Revista Brasileira de Ensino de Física, v. 37, n. 3, 3307 (2015)
www.sbfisica.org.br
DOI: http://dx.doi.org/10.1590/S1806-11173731869

Lifter - High voltage plasma levitation device

(Lifter - Dispositivo que levita sob alta tensão)

M. Cattani, A. Vannucci[1], V.G. Souza

Instituto de Física, Universidade de São Paulo, São Paulo, SP, Brasil

Recebido em 11/3/2015; Aceito em 24/4/2015; Publicado em 30/9/2015

This paper shows in detail the construction and operation of an apparatus that levitates when submitted to voltages greater or of the order of 20 kV. This device, which basically corresponds to an asymmetric capacitor, is commonly known in the literature by the name '*lifter*'. It also will be shown in this article, through rather simplified calculations, that the physics grounds of the observed levitation effect are intrinsically related to the transference of linear momentum of the ions (positive or negative) to the surrounding atmosphere. These ions are produced within the conductor of very small curvature (hence, great electrical potential) due to the so called *corona effect* and, once created, they are immediately accelerated by the intrinsic electric field lines configuration, producing multiple collisions with the air molecules, causing the transference of momentum and, therefore, provoking the observed lifter ascendant impulsion.

Keywords: air ionization, corona effect, ion propulsion, asymmetrical capacitor, ion craft, lifter.

Este artigo descreve em detalhe a construção e operação de um sistema mecânico que levita quando submetido a tensões maiores ou iguais a 20 kV. Este dispositivo, que corresponde basicamente a um capacitor assimétrico, é conhecido na literatura pelo nome de '*lifter*'. Também é mostrado neste trabalho, através de cálculos razoavelmente simplificados, que o mecanismo físico responsável pelo efeito de levitação está intrinsecamente relacionado com a transferência de momento linear de íons (positivos ou negativos) para o ar circundante. Estes íons são produzidos ao redor do condutor de menor curvatura (portanto com maior potencial elétrico) devido ao chamado efeito corona e, uma vez criados, eles são imediatamente acelerados pela configuração do campo elétrico existente, produzindo múltiplas colisões com as moléculas de ar, causando a transferência de momento e, consequentemente, provocando no lifter um movimento ascendente.

Palavras-chave: ionização do ar, efeito corona, propulsão iônica, capacitor assimétrico, nave iônica, *lifter*.

1. Introduction

The pioneer discovery of the propulsion effect (or levitation) involving the application of high voltages to an asymmetric capacitor, is accredit to Thomas Townsend Brown who, soon afterwards, accepted the supervision of the physicist Paul A. Biefeld to deeper the understanding of the phenomenon [1]. Ultimately, Brown and Biefeld proposed that anti-gravitational effects would explain the observed phenomenon and patent applications were even filled-out based on this assumption [2,3].

More recently, following the popularization of the phenomenon, many articles have been written by scientist from different laboratories, in which alternative explanations were given to the understanding of the levitation force (*thrust*). Among them the most accepted are the ones that consider the produced ions (through the *corona effect*) being accelerated by the electrical field configuration and causing, after a sequence of collisions, the transference of linear momentum to the surrounding neutral air molecules [2-8].

For this work a lifter with a unique geometry was projected, constructed and put into operation at the Physics Institute of the University of São Paulo [9]. One of the major objectives was to present to graduate students of physics and engineering a simple theoretical model that comprehensively explains the foundations of the observed propulsion force. For this task, only the fundamental aspects of the process of air ionization and momentum transfer have been considered. In section 2 we present the general aspects of the *corona* discharge (or *corona effect*) that are essential to the understanding of the phenomenon. In section 3 we describe a simple model which allows the calculation of the propulsion force F_L due to the corona wind in the case of a typical asymmetric capacitor gap. In section 4 the magnitude of the lifting force F_L is estimated. In section

---

[1] E-mail: vannucci@if.usp.br.

5 we describe the lifter construction and the respective power source.

