Design of indoor unmanned airship propelled by ionic wind

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Abstract. The indoor unmanned airship is a lighter-than-air aircraft that can hover in the air for a long time without consuming energy. Indoor unmanned airships are widely used in indoor inspections, special operations, commercial advertising, education and scientific research. In this paper, an indoor unmanned airship propelled by ionic wind is designed. The airship can complete motions such as forward and yaw, and almost no noise and vibration are generated during the working process.

1. Introduction
The indoor unmanned airship is a lighter-than-air aircraft that can hover in the air for a long time without consuming energy. Indoor unmanned airships have a wide range of applications in indoor inspection [1], special operations, commercial advertising [2], education and scientific research [3-4]. At present, the main power sources of indoor unmanned airships are electric motor-driven propellers and bionic wings. Such a power device will produce noise and vibration when it is working, and the movable mechanical parts are likely to cause damage to other objects in the environment or themselves due to collisions. The ionic wind propulsion device is a device that can generate a tiny thrust in the air [5], almost no noise and vibration. Ionic wind propulsion device as a micro power source is widely used in micro and small aircraft, such as ionic wind-powered fixed-wing UAV[6], ionic wind-powered vertical take-off and landing UAV[7] and ionic wind lift [8]. The working environment of the unmanned airship is indoor, and the ionic wind propulsion device can provide enough thrust for the indoor airship. But the direction of thrust generated by the ionic wind propulsion device is fixed, from the high-voltage emitting electrode points to the collecting electrode. We designs an indoor unmanned airship propelled by ionic wind in this paper. Two horizontally placed ionic wind propulsion devices are installed on the bottom of the indoor airship. By controlling the working status of the two ionic wind propulsion devices, the airship can complete forward and yaw actions.

2. Ionic wind propulsion device design
The ions produced by the corona discharge move directionally under the action of Coulomb force, and the moving ions transfer momentum to the neutral gas molecules through collision, which causes the collective directional movement of the neutral gas molecules, which is represented as ionic wind. The thrust direction of the ionic wind is directed from the high-voltage emitting electrode to the grounded collecting electrode. This article installs two ionic wind propulsion devices on the bottom of the airship, as shown in figure 1.
The Y direction is the flight forward direction of the airship, the X direction is the right-hand direction perpendicular to the forward direction, and the Z direction is the vertical upward direction perpendicular to the horizontal plane. The thrust generated by the ionic wind propulsion device A is $F_A$, and the thrust generated by the ionic wind propulsion device B is $F_B$. When the two ionic wind propulsion devices are powered off at the same time, no thrust is generated; when the ionic wind propulsion device A is powered, the airship’s thrust is $F_A$. The point of action of $F_A$ is not at the geometric center of the airship, and a clockwise turning moment will be generated. The airship moves forward while turning to the right; when the ionic wind propulsion device B is powered, the airship’s thrust is $F_B$. The point of action of $F_B$ is not at the geometric center of the airship, and a counterclockwise turning moment will be generated. The airship moves forward while turning to the left; when the two ionic wind propulsion devices are powered on at the same time, the thrust of the airship is $F_A + F_B$, and the airship moves forward.

The working voltage of the ionic wind propulsion device is very high, usually on the order of 10kV. The miniature high-voltage generator is light in weight, suitable for indoor unmanned airships, and can generate DC high voltage when connected to the onboard battery. In order to realize the independent control of the two ionic wind propulsion devices, two miniature high voltage generators are used to independently power the two ionic wind propulsion devices. The control of the ionic wind propulsion device can be realized through the miniature high-voltage generator. This article designs a control circuit suitable for miniature high-voltage generators. The control circuit integrates the main control chip, power drive chip, Bluetooth communication module and other equipment. The main control chip receives the user's control command through the Bluetooth communication module, and drives the corresponding miniature high voltage generator through the drive chip. The remote control terminal runs on the user's mobile phone, and its main function is to get the user's control commands and wirelessly transmit the control commands to the control circuit of the indoor unmanned airship via Bluetooth communication. The working state mapping table is shown in table 1.

| Control commands | Ionic wind propulsion device A | Ionic wind propulsion device B | Airship action |
|------------------|-------------------------------|-------------------------------|----------------|
| stop             | 0                             | 0                             | stop           |
| forward          | 1                             | 1                             | forward        |
| Forward left     | 0                             | 1                             | Forward left   |
| Forward right    | 1                             | 0                             | Forward right  |

1 indicates that the ionic wind propulsion device is powered on and generates thrust; 0 indicates that the ionic wind propulsion device is powered off and does not generate thrust.

According to the working characteristics of the corona discharge ionic wind [9] and the application environment of the indoor airship, the material and geometric dimensions of the ionic wind propulsion device are determined. The emitting electrode is a thin copper wire with a length of 200 mm and a...
diameter of 0.08 mm, and the collecting electrode is an electrode with a length of 200 mm and a width of 50 mm. The frame of the collecting electrode is a balsa wood structure, and the outer shell is aluminum foil paper. This structure can reduce weight. The distance between the emitter and the collector is 50 mm. The distance between the two emitters is 100 mm.

