EXPERIMENTAL STUDY OF SIMULTANEOUS ACCELERATION OF PROTONS AND H^- IONS IN THE CYCLOTRON

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Summary. The results of experimental study of simultaneous acceleration of two beams at U-120M isochronous cyclotron of INP (Rez, CSSR) are presented. Both beams of p and H^- were injected from an internal ion source having two separate arc chambers. The H^- ion beam was accelerated up to a stripping foil mounted on a final radius and was extracted to a luminescent screen placed on the wall of the accelerating chamber. The p beam accelerated simultaneously with H^- ions went through the stripping foil and then was registered on a special probe. The phase motion and some other parameters of the beams accelerated up to 22-24 MeV are presented.

Introduction

The main aim of the work was to experimentally prove that two beams of ions differing in mass by two electrons (with allowance for their coupling energy in the atom) can be simultaneously accelerated in a cyclotron.

In paper ref.[1] it was proposed and theoretically proved that the simultaneous acceleration of two beams is possible. According to this paper, two ion beams of close masses rotating in the opposite directions and coming out of two independent ion sources in the central zone of the cyclotron magnet can be accelerated to the maximum radius of the accelerator if $\Delta W \geqslant \pi qWm/M$, where ΔW is the maximum energy gain per turn for the accelerating harmonic number q, W is the kinetic energy at the maximum radius of the cyclotron, m/M is the electron-to-ion mass ratio, the magnetic field being shaped for an intermediate mass (neutral atom).

The above equality determines the maximum theoretically possible kinetic energy (at the given energy gain per turn) and is only valid for the external injection mode where the initial acceleration phase does not affect the extraction efficiency of ions from the source.

Another experimental task was to check the possibility of independent extraction of two beams at the maximum accelerator radius, i.e. to make sure that the stripping foil of negative ions does not affect the acceleration of positive ions, as it follows from the preliminary calculations [2].

The above problems were experimentally solved at the cyclotron[5] U-120M (Inst.Nucl. Phys.Czechoslovakian Acad.Sci.)[3] where H^+ and H^- ions were simultaneously accelerated.

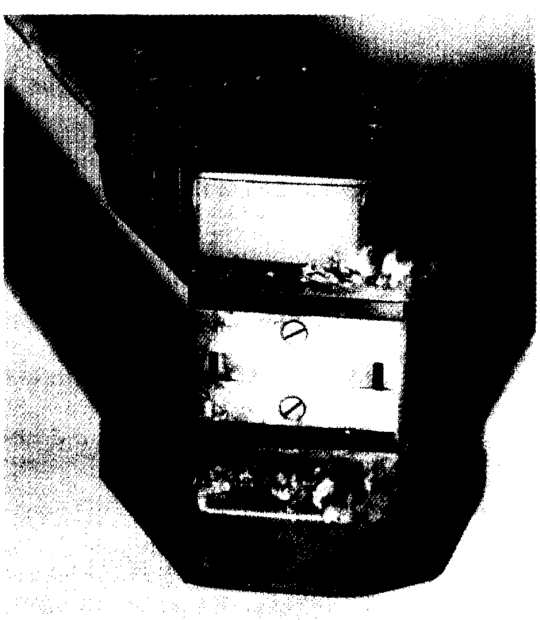

Fig. 1. Ion source head with two discharge chambers.

1. Ion Source for Protons and H^- Ions

The optimum positions of the proton and H^- ion sources in the central part of the accelerator do not coincide, because beams rotate in the opposite directions. The maximum ion extraction from ion source occurs at the zero phase of the high frequency field ($V_{acc} = V_0 \cos\varphi$) while the maximum phase shift during acceleration corresponds to the starting phases $\pm\pi/2$.

A possible compromise is turning the joined ion sources about the accelerating dee edge by a certain angle (the calculated one is 30^o) [1].

Fig. 1 shows such a head with a space of 27 mm between the slots. The space was chosen by numeric simulation of the electric field around the ion source. The geometry and operational modes of the ion sources were identical, since this stage of the experiment did not envisage the maximum intensity for the H^- beam.

2. Experimental Resonance Curves

To achieve the effective ion extraction for the given geometry of the ion sources, the accelerator magnetic field induction was chosen in range 1.415-1.420 T, which corresponds to the final energy 24 MeV. The proton beam detection was carried out by means of a measuring probe with a current meter in its circuit. The proton current was measured at a radius that was 2 cm larger than the radius at which the carbon stripping foil had been placed (0.25 μm, ΔR=0.3 cm). The conservation of parameters of the proton beam after passing the stripping foil (amplitudes of free axial and radial oscillations) were monitored by autographs which showed the axial dimension of the beam and by the shadow method of measure its radial dimension.

Fig. 2 shows typical resonant curves, both experimental and calculated, obtained many times by means of the automatic beam diagnostics system developed in INP CzAS [4].

The resonance curves are normalised to the proton beam.

To detect H^- ions after foil-stripping, a luminiscent screen was placed 0.6 m off the target.

An "autograph" of this beam on the luminiscent screen with the given scale is shown in Fig. 3.

A system of pick-up electrodes was used to measure the proton beam bunch phase (Fig. 6) simultaneously with the proton beam current along the accelerator radius (Fig. 4). The operating volume pressure of the accelerator being $1.2\cdot10^{-5}$ Torr, the H^- beam intensity decreased along the accelerator radius approximately by an order of magnitude and was not registered by the system of pick-up electrodes.

