A PROJECT OF ION LINEAR UNDULATOR ACCELERATOR WITH TRANSVERSE RF- FIELD

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Abstract

An accelerating structure for acceleration of ribbon ion beam in a linear undulator accelerator (lineondutron) is suggested. The transverse and phase stability conditions are given. The accelerating cavity contains a RF- system , combined with the plane electrostatic undulator. The RF-system consists of two oscillating systems, dc-isolated between each other. Each system involves a sequence of transversely located half- wave vibrators, their high-voltage ends being jointed by two longitudinal electrodes. The experimentally measured RF-field distributions, a method of RF-tuning are given. The designed specifications of a proton accelerator project with an output energy of 1 MeV are presented.

1. INTRODUCTION

Earlier an idea to apply a combination of electrostatic undulator field and radio-frequency field for acceleration of intense ion beams with low injection energy was suggested and some theoretical investigations of lineondutron were carried out [1]. The unique feature of this novel accelerator type is a capability to increase significantly the beam intensity as compared to conventional resonant ion accelerators at the expense of acceleration of overlapping quasi- neutral ion bunches. In this paper a specific project of linear undulator accelerator with the plane electrostatic undulator and transverse RF-field is suggested and a technique of tuning the RF-field distribution is described.

2. MAIN PRINCIPLES OF A LINEONDUTRON

In a lineondutron the same pairs of electrodes are used to form both the RF- and electrostatic fields, i.e. a RF-system is combined with the electrostatic undulator. A sequence of electrostatic potentials $\pm U_0$, imprinted across the adjacent electrodes, provides a periodic undulator field (See Fig.1b). Accordingly, to generate a desirable RF-field profile all electrodes of the top row are supplied with the RF-potentials $\tilde{U}_v$, and the ones of the bottom row- ($-\tilde{U}_v$.).

In this case the RF-field has only the thansverse component

$$E_{v,z} = 0, \qquad E_{v,y} = E_v(z)\,\sin(\,\omega t + t_0\,), \tag{1a}$$

and the undulator field components, correspondingly, are given by

$$E_{0,z} = -\,E_0(z)\,\mathrm{sh}(2\pi y/D)\sin(2\pi \int_0^z dz_1/D(z_1), \qquad E_{0,y} = E_0(z)\,\mathrm{ch}(2\pi y/D)\cos(2\pi \int_0^z dz_1/D(z_1), \tag{1b}$$

where $\omega = 2\pi c/\lambda$-the angular frequency, λ- the RF-field wavelength, $D = \beta_s\lambda$- the undulator period, β_s-the synchronous particle velocity, τ_0-the initial particle phase.

Here the fundamental space field harmonics -the zero RF-field harmonic with the amplitude E_v and the first static field harmonic with the amplitude E_0 are chosen to be the working ones. In general case higher field harmonics, as it was shown in [2], essentially effects the beam dynamics. To make the following discussion simplier, however, we let them alone. Let us note, that all the harmonics are non- synchronous with the beam. The joint influence of the fundamental harmonics results in a combined- wave field, which may have the phase velocity, close to the beam velocity, if the undulator period is selected properly, and accelerate the beam. It may be shown [1], that a combined-wave amplitude is proportional to the product of E_0 and E_v, and the energy increase of the synchronous particle per unit length

$$\Delta W_s/\Delta z = eTE_v\cos\varphi_s, \tag{2}$$

where $\varphi_s = \omega(\int_0^z dz_1/v_s - t) + \tau_0$-the slow phase in a combined-wave field, $T = eE_0\lambda/8\pi W_s$-the acceleration efficiency factor, W_s- the kinetic energy of the synchronous particle.

