3D SIMULATION OF ION RIBBON BEAM SELF-CONSISTENT DYNAMICS IN ELECTROSTATIC UNDULATOR LINAC

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The ribbon ion beam focusing and acceleration in a periodical resonant system are considered by numerical simulation. The nonsynchronous RF field and electrostatic undulator field space harmonics exist in the structure. The dependence of beam output characteristics on electric field distribution and system parameters are investigated. Optimization of accelerator parameters in order to maximize transmission coefficient is carried out. The limit beam current is estimated. It is shown that high values of transmission and output currents in the linac under discussion can be obtained. The comparison with the results of early self-consistent 2D ion beam dynamics studies is done.
PACS numbers: 41.75.L, 41.85.E, 29.27.F

1 INTRODUCTION

The creation of high-intensity low-energy ion linacs is an important problem of the modern accelerator physics. The use of ribbon beam linacs is a promising method comparatively to ordinary linacs having a cylindrical beam. As it is known the ribbon beam may have a large transverse cross-section. It is possible to increase the beam current without enlarging the current density of beam owing to this feature. The ribbon beam can be accelerated in the system having RF focusing (which accommodates to ribbon beam acceleration, [1]) also in a new type of accelerators – linear undulator accelerators (UNDULAC). The main feature of UNDULAC is the absence of the synchronous RF field harmonic. The acceleration in UNDULAC is realized in a combined wave field of two or more nonsynchronous harmonics [2-4]. UNDULAC-E having a plane electrostatic undulator is one of possible types of these accelerators ([2], Fig. 1). The acceleration in a combined wave field of RF field harmonic (with potential U_v) and transverse electrostatic undulator field (with potential U_0) is realized in this type of UNDULAC.

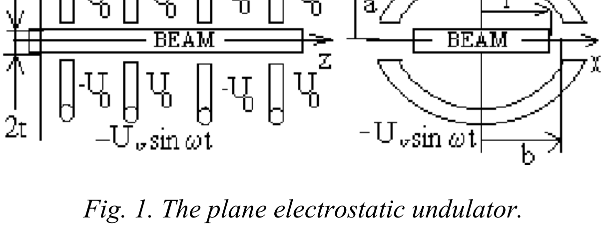

Fig. 1. The plane electrostatic undulator.

The investigation of ribbon ion beam dynamics in the UNDULAC-E having a plane electrostatic undulator was carried out using analytical methods and numerical simulation. Some results of this investigation are given in [3, 5-8]. The time-averaging motion equation was deducted in the Hamilton form. Using this equation it was shown that, to obtain the effective transverse focusing, the amplitude of the electrostatic field can not be lower than the amplitude of the RF field. This result was verified by a numerical simulation of ribbon negative deuterium ion D^- beam dynamics. The numerical simulation was carried out ignoring the influence of own space charge effects at first. This model verifies the transverse focusing conditions and shows the possibility of effective deuterium beam acceleration in UNDULAC-E to the energy 1–1.2 MeV. 2D dynamics was investigated to estimate the Coulomb field influence on the transverse beam focusing at further.

2 RESULTS OF BEAM DYNAMICS NUMERICAL SIMULATION

2.1 3D particle dynamics

Three numerical models were used for beam dynamics studies. The first model allows to investigate 3D ion beam dynamics in UNDULAC-E taking into account fast oscillations and ignoring the Coulomb field. The bunching process with further acceleration was analyzed using this method. The accelerator should consist of two regions. The synchronous phase should be decreased and the amplitudes of RF and electrostatic undulator fields increased in the first bunching region of the channel. The phase and amplitudes are constant in the second acceleration region [5]. The optimization of accelerator parameters allowed to increase the current transmission coefficient up to 80 – 82 %. It was shown that the transmission can be increased up to 90 % if the second space RF field harmonic is added. The optimum parameters of the accelerator are: length of accelerator L=250 cm, length of bunching region L_g=75 cm, accelerator channel size $2a\times2b$=0.8×20.0 cm, initial beam size $2t\times2l$=0.5×11.5 cm, initial and final synchronous phase values $\varphi_{in}=\pi/2$, $\varphi_{end}=\pi/4$ respectively, ratio of amplitude values of initial RF and undulator fields to their maxima E_{in}/E_{max}=0 - 0.2, initial ion beam energy W_{in}=150 keV, amplitude of undulator field E_1^0=120 - 180 kV/cm, amplitude of RF field E_0^v=150 - 200 kV/cm [7]. The transverse focusing conditions were verified for these parameters.

