CORRELATION METHOD OF NONPERTURBING MEASUREMENTS OF ION BEAM ENERGY SPECTRA

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Abstract

A correlation method of nonpertubing control of ions energy spectra is suggested. The method is based on measurements of mutual correlation function between a fluxes of particles or target photons, pseudorandomly modulated in time and that of fast neutrals formed at the target and detected on the drift distance. Characteristics of the apparatus realizing the proposed diagnostical method in a source of H^- ions have been evaluated.

Introduction

In order to control acceleration processes in modern accelerator complexes it is necessary to carry out nonperturbative measurements of ion beam parameters in the tpansport line areas with external electromagnetic fields, e.g., with a bending magnet. For these purpose, fast neutrals may be used which are generated as a result of ion destruction or charge exchange process at a specially shaped and practically transparent for a beam target (see, e.g.,[1,2]). The target is formed so that information carrying neutral particles (IN-particles) should follow the ion velocity in magnitude and direction with accuracies required for measurements. At the transport line bending area, they leave the ions beam without perturbing the information carried and they may be analyzed in special devices not affecting the ions. E.g., in analyzing the energy spectra of IN-particles, a time of flight method is usually used, or their ionization and consequent magnetic analysis is performed.

For ion sources, the probability of IN-particles generation on the residual gas (η_r) may be considerable. For this case, it is impossible to extract the information directly from a flux of background IN-particles at the detector at any density of the target used. In particular, it takes place when the nonperturbing diagnostical method proposed in [2] is applied to sources of H^- ions ($\eta_r \approx 0.3$).

Method

In this paper the correlation method for measuring energy spectra of ion beam using test IN-particles detected on the drift distance L is proposed. For an ideal case, under the test particles, we assume IN-particles having their autocorrelation flux function $\psi_T(t)$ equal to a periodical δ-function (a pseudorandom flux):

$$R_{TT}(\tau) = \int_{-\infty}^{\infty} \psi_T(t)\cdot\psi_T(t-\tau)\cdot dt = \sum_{K=-\infty}^{\infty} \delta(\tau - K\cdot T) \ . \qquad (1)$$

For generating such particles, at the initial area of the transport line bend a target is formed with the density $\psi_t(t)$ pseudorandomly modulated in time. For the ion beam current being unchanged during measurement, the target is spatially localized so that the flux of the particles generated at the target should adequately reproduce the target time modulation, $\psi_T(t) = \text{const}\cdot\psi_t(t)$. Pulse characteristic h(t) of the drift distance from the target to the detector is related to the velocity V_o distribution of IN-particles ($t = L/V_o$) and, hence, with the energy spectra of ions. The flux of IN-particles ψ_o at the entrance of the drift distance consists of fluxes of background (ψ_r) and test (ψ_T) IN-particles generated in the course of interaction of ions with residual gas

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components and the target, respectively. Since the drift distance is a linear system the IN-particle fluxes at the detector $f_o(t)$ and at the entrance of the path length $\psi_o(t)$ are interrelated by the convolution

$$f_o(t)=\int_0^{\infty} h(\tau)\cdot\psi_o(t-\tau)\cdot d\tau \ . \qquad (2)$$

We consider that the contribution of background IN-particles generated at the bending area after the target may be neglected. Taking the independence of ψ_r and ψ_T into consideration, we find that measurements of a mutual correlation function between the fluxes of target particles or photons and IN- particles at the detector allows us to obtain periodical reproductions of pulse characteristics of the drift distance

$$R_{to}(\tau)=\int_{-\infty}^{\infty} \psi_t(t)\cdot f_o(t-\tau)\cdot dt =$$

$$= const\cdot\int_0^{\infty} h(t)\cdot R_{TT}(\tau+t)\cdot dt = \qquad (3)$$

$$= const\cdot\sum_{K=0}^{\infty} h(\tau-K\cdot T) \ .$$

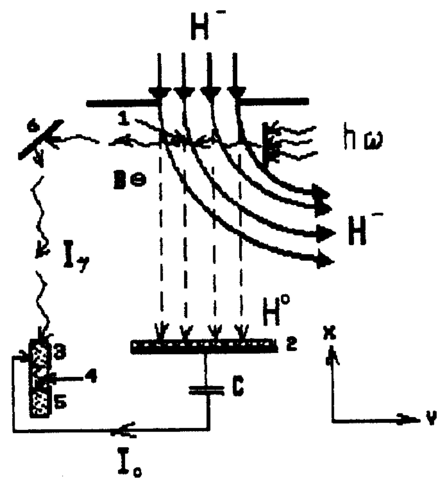
In reality, the flux of test IN-particles must be such that the convolution of h(t) and R_{TT} does not change the h(t) function. In accordance with [3] this condition means that a periodically replicating element of the autocorrelation function of the $\psi_t(t)$ signal must have a sufficiently narrow shape in time, with the width of $\Delta \ll \tau_{max}$, where $h(\tau)=0$ for $|\tau|\geqslant \tau_{max}$, and its period T must satisfy the condition $T > 2\cdot\tau_{max}$.

