Accelerated Ion Energy Measurement by Means of Circulating Electron Flow

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The object of the report is the statement of the ion beam average energy measurement method in high energy accelerators. Primary transducer design and operation are described.

Trajectories of ion (i) and electron (e) beams in two magnetic field regions and the drift space between them are shown in Fig.1. In the proposed method the ion beam is injected into a uniform stationary magnetic field region with length d (dashed line in Fig.1), where ions move on circle orbits with radius R_i. Passing the first magnetic field region the ions are deflected by the angle 2α from the original trajectory, then the ions pass the drift space of length l. After the second magnetic field region the ions are also deflected by the angle 2α. Electrons are injected along the ion beam axis in the drift space. The electron injection can be carried out by means of the small-sized heated cathode, or by ionization of residual gas.

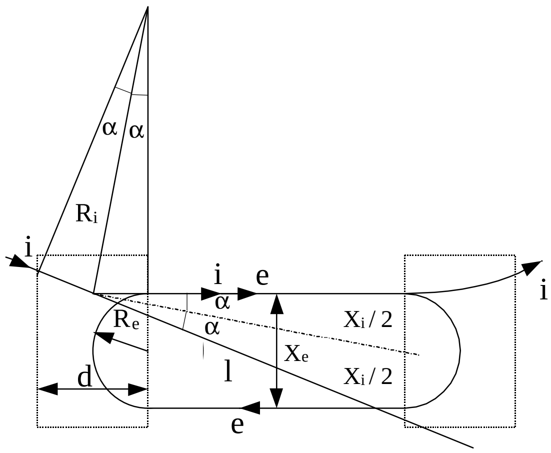

Fig.1 The scheme of particle movement.

The electron beam is bent into opposite direction by the magnetic field and gets to the ion beam trajectory again, making recirculation. After injection electrons may have as well equal as different velocities. Due to coulomb interaction electron and ion velocities become close to each other in a short time. This effect was tested experimentally. The measurement of the electron and the ion velocities was performed by means of a magnetic spectrometer. The electron spectrometer had higher accuracy and essentially smaller magnetic field induction, than the spectrometer for the energy measurement of the ion and the electron velocity.

The accuracy of th method may be characterized by dispersion D [1]:

$$D_e = \frac{d X_e}{d V}, \tag{1}$$

where X_e - displacement of the electron spectrum line in the detection plane,

V - velocity of analysed ions (electron velocity).

It can be shown that this dispersion value is:

$$D_e = \frac{2}{\eta_e B}, \tag{2}$$

where η_e - electron charge e to mass m ratio,

B - quantity of magnetic field induction, supposed equal in both regions.

From Fig.1 we can define quantity X_i, which characterizes the displacement of the ion spectrum line:

$$X_i \approx \frac{l \cdot d}{R_i}, \tag{3}$$

Then we can get the expression for the dispersion:

$$D_i = \frac{l \cdot d \cdot \eta_i \cdot B}{V^2}, \tag{4}$$

where η_i - ion charge $Z_i e$ to mass m_i ratio.

Comparing expressions (2) and (4) we can get the relation:

$$\frac{D_e}{D_i} = 2 \cdot \frac{\eta_e}{\eta_i} \cdot \frac{R_e^{\,2}}{l \cdot d}, \tag{5}$$

where R_e - radius of the electron circle orbit.

From expression (5) we can see, if significances of d, R_e and l are comparable, so in this method the device resolution is 10^3-10^4 times higher than in the prototype under the same conditions.

If electron and ion velocities are equal to each other, equality is right:

$$R_i = R_e \cdot \frac{\eta_e}{\eta_i}. \tag{6}$$

Taking into account expression (6) we can get that the displacement X_i has the value ~ $R_e \cdot \eta_e / \eta_i$, it can not exceed 10^{-1}-10^{-2} mm. If the transverse sizes of the electron and ion beams are about some mm, we can neglect value X_i . It simplifies the realization of this method.

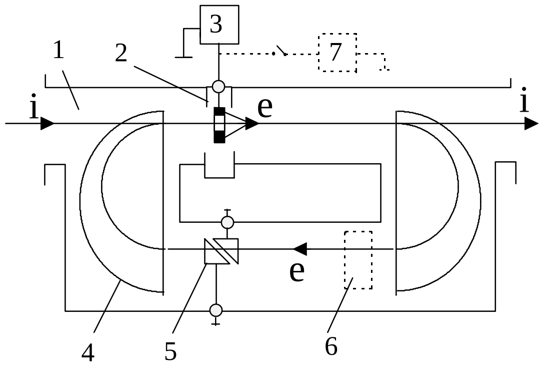

Fig.2 The scheme of facility.

Period T is the time of the equilibrium state determination when electron and ion velocities become equal to each other. We can get T from the expression (in Gauss system) [2]:

$$T = \frac{\beta_i^2 \cdot \delta\beta}{8 \cdot \pi \cdot c^3 \cdot r_e^2 \cdot L \cdot n_i}, \qquad (7)$$

where $\beta_i = \frac{V_i}{c}$ - the relative ion velocity; c - the light velocity; $\delta\beta$ - initial relative electron velocity deviation from the established significance $\beta=\beta_i$, r_e - electron beam radius (supposed that the transverse size of the electron beam does not exceed the ion one), L - coulomb logarithm, n_i - ion density, defining as:

$$n_i = \frac{I_i}{\pi \cdot r_e^2 \cdot V_i \cdot z_i \cdot e}, \qquad (8)$$

where I_i - ion current in the electron beam aperture.

For example, for a proton beam with the parameters: β_p=0.1, I_i=10μA and for an electron beam with the parameters: r_e=1mm, $\delta\beta$=0.01, time T=2sec, for I_i=10mA T=2msec.

The version of the facility shown in Fig.2 consists of vacuum chamber 1, electron injector 2, pulsed power system 3 of the electron injector, magnet 4, transparent 5 and nontransparent 6 monitors of the beam gravity centre measuring system, source of adjustable direct voltage.

The described facility works as follows. The ion beam passes inside the vacuum chamber between magnets 4 and through the hole in the cathode of the electron injector 2 without practically no deflection from the injection direction. The negative voltage pulse with an amplitude decreasing in time is supplied from the power system 3 to the electron emitter. The electron emission is carried out during this pulse by means of cold emission, either by a small-sized heated cathode, or due to ionisation in the case of a plasma emitter. The limited electron current is defined by the injector perveance P and may be equal to 10-100 mA.

However, the choice of current intensity is defined, in case of technical realization, by the compromise between sensitivity and device resolution.

The process of determining the electron beam gravity centre position (when the electron velocity is equal to the ion velocity) may be carried out by means of any known method of transparent diagnostics, for example, by means of electrostatic pickup-electrodes. In this case, the measuring error does not exceed 10^{-1} mm. A higher accuracy may be achieved if the transparent monitor is only used for registration of the moment when the electron velocity becomes equal to the ion one. Then for the definition of the beam position the nontransparent monitor of the probe is used. Furthermore the velocity of electrons may be defined by means of the known stopping potential method. Such technical decision may be easier, since the nontransparent monitor is not used in this method [1].

References

[1] Moskalev V.A. et al., Izmerenie parametrov puchkov zarjazhennyh chastits. M.: Atomizdat, 1980.

[2] Budker G.I. et. al., Electronnoe ohlazhdenie i novye vozmozhnosti v fizike elementarnyh chastits. - Uspechi fizicheskih nauk, t. 124, v. 4, 1978, s. 561-595.