2.2 2D dynamics and Coulomb field influence

The second numerical model was used for studying the Coulomb field influence on the transverse beam focusing. The beam self-consistent dynamics in UNDULAC-E was carried out taking into account the space charge effects. The model is based on the particle simulation method. It was realized ignoring particle phase motion. The influence of the shielding effect was investigated. The optimum parameters are closely to the previous one in this model. It is necessary to provide the transverse beam focusing in a direction perpendicular to the ribbon and in other transverse direction too. It is necessary due to Coulomb repulsion in this direction influence. The focusing is disregarded in a beam thickness direction usually. The focusing in this direction can be realized by appropriate modification of the electrode form. The optimum ratio of transverse wave numbers equals to k_x/k_y=1/23. This ratio is close to that calculated analytically earlier. It is possible to accelerate ion beams having a current up to 1.4 A as it was shown by this model (Fig. 2, curve 1, [6]). Such current can be accelerated without losses caused by the Coulomb fields in UNDULAC-E.

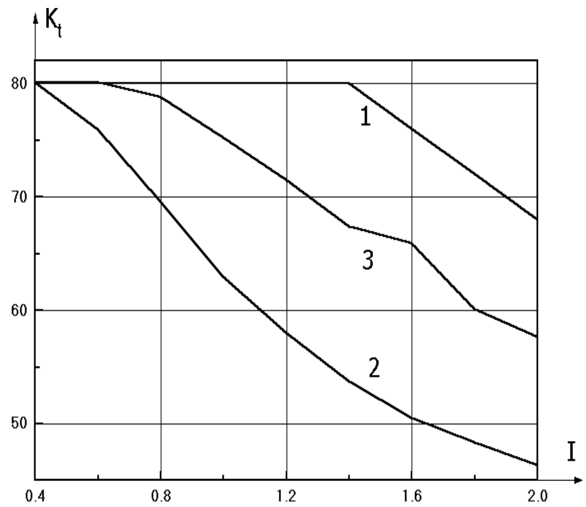

Fig. 2. Current transmission versus injection current.

2.3 3D self consistent beam dynamics

A 3D self-consistent model was developed taking account of the own space charge fields to complete the investigations of the ion ribbon beam dynamics in UNDULAC-E. The model is based also on the particle simulation method. The ion space charge distribution in the channel was calculated using the well-known CIC method. An FFT solver is used for the Poisson equation. By 1 A beam current and aforesaid parameters of the UNDULAC-E the current transmission coefficient is reduced comparatively to 2D case and equals to 60 %. It is caused by influence of phase particles motion to the transverse dynamics. The current transmission coefficient versus beam current is given for this parameters in Fig. 2, curve 2.

The current transmission was magnified to 70–75 % by means of additional optimization. It was shown that an optimum can be realized using following parameters: initial beam size 0.4·12 cm, ratio of initial field amplitude values to its maximal values E_{in}/E_{max}=0.15, amplitude of undulator field E_1^0=150 - 200 kV/cm, amplitude of RF field E_0^v=150 - 200 kV/cm (Table 1). The bunching part length does not vary L_g=75 cm (Fig. 3). The final energy expand to 1.2 MeV in this case. Beam current transmission versus beam current is given for UNDULAC-E having additionally optimized parameters in Fig. 2, curve 3.

Table 1. Current transmission versus field amplitudes

E_1^0 kV/cm E_0^v kV/cm	100	150	200	250
100	48.1	58.8	65.2	65.8
150	46.9	60.9	66.3	68.8
200	28.1	58.1	70.2	70.6
250	8.8	45.6	66.0	69.2

The particle losses along the accelerator channel are given in Fig. 4 (curve 1 shows total losses, curve 2 - transverse losses, curve 3 – phase losses). It is evident from Fig. 4 that the transverse beam losses are caused by two effects. The high intensity RF field is affected to ions in the front end of accelerator channel. In the initial bunching region the longitudinal beam velocity is low but focusing by common action of RF and electrostatic undulator fields is weak. The main transverse losses occurs in this region. In further motion the particle energy increases and losses happen due to the Coulomb defocusing mainly. This losses are uniformly distributed along the main acceleration region. Note that the focusing of beam in the direction of the beam ribbon width is effective and there is no particle losses in this direction.

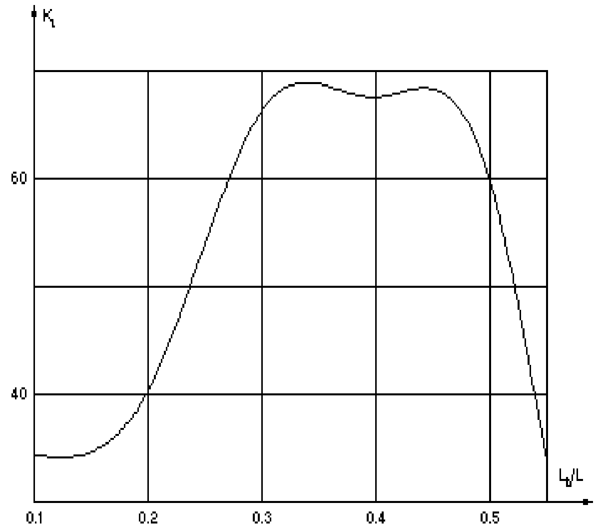

Fig. 3. Current transmission versus ratio of buncher part length to accelerator channel length.

