The paper describes the operation and construction of an electron gun designed to form beams with variable transverse energy and a variable spread of magnetic moments. Transverse energy is acquired by the electrons as the beam passes through a weakly non-adiabatic magnetic step, and in an adiabatic motion through a growing magnetic field. The small spread of magnetic moments of the beam electrons is achieved by fulfilling the so-called focusing conditions which ensure that the spread of moments resulting from different initial radii of the particles is compensated by their initial radial velocities.

1. INTRODUCTION

The transverse energy of beam particles and its distribution function play an important part in many experiments designed to study the interaction between a beam of charged particles and a plasma contained in a magnetic field. To create experimentally true conditions for our studies of these problems, we built a gun which injects the electron beam into a magnetic mirror system in the axial direction, and enables us to vary the mean transverse energy of beam particles and its spread.

The beam-producing gun is placed on the slope of the magnetic mirror. After leaving it, the beam passes through a magnetic step formed by a magnetic circuit. In this step the motion of the electrons is weakly non-adiabatic and the particles gain there their transverse energy (in a strong magnetic field it is practically impossible to produce a strongly non-adiabatic magnetic step). The magnetic step is followed by a growing adiabatic field in which the beam transverse energy is increased still further. The ultimate transverse energy and its spread is determined by the transverse energy gained in the magnetic step; consequently, by changing the latter we can change the transverse energy of the beam at the apex of the magnetic mirror. If a small spread of magnetic moments is required, too, the spread of the initial beam parameters must be a minimum. That is why it is advantageous to use a hollow beam. But, as we shall show in sect. 3, this provision alone does not guarantee a small enough spread of transverse energies. To obtain a small spread of magnetic moments we must satisfy the so-called focusing conditions to make sure that the spreads caused by different initial radial velocities and different initial radii will compensate one another. Hereafter we shall call the beams that satisfy the conditions for a small spread, focused beams. As the derivation of the focusing conditions, the study of the properties of focused beams and the numerical solution of specific cases is described in paper [1], we shall summarize in chapter 2 the main results only.

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2. TRANSIT OF BEAMS OF CHARGED PARTICLES THROUGH A NON-ADIABATIC MAGNETIC FIELD

Suppose a hollow beam of charged particles which gain their transverse velocities by passing through the short lens of focal length \( f \) so that their deviation from the \( z \)-axis is given by the relation

\[
\tan \alpha = f(r_0) = \frac{\bar{r}_0 - r_0}{f}
\]

where \( r_0 \) is the radial coordinate of the particle and \( \bar{r}_0 \) is the mean radius of the hollow beam. The solution of the equation of motion of particles in a weakly non-adiabatic magnetic field leads to the following focusing conditions:

\[
\chi + \eta = \frac{\pi}{2} + n_0 \pi, \quad n_0 = 0, \pm 1, \ldots
\]

\[
f = -\frac{\sin(\chi + \eta)}{D}
\]

where \( \eta \) and \( D \) are functions of the shape of the magnetic field and the longitudinal velocity of the particles \( v \) and \( \chi \) is the value of the integral

\[
\chi(z) = \int_{z_0}^{z_c} \frac{\omega(z)}{v} \, dz
\]

where \( \omega \) is the cyclotron frequency and \( z_c \) the \( z \)-coordinate of the centre of the non-adiabatic region. This centre point can be chosen arbitrarily but the functions \( D \) and \( \eta \), as well as \( \chi \), depend on it. In the solution of the equation of motion in the first approximation, which does not take into account the non-adiabatic terms, \( \chi \) is the phase of the Larmor rotation of particle attained in the centre of the non-adiabatic field. In the non-adiabatic approximation the function \( \chi \) is in close relation to the particle phase in the centre \( z = z_c \) so that, as the focusing condition (2.2) states, all beam particles must fly through the magnetic step in the correct phase while the second focusing condition (2.3) determines the correct relation between the magnetic field shape, the longitudinal and the radial particle velocities at the start.

The shape of the magnetic field which we used in our experiments can be approximated very well by the relation

\[
\omega(z) = \frac{e}{m} B(z) = \omega_0 \left(1 - k \sqrt{\frac{a}{m} \int_{-\infty}^{z} e^{-sz^2} \, dz} \right)^{-2}
\]

For this field we made detailed numerical calculations and found the way to choose the injector parameters which give the desired beam parameters. Further we derived some general characteristics of this type of injector. These are briefly listed below.