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Status of the INR Cyclotron

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Abstract

This paper gives an outline of the modifications which have recently been made on the INR 120-cm cyclotron. These include: increasing the beam energy, improving the beam quality and replacing the septum for increasing cyclotron reliability. The machine will be converted into a three fold sector focusing cyclotron. The designed energies are as follows: for protons 10-30 MeV, deuterons 10-16 MeV, α-particles 10-32 MeV. Some design features and work in progress are briefly described.

1. Recent status   The INR 120-cm cyclotron was first put into operation in 1964. For many years it was used mainly for low energy nuclear physics research, RI production, activation analysis and radiation effects studies with 6.8MeV protons, 13.6MeV deuterons and 27.2MeV α-particles. In recent years several modifications have been made:

1) increasing deuteron energy from 13.6 MeV to 16 MeV by readjusting the magnet shims and increasing the magnetic field from 14.6 kG to 16 kG.

2) obtaining 3.5 MeV protons and 7.0 MeV deuterons by accelerating H_3^+, DH^+ or D^+H with Q/A=1/3 molecular ions with a vacuum capacitor added to the resonant line which lowers the frequency range from 8.5 MHz to 8 MHz.

3) shrinking beam profile by a factor of 3 by installing a three bar focusing magnet channel after the deflector.

4) reducing the energy spread from 1.5% to 0.7% by improving the stablity of the deflection magnet power supply to $1\cdot10^{-4}$ and installing a synthesizer allows the stabilization of the RF frequencies to $1\cdot10^{-6}$.

5) replacing the tantalum septum with specific graphite which can stand the beam power of about 2500 watts and has been used without replacement for several years.

Recently, this machine is ultilized extensively for the analysis of ion-induced x-rays and applied science.

2. Further conversion project   To further extend the research field of low energy nuclear physics, nuclear technology and application of radioisotopes, the cyclotron will be converted into a three fold sector focusing cyclotron. The conversion project has been described earlier[1]. The main parameters as shown in table 1 and some design features are therefore briefly described.

Table 1   Main parameters

Energy constant K	32 MeV
Magnet pole diameter (vacuum chamber lid)	1386 mm
AVF sectors	3
Spiral angle	45° Max
Gap on hill	146 mm

Gap in valley	224 mm
Trim coils	9 pairs
Valley coils	3 pairs/sector
Average field	14.3 kG Max
Frequency Range	10.5-21.5 MHz
	8.5MHz (adding 2·500PF variable capacitor)
Dee	180° single
Dee height	48 mm
Beam aperture	30 mm
Dee-ground clearance	34.5 mm
Dee voltage	70 kV

2.1 Magnet Field The original 120 cm conic pole tips will be replaced by cylindrical ones of 144 cm diameter, which are made from forged carbon steel. After enlarging the pole tips, the cross-section area of the vacuum chamber lid will be nearly increased by 30%. By reducing the mean gap from 200 mm to 187 mm, it is possible to maintain the average magnetic field up to 14.3 kG without a substantial change in the main winding turns of the electromagnet. To decrease iron saturation effect and its influence upon the magnetic field configurations, the edges of the vacuum chamber lid and the sectors are rounded (2). The profile of the magnetic structure is shown in Fig.1.

