Analysis for Levitation of EHD and Electrostatic Propulsion Device in Direction of Gravity using Optical Flow Method

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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. EHD devices levitating in the direction opposite to the direction of gravity when a high voltage is applied. Detail property of the accurate propulsion direction, speed, and acceleration were clarified by imaging analysis in this time. It has been cleared from the analysis that even if the orientation of the device is initially tilted from a horizontal line, it was enforced to levitate vertically upward in the same direction as the direction of gravity, and a restoring force acts to return the orientation to a horizontal line during the levitation. These phenomena are very strange and different from drones with propellers. When the device levitates, the acceleration does not become constant immediately after the voltage is applied, but after passing through 0, it increases linearly in temporal duration of sub 0.1 s and saturates. The saturation of the acceleration changed with the input voltage.

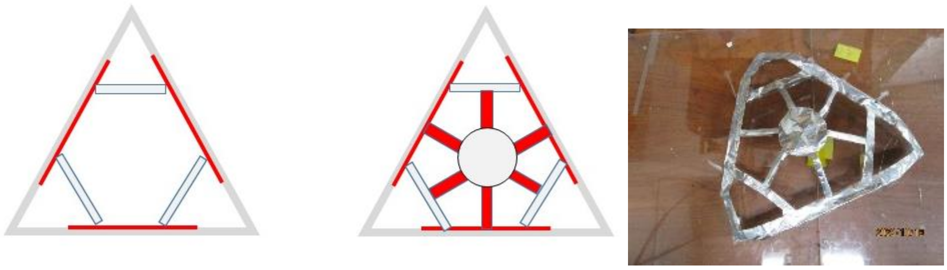
1.Introduction

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.

The purpose of this study is to clarify the levitation characteristics of EHD propulsion devices, which have not been elucidated previously. Specifically, temporal dependence of the relationship between acceleration and velocity, the direction of levitation connecting with gravity, motion properties, changes in the velocity and the acceleration, and how the levitation characteristics change when the starting point of the levitation is tilted for the input voltage. I had obtained velocity and acceleration of EHD propulsion devices by analyzing using optical flow method for the first time. The levitation properties of two triangular EHD devices with multiple electrodes and an EHD device with a central structure were cleared.

2. Experimental set up



(a) (b) (c)

Fig.1. EHD propulsion devices.

The used EHD propulsion devices are shown Fig.1. Two types of EHD propulsion devices used in this analysis is shown in Fig.1. Fig. 1(a) shows a triangular type EHD device, and (b) shows an EHD device with a star-shaped multi-electrode in the middle. (c) is a photograph of (b). The red color in the figure indicates that the structure is multi-electrode. Ten layers of electrodes are used in the frame, and five layers of electrodes are used in the central star. Three places are connected to the desk with wires about 10 cm long.

Three multi-layered electrodes are set at the tree red parts one by one. The devices are made of Aluminum foil. The length of the electrode was 25 cm. L_m is set to be 12.5cm. 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 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. In this time, we 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 7. 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.

3. Results

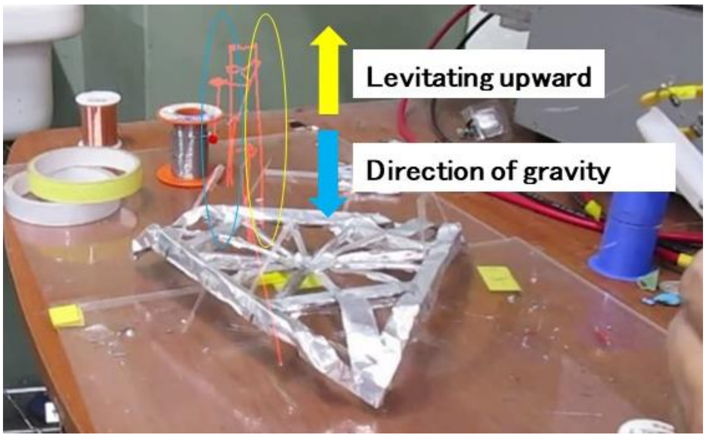


Fig.2. Experimental result of calculated optical flow.

