TOMOGRAPHIC METHOD OF EXPERIMENTAL RESEARCH OF PARTICLE DISTRIBUTION IN PHASE SPACE

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I. INTRODUCTION

In high-frequency resonant accelerators the criterion of quality of beam dynamics accounts is the set of parameters, which describe a bunch of particles in six-dimentional phase volume. As a rule, experimental methods permit to receive the authentic information only about some parameters, but not about all set. On linear electron accelerator "Fakel" for experimental researches of multidimentional distributons of particles in phase space the method is advanced which in its essense is tomographic.

II. METHOD

The base of method prescribes the work [1], in which the high-frequency field of external generator in one of accelerating sections is used for measurement of dependence of intensity of particles in the bunch of linear electron accelerator particles beam from their phases. The new opportunity was mentioned of research not only one-dimentional particles distributions on phases, but also two-dimentional on longitudinal phase plane [2]. Thus, as well as in work [1], studied distributions are average on many bunches. This approach may be used and for study of two-dimentional distributions of particles on cross phase planes.

Essense of method is the following. Let, for example, electron beam consistently passes through thin dipole magnet, thin quadrupole lens and after collimator falls on current mesuring instrument. In utmost case (narrow collimator slot and enough thin dipole magnet) current measuring instrument will registrate beam particles, presenting points of which on phase planes, for example, lie on straight line:

$$x' = -\frac{1}{L} - \frac{eB_1 l_1}{p} \quad (1)$$

where: e - electron charge, p - pulse of particles, B_1 - the magnetic field induction in dipole magnet, l_1 - magnet length ($l_1 << p/eB_1$), L - distance from magnet to collimator. Measuring dependence of intensity from field induction B_1 is proection of two-dimentional particles distribution function on $\boldsymbol{K} = (1/L, 1)$ direction of phase plane (x, x'), and induction B_1 changes in limits $-B_0 < B_1 < B_0$, where B_0 - induction, when signal from current measuring instrument is equal to zero. The direction $\boldsymbol{K}$ is possible to be changed by changing of gradient of induction B_z in quadrupole lens. When gradient in lens is dB_z/dx, on current mesurement instrument the particles fall, presenting points of which on the phase plane (x, x') lie on the straight line:

$$x' = -\left(\frac{e\frac{dB_z}{dx}l_2}{p} + \frac{1}{L}\right)x - \frac{eB_1 l_1}{p} \quad (2)$$

where l_2 is the length of quadrupole lens. Thus, repeating repeatedly the procedure of induction B_1 changing, as it was mentioned before, at various induction gradient dB_z/dx values, it is possible to define the proections of two-dimentional distribution functions of particles on any direction

$$\vec{K}\left(\frac{dB_z}{dx}\right) = \left(e\frac{dB_z}{dx}\frac{l_2}{p} + \frac{1}{L}, 1\right)$$

of plane (x, x'). For two-dimentional distribution functions measurements of particles in plane (y, y') it is necessary to turn the dipole magnet on 90^0 and to change the current direction in quadrupole lens.

In the installation for two-dimentional distribution functions measurement of particles on phase plane "energy - phase" (E, ϕ) the beam consequently passes through accelerating section, magnetic analyzer and through slot falls on current measurement instrument. This scheme is analogous to previous one. In particular, phase shifter of accelerating section, let's name its diagnostic, is the analogue of dipole magnet, and diagnostic accelerating section - the analogue of quadrupole lens. As a diagnostic section for simplification of processing of experimental results it is convenient to choose the terminal section of accelerator. On the longitudinal phase plane (E, ϕ) with the help of spectrometer and slot the narrow band is allocated, all particles of studied distribution from which fall on current measurement instrument. The measurement of current afterwards spectrometer at various values of phase and amplitude of diagnostic field represents the determination of integrals of studied distribution functions on longitudinal phase plane. We must notice, that the directions on phase planes, along which the profiles of distributions are measured, are determined by amplitudes of diagnostic field, varying inclination of sinusoidal dependence of this field from phase.

III. THE RESULTS OF MEASUREMENTS

Figure 1 shows the examples of particles phase distributions profiles in bunches on (x, x') plane, and figure 2 - the same for longitudinal plane [2]. In both cases the measurements are conducted for beams, accelerated in regimes of stored energy. The measurements were conducted in various moments of current pulses, shown on figures. For beginning of readout of diagnostic section phase it was accepted phase value, appropriate to maximum of intensity in energy spectrum.

The analysis of experimental results has shown:

1. At definite conditions of formation the appearance of bunches-satellites is possible, containing 6-10% of all accelerated electrons.
2. During current pulse the picture of distributions can change. In particular, the reduction of average energy in the bunch during current pulse and increasing of space division of these bunches, that is, appearance of "second beam" is observed.
3. Losses of accelerated beam are maximum in the beginning of current pulse and monotonously decrease to total disappearrance at the end of pulse.

