Efficiency of ionocrafts: experimental investigation

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Abstract

Ionocraft is a flight facility which lifting force is created by means of ionic wind. Ionic wind is air flow caused by corona discharge. The flux of momentum which is whirled away by ionic wind jet may be used for propulsion. The ionocraft conception is known for decades but efficiency of the prototype models is still low. The main efficiency parameter for ionocraft is the relation of consumed electric energy and lifting force (вЃЁthrust specific energy consumptionвЃ№ Q — as an analogy to вЃЁthrust specific fuel consumptionвЃ№ which is a commonly used as a term in aviation). It is necessary to reach a certain level of thrust specific energy consumption for practical applications.

A classical construction of ionocraft segment вЃY– wire-cylinder вЃY– is considered. Presumable ways of efficiency improvement are discussed. Formally thrust specific energy consumption of ionocraft may be rather high especially for large interelectrode gaps. However, it usually leads to large air volume occupied by construction with significant total lifting force. Consequently, more sophisticated criteria should be used such as: thrust specific energy consumption level by fixed lifting force from unity volume.

1 Introduction

When high voltage is applied to interelectrode gap electrons accelerate in electric field and gain energy enough to ionize air molecules. So avalanche takes place increasing number of charged particles вЃY– positive ions and electrons. If secondary processes of electrons production are intensive a new avalanche is caused by passing the first avalanche and self-maintained discharge process is formed which called corona discharge [2]. Charged particles appear in the air as a result of collision ionization in the corona layer. Coulomb force acts on charged particles in the interelectrode gap. In fact, electric force generates because of coupling electric field between electrodes and space charge. All kinds of ions (positive or negative –вЃY it depends on the active electrode polarity) moving to the ground electrode gain the momentum in the electric field and transfer it to air molecules owing to collisions and the air starts to flow. And this process generates electrohydrodynamic flow which called ionic wind [2]. The reactive jet force of ionic wind can be used as a lifting force. So the lifting force is determined by the Coulomb force which

acts on ionocraft from ions. In such a case, ions quickly transfer momentum to air molecules.
There are many different ionocraft constructions –вЂY triangular, square, ring. These systems work as reactive engine and as a result they can levitate. The main issue in ionocraft designing is low specific thrust which is defined as the relation of the lifting force to consumed power.
In this paper lifting force results from current and voltage in the wire-cylinder are presented. The lifting force depends on the current I, interelectrode gap d and ions mobility μ in air gap [3]:

$$F = \frac{I}{\mu} d \tag{1}$$

Equation for specific thrust can be obtained from (1):

$$Q = \frac{F}{UI} = \frac{d}{\mu U} \tag{2}$$

As we can see from (2) thrust is lower when the voltage is higher. Consequently, thrust decreasing is caused by lifting force increasing (in specific geometry). So the main concern is searching a suitable configuration which solution will depend on applying technical restrictions (fixed voltage or fixed occupying volume). The next simplifying can be used for equations (1–2):

1. There are electrons only near active electrode. We neglect them in air gap.
2. Air friction force acting on electrodes is much smaller than lifting force.
3. Vertical projection of the ion path between electrons equals d.

2 Experimental setup

Wire-cylinder was studied when the interelectode gap varied. Active electrode is a wire with radius 0.042 mm and the ground electrode is cylinder with radius 0.93 mm. both electrodes was pulled in the wooden frame (Fig. 1). The construction length is 20 cm. Voltage and current are registered with the help dual-channel analog-digital converter (ADC) L-Card. Current was measured by voltage registration across the resistor 19.2 kΩ in series source-discharge gap. High voltage supply occurs with the help constant-voltage source. The setup allows to define corona inception voltage in wire-cylinder system and to analyze discharge current-voltage characteristic (CVC). Ionocraft segment hang up so that the thrust was directed upward vertically. Therefore, thrust value complements the ionocraft weight and the total value is measured by scales. The measurement is differ from usually applying ionocraft scaling [4]: decreasing lifting force is caused scaling the ionic wind jet which put pressure on scales. Due to our measurement the ionic wind jet encounters board which is stiffened (it is under the scales) and it doesnвЂЄt influence on scales measurements.
Thus current and voltage oscillogramms and lifting force value can be analyzed.