Next, we show the experimental results when the EHD device is placed horizontally. Fig. 2 shows an example of the results of analysis using moving images of an EHD device with a central structure when it levitates. In the experiment, the EHD device was lifted straight up. The levitation direction was the exact opposite of the gravity direction, and the angle between the levitation direction and the gravity vector was almost 0 degrees. Although it was tilted 0.1 mrad from the desktop in the initial state, the device kept horizontal and slowly rose. Velocity changes with applied voltage. When the voltage is low, it becomes unstable.

Next, Fig. 3 and Fig. 4 show experimental results in the case of tilting arrangement. Both devices levitated in an oblique direction and then ascended while changing their orientation to return to the horizontal direction. It was the same even if the input voltage changed.

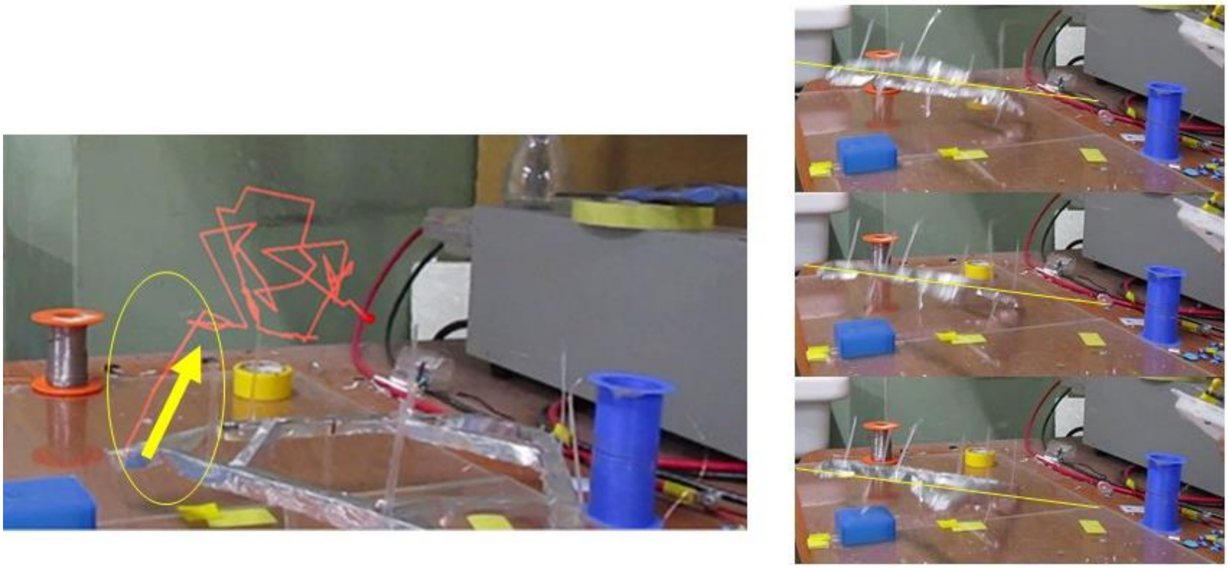


Fig.3. Analyzed result for levitation of triangle EHD device.

In the case of the frame EHD device as shown in Fig. 3, the unit levitate straight in the direction determined by the structure. A certain amount of distance was necessary for the posture to become horizontal. Compared to the EHD device, it turned out that the straightness is better. Eventually, the posture became parallel to the surface of the desktop.

