

OPERATION AND GENERATION OF ION WIND IN ION THRUSTER

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Abstract- Ion propulsion is one of the advanced propulsion methods for space travel when significant amount of thrust is not required. In other words, an ion thruster or ion drive is a form of electric propulsion used for spacecraft propulsion. It is still under research facility in their improvement stage. In this type of propulsion any natural gas is ionized by the electrons which is been extracted by the atoms of specific elements resulting in large number of positive ions which is based upon electrostatics. This paper is based on the operation and generation of the ion wind by an ion thruster. The process involves in the space between the sharp edge object and the smooth edge object which is connected to each other by a high voltage source. The basic principle and the complete one to one activity of the release of electrons from the sharp object to the generation of ion wind and how do charged particles gain their speed in an electric field that is the variation in kinetic energy of the particles are explained.

Keywords: Ion thruster, ion propulsion, space, deep space travel, ion wind.

1. INTRODUCTION

Propulsion means to push forward or drive an object forward. A propulsion system consists of a source of mechanical power and a means to convert this power into propulsive force. Spacecraft propulsion is used to change the velocity of spacecraft and artificial satellites. Most spacecraft today are propelled by heating a reaction mass to high temperatures and exhausting it from the rear of the vehicle at very high speed. Thrust produced by ions is called ionic propulsion. An ion thruster or ion drive is a form of electric propulsion used for spacecraft propulsion. It creates thrust by accelerating ions with electricity. It understandable that the thrust produced is low and this low thrust makes ion thrusters very much suitable for space propulsion which rather is unsuitable for launching a space craft or its kind into atmosphere. Ion thrusters can be differentiated between electrostatic and electromagnetic. An ion thruster produces a flow of air even though it has no moving parts. A version of this seemingly impossible device is used at large scale by NASA for propelling their space probes. The advantage to this system over any other system is that it needs only an electrical source to power it up making it nearly unbreakable. The 12000V of power that the device works with can only manage to light a blow a piece of tissue paper. Nevertheless, it doesn't produce a flow of air as it has no moving parts within it. One more notable thing is, it can just be built with very easily available materials like pipe fittings, nails and neon sign transformers. The device can partially be achieved with just two poles of a high voltage source.



Fig 1: Schematic diagram of an Ion drive.

The poles are kept far enough from each other so that they ionize the surrounding air but not form an arc of their own. The ions produced flow towards the other pole of the voltage. Although the ions are all absorbed the surrounding air that wasn't ionized gain enough momentum so that it keeps going in the direction you aim for.

2. BASIC PRINCIPAL

An electrostatic ion engine works by ionizing a fuel (often xenon or Argon or Neon) by knocking off an electron to make a positive ion. The positive ion then diffuses into a region between two charged grids that contain an electrostatic field. This accelerates the positive ion out of the engine that's called ion wind or electric wind ^[1] and away from the spacecraft thereby generating thrust.

3. HISTORY

B. Wilson in 1750^[2] demonstrated the recoil force associated to the same corona discharge and precursor to the ion thruster was the corona discharge pinwheel.^[3] The corona discharge from the freely rotating pinwheel arm with ends bent to sharp points^{[4][5]} gives the air a space charge which repels the point because the polarity is the same for the point and the air.^{[6][7]} Francis Hauksbee, curator of instruments for the Royal Society of London,

made the earliest report of electric wind in 1709.^[8] Myron Robinson completed an extensive bibliography and literature review during the 1950s resurgence of interest in the phenomena.^[9]

4. METHODOLOGY OF GENERATION PROCESS

Here you put a sharp edge object in your smooth edge object. Both usually are electrically conducted materials. You then put a high voltage across them. Like we use and NST (Neon sign transformer) as a high voltage source.

4.1 Why is having one object sharp and other smooth is important?

Let's look at how it works. As I said we apply high voltage using high voltage power supply. Let say these are the atoms make up the materials. Each atom has a bunch of

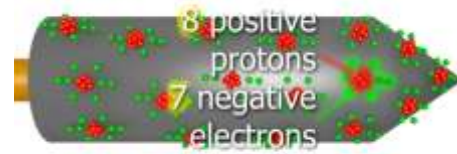


Fig 4: More positive proton.

The atoms are now positively charged. Similarly, since we connected the smooth object with the negative terminal. Extra electrons are sent to the smooth object. There is now more negative electron than the positive protons; so that side is negatively charged.



Fig 5: More negative electron.

Now in this there are the same number of charges in both the sides, not importantly now they are packed more closely together on the sharp object than the smooth object. There is something called as electric field between the two sides. We can visualize this electric field by drawing lines between each pair of charges. In real life there aren't any lines that helps for visualization. The closeness or density of the lines says how strong the electric field is. The further apart they are in region 1, the weaker the electric field is the closer they are together in region 2. The stronger the electric field is the closeness of the charges on the sharp object that make the electric field stronger in region 2.



Fig 2: Atoms make up the materials.

positive protons and a bunch of negative electrons. They are the same number of both. So, the positive balance out the negatives.

