PRELIMINARY OPERATIONAL EXPERIENCE WITH THE UNIVERSITY OF MICHIGAN 83-INCH SECTOR-FOCUSED CYCLOTRON

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Introduction

The University of Michigan 83-inch sector-focused cyclotron, the basic features of which have been described previously[1] was designed primarily to provide beams of protons, deuterons, and alpha particles of maximum energies 35 MeV, 40 MeV, and 80 MeV respectively for use in high resolution nuclear spectroscopy. Design and construction of the cyclotron were begun in July 1960, and the first internal beams of protons and deuterons were obtained in November 1962. The purpose of this paper is to discuss the results of operation to date.

The Cyclotron

The RF system is unique in that it is a two-dee half-wave system using dee-stem insulators and two quarter-wave "silos" as resonators. The frequency can be tuned over the range from 6 to 16 Mc/s under full power by sliding shorting planes in each silo. A view of a silo in process of assembly is shown in Fig. 1, before the last of the eight panels was installed. One of the two 10" dia. lines, the elbows, and flanges for coupling to the dee-stem insulators are visible in the photograph. The shorting plane is in its raised position and is not visible. The assembled silo is shown coupled to the south side of the vacuum chamber in Fig. 2. The two cylinders mounted at the base of the silo contain capacitors for fine frequency tuning. The dee-stem insulators, which act as a vacuum seal and also furnish mechanical support for the dees, are located where the silo stems bolt to the vacuum chamber. The top of the north silo can be seen extending above the magnet yoke. A view of the assembled machine looking from the north is shown in Fig. 3. The cabinet containing the RF oscillator, a self-excited, single-sided, tuned-grid, tuned-plate circuit is shown adjacent to and coupled to the silo at the left of the picture.

Tests of the RF system with cw operation indicate that it operates satisfactorily over the design range of frequencies. To date there has been no difficulty with the dee-stem insulators; the indications are that they will prove to be satisfactory. Because the resonant lines are in air rather than vacuum, there are no problems with multipactoring. At the high end of the frequency range, the push-pull and push-push modes are separated by only 250 kc/s, and as a result sharp grid tuning is required to prevent the oscillator from switching to the push-push mode. The separation of the two modes is being increased by installation of a push-push mode suppressor which will increase the inductive coupling between the stems.

The twelve sets of circular gradient coils are constructed by electrically insulating 5/16-in. round copper tubing with two layers of epoxy-loaded braided glass sleeving and pulling it through a 7/16-in. dia. copper tubing which serves as a vacuum enclosure. The insulated 5/16 in. tubing carries the current and is water cooled. The coils are wound on an aluminum frame to form an integral assembly separate from the ground sheets. After the coils were wound, the epoxy was heated to the curing temperature by passing current through the coils. The two gradient coil assemblies are bolted to the magnet pole lids and covered by the ground sheets. Each gradient coil has its own regulated power supply, the two outermost coils being rated for 500 A, three sets rated for 300 A, and the remaining coils for 250 A. The total gradient coil power is approximately 60 kW.

A conventional electrostatic deflector 84° in angular width is employed for beam extraction. The results of computer studies which tracked particles through the deflector channel were used to determine the channel contour. The septum, at 36.5" radius, is located approximately 60° beyond the dee center-line and is very near the middle of a hill. A temporary septum, suitable only for low power dissipation, is being used until the actual orbits through the channel have been accurately determined.

Experience With Accelerated Beams

The first internal beams of protons and deuterons were obtained in November 1962, with pulsed RF voltages (0.1% duty cycle) and without gradient coils. At this time the 360 kW RF power supply and the gradient coil power supplies had not been received. Power for the oscillator was obtained from a bank of capacitors charged by a 15 kV low power supply (from a wartime SCR-584 radar). Pulsed operation permitted qualitative visual observation of the beam on three fluorescent probes spaced at 120° and adjustable in radius. Most of these studies were made with the cyclotron adjusted for the lowest possible proton energy (7.2 MeV) corresponding to an average magnetic field of approximately 4.2 kG and an RF frequency of 6.5 Mc/s. With this low particle energy and a 0.1% duty cycle there was no detectable increase of radiation; visual observations could be made at the vacuum chamber. The beam could be centered at all radii by adjusting the position of the ion source and/or the dee voltage. Good focusing was obtained out to a radius of approximately 34 in., but a fuzzing-out occurred from 34 in. to the extraction radius of 36.5 inches. Computer studies using the measured (non-isochronous) magnetic field indicated that because of an excessive rise in the field defocusing should have occurred near a radius of 34 inches.

