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STATUS REPORT ON THE INR CYCLOTRON

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Abstract

The INR cyclotron has been converted into an isochronous cyclotron with $E_{Max}=40Q^2/A$. Works for replacement and installation were started in June 1982. The external beam of 10-30MeV protons with extraction efficiency of 75-80% was got in November 1983. In this paper, a general status, operating performance and some dates concerning the main parts are reported.

1. General Description

The INR cyclotron, built in 1964, is a fixed energy cyclotron for 6.8MeV protons with 1.2M pole diameter and two Dees. In order to broaden the field of use of the machine, it needs to be modernizated. In 1978, we started to convert this cyclotron into an isochronous cyclotron. After six years of design, construction and assembly, the machine was completed towards the end of 1983. At present, the cyclotron is a three sectors, single Dee machine over a wide range of energies. Its performance has been considerably improved. Tests have indicated that all components behaved as precalculated and designed. Preliminary operation has shown that the machine has good reliability and reproducibility.

Detailed accounts of design specifications and design features have been given earlier [1)2)3)]. The basic design parameters of the cyclotron are given in table 1.

2. Operating Performance

The internal beam tuning began on 9 August 1983 after Dee conditioning was completed. It took ten days to obtain the beam at full radius for 9MeV, 20MeV and 30MeV protons. Latter, the beam of 16MeV H_2^+ ions, 32MeV α particles were accelerated and the beam of 4.1MeV H_2^+ ions was accelerated on third harmonic. To obtain the internal beam, the orbit programing and the trim coil settings were calculated in

Table 1. Main Parameters of INR Cyclotron

Energy	P	10-30MeV
	D	10-16MeV
	α	20-32MeV
Magnet pole diameter (vacuum chamberlid)		1386mm
Sectors		3
Gap on hill		146mm
Gap on valley		224mm
Frequency range		10.5-20.5MHz 8.5MHz (with 2x500pf vacuum variable capacitors)
Dee		1x180°
Extraction		with electrostatic deflector of 2 sections

A general review of INR cyclotron conversion history is shown in Fig.1.

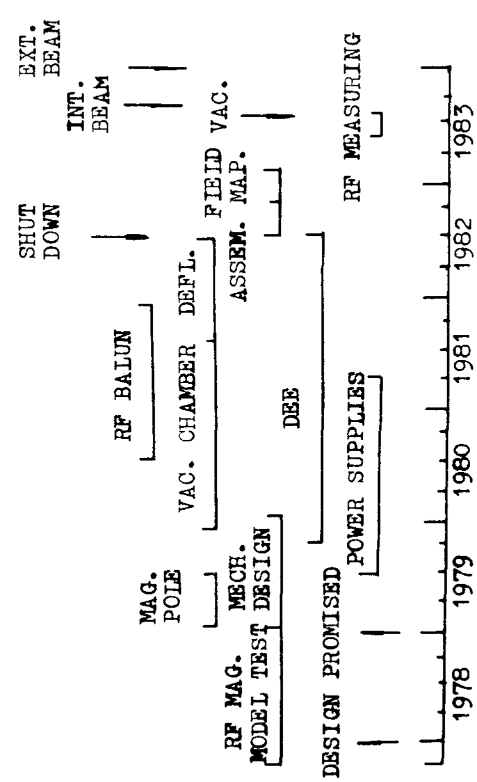

Fig.1 INR cyclotron conversion history

advance. For all beams we have produced so far it was possible to accelerate the particles to full radius with precalculated settings of trim coils by only adjusting the main field.

The external beam tuning was started on November 1983. The external beam of 9MeV, 20 MeV and 30MeV protons was obtained before the middle of November. The deflector is optimized for 20MeV protons. But it is also suitable to the energy of 9MeV and 30MeV protons without changing the position of the electrode.

The beam line tuning was completed in the middle of December. The beam transmission efficiency, as measured through the total beam transport system from the exit of the deflector to the target was 95%. The intensity of the 20MeV beam is 35μa at the target room.

The time required for changing the energy from one to the other mode of operation is less than one hour.

Preliminary operating performance are shown in table 2.