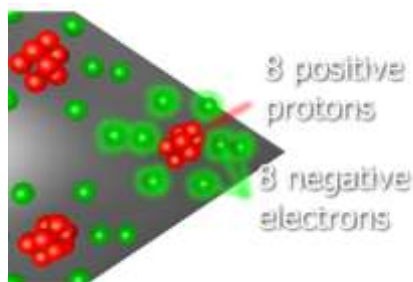


Fig 3: The positive balance out the negatives.

In that case we say that the atoms are neutral. Let's also say that we connect the sharp object to the power supplies positive terminal and the smooth object to the power supplies negative terminal. But we could have done in the other way instead. Both ways can work. Since we connected the sharp object to the power supplies positive terminal; when the power supply is turned on, the electrons from the atoms are pulled away. Leaving the atoms with more positive proton than negative electron.

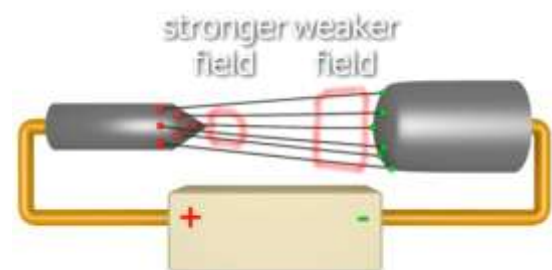


Fig 6: The closeness of the lines says how strong the electric field is.

That's why we choose the sharp object to get in the first place to get that strong electric field there. But there are other atoms involve too. The atoms in the air between those atoms contain positive proton. The electric field is so strong near the sharp object that it can pull electrons from an atom. The direction in which the electron moves is

determined by the polarity of the charges. Unlike charges attract each other so the negative electron attracted towards the positively charged object. Meanwhile like charges repel each other so the negative electron is repelled from the negatively charged object that leaves the atom with more positive protons than negative electrons. So, it is positively charged. An atom with an unbalanced charge is called as an ion. It repels positively charged object and attracts the negatively charged one.

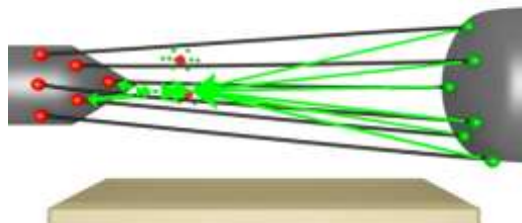


Fig 7: The properties of an Ion.

So far nothing here would have caused any propulsion, if forces involved in all directions are balanced out and there was no outside influence on the object. Consider an atom from which an electron is to be removed. If we have to look at it with a metaphor then removing an electron would be like holding a piece of bread in your hand in front of you and tearing it apart that doesn't cause you to move sideways in either direction. When the electron arrives at the sharp object. That doesn't result in any propulsion either. Since it's the electric field from the object that put it there. Again, if you are wearing roller blades and you have a ball in your hand and push yourself with it. That won't cause you to move. Since you are doing the pushing and you are the one being pushed, but there is another player involved here. In the air of region 2 where the electric field is weaker there are more atoms with equal number of protons and electrons.

4.2 What are called neutral atoms?

Since it is neutral, they don't interact with the electric field. They are not connected to a charged object in any useful way. When one of the positive ions that we created collides with one of the neutral atoms, sometimes it has the energy to knock an electron free. The negative electron will be attracted to the positively charged object and we will have another positively charged object moving towards the smooth surface.

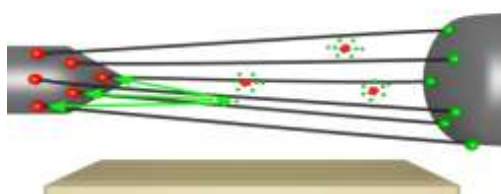


Fig 8: Movement of negative electron.

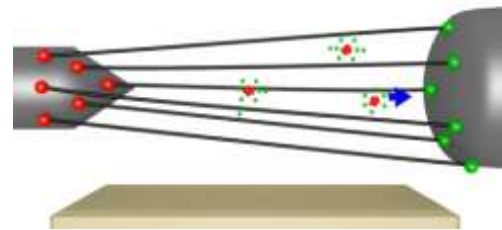


Fig 9: movement of positively charged object.

4.3 No connection of object with ions

More often though the collision doesn't have enough energy to knock an electron free and instead it will just be slow down and may be even change the direction. Then you may think that shouldn't affect our object since the ions are not connected to our objects.

4.4 The ion experiences a force

But they are the positive ions was moving towards region 2 because was being attracted by the negatively charged smooth object and repelled by the positively charged sharp object. They are connected by the electric field as if their arms holding ions and moving it. When the ion collides with the neutral atom, the ion experiences a force towards the smooth surface. The charged objects are dragged along with it. That is like as if you are holding the ball in your hand and use it to push against the chair that you are not connected to. This time you do move. The chair is like a neutral atom. It's not a part of the system, so the whole device moves in this direction of the sharp object. Some of the neutral atom will collides with the other ones and the overall direction will become random and can end up as heat. The many will also continue to move in the direction of smooth object or many collide with others which will move in that direction. Since they are neutral, they won't interact with the device. And that's the ion wind or electric wind, even though much of it is not ions.