Observations were also made with 15 MeV deuterons at 8.5 kG and 6.5 Mc/s. As with protons, no difficulty was encountered in obtaining a well centered deuteron beam out to the extraction radius. In this case however, the beam appeared well focused at extraction, as was predicted by the computer studies. Although some neutron and gamma radiation was observed when the beam was accelerated to full

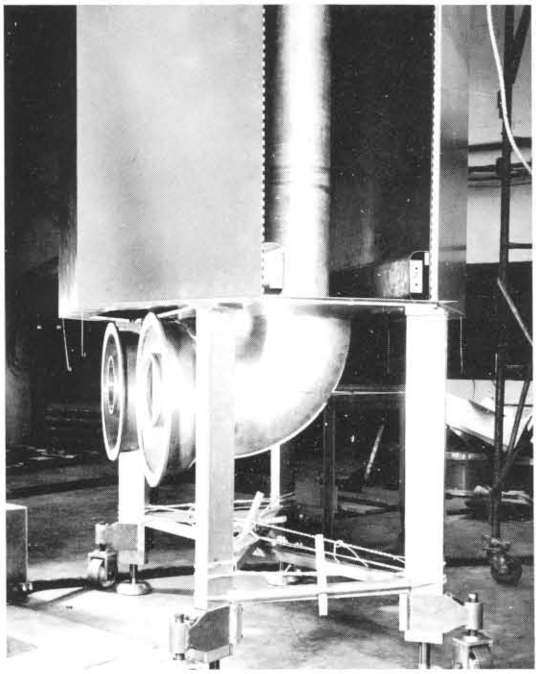

Fig. 1

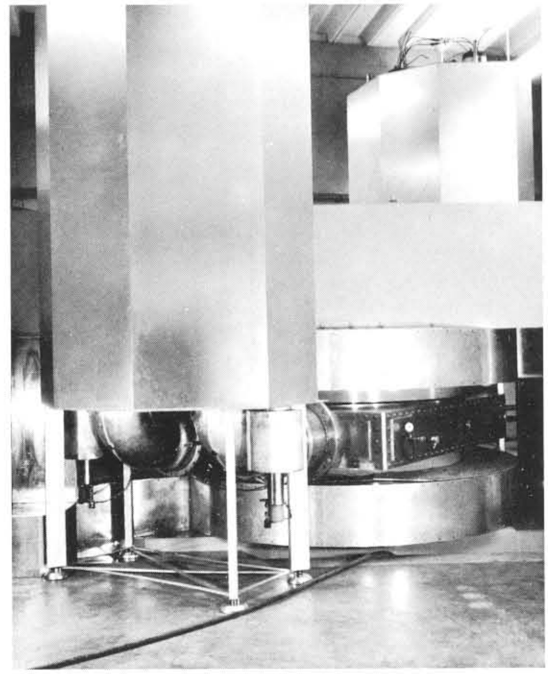

Fig. 2

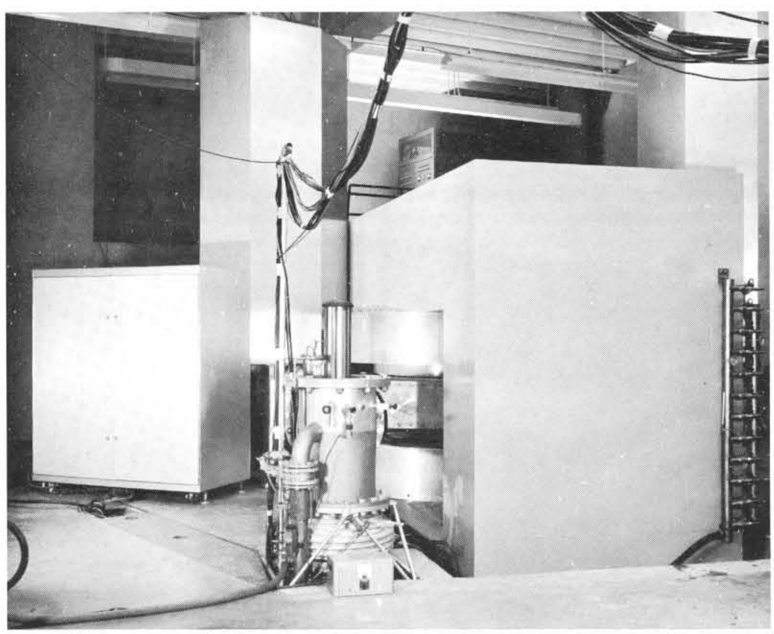

Fig. 3

radius, this was not permitted to exceed the allowable tolerance.

Before beam extraction was attempted, the inside surface of the deflector channel was painted with fluorescent material. By adjusting the ion source and puller slit, it was possible to cause the deuteron beam to strike the inner surface of the deflector channel a few inches beyond the septum. As the deflector voltage was increased from zero, the beam was observed to move along the channel and at about 40 kV struck the dee-stem at the exit port. The beam appeared to be about 1/4 in. vertical, and well defined in the radial direction.

After installation of the permanent power supplies, field measurements were made to determine the effects of the gradient coils. The first quantitative study of particle acceleration using the gradient coils and continuous RF voltages on the dees was begun in March 1963. Because the RF system was not "baked-in" the dee-to-ground voltage was restricted to less than 40 kV.

To avoid the problems associated with induced radioactivity, most of the measurements have been made with 8 and 12 MeV protons. Measurements made without the gradient coils energized confirmed the vertical defocusing at 34 in. noted in November. The beam intensity at the extraction radius of 36.5 in. is less by a factor of 30 to 40 than the current at 33 inches. With the gradient coils set to the computed values there is essentially no loss in beam between 33 in. and full radius. Although the dees and deflector have been held to low voltages, 10 μA of 12 MeV protons have been extracted with 40% extraction efficiency. The energy has been verified by injecting the extracted beam into one of the two beam-preparation magnets and viewing the analyzed beam on a fluorescent screen with a TV camera. By moving the screen along the optic axis of the beam preparation magnet, the image point was determined and