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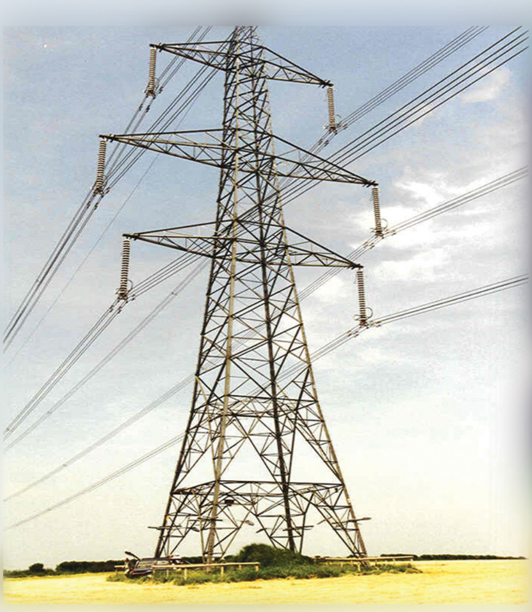
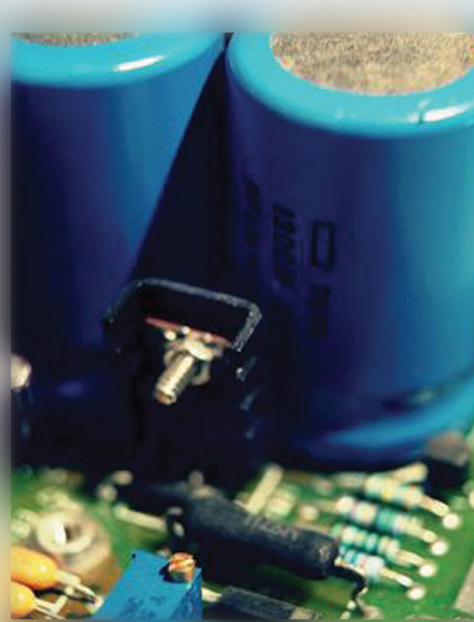

HOD's Desk

Phenomenal progress and development is taking place in the field of science and technology around the world. In this connection we have to sit back and think what contributions we have made to the technological advancements from our side. Technological institutions have a great roll to play in this regard. We, the teachers, are supposed to mould the students. We should closely observe their skills, learning pattern and behavioural pattern and should make the necessary corrections so that they are being groomed to be good engineers to do good to the society and provide service to the mankind.

The need of the hour is to train them in a proper way, enhance their practical skills and prepare them for taking up employment. We should strive hard to provide immense value education to all of our students and to prepare them for a bright future and rewarding career.

Let us not forget that as per a recent NASSCOM report, only 25% of engineering students are employable. If all fresh graduates are included, only 10% of them are actually eligible to take up a job.

Keeping this in mind let us not forget that we have miles and miles to go.

-Prof. K R Varmah

Food for thought

"Now I have discovered something here. By flipping these pages at random, and putting my finger in and reading the sentences on that page, I can show you that no science is being taught here and how it's not science, but memorizing, in every circumstance.
[he opens a random page from a physics text book and begins to read]
Triboluminescence. Triboluminescence is the light emitted when crystals are crushed ..." ... "and there, have you got science? NO! You have only told what a word means in terms of other words. You haven't told anything about nature; what crystals produce light when you crush them, why they produce light. Did you see any student go home and try it? He can't. But if, instead, you were to write, 'When you take a lump of sugar and crush it with a pair of pliers in the dark, you can see a bluish flash. Some other crystals do that too. Nobody knows why. The phenomenon is called triboluminescence.' Then someone will go home and try it. Then there's an experience of nature."

-Dr. Richard P. Feynman during a lecture on science education in Brazil

Goodness Factor

Prof. K R Varmah

What is meant by goodness of a machine? It is rather difficult to answer this question, in a broad sense. High efficiency, high $\left(\frac{power}{weight}\right)$ ratio and high $\left(\frac{power}{cost}\right)$ ratio are some of the indices for good quality. With increasing complexity of a machine, minimum maintenance requirements, minimum maintenance cost, and maximum reliability and so on are certain other desirable qualities of a machine. These may even supplant the requirements of high $\left(\frac{power}{weight}\right)$ ratio and high $\left(\frac{power}{cost}\right)$ ratio. The efficiency of an electric machine can always be improved at the expense of its power factor, its weight and its cost. Its cost can always be reduced at the expense of its efficiency and reliability. Still, if you ask, "What makes a good electrical machine?" it is rather easy to answer the question, considering the fact that in an electrical machine an electric circuit interlinks with a magnetic circuit. Hence, it is sufficient to analyse the qualities of the electric circuit and the magnetic circuit in an electrical machine to arrive at the level of goodness of it.

