Construction and application of linear accelerators

A linear accelerator particle is a type of particle which accelerator greatly increases the velocity of charged subatomic particles or ions by subjecting the charged particles to a series of oscillating electric potentials along a linear beam line; this method of particle acceleration was invented in 1928 by Rolf Wideroe.

Linear accelerators have many applications, from the generation of X-rays for medical purposes, to being an injector for a higher-energy of accelerators, to the investigation of the properties of subatomic particles. The design of a linear accelerator depends on the type of particle that is being accelerated: electrons, protons or ions.

Introduction:

The first linear accelerators used only a single stage of acceleration, with a direct current potential providing the energy. This could be provided by a Van de Graaff generator or a voltage multiplier power supply. Such the accelerators are severely limited in accelerating power since at high voltage; energy is lost due to corona discharge with electrical energy dissipated into the surrounding atmosphere. Such devices are still used as ion injectors for other accelerating devices. The accelerating potential in electron volts is equal to the voltage potential between the ion source and the target. The maximum voltage potential relative to the ground potential is generally not limited by the generator but rather by the tendency of voltage potential to leak away due to corona discharge or to suddenly drop due to a spark. While various techniques may be applied to raise this maximum potential the structures required become impractically massive or expensive.

The multiple-stage accelerators were limited by the lack of suitable electron tubes capable of operating at high frequency and high power while maintaining both precise frequency and phase control. Various other types of accelerators such as the cyclotron and synchrocyclotron were developed to overcome these limitations. With the development of the high power klystron tube it became practical to continue the development of the linear accelerator, first for use as a high-speed injector for the synchrotron and finally as a high-power accelerator for research use, culminating in the two-mile-long Stanford Linear Accelerator (SLAC).

Construction and Working:

It will be consist of following components:

(1) The design of the source depends on the particle that is being moved. Electrons are generated by a cold cathode, the hot cathode and photocathode, or radio frequency ion sources. Protons are generated in an ion source, which can have many different designs. If the heavier particles are to be accelerated, e. g. uranium ions and the specialized ion source are needed.

(2) A high voltage source for the initial injection of particles.

(3) A hollow pipe vacuum chamber. The length will vary with the application. If the device is used for the production of X-rays for inspection or therapy the pipe may be only 0. 5 to 1. 5 meters long. If the device is to be an injector for a synchrotron it may be about 10 meters long. If the device is used as the primary accelerator for nuclear particle investigations, it may be several thousand meters long.

(4) Within the chamber, electrically isolated cylindrical electrodes are placed, whose length varies with the distance along the pipe. The length of each electrode is determined by the frequency and power of the driving power source and the nature of the particle to be accelerated, with shorter segments near the source and longer segments near the target. The mass of the particle has a large effect on the length of the cylindrical electrodes; for e. g. An electron is considerably lighter than a proton and so will generally require a much smaller section of cylindrical electrodes as it accelerates very quickly â€" think about a boulder versus a ping pong ball; it is easier to accelerate the ping pong ball. Likewise, because its mass is so small, even compared to the nucleus of an atom, electrons have much less kinetic energy than protons at the same speed. Because of the possibility of electron emissions from highly charged surfaces, the voltages used in the accelerator have an upper limit, so this cannot be as simple as just increasing voltage to match increased mass.

(5) One or more sources of radio frequency energy used to energize the cylindrical electrodes. The very high power accelerator will use one source for each electrode. The sources must operate at precise power, frequency and phase appropriate to the particle type to be accelerated to obtain maximum device power Quadrupole magnets surrounding the linac of the Australian Synchrotron are used to help focus the electron beam

(6) An appropriate target the electrons are accelerated to produce X-rays then water cooled tungsten target is used. Various target materials are used when protons or other nuclei are accelerated, depending upon the specific investigation. For particle-to-particle collision investigations the beam may

be directed to a pair of storage rings, with the particles kept within the ring by magnetic fields. The beams may then be extracted from the storage rings to create head on particle collisions. As the particle bunch passes through the tube it is unaffected while the frequency of the driving signal and the spacing of the gaps between electrodes are designed so that the maximum voltage differential appears as the particle crosses the gap. This accelerates the particle, imparting energy to it in the form of increased velocity. At speeds near the speed of light, the incremental velocity increase will be small, with the energy appearing as an increase in the mass of the particles. In portions of the accelerator where this occurs, the tubular electrode lengths will be almost constant.

(7) The additional magnetic or electrostatic lens elements may be included to ensure that the beam remains in the center of the pipe and its electrodes.

(8) The very long accelerators may maintain a precise alignment of their components through the use of servo systems guided by a laser beam.

Fig. (1. 1) 805MHz SCC LINAC

Working:

A linear accelerator works on the principle of electric attraction and repulsion. A charged particle such as an electron or a proton is injected into a tube with a similar charge (negative for electrons, positive for protons). Just beyond that tube is another tube with an opposite charge. The particle gets attracted by the far tube, so it moves towards the next tube. Recall that inside a conductor, the electric field is zero therefore the charge of the tube it’s in doesn’t affect it. But when it’s in the space between the tubes, it experiences an electric field which drives it forward. Just as it hits the next tube, its polarity switches so now it's the same as the particle. A third tube, just beyond the second one, gets charged with the opposite polarity, and the same thing happens. This continues on, tube after tube. The particle gets a kick of energy each time it sees a new field, and the electric potential gets converted into kinetic energy. As the particle gets faster, the tubes have to get longer; the particle spends the same amount of time in each tube. Obviously, the geometry of the tubes and the frequency with which they're switched needs to be calculated precisely. Linear accelerators of this type can be many miles long; they're often long enough that the curvature of the earth needs to be accounted for during their construction. But they can accelerate particles to a significant fraction of the speed of light.

