# APPLICATION OF MAGNETIC SLITS FOR FORMING CIRCULAR CHARGED-PARTICLE TRAJECTORIES

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An electron-optical system is proposed for forming circular charged-particle trajectories; the system consists of magnetic slits arranged in a circle. The strength of the magnetic field in this system increases rapidly with distance from the axis, but there is no vertical defocusing. A system of this type can be used in an accelerator with a fixed guide field. An experimental investigation has been made of the first circuit of an electron beam in a system of this kind.

IN the present note we consider an electron-optical system for forming circular charged-particle trajectories by means of a magnetic field which increases rapidly toward the periphery of the systems; this field does not cause vertical defocusing.

The system consists of magnetic slits,* located at equal intervals about the periphery of a circle. The fields in adjacent slits are in opposite directions. Regardless of the field direction each slit deflects charged particles toward the axis of the system; with appropriate choice of magnetic field and particle vector velocity the particle will describe a trajectory which is essentially circular.

In order to simplify the analysis we replace the slit system by an equivalent system; the equivalent system consists of linear conductors in which the direction of current flow alternates as one goes around the circle (Fig. 1).

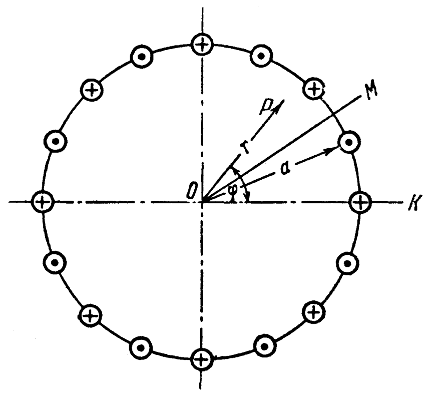


FIG. 1

In this system the vector potential is:

$$\frac{m}{e}\ddot{x} = -\frac{\partial Q}{\partial x}, \quad \frac{m}{e}\ddot{y} = -\frac{\partial Q}{\partial y},$$

$$Q = \frac{e}{2m}A^2$$

Here I is the current in each conductor; r is the distance from the system axis O to the point P at which the vector potential is computed; $\varphi$ is the polar angle, measured from a line OK which passes through the system axis O and one of the conductors; a is the distance from the axis to the conductor and 2n is the number of conductors.

Because the vector potential is independent of z this coordinate is cyclical. Hence the generalized momentum component $P_z$ is a constant:

$$P_z = \frac{\partial L}{\partial \dot{z}} = m\dot{z} + \frac{e}{c}A = m\dot{z}_0 + \frac{e}{c}A_0 = \text{const},$$

where

$$L = \frac{m}{2}(\dot{x}^2 + \dot{y}^2 + \dot{z}^2) + \frac{e}{c}A\dot{z}$$

is the Lagrangian. In a plane OM which passes through O and midway between any two neighboring conductors the vector potential vanishes. If the particle starts at any one of these planes with $\dot{z}_0 = 0$, in passing through any other of these planes its velocity component $\dot{z}$ will always be zero. Between any of the planes OM the particle is deflected upward and then downward (we assume that the conductors are oriented vertically); however, since

*By "magnetic slit" is meant an electron-optical deflection element which consists of two magnetic poles of opposite sign (elongated in one direction); in contrast with an ordinary deflection magnet, an electron is affected by the "fringing field" rather than the field in the gap itself. If the electrons which enter the field of a magnetic slit move in a direction which is perpendicular to the long dimension of the poles the trajectories are characterized by displacement in this direction and deflection in the direction of the magnetic slit.[1-3]

these deflections are equal, the particle oscillates about a plane perpendicular to the axis. The projection of the particle motion on this plane is described by the equation (in Cartesian coordinates)

$$\frac{m}{e}\ddot{x} = -\frac{\partial Q}{\partial x}, \quad \frac{m}{e}\ddot{y} = -\frac{\partial Q}{\partial y},$$

$$Q = \frac{e}{2m}A^2$$

and can be represented by a rubber-sheet model in which small balls move under the influence of gravitational forces.[4]

The profile of the rubber-sheet model consists of a number of elevated points (equal to the number of conductors) located in a circle. The height of the profile h is proportional to Q. It is apparent that conditions can be found for which a small ball will roll along the inner sides of the slopes, describing a trajectory which is almost circular. Because of frictional effects, however, only one complete circuit can be achieved. Nevertheless, this is sufficient to demonstrate the essential nature of the particle motion. We also note that a system of conductors in which the current flows in the same direction can also be used to confine charged particles. However, in a system of this kind it would be difficult to avoid loss of particles in the vertical directions.

An experimental device has been built to check the analysis given above (Fig. 2). The deflection elements are magnetic slits, since these provide considerably stronger magnetic fields than can be achieved with current-carrying conductors. The fields in adjacent slits are in opposite directions. In order to provide vertical focusing, the poles 1 which form the magnetic slits are concave in shape; although it would not defocus the beam, a system of straight magnetic slits would not produce focusing in the vertical direction. Each pole has a coil 2 of 200 turns. The chamber 3 is barrel-shaped and is provided with observation windows 4. Inside the chamber there is an electron gun 5 and a fluorescent screen 6. The electron gun forms a cylindrical beam with a divergence angle of 3°. It can be rotated about axis 7 and displaced over a small range. The screen can be moved around the axis of the system.

An investigation was made of the shape of the electron beam when the following parameters were varied: magnetic field strength, electron energy, position of the electron gun, and starting direction of the beam. At appropriate values of these parameters the electron beam is deflected in alternate directions by the magnetic slits, forming a complete circle.

An examination of the displacement of the luminous spot on the screen when the latter is moved shows that the electrons describe a spatial trajectory characterized by periodic radial and vertical oscillations, which are superimposed on a circle. With 16 poles and with the gun 4 to 5 cm from the poles the amplitude of the radial oscillations is approximately 2 cm and the amplitude of the vertical oscillations is approximately 5 cm. Under these conditions the electron energy is 5 kv and the current in the windings, which is a strong function of the distance between the gun and the poles, is 5 to 10 amps. The width of the image, which is a slightly curved band, varies between 1 and 3 mm, depending on the position of the screen. The image height is 10 to 20 mm. Similar results are obtained with 32 poles, although the oscillation amplitude is somewhat smaller.

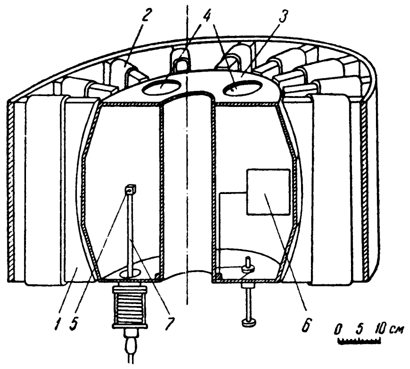


FIG. 2

Thus it would appear that a system consisting of magnetic slits arranged in a circle can provide a charged-particle trajectory that is almost circular.

Because the strength of the magnetic field increases rapidly with increasing distance from the axis of the system and because there are no vertical defocusing forces, a system of this kind can be used in an accelerator with a fixed (also variable) magnetic guide field. The charged particles in such a system can be accelerated by an induction scheme or by a variable electric field.

[1] Baranovskii, Kaminskii and Kel'man, J. Tech. Phys. (U.S.S.R.) **25**, 610 (1955).

[2] Baranovskii, Kaminskii and Kel'man, J. Tech. Phys. (U.S.S.R.) **25**, 1954 (1955).

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[4] Kel'man, Kaminskii and Iavor, J. Tech. Phys. (U.S.S.R.) **24**, 1410 (1954).

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