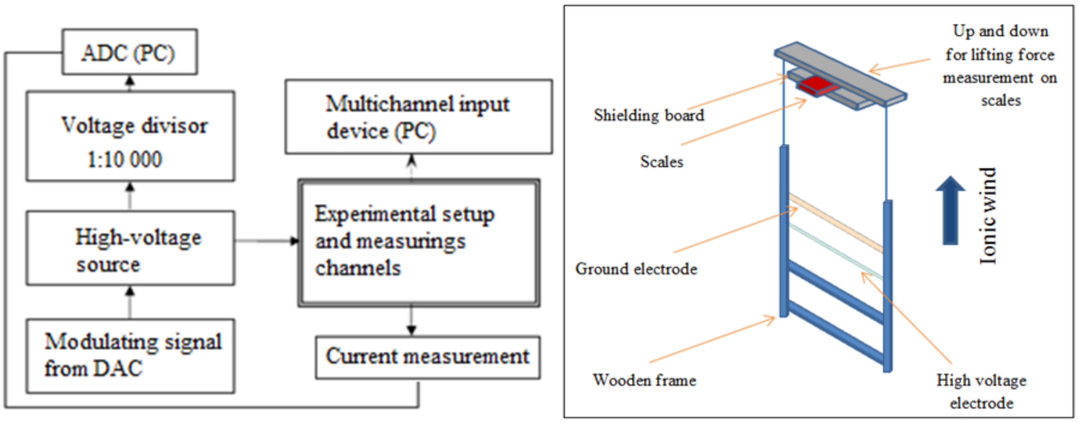

Figure 1: Experimental setup flow diagram (on the left) and lifting force measurement design (on the right).

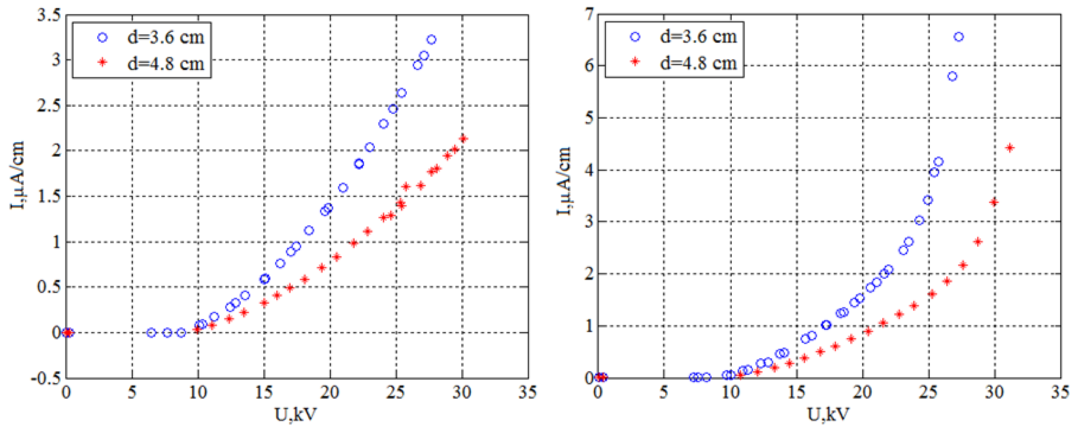

Figure 2: Current-voltage characteristics under positive (on the left) and negative (on the right) polarities. d вЃY- electrode gap.

3 Results

In Fig. 2 CVCs are presented. On the one hand they are classical squared but it is incorrect for negative polarity. Analyzing the reduced CVC allows to state this fact (the relation U/I from U вЃY linear function for classical discharge CVC) (Fig. 3). There is a deviation from linearity for reduced CVC with applying voltage over 20 kV under negative polarity.

