FIRST BEAMS FROM THE TEXAS A&M SUPERCONDUCTING CYCLOTRON

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ABSTRACT

The Texas A&M K500 superconducting cyclotron has accelerated, extracted and delivered to target beams from 2.4 MeV/n to 35 MeV/n. In addition, higher energy-per-nucleon beams have been accelerated to extraction radius. We are now moving from a trial phase, where new systems have been tested, modified and retested, to a phase where the K500 can deliver beams reliably to experiments while its capabilities continue to be upgraded. The computer control system[1] (described elsewhere in these proceedings) the rf system and the deflectors all work well and continue to improve. Moreover, a beam from an external ECR ion source will soon be injected into the K500, and cryopanels for much improved pumping will soon be installed in the dees.

CHRONOLOGY

Within the last year the Texas A&M K500 cyclotron has moved from first beam extraction to approaching reliable delivery of beams of up to 35 MeV/n to target. The significant events in this accomplishment have been:

Dec. 16,1987 -- First three-phase operation of the dees.

Jan. 21,1988 -- First neutrons detected. The dee-to-dee phases were 240° so that the beam ran on the second harmonic of the rf frequency (5 MeV/n $^{14}N^{2+}$).

Feb. 24,1988 -- First beam reached extraction radius (2 na of 20 MeV/n $^{14}N^{4+}$).

Mar. 22,1988 -- Motorized drive for beam probe installed.

May 24,1988 -- Two 30 MeV/n beams were accelerated to extraction radius ($^{14}N^{5+}$ and $^{16}O^{6+}$).

June 15,1988 -- First extracted beam (20MeV/n $^{14}N^{4+}$).

July 13,1988 -- A beam of 35 MeV/n $^{14}N^{5+}$ was accelerated to extraction radius.

July 20,1988 -- A beam of 35 MeV/n $^{14}N^{5+}$ was extracted and became the first beam to be transported to a target in an experimental cave.

Oct. 28,1988 -- A beam of 55 MeV/n alpha particles was brought to extraction radius.

Feb. 14,1989 -- A 2.42 MeV/n $^{40}Ar^{4+}$ beam was developed and delivered to target. This runs near the bottom of the second harmonic of the rf frequency range.

FIRST BEAM TRIALS

The Texas A&M K500 does not yet have many devices for beam diagnostics. There is a three-finger beam probe which moves along a spiral track on the "C" hill (Fig. 1) and through the extraction path between the fourth and fifth

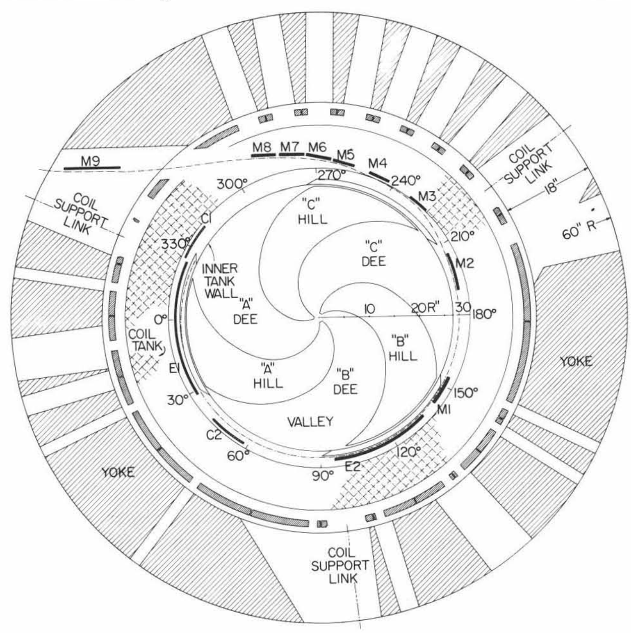

Figure 1. Cross-section of the K500 cyclotron through the median plane showing the electrostatic deflectors, E1 and E2, and the magnetic channels, M1-M9.

magnetic channels. There is also a probe which can measure the current of the beam at the exit of the first magnetic channel which is positioned after the two electrostatic deflectors in the extraction path. In the first efforts at beam acceleration, the three-finger probe was not motor-driven and had to be positioned by hand with the cyclotron turned off.

In the first trials with beam extraction, a temporary probe was mounted on the exit of the first electrostatic deflector. We soon learned that the two deflectors, which had initially been manufactured with incorrect curvature, would not be acceptable, especially the longer E1 which would only transmit beam at much higher than the nominal electric field. It was also determined that the measurement of the first harmonic of the magnetic field[2] was essentially correct. The magnitude and angle of the magnetic-field bump produced by the outermost trim-coil that was necessary to steer the beam into the first deflector would serve to cancel out the field bump measured at outer radii.

