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LINEAR ION ACCELERATORS

Edward L. Hubbard

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A linear ion accelerator consists of a large evacuated cylindrical cavity resonator excited in the $\text{TM}_{010}$ mode. The chief electric field is along the axis of the cylinder and is in the same phase at all points. Doughnut-shaped electrodes, called drift tubes, are placed along the axis of the cavity as shown in Figure 1. Ions injected along the axis are accelerated by the electric field in the gaps between drift tubes when the electric field is in the same direction as the ion velocity. During the reverse part of the rf cycle the ions are shielded from the field by the drift tubes. Since the ions pass from one gap to the next in one rf cycle, the lengths of both gaps and drift tubes increase with ion velocity.

In practice there are deviations from the ideal in field strength, in ion velocity, and in phase at which the ions cross the gaps. These deviations do not cause the ions to get out of synchronism with the rf field if the ions cross the gaps when the accelerating field is increasing. Ions that cross a gap late gain more velocity and catch up with ions that cross at the ideal or synchronous phase. Similarly ions that cross early or that have the wrong velocity tend toward the synchronous values, and the motion is phase-stable.

The radial component of the accelerating fields shown in Figure 1 point inward on the low-energy side of the accelerating gap and outward on the high-energy side. Since for phase stability the ions must cross the gaps while the electric field is increasing, the defocusing field (on the
high-energy side) is stronger than the focusing field. The defocusing component of the field can be eliminated by grids across the input apertures of the drift tubes, but in a linac with many drift tubes such grids intercept a large part of the beam. Alternatively, focusing magnets can be placed inside the drift tubes—either solenoidal magnets producing an axial magnetic field or quadrupole magnets producing a transverse field. The polarity of quadrupole magnets must be alternated to produce alternating-gradient focusing or strong focusing.

Ions are usually injected with a velocity of about 0.03 c by a 500-kv Cockcroft-Walton accelerator. The rf frequencies are from 50 to 200 Mc. Above 200 Mc the drift tubes at the input end are impractically small; below 50 Mc the size of the cavity and the rf power consumption become too large to be attractive. The several million watts of rf power required is supplied by several triodes. Operation is usually pulsed to reduce the average rf power consumption. Proton linacs are from 20 to 110 ft long, and their output energy is from 3.7 to 68 Mev.

Acceleration of heavy ions such as nitrogen or neon is inefficient unless they are highly ionized. Beams from ion sources, however, contain few highly ionized ions. Therefore in some linacs built for heavy ions the beam is accelerated to a moderate energy, then passed through a thin layer of matter to strip more electrons off the ions before they are accelerated further. These accelerators, called hilacs, produce beams with 10 Mev for each nucleon in the nucleus (e.g., 140 Mev for nitrogen, 400 Mev for argon).

The beam is more easily extracted from linear accelerators than from circular machines, and intense external beams of monoenergetic well-focused
ions can be obtained. A linac with a special injection system has produced an external beam of 200 ma. The properties of the external beam make linacs useful as injectors for proton synchrotrons as well as for nuclear research.
Figure Legend

Figure 1. Cross section of linac cavity showing electric field lines.