BOHR

BOHR International Journal of Engineering
2022, Vol. 1, No. 1, pp. 33–36
DOI: 10.54646/bije.2022.07
www.bohrpub.com

RESEARCH PAPER

Design of power supply and EHD system for ion-propulsion drone

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Received: 22 August 2022; **Accepted:** 02 September 2022; **Published:** 15 September 2022

An initial preparation stage for the design of an ion-propulsion drone with no moving parts is presented in this study. Ion-propulsion drone technology is still not significantly mature; however, the technology has the potential to bring about evolution in the drone and aerospace industries. An essential part of the system is to generate a high-voltage (HV) DC power supply in order to propel the drone. This study presents the design of a power supply circuit to generate a HV DC supply system along with the design of electrohydrodynamics is presented in this study.

Keywords: ion propulsion, electrohydrodynamics, eVTOL, UAV, drone

1. Introduction

Ion-propulsion drone is a type of unmanned aerial vehicle that uses electrohydrodynamics (EHD) to create ionic wind to propel the drone (1). The very first ioncraft was able to manifest a considerable performance by lifting the power supply; the experiment was demonstrated by Krauss (2). A tech startup called "Undefined Technologies" based in Florida has successfully tested their first eVTOL vehicle using ionic propulsion in April 2021, followed by a second test in December 2021. The amount of thrust generated by ion engines is not significant as compared to other propulsion systems, although they have a high specific impulse, which makes them ideal for space propulsion (3). The most common method used in order to generate ionic wind is electrical or corona discharge (4). The corona discharge is effectively stable at small scales in the atmosphere. It consists of two asymmetrical electrodes called the emitter and collector, in which a potential difference is applied across both the electrodes. A large DC voltage supply is given to the emitter while the collector is grounded; the large potential gradient causes the air molecules to be ionized around the emitter; these ionized particles then race toward the collector. In this process, the transfer of momentum takes place when ionized particles collide with air molecules that accelerate airflow, resulting in ionic wind. The schematic depiction of the process is shown in **Figure 1**.

A simple physical model of an EHD thruster is shown in **Figure 2**.

This study is further divided into four categories: literature review, design of power supply and EHD thruster, future scope, and conclusion.

2. Literature review

As mentioned earlier, "Undefined Technologies" made a breakthrough in the development of ion-propulsion drone that showed magnificent improvement in ion-powered flight. Furthermore, they are developing their first product, called "Silent Ventus," which promises to reduce the noise level of drones below 70 dB. The current prototype was able to stay in the atmosphere for more than 2 min with a noise level near 85 dB. They further promised to reduce this noise level below 70 dB. Recently, in September 2022, they carried out a critical flight test with an endurance of 4 min and 30 s; during this flight, the ioncraft manifested higher efficiency, flight performance beyond steady-state conditions, and a noise level below 75 dB. They further aim to achieve a flight time of 15 min or more with noise levels below 70 dB. The proposed prototype by Undefined Technologies is shown in Figure 3.

In 2018, MIT built an ion-drive aircraft with no moving parts. It was a large and lightweight glider with 2.26 kg of mass and a 5-m wingspan. This was the very first breakthrough in this decade which took 60-m flight. The physical model built by MIT is depicted in Figure 4. The air vehicle needs a high-voltage (HV) DC supply, emitter, and collector in order to generate ionic wind to propel itself forward. Potentially, this caused further advancements in the ion-propulsion technology. The design was possibly the simplest in order to prove the ion-propulsion technology. The specifications of this design will be further clarified in the design study section.

Indoor unmanned aerial ship is an ion–propelled, lightweight aircraft designed by Zhongzheng He et al. (5). This airship is capable to move along all three axes without making any noise. The proposed design in this paper uses two propulsion systems in order to achieve full motion control in forward direction. The helium blimp presented in this paper is shown in Figure 5.

Ion propulsion is proven to be sustainable in space, and various designs are already available for ion thrusters for space propulsion as primary propulsion system. The interaction of electro-hydrodynamic propulsion (EHP) system with spacecraft and design requirements for compatible ion thruster is presented by K Holste et al. (6). Until now, there has been no propellant that could be ideal for an ion-propulsion system; xenon is assumed to be the most reliable propellant because it carries a high atomic mass that results in a high specific impulse when ions are accelerated. This paper reviews various kinds of potential molecular propellants that can be used for ion propulsion. The compatibility of iodine with EHP is further discussed by Patrick Dietz et al. (7).

