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CORRELATION METHOD OF MEASUREMENTS OF ION BEAM PARAMETERS

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Introduction

For high-brightness ion accelerators it is important to obtain information on beam parameters not affecting them appreciably during measurements (nonperturbative diagnostics). For this purpose in a bending transport line area fast neutral particles can be used. These particles are produced as a result of ion destruction or the charge-exchange process in a specially shaped target which is practically transparent for a beam (for H^- beams see [1-5]). The target is formed so that these information-carrier neutral particles (IN-particles) follow the ion velocity in magnitude (in relative units) and in direction (in rad) with accuracies required for measurements. These accuracies can be estimated by $\leqslant (\mu_o \cdot I_o / M_i \cdot E_i)^{0.5}$ where μ_o is the reduced mass of the neutral particle and the remaining part of the ion in its destruction or the ion and electrons in their recombinanion, I_o is the affinity energy, M_i and E_i are the ion mass and energy, respectively. In sources, for example of negative ions, the probability of IN-particle generation (η) in residual gas can be quite considerable ($\eta_r \approx 0.2 \div 0.4$). In this case, using the well known methods [1-5] for any density of a probing target, it is impossible to separate directly information on beam parameters from a flux of background IN-particles on a detector. The correlation method of nonperturbative measurements of ion beam parameters considered in this paper allows one to overcome these difficulties.

Method

The correlation method of nonperturbative measurements of the ion energy spectrum has been previously proposed [6,7]. It is based on the use of test IN-particles produced in a target, pseudorandomly modulated in time, and detected at drift distanse L. To measure the transverse beam emittance, for example in the (Y,Y')-plane (see Figure), one or a few thread-type targets parallel to the (X,Z)-plane can be formed in front of a bending transport line area. If the ion beam current is invariable during

measurements, the spatial X-dimension of the target must be required for reproducing target time modulation by the flux ψ°_{pn} of test IN-particles

$$\psi^\circ_{pn}(t) = \mathrm{const}_{(n)} \cdot I^\gamma_n(t), \qquad (1)$$

where I^γ_n is the flux of photons or particles in the n-target. The targets are fixed in space and separated from each other along the Y-axis. When one target is used, it moves in parallel along the Y-axis. Taking into account (1), the autocorrelation function of the flux of test IN-particles on a m-detector is equal to

$$R^{PP}_{nm}(\tau) = \int_{-\infty}^{\infty} \psi^\circ_{pn}(t) \cdot \psi^\circ_{pn}(t-\tau) \cdot dt = \sum_{K=-\infty}^{\infty} \delta(\tau - K \cdot T). \qquad (2)$$

The pulsed characteristic $h_{nm}(t)$ of the drift distance from the n-target to the m-band-type detector (Y'=fix) is related to the velocity (V) distribution of IN-particles (t= L/V) in the n-m direction and, hence, to the energy spectrum of ions. The fluxes of IN- particles in the n-target area (ψ°_n) and on the m-detector (f°_{nm}) are related by the convolution

$$f^\circ_{nm}(t) = C_m \cdot \int_0^{\infty} h_{nm}(\tau) \cdot \psi^\circ_n(t-\tau) \cdot d\tau \ , \qquad \sum_m C_m = 1 \ , \qquad (3)$$

where $\psi^\circ_n = \psi^\circ_{bn} + \psi^\circ_{pn}$, ψ°_{bn} is the flux of background IN-particles produced in the residual gas. Taking into account the independence of ψ°_{bn} and ψ°_{pn} and measuring the cross-correlation function between the fluxes of target particles or photons and IN-particles on the detector

$$R^{\gamma\circ}_{nm}(\tau) = \int_{-\infty}^{\infty} I^\gamma_{nm}(t) \cdot f^\circ_{nm}(t-\tau) \cdot dt = B_{nm} \cdot \int_0^{\infty} h_{nm}(t) \cdot R^{PP}_{nm}(\tau+t) \cdot dt =$$
$$= B_{nm} \cdot \sum_{K=0}^{\infty} h_{nm}(\tau - K \cdot T) \ , \qquad (4)$$

we obtain the pulsed characteristic of the drift distance in the n-m direction ($I^\gamma_{nm} \propto I^\gamma_n$). Using normalization $\int h_{nm}(\tau) d\tau = 1$, we get from the B_{nm}-matrix information on the ion distribution in the (Y,Y')-plane and thus on the beam Y-profile and transverse emittance.

In reality, we must form such targets when convolution (4) of h_{nm} and R^{PP}_{nm} does not change the supposed $h_{nm}(t)$-function. In accordance with [8], this condition means that a periodically replicating element of the autocorrelation function of the I^γ_n-flux must have a sufficiently narrow shape in time with width $\Delta \ll \tau_{max}$, where $h_{nm}(\tau) = 0$ for $|\tau| \geq \tau_{max}$, and its period T must meet the condition $T > 2 \cdot \tau_{max}$. Correlation methods measure a useful signal with a background which is several orders of magnitude more than the signal. Thus, measuring $R^{\gamma o}_{nm}(\tau)$ by "n·m" correlometers, the energy spectrum and distribution of ions in the (Y,Y')-plane can be controlled without perturbation of beam parameters.

