ON MEASUREMENT OF ION BEAM PHASE VOLUME

by

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Two basic methods of measuring the phase density distribution in a charged particle beam are known: a two-slit method and a four-slit method.[1]

In the two-slit method, a portion of a beam corresponding to a certain value of Cartesian coordinate x, is at first cut by a narrow slit, and then in the cut portion of the beam the distribution of relative transverse velocities x' is analyzed by the second slit, parallel to the first one. This method is comparatively simple and is widely used recently with completely automatic measuring and processing of experimental data.[2,3] This method of measurement gives distribution function values integrated over another pair of coordinates (y and y'). In the four-slit method, slits, cutting the beam, are practically replaced by movable diaphragms. This method allows to obtain the distribution of phase density in the four-dimensional space of transverse coordinates (x,y,x',y').

Let us consider the possibilities of each method from the viewpoint of obtaining information on the beam and applying the obtained data for calculations and analysis of the motion of charged particle flux in the accelerator.

The distribution of particles in the transverse phase space can be characterized by the distribution function

$$f\,(x,y,P_x,P_y) = \int_{-\Delta P_z}^{\Delta P_z} \Psi\,(x,y,P_x,P_y,P_z)\,dP_z$$

The total beam current can be obtained as

$$I = e\,V_z \iiiint f\,(x,y,x',y')\,dx\,dy\,dx'\,dy' \quad .$$

The measurement of phase volume by the two-slit method defines the function, integrated over y and y'

$$D\,(x,x') = \iint f\,(x,y,x'y')\,dy\,dy' \quad .$$

This method allows to define the projection of phase volume onto the plane (x,x') and to find the distribution of current in the projection, i.e., to define

$$\frac{I_p}{I_{total}} = \frac{\int_{x_1}^{x_2} dx \left(\int_{x_1'(x)}^{x_2'(x)} D\,(x_1 x')\,dx' \right)}{\int_{-\infty}^{\infty} dx \left(\int_{-\infty}^{\infty} D\cdot(x_1 x')\,dx' \right)}$$

where x_1, x_2, $x_1'(x)$, and $x_2'(x)$ are the boundary points of internal regions of the phase volume projection; I_{fp} the beam current, corresponding to the phase volume projection inside the complete projection.

Knowledge of the complete projection makes it possible only to determine maximum amplitudes of particle oscillations in the beam in further passage of the beam particles through the transport channel. From this point of view this information is only suited for analysis of the motion of the charged particle flux in microcanonical approximation and then it is hardly worthwhile to determine the distribution of current in the projection.

Therefore, for the measurement of the ion beam characteristics, it is sufficient to define the value and shape of the projection onto one of the xx' or yy' planes and the total beam current. This will be sufficient for obtaining the operative information in the accelerator operation.

The more detailed investigation of beam characteristics requires the application of the four-slit method. This method is simplified for axisymmetric beams. These ion beams are basically used in direct current accelerators and, particularly, in injectors or linear accelerators. For these beams the distribution function can be presented in the space of three coordinates R,R' and $t=R\theta'$.[4,5] (R,R' and t are radius, relative radial and azimuthal velocities, respectively.) In this case for the measurement of the phase density distribution it is sufficient to measure Dy = (x,x',y'); this gives the complete information on the beam in the arbitrary azimuthal and radial velocity distribution of particles. The passing to the cylindrical system of coordinates makes it possible to consider the motion of particles with constant moment of pulse independently. Here all representative points of the beam particles can be presented in the planes R_t = const in coordinates R R'; for each section by the plane R_t = const Liouville's theorem is valid.

Existing methods of calculation[6,7] make it possible to calculate such a flux of charged particles in arbitrary fields.

The analysis of experimental data shows that even the measurement of only the transverse phase-volume section by the y=y'-0 plane (or in the R_t=0 plane) gives more complete information on the character of the motion of particles in the beam than knowledge of the projection can give.

Figure 1 shows the photos of the beam images cut by the slit and observed on a quartz-glass at different positions of the slit (coordinates x).

Figure 2 shows the image photos of the same beam, diaphragmed by the circular hole at different positions of the diaphragm (coordinate R).

Figures 3 and 4 give the section and projection images of transverse phase volume. As seen from Figs. 3 and 4, the projection differs greatly from the section. From the analysis of the section, the conclusion can be made on the character of the beam particle motion in the drift region and in the acceleration tube and on the reasons causing the distortions of the phase volume configuration. Examples under consideration show the presence of strong aberrations in ion optics. Thus, the investigation of ion sources and ion-optical properties of forming systems of the charged particle beam requires the measurement of the distribution function in four-dimensional phase volume (for the circular beam the measurement by three coordinates R,R',t is sufficient).

In a number of cases the measurement of the distribution function in the R_t=0 plane is sufficient for obtaining the operative information and also for simplicity.

It should be pointed out that a rather complicated form of the image of the beam is cut by the slit (Fig. 1). Therefore, during the electrical measurements especially with automated systems, when the amplification factor of measuring devices is chosen with regard for the nonuniform distribution of the current density in the beam cross section, a part of the beam is inevitably lost in the measurements and the obtained particle distributions in the projection will be smoothed off and will not give the information on the character of transverse velocity distribution of particles.

