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Contract No. W-7405-eng-48

FIRST LARGE SYNCHROTRON PLACED IN OPERATION

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February 23, 1949

Berkeley, California

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The fastest particles yet produced in the laboratory, electrons whirling with 99.99999% of the velocity of light, have recently been realized in the University of California's latest atom smasher, the 300,000,000 electron volt synchrotron! The machine, which took three years to build, is the newest addition to the Atomic Energy Commission's expanding nuclear research program.

The synchrotron was first proposed in 1945 by Professor E. M. McMillan. Independently, and slightly earlier, Professor Veksler of Russia had put forward the same basic theory, although this news did not reach the United States until the design of the present machine was well under way. The machine was originally devised to accommodate the relativistic increase in mass of high speed particles which, at the time, was limiting the maximum energy available from such atom smashers as the cyclotron. In addition, the synchrotron promised to be less expensive, in both construction and operation, than alternate methods of achieving the same energies.

The synchrotron is purely an instrument of research, used to investigate the interaction with matter of x-rays and high speed electrons. Currently the meson, a very short lived particle resulting from nuclear disintegrations and intimately related to the forces holding atomic nuclei together, is being studied.

Like the better known cyclotron, the synchrotron accelerates particles by adding thousands of small increments of energy to them as they are restrained by a magnetic field to a whirling circular orbit. However, the synchrotron accelerates by using a constant frequency accelerating voltage in conjunction with a varying magnetic field, while present day cyclotrons use a modulated accelerating voltage together with a constant intensity magnetic field.

Electron acceleration is accomplished in three successive stages; 1) Injection, which gives the particles an initial boost of 90,000 volts, 2) "Betatron start" which brings the energy to 2 million electron volts (MEV), and 3) Synchrotron action, which takes the particles from 2 to 300 MEV.

The injector or "ion gun", which extends through the outer wall into the accelerating chamber, contains an electrically heated, white hot tungsten filament. At 2100° C. electrons in the tungsten metal receive enough thermal energy to escape-- they are literally boiled off. This filament is at a negative potential of 90,000 volts with repect to a ground shield surrounding it, the voltage being supplied by a pulse transformer. As soon as these electrons feel this potential they are injected tangentially into the accelerating chamber through a slit in the ground shield.

At the instant of injection, the intensity of the magnetic field through the accelerating chamber is increasing. If magnetic flux is changing through a closed loop of wire, an electric current begins to flow in the wire. This is the basis of betatron action. The rate-of-change of the magnetic flux through the center of the circular accelerating chamber is increased by the use of flux bars (magnetic shunts) which channel the flux from the upper to the lower magnet yokes. This induces an electromotive force at the accelerating orbit which speeds up the particles. Approximately 200 microseconds after injection the flux bars saturate and the betatron cycle is completed, after having boosted the electrons to a speed of 98% of the velocity of light. The particles now have sufficient speed to be accepted for synchrotron action.

True synchrotron operation commences when the oscillator supplying the accelerating voltage is turned on. A constant frequency voltage then appears across a transverse gap in the electron path. The frequency and phase timing of this voltage is such that the electrons are "kicked" forward once per revolution.

As the energy of these particles increases, they become heavier. In fact, due to the relativistic effect, the mass of the electrons increases 600 fold during the accelerating cycle. If the electrons moved in a magnetic field of constant intensity, they would describe larger and larger circles, getting out of step with the accelerating voltage. However, during each revolution of the electrons, the synchrotron's magnetic field increases enough to hold them to an essentially constant orbit.