In Fig. 4 lifting force dependence on current is shown. The linear dependence has to be seen due to (1). It is held under positive polarity. However, the lifting force isnвЃЄt proportional to the current where the CVCs deviate from quadratic form under negative polarity. The structure of positive and negative corona discharge is significantly different. but it is thought to be the outer zone characteristic which structure less depends on polarity is more important for CVC and lifting force. We can add that special aspects outer zone have a streamer form of corona discharge in this case it is not seen the streamers in this system. At least there Is only one significant difference in positive or negative outer zone is electron existence in

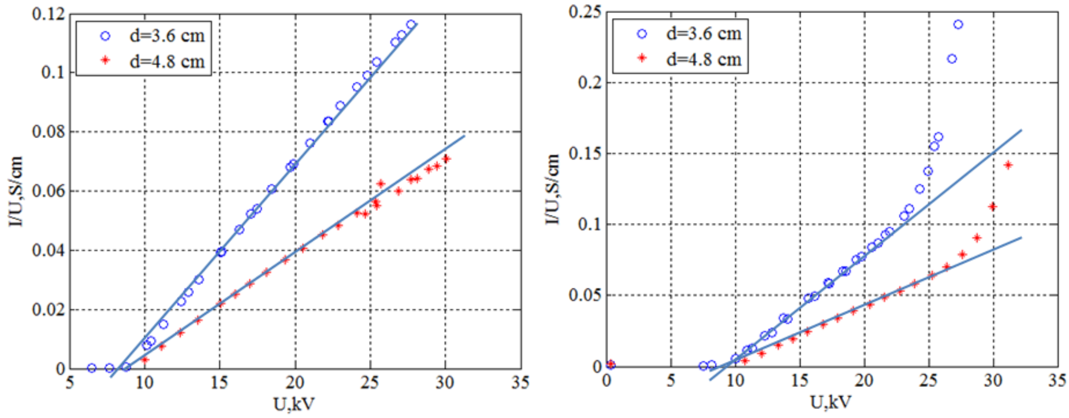

Figure 3: Reduced current-voltage characteristics under positive (on the left) and negative (on the right) polarities. *d* вЂ“ electrode gap.

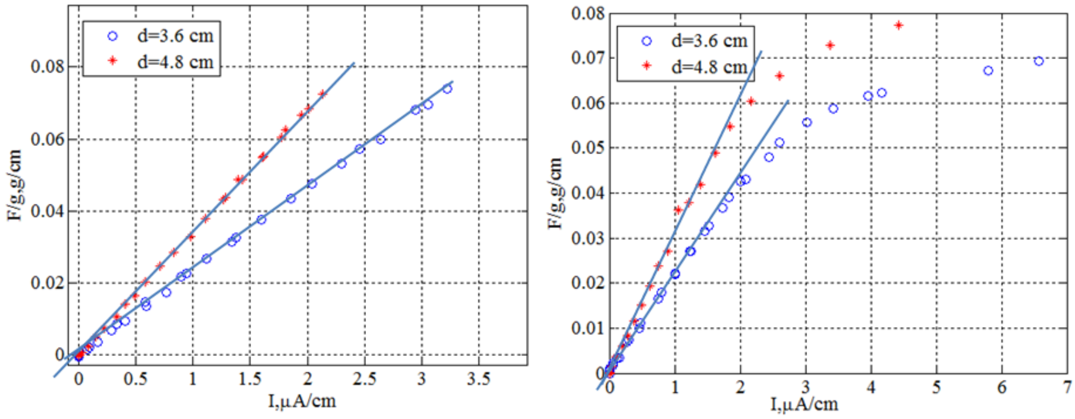

Figure 4: Lifting force dependence from current (per unit length) under positive (on the left) and negative (on the right) polarities. *d* вЂ“ electrode gap.

outer zone. It is thought to be that there arenвЂ™t electrons in outer zone under both polarities. But they can penetrate to the special distance which depends on velocity adhesion under negative polarity. The more is voltage the higher is electric field intensity and less velocity adhesion that is why by high voltage the length of electron propagation into outer zone [3] [6]. However, there are no electrons in outer zone under positive polarity because of the movement direction to the active electrode. They canвЂ™t go out from the corona layer.