from the known properties of the $n = 1/2$ magnet, the apparent object was calculated to be about 10" upstream from the exit of the deflector channel. From the width of the image and the dispersion of the magnet, the energy spread in the external beam was estimated to be approximately 80 keV, corresponding to the energy gain per turn. By tuning the RF frequency slightly, successive images were obtained, corresponding to extraction of successive orbits, indicating the presence of some radial oscillations. These results must be viewed as tentative, however, as fluorescent screen observations can be misleading.

Beams of 25 MeV protons and 27 MeV deuterons have been accelerated to the extraction radius without difficulty, although no attempts to extract these particles have been made as yet.

Reference

1. Nucl. Instr. and Meth. 18, 19, 93 (1962).

DISCUSSION

VERSTER : Did you observe multipactoring?

TICKLE : We have seen it occasionally but have had no difficulty. The self-excited oscillator gives no trouble.

HOWE : What experience have you had with your RF insulators, and how much voltage have you held on them?

TICKLE : We are using two types of insulators, alumina and used quartz. They are designed for a maximum voltage of about 40 kV. We put this voltage on them and have had no difficulty.

JONES, R.J. : What is the current density in your fingers?

TICKLE : It is about 90 A/in. peak.

LAPOSTOLLE : What repetition rate was used in the pulsed operation?

TICKLE : One pulse per second, with 10% duty cycle.

SCHMIDT : Could you describe the method of measurement of the beam on a fluorescent screen? How big was the image you saw?

TICKLE : The results I mentioned should be viewed as tentative. We have a fluorescent screen which is movable along the optic axis. We moved the screen in and out till we got a minimum spot. The image was perhaps about one inch wide.

BERKES : I was impressed by the short time of the constructing period of your machine. Did you include also the period of planning and design?

TICKLE : There had been nothing done on the machine until July 1960. You must remember that we come behind others and are able to take advantage of their knowledge, which is a tremendous help.

LAWSON : Could you sketch the geometry of the insulators which withstand 40 kV?

TICKLE : The insulators have an o.d. of 22 in. and an i.d., where the steam goes through, of about 8 in.; they are 1 1/4 in. thick.