DEPARTMENT OF AEROSPACE ENGINEERING

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UNIT V - PERFORMANCE OF AEROSPACE VEHICLES

Electric Propulsion and Magnetic Levitation Systems

Electric propulsion

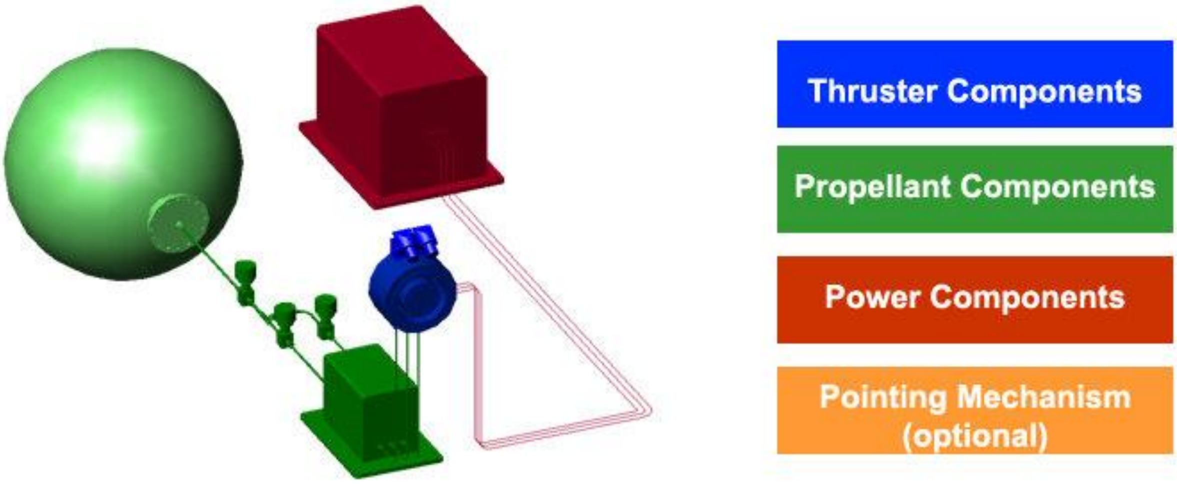
Electric Propulsion (EP) is a class of space propulsion that makes use of electrical power to accelerate a propellant by different possible electrical and/or magnetic means. The use of electrical power enhances the propulsive performances of the EP thrusters compared with conventional chemical thrusters. Unlike chemical systems, electric propulsion requires very little mass to accelerate a spacecraft. The propellant is ejected up to twenty times faster than from a classical chemical thruster and therefore the overall system is many times more mass efficient.

Electric Propulsion, when compared with chemical propulsion, is not limited in energy but is only limited by the available electrical power on board the spacecraft. Therefore, EP is suitable for low-thrust (micro and milli-newton levels) long-duration applications onboard spacecraft. The propellant used in EP systems varies with the type of thruster and can be a rare gas (i.e. xenon or argon), a liquid metal, or, in some cases, a conventional propellant.

Electric Propulsion System components

An Electric Propulsion System is composed of four different building blocks:

- The thruster components,
- The propellant components or fluidic management system,
- The power components, which include the PPU,
- The pointing mechanisms (optional),



Electric Propulsion Applications

The different applications which currently make or may make use of Electric Propulsion Systems in the future, are:

- LEO (e.g. Earth Observation, Earth Science, constellations)
- MEO (e.g. Navigation)
- GEO (e.g. Telecommunications)
- Space Transportation (e.g. launcher kick stages, space tugs)
- Space Science, Interplanetary, and Space exploration.

Magnetic Levitation

The magnetic levitation is based on the creation of magnetic forces which exist because of various things. It can either be caused by a permanent magnet made up of solid material with induced north and south pole or the other way through which a magnetic field is established is through an electric field changing linearly with time. Yet another way to create a magnetic field is through the use of direct current.

Two fundamental principles are involved in studying the concept of magnetic levitation. The first principle is in the form of a law which is suggested by Michael Faraday commonly known as Faraday's laws of electromagnetic induction.

Faraday's law states that if there is a change in the magnetic field on a coil of wire, a change in voltage is observed. It can also be said that with a change in voltage, a change in magnetic field occurs. This is due to induced current in the coil as a result of that change in voltage. The strength of the magnetic field is proportional to the current flowing through the coil. If the current is higher, a stronger magnetic field is produced with greater magnetic forces.

