Introduction to Particle Accelerators

An Online Continuing Education Course for Engineers

Course Number: E-2004

Credit: 2 Hours / 2 PDH / 2 CPD

Introduction to Particle Accelerators (2 PDH)

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Introduction

The purpose of a particle accelerator is to accelerate particles, electrons or protons, (generated, for example, by an electron gun device) to a high speed. Why would you want to accelerate a particle to a high speed? The answer is *energy*. A faster moving particle has more energy than a slower moving one. When any charged particle is accelerated, it emits electromagnetic radiation. Once you build up the energy, you can then slam the particle into a target, for various reasons, or make use of the radiation that is given off by the accelerated particle.

There are two different kinds of particle accelerators. One kind is a linear accelerator that moves particles in a straight line. The other type is a circular accelerator that moves particles in a circular fashion. No matter whether linear or circular, the end goal is to accelerate a particle to a sufficient energy, for the application, then either collide it with a target or use the radiation given off by the accelerated particle.

We will discuss linear accelerators first then circular accelerators. Next, we will discuss the targets that get hit with the particles. Finally, we will discuss what happens when we are finished with the particles.

Linear Accelerators

Linear accelerators, called linacs for short, move particles in a straight line and they usually have a target at the end. One of the largest linacs in the world is the Stanford Linear Accelerator, called the SLAC, which is 2 miles long. Physicists frequently refer to the SLAC when talking about particle accelerators. In fact, many smaller scale linacs are based on the SLAC design.

An aerial view of the SLAC is shown in Figure 1. An example of a somewhat smaller proton linac from Brookhaven National Labs (BNL) is shown in Figure 2.

Figure 1. An aerial view of the Stanford Linear Accelerator (SLAC).

Figure 2. A 200 MeV proton accelerator at BNL.

If you are looking to construct a linear accelerator of your own, there are only a few companies in the world that will tackle such projects with the least costly options typically coming from Chinese or Russian companies. You can also buy pre-owned linear accelerators. Two things you have to specify for a linac are the energy in millions of electron volts (MeV) and the frequency of operation (for example, S-band or around 2.4 GHz).

Low energy accelerators such as cathode ray tubes and most X-ray generators use a single pair of electrodes with a dc voltage of a few thousand volts between them. In most X-ray generators, the target itself is one of the electrodes. Using linear accelerators, X-rays are generated by colliding an accelerated electron into a target made of a material with a high atomic number. The x-ray energy increases as the square of the particle beam energy for x-ray energies much less than the particle energy (for example, 50 MeV linear accelerator and a 50 keV x-ray output).

If needed, the particle beam can be guided by electromagnets. For example, if there is a need to slightly shift the particle beam for some reason, an electromagnet can be designed and implemented to steer the particles in the desired direction by running the particle beam guide or waveguide through the magnet. Pole pieces (pieces of steel placed inside the magnet) can be used to shape the magnetic field to get the desired effect on the particle beam. Figure 3 shows an example of a particle waveguide passing through a magnet for steering purposes. Note that if you just shift the waveguide without steering the particle beam along with it, the particles will hit the inside of the waveguide and emit undesireables such as gama waves and x-rays.