The last point of dimension that it also works if you connect negative terminal to the sharp object and positive to the smooth object instead. There are some differences that happens but the basic idea is the same and that's how ion propulsion works.

4.5 Charged particles gain speed in electric field

From the basic physics, the kinetic energy of a particle can be represented as:

$$\text{Kinetic Energy (K.E)} = \frac{1}{2}mv^2$$

Where m is the mass of the particle and v is the velocity. And the energy of the particles is shown as:

$$E = qV$$

Where q is the charge of the particle and V is the potential difference in volts in which particle falls and gain energy. The variation of the potential difference varies the energy of the particles. Higher the potential difference, higher is the energy and higher is the energy, higher is the velocity of the charged particle. Let's consider an ion thruster developed for a deep space mission to be used in a satellite that is NSTAR ion engine. This ion engine used Xenon atoms as a propellant that have a mass (m) = $2.2 \times 10^{-25} \text{ kg}$ and a charge (q) = $1.6 \times 10^{-19} \text{ C}$ (Coulombs).

From the above equations we know that:

$$\frac{1}{2}mv^2(\text{Kinetic Energy}) = q(\text{Charge}) \times V(\text{Voltage})$$

So, to calculate the speed of a Xenon atom in km/hr, let's assume the voltage grid V of the ion engine is 1,300 V. As we now know:

$$K.E = E$$

We solve for v

$$(\text{Kinetic Energy}) = (\text{Charge}) \times (\text{Voltage})$$

$$\frac{1}{2}mv^2 = q \times V$$

$$v^2 = \frac{2qV}{m}$$

$$v^2 = \frac{2 \times 1.6 \times 10^{-19} \text{ C} \times 1300 \text{ V}}{2.2 \times 10^{-25} \text{ kg}}$$

$$v^2 = 2.0 \times 10^9$$

$$v = 44.2 \text{ km/s}$$

(or)

$$v = 159,000 \text{ km/hr}$$

So, the velocity of a charged particle of xenon atom in an electric field is 159,000 km/hr. That's fast.

5. CONCLUSION

The generation of the ion wind is the complex process but yet effective and most efficient way of propulsion in deep space. The internal generation process of the ion wind involves many. A charged particle gain speed in an electric field which is also an important phenomenon in the generation of ion wind in ion thruster.

6. REFERENCES

[1]Zyga, Lisa (February 7, 2018). "What causes ionic wind?". Phys.org. Retrieved August 27, 2018.

[2] DIVISION OF ENGINEERING: ENGINEERING ASPECTS OF ELECTROGASDYNAMICS*- by MC Gourdine - 1968 -

Transactions of the New York Academy of Sciences - Wiley Online Library.

[3] Demo 41-06 Pinwheel - Video Encyclopedia of Physics Demonstrations Archived 2014-04-16 at the Wayback Machine.

[4] Electrostatic pinwheel: Van de Graaff makes pinwheel spin - Lecture Demonstrations - UC Berkeley Physics.

[5] Fun with Static Electricity, Elliott County 4H - Science Fun, Inc. - Alan Kuehner (ret.) Brookhaven National Laboratory.

[6] Electostatic pinwheel - Indiana University Demo Reservation.

[7] Electrostatic Pinwheel, European, later 19th century - The Bakken - A Library and Museum of Electricity in Life Archived 2014-04-16 at the Wayback Machine

[8] Robinson, M. (1962, May). History of the electric wind. American Journal of Physics, 30(5), 366-372.

[9] Robinson, M. (1960, June 8). Movement of Air in the Electric Wind of the Corona Discharge. (AD0262830).

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Rishab Kumar Agrawal was born in Odisha, India, in 1996. He received the B. Tech degree in Aerospace engineering from Hindustan Institute of Technology & Science, Chennai, India, in 2019. In 2018, he worked as an Intern for Engenious Aerospace Ltd., Ukraine as a Jr. Design Engineer in the field of Rockets & Missile. He is in the core team of National Space Society (USA)-Mumbai Chapter, working as a Lead Researcher. He is also the Technical Director of Cosmagen Space Organization of Tamil Nadu region, Chief Technical Officer of a startup named JHATAYU; in which he received INDIA BOOK OF RECORD & ASIA BOOK OF RECORD for manufacturing Asia's first flying bike. His research interest includes Solid Rocket Propulsion, Rocket motor, Dark matter.



Nived Hareesh has completed B.E in mechanical engineering from Gujarat technological university, a space enthusiast working on different projects on space missions, lead scientist in the development of smallest and lightest satellite named HAWKSAT and Holds record from Worlds records of India and Universal Records Forum for building the satellite, currently working propulsion systems for rockets and satellite. He is an entrepreneur and serves at the Post of CEO in Nova Jet propulsion laboratory and CO-founder in Cosmagen Space organization.