Control of altitude and acceleration in direction of gravity for EHD and Electrostatic Propulsion Devices

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Abstract

Electro hydro dynamic (EHD) and electrostatic propulsion devices has no moving parts and, in the air, operates on electrical energy. It is expected to develop electric propulsion systems without future moving parts of airplanes and helicopters propellers in the future. I had succeeded in hovering EHD device in an arbitrary space for the first time. It means that we can control height at floating in the air. Also, I had succeeded in controlling the speed and acceleration of the EHD device and decreased to a significantly low level. I considered a theory for hovering EHD device. Here, high output voltage of small Tesla coil was modulated at a low repetition frequency, and output voltage of Cock-Walton circuit was controlled in a rectangular pulse shape temporally. Furthermore, I analyzed position, velocity, and acceleration of EHD device for levitation and descent using the optical-flow method. I confirmed that the velocity and acceleration were significantly lower than when a high DC voltage was applied.

1.Introduction

It is expected to develop electric propulsion systems without future moving parts of airplanes and helicopters propellers in the future. The advantage of this propulsion system is that 1) there are no moving parts, easy to maintain and 2) the propulsion efficiency may exceed the conventional engine.

There is a report that the principle of ion craft considered as a part of a series of thrust generation experiment by Brown effect using high voltage is propulsion by the imbalance of electrostatic force, attraction by space charge. We also think so from many experimental results other than that paper. It is considered that the propulsion principle is determined not by the ion wind but by the external electric field (applied voltage) and the amount of electric charge accumulated in the electrode. Much research has been done on the principle of lifters.

For hovering of EHD propulsion devices in air, the device can only levitate and descend simply by turning on and off the applied high voltage. A new purpose which we want to achieve is to make the EHD propulsion device hovering in any space like a conventional drone with propellers. But, it is very hard to realize the hovering of EHD devices. No one knows that can be possible. As far as I know no one has done it. If it is a quadrotor drone with wings, the propeller rotation speed can be slowed down or sped up. A rotational speed that the weight just balanced the levitation force exists. Thus, we can control the motors at the rotational speed with ESC. However, it has been known that if we try to do the same control for an EHD device and the applied high voltage changed to be lower, the device becomes unstable in space and sways from side to side and falls down like a leaf. In other words, no stable levitation state exists when a high DC voltage is applied. Another approach is required to achieve the hovering of the EHD devices.

Here, I propose a new method that applying temporal modulation of the output voltage with low repetition frequency to control the EHD devices. We had applied DC output high voltage to EHD devices conventionally. I investigated and confirmed the hovering property and the reduction property of the speed and the acceleration during levitating and descent experimentally. Thus, I will report them here.

2. Theory

Here, I explain the principle of hovering for EHD devices. It is shown rectangular PWM modulation of output high voltage in Fig.1. Fig. 2 shows the principle. Electric fields and charges are fundamentally concerned with the generation of levitation forces in EHD devices. I thought that a part of the device where electric charge is accumulated and a part where electric charge is not accumulated should be applied to realize the hovering.

I supposed that it would be possible to control the levitation force by switching on the circuit for charging and accumulating electric charges in areas where electric charges had not been accumulated.

Hovering may be realized by perform the temporal averaging of the levitation force and the gravity. It means that the amount of work (= multiplication of the forces and time) changed to be close to 0. PWM is described in Fig. 1. P1 is a status that the weight of the EHD device and the levitation force are nearly balanced, and P2 is a status that the levitation force completely exceeds the weight of the device. A levitation case is written in is Fig. 1. It shows that the EHD device alternates between a falling and a levitation in a short time. Here, we take advantage of the fact that the EHD device is stable at levitation. In fact, the height is slightly up and down, but it should look like it is hovering in a certain space.

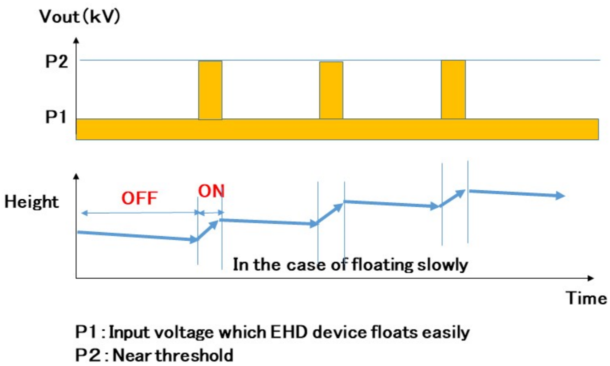


Fig.1. Image of the output high voltage for CW circuit.