Table 2 Preliminary results of beam test

Energy(MeV)		Extraction efficiency(%)	Energy spread($\frac{\Delta E}{E}$ %)
p	9	75	
	15		0.48
	20	80	
	30	75	
d	16	73	
α	32	83	

3. Magnet Field

The original 1.2M conic pole was replaced by a 1.44M cylindrical pole made from forged steel with carbon contents of 0.1%. To reduce the iron saturation effect the pole tip (vacuum chamber lid) and the sectors are made from pure iron with carbon contents of 0.01%, and to be such a profile that the magnetic flux density is approximately constant. We pay more attention to the magnet manufacturing and assembly and to elimination of the possible first harmonic of the magnetic field. The majority of tolerance such as the homogeneity, the 120° symmetry setting of the sectors and the nonconcentric deviations of the pole and vacuum chamber lid are some hundredths of 1mm. In order to simplify the design of the vacuum chamber, it was decided to make the chamber with a monolithic structure. But there is a deformation of vacuum chamber lid caused by the atmospherical pressure at the access of Dee for the spacer here has been taken off. This deformation is essentially cancelled due to both the atmospherical pressure and magnetic forces with exciting current of 200A (i.e 9kG). All the power supplies are regulated with a current stability of 5×10^{-5} for the main coil, 1×10^{-4} for the trim coil and 1×10^{-3} for the valley coil.

In order to obtain the practical magnetic field data in operation condition, all the procedure in field measurements are in the state of vacuum. The accuracy of the measurements was 1.4×10^{-4}. Magnetic field mapping gives very good shapes. The fields for all energies deviated by less ±5 gauss from the theoretical isochronism law and the amplitude of the first harmonic is less than 5 gauss. The main results are shown in Fig.2-4.

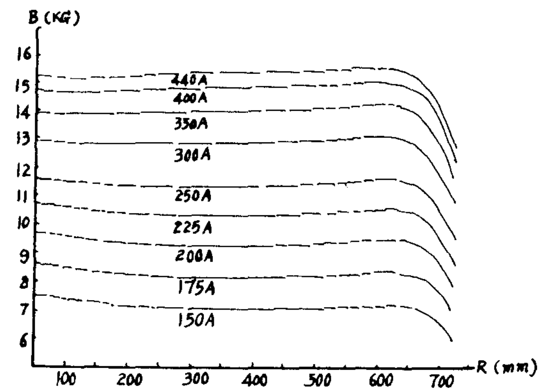

Fig.2 Average fields vs vadius for main coil excitation

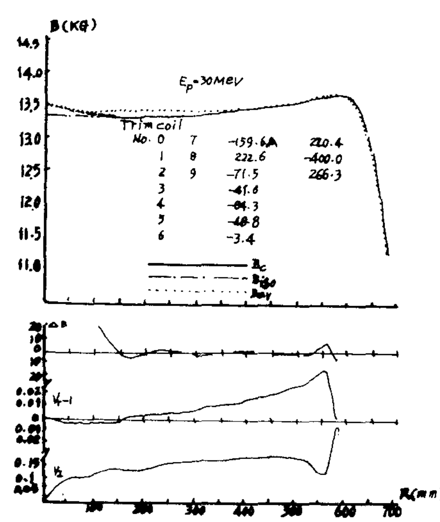

Fig.3 corrected field, field deviation from the isochrous, and ν_r, ν_z

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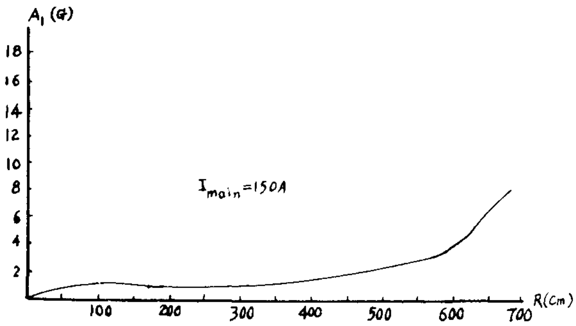