The received results allowed to study more deeply the process of accelerated beams formation and, in particular, to find out the role of different variants of operative setup, particles capture on parts of electrodynnamic structures with sharp unhomogeneities, breakage of distributions on longitudinal phase plane owing to losses because of cross movement, leading magnetic fields unhomogeneitiess and other factors.

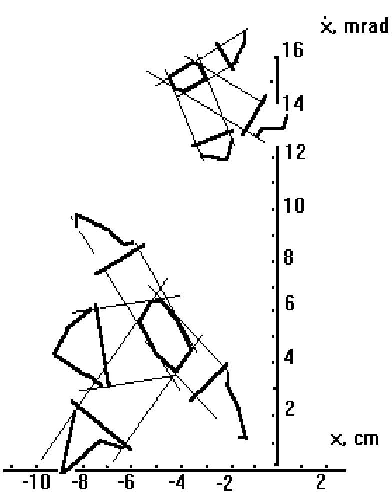

Figure 1. The trasverse phase space (x, x'). Four proections locate the main part of beam particle distribution (lower). The rest three proections (upper) give the position of satellite.

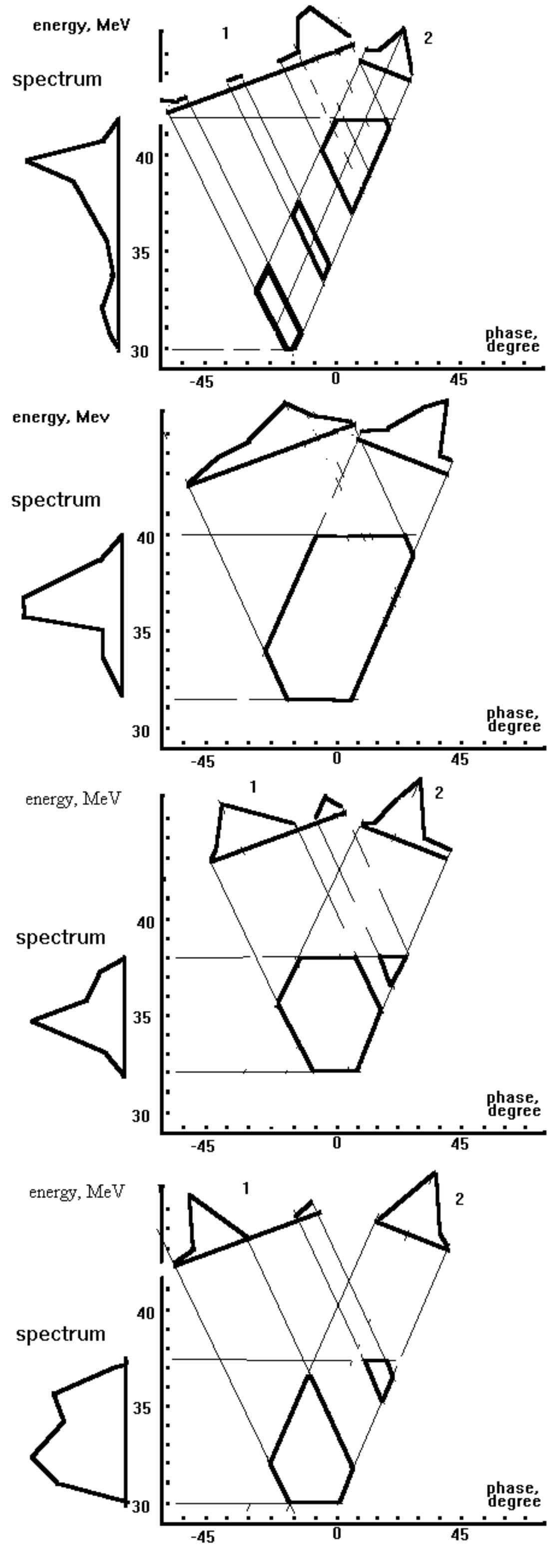

Figure 2. Longitudinal phase space (E, ϕ). Evolution of beam particle distribution during pulse of beam current: at 25 ns (upper picture), 45 ns, 65 ns and 85 ns (lower picture).

IV. CONCLUSION

The method, considered here, of resonant accelerator bunches research, in its essense, as it already was indicated, is tomographic. In it the role of "layer scanning sources" of bunches is executed in cross planes by dipole and quadrupole magnets, and in longitudinal - by diagnostic section and its phase shifter. Current measuring instrument, installed on output of considered schemes, fixes the integrated value of beam - "beam-sum". This signal with the help of analog-digital converter can be entered in the computer memory. Further, manipulating according to definite laws by analogues of layer scanning sources, it is possible to receive the set of "beam-sums", determining necessary proection distributions. In the case of restoration distributions in cross plane the task is linear, and in case of longitudinal plane - nonlinear one.

V. REFERENCES

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[2] Kalashnikov V.V., Moisseev V.I., Petrenko V.V. Experimental investigation of self-consistent longitudinal beam dynamics in transition acceleration mode of linear accelerator "Fakel". -In the book::IX All-Union conference on charged particles accelerators. -Dubna, 1989, v.1, p.453-455.