The direction of magnetic forces is given using Lenz's law which states that the emf induced in an electric circuit always acts in such a way that the current driven by it in the circuit will oppose the change in the magnetic flux producing the emf. This means that if a current is induced in the coil then the magnetic field produced will be perpendicular to the direction of current. Due to the prediction of the direction of the magnetic field, it can be maximized by setting up a suitable set and magnetic levitation finds many applications such as in transportation and other industrial applications.

Maglev is a combination of superconducting magnets and linear motor technology which in turn realizes a super high-speed transport system. It is safe, and reliable, with less impact on the environment, and requires minimum maintenance. In the Maglev system, a vehicle rims levitated from the guideway with the use of electromagnetic forces between superconducting magnets and coils on the ground. The principle of Maglev can be understood from Fig. 9.12.1.

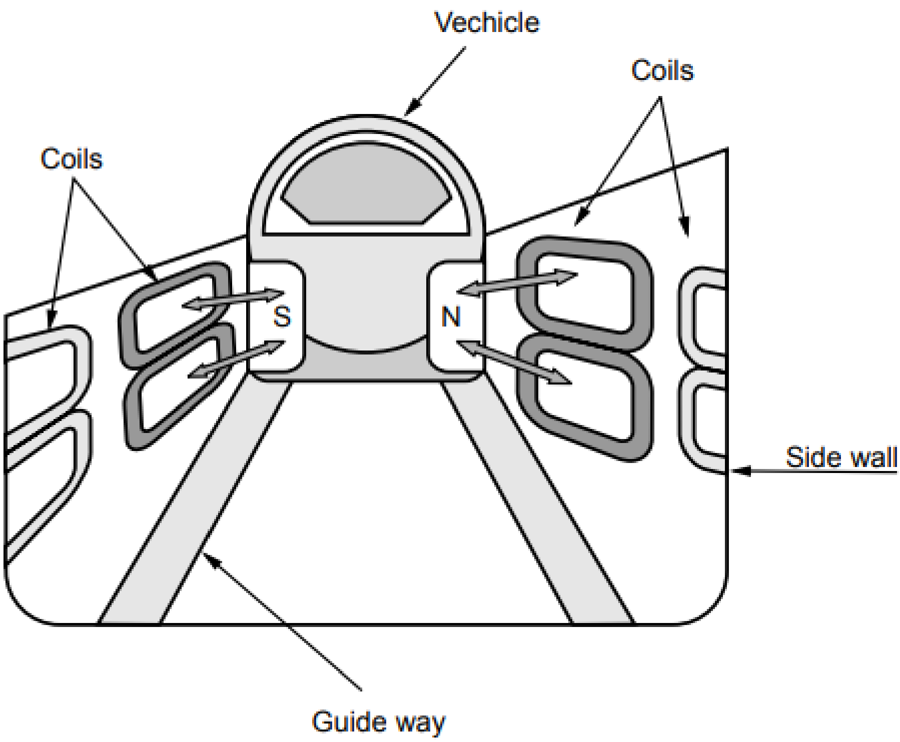


Fig. 9.12.1 Principle of magnetic levitation

The coils are installed on the side walls of the guideway. The superconducting magnets are attached to the vehicle itself. Due to the high speed of the vehicle, there is an induced current in the coils during the instant when it passes the coils. The coils act as electromagnets for a short duration. The interaction between the coils on the guideway and the magnets on the vehicle allows the vehicle to stay levitated above a track for a few centimeters. One side of the vehicle experiences a magnetic force tending to push it from the bottom while at the same time, there is a pulling force from the top part of the coil which pulls the other side of the vehicle away from the coil. This forms the basis for the levitation principle for the track. It is also required to take proper care so that the vehicle does not slide from side to side. Let us try to understand this levitation principle in detail with the various forces involved and their interactions.

For simplicity in understanding, let us consider a permanent magnet that is moving at a speed of v m/s across a conducting ladder as shown in Fig. 9.12.2.

