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SECONDARY ELECTRON METHODS FOR ION PHASE MOTION RESEARCH

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ABSTRACT

Methods for phase spectrum and longitudinal emittance research of ion beam are considered. They has been grounded upon a secondary electron detectors (IFS) which isochroniously transform a primary ion beam into secondary electron and then collect it in accordance with its particles phase relatively to RF chopper of detector. The IFS has small size along accelerating channel up to 10 cm and high phase resolution nearly 1 degree calculated according to bunch repetition frequency. The results of IFS testing under 100 MeV proton beam have been described. For meson facility linacs IFS with longitudinal modulation must be used.

INTRODUCTION

A problem of bunches' phase length measurement and beam boundary determination in longitudinal phase space in real accelerating and focusing channels of linacs is practically important for longitudinal phase space matching. Two methods of measurement are known recently. First one is based on elliptical phase boundary restoration by three bunches' lengths measurements. Second consists of phase spectrum detection for a number of momentum values and computor restoration of elliptical beam phase boundary. First method has been described in details in [1,2] and more generally for five parameter phase ellipse restoration in one of papers presented on this conference. In this paper second method is discussed.

PHASE-SPECTRUM DETECTOR REQUIREMENTS

A major device for experimental research of ion phase motion is a phase-spectrum detector (IFS). Applied to medium energy and high average current ion accelerators IFS have to satisfy a number of strong requirements.

For ion bunches with phase extent about 10° IFS phase resolution must be not more than $1^{\circ}...2^{\circ}$ according to pulse repetition freq. A detector's length along accelerator axis have to be not more than 20 cm, a beam perturbation by it must be small. IFS construction have to ensure its serviceability check without equipment disassembling in accelerating channel. Major IFS parameters are to be independent of ion energy what makes possible its single type applying for entire accelerator.

According to Kotelnikov's theorem [3] phase resolution of 1...2 degree at .2 GHz corresponds to detector's bandwidth 36...48 GHz or time resolution of 14...28 ns.

RF secondary electron phase-spectrum detectors [4,5,6,7,8] most completely satisfy mentioned above requirements. In this devices secondary electrons transfer ion beam's phase spectrum from high to low energy domain.

One of the first detectors of this type was a device for secondary electrons outlet time dispersion measurement [4]. The dispersion is not more than 6 ps and it determines a limit on secondary electron methods of phase spectrum measurement.

DETECTOR OF PHASE SPECTRUM

IFS consists of primary converter (PC), RF chopper, collector of secondary electrons and corresponding hardware.

PC is used for isochronous transformation of primary beam into secondary electron and for electron beam focusing on RF chopper income, an axis of which is perpendicular to ion beam. PC must be installed within ion channel aperture to minimise an influence of primary and secondary beams' own fields upon IFS resolution. PC represents a target unit with threadlike focusing electrodes a plot of which is given in fig.1. Target sizes and mutual layout becomes clear from this figure. When a proton beam with an energy 100-600 MeV is analysed, potentials of target and A electrode are equal to U, while B electrodes are under .3·U.

Beam's finite transverse sizes in PC and electron initial velocity spread results in electron dephasing $\Delta\varphi_1$, $\Delta\varphi_2$ respectively. By choosing PC parameters for corresponding proton energy a value $\Delta\varphi_1$ may be reduced to negligibly small compared with $\Delta\varphi_2$. Dependences $\Delta\varphi_1(W_o)$, $\Delta\varphi_2(W_o)$ on electrons' energy W_o which are connected with target potential by $W_o=eU$ for given target configuration and 100 MeV proton energy are displayed in fig.2. According to this figure the isocronism breakdown in PC at W =4keV is less than 1° at .2 GHz.

Supplement error mainly originates from electron and ion bunches own fields. Dependences of secondary electron beam divergence $\Delta x'$ on PC outcome, its momentum spectrum width δ and electron dephasing $\Delta\varphi_q$ upon ion own field influence are displayed in figs 3,4. Proton beam parameters were: energy 100 MeV, diameter 5 mm, bunch phase length 10° at .2 GHz and pulsed current .05 A. PC parameters were: for fig.3-target potential U=-4kV, distance from target and ion beam axis to rf cavity wall is equal to 20 mm; for fig.4 distance x_1 from target to the wall was changing, other parameters were the same as for fig.3.

