

THE COMPACT INDUCTION CIRCULAR ACCELERATOR FOR RADIATION TECHNOLOGIES

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Abstract

The variant of the circular accelerator of electrons with energy up to 10 MeV is discussed. Acceleration is carried out by an induction electric field on a constant equilibrium orbit of radius about 50 cm. For reduction of reactive power of the accelerator the alternating magnetic fields are concentrated in small volume near to the equilibrium orbit. Use of high-frequency magnetic fields (tens or hundreds kHz) allows to increase power of the accelerated electron beam up to some tens kW or some hundreds kW.

INTRODUCTION

The wide range of possible parameters of a electron beam allows to use these accelerator for a wide spectrum of applications: protection of an environment (for example: clearing flue gases of the industrial enterprises from harmful impurity NO_x, SO_x, etc.), updating and reception of the new materials, new technologies without application of harmful chemicals (polymerization of various materials, etc.), sterilization of medical tools, disinfection of medical and other waste products. Researches have shown, that methods of radiating processing of foodstuff (radurisation) in many cases successfully solve the problem long storage of products without infringement of their flavouring and nutritious qualities. Small dimensions and low cost of the accelerator, will allow to use it on fishing seiners for sterilization of fish products. Manuscripts

For many radiation technologies electron beams with energy 0.5 – 10 MeV with average energy of a beam from $\sim 10^3$ to $\sim 10^5$ W are required. As to energy such beams can be received by acceleration of electrons in the circular induction accelerator – betatron. Essential feature of the betatron work consists in the fact that speed of change of the average magnitude of a magnetic field induction B_{aver} should exceed twice speed of change of an induction in an equilibrium orbit B_0 . It is well-known a betatron condition « $B_{aver} : B_0 = 2:1$ » when the radius of an electron orbit remains to constants in a magnetic field growing in time.

Betatron rate «2:1» limit an average power of an accelerated electron beam because magnetic flux inside an equilibrium orbit and magnetic energy are very high. The number of particles, accelerated in one cycle of acceleration, is limited to instability of an electron beam, and the increase of a repetition rate demands increase in average power of accelerator power supplies which has a limit too.

The radius of an equilibrium orbit can remain to constants at increase in a magnetic induction in an orbit at

$B_{aver} : B_0 \ll 1$ if special ratio between amplitude-time characteristics of a magnetic induction in an orbit and an induced accelerating voltage are carried out. At $B_{aver} \ll B_0$ magnetic energy of the accelerator decreases and so both frequency of accelerating cycles and average capacity of the accelerated beam can be essentially increased. And use of rigid focusing by magnetic field B_0 with the high radial gradient (the module $|n| \gg 1$) allows to increase number of electrons in the orbit and to reduce dimensions of magnetic system.

MAGNETIC SYSTEM

The magnetic field in an equilibrium orbit is formed by C-shaped electromagnets with the high parameter of the field $n_1 \gg 1$ (Figure 1(a)) and $n_2 \ll -1$ (Figure 1(b)). The combination of such magnets allows to realize rigid focusing of electrons. Electromagnets are fed by a rectangular wave of a voltage V_0 (Figure 2(a)) and form the magnetic B_0 induction which form is shown on Figure 2(b). For reduction of energy losses at magnetic reversal of electromagnet cores the magnitude of induction chooses much less induction of saturation of a core material.

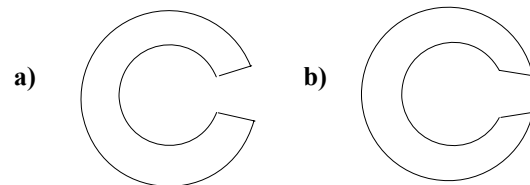


Figure 1: C-shaped cores of electromagnets: a) $n \gg 1$, b) $n \ll -1$.

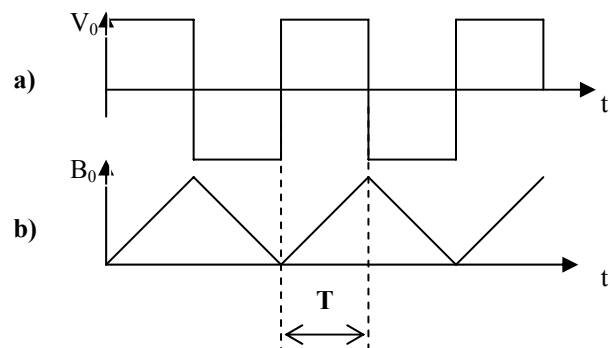


Figure 2: a) Square wave of Power System, produced by transistor converter, b) Form of magnetic induction B_0 .