2. Corona effect and propulsion by air ionization

Perhaps the best known simple apparatus that yields mechanical motion due to ions creation and theirs consequent ejections, when high voltages are applied to conductors, is the *electrostatic pinwheel* [10,11]. This curious device (Fig. 1) rotates when its sharp points acquire great potential values, sustained by an electrostatic generator, for example. This effect results from the occurrence of *corona discharges*, by which an ion current flows from an electrode with high electric potential into a neutral fluid (air for example) by ionizing that fluid so as to create a region of plasma around the electrode. The ions generated eventually transfer charges to nearby areas of lower potential or recombine themselves to form neutral gas molecules. After the ionization of the surrounding air molecules the created ions are repelled away from the conductor sharp points (both the conductor and the ions turn out to become charged with the same polarity – either positive or negative), creating a type of *electric wind*. Consequently, the conductor needle-like points are compelled to move in the opposite direction, giving rise to the rotational movement [12-14].

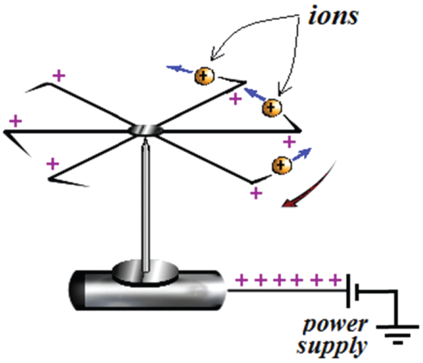

Figura 1 - The electrostatic pinwheel rotates as result of the ions created by the corona effects being repelled away from the needle-like points.

The same physics mechanism can be recalled as to explain the force that acts on lifter devices and makes them levitate. Three lifters of different geometric models were built at the Physics Institute of the University of São Paulo and all of them yielded similar results. The model showed in Fig. 2, which exhibited the best performance, was constructed accordingly to a geometric configuration which has not been yet mentioned in the literature, up to our knowledge.

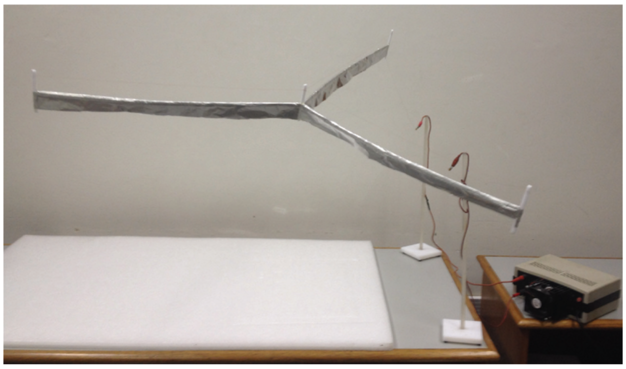

Figura 2 - Lifter (in flight) constructed at the Physics Institute of the University of São Paulo, exhibiting its unique geometry.

3. Simple theoretical backgrounds

The repulsive force between the ions and the charged sharp points of the *electrostatic pinwheel* (or the thin wire conductor of the lifter) can be evaluated by analyzing the motion of the ions which carry a charge q (either positive or negative) and submitted to a force $\mathbf{F} = q\mathbf{E}$, where $\mathbf{E}$ is the strong electric field surrounding the conductor extremity (surface with the smallest curvature radius and, therefore, with the strongest electric field gradient). Consequently, the force felt by the pinwheel sharp points (or the lifter's thin wire), accordingly to the third Newton's law, will be $-\mathbf{F}$.

Concerning the lifter two-conductors configuration, an electric field will be created as soon as the high voltage is applied (Fig. 3). Each ion will then be accelerated by the intrinsic electric field to an average distance expressed by the free mean path λ and will produce multiple collisions with the neutral air molecules. Consequently, the ions will end up transferring almost all the energy they extracted from the electric field to the surrounding mass of air.