It has been shown that to obtain phase resolution in the range $1^{\circ}...2^{\circ}$ values δ, $\Delta x'$, $\Delta\varphi_q$ must be not more than 1%, .01 rad,

.5°...1° respectively. Then as it follows from figs 3,4 an equivalent target radius R_t must be not less than 2 mm and the target have to be in ion current density maximum.

Simulation of secondary-electron own fields' influence on their dephasing has shown that target voltage must be less than -4 kV, electron beam width -minimum and RF cavity capasitive gap has to be installed on ionguide boundary. That's why a target as a thin 4 mm strip has been chosen, and cavity had transit hole of 1mm width.

RF CHOPPER OF IFS

Choppers of longitudinal [5,6] and transverse [4,7,8] types have been used. In first one electrons have been modulated on momentum component parallel to beam axis (with regard to their initial phase) are spatially separated by spectrometer. In second RF modulation perpendicular to beam axis is used and electrons are separated in free of fields interval.

Chopper operation must be independent of particles' position on its income. It can be more easely realised in longitudinal type of devices. For example by choosing a thoroidal cavity with a 5...6 mm gap one can ensure essential uniform RF field in electron transit 1...2 mm slot and in the same time suppres multipactoring in meter wavelength range.

Chopper's phase resolution may be defined as relation of electron momentum spread or their divergence on chopper's inlet to this values maximum gain on the outlet. Then as it follows from figs 3,4 bunches own fields influence on phase resolution will be minimum for longitudinal chopper.

A choice of this chopper type and this cavity position on ionguide boundary provide IFS high resolution. It must be noted that one should never install capasitive gap in ion beam space because electrons are modulated by resulting field of generator and beam in this case.

In terms of matrix formalism one can easily determine choppers phase resolution under condition of spatial separation of two beams' outlet phase portraits depending from each other by inlet phase $\Delta\varphi_3$.

Dependences $\Delta\varphi_1$, $\Delta\varphi_2$, $\Delta\varphi_3$ and IFS space resolution $\Delta\varphi$ with an account of W_e for two chopper cavity gap voltages 1 kV and 3 kV are displayed in fig 2. Dependence $\Delta\varphi_3(W_e)$ is given for next chopper parameters at twofold accelerator bunch repetition frequency for I-100 linac: 5.5 mm gap, angle and bending radius of magnetic spectrometer 180° and 90 mm respectively. In fig 5 the chopper phase resolution dependences on inlet phase φ_0 for 4 keV electrons were shown when moduling amplitude has been 1 kV (solid line) or 3 kV (broken line). Adduced dependences show that this choper ensures high resolution in wide range of inlet phases. Thus with an installation of multichannel secondary electron current collector on spectrometer outlet one can realise an IFS with phase spectrum detection time less than duration of current pulse. When U_1 =1kV a dependence $\Delta\varphi(W_e)$ has an optimum for U =4kV and it has been realised in IFS tested under I-100 beam.

MEASUREMENT OF PHASE-ENERGY DISTRIBUTION IN ION BUNCH

Ion phase-energy distribution in a bunch on linac outlet has been measured by two-slot method in longitudinal phase space. This distrbution represented a number of phase spectra obtained by means of IFS described above in the form of bar charts for beam particles momentum that have been picked out by magnetic spectrometer. Spectrometer's value of relative resolution by particles' momentum was equal to .0011 . To eliminate phase distribution measurement error of particles in a bunch as a result of coherent longitudinal oscilations a power of IFS has been phase-locked with an accelerated current second harmonic by feed of its detector (see fig.6) signal on IFS' RF amplifier input.

Steps of phase spectra sampling and spectrometer re-tuning in relative momentum units were equal to resp. 2.2° at 297 MHz and .0011 . Given intervals were taken as scale units in fig 7.

In longitudinal phase space δ, φ ($\delta \equiv \Delta p/p$) points of particles' equal density (see fig.7) are distinguished. They have been determined on .1 and .5 levels from maximum of phase-energy distributions for beam close-to-axis particles (points near curves 1,2) and particles at a distance .5 cm. This particles' situation have been determined by intersection of respecting level line with phase-spectra functions.

