HYBRID ELECTRON LINAC WITH STANDING AND TRAVELLING WAVE ACCELERATING SECTIONS*

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Abstract

Hybrid electron linacs with standing and travelling wave accelerating sections are not well described in literature. Limited number of studies have shown that application of these systems makes it possible to develop a compact linac with high efficiency and simpler power system. Typically, these systems use well-studied bi-periodical accelerating structure (BAS) cells for a standing wave section and disc-loaded waveguides (DLW) for a travelling wave section. This paper describes the development of such system using DLW cells with magnetic coupling (DLW-M). Here BAS appears as an absorbing load connected to the DLW-M accelerating structure by rectangular waveguide allowing to have theoretical zero reflection at RF input. Such system also provides possibility of plain beam output energy adjustment. Studies of the structure were carried out using equivalent circuits methods and numerical 3D-modeling. Beam dynamics was calculated.

INTRODUCTION

For industrial purposes, pure standing wave (SW) and travelling wave (TW) accelerators have their own advantages and disadvantages [1]. Hybrid linacs combine best features of the SW and the TW accelerators: bunching of the beam is done in the SW part of the accelerator and does not require focusing magnetic field for the buncher; RF power is supplied to the TW part of the accelerator, eliminating problems with the reflection towards the power source. If the TW section uses cells with positive phase velocity β_{ph}, unused RF power is dumped in the load at the end of the accelerating structure.

This paper describes development of the hybrid linac with negative phase velocity β_{ph}. The accelerator is fed through the last cell of the accelerating structure and the SW part acts as a absorbing load for the excess RF power of the TW part. Power source supplies accelerator with 5.5 MW of RF power at frequency of 2856 MHz.

Electric field distribution in the accelerator was calculated using equivalent circuit method based LinacCalc software. Electron dynamics was calculated with Parmela program.

LINAC DESIGN

Linac structure comprises SW, TW sections and section connecting rectangular waveguide. SW section is connected directly to a DC electron source producing 30 keV beam with current varying from 0.1 A to 0.7 A. Thus the first cells of the SW section are bound to be bunching cells. Bi-periodic accelerating structure (BAS) cells were chosen for this section of the accelerator because of their hight shunt impedance and reliability. For the TW section of the accelerator diaphragm loaded waveguides with magnetic coupling (DLW-M) were used. Because of the magnetic coupling, shunt impedance and Q-factor of these structures are higher than in regular DLWs. In addition, DLW-M's accelerating wave mode has a negative phase velocity. Therefore, accelerator is powered through the last cell of the TW section, and connection to the SW section is done by coupling it to the first cell of the TW section. Number of the TW cells and field amplitudes in them are determined by the the input RF power and the power, needed for the SW part of the accelerator.

In the Fig. 1 early model of this such a structure is shown. For the simplification of the calculations, phase shifter in the model was replaced by a waveguide.

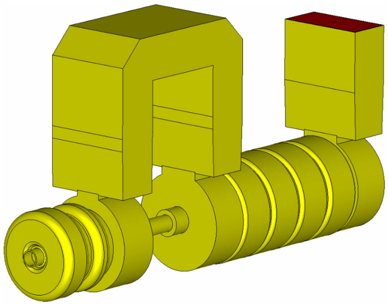

Figure 1: Model of the hybrid linac with negative phase velocity TW cells

Using analytical equations for maximum particle energy and accelerator efficiency [2], optimal length of the TW section of the accelerator was determined to be 1.4 meters with a/λ ratio of 0.1.

Standing Wave Section Tuning

In the SW section of accelerator four cell buncher was used. Amplitudes of the electric field in these cells were tuned to achieve the maximum captivity coefficient while retaining a narrow energy spectrum. Electric fields in first, second, third and fourth cells were set to be in ratio of 1.7/11/16/20 with relative phase velocities β_{ph} of 0.7, 0.5, 0.95 and 0.99 accordingly. Coupling coefficients for the BAS cells were obtained for these field amplitudes as well as the coupling coefficient for the SW section power input cell. Module of the electric field amplitude for each cell of

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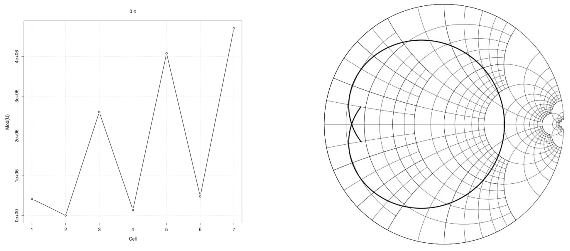
the SW section is presented in the Fig. 2 a). In Fig. 2 b) input impedance of the SW section is shown. These characteristics here and later in this paper were obtained using the equivalent circuit method.



a) b)

Figure 2: a) Module of the electric field amplitude over cell number (including coupling cells) for the SW section b) Input impedance of the SW section

The parameters and the transverse section of the beam on the exit of the SW section of the accelerator are presented in Table 1 and in Fig. 3.