The best electric circuit is one that permits the passage of greatest current for a given e.m.f. The circuit should offer maximum conductance. Hence, resistance is an undesirable parameter or a "badness" of an electric circuit. A best magnetic circuit is one, which sets up the greatest flux for a given m.m.f. A good magnetic circuit is expected to be highly permeable. In this case, the restraint is the reluctance of magnetic circuit. The electromagnetic torque developed in an electric machine is proportional to the product of flux in the magnetic circuit and current in the electric circuit. If we consider the product of flux and current as a measure of the "goodness" of a machine, the product of resistance and reluctance must represent the "badness" of the machine. Thus, the goodness of an electric machine can be expressed as a factor,

$$G \,\alpha\, \frac{1}{Resistance.Reluctance}$$

Recall that resistance is the ratio of e.m.f. to current and reluctance is the ratio of m.m.f. to flux. E.m.f is proportional to the rate of change of flux and the m.m.f. has the same dimension as current. This means that the goodness factor G is proportional to time. To make G a universal constant, the constant of proportionality must be a time-dependent quantity. Hence, for an a.c. machine, the constant of proportionality is the angular frequency of the supply . In the case of a d.c. machine, the constant of proportionality must be a velocity-dependent quantity. For an a.c. machine, the expression for the goodness factor now becomes,

$$G = \frac{\omega}{R.\Re}$$

For an electric circuit, resistance R can be expressed in terms of the length l_e, area, A_e and conductivity σ.

$$R = \frac{l_e}{\sigma A_e}$$

For a magnetic circuit, reluctance can be expressed in terms of length l_m, area A_m and permeability μ.

$$\Re = \frac{l_m}{\mu_0 \mu_r A_m}$$

Finally the expression for the goodness factor is,

$$G = \frac{\omega}{\left(\frac{l_e}{\sigma A_e}\right)\left(\frac{l_m}{\mu_0 \mu_r A_m}\right)} = (\omega \mu_0 \mu_r \sigma)\left(\frac{A_e A_m}{l_e l_m}\right)$$

This equation is quite fundamental to all electromagnetic machines. In a rotating machine, where the air gap separates the primary and the secondary member, bulk of the reluctance of the magnetic circuit is offered by the air gap. This conclusion is based on the assumption that the iron path in the magnetic circuit is highly permeable. In such a case, $\mu_r = 1$ and l_m is the length of the air gap itself.

But how important is the goodness factor of an electromagnetic machine, for an electrical engineer? If we examine the expression for goodness factor, the quantities in the first bracket depend on the materials chosen for the construction of the machine and the frequency of supply. Within the quantities of the second bracket, a designer can apply his skill or an inventor can use his ingenuity to utilize greater areas and minimum lengths of electric and magnetic circuits to achieve a high value for the goodness factor.

References

[1] Laithwaite,E.R, *Linear Electric Motors*, London,Mills & Boon Ltd.,1971.

Power Quality

Suresh Krishna I P

Introduction

The deviations in the nominal values of voltage, frequency and wave shape of voltage and current results in power quality problems. Modern electrical equipment imposes stringent demands on voltage stability and power quality. The power network has to be free from any sort of electrical disturbances. A disturbance free network also imposes much less strain on equipment and lengthens its life span. This means lower maintenance cost and lower cost for replacing worn-out equipment. Power quality events are generally classified according to their origin.

Voltage events

Changes in the voltage magnitude outside the nominal range and small time disturbances like voltage sags and swells.

Frequency events

Change of supply frequency outside nominal range.

Waveform events

Distortions from the supply side causes distortion in the voltage at consumer site. However current distortion is caused by the type of loads. Presence of non linear loads causes current wave shape to deviate from sinusoidal shape. Some of common problems occurring due to poor quality of power supply are listed below.

1. Machinery control system breaking down
2. Circuit breaker tripping
3. Motor performance drops
4. Tripping of Variable frequency drives and corruption of PLC programs

5. Instrumentation failures
6. Cabling and transformer getting too hot
7. Fire hazard increases

Power Quality Disturbances

Frequency Events

These are typically caused during the disturbances occurring in the generating station. This event also occurs when the electricity is supplied from the distributed generation system which is sourced by wind.

Voltage Events

Some common voltage events along with details on them as well as their sources have been listed in Fig 1.