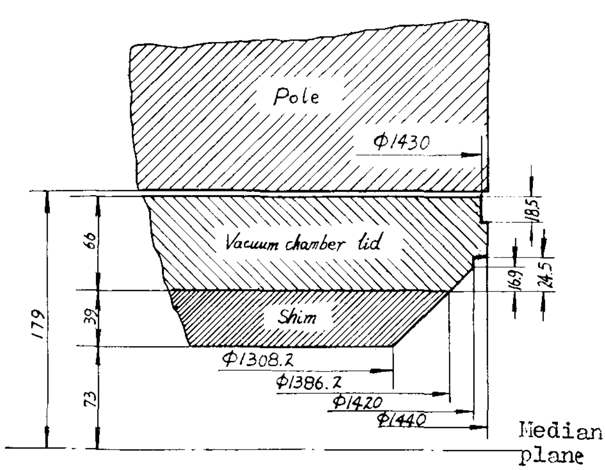
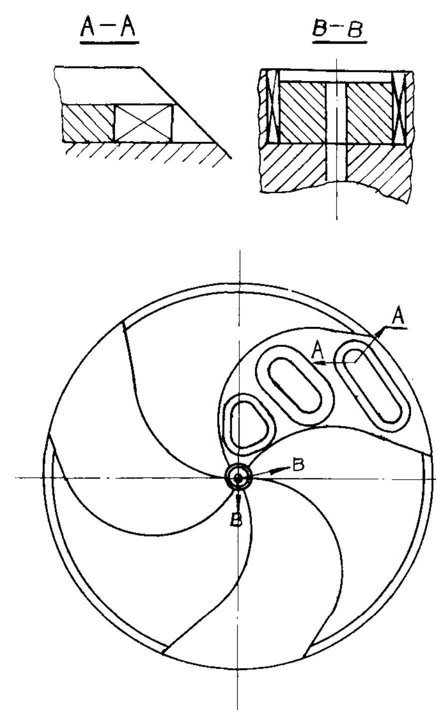


Fig.1 Pole profile of the magnet

Both the trim and valley coils are fabricated with mineral-insulated cables. In the central region, a pair of coils around the central iron disk for adjusting the conic magnetic field are provided. The upper and lower coil currents of the innermost trim coils can be unbalanced using separate power supply for adjusting the central median plane(3). Nine power supplies with stability of $1\cdot10^{-4}$ are used to achieve isochronism law at all energies. The valley coils are connected and powered in the way that the resultant mean magnetic field contribution is zero, meanwhile the first harmonic field can be produced and its phase can be controlled(4). Three valley coil power supplies with stability $3\cdot10^{-4}$ drived from three taps, spaced by 120 electrical degrees, of a sine-cosine potentiometer are provided. Fig.2 shows the arrangement of trim and valley coils.



No.	R	T
0	35	4
1	120	5
2	190	5
3	260	5
4	330	4
5	400	4
6	470	4
7	530	4
8	590	5
9	650	4

Fig.2 Sector forms and arrangement of trim and valley coils

The vacuum chamber follows the design of the old ones, except the dimensions are enlarged. In order to fit the original resonator both the corners are tapered.

2.2 RF System   The RF accelerating system will be converted from a two 180° dee system to a single 180° dee system which is supported by two stems and **tilted** at 20° from ion source axis. The frequency ranges will be therefore changed from 8.5-16MHz to 10.5-21.5 MHz, respectively. The single 180° dee system offers some advantages. The short plate is capable of carry a short current of 3650A at a current density of 58A/cm for a 75kV (peak) excitation at 21.5 MHz. The equivalent first harmonic due to the unbalanced dee voltage along the electrode is reduced and the control of the central orbits, in particular the selection of phase width, is facilitated. According to the designing requirements, it is better to reduce the lower frequency range from 10.5 MHz to 8.5 MHz. This range will be tuned by two 500PF variable capacitors, located on the separate resonator lines. These capacitors may also serve as trimmers at all frequencies.

At the transmitter end, the problem arises from matching the unbalanced impedance of the coaxial feeder and resonator to balanced output impedance of the transmitter. This could be solved by modifying the power amplifier stage of the transmitter. But in practice this is not straightforward. It is decided not to modify transmitter but to incorporate a balun unit. The schematic diagram of the RF system and the balun unit are shown in Fig.3 and Fig.4, respectively.

2.3 Ion Source, central Region and Extraction System   The present design of the central region is shown in Fig.5. The ion source is similar to the original PIG ones, except the height and the head steering structure are changed. The position of the ion source as well as the dee puller can be adjusted from the outside of the cyclotron. Using the electric field measured from the three dimensional electrolytic tank, calculations of particle orbits in the central region have been carried out. It was found that:

1) with the dee offset at an angle of 20° to the ion source axis, the axial focusing force is increased evidently (5).

