Basic design parameters of a small size isochronous cyclotron

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ABSTRACT

The design of a small sector-focusing cyclotron with variable-energy particles is described. The possible energy range is as follows: for protons 4-15 MeV, deuterium ions 2-10 MeV, doubly-charged ions of helium 3 and helium 4, 5-25 MeV and 4-20 MeV respectively. The expected intensity of the internal beam is 300 μA, with up to 50 μA extracted.

The magnetic structure of the cyclotron is chosen as a result of work on a magnet model which is 1:1·5 of full size. By choosing a low operating induction a single trim coil consisting of 4 sections placed at radii according to a definite law may be used to give the required characteristics of magnetic field in the whole range of energy for the different types of particle.

1. INTRODUCTION

The Efremov Scientific Research Institute of Electrophysical Apparatus is at present designing a small sector-focusing cyclotron. The accelerator is mainly intended for use in activation analysis, though it would also permit a wide programme of physical and medical/biological investigations. When designing the cyclotron great attention was paid to the development of a compact, economical, simple and safe to operate machine.

2. MAGNET, CORRECTION WINDINGS, AND VACUUM CHAMBER

The magnet pole diameter is 103 cm, the overall dimensions are $2{\cdot}5 \times 1{\cdot}5 \times 1{\cdot}5$ m^3 and the total weight 24T (see Fig. 1). The hill and valley gaps are 72 mm and

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120 mm respectively. The thyristor-controlled supply for the main windings has a power output of 30 kW and a current stability of better than five parts in 10^5.

For convenient maintenance, hydraulic lifting of the upper magnet yoke together with the winding is envisaged. The coil pancakes form the lids of the accelerating chamber. Two turbomolecular vacuum pumps with a capacity of

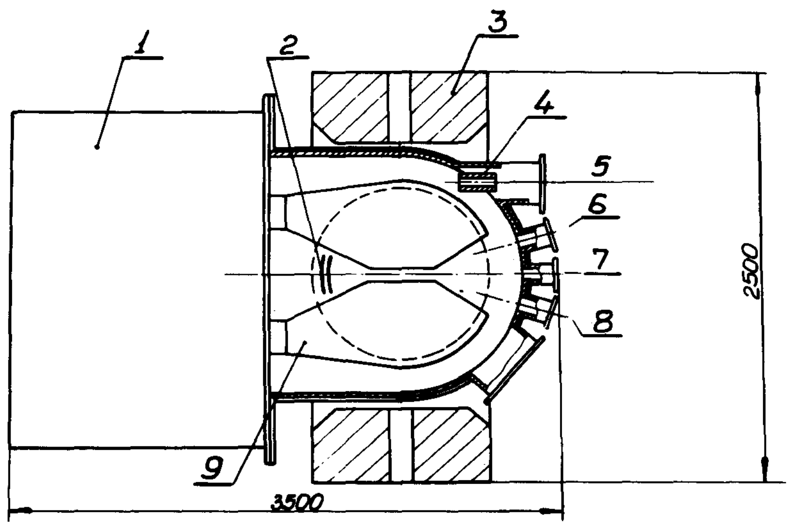

Fig. 1. Plan view of cyclotron at median plane. 1. Panel resonator; 2. Deflector; 3. Electromagnet yoke; 4. Magnetic channel; 5. External beam axis; 6. Target; 7. Probes; 8. Target; 9. Dee

10 000 1/s provide fast pumping to the operating pressure (5×10^{-6} mm Hg).

The sector shape was defined as a result of model tests on the magnet at 1:1·5 of full size. In choosing the sector shape the constraints were: sufficient azimuthal variation of magnetic field with a corresponding spiral angle to obtain vertical stability of the beam; a mean field shape with radius permitting correction of the field by a single trim coil, consisting of four separate sections; and minimal saturation effects.

At the final radius of acceleration (45 cm) the mean magnetic field value does not exceed 14 kG, and for obtaining 15 MeV protons the mean field is chosen to be 12·4 kG, giving a maximum field in the gap (in the 'hill') some 11% higher than the mean value.

The magnetic field has a three-fold structure. The angular length of the sectors is constant with radius and equal to 90°, and the radial boundaries of the sectors are curved in such a way that the spiral angle of the magnetic field increases linearly up to 38° at the final radius. Over most radii the flutter is 0·24, which gives a vertical betatron oscillation frequency near 0·2 for any acceleration mode.

Up to a mean magnetic field of about 12·5 kG the field was independent of radius and this made it possible to shape the field for isochronism by means of a single trim coil wound in four sections and connected electrically in series (see Fig. 2).