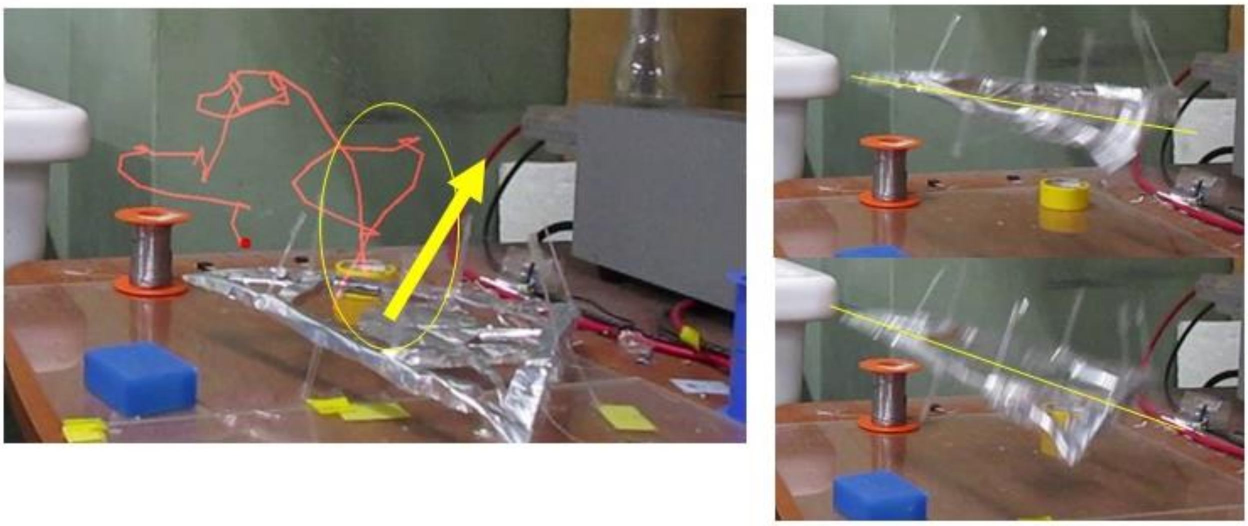


Fig.4. Analyzed result for levitation of triangle EHD device.

Next, as shown in Fig. 4, it was confirmed that the EHD device with the central structure levitated in a tilted direction and immediately returned to the horizontal direction as it ascended. This characteristic remained the same even when the input voltage was changed.

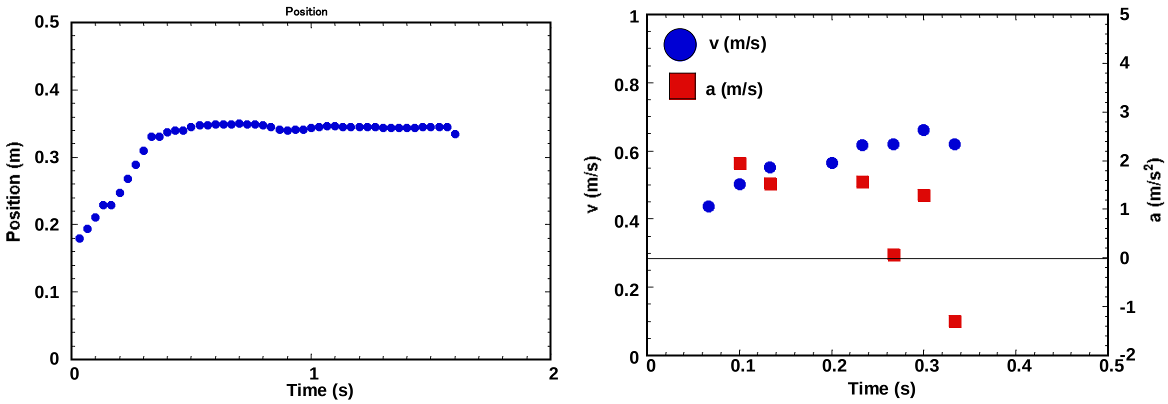


Fig.5. Analyzed results. (a) Position. (b)Velocity and acceleration.