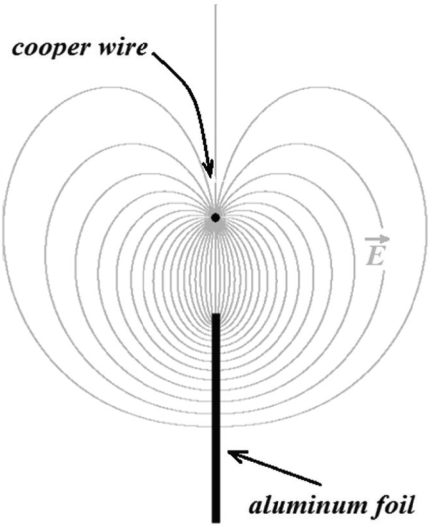

Figura 3 - Geometric configuration of the lifter's electrodes and the resulting electric field lines [3].

Lets consider that in a time interval dt the ions will transfer an amount of linear momentum $d\mathbf{p}$ to the surrounding air. This means the field will exert a force $\mathbf{F} = d\mathbf{p}/dt$ to the surrounding mass of air as a whole.

After a large number of random collisions have taken place, the ions can be considered to have an average (*drift*) velocity which can be expressed as [15,16]

$$\mathbf{v}_d = \frac{q\mathbf{E}}{m}\tau, \tag{1}$$

where the average time between collisions and free mean path, respectively, can be written as

$$\tau = \frac{\lambda}{< v >}; \ \lambda = \frac{1}{n\sigma\sqrt{2}}, \tag{2}$$

while the mean velocity [15,16]

$$< v > \ = \left(\frac{8kT}{\pi m}\right)^{1/2}. \tag{3}$$

In these equations, m stands for the ion mass; k is the Boltzmann constant; T the formed plasma's absolute temperature; n the number of air molecules by unit of volume and σ the ion-air molecule collision cross section.

Consequently, an electric current density can be associated to the moving ions which, in a fairly good approximation, can be written as [15,16]

$$\mathbf{J}_i = n_i q\, \mathbf{v}_d = \left(\frac{n_i q^2 \mathbf{E}}{m}\right)\tau, \tag{4}$$

where n_i is the number of ions per unit of volume ($n_i = N/V$); while q and m are the charge and the mass of each ion, respectively.

The ions *drift* velocity on the other hand, can be expressed in terms of a useful parameter, $\alpha = q\tau/m$, called *electric mobility*, so that

$$\mathbf{v}_d = \alpha\mathbf{E} = \left(\frac{q\tau}{m}\right)\mathbf{E}. \tag{5}$$

Furthermore, the *diffusion coefficient* D can be written as [17,18]

$$D = \frac{\lambda < v >}{3}, \tag{6}$$

so that, from the above equations, the electric mobility can be expressed as

$$\alpha = \frac{q\tau}{m} = \left(\frac{3\pi}{8}\right)\frac{qD}{kT}. \tag{7}$$

Taking into consideration the geometric configuration of the lifter's conductors, whenever an ion moves along an electric field line (Fig. 3), following an element of arc ds in a time interval dt, energy is absorbed from the electric field $\mathbf{E}$ which can be calculated

$$dW = \mathbf{F}\cdot d\mathbf{s} = q\mathbf{E}\cdot\left(\frac{d\mathbf{s}}{dt}\right)dt = q\mathbf{E}\cdot\mathbf{v}_d\, dt. \tag{8}$$

Also, using Eq. (5), the impulse dI related to the element of ion's displacement $d\mathbf{s}$ is given (in module) by

$$dI = Fdt = q\,E\left(\frac{dt}{ds}\right)ds = qE\frac{ds}{v_d} = \frac{q}{\alpha}ds. \tag{9}$$

Hence, the resulting vector impulse $\mathbf{I}$ gained by the ion after following an electric field line γ can be written as

$$\mathbf{I} = \frac{q}{\alpha}\int_\gamma d\mathbf{s}. \tag{10}$$

Considering that an ion takes a time interval T to follow one field line γ, the resulting force acting upon this single ion will be

$$\mathbf{f} = \frac{\mathbf{I}}{T} = \frac{q}{T}\int_\gamma \frac{d\mathbf{s}}{\alpha}. \tag{11}$$