K500 OPERATION

After the installation of deflectors with the correct curvature, beam was extracted almost immediately from the cyclotron. Beams with higher energy-to-charge ratios were tried soon after with consequently greater demand on the voltage-holding capability of the deflectors. When a high-energy beam was run, the deflectors would have to be removed from the machine every few days so that spark damage to the deflectors could be repaired. This procedure and the necessary rf and deflector reconditioning can cause a delay of approximately two days. The first improvement to deflector operation came by placing the high-voltage power supplies next to the cyclotron, minimizing the cable length and the stored energy available for a spark.

The second improvement has occurred just recently, this being the introduction of a flow of argon gas on the deflector feed-through while the deflector is spark-conditioned. A flow that raises the median-plane pressure to approximately $3X10^{-4}$ torr seems to be sufficient. This spark-conditioning allows the deflector to hold higher voltages for longer periods and also seems to be useful in recovering the deflector after some spark-damage has occurred. Previously the cyclotron would be opened and the deflector removed in this situation.

With the improved performance of deflectors, our skill at beam extraction has increased. The ratio of extracted beam current to beam current measured at extraction radius has improved to 0.44 for the 20 MeV/n $^{14}N^{4+}$ beam with the extracted beam current reaching 0.5 microampere. Figure 2 is an I vs. R plot for this beam using the main beam probe.

The two main-coil currents and the 14 trim-coil currents are successfully calculated for all the beams using the code TCFIT from NSCL. The agreement between the predicted and the actual

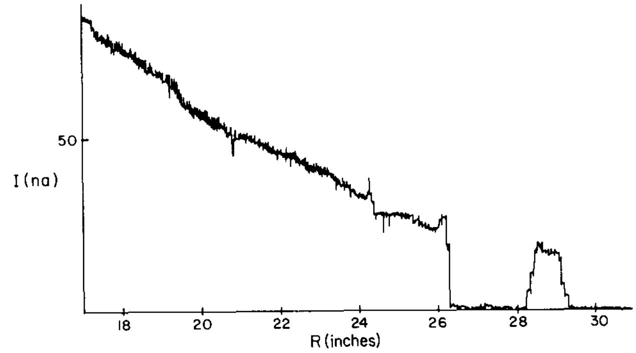

Figure 2. Beam intensity vs. radius for 20 MeV/n $^{14}N^{4+}$. The beam is extracted after R=26.4 in. with the bump after 28 in. showing beam in the extraction channel.

frequency is quite good, and new beams have been accelerated and extracted from the cyclotron using calculated settings with the internal probes out of service. The magnitude and the angle of the outer-radius magnetic-field bump necessary to center the beam at outer radius can be estimated from the field maps. The magnitude of the bump produced by the outermost trim-coil where the radial betatron frequency ν_R passes through 1.0 is usually around 6-8 gauss in the approximate direction of the main-coil offset (Ref. 2). The first-harmonic field bump required for maximizing the extracted beam is a small vector-addition to this bump.

Figure 3 is an I vs. R plot for 30 MeV/n $^{14}N^{5+}$. The attenuation at the outer radii is small. Figure 4 shows the attenuation of a 15 MeV/n $^{16}O^{4+}$ beam at outer radii. Both beams are run with an internal PIG source; the median-plane vacuum with source on is no better than the low 10^{-5} torr range. With this operating vacuum, it has so far been impossible to run neon or argon beams on the first harmonic of the rf frequency.

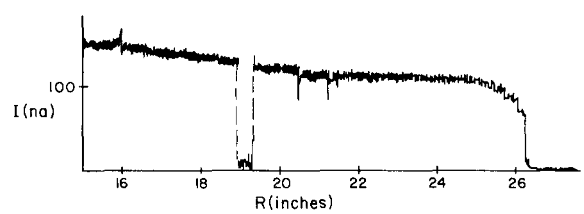

Figure 3. Beam intensity vs. radius for 30 MeV/n $^{14}N^{5+}$.

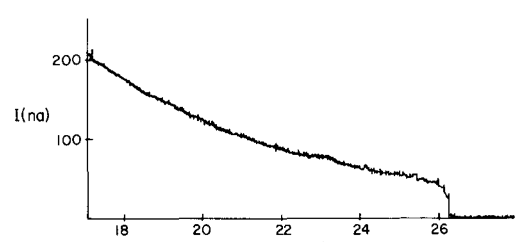

Figure 4. Beam intensity vs. radius for 15 MeV/n $^{16}O^{4+}$.

Beams of $^{40}Ar^{4+}$ and $^{40}Ar^{6+}$ have been run on the second harmonic of the rf frequency, however, with far fewer turns than first harmonic operation. Even so, the gas flow to the PIG source must be severely limited to obtain beam at the outer radii. This is counter to prior experience in running these charge states with PIG sources and must be due to the fact that the turbomolecular pumps are located so far from the median plane that the gas load due to the source is poorly pumped.