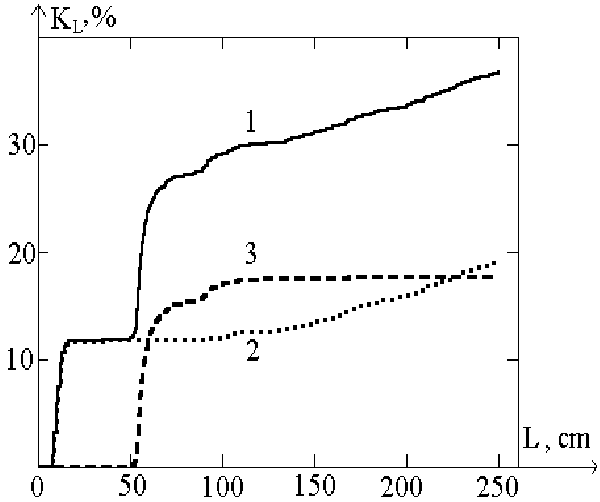

Fig. 4. Particle losses along the accelerator channel.

The limit current density was estimated using this 3D model. It must be lower than 0.2 A/cm^2 as it was shown above (Fig. 5). It is clearly from this figure that the current transmission does not vary essentially with beam thickness. The limit beam current equals to 0.8-1.0 A.

Note that the initial value of beam emittance does not effect significantly on its dynamics.

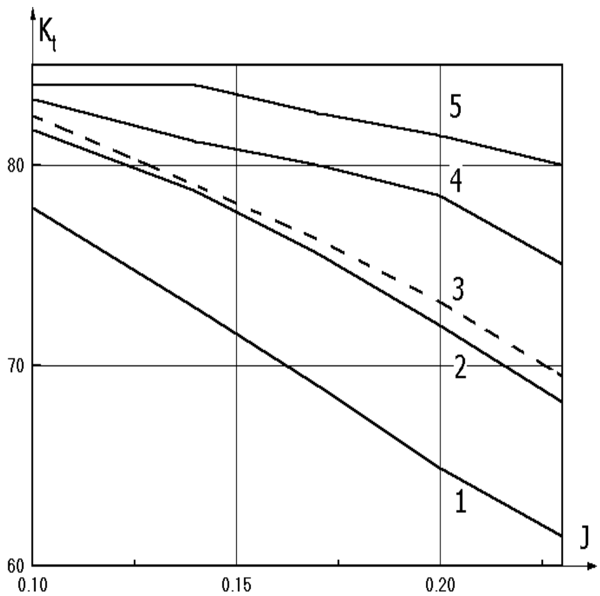

Fig. 5. Current transmission versus current density J (A/cm^2). Initial beam sizes: 1 - 2t×2l=0.5×12 cm^2, 2 - 2t×2l =0.4×12 cm^2, 3- 2t×2l =0.4×14 cm^2, 4 - 2t×2l =0.3×12 cm^2, 5 - 2t×2l =0.2×12 cm^2.

Some main parameters of UNDULAC-E are given in Table 2.

It can be possible to increase the transmission coefficient by additional optimization of bunching region parameters. It should be useful also to consider a high order space RF field harmonics influence on beam transverse focusing.

Table 2. Main parameters of UNDULAC-E

Final energy of D^- ions, MeV	1.0 – 1.2
Initial energy, keV	150
Length of accelerator channel, m	2.5
Length of bunching region, m	0.75
Amplitude of RF field, kV/cm	150 - 200
Amplitude of electrostatic undulator field, kV/cm	175 - 200
Injection current, A	up to 1
Current transmission coefficient, %	70 – 75

3 CONCLUSION

The UNDULAC-E construction proposed is rather effective for ribbon ion beam acceleration as is shown by the investigations executed. The current transmission in it is a few less than that in the system having ribbon RF focusing (5 – 10 % worse) proposed in [1]. Thus, this system has some advantages. Firstly, the RF and undulator fields required for effective focusing and acceleration are significantly lower than these in the ribbon RF focusing structure. Secondly, it is possible to accelerate a quasi-neutral ion beams in this new linac [5-6]. Owing to this feature the new structure makes is possible to increase significantly the beam current in future.

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