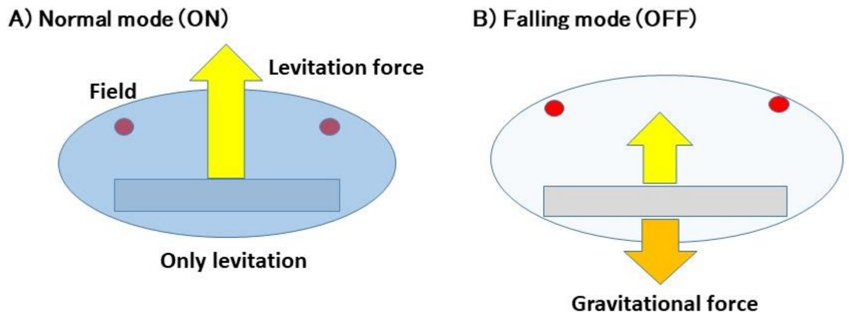


Fig.2. Action modes of EHD propulsion devices.

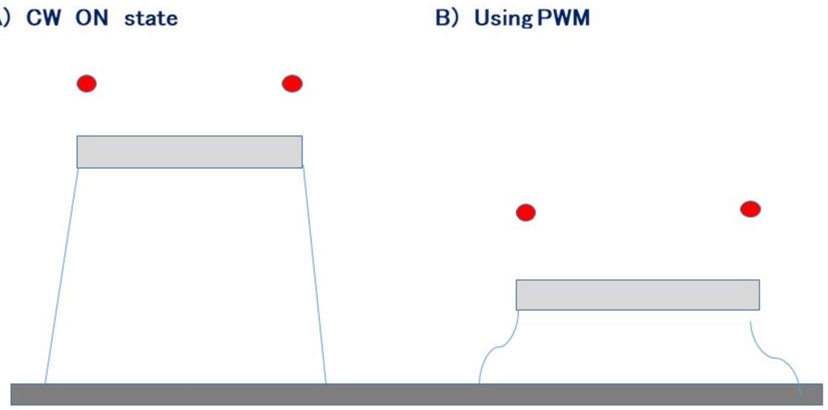


Fig.3. Hovering of EHD device controlled by PWM.

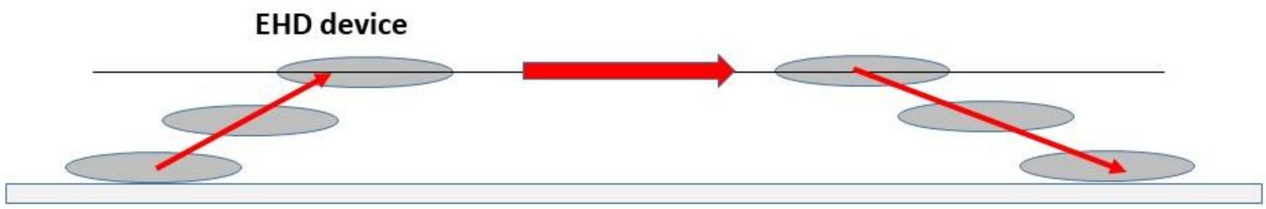


Fig.4. Levitation and landing.

Here, I will explain about levitation and descending. Fig. 4 shows an image of the levitation and falling for the EHD device. If the hovering is possible, levitation and descending are an extension of it. The EHD device can levitate by increasing the current supplied to TC rapidly when high voltage is applied, and the EHD device can descend by decreasing the current. Fig. 4 shows a slow levitation, hovering for a certain amount of time, and a slow landing without allowing free fall.

3. Experimental set up

(a) (b)

Fig.5. EHD propulsion devices.

The used EHD propulsion devices are shown Fig.5. Two types of EHD propulsion devices is shown in Fig.5. The EHD device has ten layers of electrodes in the frame. Three places are connected to the desk with 15 cm length tin wire. The devices are made of Aluminum foil. The length of the electrode was 40 cm. The maximum output voltage of the used DC rectified power supply in this experiment was 30 kV. A Cockcroft-Walton rectifier driving by single output wire of Tesla coil with CW mode operation was used to obtain DC high voltage output. The output frequency of the TC was 1.9 MHz. We can rectify the output signal from TC by connecting only single wire. The gap length was chosen to be 4.5 cm. The used ultra-thin wire (the thickness was 50 μm) was connected to the + electrode, and the long plate electrode was connected to - electrode. The reason for using the ultra-thin wire is to enable low voltage operation. The EHD devices can operate up to be 30 kV. The TC was improved to modulate the output high voltage temporally by using an additional FET to switch the resistance.

