METHOD AND APPARATUS FOR MULTIFUNCTIONAL NONPERTURBING DIAGNOSTICS OF H^- BEAMS

A.S.Artiomov, N.G.Vaganov, A.K.Gevorkov,
V.V.Limar, V.P.Sidorov
I.N.Vekua Institute of Physics and Technology
Sukhumi 384914, USSR

Abstract

A method of nonperturbing diagnostics for negative ion beams based on electrons resulting from their near-threshold photodetachment is considered. A compact apparatus for realizing this method in the Moskow Meson Factory Linac (MMFL) and measuring various parameters of H^- ions beam is proposed.

Method

For high current ion accelerators, it is important to obtain information on various parameters of a beam not affecting whem appreciably during measurements (nonperturbing diagnostics). In the linear areas of the transport line for negative ions beam such information may be obtained via the method based on the electrons resulting from the near-threshold ($\varepsilon_{\text{п}}$) photodetachment of some negative ions. A kinematic analysis of a elementary single-photon photodetachment acts shows that accuracies of determination of the energy and momentum direction of the ion by means of electron parameters are found

$$\frac{\Delta E_e}{\bar{E}_e} = \frac{2\cdot\beta\cdot\gamma}{(\gamma-I)\cdot M_e\cdot C}\sqrt{2\cdot\mu_{eo}\cdot(\hbar\omega-\varepsilon_{\text{п}})}\ ;$$

$$\Delta\theta_e\ [\text{рад}] = 2\cdot\frac{\sqrt{2\cdot\mu_{eo}\cdot(\hbar\omega-\varepsilon_{\text{п}})}}{\gamma\cdot\beta\cdot M_e\cdot C}\ ; \qquad (1)$$

where $\mu_{eo}= M_e\cdot M_o/(M_e+ M_o)\approx M_e$, $\gamma= (1-\beta^2)^{-0.5}$, $\beta= V_i/C$, V_i is the velocity of an ion with the energy E_i and the mass M_i, $\omega= \omega_o\cdot\gamma\cdot(1-\beta\cdot\cos\eta)$, ω_o is the photon frequency in a laboratory frame, η is the angle between ion and photon momenta, $\bar{E}_e= E_i\cdot\underline{M}_e/M_i$. For fixed ω_o and η values, the $\Delta E_e/\bar{E}_e$ and $\Delta\theta_e$ accuracies may be improved nearly five and nine times, respectively, with the photon polarization suitably chosen [1]. When forming a stripping target using laser radiation with highly monochromatic and directed photons the nonperturbing diagnostic accuracy for high energy ion beams is mainly limited by energy ($\Delta\beta$) and angular ($\Delta\theta_i$) spreads of ions in a beam due to a strong dependence of near-threshold photodetachment cross section $\sigma(\omega)= 2\cdot IO^{-16}\cdot(\hbar\omega-\varepsilon_{\text{п}})^{1.5}\cdot(\hbar\omega)^{-3}$ [2] on photon energy in the ion reference system. To obtain the best accuracies for $\Delta\beta$ and $\Delta\theta_i$ given, the minimum value of $\hbar\omega-\varepsilon_{\text{п}}$ in (1) is chosen so that photodetachment cross sections $\sigma(\omega)$ are the same for all H^- ions. This condition take place when

$$\hbar\omega-\varepsilon_{\text{п}}\gg \gamma\cdot\hbar\omega_o\cdot[\Delta\beta\cdot[\beta\cdot(I-\beta\cdot\cos\eta)\cdot\gamma^2- \cos\eta]+\beta\cdot\sin\eta\cdot\Delta\theta_i\,]. \qquad (2)$$

From this e.g., for the MMFL with the energy of H^- ions 600 Mev, $\Delta\beta/\beta\approx \pm I$ mrad and suitably polarized photons with $\hbar\omega_o= I.I7$ ev, one may obtain accuracies of correspondence between electron and ion distributions in a beam $\approx 3\cdot IO^{-2}\%$ in energy and $\approx 2\cdot IO^{-4}$rad in angle. The photon target power necessary for measurements is defined by the conditions of information extraction from the total flux of electrons from the target and residual gas.

Apparatus

In this paper a compact multifunctional apparatus for realization of this nonperturbing diagnostical method is proposed. A schematic layout is shown in figure. A dipole magnet with a homogeneous field (MA) is used to extract electrons from the ion beam and to analyze the information carried by them. The interpolar distance Π_m

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is chosen to be sufficient to let ions pass through the analyzer unhindered.