Next, the analysis results of velocity and acceleration are shown. Fig. 5 shows the analysis results of the position, velocity, and acceleration of the EHD with the central structure. This result corresponds to the apparatus used in Fig.2. Input voltage was 30 kV. Device slowly ascends with increasing speed while remaining level. Speed increased proportionally. Acceleration seemed constant. The gravitational acceleration is 9.8 m/s^2, the acceleration reversed and became about 1/5 of the gravitational acceleration.

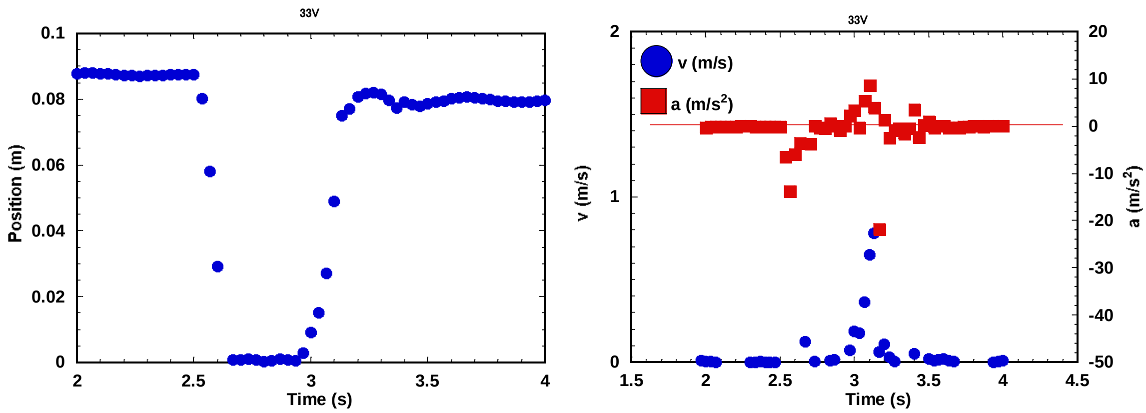


Fig.6. Analyzed results. (a) Position. (b)Velocity and acceleration.

Fig. 6 shows the analysis results of the position, velocity and acceleration of the triangular EHD. Input voltage was 30 kV. Device acceleration varied from 0 to 10 m/s^2. The maximum velocity was 0.8m/s.

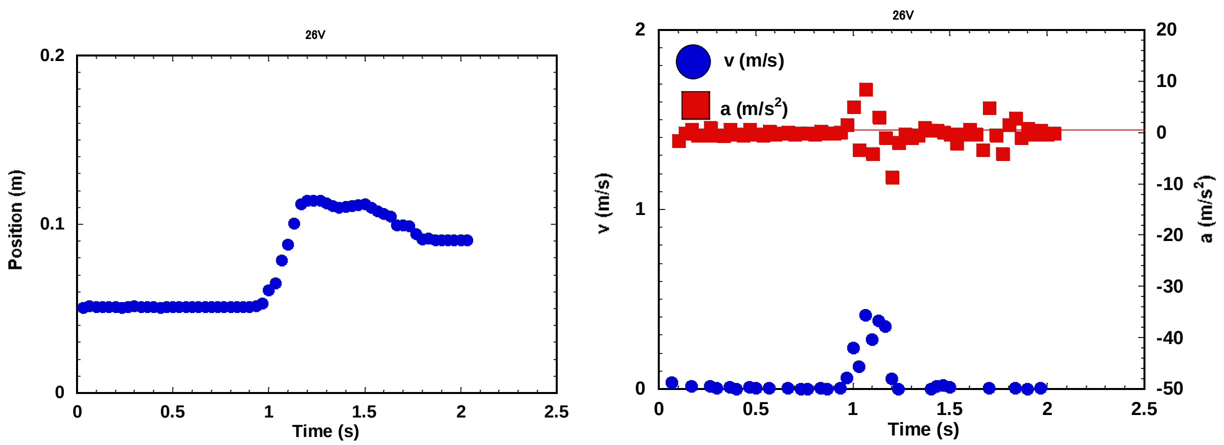


Fig.7. Analyzed results. (a) Position. (b)Velocity and acceleration.