The amplitude of the output high voltage was modulated with PWM method at low repetition.
Here, as a proposed method, the oscillation amplitude of the CW output Tesla coil is controlled with PWM. Specifically, the limiting resistance in the self-excited oscillation circuit of the Tesla coil is changed to two values, and the output voltage is changed as above when the vertical axis is the output voltage as shown in the image of Fig.1.

Table. 1 . Parameter for experiment.

Parameter	Value
Repetitive frequency	10Hz
Duty cycle	0.2-0.9
Length of EHD device (Triangular type)	40 cm

By changing the ON pulse width, the effective levitation force changes. I changed the resistance by turning ON and OFF the circuit using single FET. A pulse generator was used as the input signal for the gate ON/OFF control of the FET to change the resistance. For the power supply, we used a DC power supply capable of outputting 90V for the TC. We also used a function generator that can oscillate a rectangular wave to drive the gate of the FET and perform PWM.

The optical flow method is widely known as one of analysis methods by estimating position, velocity, and acceleration. The optical flow method is a method of expressing the motion of an object in a digital image as a vector, and is mainly used for detecting moving objects and analyzing their motions. The analysis in this code extracts image feature points and tracks multiple feature points in the image. The advantage of this method is that the EHD device is applied with a high voltage and is difficult to contact, so the position, velocity, and acceleration of the object can be estimated by calculation without contact, which is highly effective. I attempted to analyze the position, velocity, and acceleration of a moving object using the famous Lucas-Kanade method among optical flow methods. In the video analysis, the kernel size was set to an appropriate value, the number of layers was set to 2, and the block peripheral area size used to calculate feature points was set to 16. The temporal resolution of the mpeg video was 30fps. The image size was 1280 pixels horizontally and 750 pixels vertically. I wrote the Python code and used OpenCV, which is an open source library for image analysis. Using the above optical flow method, we attempted to analyze the characteristics of two types of EHD devices in horizontal and oblique levitation.

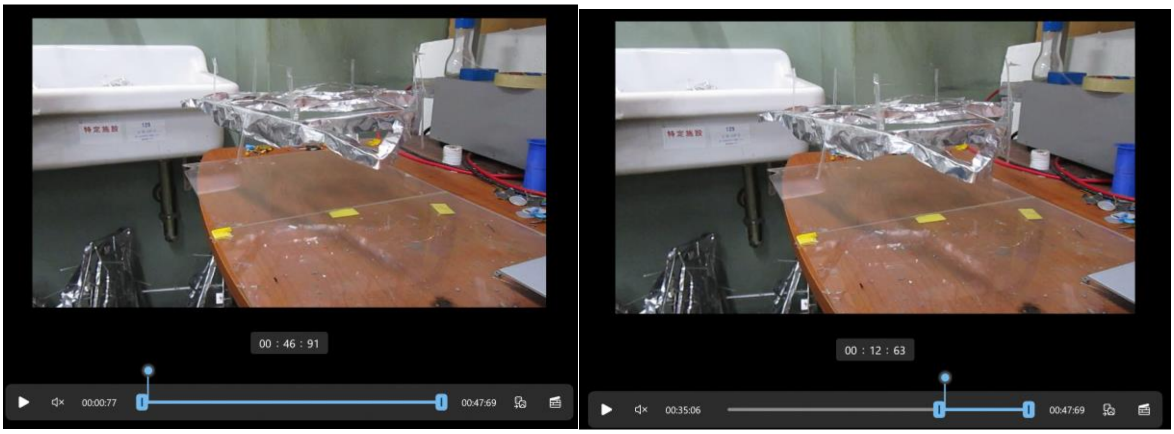
4. Results

4.1 Hovering

I conducted an experiment to prove that the theoretical considerations in the chapter 2 are correct. The experiment al results for the altitude control are shown below. I had succeeded in controlling the height with an EHD device driven by a CW output voltage of small Tesla coil. The method used here is as follows. First, the high voltage output of the CW rectifier circuit was assumed to be DC mode, and the EHD device was levitated. The EHD device is fixed with three wires so that it does not fly in the sky, once it is raised to the maximum height. Here, the altitude of the EHD device is almost constant. After that, CW output was modulated by applying a pulse signal to the FET gate. Here, I applied PWM to output of CW rectifier. Here, duty cycle was set to be 0.8. Then the altitude of the EHD device gradually decreased. Fig. 6 shows the experimental results. Fig. 6(a) shows the case when a CW DC high voltage is applied and reaches the maximum height, and Fig. 6(b) shows the case when PWM is applied. After applying PWM, the device was hovering with the height lowered by about 4 cm. It was observed that it floated up and down and left and right while swaying at a slow cycle of several mm. I was able to maintain this state for about 1 minute.