Ion-propulsion UAV with blimp fuselage design is also considered efficient in the earth's atmosphere. The design of airship that uses blimps filled with helium gas is presented by Ho Shing Poon et al. (8). The model presented in this paper is depicted in Figure 6. To accelerate the ions, the power system needs more than 20,000 volts of continuous DC supply; the detailed architecture of power supply for this airship is further discussed in this paper.

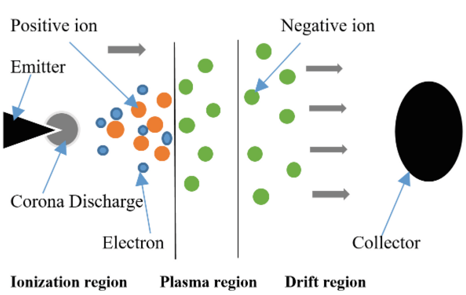

FIGURE 1 | Corona discharge.

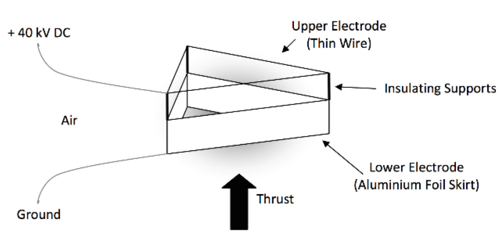

FIGURE 2 | Simple ionic thruster (image: UAS vision).

FIGURE 3 | Silent Ventus by undefined technologies (image: undefined technologies).

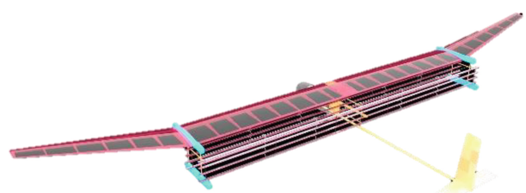

FIGURE 4 | Ion-drive UAV by MIT (image: MIT news).

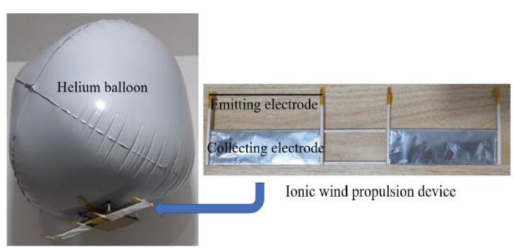

FIGURE 5 | Ion-propelled Airship (5).

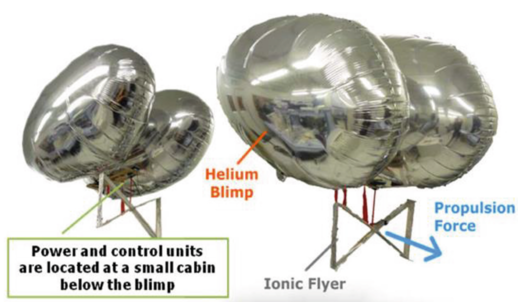

FIGURE 6 | Prototype of ion-propelled unmanned aerial blimp (8).

3. Design of power supply and EHD thruster

In this section, we will be looking into the detailed design of ion-propulsion drone.

3.1. Design of EHD thruster

The EHD thruster is an essential part of the ion-propulsion system. The thruster consists of a thin metal wire as emitter and a metal foil as collector, as shown in **Figure 7**. The emitter metal can be copper, tungsten, platinum, or titanium, bearing a voltage of around + 40 kV. On the counterpart, a thin foil of aluminum or gold can be used as a collector with −40 kV.

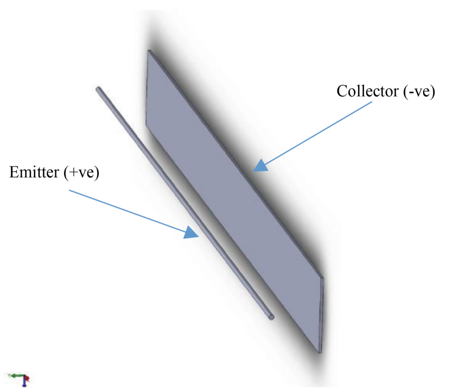

FIGURE 7 | Design of EHD thruster.

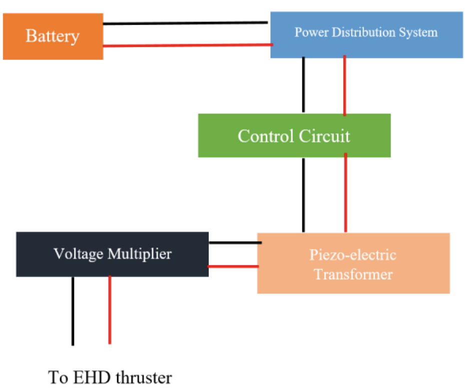

FIGURE 8 | High-voltage power supply.