Figs.7, 8, and 9 show the analysis results of the position, velocity, and acceleration for different input voltages of an EHD device having a central structure. In Fig. 8, the input voltage was 25 kV. Acceleration varied from 0 to 2 m/s^2. The maximum velocity was 0.4m/s.

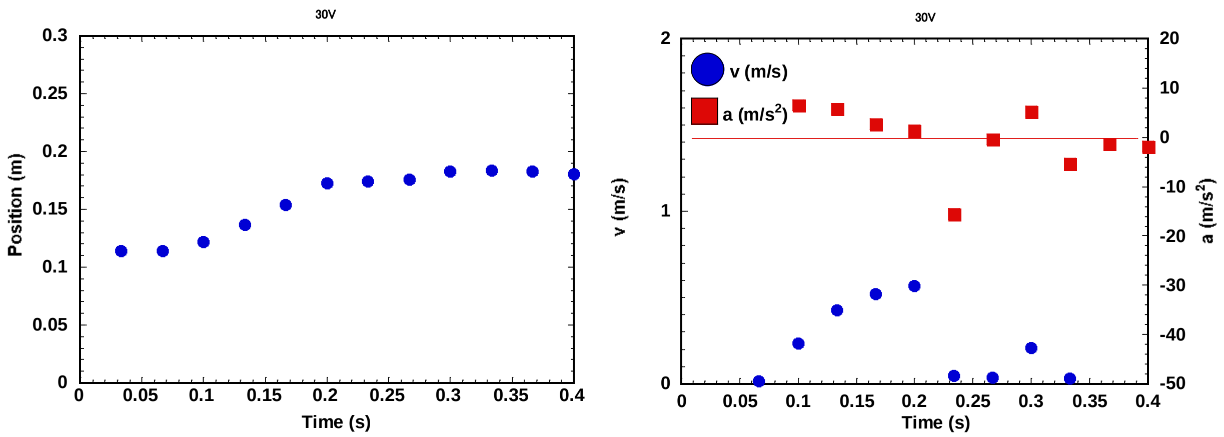
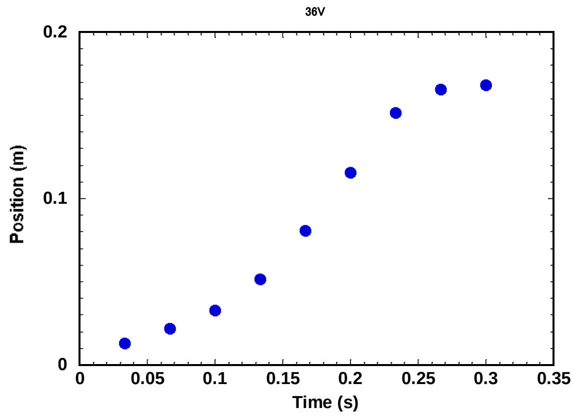


Fig.8. Analyzed results. (a) Position. (b)Velocity and acceleration.

In Fig. 8, the input voltage was 28 kV. Acceleration varied from 0 to 6 m/s^2. The maximum velocity was 0.6m/s.