4.2 levitation and descent

An experiment has been conducted on the levitation and descent of the EHD device. Fig. 7 shows the analysis results of the height, and Fig. 8 shows the analysis results of the velocity, and the acceleration by the optical flow method. Here, we used the EHD device shown in Fig. 5(b), which has high posture stability during levitation and descent. In the case of applying pulsed high voltage, when the current supplied to the TC is rapidly increased, the EHD device rises significantly more slowly than the case when DC is applied. In the case of reducing the current and falling, the EHD device is more stable than free fall. I also confirmed that the EHD device can descend slowly. Here, duty cycle was 0.8. The acceleration at the descent was about 1/5 of the gravitational acceleration. In the levitation case, the acceleration of the EHD device decreased to 1/5 and the velocity decreased to 1/4 compared with the case of DC application. Here, duty cycle was 0.5-0.6.



(a) (b)

Fig.6. Experimental result for hovering of EHD device (Fig.5(a)). (a) Normal, (b) With PWM.

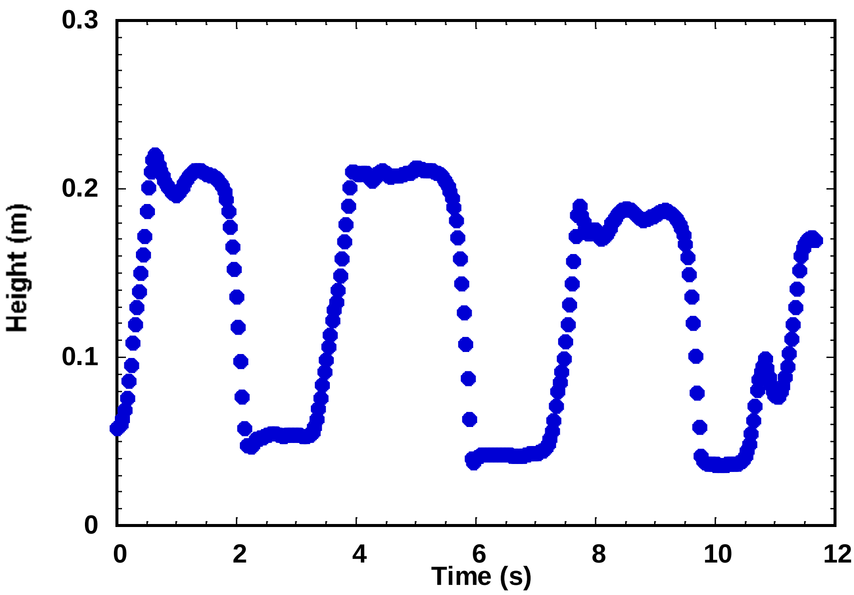


Fig.7. Analyzed result of height.

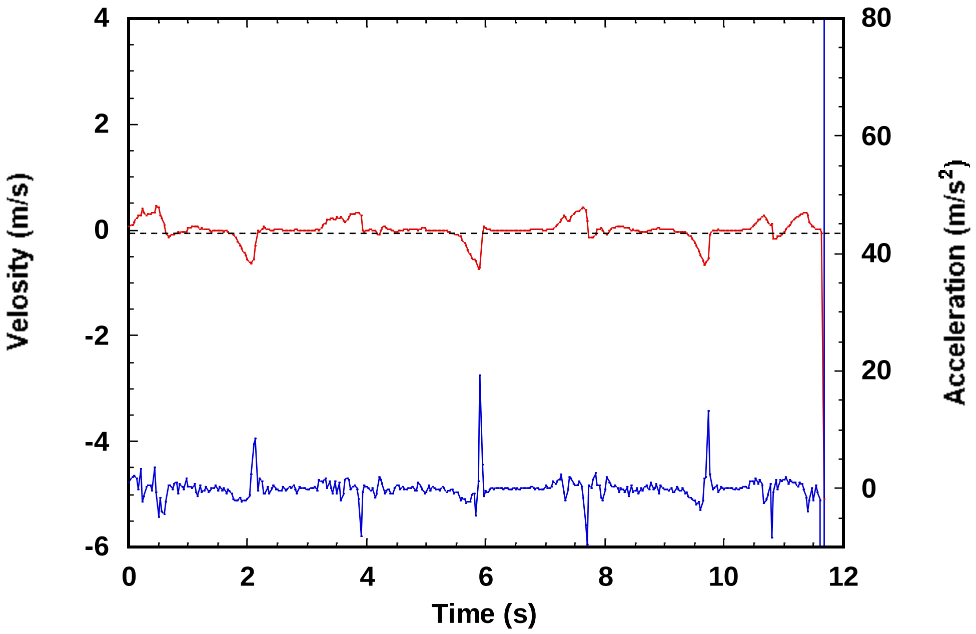


Fig.8. Analyzed results. (a) Velocity. (b) Acceleration.