If we consider, in a first approximation, that all N ions will follow parallel trajectories, that is $d\mathbf{s}_i \approx d\mathbf{s}$, then the total force will be $\mathbf{F} = N\mathbf{f}$ and, therefore

$$\mathbf{F} = N\frac{q}{T}\int_\gamma \frac{d\mathbf{s}}{\alpha} = \frac{Q}{T}\int_\gamma \frac{d\mathbf{s}}{\alpha} = -\mathbf{F}_L, \tag{12}$$

where $Q = Nq$ stands for the sum of all the charges related to the N ions.

Analyzing this equation we observe that the impulsion force $\mathbf{F}_L$ acting on the lifter is inversely proportional to the time interval the ions take to travel from the thin wire to the aluminum foil. Therefore, the less are the electric field lines scattered in space (see Fig. 3), the more intense will be the thrust propelling the lifter. It is important to note, also, that the sum $\int_\gamma d\mathbf{s}/\alpha$ (in Eq. (12)) yields as result a vector with direction parallel to the plane formed by the lifter's thin wire and aluminum foil (see Fig. 3); that is, there is not any contribution due to the perpendicular component of the force.

4. Modeling the lifter as an ideal plane capacitor

Let's start considering an ion current flowing along the electric field lines created by an ideal plane capacitor. The field lines are parallel to each other so that $d\mathbf{s}_i = d\mathbf{s}$ and the parameter $\alpha = q\tau/m$ is a constant. Considering that the conductors are separated by a distance ℓ and submitted to a difference of potential $V = E\ell$, then from Eq. (12) we have

$$F = \left(\frac{Q}{T}\right)\left(\frac{\ell}{\alpha}\right) = (i)\left(\frac{m\ell}{q\tau}\right), \tag{13}$$

where the total ion current $i = Q/T$.

It is interesting to note that the ratio (m/τ) in Eq. (13) will yield different results whether electrons are considered as charge carriers rather than ions. The simplest way to demonstrate this, using Eqs. (2) and (3), is as follows

$$\frac{m}{\tau} = \frac{m < v >}{\lambda} = mn\sigma\sqrt{2}\left(\frac{8kT}{\pi m}\right)^{1/2}, \quad (14)$$

where m is the mass of the charge carrier (ion or electron) and σ is the collision cross section between the corresponding charge carrier and the neutral air molecules.

Under normal atmospheric conditions of pressure and temperature ($T = 300$ K and $P = 1$ atm $\sim 10^5\,\mathrm{N/m^2}$) and using that $PV = NkT$ we get that the number of air molecules per unit of volume will be $n = (N/V) = P/kT \sim 2.45 \times 10^{25}$ molecules/m^3.

Bearing in mind the lifter apparatus and considering that due to the multiple ion collisions with air molecules a local plasma region will created between the electrodes, with typical temperature $T \sim 2000$ K [18], we get that $(8kT/\pi)^{1/2} \approx 2.7 \times 10^{-10}$ (MKS). Hence Eq. (14) can be written as

$$\frac{m}{\tau} = 6.5 \times 10^{15}\sigma\sqrt{2m} \text{ (MKS)}. \quad (15)$$

Assuming that the values of n, d and q are the same for both electrons and ions charge carriers then, accordingly to Eq. (13), we will get the thrust forces produce by the ion and electron currents as being, respectively

$$F_i = \left(\frac{i_i\ell}{q}\right)\left(\frac{m_i}{\tau_i}\right) \text{ and } F_e = \left(\frac{i_e\ell}{q}\right)\left(\frac{m_e}{\tau_e}\right). \quad (16)$$

Therefore, the ratio $F_i/F_e = (m_i/m_e(\tau_e/\tau_i)$ yields

$$\frac{F_i}{F_e} = \left(\frac{i_i}{i_e}\right)\left(\frac{m_i}{m_e}\right)\left(\frac{\tau_e}{\tau_i}\right) = \left(\frac{i_i}{i_e}\right)\left(\frac{m_i}{m_e}\right)\left(\frac{\sigma_i}{\sigma_e}\right). \quad (17)$$