RF SYSTEM

The rf system has performed well with no external neutralization of the dee-to-dee capacitance and with only moderate shielding between the dees in the center region. Some features of the system are :

-- Only the resonators and final-stage amplifier anodes are tuned for each frequency. All other circuits are broad-band including the amplifier grid circuit.
-- The three-phase generator is directly tuned using one frequency synthesizer.
-- Careful shaping of the resonator line impedance avoids accidental resonances with the 3rd and the 5th harmonics of the operating frequency.
-- The actual frequency response of the final-stage amplifiers agrees with calculations. The cylindrical geometry of the amplifier made this easy to calculate using the SUPERFISH code and resulted in a very compact design.
-- The blocking capacitors on the amplifiers and the capacitors on the screen-bypass ring are commercially available.
-- The dee edges were numerically machined enhancing the uniformity of the electric field.
-- Only one (the upper) trimming capacitor per dee is used; the three holes underneath the cyclotron which were planned for use with the lower trimmers are now used for pumping.

The dee voltage obtained for the 55 MeV/n alpha beam is about 73 kV per dee at 23.5 MHz.

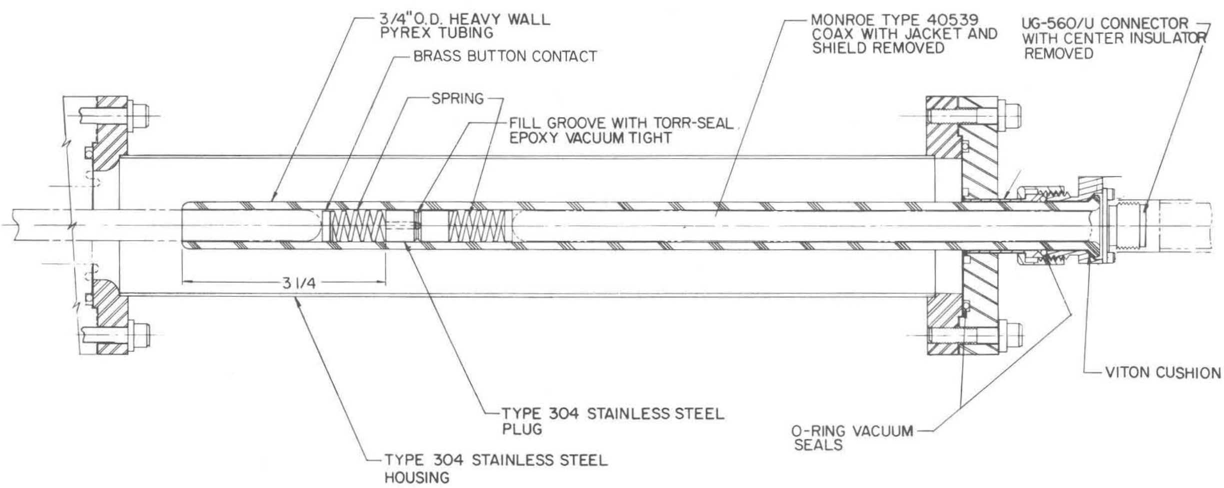

Figure 5. Deflector high-voltage feed-through assembly.

DEFLECTORS

The deflectors use a novel design which is illustrated in Fig. 5. The high voltage is fully contained in a grounded shield which is continuous from each power supply to the electrode. Since access to the deflector electrode is through a stainless-steel tube with an inside diameter of 30 mm, the feedthrough is a length of high-voltage coaxial cable from which the outer jacket and shield have been removed. The cable is then encapsulated in a standard 12 mm O.D. Pyrex glass tube with appropriate end contacts to make the assembly vacuum-tight. This assembly was tested in a vacuum chamber to 100 kV for many hours. In operation on the cyclotron the cable insulator eventually shrank in length, causing the glass to crack. Preshrinking the cable by heating it is being tried to solve this problem. A deflector has held 65 kV for several weeks of cyclotron operation with no apparent damage to this feed-through.

FUTURE OPERATION

The ECR ion source is nearing completion with turn-on scheduled for July of 1989. The injection line is being constructed at the same time and is scheduled to be connected to the K500 cyclotron in September. This should greatly enhance cyclotron operation. Also scheduled for September installation are the internal cryopanels. The better vacuum should improve the voltage-holding capabilities of the deflector and the rf system significantly and result in better operation for all ions available.

REFERENCES

1. D. R. Haenni, T. Cowden, C. Hargis, J. Reimund and R. C. Rogers, "Personal Computer Control System for the TAMU K500 Cyclotron," presented at the Twelfth International Conference on Cyclotrons and their Applications, Berlin, West Germany,

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