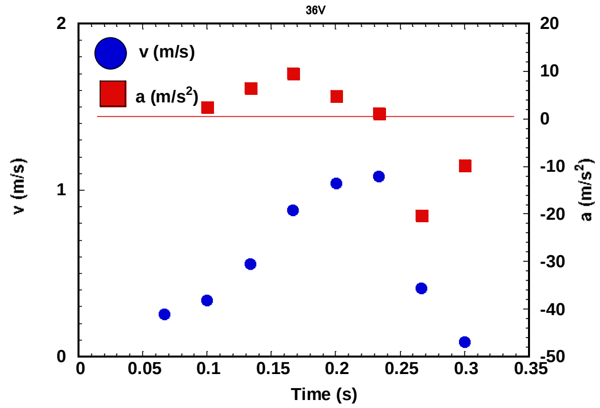
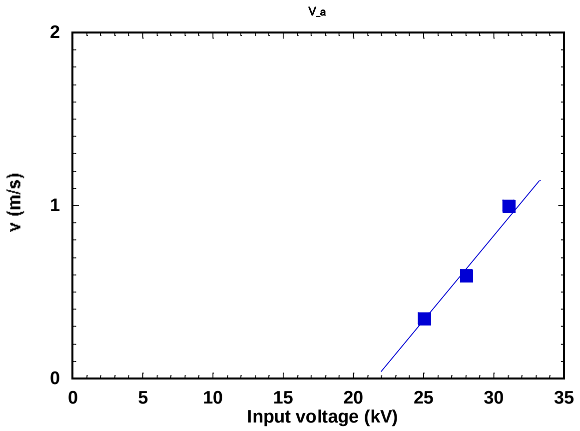
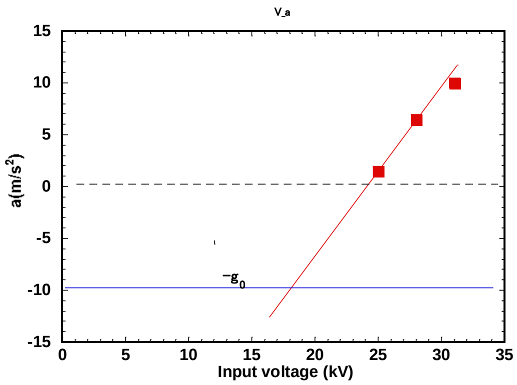


Fig.9. Analyzed results. (a) Position. (b)Velocity and acceleration.

In Fig. 9 the input voltage was 30 kV. Acceleration changed from 0 to 10 m/s^2. The maximum velocity is 1.1m/s.



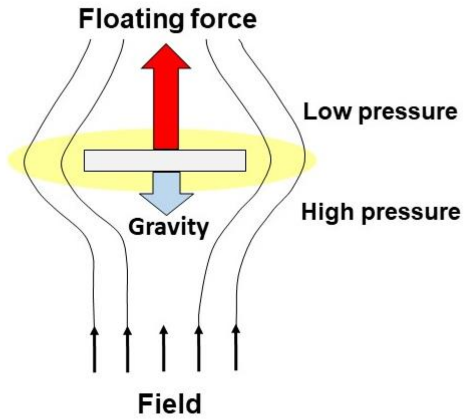


(a) (b)

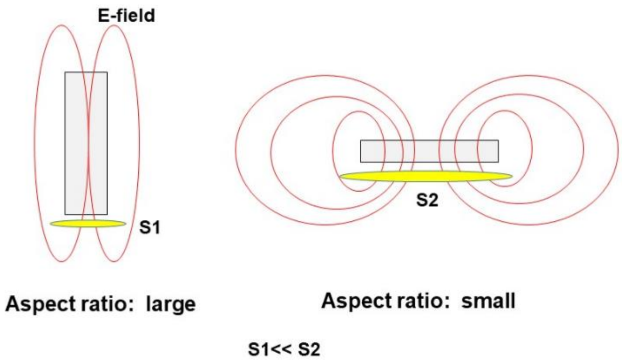
Fig. 10. Analyzed results. (a) Velocity and (b) Acceleration as a function of input voltage.

Fig. 10(a) shows the velocity vs. input voltage in an EHD device with a central structure, and Fig. 10(b) shows the analyzed results by estimating the acceleration. Regarding the graph of acceleration against input voltage in Fig. 10(b), if you draw a line to -g0 (g_0 is the acceleration of the earth gravity), it seems that there is a levitation force generation threshold at 18 kV.

Discussion



(a)



(b)

Fig. 11 Explanations for levitation.

In this experiment, it became clear that there is a property that the direction in which gravity is applied to the EHD device and the direction in which it floats are exactly opposite. The angle between the direction of gravity and the direction of propulsion is less than 10mrad and almost the same direction. Wires and electrodes are circular. The positive wire of the EHD device is a perfectly continuous cylindrically symmetrical structure.