Actual machines have local variations in the magnetic and electric fields, due to limitations of material and manufacture, which cause deviations from ideal theory. The synchrotron is rendered dynamically stable (when disturbed, the particles will return to the proper orbit and phasing) through the use of a focusing magnetic field and because of "The Principle of Phase Stability". The focusing magnetic field is supplied by properly shaping the cross section of the magnet air gap pole tips. The Principle of Phase Stability is utilized by providing the equilibrium value of the accelerating voltage below the peak accelerating voltage. If the whirling electron receives only the equilibrium quota of energy during each revolution, the increasing magnetic field will hold it to an orbit of constant radius. If some of the particles have more than the equilibrium velocity, or if they have been deflected to a smaller radius than the design orbit, they will arrive at the accelerating gap early, before the voltage has built up to normal value. They then get less than the normal forward push and are slowed down. If a particle is traveling too slowly, or has been deflected to a large radius, it arrives late at the accelerating gap and finds that the accelerating voltage has increased over the equilibrium value. The particle receives more than its normal quota of energy and is therefore speeded up. The similarity of this action with that of synchronous motors suggested the name of the machine.

The energy of the particles is removed from the accelerating chamber by converting the electrons to short wave length x-rays, called gamma rays or photons. After 4000 microseconds of operation, and before the magnetic field has reached maximum intensity, the oscillator is turned off. The electrons are now forced into smaller and smaller circles until they finally strike a target of uranium rod projecting from the inner wall of the accelerating chamber. Gamma rays are formed which are not affected by the magnetic field and this radiation emerges through the accelerating chamber wall in a straight line from the target. If electrons are to be studied, the gamma rays may be converted to positrons and electrons (the phenomenon known as Pair Production) by passing them through another target, although this process is accompanied by energy loss.

In order to achieve the necessary rate-of-change of the magnetic field, and to conserve electrical energy, the synchrotron magnet is part of an huge oscillating circuit. The largest capacitor bank in the world, consisting of 3328 individual units with a combined reactance rating of 40,000 KVA (805 microfarads), makes up the other part of the circuit. This circuit, passing 5,000 amperes peak current, is triggered by four large "Ignitron" tubes. Each surge between capacitors and magnet involves the transfer of 105,000 joules of energy, enough to lift a 200 pound man twenty five stories straight up!

When the magnet is pulsed, the two yokes are attracted with a maximum force of 60 tons. This pulse produces small deflections in the magnet structure with resulting noise. The machine sounds like an huge diesel engine in operation.

Since the magnetic field changes, the magnet had to be constructed like a transformer to resist eddy currents. The 135 tons of steel in the magnet is in the form of .014" sheet, bonded together to form 6 inch thick slabs. The magnet has a double return path yoke with a circular air gap of one meter radius on the horizontal centerline. Looking down on top of the magnet, one sees a rectangular hole which is provided to allow access to the inner side of the accelerating chamber, and to accommodate the 18 flux bars used during the betatron start.

The accelerating chamber, which is suspended on a shock mounting in the middle of the magnet's air gap, is composed of eight silica segments of elliptical cross section. The ends of the segments are joined with rubber sleeve vacuum seals. This system is evacuated to a pressure of .01 microns (millionths of a meter of mercury) by two small oil diffusion pumps which work continuously. If the gas present under high vacuum conditions in the 2.1 cubic foot volume of the accelerating chamber were to be compressed back to sea level pressure, it would occupy no more volume than a pin head. This degree of exhaustion is necessary to prevent the high speed electrons from losing their energy in collisions with air molecules.

One segment of the accelerating chamber is copper plated, except for a 3/8" transverse gap at one end, to form the resonant cavity in which the accelerating voltage is produced. A grounded grid oscillator drives this cavity at a constant frequency of 47.7 megacycles, producing a radio frequency voltage of approximately 3000 volts maximum across the accelerating gap.

Although the synchrotron just described has been designed to accelerate the lightest particles, no inherent theoretical limitations restrict all synchrotrons to electrons. The huge new "Bevatron", now under construction and expected to reach energies in the billions of electron volts, is a synchrotron which will accelerate the three heavy particles, protons, deuterons, and alpha particles.

This paper is based on work performed under the auspices of the Atomic Energy Commission.

RLID/hw/2-24-49