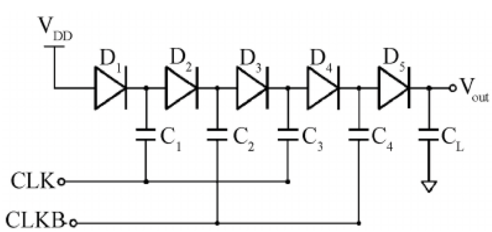

FIGURE 9 | A total of 5-stage Dickson charge pump (image: ResearchGate).

An analysis for weight optimization of EHD thruster with increased efficiency is needed for lift generation. When EHD thruster is powered on, in a sense that the emitter has a positive charge, it will trigger the nitrogen that is available in the atmosphere, resulting in an electromagnetic field. Then, electro-charged nitrogen atoms will start racing toward the collector plate, as shown in **Figure 1**.

The current-voltage (I–V) relation at the time of corona discharge depicts ionization between the emitter and collector. Townsend derived this relationship in 1914 and successfully validated it for co-axial configuration of corona.

$$I = Kv\,(v - v0) \tag{1}$$

Where I and v are the current and voltage of the corona, v_0 is the onset voltage of the corona, and K is denoted as fitting parameter.

The electrical power generated during the discharge is calculated as follows:

$$P = vI \tag{2}$$

The equation for the thrust produced due to ionization can be derived using (3.1), and Mott-Gurney's law can be used to derive the equation for the maximum thrust. The Coulomb force on the fluid volume between the cathode (emitter) and anode (collector) is equal to the thrust and is given by:

$$T = \int \rho_E e dV = \int \rho_E eAdx = \frac{\int \mathrm{JA\,dx}}{\mu \mathrm{B}} = \frac{\mathrm{Id}}{\mu \mathrm{B}} = \frac{Kv(v - v0)}{\mu B} \tag{3}$$

Where T is thrust, ρ_E is charge density, e and μ_B denote electric field and ion mobility, respectively, and d denotes the distance between the cathode (emitter) and anode (collector). Hence, thrust efficiency is given by:

$$\frac{T}{P} = \frac{Id}{\mu_B vI} = \frac{d}{\mu_B v'} \tag{4}$$

Where P is the power consumption due to corona discharge (9).

3.2. Design of power supply

The power supply needs to deliver 20–40 kV DC supply to the thruster from a lightweight battery; hence, we need a design with a control circuit with a voltage multiplier. A single battery with 25 V output can be used to provide an output of 20–40 kV (10). The power supply consists of a lithium polymer battery, a power distribution system, a control circuit, a set-up transformer, and a voltage multiplier; the arrangement is shown in **Figure 8**.

(a) Battery

We need a battery with small size and weight that can deliver adequate power to the system. Lithium-polymer (Li-Po) battery is considered to be the most efficient for drones because of its high performance-to-weight ratio.

(b) Piezo-electric Transformer (PZT)

It is essential that we use a transformer that delivers a HV and carries less weight. The PZT induces negligible EMF that has no considerable effect on the control system, and it has a high power-to-weight ratio near 0.9 g/Watt.

(c) Voltage Multiplier

The Cockcroft-Walton (CW) voltage multiplier is essentially used to deliver the HV supply. The CW circuit consists of a ladder network of diodes and capacitors in order to multiply the voltage (11).

Alternatively, the Dickson charge pump (DCP) can be used effectively to generate HV up to few kilovolts. It offers a comparatively better efficiency than CW voltage multiplier and considerably better power quality. DCP consists of cascade connection of diodes and capacitors with a bottom plate at every alternate capacitor to be driven by a series of clock pulses.

Theoretically, the output voltage of the DCP circuit is given by:

$$V_{OUT} = N(V_{PP} - V_D) + V_{DC} \tag{5}$$

Where V_{OUT} is the output voltage, N is the number of stages in the circuit, V_{PP} is peak-to-peak voltage, V_D is voltage drop, and V_{DC} refers to the DC voltage.

The 5-stage DCP is shown in **Figure 9**. As per the voltage requirement, we can increase the number of stages in the circuit in order to increase the output voltage.

4. Conclusion and future work

This study presents a brief review of ion-propulsion technology and design of EHD system and HV power supply. To make the drone fly in the earth's atmosphere, weight and performance optimization are essential stages. The power supply presented in this study is miniaturized and lightweight; besides, the EHD system is a web of emitter wire and collector foil. An advanced prototype design with an advanced control and navigation system will be presented in the next stage, which will provide a clear picture of the ion-propulsion drone.

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