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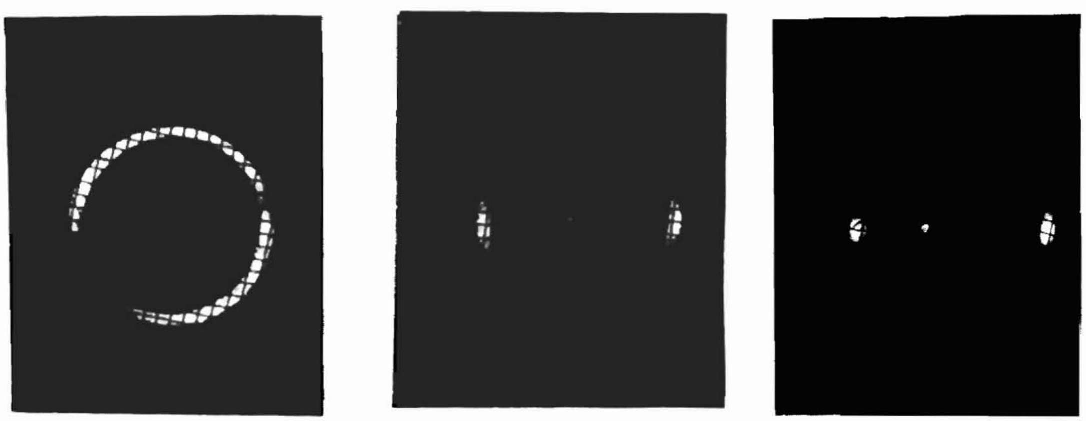
x=0 x=0.14cm x=0.28cm

Fig. 1. Photos of beam images after the slit (beam energy is 150 KeV, current is 3 mA).



R=0 R=0.14cm R=0.28cm

Fig. 2. Photos of the same beam images after the diaphragm.

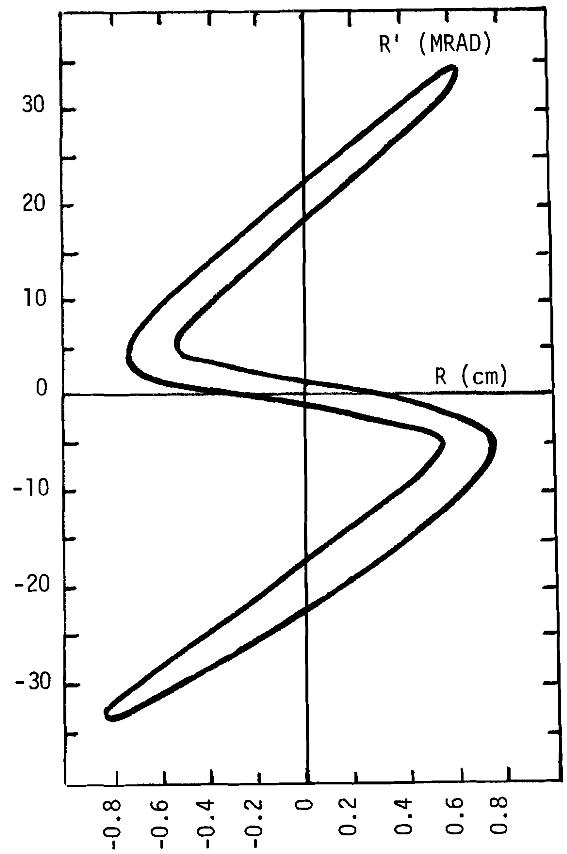


Fig. 3. Section of transverse phase volume by R_t=0 plane.

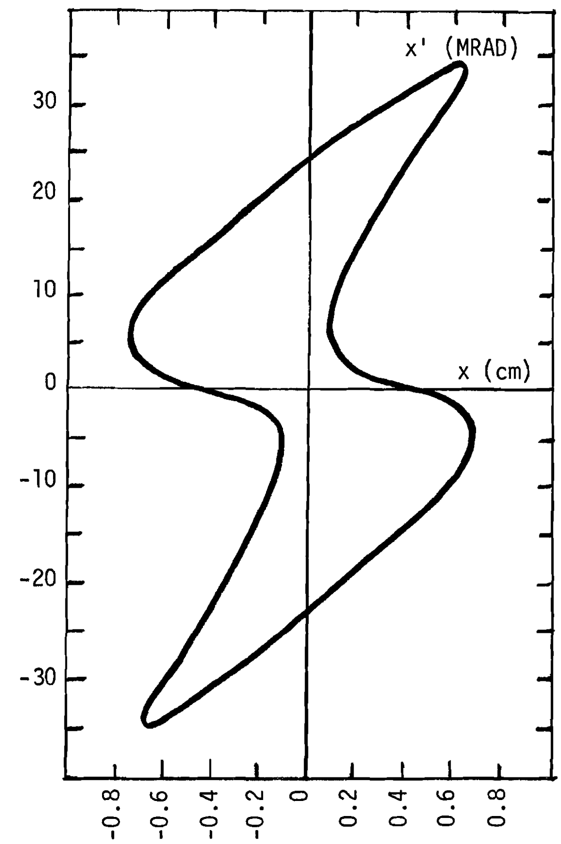


Fig. 4. Projection of transverse phase volume onto xx' plane.