Experimental results also showed that there is a restoring force that keeps the EHD device in the horizontal direction. Although it is only single hypothesis, there is a flow of some medium in the gravitational field of the earth, and as shown in Fig. 11(a), the flow is eliminated and the pressure of the device itself and its surroundings is like a gas (medium). It has been considered that the pressure difference is generated between the upper and lower sides due to the falling negative state. However, more experiments are needed to prove this hypothesis. The experiment also revealed that the triangular EHD device with only the frame has high straightness and low resilience, while the EHD device with the structure in the center has strong resilience to move in the direction opposite to this gravity. became. As the reason for this, it is considered that the area of the lower surface of the triangle is small with respect to gravity as shown in Fig.11(b).

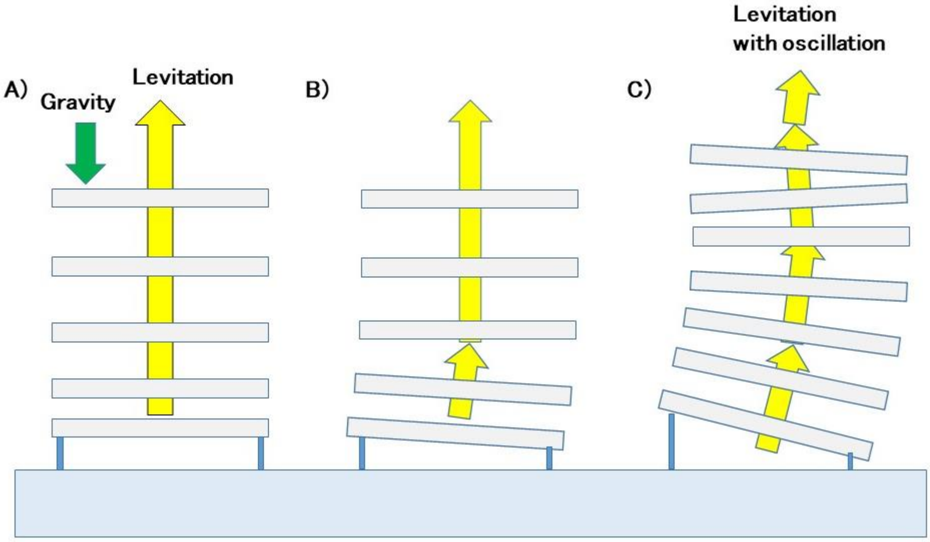


Fig. 12. Differences in levitation properties due to differences in device orientation.

As for the effect on the tilt of the device, when the EHD device was placed almost horizontally and levitated, it rose in the vertical direction opposite to gravity as shown in Fig. 12(A). Triangle unit and EHD device had the same characteristics. Even when the initial tilt angle of the device was as small as several mrad, the device rose vertically upward, which is exactly opposite to the gravity, as shown in Fig. 12(B). Experiments have revealed that when the the initial tilt angle of the device is large, the device levitates diagonally once and then tries to return to the horizontal direction, as shown in Fig. 12(C). Here, the device vibrates and becomes unstable.

Acceleration changed gradually during applying voltage. It is thought that the reason why the acceleration takes time is that some state of the metal itself and its surroundings changes. The acceleration changed from -g_0 to a positive value similar to g_0 via 0. Here, it was found that the acceleration changes in a slow time of the order of 0.1 seconds when it changes from 0 to positive. Since the charging time of the rectifier circuit is on the order of milliseconds, this may not be due to the rectifier circuit, but the cause and reason are unknown. The time constant of this phenomenon is long. The charge accumulation time in the Al metal electrodes is not so slow. Experiments show that the acceleration increases linearly and then saturate and becomes constant. From experiments it appears that there is a device input voltage threshold for the acceleration to decrease.

In the future, experiments for detailed confirmation of these phenomena should be necessary.

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