QUEENS COLLEGE OF ARTS AND SCIENCE, PUNALKULAM, NEAR THANJAVUR, PUDUKOTTAI

DEPARTMENT OF PHYSICS

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Betatron

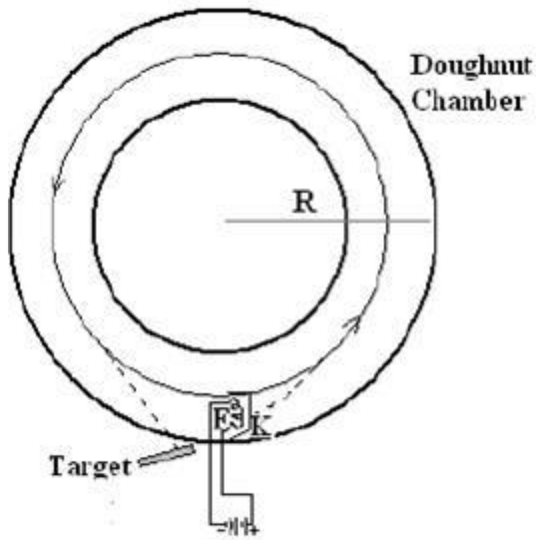
A Betatron was developed by D W Kerst to accelerate the electrons to high energies.

Principle

The principle of the Betatron is same as that of the transformer. In transformer, if an alternating current is passed through the primary coil an alternating magnetic field will appear in the coil. This field produces an induced *e.m.f.* in the secondary coil. Similarly the changing magnetic flux induces an *e.m.f.* tangentially along a circular path for the electron which accelerates the electrons to high energies. The electrons is kept accelerating in circular path of constant radius with the help of increasing magnetic field.

Construction

The Betatron is consists of an evacuated doughnut chamber in which electrons are produced by indirectly heated cathode. The doughnut tube is placed between two strong electromagnet such that, when the a.c current is passed in the electromagnets the flux increases in the centre of doughnut (single coil).



Working

When the electron appears at K (cathode) in doughnut tube and the electromagnets are energized the magnetic field increases, the increasing magnetic field has two effects

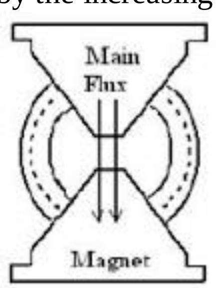
(i) Induced e.m.f. is produced in electron orbit by changing magnetic flux that gives an additional energy to electron. According to Faraday's law

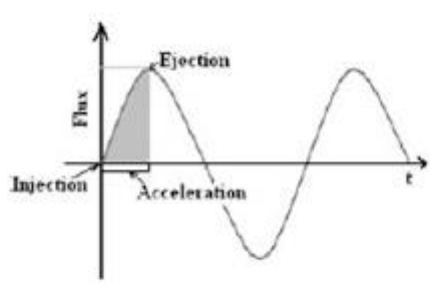
induced $e.m.f = -\frac{d\phi}{dt}$ ....(3.11)

(ii) A radial force (magnetic force) is produced by action of magnetic field whose direction is perpendicular to the electron velocity which keeps the electron moving in circular path. The force is balanced by centripetal force, i.e.,

$qvB = \frac{mv^2}{r}$,............(3.12)

The particle acceleration occurs only with increasing flux (the duration when the flux increases from zero to a maximum value) i.e., the first quarter of the a.c. cycle (T/4 sec), after this the flux starts decreasing which result in decreasing velocity therefore the electron is kept in the tube only for T/4 sec. As the electrons get faster they need a larger magnetic field to keep moving at a constant radius, which is provided by the increasing field.





Betatron Condition

Induced e.m.f in the coil from Faraday's law of electromagnetic induction

$$e.m.f = -\frac{d\phi}{dt}$$

Work done on an electron in one revolution

$$W = e.m.f \times chargeofelectron$$

$$W = e\frac{d\phi}{dt}$$

Work done = tangential Force 'F' on electron x distance traveled in one revolution

$$W = F \times 2\pi r = e\frac{d\phi}{dt}$$

$$F = \frac{e}{2\pi r}\frac{d\phi}{dt} \quad \text{.................................(3.13)}$$

The electron moves in circular path. The magnetic force is balanced by centripetal force, i.e.,

$$evB = \frac{mv^2}{r}$$

$$eBr = mv = p \quad \text{.........................(3.14)}$$

From Newtons second law radial force

$$F = \frac{dp}{dt} = \frac{d(mv)}{dt}$$

$$F = \frac{d(eBr)}{dt}$$

In order to maintain path of constant radius (r is constt.)

$$F = er\frac{dB}{dt} \quad \text{......................(3.15)}$$

Equations 3.13 and 3.15 are equal, equating both

$$F = er\frac{dB}{dt} = \frac{e}{2\pi r}\frac{d\phi}{dt}$$

$$\frac{d\phi}{dt} = 2\pi r^2\frac{dB}{dt}$$

Integrating the above equation

$$\phi = 2\pi r^2 B \quad \text{..............(3.16)}$$

The relation is known as Betatron condition. It shows that to ensure that the electron moves in circular path of constant radius, the magnetic flux within the orbit of radius R is always twice what it would have been if magnetic field were uniform throughout the orbit.