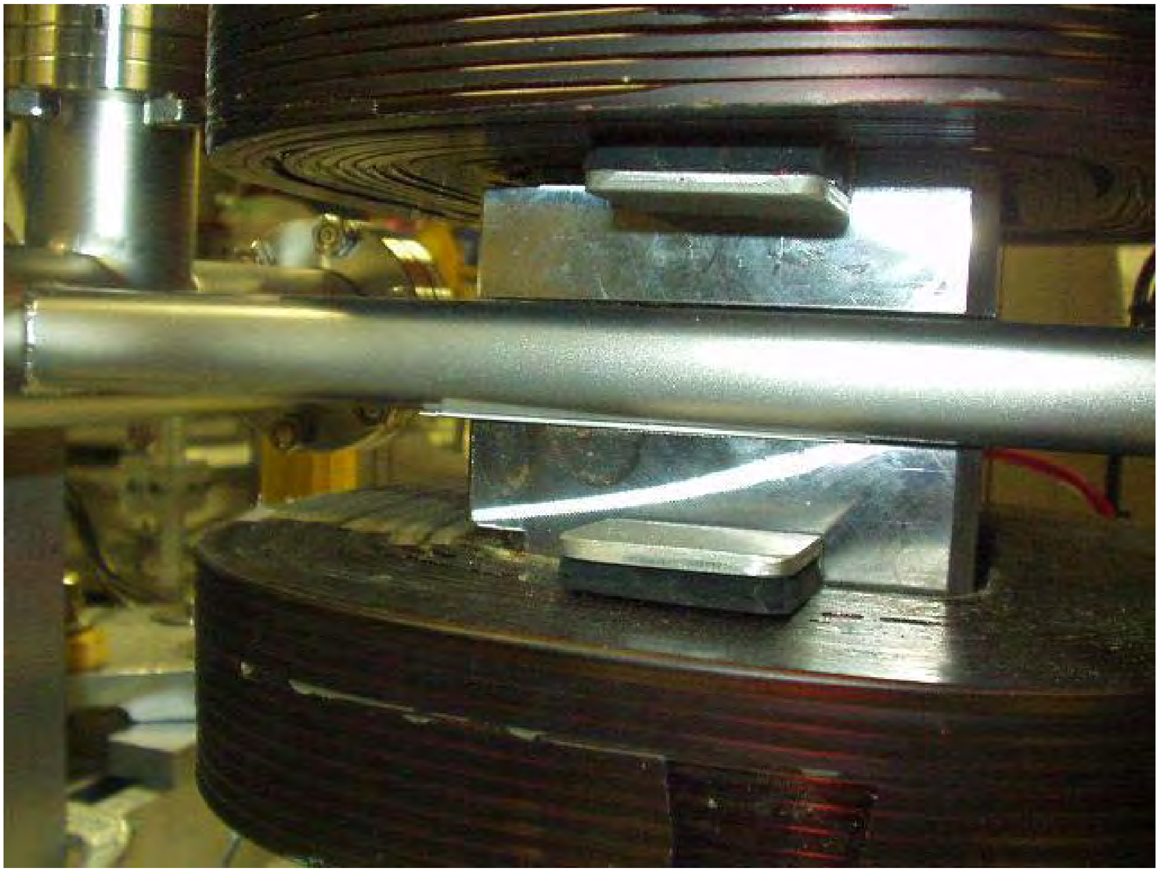


Figure 3. A particle waveguide passing through a steering magnet.

Before collision with the end target, the particles, traveling in a bunch, are often “focused” using magnets to squeeze down the size of the particle “missile.” The higher the energy of the particles the more magnetic energy is required to squeeze the particles together. It is advantageous to keep the particles from hitting anything until the target since collisions cause x-rays and gamma rays to be given off. You only want x-rays given off if that is your goal and, even then, only at the appropriate point in the process.

Higher energy accelerators use a linear array of plates (or drift tubes) to which an alternating high-energy field is applied. This high-energy field is typically supplied by a klystron which is a microwave tube that serves as an amplifier. As the particles approach a plate they are accelerated towards it by an opposite polarity charge applied to the plate. As they pass through a hole in the plate, the polarity is switched so that the plate now repels them and they are now accelerated by it towards the next plate. The particles, for a brief period, drift at constant velocity between plates hence the name “drift” tube. Normally, a stream of bunches of particles are accelerated, so a carefully controlled AC voltage is applied to each plate to continuously repeat this for each bunch. The particles pick up more and more energy in the drift tube until they shoot out the end of the accelerator. This is sort of analogous to an electromagnetic catapult. The microwave energy “carries” the particles along the drift tube. An example drift tube is shown in Figure 4.

Figure 4. Linac drift tube at Oak Ridge National Laboratory.

