviors.

Fig. 15 demonstrates and verified a known property where the thrust force is increase with the increase of corona current [3]. The curves are plotted using polynomial best fit with 4th degree (in fact a 2nd degree can equally good for the curve fitting).

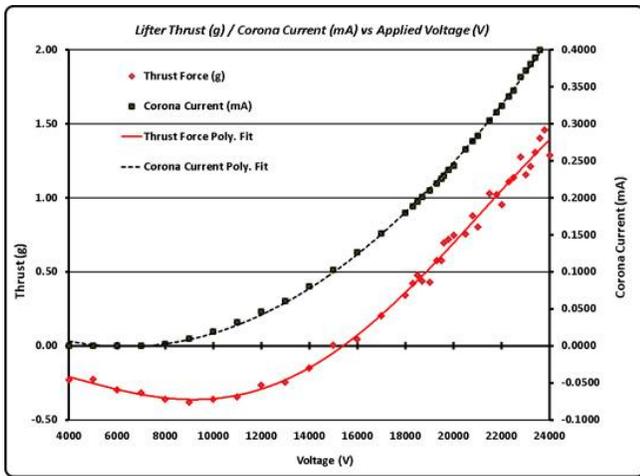


Fig. 15 Thrust force / corona current vs. applied voltage

Fig. 16 shows 3 experimental runs with different separation distance between the corona wire and the ground electrode. There are 20mm, 40mm and 60mm respectively. The observation clearly indicated that the thrust force decreases in with the increases of separation distance in the upper voltage region (16kV – 24kV). It is worthy again to

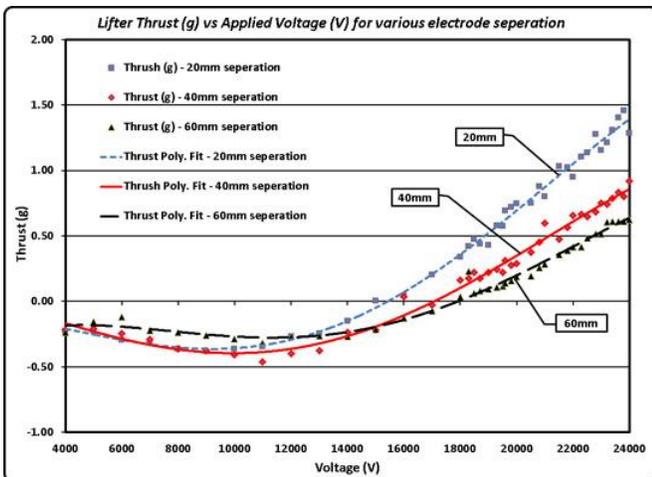


Fig. 16 Experimental result for various electrode separation distances

point out again that at the low voltage region, the 3 curve consistently showing negative thrust force.

№	Voltage (V)	Thrust (g)	Min. Thrust (g)	Max. Thrust (g)	Lower Std Dev	Upper Std Dev	Source Monitor Voltage (V) V1	Ground Resistor Voltage (V) V2	Source Current (mA) I1	Ground Current (mA) I2	Approx Leaking Current (mA) I3
1	4000	-0.23	-0.23	-0.22	0.01	0.00	0.0000	0.0097	0.0000	0.0000	0.0000
2	5000	-0.23	-0.25	-0.21	0.01	0.02	0.0000	0.0132	0.0000	0.0000	0.0000
3	6000	-0.30	-0.31	-0.29	0.01	0.01	0.0000	0.0176	0.0000	0.0000	0.0000
4	7000	-0.32	-0.36	-0.28	0.02	0.03	0.0000	0.0241	0.0000	0.0001	-0.0001
5	8000	-0.36	-0.84	0.03	0.27	0.23	0.0006	0.9292	0.0017	0.0024	-0.0007
6	9000	-0.38	-0.40	-0.36	0.01	0.01	0.0068	3.7075	0.0140	0.0096	0.0044
7	10000	-0.36	-0.38	-0.34	0.02	0.01	0.0121	7.4390	0.0255	0.0192	0.0062
8	11000	-0.35	-0.36	-0.33	0.01	0.01	0.0189	12.2860	0.0372	0.0317	0.0055
9	12000	-0.27	-0.28	-0.25	0.01	0.01	0.0283	17.7980	0.0518	0.0460	0.0058
10	13000	-0.24	-0.28	-0.20	0.03	0.02	0.0382	23.5000	0.0667	0.0607	0.0060
11	14000	-0.15	-0.21	-0.02	0.06	0.05	0.0513	31.1900	0.0869	0.0806	0.0063
12	15000	0.01	-0.04	0.04	0.02	0.03	0.0663	39.6430	0.1094	0.1024	0.0070
13	16000	0.04	0.00	0.07	0.02	0.03	0.0825	48.7590	0.1329	0.1260	0.0069
14	17000	0.20	0.11	0.27	0.05	0.06	0.1003	58.6840	0.1601	0.1516	0.0085
15	18000	0.34	0.31	0.43	0.06	0.02	0.1196	69.4400	0.1892	0.1794	0.0097

Fig. 14 Excel spreadsheet output from data captured from

IV. CONCLUSIONS AND FURTHER STUDY

A novel design of automated test workbench is proposed for investigating the performance characteristics of EHD lifter. Selected experiment results are analyzed to illustrate capability and advantage of using such system. The following conclusions can be drawn:

1. The applied voltage can be adjusted accurately with preset settings with user desirable pattern
2. Current and force can be measured remotely with multiple trials and the data can be easily collected, manipulated and saved for further study.
3. The thrust is in trend with corona current independent of lifter configuration
4. Leaking current is one factor to consider for optimum thrust performance design.

Unexpected results are observed with the thrust at low applied voltage region which exhibits negative thrust force. Further experiments are required to provide new evidence for this phenomenon.

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