To evaluate the meaning of this last equation, we will consider all air particles as being nitrogen molecules (recalling that almost 80% of the air composition corresponds to N_2 one time ionized ($i_i = i_e$), with approximate mass $m_i = 5.15 \times 10^4 m_e$. Therefore

$$\frac{F_i}{F_e} = 5.15{\times}10^4\left(\frac{i_i}{i_e}\right)\left(\frac{\tau_e}{\tau_i}\right) = 5.15{\times}10^4\left(\frac{i_i}{i_e}\right)\left(\frac{\sigma_i}{\sigma_e}\right). \quad (18)$$

Since the collision cross section of nitrogen ions with the atmospheric air is $\sigma_i \sim 10^{-19}$ m^2 and the electrons' cross section is $\sigma_e \sim 10^{-19} - 10^{-20}$ m^2 [20], then in the best case we get

$$\frac{F_i}{F_e} \approx 5,15 \times 10^4\left(\frac{i_i}{i_e}\right) \quad (19)$$

that is, the influence of the electron's flow can be ignored unless $i_e > 10^5 i_i$; which would never be the case.

We will now assume that the main responsible for the lifter thrust is indeed the momentum transfer due to inelastic collisions that take place between nitrogen ions and N_2 neutral molecules, and we will consider them as ideal rigid spheres. Therefore, the corresponding collision cross section will be $\sigma = \pi d^2$, where $d = 2 \times 10^{-10}$ m is the nitrogen molecule diameter.

Substituting this cross section value in Eq. (15) then, from Eq. (13) and assuming that the nitrogen molecules ($m = m_i = 4.69x10^{-26}$) kg one time ionized ($q = 1.6 \times 10^{-19}$ C) will be the responsible for the lifting effect, we get that the lifting force will be

$$F_L \approx 1.6 \times 10^3\, I\,\ell \text{ (MKS)}. \quad (20)$$

5. The lifter construction

The schematic design of the lifter constructed at the Physics Institute of the University of São Paulo, which yielded the best results (most probably because of its unique geometry), is shown in Fig. 4. It was built using a thin cooper wire (28 AWG) and a 50 mm width aluminum foil. Both conductors were maintained separated 40 mm apart from each other by *Styrofoam* rods and they were submitted to a difference of potential greater or of the order of 20 kV. Each arm of the lifter measured 42 cm long and the whole apparatus has a mass of only 4.7 g.

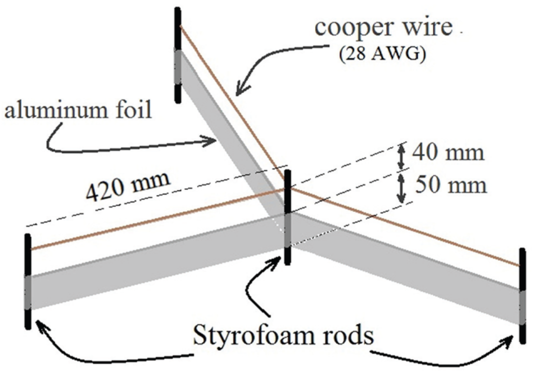

Figura 4 - Schematic drawing of the lifter that yielded the best experimental results.

Since one of the purposes of this work was to develop a research project that could also be suitable for classroom demonstrations, the power supply was constructed following a very simplified electronic circuit which uses, as its main component, a *flyback* transformer of an old PC monitor. An integrated circuit (*NE555*) was used as an oscillator to generate a square wave (which is rectified afterwards) with values of frequency adjustable in the range 8 kHz to 20 kHz. Interestingly, it was observed that the lifter levitates even when the polarities of the conductors are inverted.

