1-1/2 METER FIXED-FREQUENCY CYCLOTRON

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A brief description is given of a 1-1/2 meter cyclotron. Questions connected with the acceleration of ions in the central part of the cyclotron are considered. The most important points for the correction of magnetic field are indicated. The deflection and focusing of the accelerated ion beam are considered. Data on the energy and flux of accelerated particles are presented.

INTRODUCTION

The design of this cyclotron was initiated in 1945. At the same time design studies were started on the building in which the machine and laboratory facilities were to be housed. Construction was completed in 1946 and in 1947 a deuteron beam was produced and extracted from the chamber.

To provide radiation shielding for personnel and instruments the cyclotron is enclosed by a water shield 1 m in thickness. The cyclotron is operated from a central control station which is located behind the shield.

The presence of intense ion beams causes considerable activity in the various elements of the machine; hence, a good deal of attention was paid to radiation safety measures. In addition to providing special radiation-level monitoring facilities, at this installation all operations which might be attended by radiation hazards are mechanized and performed by remote control. When the machine was started, in addition to nuclear physics research, studies of the various processes which take place in the cyclotron itself were started.

In 1950, in order to carry out experiments free from the background of radiation of the cyclotron itself, the ion beam was extracted through the main shield into a special installation, located 12 m from the chamber. This installation has its own shield.

In addition to deuterons, α particles and molecular hydrogen ions, this machine has been used to accelerate protons and multiply-charged nitrogen ions.

Electromagnet. The magnetic circuit is a closed frame, rectangular in cross section, with pole pieces. The frame elements are fabricated from separate sheets of rolled steel 30 mm thick. The magnet pole pieces are made from forged pieces of “Armco” iron in the form of truncated cones. The diameter of the pole piece is 1500 mm. The electromagnet is air-cooled. The total weight is 330 tons. This magnet provides in the operating gap, which is 180 mm, a field intensity of 18,000 gauss.

Resonance System and Radio-Frequency System

The resonance circuit of the cyclotron consists of the dees and two quarter-wave terminated coaxial lines. The resonant system is fed from a multi-stage amplifier through two coaxial feeders which are inductively coupled to the resonant lines. The available output power of the generator is of the order of 120 kw. The generator can be driven by an independent oscillator or operated as a self-excited oscillator; in this case the feedback loop includes the resonant circuit of the cyclotron.
A special modulator makes it possible to work with pulse operation or cw-operation. When in operation the potential difference between the dees is of the order 160-170 kv. The peak value of the potential of the dee in which the ions are extracted from the source is stabilized. There is a special setup for shielding the generator and dees in order to make tests in the chamber. The resonant lines operate over wavelengths ranging from 26 to 33 m. The electrical length of each line is adjusted by a grounding bar which is moved by an electric motor. In addition, there are two trimmer condensers which are located in the acceleration chamber and controlled remotely.

Center Part of the Cyclotron. The initial motion of the ions plays an extremely important role in the acceleration process. Calculations were carried out which delineated the dependence of ion phase in the first accelerating cycles on the width of the accelerating slit and the potential difference between the dees. It was shown (1950) that when a wide slit is employed there is a phase bunching of the ions similar to that which takes place in a synchrocyclotron. As a consequence, the phase differential of the majority of ions, after two or three acceleration cycles, becomes approximately zero. This situation leads to a considerable ion loss in the central part of the cyclotron. In order to inhibit the ion phase bunching, the horizontal and vertical distances between the edges of the dees were reduced by means of special shoulders. (The shoulders on the dees extended out to a radius of 20 cm). In order to reduce the energy spread in the output beam, ion extraction was carried out in one dee.

In order to improve the focusing action in the first acceleration cycle, the central part of the shoulder was subsequently replaced by a flat electrode in order to eliminate the inhomogeneity in the electric field which tended to defocus the ion beam in the vertical direction.

In 1953 an arc-type, ion source with a slit, was developed by the authors. As a supplementary means of improving the stability of operation of the cyclotron, the discharge current of the arc source was stabilized.

The Magnetic Field of the Cyclotron and Corrections. The motion of the particles in the later acceleration cycles is determined chiefly by the magnetic field of the cyclotron. The absolute value of the magnetic field intensity was measured, with the cyclotron in operation, by means of a magnetometer which made use of a nuclear resonance absorption.

The magnetic field was kept constant by stabilizing the current in the windings of the electromagnet. In addition to current stabilization, in 1949-1950, a field stabilizer was developed and tested which made use of a specially constructed magnetic sensing unit which was placed in the fringing field of the magnet.

To investigate the inhomogeneities in the magnetic field, in 1950 a special device was constructed, in which a ballistic measurement method was used. To improve the accuracy of the measurements a sensing unit with a pendulum-bob coil and a sensitive electronic flux meter were developed. Using this instrument it was possible to carry out separate highly accurate measurements of the radial and vertical components of the magnetic field intensity.

A study was made of the effect of inhomogeneities in the magnetic field on the vertical displacement of the beam; this was done by installing auxiliary windings, connected in opposition, at the poles of the electromagnet. Using these windings it was possible to vary the position of the beam of accelerated particles in the vertical direction without disturbing the ion-acceleration resonance conditions. The ejection radius of the cyclotron is 670 mm. The total decay of the field at the terminal radius is 1.7%.

The magnetic field corrections were introduced through the use of internal rings and discs positioned in the gaps between the full pieces and of the electromagnet and the covers of the chamber. The gaps were 35 mm. The azimuthal corrections for the magnetic field were provided in the same gaps by means of iron elements, which were moved radially by remote control or by auxiliary coils.

Acceleration Chamber, Resonance Lines, and the Dees

The cyclotron chamber with the resonance lines was mounted on a self-powered trolley so that it was possible to carry out the basic assembly and disassembly operations on these components with a powered driving system (Fig. 1). The body of the chamber, fabricated from brass, provides the necessary structural rigidity. The end caps of the chamber, made from "Armco" steel, are 1500 mm in diameter and 100 mm thick. In one side of the chamber there is a rectangular window through which it is possible to pass the dees into the chamber. In