An adjustable DC high-voltage power supply is used to power the ionic wind thrust device, the emitting electrode is connected to the high-voltage electrode of the power supply, and the collecting electrode is grounded. The weight difference method [10-11] is used to measure the thrust generated by the ionic wind propulsion device, and the relationship between thrust and voltage is shown in figure 2.

![Figure 2. Thrust-voltage graph](image)

When the driving voltage is less than 5 kV, no corona discharge is generated around the emitting electrode, and the ionic wind propulsion device does not generate thrust. When the driving voltage is greater than 30 kV, the electric field strength between electrodes is very strong, the air between the electrodes is easily broken down, and the ionic wind propulsion device fails. The operating voltage range of the ionic wind propulsion device is greater than 5 kV and less than 30 kV. Within the working voltage range, the thrust generated by the ionic wind propulsion device increases with the increase of the driving voltage, up to 16 mN. In this article, a 7.4 V lithium battery pack is used for power supply. The miniature high-voltage generator can generate a voltage of about 25 kV, and a single ionic wind propulsion device can generate a thrust of about 10 mN.

3. Airship design

The ionic wind powered airship is mainly composed of ionic wind propulsion device and helium balloon. The ionic wind propulsion device is installed horizontally at the bottom of the helium balloon to provide horizontal thrust for the airship. The mass of the ionic wind propulsion device is large, while the mass of the helium balloon is small. The center of gravity of the airship is at the bottom of the helium balloon. The helium balloon is filled with helium to provide lift for the airship. The point of action of the buoyancy on the helium balloon is basically the same as the geometric center of the helium balloon. Because the point of buoyancy is higher than the center of gravity of the airship, the airship is in a static and stable state in the direction of gravity. When the airship is in normal flight, the buoyancy of the airship in the air is equal to the gravity of the airship. The buoyancy $F_h$ of the helium balloon in the air.

$$F_h = (\rho_{air} - \rho_{he}) \times Vol$$  \hspace{1cm} (1)

$$Vol = \frac{4}{3} \pi r^3$$  \hspace{1cm} (2)

$\rho_{air}$ is the density of air, which is 1.29 g/L at room temperature; $\rho_{he}$ is the density of helium, which is 0.18 g/L at room temperature; $Vol$ is the volume of a spherical helium balloon, in L; $r$ is the radius of the helium balloon, in mm.
The total weight of the airship designed in this paper is about 120g. After calculation, a floating balloon with \( r = 350 \text{mm} \) is selected to provide lift for the airship. In a normal temperature environment, the balloon can lift a load of about 180g in the air. The buoyancy of the balloon will change due to temperature changes, helium leakage and other reasons. Placing an adjustable weight on the bottom of the airship balances the buoyancy and gravity of the airship in the vertical direction, and the airship is always in suspension.

The airship is subject to air resistance during its movement. In this paper, fluent software is used for numerical simulation of airship. In the software, an approximate model of airship is established according to the determined geometric parameters, ignoring the influence of ionic wind propulsion device. The simulation calculated the air resistance of the airship under different air velocity. Figure 3 shows the relationship between the air resistance and the airflow velocity. \( V_e \) is the airflow velocity, in m/s; \( F_d \) is the air resistance, in mN.

![Figure 3. Air resistance-speed graph](image)

When the airship is flying at a constant speed, the thrust of the ionic wind propulsion device is equal to the air resistance of the airship. The air resistance of the airship increases as the flying speed of the airship increases, while the thrust of the ionic wind propulsion device is limited. When two ionic wind propulsion devices work at the same time, a total thrust of about 20mN can be generated. According to the analysis of the simulation results, the maximum speed of the airship propelled by the ionic wind is 0.6m/s in an ideal state.

4. **Flight experiment**

According to the design plan, an ionic wind powered airship is made, as shown in figure 4. The airship is powered on, and the operator uses the mobile phone for remote control. The operator's control command is wirelessly transmitted to the control circuit of the airship via Bluetooth, and the control circuit powers up the corresponding ionic wind propulsion device according to the received control command.

![Figure 4. Ionic wind powered airship](image)
The airship is in a quiet indoor environment. When the control command is "stop", ionic wind propulsion device A and ionic wind propulsion device B are powered off at the same time, and the airship maintains its current position; when the control command is "forward", ionic wind propulsion device A and ionic wind propulsion device B are at the same time powered on, the airship flies forward; when the control command is "forward left", ionic wind propulsion device A is powered off, and ionic wind propulsion device B is powered on, and the airship flies forward while rotating to the left; when the control command is "forward right" When the ionic wind propulsion device A is powered on, the ionic wind propulsion device B is powered off, and the airship flies forward while rotating to the right.

5. Conclusion

Compared with the propeller and the bionic wing propulsion device, the ionic wind propulsion device is quieter when it is working, and there are no high-speed moving mechanical parts that threaten the surrounding environment and its own safety. The ionic wind powered airship designed in this paper uses two ionic wind propulsion devices as power sources. The airship propelled by ionic wind can complete forward and yaw movements under the remote control of the operator, and almost no noise and vibration are generated during the flight.

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