Event	Duration	Magnitude	Sources
Impulsive transients	Less than 1ms		Lightning, Capacitor switching
Voltage Sags	0.5 -30 cycles	0.1 -0.9 pu	System faults, Clearing of faults
Voltage swells	0.5 -30 cycles	1.1 -1.8 pu	System faults, Clearing of faults
Long duration overvoltages	>1 min	1.1 – 1.2 pu	Load variation
Undervoltages	>1 min	0.8 – 0.9 pu	Motor starting
Interruptions	>1 min	0 pu	System protection breaker, Maintainance
Voltage Unbalance	Steady state	0.5 – 2%	
Voltage fluctuations	Intermittent	0.1 – 0.7%	Intermittent switching, arc furnaces, welding operation
Harmonics			Non linear loads, System resonance

Figure 1: Voltage events

Waveform Events

Presence of non linear loads causes generation of harmonics in the current waveform. Larger amount of current harmonics in a large network also causes voltage harmonics. Although the generators may provide a near-perfect sine-wave voltage, the current passing through the impedance of the system can cause a variety of disturbances to the voltage. For example,

- The current resulting from a short circuit causes the voltage to sag or disappear completely, as the case may be.

- Currents from lightning strokes passing through the power system cause high-impulse voltages that frequently flash over insulation and lead to other phenomena, such as short circuits.

- Distorted currents from harmonic-producing loads also distort the voltage as they pass through the system impedance. Thus a distorted voltage is presented to other end users. Therefore, while it is the voltage with which we are ultimately concerned, we must also address phenomena in the current to understand the basis of many power quality problems.

Nonlinear loads

There are today many types of nonlinear loads. They include all types of electronic equipment that use switched-mode power supplies, adjustable-speed drives, rectifiers converting ac to dc, inverters converting dc to ac, arc welders and arc furnaces, electronic and magnetic ballast in fluorescent lighting, and medical equipment like MRI (magnetic radiation imaging) and x-ray machines.

Other devices that convert ac to dc and generate harmonics include battery chargers, UPSs, electron beam furnaces, and induction furnaces, to name just a few. All these devices change a smooth sinusoidal wave into irregular distorted wave shapes. The distorted wave shapes produce harmonics. Harmonics become apparent when a distorted sinus curve is mathematically analysed. Through Fourier analysis, an arbitrary periodic function can be divided into a number of sine waves.

Effects of Harmonics

1. Higher neutral current
2. Instrumentation failure
3. Failure of PF improvement capacitor
4. Tripping of circuit breaker and other nuisance tripping
5. Monitor flicker
6. Huge economic losses if equipment fails or malfunctions
7. Increased losses, e.g. machines will operate at increased temperature and can be overheated
8. Overheating of cables, motors and transformers
9. Resonance problems between the inductive and capacitive parts of the power network
10. Malfunctioning of control systems since electronic meters, relays, etc. are matched to the fundamental frequency
11. Overloading of capacitors and other equipments, leading to malfunctioning and premature aging
12. Interference with telecommunications and computers

IEEE 519 Standards specify limits for the individual harmonic content and THD for currents drawn by non-linear loads from a Point of Common Coupling (PCC). Voltage Harmonics Limits as per IEEE 519 are listed in Table 1.

Harmonic Filters

The harmonics present in the system are to be eliminated for smooth and better operation of actual power system. This is done using

1. Passive harmonic filters
2. Zig- zag transformer
3. Active filters

Table 1: Voltage Harmonics Limits as per IEEE 519 standards

Bus Voltage	Maximum Individual Harmonic Component(%)	Maximum THD %
69kV and below	3.0%	5.0%
115kV to 161kV	1.5%	2.5%
Above 161kV	1.0%	1.5%

By installing harmonic filters several benefits are obtained:

1. Higher power factor, improved voltage stability and network losses
2. Filtering of harmonics in the system
3. Avoidance of resonance problems and amplification of electrical disturbances.

Power Quality Filter injects harmonics to the load such that the current drawn from the supply is always sinusoidal and power quality is maintained at the Point of common coupling. The feeding transformer does not carry any polluting current. There are many devices which are used in ensuring the proper power quality. They are Surge Suppressor, Crow bar protection, Voltage clamping devices, Noise filters, Isolation transformers, Line voltage regulators, Constant voltage transformers (CVT), Static VAR compensator, UPS, Harmonic filter(Active and Passive). In order to understand the actual cause of power quality disorder, it is better to do a complete power quality audit, which has several benefits.

Benefits of Power Quality Audit

1. Complete harmonics measurement and remedial measures
2. Analysis of waveform distortion and finding the causes
3. Enhanced life of electrical network and components
4. Improved safety
5. Savings in energy bills due to reduced losses
6. Accurate measurement by installed meters
7. Reduced kVA demand
8. Improved system efficiency
9. Improved power factor
10. Better capacity utilisation of network
11. Better production rate and quality due to reduced interruptions
12. Improved system power factor

Conclusion

Increased power quality has many hidden advantages. Life of equipment increases. Electrical equipments begin to operate at a higher efficiency. Different benchmarks have been set for the limitation of harmonics and soon it will become a regulation.