Also, an important part of the project was to choose how to make accurate measurements of the power consumed by the lifter when it is in levitation, in order to verify whether the theoretical model previously described would adequately explain the experimental data obtained. The adjustable voltage values of the high voltage power supply were calibrated using a *HP333* commercial probe while the electric current was measured using a micro galvanometer that was specially ordered (and constructed) for the experiment.

6. Data analysis and working model

The voltage and current thresholds values for the levitation of the constructed lifters were experimentally observed to be typically around 18 kV and 0.5 mA ($P \sim 10$ Watts).

For the lifter model showed in Figs. 1 and 4, if we consider $\ell \sim 7$ cm in average and that $I \sim 0.7$ mA (to sustain a stable flight) then we have, accordingly to Eq. (13), $F \sim 0.08$ N.

Now, since the lifter mass is $M = 4.7 \text{ x } 10^{-3}$ kg, then its weight will be $P \sim 0.05$ N. As we observe, the propulsion force is about 60% larger than the weight of the asymmetric capacitor. Therefore, the theoretical physical mechanism proposed in this paper can be considered a plausible explanation for the levitation effect.

7. Conclusion

Three simple asymmetric capacitors, or lifters, were projected and constructed. All of them were observed to levitate when submitted to voltages $V \geq 20$ kV. The power supply specifically constructed for the experiment used a *flyback* transformer of an old PC monitor as one of its main component. A simple physics model based on a continuous transference of linear momentum carried by the ions created through the *corona effect*, to the surrounding neutral air molecules, could demonstrated that this is the basic mechanism which explains consistently the experimental observations.

References

[1] M. Chen, L. Rong-de and Y. Bang-jiao, Journal of Electrostatics **71**, 134 (2013).

[2] T.B. Bahder and C. Fazi, *Force on an Asymmetric Capacitor* (Army Research Laboratory Report, Adelphi, 2003).

[3] F.X. Canning, C. Melcher and E. Winet, NASA Report, NASA/CR-2004-213312, 2004.

[4] A.A. Martins and M.J. Pinheiro, Physics Procedia **20**, 103 (2011).

[5] M. Tajmar, American Institute of Aeronautics and Astronautics Journal **42**, 315 (2004).

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

[7] A.A. Martins and M.J. Pinheiro, Physics of Plasmas **18**, 033512 (2011).

[8] R. Ianconescu, D. Sohar and M. Mudrik, Journal of Electrostatics **69**, 512 (2011).

[9] V.G. Souza, M. Cattani and A. Vannucci, Proc. 2014 Conference on Precision Electromagnetic Measurements (*CPEM 2014*), IEEE-Xplore Digital Library, p. 178.

[10] A.D. Moore, *Electrostatics: Exploring, Controlling, and Using Static Electricity* (Laplacian Press, Morgan Hill, 1997).

[11] O.D. Jefimenko, *Electrostatic Motors - Their History, Types, and Principles of Operation* (Electret Scientific Company, Waynesburg, 1978).

[12] J. Chang, P.A. Lawless and T. Yamamoto, IEEE Transactions on Plasma Science **19**, 1152 (1991).

[13] C.F. Gallo, IEEE Transactions on Industry Applications **IA-13**, 550 (1977).

[14] H. Parekh and K. D. Srivastava, IEEE Transactions on Electrical Insulation **EI-14**, 181 (1979).

[15] R.A. Serway, *Física 3 – Eletricidade, Magnetismo e Ótica* (Livros Técnicos e Científicos, São Paulo, 1992), 3ª ed.

[16] H.D. Young e R.A. Freedman, *Sears & Zemansky Fisica III – Eletromagnetismo* (Pearson, São Paulo, 2009).

[17] C. Kittel, *Thermal Physics* (John Wiley & Sons, New York, 1969).

[18] F. Reif, *Fundamentals of Statistical and Thermal Physics* (McGraw Hill, New York, 1965).

[19] Z. Machala, I. Jedlovsky and V. Martisovits, IEEE Transactions on Plasma Science **36**, 918 (2008).

[20] Y. Itikawa, Journal of Chemical Physics Ref. Data **35**, 31 (2006).