Fig.4 first harmonic amplitude vs radius

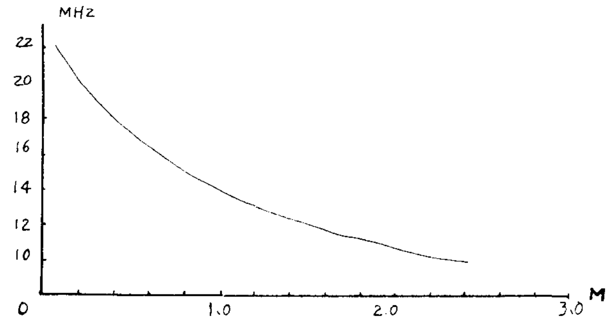

Fig.5 Resonance frequency vs length of resonator

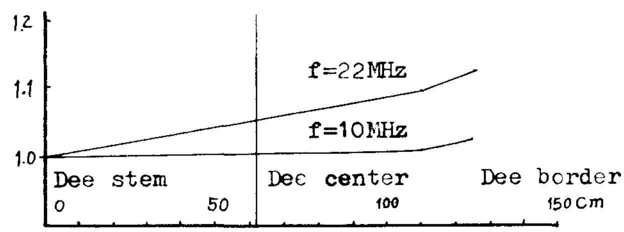

Fig.6 Relative radial voltage distribution along the Dee

4. Rf system

A single 180° Dee supported by two stems was used as a new accelerating system with resonance frequency of 10-22MHz. The Dee has a height, aperture and inner radius of 48mm, 30mm and 675mm respectively. The ground clearance is 34.5mm for standing 70kV. Rf power fed into the resonator through a balun unit, which consists of a coaxil line with 60Ω impedance. Rf power excites the Dee via capacitive coupling, which is near the front of Dee edge. The capacitance can be adjusted from 8.3pf to 5.5pf. In fact, in our case, there is no need for capacitance to change. To meet the design requirements the transmitter has been changed from 8-16MHz to 8-20.5MHz with 100kW by modifying the plate loop of final power amplifier. In order to keep accurate position of the Dee during moving the short plate, an insulator supports located near the front of the resonator cavity were used. Using this unit the moving level does not exceed several tens micron. It has been proved to be extremely useful during changing energy. The resonance frequency and radial distribution of rf field along the Dee edge are shown in Fig.5 and Fig.6.

5. Central region and extraction system

The Dee puller made from alloy of aluminum and titanium can be moved along with and perpendicalarly to the extraction slit of ion source. In order to increase the electrical focusing force, it was located at an angle of 20° to the Dee edge.

An internal hot filament PIG source with an extraction slit 1.5x5mm was used. The arc chamber is 6mm in diameter.

The extraction system includes two sections of electrostatic deflector, a focusing magnetic channel, a magnetic weakening channel and a steering magnet. The first section of deflector with parallel plate is 50° in azimuthal width and the second one with hyperbolic type is 52° in azimuthal width. The position of the inlet, the exit and the middle of electrode can be adjusted remotely. The electrode movements were checked for backlash and reproducibility. The reproducibility was found to be better than 0.1-0.2mm by remote control.

We thought that the deflector was belived to be a critical part. In order to test it as early as possible. The deflector was tested at an earlier time and at the time of internal beam trials. It took much time to work on it. It was impossible to work the voltage above 50kV for the 2nd electrode even after long conditioning, for there were a heavy electron load and spark. We solved this problem by changing some bronze parts for copper ones, rounding the edge of hyperbolic electrode and well polishing the surface of the electrode. After this procedure, an electric field gradient of 100kV/cm was achieved. The operation of the deflector already indicated that the deflector behaved as precalculated.

The field gradient of focusing magnetic channel and the shielding efficiency of the magnetic weakening channel are shown in Fig.7 and Fig.8 respectively.

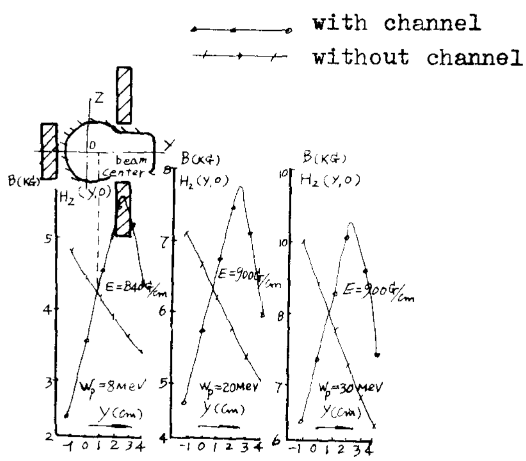

Fig.7 field gradient of the focusing magnetic channel

Magnetic weakening channel with two layer iron

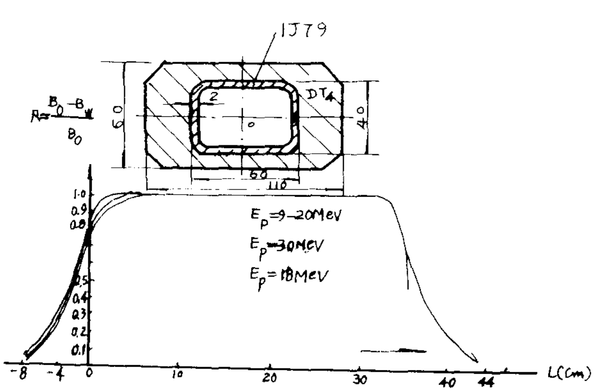

Fig.8 Magnetic shielding coefficient

6. Outlook

The main task for the future will be developing beam diagnostic devices, improving the beam quality, providing light heavy ions and trying to install a computer assisted control system. The setting up of the beam transport system to the new experiment room will be the major task for the coming year.

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