References

1. IEEE Standard 1100-1992
2. IEEE Standard 519-1992

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Helical Windings in Electrical Machines

Prof. K R Varmah

Helical windings are not new and found limited favour for dynamos in Germany in the late 1880s. Today they are widely used for small d.c. machines of the ironless type, where they offer the advantage of low inertia and smooth torque at low speeds. They have also been used for linear motors and transverse flux tubular motors. The use in large a.c. machines was first proposed by Ross, Anderson and Macnab of the International Research and Development Company Ltd, who suggested it as a suitable armature for superconducting a.c. generators [UK patent 1975] and this was followed up by a detailed theoretical analysis [Anderson, Bumby & Hassall] published in 1980. A 4 MVA helical armature winding was used by Watnabe et al. as the armature winding for use in either a slotless or a superconducting generator. Conley et al. used a helical winding in an experimental 10 MVA superconducting generator at MIT in the late 1970s.

Explanation of the helical winding

Unlike the conventional winding, the helical winding has no distinct division into active and end regions, because each conductor follows a helical path of constant pitch and diameter from one end of the machine to the other. In the conventional winding, each conductor follows an axial path in the active region and only has a circumferential component to its path in the end regions.

To understand how a helical winding works, consider the winding length of a diamond lap winding shown in the figure 1, (a) to be progressively reduced as (b), by eliminating the so-called central "active" region and allowing the two diamond end windings to coalesce and form a semi-helical winding (c). The true helical winding (d) evolves from the wave wound diamond winding (d).

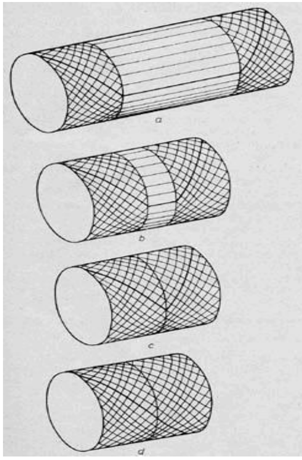

Fig:1 Diamond Lap Winding

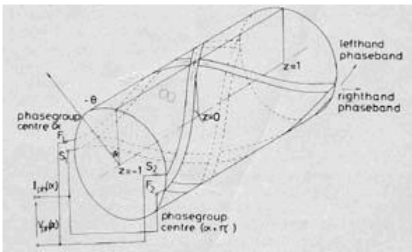

Fig:2 One phase of a two pole helical winding

One phase of a two pole helical winding is shown above. Each phase consists of two parallel-connected helical loops, each of which is termed a phase group. Each phase group comprises one right-hand (inner) helical phase band connected in series with a returning left-hand (outer) helical phase band; a right hand phase band being defined as that which traces a right hand screw.

Reference

[1] Dr. Anderson,A, IEE PROC Vol I, Pt.C. May 1980

The Fibonacci Series

Sreedhar S Kumar

Last semester, in the C- programming Lab, when the students were asked to 'Write a program to print the first 'n' numbers of the Fibonacci series', one of them had raised a doubt. "What is the Fibonacci series, Sir?", he enquired. I promptly replied that it was a sequence in which each new number was the sum of the previous pair, 0 and 1 being the first. What immediately struck me was how little I knew about it. Granted that the 'sum of the previous pair of numbers' algorithm was unambiguous enough, but there are questions that need answering. One could easily have combined the pervious numbers in any other fashion, perhaps as weighted sums or products or even quotients, resulting in infinite other number series. But would they have been significant enough to be conferred a name? There certainly was a missing link in my explanation. This article seeks to present an overview of what interesting facts I could gather about the possible significance of this series.

To begin with, the Fibonacci series is named after an Italian mathematician of the 13th century, Leonardo of Pisa, nicknamed Fibonacci. Though this number sequence was known to Indian mathematicians as early as the 6th century, it was Fibonacci's work, *Liber Abaci* (Book of calculation) that introduced it to the West, which led to the series being named after him. In the Liber Abaci, he had posed and solved a problem involving the growth of a population of rabbits based on idealized assumptions. The solution, generation by generation, was the Fibonacci sequence. However, its significance was discovered only about 400 years later by the astronomer Johannes Kepler.

Fig:1 Leonardo of Pisa

Any enquiry into the significance of the Fibonacci series would be futile without introducing another term, popular equally in mathematics as in arts; The Golden Ratio. Two quantities are said to be in the golden ratio if the ratio of the sum of the quantities to the larger quantity is equal to the ratio of the larger quantity to the smaller one. The golden ratio is an irrational mathematical constant, approximately 1.6180339887, and is represented by the greek letter φ. Other names frequently used for the golden ratio are the golden section and the divine proportion.