In such a way electrons locates in a wider space under negative polarity than under positive polarity. Moreover, the location space of electrons will expand with increasing voltage under negative polarity. That is why it is assumed that widening electron presence space in interelectrode gap with increasing voltage results in reduced CVC and lifting force deviation from linearity. Actually average charged particles mobility increasing in air gap is caused by the widening electron presence space and it leads to current increasing (at preset voltage) and lifting force decreasing (at preset current).

In Fig. 5 specific thrust dependence on lifting force are presented. According to (2)

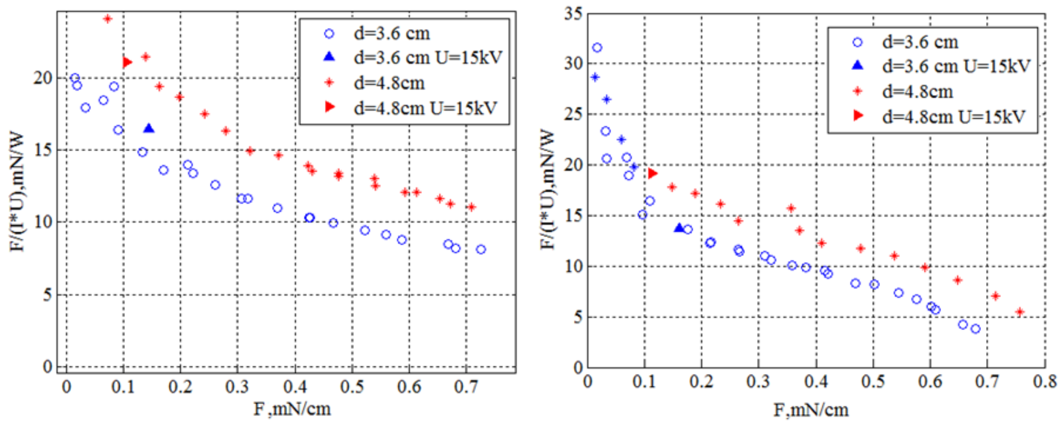

Figure 5: Specific thrust dependence from lifting force (per unit length) under positive (on the left) and negative (on the right) polarities. d вЃY- electrode gap.

specific thrust decreases with lifting force increasing besides electrode gap increasing for fixed lifting force leads to specific thrust increasing. Is it more profitable to use higher electrode gap in constructions? Consider this issue in detail.

In Fig. 5 there are points according to specific applying voltage (e.g. 15kV). Although the curve is higher with higher electrode gap but electrode gap increasing (at preset voltage) leads to specific thrust increasing and lifting force decreasing. Thus if one has a limitation on the operating voltage and the objective value of the lifting force then the optimal interelectrode gap distance may be evaluated. The voltage limitation may be linked to volume and isolation weight and also with size and increasing voltage electric transformer weight.

The question of ionocraft optimization may be as well turned round the other way. In a real construction one would rather have to use a set of parallel electrode systems to reach a valuable lifting force value. Neighbored electrodes of the same polarity influence against each other. It may be shown that wire-cylinder systems are possible to pull together only at the distance proportional to electrode gap. The next pulling together leads to quick growth the corona inception voltage. In this cast lifting force from N pairs of electrode will be more less than NF (F is lifting force from one pair of electrode). Therefore, occupying volume of one pair of electrodes can be evaluate as $2d3dL$, PҮPҮPҳ L вЃY system length, d вЃY electrode gap. d increasing leads to quick volume increasing occupying the system of electrode.