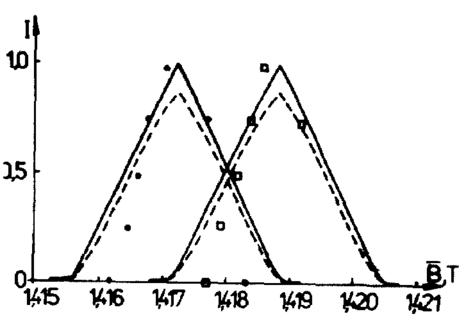

Fig. 2. Resonance curves for proton and H^- ions calculated on the assumption that I_{is} $V^{3/2}_{acc}$ (solid line), I_{is} V^{3}_{acc} (dashed line) and measured experimentally (circles and squares).

In general, the foil stripper affected neither the intensity, nor the proton beam structure within the experimental accuracy.

The theoretical resonance curves (Fig. 2) were obtained on the assumption that the intensity of the proton and H^- beams extracted from ion source (at the fixed amplitude of the accelerating voltage of the dee) obey the law:

$$i \sim (\cos \varphi)^n \qquad (1)$$

where the power index n varied in the range n = 3/2 ÷ 3; is the phase of beam extraction from the ion source.

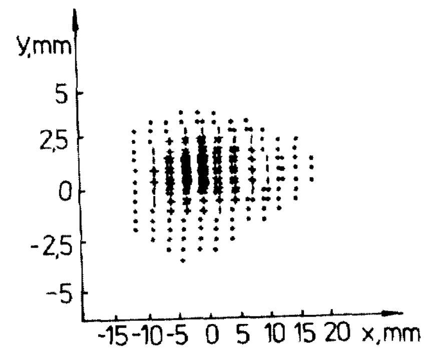

Fig. 3. Autograph of the H^- beam on the luminiscent screen after stripping.

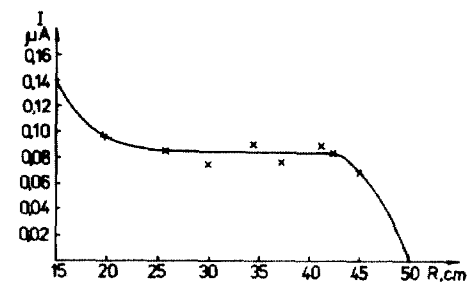

Fig. 4. Radial dependence of the proton current.

It is seen that the shape of the resonant curves changes slightly (dashed curves in Fig. 2), whatever beam intensity level is.

The distance between the experimental maxima of the resonance curves corresponds to the mass of two electrons:

$$2\frac{m}{M} = \frac{\Delta H}{H} = \frac{1.4187-1.4171}{1.418} = 1.12\cdot10^{-3} \qquad (2)$$

Here the difference from the accurate electron mass does not exceed 2%. This result can be refined by more accurate measurements of the intensity maximum position in each beam.

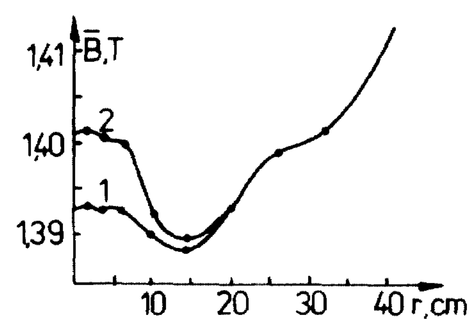

Fig. 5. The shape of the magnetic field in the experiments:
(1) optimal tuning for protons,
(2) optimal tuning for simultaneous acceleration of two beams.

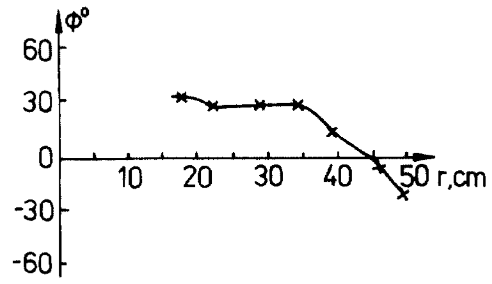

Fig. 6. Phase motion of the proton bunch for field 5 (1).

3. Requirement to Magnetic Field Isochronism

The conditions for simultaneous acceleration of P and H^- ions were theoretically considered for an ideal isochronous magnetic field tuned to an intermediate mass. Since there are always deviations from this law in real accelerators, and this leads to the shift of the bunch centre phase within certain limits, the experiment with different deviations of the magnetic field from the isochronous one in the two-beam acceleration mode is of great interest. Theoretically, any tuning of the isochronous acceleration mode of protons with the field or accelerating voltage frequency mismatch of $5 \cdot 10^{-4}$ must also correspond to the acceleration mode of H^- ions. A series of experiments was carried out with a magnetic field shape changed by means of the central concentric coil and the phase motion of the bunch was monitored (see Fig. 6).

Fig. 5 (1, 2) shows the limits within which the magnetic field of the accelerator varied in the central zone, and the optimum value of the field bump at the tuning to the simultaneous acceleration of two beams.

Conclusion

The work is the first to experimentally show a possibility of simultaneous acceleration of two beams in isochronous cyclotrons. This process agrees with the theory of resonance beam acceleration in cyclotrons within the experimental errors. The distance between the maxima of the resonance curves corresponds to the mass of two electrons within the experimental accuracy.

The method of simultaneous acceleration of negative and positive ion beams opens new experimental opportunities for cyclotron facilities.

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