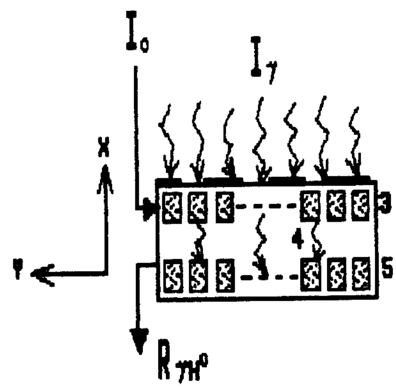
Correlation methods allow to perform measurements in condition when background signal exceeds by several orders of magnitude the required one. Hence, in measuring $R_{ro}(\tau)$ using correlators the energy spectra of the ion beam may be controlled nonperturbatively.

Apparatus

The considered method of energy spectra measurements may be used, e.g., in surface plasma sources of H^- ions [4] according to the scheme shown in figure. H^o atoms, generated from the stripping of H^- ions on the residual gas or the photon target, reproduce the ion energes with high accuracy ($\approx 2\cdot10^{-4}$) and can be used as IN-particles. The stripping target 1 is formed at the beginning of the bend area by diaphragming the radiation with the wavelength of λ= 10600 Å ($\hbar\omega$= 1.17 ev) from the Nd^{+3}:YAG laser with synchronized modes. Duration of series of pseudorandom picosecond radiation pulses is $T_s\approx$ 100 ns and their autocorrelation function has a shape close to a triangular one with the width $\Delta\approx$ 50 ps [5]. Such a photon target with H^- ions stripped at it may serve as an efficient generator of H^o test-atoms allowing to measure pulse characteristics of the drift distance $h(\tau)$ which are fairly short in time. To generate them in accordance with the target autocorrelation function the interaction area length should not exceed $\Delta\cdot V_{H^-}\approx 10^{-2}$sm. At present, potentialities of the above measurement method are limited mainly by the fast acting capability of correlators.

The mutual correlation function $R_{\gamma o}(\tau)$ between the target photon flux and that of H^o-atoms at the detector 2 may be measured by means of time-integrating correlators in charge-coupled (CC) devices similar to that suggested in [6]. Some laser radiation after the interaction area is spatially modulated by means of a GaAS CC-linear structure 3, in which an spatial distribution of pixel charges corresponds to a discrete-in-time representation of the shape of a current signal from the H^o-atom detector. The radiation 4 modulated by the photoelectric absorption is detected by the silicon CC-linear structure 5. Spatial distribution of the charge accumulated there during the measurement time corresponds to the correlation function $R_{\gamma o}(\tau)$. The function may be read out, e.g., during intervals between the target switchings or the ion beam pulses and then it may be transformed into the time scale, the charge transfer velocity along the modulating CC-linear structure being known. Assuming that for a source of a band-type ($\approx$ 0.1 × 1 sm^2) beam of H^- ions with energy $E_{H^-}\approx$ 20 keV and $\eta_T\approx$ 0.3 measurements are possible for $\psi_r/\psi_T\approx 10^2$ we obtain the needed power of the photon target $P_\gamma \approx$ 350 W. The target required, having the transverse dimensions ≈ $10^{-2} \times 0.1$ sm^2 within the interaction region, may be formed by diaphragming the compact laser radiation with an average power within duration of series pulses being $P_l \approx 200$ kW. Fairly large target photon fluxes make it possible to use a waveguide propagatin of the radiation in the CC-linear structure 3 and to reach the maximum dynamical range of modulation (≈ 100%). Moreover, this fact allows to provide the detector pixels with the sufficient charge and to carry out energy spectra measurements during the time $T_s \approx 100$ ns when needed in the course of the pulse of ion beam. Fast acting capability of the corellator and the apparatus as a whole is determined by the guiding frequency of the modulator CC-linear structure which may amount to ≈ GHz for GaAs CC-devices [7]. Thus operating one may measure $h(\tau)$ in detail with the minimum value of $\tau_{max} \approx 10$ ns. For the source considered, with the path length for H^0 atoms L≈ 100 sm, the apparatus suggested permits to carry out nonperturbative measurements of energy spectra of H^- ions with accuracies ≈ 0.4 %.





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