Energy Gained by Electron

The particles have maximum energy when the magnetic field is at its strongest value but the formula used for the cyclotron will not work for Betatron because the electron motion is relativistic. However, if the total energy is much greater than the rest energy then

$$E = pc \quad \text{...................(3.17)}$$

As the centripetal force is again provided by the Lorentz force,The momentum of the electron will

$$eBr = mv = p$$

and hence Energy

$$E = Berc \quad ....(3.18)$$

Number of Revolutions Taken by Electron

In T/4 seconds if the electron takes N revolutions in circular path of constant radii then the total distance traveled by the electron in gaining the maximum energy E is

$$S = N \times 2\pi r$$

$$N \times 2\pi r = c \times \frac{T}{4}$$

$$N = \frac{c}{4 \times 2\pi f \times r}$$

$$N = \frac{c}{4\omega r} \quad ....(3.19)$$

Average Energy Gained per Revolution

Average energy gained per revolution (E_{av}) will be given as

$$E_{av} = \frac{E}{N} \quad ....(3.20)$$

where E =Total energy gained by electron and

N = Number of Revolutions taken

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Proton synchrotron

The Proton Synchrotron (PS) is a key component in CERN’s accelerator complex, where it usually accelerates either protons delivered by the Proton Synchrotron Booster or heavy ions from the Low Energy Ion Ring (LEIR). In the course of its history it has juggled many different kinds of particles, feeding them directly to experiments or to more powerful accelerators.

The PS first accelerated protons on 24 November 1959, becoming for a brief period the world’s highest energy particle accelerator. The PS was CERN’s first synchrotron. It was initially CERN's flagship accelerator, but when the laboratory built new accelerators in the 1970s, the PS’s principal role became to supply particles to the new machines. Over the years, it has undergone many modifications and the intensity of its proton beam has increased a thousandfold.

With a circumference of 628 metres, the PS has 277 conventional (room-temperature) electromagnets, including 100 dipoles to bend the beams round the ring. The accelerator operates at up to 25 GeV. In addition to protons, it has accelerated alpha particles (helium nuclei), oxygen and sulphur nuclei, electrons, positrons and antiprotons.

What is an accelerator?

An accelerator propels charged particles, such as protons or electrons, at high speeds, close to the speed of light. They are then smashed either onto a target or against other particles circulating in the opposite direction. By studying these collisions, physicists are able to probe the world of the infinitely small.

When the particles are sufficiently energetic, a phenomenon that defies the imagination happens: the energy of the collision is transformed into matter in the form of new particles, the most massive of which existed in the early Universe. This phenomenon is described by Einstein's famous equation $E=mc^2$, according to which matter is a concentrated form of energy, and the two are interchangeable.

The Large Hadron Collider is the most powerful accelerator in the world. It boosts particles, such as protons, which form all the matter we know. Accelerated to a speed close to that of light, they collide with other protons. These collisions produce massive particles, such as the Higgs boson or the top quark. By measuring their properties, scientists increase our understanding of matter and of the origins of the Universe. These massive particles only last in the blink of an eye, and cannot be observed directly. Almost immediately they transform (or decay) into lighter particles, which in turn also decay. The particles emerging from the successive links in this decay chain are identified in the layers of the detector.

Animation showing the path of the particles in the accelerator complex up to their collisions in the LHC. (Video: Daniel Dominguez/CERN)

How does an accelerator work?

Accelerators use electromagnetic fields to accelerate and steer particles. Radiofrequency cavities boost the particle beams, while magnets focus the beams and bend their trajectory.

In a circular accelerator, the particles repeat the same circuit for as long as necessary, getting an energy boost at each turn. In theory, the energy could be increased over and over again. However, the more energy the particles have, the more powerful the magnetic fields have to be to keep them in their circular orbit.

A linear accelerator, on the contrary, is exclusively formed of accelerating structures since the particles do not need to be deflected, but they only benefit from a single acceleration pass. In this case, increasing the energy means increasing the length of the accelerator.

As physicists have been explored higher and higher energies, accelerators have become larger and larger: the size of an accelerator is a compromise between energy, the radius of curvature (if it's circular), the feasibility and the cost.

Colliders are accelerators that generate head-on collisions between particles. Thanks to this technique, the collision energy is higher because the energy of the two particles is added together.

The Large Hadron Collider is the largest and most powerful collider in the world. It boosts the particles in a loop 27 kilometres in circumference at an energy of 6.5 TeV (teraelectronvolts), generating collisions at an energy of 13 TeV.

How it works

The accelerating cavities