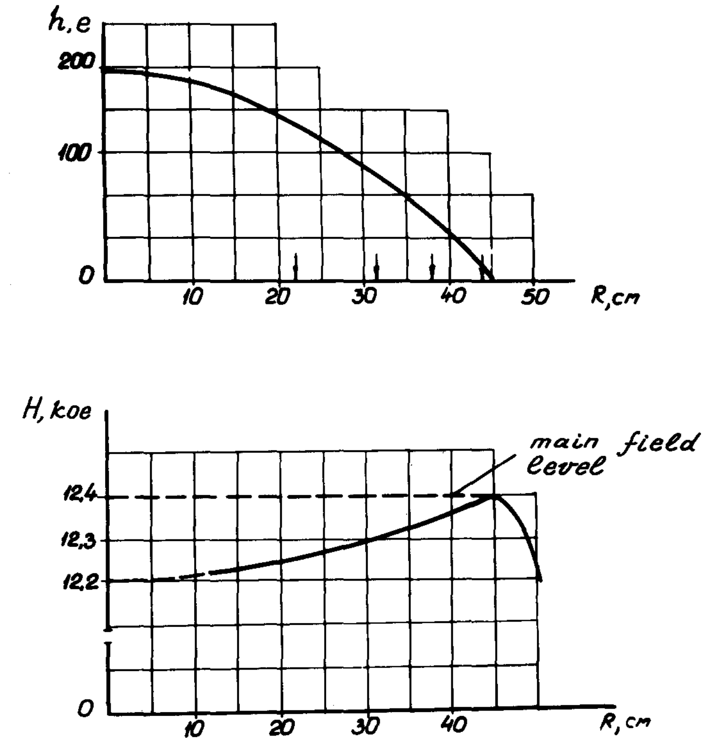

Fig. 2. Top: Magnetic field of trim coil. (Arrows indicate the position of sections.) Bottom: The isochronous field as a function of the radius for proton acceleration up to 15 MeV

The radial position of the winding sections can be calculated. However, to eliminate oscillatory deviations from the required parabolic field distribution

$$h(r) = aj\left(1 - \frac{r^2}{R_{max}^2}\right),$$

where a = efficiency
and j = current in the windings,

the radial width and number of turns in each section were optimised in the model tests.

Inverse energising of such a coil, superimposed on a main field constant with radius, gives the required isochronous dependence

$$\bar{H}_{is}(r) = H_o - h(r) = H'_o\left(1 + \tfrac{1}{2}\frac{r^2}{R_\infty^2}\right),$$

where $H_o' = H_o - h(o)$ and H_o = the main field level,

$h(o) = \frac{1}{2} H_o R_{max}^2 / R_\infty^2$ = the field of the coil at the centre of the magnet,

and R_∞ = the 'cyclotron radius' ($R_\infty \gg R_{max}$).

From the above equations it follows that by choosing a value of coil current for each level of magnet excitation an isochronous regime of acceleration can be obtained. At a given efficiency 'a' the current in the coil is defined by the value of its field in the centre. The trim coil is laid in grooves in the plates which cover the sectors. The coil has a small power supply (less than 1 kW) and is cooled by means of thermal contact with its mounting plates.

Six pairs (two in each 'valley') of harmonic coils are used.

The power supplies of all the correction windings are unified and their current stability is 5×10^{-3}.

3. RADIOFREQUENCY SYSTEM

The accelerating system consists of two dees of angle 180° (from the centre to 0·5 R_{max}) changing to 140° at maximum radius. The dee aperture is 2 cm and the dee-to-ground gap is 1·5 cm, which permits voltages on the dee of up to 40 kV. The operating voltage is 35 kV and the resonator is of a panel type. The resonant frequency of the system can be varied from 9 to 27 Mc/s and the rf generator is of a conventional type with an output power of up to 60 kW. The system includes automatic tuning and stabilisation of the accelerating voltage.

4. ION SOURCE AND EXTRACTION SYSTEM

It is proposed to use a conventional hot cathode ion source in the cyclotron. Two versions have been developed to permit installation axially or between the dees, and a mechanism for positioning the source in the chamber is provided.

The extraction system consists of a 40° electrostatic deflector with a potential of up to 60 kV followed by an iron (focusing) channel. Calculated extraction efficiencies are 40–60%.

5. TARGET, PROBES, TRANSPORT SYSTEM

For beam diagnostics during alignment the cyclotron is equipped with a remotely-controlled probe, and an internal target capable of handling high powers (up to 5 kW) is provided.

The beam will be transported into one of three shielded experimental areas equipped for work with slow neutrons, for activation analysis using a beam extracted into the atmosphere, and for surface irradiation (in vacuum) of samples with an area up to 25 or 30 cm^2. The transport system will have standardised equipment (lenses, bending magnets, beam pipe with probes and independent vacuum systems) which can be arranged to suit particular experiments.

DISCUSSION

Speaker addressed: R. N. Litunovskii (Electrophysical Apparatus Research Institute, Leningrad)

Question by H. W. Schreuder (Delft): Is there an axial injection system?
Answer: We are not providing one at present.