In turn, the focusing effect is defined by the ratio of the harmonic amplitudes E_0 and E_y. The analysis of the transverse stability shows, that a trajectory of the particle with any phase is stable in the transverse plane, if

$$\alpha_{\min} \leq E_y / E_0 \leq \alpha_{\max} , \qquad (3)$$

where $\alpha_{\max} \cong 2$, and $\alpha_{\min}$ is determined mainly by means of numerical simulation methods [2]. In practice it's suitable to decrease the static field amplitude E_0, i.e. to take the operating value $\alpha \cong \alpha_{\max}$. The calculation results showed, that in order to achieve effective beam bunching and capture, as well as transverse matching with the channel, the functions $E_0(z)$ and $E_y(z)$ first have to grow gradually practically from zero up to the maximum value and then may be constant. In its turn, the synchronous phase should be decreased from $\pi/2$ up to some constant value, and further may be kept constant as well.

3. DESIGN OF AN ACCELERATING RESONATOR

A model of accelerating cavity was fabricated and experimentally tested. A schematic of resonator and cross-section of accelerating-focusing channel are shown in Fig.1a and Fig. 1b , respectively.

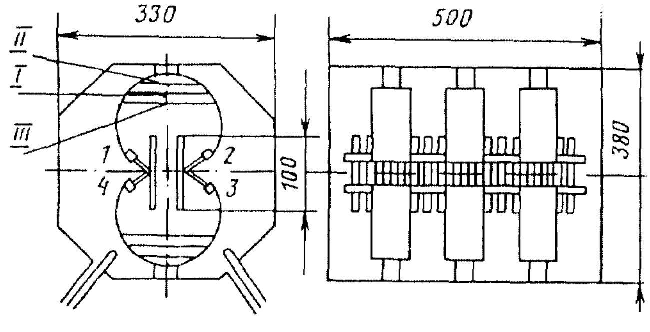

Fig.1a Schematic drawing of resonator

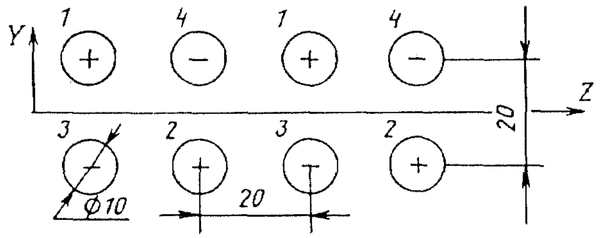

Fig.1b Cross-section of accelerating channel

The resonator consists of a cylindrical body, which contains two oscillating systems, dc-isolated between each other and the body. Each system is an array of transversely located half- wave vibrators. Their high - potential ends are linked with two longitudinal electrodes. Dc-voltage sources are switched to different oscillating systems, and RF-generator excites the vibrators in the operating oscillation mode. The accelerating- focusing channel is made by pairs of rod electrodes, mounted by turns to the opposite longitudinal electrodes, belonging to different oscillating systems. The numbers of longitudinal electrodes are indicated by figures in Fig. 1a, and Fig.1b shows an order of switching the transverse electrodes. An outline of a resonator is shown in Fig.2. The accelerating structure may be excited in the in- phase mode (if the oppositely located electrodes are excited in phase) or in the out-of-phase mode (when they are excited out of phase by π). The order of switching the electrodes , forming transverse RF-field, is chosen so that the in-phase mode will be the working one. In this case there is no additional loading capacitance between the longitudinal electrodes 1,4 and 2,3, that allows to reduce the capacitive load to the whole accelerating structure and thus to keep its shunt impedance high enough.

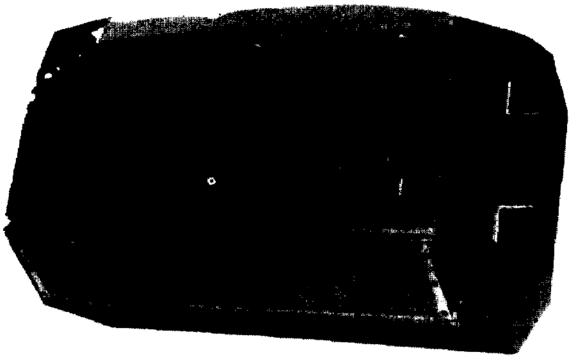

Fig 2. Photograph of a resonator

Otherwise, in exciting the resonator in the in-phase mode only the longitudinal RF-field component is generated on the axis of the accelerating channel. The model measurements showed, that the resonant frequencies of in-phase and out-of-phase modes are equal to $\omega_+ /2\pi = 156.8$ MHz and $\omega_- /2\pi = 118.8$ MHz. In the in-phase mode the quality factor Q≃4000.