2) By providing a central conic magnetic field above the isochronous field about 1-2%, the phase lag could be compensated. This field also offers the magnetic focusing out to the radius of 10-12 cm, where the flutter focusing becomes effective.

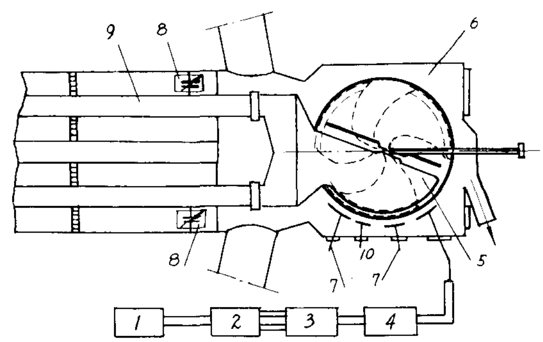


Fig.3 Schematic diagram of RF system
(1)Synthesizer; (2)Transmitter; (3)Balun unit; (4)Power detector; (5)Dee; (6)Vacuum chamber; (7)RF trimmer; (8)Variable capacitor; (9)Inner stem; (10)Measuring capacitor.

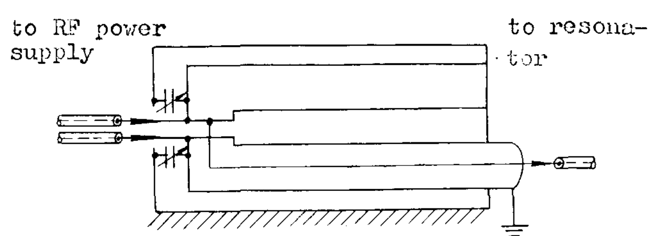
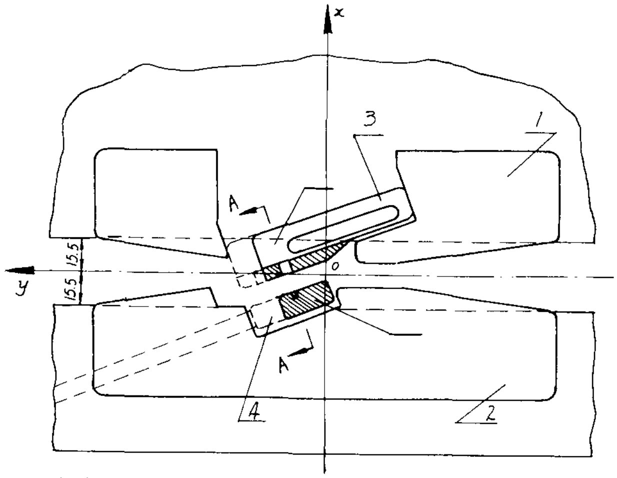


Fig.4 Schematic view of the balun unit

The beam is extracted by two sets of electrostatic deflectors with angular length of 50° and 52° respectively. The first set has a homogeneous field in order to ensure a minimum thickness of a septum. The second one has radial focusing electrostatic field that compensates radial defocusing forces in the rapid dropping field. Extration takes place at