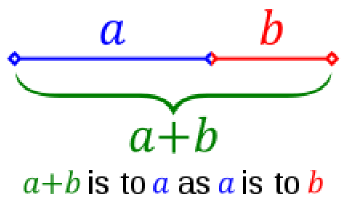

Fig:2 Golden Ratio

$$\frac{a+b}{a} = \frac{a}{b} = \varphi$$

The golden ratio has fascinated Western intellectuals of diverse interests for at least 2,400 years. Some of the greatest mathematical minds of all ages, from Pythagoras and Euclid in ancient

Greece, through the medieval mathematicians Leonardo of Pisa and the Renaissance astronomer Johannes Kepler, to present-day scientific figures such as Oxford physicist Roger Penrose, have spent endless hours over this simple ratio and its properties. But the fascination with the Golden Ratio is not confined just to mathematicians. Biologists, artists, musicians, historians, architects, engineers, psychologists, and even mystics have pondered and debated the basis of its ubiquity and appeal. In fact, it is probably fair to say that the Golden Ratio has inspired thinkers of all disciplines like no other number in the history of mathematics. But what is so fascinating about φ?

The truly mind-boggling aspect of φ is its role as a fundamental building block of nature. Plants, animals and even humans all possess dimensional properties that adhere with eerie exactitude to the golden ratio, which is why early scientists heralded this ratio as the divine proportion. A few observations:

- In a honeybee community, the female bees always outnumber the males. The ratio of females to the males in any community is approximately 1.61803!

- In the shells of cephalopod mollusks, the diameter of one spiral to that of its neighbour is approximately 1.618!

- Sunflower seeds grow in opposing spirals. The ratio of each rotation's diameter to that of the next, once again approximates to φ!

- The proportions of different plant components (numbers of leaves to branches, diameters of geometrical figures inside flowers) are often claimed to show the golden ratio proportion in several species!

- Psychologists hypothesize that the golden ratio has a say in the human perception of beauty!!!

- Golden ratio has been a prominent presence in art, with generations of painters and sculptors like Da Vinci, Michelangelo, Dali etc. adhering to this ratio in the layout of their compositions!

- Architecture marvels like the Greek Parthenon, the Pyramids of Egypt and even modern structures like the UN Building in New York for example have φ as a prominent presence in their dimensions!

- φ features prominently in the sonatas of Mozart, Beethoven's fifth Symphony, works of Bartok, Schubert etc, as well in the construction of musical instruments!

- In investing, some practitioners of technical analysis use the golden ratio to calculate support of a price level, or resistance to price increases, of a stock or commodity; after significant price changes up or down, new support and resistance levels are supposedly found at or near prices related to the starting price via the golden ratio!

- In 2003 Weiss and Weiss came on a background of psychometric data and theoretical considerations to the conclusion that the golden ratio underlies the clock cycle of brain waves!

- In the human body, the ratio of the length from head to toe to that of the length from the belly button to the toe is close to 1.618. Similar results are obtained for hip to floor upon knee to floor, finger joint lengths, spinal division lengths etc.

as discovered by Leonardo da vinci in his famous drawing, The Vitruvian man!

Fig:3 The Vitruvian Man

These and numerous other observations have only added to the mystery of the golden ratio.

But how do these connect to the significance of the Fibonacci series? It was Johannes Kepler who literally shocked the mathematicians of his time by making a simple observation that the mathematics of the golden ratio and of the Fibonacci series were closely connected. If a Fibonacci number is divided by its immediate predecessor in the sequence, the quotient approximates a constant; none other than the ubiquitous φ. As the Fibonacci numbers increase, the constant converges with astonishing precision to the golden ratio. Hence The Golden Ratio has alternatively been defined as the limit of the Fibonacci series.

$$\lim_{n\to\infty} \frac{F(n+1)}{F(n)} = \varphi$$

This result is what lent the apparently simple series its heightened significance. This spurred a lot of interest in the detailed study of the Fibonacci series, by now, also known as the divine series, having inherited the mystique of the golden ratio. Even today, hypotheses and experimental results involving the Fibonacci series keep coming out, offering a numerological key to the inter-relationships between man and the cosmos, thereby perhaps stretching its significance beyond that of being able to arrive at the golden ratio. Like for example, I came across this recent paper by Valerie Vaughan tracing the Fibonacci series in ancient calendrical systems. He also shows that by alternate addition and subtraction to 365, the reciprocals of the Fibonacci numbers, ie.

$$365 + \frac{1}{2} - \frac{1}{3} + \frac{1}{5} - \frac{1}{8} + \frac{1}{13} \cdots = 365.241666$$

We get the duration of the solar year (which we assume as 365.25 for leap year calculations) with astounding accuracy. The results have been verified by modern techniques.