Consider dependence of the thrust specific energy consumption from the unite volume (Fig. 6). As we can see the corresponding dependences come to an agreement with different electrode gap within the scatter accuracy. It would be possible to conclude that both electrode hap are equally profitable. But it has been seen that using less electrode gape at preset voltage we can reach more lifting force from unit of volume if we consider the points according to the same applying voltage. On the other hand the more electrode gap at preset voltage the more specific thrust.

These regularities may be useful in designing construction with a specific set of limitations (thrust specific energy consumption, total lifting force, operationg voatge, occupied volume).

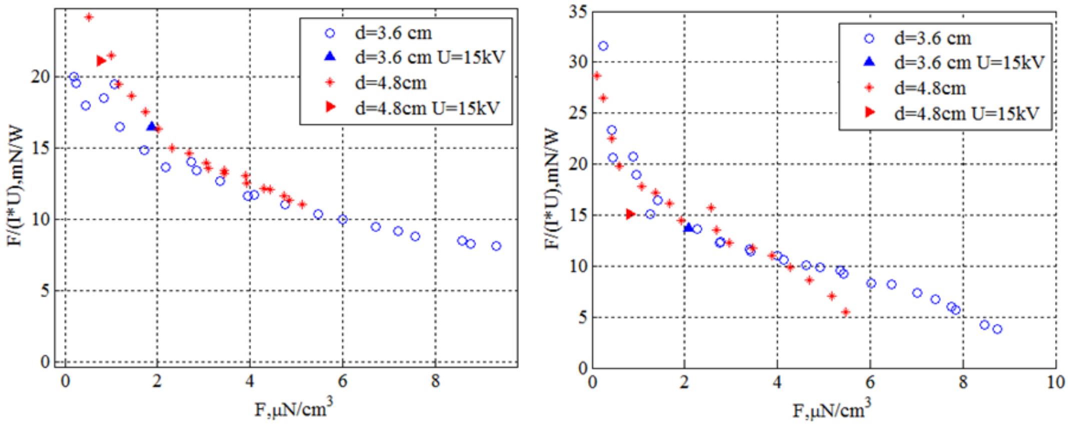

Figure 6: Specific thrust dependence from lifting force (per unit volume) under positive (on the left) and negative (on the right) polarities. d -вЃY electrode gap.

4 Conclusions

1. The reduced current-voltage characteristics and lifting force dependence on current deviation from linearity has been seen under negative polarity under a high applying voltage.

2. Using a system of electrode with higher electrode gap allows to gain more efficiency at preset lifting force from unit of distance but using a system with less electrode gap may prove to be more profitable in the case of the voltage and volume limitation.

References

[1] Yu. P. Raizer. Gas Discharge Physics. Springer, 1991. 449 p.

[2] Vereschagin I.P. Corona discharge in apparatus of electron-ion technology (in Russian). Russia: Energoatomizdat. 1985. 160 P.

[3] Eric Moreau, Nicolas Benard, Jean-Daniel Lan-Sun-Luk and Jean-Pierre Chabriat Electrohydrodynamic force produced by a wire-to-cylinder dc corona discharge in air at atmospheric pressure. J. Phys. D: Appl. Phys. 46 (2013) 475204 (14pp)

[4] Eric Moreau, Nicolas Benard, Frederic Alicalapa, Alexandre Douyere Electrohydrodynamic force produced by a corona discharge between a wire active electrode and several cylinder electrodes вЃY Application to electric propulsion. Journal of Electrostatics 76 (2015) 194-200

[5] Yu.K. Stishkov and A. V. Samusenko. Computer simulation of corona discharge in an inert gas. Surface engineering and applied electrochemistry. 2008. Vol. 44. No. 4. P. 271вЃY280.

[6] Zubkov, T.N., Samusenko, A.V., Stishkov, Y.K. Simulation of the seat form of a negative corona discharge in a point-plane electrode system. Surface Engineering and Applied Electrochemistry. 2013 49 (6) P. 474 - 479

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