Phase trajectories were determined by least-square technique as ellipses an equation of which was taken

$$M\equiv A\varphi^2+2B\varphi\delta+C\delta^2+2D\varphi+2E\delta+F=0$$

where $A=\cos^2\alpha/R+R\sin^2\alpha$, $2B=\sin2\alpha\,(R-1/R)$, $C=\sin^2\alpha/R+R\cos^2\alpha$.

Ratio R is a relation of ellipse's axii. As it is known from linear theory of syncrotron oscillations by measuring this ratio one can determine their frequency and average axial field.

It follows from an above consideration that software development for phase-energy spectra measurement produces new additional information on longitudinal phase motion parameters with a required high precision.

It must be mentioned in conclusion that by substituting spectrometer of this type in IFS on spectrometer with crossed electric and magnetic fields IFS' sizes along accelerating channel may be reduced up to 10 cm.

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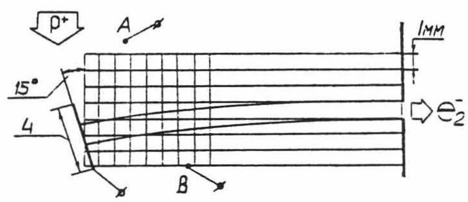

Fig.1 Plot of primary converter

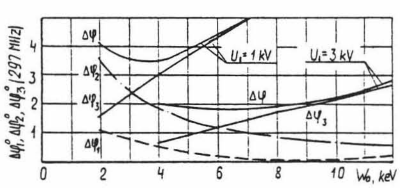

Fig.2 Dependences of chopper resolution $\Delta\varphi_3$, IFS resolution $\Delta\varphi$ and dephasing $\Delta\varphi_1$, $\Delta\varphi_2$, on electrons' energy W_o.

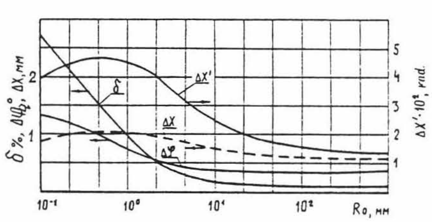

Fig.3 Values δ,$\Delta\varphi_2$,$\Delta x'$,Δx dependences on target equivalent radius R_o.

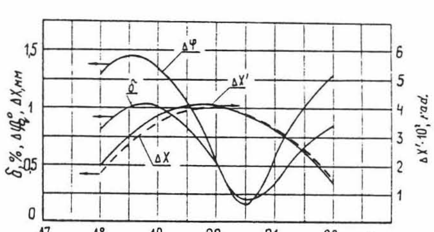

Fig.4 Values δ, $\Delta\varphi_2$,$\Delta x'$,Δx dependences on target position in relation to ion beam axix x_1.

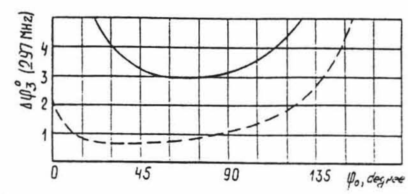

Fig.5 Chopper phase resolution on electrons inlet phase φ_c. Upper curve for gap voltage 1kV, lower 3kV.

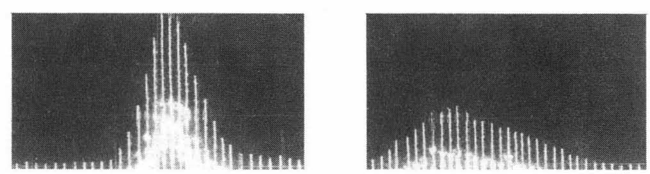

Fig.6 Proton beam's phase spectra under IFS syncronization with current second harmonic and linac's RF field. Device for compensating field decrease due beam loading is switched off.

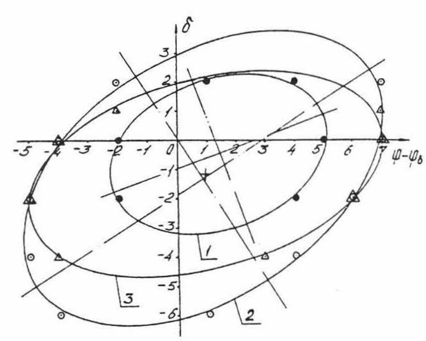

Fig.7 Equal phase density lines for 100 MeV proton beam on the I-100 linac outlet.