The entire significance of the Fibonacci numbers is something we may never know. All we have are observations, hunches and hypotheses and of course unanswered questions. Why does nature choose mathematics as its language? Is it a co-incidence that the overarching principles of the universe can be broken down into numbers, equations and series? But what is exciting is that all this intuitively sparks off a spirit of enquiry. One then tends to respect the known as promising means to probe the unknown. That is when more and more of the puzzle will reveal itself.

None of this is ever going to feature in a C-programming lab. That is perhaps not necessary either. But in my humble opinion, buried deep within such thought provoking observations, is the real urge; the impulse to widen one's realms of knowledge. One only has to discover it.

Ion Propulsion

Aravind C T

Introduction

Spacecraft propulsion is based on jet propulsion as used by rocket motors. It is well recognized that chemical-based spacecraft propulsion systems are inherently limited and that exploration of the solar system and beyond will require non-chemical approaches to propulsion technology, a number of alternative propulsion concepts have been proposed and studied, and ion beam propulsion systems have been used with considerable success. Commonly referred to as electric propulsion, ion propulsion systems are a particular type of electric propulsion. Ion propulsion systems that have been brought into practice use an onboard ion source to form an energetic ion beam, typically Xe+ ions, as the propellant. The most noticeable difference between a fully loaded conventional rocket and an electric propulsion system would be the mass of fuel required to produce thrust. While conventional chemically fueled rockets require millions of kilograms of propellant, ion propulsion systems require only a miniscule amount of propellant by comparison. Also, all electric engines are highly efficient and reliable, making them excellent choices for long, unattended operation.

Ion propulsion has now entered the mainstream of propulsion options available for deep space missions. This is important because many of the deep-space missions that are relatively easy to perform from a propulsion standpoint, such as planetary flybys, have already been accomplished. Future high priority mission classes, which include sample return missions and outer planet orbiters, place substantially greater demands on the capabilities of on-board propulsion systems. Ion propulsion can help make these missions affordable and scientifically more attractive by enabling the use of smaller, lower-cost launch vehicles, and by reducing flight times.

Ion propulsion is a form of electric space propulsion in which ions are accelerated by an electrostatic field to produce a high-speed (typically about 30 km/s) exhaust. An ion engine has a high specific impulse (making it very fuel-efficient) but a very low thrust. Therefore, it is useless in the atmosphere or as a launch vehicle, but extremely useful in space where a small amount of thrust over a long period can result in a big difference in velocity. This makes an ion engine particularly useful for two applications (1) as a final thruster to nudge a satellite into a higher orbit and or for orbital maneuvering or station-keeping, and (2) as a means of propelling deep-space probes by thrusting over a period of months to provide a high final velocity. Chemical rockets have demonstrated fuel efficiencies up to 35%, but ion thrusters have demonstrated fuel efficiencies over 90%. The source of electrical energy for an ion engine can be either solar or nuclear.

The propulsion of choice for science fiction writers has become the propulsion of choice for scientists and engineers at NASA. Ion thrusters are currently used for stationkeeping on communication satellites and for main propulsion on deep space probes. Ion thrusters expel ions to create thrust and can provide higher spacecraft top speeds than any other rocket currently available. The ion propulsion system's efficient use of fuel and electrical power enable modern spacecraft to travel farther, faster, and cheaper than any other propulsion technology currently available. The electric ion propulsion system is the next step in mankind's forward progress into space exploration.

Basics of Space Exploration

Spacecraft propulsion is any method used to change the velocity of spacecraft and artificial satellites. The only known way to meet space-flight velocity requirements is through the use of the rocket in one of its several forms. Rocket thrust is the reaction force produced by expelling particles at high velocity from a nozzle opening. These expelled particles may be solid, liquid, gaseous, or even bundles of radiant energy. The engine's ability to produce thrust will endure only so long as the supply of particles, or working fluid, holds out. Expulsion of material is the essence of the thrust production and without material to expel no thrust can be produced, regardless of how much energy is available. Explained below are some of the terminologies which will be used in due course:

Electric Propulsion

Electric thrusters' source of power is electricity. This electricity may be used to supply thermal energy or electrostatic/electromagnetic energy to the working fluid. The following sections discuss electrostatic, electrothermal, and electromagnetic systems.