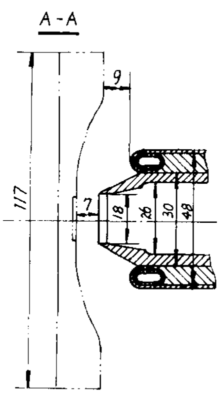


Fig.5 Lay-out of central region

(1) Dee insert
(2) Dummy Dee insert
(3) Puller
(4) Ion source

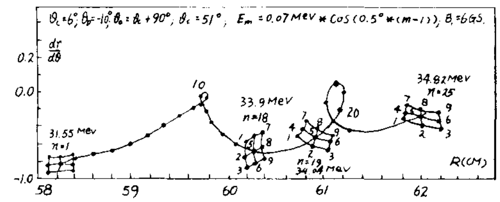


Fig.6 Radial phase space turn pattern

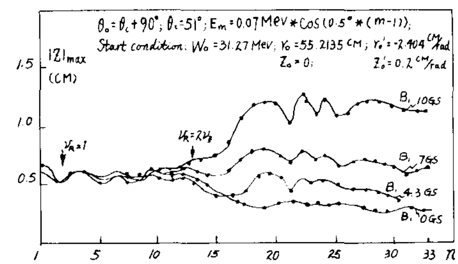


Fig.7 Axial amplitude for the different turn numbers (for several first harmonics)

$\nu_r = 0.8-0.85$. The orbit separation before deflection is to be generated by a first harmonic magnetic field component causing a coherent oscillation amplitude followed by a precessional motion of the orbit beyond the radius where $\nu_r = 1$. Calculations show that, for instance, the 34 MeV proton beam at the radius 610 mm obtain a total orbit separation of 5 mm with a first harmonic magnetic field of 6 G, as shown in Fig.6. The beam has to pass the $\nu_r = 2\nu_z$ resonance. One can observe that the blowing up of the beam due to this resonance can be avoided if the first harmonic magnetic field is less than 7 G (6), as shown in Fig.7.

After the deflector, the beam enters the focusing magnetic channel, which is made of three bars of circular or elliptic cross section. It can provide approximately constant focusing gradient for variable energy.

In order to reduce the fringing field, a magnetic weakening channel with soft iron is provided. It gives the shielding coefficient from 0.01-0.05 at change of the external field of 3-5kG.

Just into the beam line is a pair of steering magnets which deflect the beam both in horizontal and vertical direction up to $\pm 1^\circ$, $\pm 0.5^\circ$, respectively.

Fig.8 shows the arrangement of several units in the vacuum chamber.

3. Work In Progress We are presently engaged in conversion studies and in preparation for conversion project. At the time of writing (July , 1981) many elements have been completed or are under test in the following areas:

The magnet pole is completed.

The vacuum chamber including sectors, trim and valley coils are completely assembled at the factory for electrical test of the entire set of coils.

All the trim and valley coil power supplies have been installed and tested. Their control console has been installed and con-

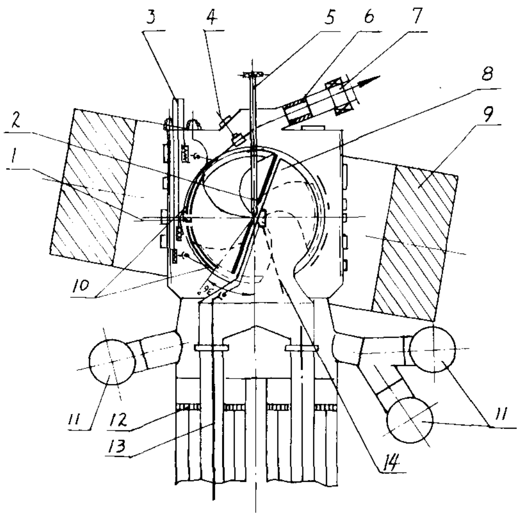


Fig.8 Lay-out of the cyclotron (1)Deflector probe; (2)Dummy Dee; (3)Deflector adjustment device; (4)Focusing magnetic channel;(5) Ion source & main probe;(6)Magnetic weakening channel;(7)Steering magnet;(8)Dee;(9)Magnet;(10)Deflector;(11)Diff. pump;(12)Short plate;(13)Puller adjustment device;(14) Dee probe.

trol wiring is in progress.

The RF balum unit is completed and under test using simulated loads.

The magnetic field measuring equipment is being tested.

The ion sources are ready for test.

The dee is under fabrication at the factory. It is expected to be delivered soon.

Many other items are in the preparation stage of fabrication in the workshop of our institute, e.g. the deflector system, the magnet channel and the RF trimmer.

Acknowledgements

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