Ion energy spectrum and longitudinal emittance measurements are performed according to a scheme (a) well known for magnetic analyzers where, using the laser radiation, instead of a diaphragming slit of the analyzer, a band type target (O) is formed with the required spatial localization ΔX_o along the X_o axis. The energy spectrum of ions is reproduced according to the spatial distribution of the electron flux density along the X axis measured by the detector $Д_{e1}$ with the its spatial resolution d taken into account. In order to measure an electron momentum with the accuracy of $\delta P/P \approx 2\cdot 10^{-4}$ for $\Delta X_o \approx (5+10)\cdot 10^{-2}$ mm, $d \approx (4+5)\cdot 10^{-2}$ mm, $П_m = 40$ mm and for the expected angular spread of ions $\Delta\theta_i \approx \pm 1$ mrad, one may choose, e.g., magnetic analyzers with $\phi = \pi/2$, R= 200 mm, $L_1 = 240$ mm and $L_2 = 160$ mm, or with $\phi = \pi$, R= 230 mm and $L_1 = L_2 = 0$. The latter choice ensures the minimum effect of the ion beam space charge on electrons. Electrons with energies needed for phase analysis are separated via diaphragming when the analyzer magnetic field sign and value are changed. The diaphragmed electron beam may be dispersed in phase at the detector $Д_{e2}$ in a cavity with a circularly polarized rf-field [3] or with rf-transverse deflector [4]. The accuracy of transformation of the ion beam phase structure into an electron flux at the entrance of the cavity dispersed in phase (CDF) is mainly defined by the projection ΔZ_m of the target area (where the electrons are collected from) onto the Z-axis and by the difference of electron trajectory lengths in the magnetic analyzer due to the ion angular spread in the beam and its space charge. E.g. to ensure the phase resolution of $\approx 1^\circ$ for a beam of H^- ions with the energy of 160 Mev (f≈ 200 MHz), in the second type of analyzer, one must provide $\Delta Z_m \approx 1$ mm. When using a photon target inclined towards the ion beam, with a sufficiently small transverse dimension along the Z axis, the required operating region of the target may be localized by choosing the diaphragming slit (S) correspondingly limited along the Y axis.

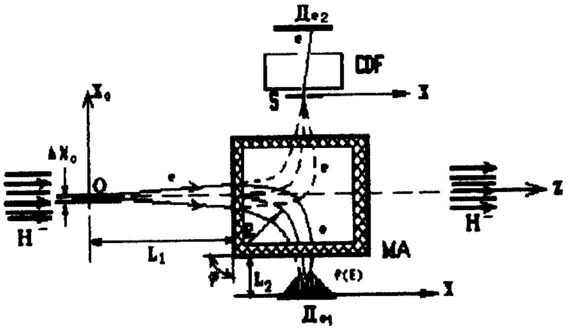
While measuring the ion transverse emittance and profile, the band-type photon target is localized within the X_oZ plane, moves in parallel along the Y_o axis and has a spatial localization $\Delta Y_o \approx (5+10)\cdot 10^{-2}$mm required for measurements (b). The analysis of electron distributions at the detector $Д_{e1}$ within the plane of (Y'Y) obtained as a result of computer experiments have shown that for ion energies $E_{H^-} = 600$ Mev, $\Delta\beta/\beta \leqslant 10^{-2}$, $|X_o, Y_o| \leqslant 0.5$ sm, $|X'_o, Y'_o| \leqslant 1$ mrad effects of boundary fields and the analyzer geometry may be taken into account via expression

$$Y = A\cdot Y_o + B\cdot Y'_o \qquad (3)$$

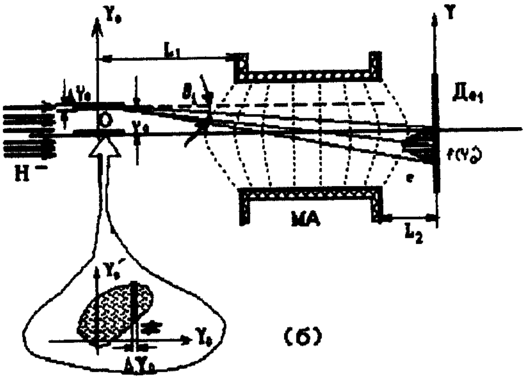
where A and B are defined according to the type of the analyzer chosen, and equal to A= 1.47 and B= 0.086 sm/mrad for the first choice, and A= 1 and B= 0.072 sm/mrad for the second one, respectively. The Y'_o distribution is reproduced with the accuracy of $\delta Y'_o \approx 2\cdot 10^{-4}$rad from the measured spatial distributions of electron fluxes at the detector along the Y axis for controllable characteristics of the target (defining the probability of an electron generating) and its position in the space (Y_o). At the same time, a functional dependence of the integral electron flux at the detector upon the target position defines the ion beam profile along the Y_o axis.

For a short time interval (e.g. during a pulse of the ion beam) a certain information on the ion distribution over the (Y'_o, Y_o) plane may be obtained by means of several band-type targets fixed in space, created and separated from each other along the Y_o axis by diaphragming the laser radiation. The distance between them is defined by the condition of the electron distributions overlapping at the detector along the Y axis and can be estimated as $\delta Y_o \approx 1.5$ mm in the both types of analyzers for the ion beam of 600 Mev energy.

For measuring energy spectra and transverse emittance of the H^- ions beam, with accuracies sufficient for the MMFL $\Delta Z_m \approx$ 2 sm may be use. For the first, simpler in realization, type of the analyzer the ion beam space charge does not practically reveal itself within the accelerator area with ion energies 600 Mev and it exert an essential influence on the accuracy of beam parameter measurements in the area with $E_{H^-} = 160$ Mev. Inaccuracies in adjusting and manufacturing of the magnetic dipole result in systematic errors of measurement may be taken into account by preliminary calibration of the apparatus by means of a testing electron beam and experimental definitions of A and B values. For the precision operation of the apparatus, spatial positions of the band-type photon target should be controlled with accuracies of $\delta(X_o) \approx \delta(Y_o) \approx (5\div10)\cdot10^{-2}$ mm, $\alpha(X_o) \approx \alpha(Y_o) \approx (2\div5)$ mrad. Moreover, background magnetic fields H_b should be well shielded off as well as high accuracies of the required magnetic field magnitude H in the analyzer should be achieved ($\delta H \approx H_b \approx 3\cdot10^{-4}\cdot H$). Expected relative losses of the H^- ions beam during the process of measurement are $\approx 10^{-7}$.



(a)



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