ACCELERATING SYSTEM

Electrons are accelerated by the electric field induced by O-shaped ferromagnetic cores which are located on

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one or several azimuths of an electron orbit. To keep radius of an orbit to constants during acceleration, the gain of an electron energy $e\Delta U_{\text{aver}}$ for one turn should be equal

$$e\Delta U_{\text{ac}} = e\Delta B_0 v R_0,$$

where ΔB_0 – the gain of a magnetic induction of C-shaped magnets during for one turn, R_0 – equilibrium radius of an orbit, v – speed.

At linear growth of an induction in time

$$B_0(t) = B_{0\text{max}} (t / T)$$

where T – time of increase of an induction, the amplitude of induced pulses of accelerating voltage ΔU_{ac} should be equal

$$\Delta U_{\text{ac}} = 2\pi R_0^2 (B_{0\text{max}} / T)$$

The form of a wave of accelerating voltage $U_{\text{ac}}(t)$ is shown on Figure 3.

Pulse duration τ of accelerating voltage U_{ac} is equal to half of time of a electron turn in an orbit

$$\tau = \pi R_0 / v$$

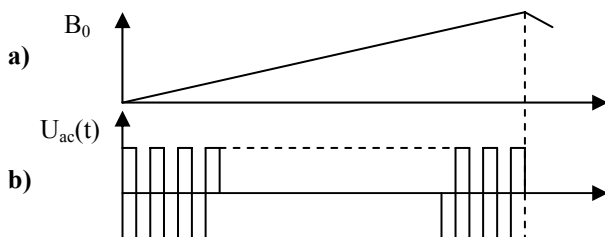


Figure 3: a) Magnetic Induction in equilibrium orbit. b) Waveform of accelerating voltage induced by O-shaped cores.

ACCELERATOR PARAMETERS

For an example we shall consider key parameters of the electron accelerator on energy $E = 10\text{MeV}$ with radius of equilibrium orbit $R_0 = 0.5\text{m}$ and time of induction increase $T = 5\mu\text{s}$.

The maximal size of a magnetic induction of C-shaped cores is equal

$$B_{0\text{max}} = m\gamma v / eR_0 = 0.067 \text{ T}$$

This magnitude is much less than induction of saturation of ferromagnetic cores, therefore losses of energy on their magnetic reversal will be small.

The amplitude of accelerating pulses is equal

$$\Delta U_{\text{ac}} = 2\pi R_0 (B_{0\text{max}} / T) = 42\text{kV}$$

If the magnetic induction O-shaped cores does not exceed $B = 0.1\text{T}$ losses in cores will be small. At such magnitude of an induction the total section accelerating O-shaped cores should be equal not less

$$S = \Delta U_{\text{ac}} \tau / B = 22\text{cm}^2$$

To realize such accelerating system the minimum of 10 ferromagnetic cores with the sizes $125 \times 80 \times 10 \text{ mm}$ is required.

From all variants of the power supply system of the accelerator the transistor variant has preference. Transistor converters of a voltage from DC in AC have high reliability and efficiency. Creation of such converter for magnetic system of the suggested accelerator does not represent complexities. Now 1.5 MW converters with frequency of switching up to 150 kHz ($T = 3.3 \mu\text{s}$) are realized [1]. Development of converters with frequency of switching $\sim 100 \text{ MHz}$ represents more difficult task. From existing transistor RF switches DE475-102N21A RF Power MOSFET possesses the maximal frequency of switching 30 MHz. Average power of the switch – 1.8 kW. For increasing output frequency and output power are used special Converter Systems. The high output frequency is achieved using a phase-shifted gating of "n" converter modules [2].

Use of rigid focusing of electrons will allow to receive a steady current of a beam with number of particles $\sim 5 \cdot 10^{11}$ and an average current of the accelerated beam - 8 mA. At energy of electrons 10 MeV average power of the beam will make 80 kW.

The rapid progress in the field of semi-conductor switches allows to hope, that powerful devices with operating frequency up to 100 MHz in the near future will be developed.

SUMMARY

For reduction of magnetic energy of the induction circular accelerator (betatron) with the purpose to increase the cycles frequency and increase of average power of the accelerated electron beam it is offered to use the C-shaped electromagnets for formation magnetic field in an equilibrium orbit and the electric field induced by O-shaped ferromagnetic cores for electron acceleration.

Application of C-shaped cores of electromagnets allows to form magnetic fields with the high radial gradient and to realize rigid focusing of electrons.

REFERENCES

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