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BOUNDARY OF ELECTRON BEAM RELEASE IN BETATRON WITH COMB-TYPE POLES

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Boundary of electron beam release in betatron with comb-type poles has been determined. It was shown that at the moment of beam extraction electron release from the influence of electromagnetic field focus forces on the border of comb and cavity of betatron poles. Beam particles in the process of extraction are grouped on azimuths located near lateral edges of pole combs. The results of researches may be practically applied when developing formation and extraction systems of betatron electron beam.

Introduction

In spite of a rather long period of successful use of betatron with azimuth field variation and electron beam extraction in practice the process of electron beam formation at the moment of extraction is still weakly studied [1–4].

The investigation of electron beam dynamics at the beginning of extraction process showed that electrons cross the release orbit on the azimuths coinciding with the arrangement of lateral edges of betatron poles combs. Particles at the moment of crossing release orbit are grouped on the azimuths defined by the position of pole combs. In this case azimuth distribution of electron beam on the release orbit has discrete behavior.

The release orbit of the particles from the influence of focus force in betatron with azimuthally symmetric field is determined by the magnetic hardness and represents circular orbit [1, 4]. The position of release boundaries in betatron with comb type poles is still unknown.

In the given paper the release boundaries of electron beam in betatron field with azimuth field variation are defined.

Release boundaries

Electron release boundary from the influence of betatron field focus force may be obtained from the system of differential motion equations [1]. Being limited by considering electron motion dynamics in equilibrium orbit plane of accelerator in cylindrical coordinate system at z=0 we obtain:

$$\frac{d\alpha}{d\varphi}+1=\frac{1}{r_0B_0}\frac{r\cdot B_z}{\sin\alpha},$$
$$\frac{dr}{d\varphi}=\frac{r\cdot\cos\alpha}{\sin\alpha}, \qquad (1)$$

where B_0 is the magnitude of magnetic induction on equilibrium orbit with the radius r_0; B_z is the induction vertical component on radius r; φ is the azimuth coordinate; α is the angle between the projection direction of electron velocity to the equilibrium orbit plane and direction of radius-vector $\boldsymbol{r}$.

Excepting azimuth coordinate in the equation system (1) we obtain the expression describing the conservation law of generalized angular momentum in magnetic field

$$-\frac{d}{dr}\sin\alpha=\frac{1}{r}\sin\alpha-\frac{1}{r_0}\frac{B_z}{B_0}. \qquad (2)$$

Conditions of vibration of extracted beam particles near equilibrium orbit are so that radial vibration boundaries are determined by the value of relative azimuth component of the velocity $\sin\alpha(r)=1$ that corresponds to circular motion with the angle α equal $\pi/2$. Thus, the following ratios are valid for the equilibrium orbit with radius r_0 and release orbit with radius r_k [1]:

$$\frac{d}{dr}\sin\alpha=0;$$
$$\sin\alpha=1. \qquad (3)$$

As a result, we obtain

$$r_0\cdot B_0=r_k\cdot B_z(r_k), \qquad (4)$$

from the expression (2) subject to conditions (3) that is particle release orbit r_k is determined by field magnetic hardness.

Induction vertical component B_z of betatron magnetic field with poles of comb construction [2, 4] in the plane of equilibrium orbit is determined by the following expression:

$$\begin{aligned}B_z(r,\varphi)&=p\cdot B_0+r_0B_0\cdot k_1[a_1J_0(k_1r)+b_1N_0(k_1r)]+\\&+\delta\cdot r_0B_0\{k_2[a_2J_\nu(k_2r)+b_2N_\nu(k_2r)]-\\&-(2\nu/r)[a_2J_{\nu+1}(k_2r)+b_2N_{\nu+1}(k_2r)]\}\cos(\nu\varphi). \qquad (5)\end{aligned}$$

Here $J_0(k_1r)$, $N_0(k_1r)$ are Bessel and Neumann zero-order functions of and $J_\nu(k_2r)$, $N_\nu(k_2r)$, $J_{\nu+1}(k_2r)$, $N_{\nu+1}(k_2r)$ are Bessel and Neumann functions of order ν and (ν+1); p is the constant constituent of vertical component of magnetic induction [3]; ν is the number of comb pairs; δ is the magnitude of field variation; a_1, b_1, a_2, b_2 are the amplitudes; k_1 and k_2 are the parameters of separation [2, 4].