4. TUNING FIELD DISTRIBUTIONS

In a version of accelerating structure concerned each accelerating system contains by three uniformely placed half- wave vibrators. In a case when all electrodes are on the same distance, obviously, the RF- field distribution on the axis is nearly uniform. To tune up the required field distribution distribution along the channel it is necessary to detune by frequency the vibrators of both oscillating systems. To hit the target special tuning elements are used, representing the cross- pieces, mounted on each vibrator. Various positions of these elements are indicated in Fig. 1a by the numbers I, II, III. The installation of each tuning element leads to a change of intrinsic inductance of a vibrator and reduces the RF-field oscillation amplitude inside the channel gaps, close to this vibrator. Having changed a position of the cross-piece on each half-wave vibrator, one may quite easily retune the RF-field distribution along the channel.

Fig.3 shows some RF-field distributions, which can be realized in the resonator design. The distribution 2 is achieved, if the tuning elements are installed only on the first pair of vibrators , 1-if they are on the first and the second pair. In a similar way different RF-field distributions can be made. It is important to note, that the tuning RF-field distribution along the resonator is produced irrespective of the positions of electrodes, constituting the accelerating channel. So, necessary longitudinal dependencies of the electrostatic field can be made independently by specified positioning the transverse electrodes along the resonator. In a such way slowly varying laws of RF and electrostatic field amplitudes [2] can be simultaneously provided.

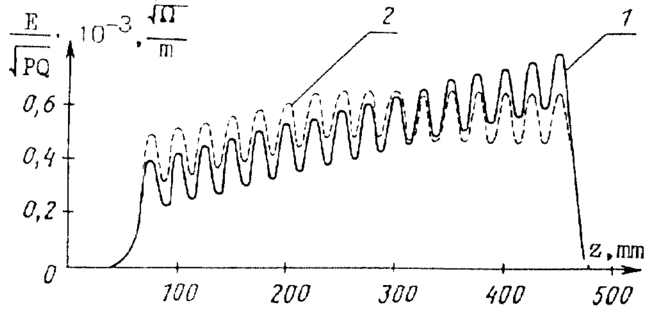

Fig.3 RF-field distributions

5. DESIGNED PARAMETERS OF ACCELERATOR

On the basis of detailed beam dynamics studies and computer simulation runs a project of an undulator accelerator for acceleration of H^+(H^-) ions was suggested and its main specifications were calculated. An accelerator consists of a bunching and accelerating sections. The former section has the length l_{bun}= 50 cm and the amplitudes of the operating field harmonics and the synchronous phase vary as follows: $E_{0,v}(z)= E_{0,v\ max}*\sin(\pi z/2l_{bun})$, $\varphi_s(z)=\pi/2-(\pi/2-\varphi_{s0})/\ l_{bun}*z$. On the latter section these values are constant: $E_{0,v}(z) = E_{0,v\ max}$, $\varphi_s(z)= \varphi_{s0}$. The designed parameters are given below.

Input (output) energy, keV	50(1000)
Operation RF- frequency, MHz	150
Accelerator length, m	1.8
Number of pairs of transverse electrodes	72
RF- field amplitude on the axis, kV/cm	180
Electrostatic field amplitude, kV/cm	65
Minimum ribbon aperture half-size , mm	4
Transversal acceptance, cm mrad	≃0.1

Space- charge effect estimates showed, that a current value in such a ribbon single-charged beam could approach several Amperes.

6. CONCLUSION

Theoretical and experimental studies of a lineondutron showed a possibility to create this new ribbon ion beam accelerator. In particular, such an accelerator of H^- ions can be used for the purposes of magnetic fusion energy program. Different applications of intense single- charged and quasi- neutral beams are also of interest.

7. REFERENCES

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[2] E.S.Masunov, A.P.Novicov "Application of Electrostatic Undulators for Acceleration of Intense Ion Beams", Bull.Am.Phys. Soc., Vol.36, p.1657, May 1991.