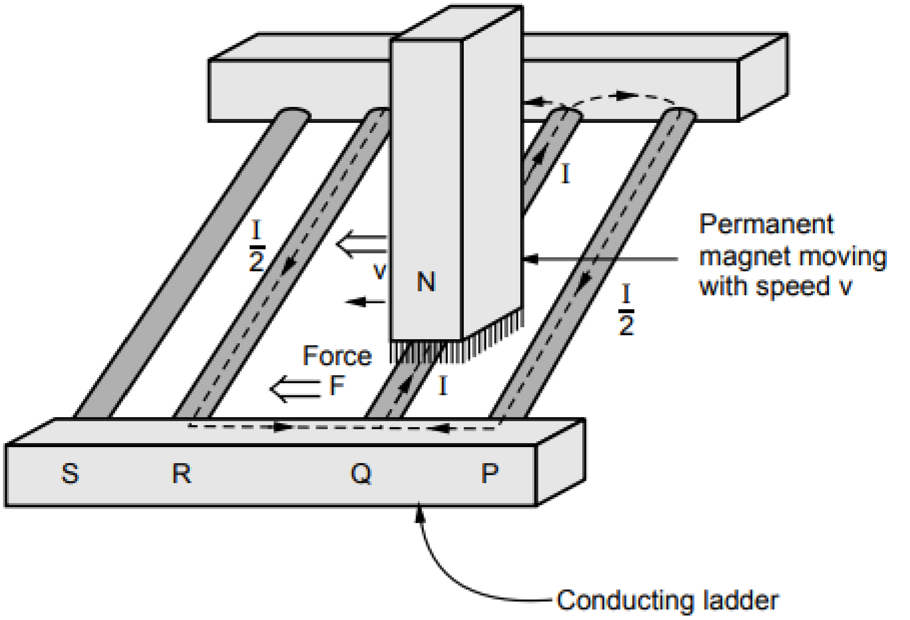


Fig. 9.12.2 Permanent magnet moving on conducting ladder

This moving magnet tends to drag the conducting ladder along with it because of the application of horizontal tractive force, $F = BIl$ where B is flux density in Web/m^2,

I am the current flowing through the conductor and l is the active length of the conductor under the influence of the magnetic field. The plane of motion of the magnet and the plane of the conducting ladder are perpendicular to each other due to which maximum force is exerted and its direction can be found using Fleming's left-hand rule.

In addition to this horizontal tractive force, a vertical force also exists between the moving magnet and the conducting ladder which pushes the magnet away from the ladder in the upward direction. Let I be the current flowing through conductor Q. The front view of the above figure is shown in Fig. 9.12.3. Let us initially assume that the magnet is moving at a low speed.

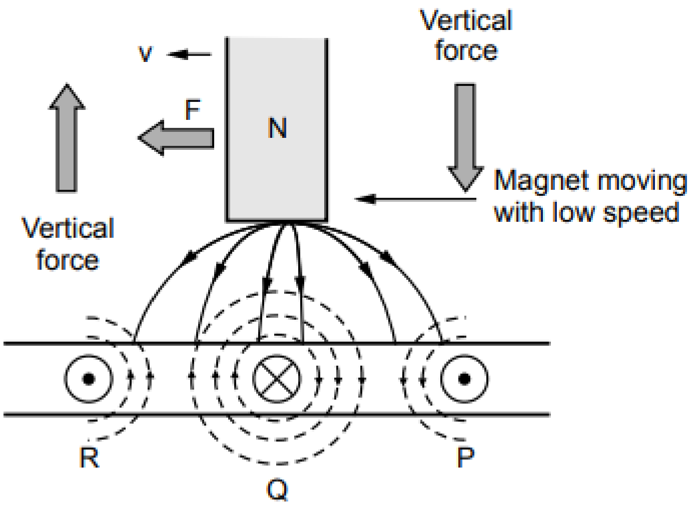


Fig. 9.12.3

The magnetic flux ϕ at the center of the magnet is maximum so the emf induced in conductor Q is maximum. If the conductor is assumed to have low inductance then the induced current will also reach its maximum value approximately at the same instant when voltage reaches its maximum value. This current flows through conductors P and R with magnitude I/2. The currents in conductors P, Q, and R will produce their magnetic fields, which can be found by using the Right-hand rule. These magnetic fields produced by the conductors will interact with the magnetic field of the magnet so that vertical force is exerted on the magnet. The front half of the magnet is pushed upwards while the rear half of the magnet is pulled downwards. Concerning the center of the magnet, the vertical forces of attraction and repulsion, being equal and opposite, cancel each other due to symmetry and only horizontal tractive force is present.

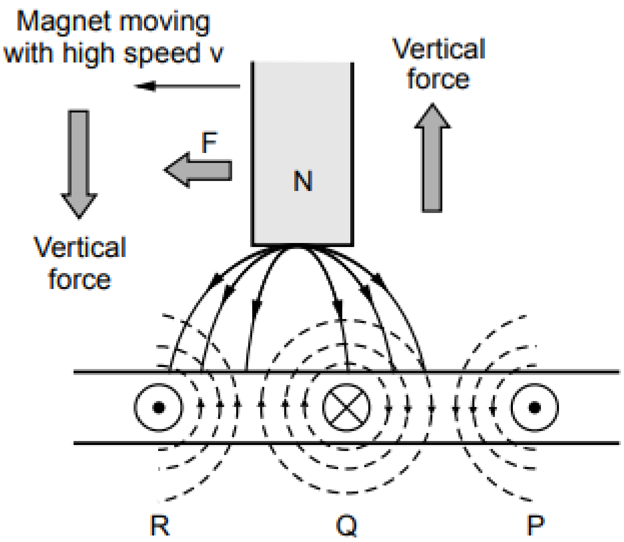


Fig. 9.12.4

Now let us consider that the magnet is moving at a very high speed. This condition is represented in the Fig. 9.12.4 with the front view as shown earlier.