Fig. (1. 2) 208MHz DT LINAC

Fig.(1. 3)

Applications of LINAC:

The LINAC System highly efficient accelerators are ideally suited to many applications in industry, medicine, and research.

(1) LINAC Synchrotron Injector is serving as the perfect first stage to other higher energy accelerators.

(2) Semiconductor Processing.

(3) Boron Neutron Capture Therapy (BNCT) conventionally uses a nuclear reactor as the neutron source. Our LINAC-based neutron source provides a

better controlled neutron energy spectrum, at lower cost, without the concern of radioactive waste associated with a reactor.

(4) Isotope Production Our LINACs are ideally suited for isotope production, such as the PET isotopes.

(5) Neutron Radiography.

(6) Neutron Activation Analysis.

(7) Surface Science.

(8) Particle-Induced X-ray Emission (PIXE).

(9) Pulsed Neutron Applications is LINAC-based neutron source allows for pulsed neutron beams for applications such as time-of-flight measurements.

Uses:

A linear accelerator (LINAC) is most commonly used for external beam radiation patients with cancer. It delivers a uniform dose of high-energy x-ray to the region of the patient′s tumor. These x-rays can destroy the cancer cells, while sparing the surrounding normal tissue.

The linear accelerator uses microwave technology to accelerate electrons in a part of the accelerator called the wave guide and then allows these electrons to collide with a heavy metal target. As a result of these collisions, high energy x-rays are scattered from the target. A portion of these x-rays is collected and then shaped to form a beam that matches the patient’s tumor. The beam comes out of a part of the accelerator called a gantry, which rotates around the patient. The patient lies on a moveable treatment couch and lasers are used to make sure the patient is in the proper position. Radiation can be delivered to the tumor from any angle by rotating the gantry and moving the treatment couch.

Fig. (1. 4) LINAC

Advantages and Disadvantages of linear accelerator:

Advantages:

Linear accelerator of appropriate design are capable of accelerating heavy ions to energies exceeding those available in ring-type accelerators, which are limited by the strength of the magnetic fields required to maintain the ions on a curved path. The High power LINACs are also being developed for production of electrons at relativistic speeds, required since fast electrons traveling in an arc will lose energy through synchrotron radiation; this is the limits the maximum power that can be imparted to electrons in a synchrotron of given size.

LINACs are also capable of prodigious output, producing a nearly continuous stream of particles, whereas a synchrotron will only periodically raise the particles to sufficient energy to merit a shot at the target. The burst can be held or stored in the ring at energy to give the experimental electronics time to work, but the average output current is still limited. The high density of the output makes the LINAC particularly attractive for use in loading storage ring facilities with particles in preparation for particle to particle collisions. The high mass output also makes the device practical for the production of antimatter particles, which are generally difficult to obtain, being only a small fraction of a target’s collision products. These may then be stored and further used to study matter-antimatter annihilation. As there are no primary bending magnets, this cost of an accelerator is reduced.

Medical grades LINACs accelerate electrons using a complex bending magnet arrangement and a 6-30 million electron-volt potential to treat both benign and malignant disease. The reliability, flexibility and accuracy of the radiation beam produced have largely supplanted cobalt therapy as a treatment tool. The device can simply be powered off when not in use; there is no source requiring heavy shielding.

Disadvantages:

(1) The device length limits the locations where one may be placed.

(2) A great number of driver devices and their associated power supplies are required, increasing the construction and maintenance expense of this portion.

(3) The walls of the accelerating cavities are made of normally conducting material and the accelerating fields are large, the wall resistivity converts electric energy into heat quickly. On the other hand superconductors have various limits and are too expensive for very large accelerators. Therefore, high energy accelerators such as SLAC, still the longest in the world, limiting the average current output and forcing the experimental detectors to handle data coming in short bursts.

Future Scope:

Any of the next generation accelerators will need high power of sources and if accelerating systems that transfer ac power to beam power efficiently. The challenges though span a wide range of technologies and wavelength. From very low frequency cavities used in Muon Colliders (70 MHz) to very high frequency cavities in Multi TeV linear colliders (30 GHz and more), many of the designs are based on experience and where experience is missing, scaling laws are used. How does Breakdown scale with electric field stength, pulse length and frequency? What limits peak power and effciency in modern power sources?

The experts in this field should generally try to answer these questions and therefore give guidance to the accelerator designers. Limits on fields, peak powers and efficiencies should therefore be an outcome of the working group. Given the experience in the ongoing R&D programs for normal and superconducting cavities the performance achieved today should be described, as well as the limitations and possible cures. The time scale for establishing these cures should be summarized as well. For both, the normal conducting and the superconducting case the subsystems (Modulators, Klystrons, Pulse Compression systems) and cavities should be addressed independently with a description of present status and of the progress being made over the last five years to allow some extrapolation. For the power sources itself, a very active field only partially driven by accelerator builders, future trends and new directions of improvements should be described.

This group should also describe the likely spinoffs of these different technologies into other fields, coming out of the technical developments being done in the HEP research environment.