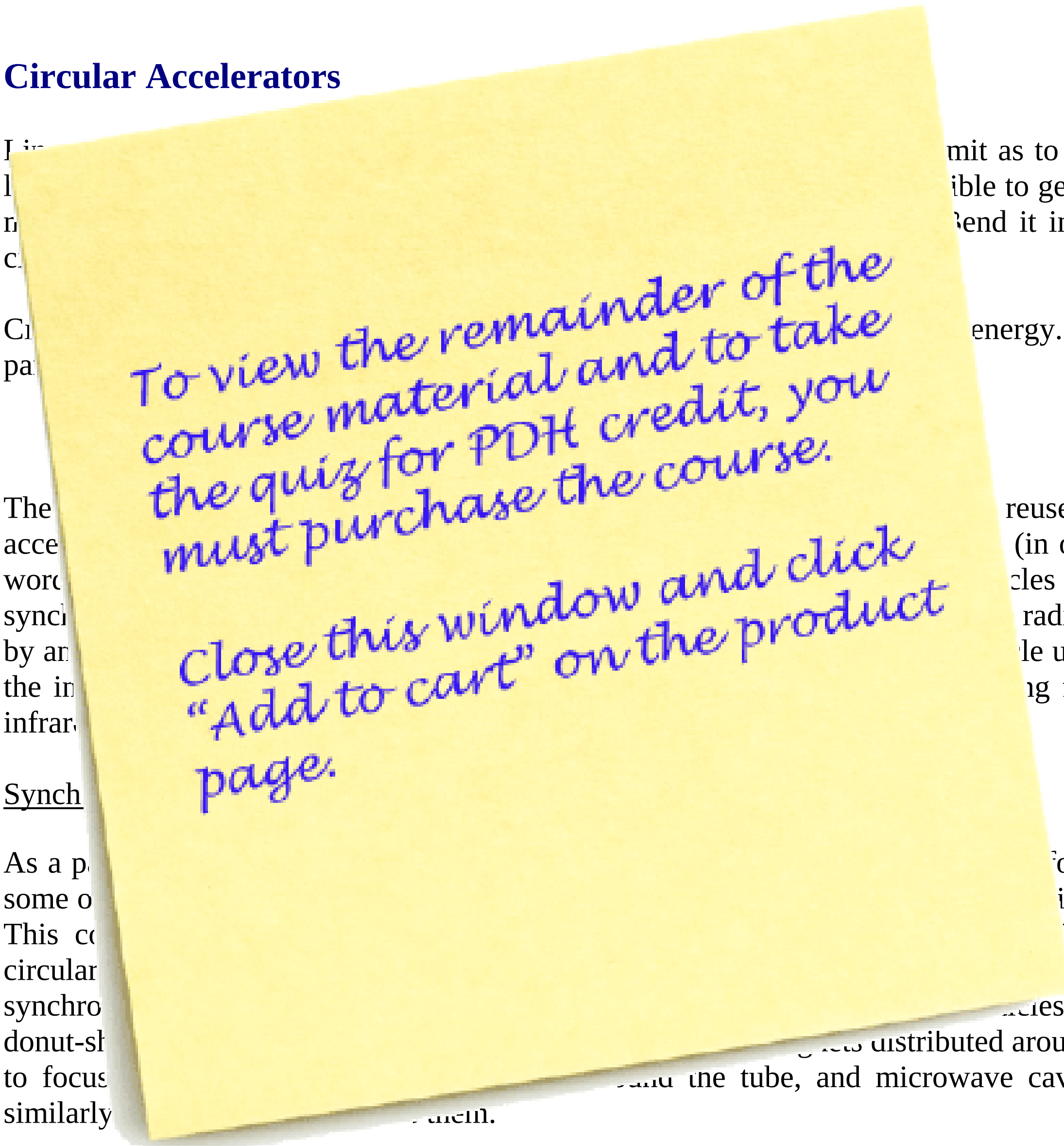
As the particles approach the speed of light the switching rate of the electric fields becomes so high that they operate at microwave frequencies such as S-band, and so microwave cavities are used in higher energy machines instead of simple plates.

Linear accelerators are very widely used - every cathode ray tube contains one, and they are also used to provide an initial low energy kick to particles before they are injected into our next topic, circular accelerators. Linear accelerators can also produce proton beams, which can produce "proton-heavy" medical or research isotopes as opposed to the "neutron-heavy" ones made in reactors.

Klystron focus coils are typically around the drift tube to keep the particles tightly focused and away from the sides of the drift tube. Harmful x-rays and gamma-rays result from collisions of the particles with the side of the tube. As a precaution, linear accelerators often have lead shields around them for shielding x-rays and gamma rays if people are going to be in close proximity.

A research linac may just look like a metal tube (at least the drift tube part of it) but it is precisely built and costly even without all the supporting hardware such as the particle gun, microwave source, shielding, etc.

Circular Accelerators



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Very large circular accelerators are invariably built in underground tunnels a few meters wide to minimize the disruption and cost of building such a structure on the surface, and to provide shielding against the intense synchrotron radiation. An aerial view of a Brookhaven National Laboratory (BNL) synchrotron is shown in Figure 5.