Due to inductance associated with the conductor, current in conductor Q reaches its maximum value a fraction of time, At, after voltage reaches its maximum value. This time interval At depends on the L/R time constant of the conductor circuit. This delay is very small at low speeds such that voltage and current reach their maximum value virtually at the same time and place. Δt large speeds, this time delay At is sufficient enough to produce a large shift in space between the points where the voltage and current achieve their maximum values.

By the time the current in Q reaches its maximum value, the center of the magnet is already ahead of conductor Q by a distance given as vAt. The currents in conductors P, Q, and R are established as explained earlier and their interaction with the field of magnet exerts a vertical force in such a way that the front end of the magnet is pushed downwards while the rear end is pulled upwards. This is a basic principle of magnetic levitation which means floating in air.

This principle is used in ultra high-speed trains running at speeds in the range of 300 km/hr and which float in the air about 100 mm to 300 mm above the track. These trains do not need traditional steel rail and will not require any wheels.

A powerful superconducting magnet is mounted at the bottom of the train which induces current in the rail. This produces a vertical force called levitation force which keeps the train pushed up in the air above the track.

A linear induction motor is employed to propel the train. A linear induction motor consists of a flat stator that produces a flux that moves in a straight line from one end to the other at a linear synchronous speed. This speed is given by,

$v_s = 2\ w\ f$

where v_s = Linear synchronous speed

W = Width of one pole pitch in m

f = Supply frequency in Hz.

The above speed is independent of the number of poles. The rotor consists of a plate made up of aluminium, copper, or iron. The flux moves linearly and drags the rotor plate along with it in the same direction. Practically the stator moves while the rotor plate is kept stationary in the applications.

It is employed in high-speed trains which use principle of magnetic levitation as explained earlier. The rotor consists of a thick aluminium plate which is fixed to the ground and extends over the entire length of the track. The stator which is linear is bolted in the Fig. 9.12. 5.

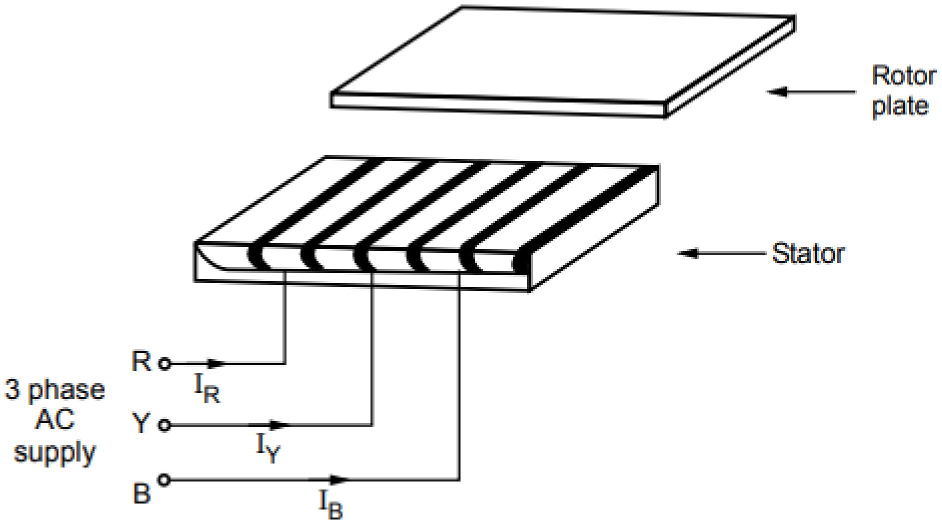


Fig. 9.12.5 Linear induction motor

The slip in the case of linear induction motor is given as,

Slip, $s = v_s - v / v_s$ where $v_s = 2$ wf

And v = Actual speed in m/s

The force or thrust exerted is given by,

$F = p_m / v_s$

where P_{in} is active power supplied to the rotor. The flow of active power remains the same as that in the case of a normal induction motor.