Ion Propulsion

The working fluid in ion engines are ions. Ion engines develop very high specific impulses on the order of 2,000 to 10,000 seconds but at very low thrust levels. These engines produce very low accelerations over long periods of time. Ion engines produce thrust by pumping a neutral propellant into an ion production chamber where ions and electrons are separated into two different streams. The ions pass through a strong electrostatic field and are accelerated into an exhaust stream. The thrust is the total reaction to the accelerating forces[1]. A large amount of electricity is required to produce this electrostatic field; therefore a nuclear reactor is often used to supply the power to the engines. Another option is to use solar power to generate the electricity

Ion Propulsion Principle

In a basic Electric Propulsion System, the energy to produce thrust is not stored in the propellant but has to be supplied from outside by an extra power source, e.g. nuclear, solar radiation receivers or batteries. Thrust is produced by expansion of hot gas (which is heated by electric current) followed by acceleration of charged particles in electric or magnetic fields to high expulsion velocities.

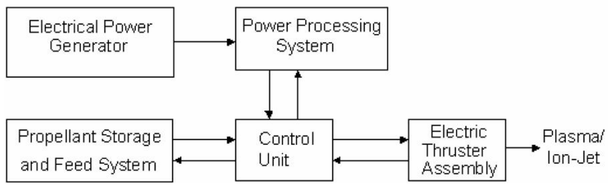

Fig:1 Block schematic of Electric Propulsion System

Electric propulsion systems comprise the following main components: Storage and feed system that stores and feeds the propellant to the thrusters to generate thrust Valves, piping which connects the propellant storage system with the thruster Electric control unit to operate electrically the valves and thrusters Electric power supply and power processing system. The best electric propulsion system we have is the ion engine, which obtains the highest degree of conversion of electric power into thrust, highest specific impulse (around 3000s) and the longest operational lifetime.

An ion is simply an atom or molecule that is electrically charged. Ionization is the process of electrically charging an atom or molecule by adding or removing electrons. Ions can be positive (when they lose one or more electrons) or negative (when they gain one or more electrons). A gas is considered ionized when some or all the atoms or molecules contained in it are converted into ions.

Plasma is an electrically neutral gas in which all positive and negative charges-from neutral atoms, negatively charged electrons, and positively charged ions-add up to zero. Plasma exists everywhere in nature; it is designated as the fourth state of matter (the others are solid, liquid, and gas). It has some of the properties of a gas but is affected by electric and magnetic fields and is a good conductor of electricity. Plasma is the building block for all types of electric propulsion, where electric and/or magnetic fields are used to push on the electrically charged ions and electrons to provide thrust. Examples of plasmas seen every day are lightning and fluorescent light bulbs.

The conventional method for ionizing the propellant atoms in an ion thruster is called electron bombardment. The majority of NASA's research consists of electron bombardment ion thrusters. When a high-energy electron (negative charge) collides with a propellant atom (neutral charge), a second electron is released, yielding two negative electrons and one positive ion.

An alternative method of ionization called electron cyclotron resonance (ECR) is also being researched at NASA. This method uses high-frequency radiation (usually microwaves), coupled with a high magnetic field to heat the electrons in the propellant atoms, causing them to break free of the propellant atoms, creating plasma. Ions can then be extracted from this plasma. The best electric propulsion system we have is the ion engine, which obtains the highest degree of conversion of electric power into thrust, highest specific impulse (around 3000s) and the longest operational lifetime.

The Ion Propulsion System (IPS) has the best efficiency among the electric propulsion systems, and it is one of the most developed systems currently available. The main difference between an ion thruster and other nuclear, or chemical systems is that the exhaust particles of the rocket are not accelerated by heat energy but by electrical energy.

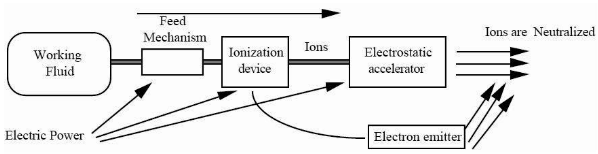

Fig. 2 Block schematic of ion propulsion system

The IPS consists of five main parts: the power source, power processing unit (PPU), propellant management system (PMS), the control computer, and the ion thruster. The IPS power source can be any source of electrical power, but solar and nuclear are the primary options. A solar electric propulsion system (SEP) uses sunlight and solar cells for power generation. A nuclear electric propulsion (NEP) system uses a nuclear heat source coupled to an electric generator. The PPU converts the electrical power generated by the power source into the power required for each component of the ion thruster. It generates the voltages required by the ion optics and discharge chamber and the high currents required for the hollow cathodes. The PMS controls the propellant flow from the propellant tank to the thruster and hollow cathodes. Modern PMS units have evolved to a level of sophisticated design that no longer requires moving parts. The control computer controls and monitors system performance. The ion thruster then processes the propellant and power to perform work.