Discussion

As a result of the altitude control experiment for the EHD device, I had succeeded in making the device hover in any space for the first time. In other words, the EHD propulsion device was fixed (pinned) at a certain spatial position. This hovering state is equivalently considered to be a state when the gravitational acceleration applied to the EHD device is zero. In experiments, I tested several EHD devices. Here, only those with good results are shown. It has been found that when the EHD device is small, the levitation becomes unstable and it is difficult to control. The EHD device wobbles slightly left to right and up and down when hovering.

When a high DC voltage is applied to the EHD device, it will only levitate and such hovering is never possible. The phenomena should connect to the principle of the levitation. No voltage that can maintain the hovering state. If the voltage is lowered, the device will sway from side to side, it become unstable, and fall down. Although the height was shown with only one parameter in this time, it is possible to freely change the altitude by limiting the applied current and increasing the duty cycle.

For the repetition frequency of the modulation, the upper limit of the repetition frequency was determined considering the charging time constant of the CW rectifier circuit. I tested 3Hz to 20Hz of the repetition frequency for the TC output modulation, but found that hovering is difficult if the repetition is too slow or too fast. I also improved the structure of the EHD device so that it would be stable.

For the reduction of speed and acceleration during the levitating and descent of the EHD device, it can not land on the ground in a state of high speed, similar to the landing of drones and rockets. If the acceleration is large during descent and landing, the EHD device may be damaged or destroyed, and it may affect people. Thus, it is necessary to avoid this. In addition, a large acceleration during levitation may be a problem of destruction of the EHD device and impact on human beings. Therefore, the reduction of velocity and acceleration in levitation and descent of the EHD device proposed here should be useful.

In this experiment, I had succeeded in levitating from the desk and landing on the desk slowly. For the levitation, this proposal seems to function well, but the falling should be improvement. During the landing, the EHD device is falling with increasing velocity. This is a problem, which is connected to the principle, and should be improved. Another solution is necessary. For an example, changing the current more slowly is needed.

References

[1] T. T. Brown, “Electrokinetic Apparatus,” U.S. Patent N°2949550, 1960.

[2] http://www.jlnlab.com/

[3] http://www.blazelabs.com/

[4] M. Tajmar, “Biefeld–Brown Effect: Misinterpretation of Corona Wind Phenomena”, AIAA Journal 42(2) (2004).

[5] L. Zhao and K. Adamiak, “Numerical analysis of forces in an electrostatic levitation unit,” J. of Electrostatics, **63**, pp.729-734 (2005).

[6] L. Zhao, K. Adamiak, “EHD gas flow in electrostatic levitationunit”, J. of Electrostatics, **64**, pp. 639–645 (2006).

[7] K. Masuyama and S.R.H. Barrett, Proc. of the Royal Society A - Mathematical, Physical and Engineering Sciences **469**, 20120623 (2013)

[8] T. Saiki, "Enhanced EHD and Electrostatic Propulsion Devices Based on Polarization Effect Using Asymmetrical Metal Structure", J. of Electrical and Electronic Engineering, (2015), 3 (4), Jul., pp.76-86.

[9] T. Saiki, “High-voltage Pulse Generation Using Electrostatic Induction in Capacitor”, Int. J. of Electrical Components and Energy Conversion, 5(2), Dec. pp.20-29 (2019).

[10] Taku Saiki, ”EHD and Electrostatic Propulsion Device Mounted with High Voltage Generator”, viXra.org e-Print archive, viXra:2201.0042. https://vixra.org/abs/2201.0042

[11] Taku Saiki, “Property on Levitation for EHD and Electrostatic Propulsion Device Using Multi-Layered Electrode”, viXra.org e-Print archive, viXra:2211.0104. https://vixra.org/abs/2211.0104

[12] Taku Saiki, “Analysis for Levitation of EHD and Electrostatic Propulsion Device in Direction of Gravity using Optical Flow Method”, viXra.org e-Print archive, viXra:2212.0005. https://vixra.org/abs/2212.0005