Apparatus

Nonperturbative measurements of ion beam parameters, for example in a source of H^- ions, can be realized according to the scheme shown in Figure. It is analogous to the previously proposed one [7], but it contains "n" identical photon targets (I^{γ}_{n}) and photon detectors (D^{γ}_{n}), "n·m" correlometers (C_{nm}) and band-type detectors (D^{o}_{nm}) of fast H^{o} atoms. When probing targets are formed by diaphragming radiation with an optimum polarization and a wavelength of $\lambda = 10600$ Å from the Nd:YAG laser with synchronized modes (see Fig.a,b), the test H^{o} atoms follow the H^- velocity in magnitude (in relative units) and in direction (in rad) with accuracies of $\sim 4 \cdot 10^{-3} \cdot (E_{i(keV)})^{-0.5}$. The series duration of pseudorandom radiation pulses is $T_s \approx 100$ ns and the width of the autocorrelation function is $\Delta \approx 50$ ps [9]. Thus, such photon targets due to H^- photodetachment can efficiently generate test IN-particles (H^{o}) and allow one to measure pulsed characteristics of the drift distance $h_{nm}(\tau)$ which are fairly short in time. At present, potentialities of the above diagnostics are mainly limited by the fast action of correlometers.

The cross-correlation function $R^{\gamma o}_{nm}(\tau)$ between the photon flux I^{γ}_{nm} from a partly reflecting M_{nm}-mirror and current $I^{o}_{nm} \propto f^{o}_{nm}$ from the D^{o}_{nm}-detector can be measured by means of a time-integrated C_{nm}-correlometer based on charge-coupled (CC) linear structures [7,10]. As a result of the wavequide propagation of photons through GaAS CC-linear structure 1 (see Fig.c), the I^{o}_{nm}-current modulates the flux I^{γ}_{nm} by the photoelectric absorption effect within a $\approx$ 100% dynamical range of modulation. An instantaneous spatial distribution of charges over the pixels of this structure corresponds to the discrete-in-time representation of the shape of

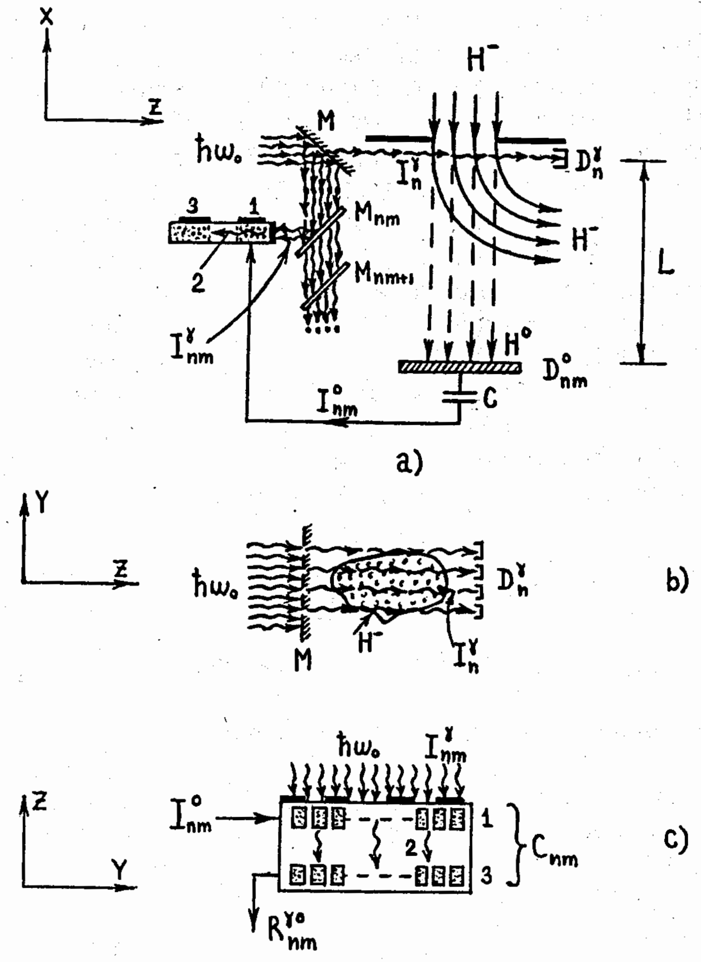

Fig. Schematic of measurement apparatus.

a I°_{nm}-current signal. After the modulation, photon flux 2 is detected by silicon CC-linear structure 3. The spatial distribution of charges accumulated there during the measurement time T_m corresponds to the discrete-in-time presentation of the $R^{\gamma\circ}_{nm}$-function. Fairly large I^{γ}_{nm}-fluxes of photons provide the needed charge within the pixels of the detected CC-linear structure during a short time within a pulse of the ion beam. The $R^{\gamma\circ}_{nm}$-functions can be read out during intervals between target switchings or between ion beam pulses and taking into account the guiding frequency of modulating structures 1.

As estimates for the source of H^- ions with an energy of $E_i \approx 20$ keV, $L \approx 100$ cm and the average power density of laser radiation within the duration of a series of pulses $I^{\gamma}_{n} \approx 4 \cdot 10^5$ W/cm^2 ($\psi_{bn}/\psi_{pn} \approx 10^2$), the proposed apparatus allows one to realize nonperturbative measurements of beam parameters during $T_m \geqslant T_s \approx 100$ ns with accuracies, e.g., of ≈ 0.4 % in energy and of $\approx 2 \cdot 10^{-4}$ rad in Y'.

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