Rutherford Laboratory

Technical Leaflet

C5.2

THE EVOLUTION OF THE CYCLOTRON

The cyclotron was developed by E. O. Lawrence in California in the early 1930's. The secret of its success in accelerating nuclear particles to high energies is that the time for a charged particle to make one revolution in a magnetic field is independent of its speed. If the voltage on the "dee" accelerating electrodes alternates at the same rate as the particle revolves, acceleration will take place and the particle beam will spiral outward from the centre. Thus a particle is accelerated many times by the dee.

The energy of this first generation "fixed frequency" cyclotron was limited because the particles became more massive as they gained energy, according to the predictions of Einstein's relativity theory. This caused a particle's revolution time to decrease so that it got out of step, or phase, with the accelerating dee voltage. For example, when a proton is accelerated to 20 MeV it is 2% heavier, and revolves 2% more slowly than when it starts at the cyclotron centre.

Another problem in cyclotron acceleration is that the particle beam should be confined between the magnet poles in a space some 2 inches high. If particles head away from this space they must be forced to return by magnetic focusing forces. This vertical focusing was achieved in the fixed frequency cyclotron by causing the magnetic field to decrease near the edge of the magnet. This decrease actually made the phase problem worse, since it caused the particles to go even slower at large radius. So the energy of this first generation cyclotron was limited to about 20 MeV for protons.

The second generation of cyclotrons came about 1946, with the synchrocyclotron. There, the dee frequency was varied to match that of the particle, but the beam was accelerated only 1% of the time. Energies up to 700 MeV have been obtained.

In the search for higher energy and intensity for cyclotron beams, L. H. Thomas suggested placing iron sectors on the poles of a fixed-frequency cyclotron. These would scallop the circular orbit and act as magnetic lenses to give much stronger vertical focusing forces. These forces would replace those previously obtained by decreasing the magnetic field with increasing radius. Now the field could actually increase with radius and compensate for the phase-slip due to the increase in particle mass. To obtain more focusing the sectors can be spiralled, and this is usually done in present designs. This principle has made possible the acceleration of high intensity particle beams to energies of hundreds of MeV in this third generation "sector-focused" cyclotron.

The Rutherford Laboratory is building a sector-focused cyclotron for the Atomic Energy Authority, to assist in the design of nuclear reactors. The exhibit shown is a working model of the central region of this cyclotron, and is used for design studies. It is arranged to work in bursts or "pulses" long enough to permit observations to be taken but short enough to render radiation negligible.

Essentially the machine is a large electro-magnet with a vacuum chamber between its poles. A long tubular resonator supplies an electric accelerating voltage of suitable frequency and amplitude, which appears on the "dee" electrode in the vacuum chamber. Racks nearby carry apparatus for controlling the magnetic and electric fields, and a generator outside supplies current for the magnetic field. Vacuum pumps exhaust the chamber continuously. Hydrogen gas (each molecule of which contains two protons) is leaked through a tube to a source chimney at the centre of the machine where it is ionised in an electric arc maintained with a steady power of 50 watts. The beam of protons can be seen emerging from a slit in this chimney as they impart a faint pink glow to the few molecules of residual gas. Stray beam can be seen hitting various parts of the inside which have been painted with green phosphorescent material. Arms in the side walls carry targets, one of which can be seen glowing with the impact heat as the beam of protons strikes it. The instantaneous power during the pulse is about 2 kW., reduced to an average 20 watts by the 1% on-off ratio of the pulse. Some idea of the beam profile can be gathered by the size of the hot patch on the target. The electrodes which produce the accelerating field can also be seen.