The ion rocket is a means of providing thrust, more gradually but also more efficiently than a conventional rocket. The material ejected here is generally xenon, a heavy inert gas, compressed inside strong containers (mercury vapor was also considered). As in the nuclear rocket, the energy which propels the xenon jet comes from a different source; here it is electrical energy. The reason an ion rocket is much more efficient than ordinary rockets is the way its jet is produced. Rather than confining a hot gas in a chamber and ejecting it through a nozzle–a process limited by the temperature which the nozzle can stand–an ion rocket first strips negative electrons from the xenon atoms, leaving them as 'ions', atoms with a net (positive) electric charge. The ions can now be accelerated by electrical forces, to velocities much higher than those obtained from a hot gas, but without the need for a high temperature. Inside every video tube is an 'electron gun' which similarly accelerates the narrow beam of electrons that paints the video picture on the screen. Incidentally, the emerging jet of ions must be combined with a stream of negative electrons from a separate electron gun. Without this addition, only positive ions would be emitted, and the satellite would quickly become negatively charged by the stripped electrons left behind. The negative charge would then pull back the ions and undo all the work of the ion gun.

Ion Thruster

An ion thruster (or ion drive) is one of several types of spacecraft propulsion, specifically electric propulsion. It uses beams of ions - electrically charged atoms or molecules - for propulsion. The precise method for accelerating the ions may vary, but all designs take advantage of the charge-to-mass ratio of ions to accelerate them to very high velocities using a high electric field. Ion thrusters are therefore able to achieve high specific impulse, reducing the amount of reaction mass required, but increasing the amount of power required compared to chemical rockets. Ion thrusters can deliver one order of magnitude greater propellant efficiency than traditional liquid fuel rocket engines, but are constrained to very low accelerations by the power/weight ratios of available power systems.

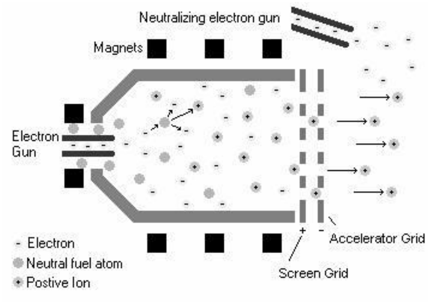

Fig.3 Ion Thruster

In a conventional ion thruster, electrons are generated by a hollow cathode, called the discharge cathode, located at the center of the engine on the upstream end. The electrons flow out of the discharge cathode and are attracted to the discharge chamber walls, which are charged to a high positive potential by the thruster's power supply. The electrons from the discharge cathode ionize the propellant by means of electron bombardment. High-strength magnets are placed along the discharge chamber walls so that as electrons approach the walls, they are redirected into the discharge chamber by the magnetic fields. By maximizing the length of time that electrons and propellant atoms remain in the discharge chamber, the chance of ionization is maximized, which makes the ionization process as efficient as possible. In an ion thruster, ions are accelerated by electrostatic forces. The electric fields used for acceleration are generated by electrodes positioned at the downstream end of the thruster. Each set of electrodes, called ion optics or grids, contains thousands of coaxial apertures. Each set of apertures acts as a lens that electrically focuses ions through the optics. NASA's ion thrusters use a two-electrode system, where the upstream electrode (called the screen grid) is charged highly positive, and the downstream electrode (called the accelerator grid) is charged highly negative. Since the ions are generated in a region of high positive and the accelerator grid's potential is negative, the ions are attracted toward the accelerator grid and are focused out of the discharge chamber through the apertures, creating thousands of ion jets. The stream of all the ion jets together is called the ion beam. The thrust force is the force that exists between the upstream ions and the accelerator grid. The exhaust velocity of the ions in the beam is based on the voltage applied to the optics. While a chemical rocket's top speed is limited by the thermal capability of the rocket nozzle, the ion thruster's top speed is limited by the voltage that is applied to the ion optics (which is theoretically unlimited).Because the ion thruster expels a large amount of positive ions, an equal amount of negative charge must be expelled to keep the total charge of the exhaust beam neutral. A second hollow cathode called the neutralizer is located on the downstream perimeter of the thruster and expels the needed electrons.

Conclusion

It has been brought out that ion propulsion can achieve a high specific impulse using reduced propellant mass. The thrust output of the ion engine is very small, but the fuel efficiency is an order of a magnitude higher than chemical rockets. Given a sufficiently long mission time, an ion engine is able to achieve speeds far greater than any chemical rocket. One of the most applicable areas for ion propulsion is space exploration. The only drawback of ion propulsion system is requirement of large input power. With advancement in nuclear and solar technologies if power sources capable of meeting the power requirements easily are developed the use of the ion engine will undoubtedly be the best choice of propulsion for space probes in the 21st century.

References

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"The ideal engineer is a composite. He is not a scientist, he is not a mathematician, he is not a sociologist or a writer; but he may use the knowledge and techniques of any or all of these disciplines in solving engineering problems."
- N. W. Dougherty, 1955