Table. *Estimated characteristics of betatrons with azimuth field variation*

Betatron	MIB-6	MIB-1
Maximal energy of accelerated electrons, MeV	6	1
Number of comb pairs	6	4
Equilibrium orbit radius r_0, cm	6	5,2
Factor of field decrease n	0,667	0,67
Field variation magnitude	0,21	0,14
Release orbit radius defined by azimuthally symmetrical field part r_k, cm	8,95	7,72

Usually in practice for betatrons with azimuth field variation the azimuth averaged experimental distribution of vertical component of magnetic field induction is determined by radius in accelerator median plane z=0 and radial component is defined by means of Maxwell equation. Therefore, both induction components may be presented as two functions one of which experimentally measured depends on radius r and another one depends on vertical coordinate z. In this case in the expression (5) theoretical distribution of azimuthally homogeneous part of magnetic field induction may be replaced by experimental distribution of field vertical component $B_z(\boldsymbol{r})$ on radius taken in the plane z=0.

Boundaries of electron beam release in chamber of betatron with azimuth field variation were defined on the basis of numerical method of roots finding. In this case either theoretical distribution of field magnetic induction (5) or the same distribution but azimuthally homogeneous part of which is touched up by experimentally taken azimuth averaged induction distribution were substituted to the right part of the equation (4). When calculating the release boundaries were determined additionally by azimuthally symmetric parts of accelerator fields (circular orbits with radius r_k) for comparison.

All calculations were carried out for small-sized betatrons with six comb poles of MIB-6 type and four comb poles of MIB-1 type the characteristics of which are given in the table.

Results

The design boundary distributions of electron release from the influence of focus field in the in chamber of betatron with azimuth field variation in the case of theoretical description of magnetic field vertical induction are given in Fig. 1.

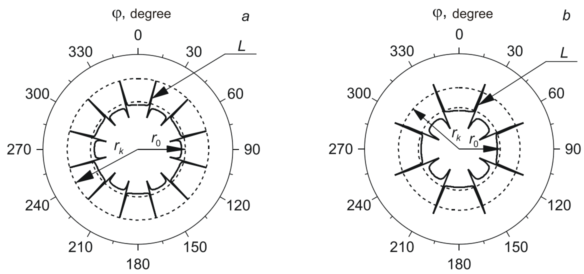

Fig. 1. *Boundary of release for betatrons of the type: a) MIB-6; б) MIB-1; L is the boundary of release*

It is seen from the Figure that the position of particle release boundaries in acceleration chamber of betatron with radial-comb poles differs from the one defined by azimuthally symmetric part of accelerator sum field. If in betatron with azimuthally symmetrical field the release boundary represents a circular orbit then in betatron with azimuth field variation the release boundary is the boundary between pole cavity and comb. The release boundary defined by azimuthally symmetrical part of accelerator sum field represents a circular orbit with radius r_k, equal 8,12 cm for betatron MIB-6 and radius r_k=7,42 cm for betatron MIB-1.

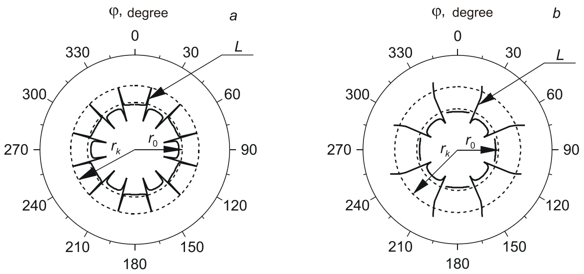

Fig. 2. *Release boundary for betatron of type: a) MIB-6; b) MIB-1*

The position of release boundary in betatron of type MIB-6 is shown in Fig. 2, *a*. The azimuthally symmetrical part of its magnetic field in accelerator median plane is described with the help of experimentally taken azimuth average distribution. And the position of release boundary in betatron of type MIB-1 is shown in Fig. 2, *b*. Particles at the extraction moment are released from the influence of field focus forces on the boundary of cavity and comb of betatron poles. Thus, at the beginning of the extraction process particles are grouped at azimuths correlated with the position of betatron pole comb.

Conclusion

As a result of carried out calculations the release boundaries of electron beam in betatron with azimuth field variation were determined. It was determined that the release boundaries represent the boundary between the cavity and the comb of betatron poles in contrast to the boundaries of electrons release from the influence of field focus forces in betatron with azimuthally homogeneous field.

The obtained results may be practically applied at development and adjustment of devices of electron beam formation and extraction from the betatron with azimuth field variation.

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