Table 1: Beam Parameters after the SW Section of the Accelerator

Input power, MW	0.77
Losses, MW	0.25
Beam average energy, MeV	1.5
Input current, A	0.4
Captivity coefficient, %	85
Length, cm	15.3

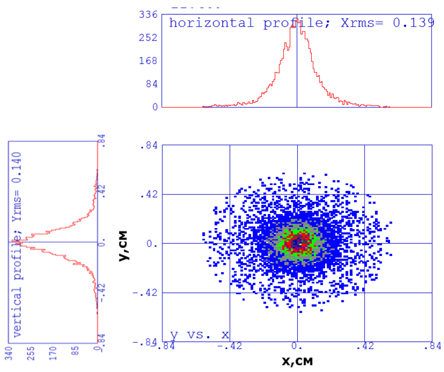
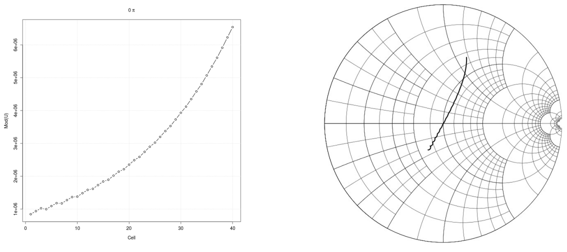


Figure 3: Transverse section of the beam after the SW section of the accelerator

Travelling Wave Section Tuning

As the input power of the accelerator is 5.5 MW and 0.77 MW of it goes to the SW section of the accelerator, parameters of the TW section of the accelerator can be calculated. As mentioned previously, total length of the TW section is 1.4 meters, which corresponds to 40 DLW-M cells tuned to phase velocity $\beta_{ph} = 1$ at frequency of 2856 MHz.

Module of the electric field amplitude for each cell of the TW section is presented in the Fig. 4 a). In Fig. 4 b) input impedance of the TW section is shown.



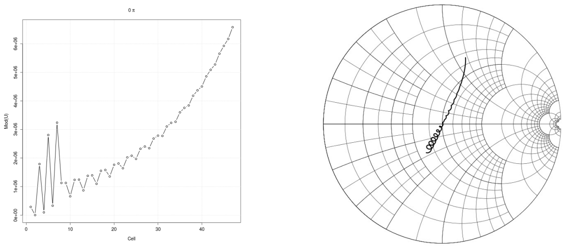
a) b)

Figure 4: a) Module of the electric field amplitude over cell number for the TW section b) Input impedance of the TW section

Combined Accelerator Calculation

The accelerator sections are coupled together via rectangular waveguide. In this case the simplest way to adjust output beam energy is to add phase difference between the last cell of the SW section and the first cell of the TW section by using a phase shifter. This technical solution sets the limitation on the minimal space between the sections. It was chosen to be 10.5 cm.

Module of the electric field amplitude for each cell was calculated and presented in the Fig. 5 a). In Fig. 5 b) input impedance of the accelerating structure is shown.



a) b)

Figure 5: a) Module of the electric field amplitude over cell number (including coupling cells) for the accelerating structure b) Input impedance of the accelerating structure

In order to transfer maximum energy from RF field of the accelerator to the electron beam, optimal phase difference between the SW and the TW parts has to be set. For the gap of 10.5 cm it was calculated to be $\varphi_{diff} = 135°$.

The calculated output parameters of the accelerator are presented in the Table 2. Transverse section of the beam is presented in the Fig. 6.

Focusing Magnetic Field

As shown in Fig. 6, rms size of the particle beam an the end of the accelerator is about a one third of the beam pipe size. It also has a halo, filling up all the space in the beam

Table 2: Accelerated Beam Parameters

Input power, MW	5.5
Losses, MW	2.52
Beam average energy, MeV	10
Beam maximum energy, MeV	11.7
Output current, A	0.29
Captivity coefficient, %	71

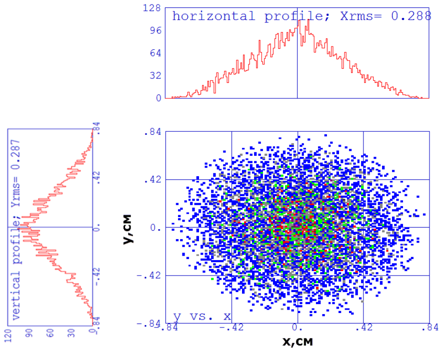


Figure 6: Transverse section of the beam

pipe. In presence of external magnetic noises this can lead to a beam instabilities. In order to bring the possibility if it to a minimum, additional magnetic focusing was introduced to the TW part of the accelerator. Three solenoid magnets were placed across the structure. Resulting field distribution is shown in the Fig. 7.

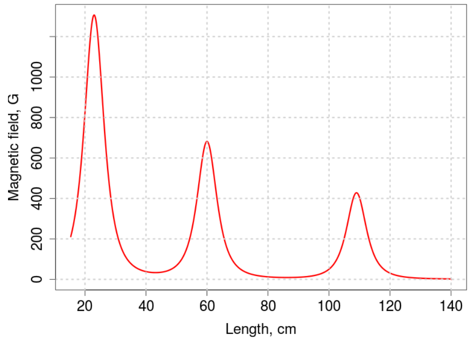


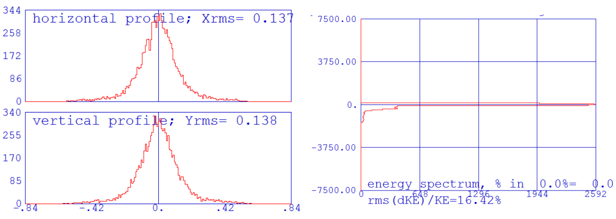
Figure 7: Focusing magnetic field distribution across the structure

The resulting transverse section of the output beam and its energy spectrum are presented in Fig. 8.

After the introduction of the magnetic field, beam profile became smaller and its halo almost disappeared.

Energy Adjustment Investigation

In a lot of cases possibility of beam energy adjustment is needed. As mentioned previously, for this structure the easiest method of energy adjustment is changing the phase difference between the accelerator SW and TW parts.



a) b)

Figure 8: a) Transverse section of the beam with magnetic focusing b) Output beam energy spectrum

Energy adjustment was investigated for the accelerator with and without focusing magnetic fields. In the Fig 9 average output energy of the accelerator over phase difference between the SW and the TW parts plot is presented. The red plot represents the curve for the accelerator without magnetic focusing, the green plot - with magnetic focusing.

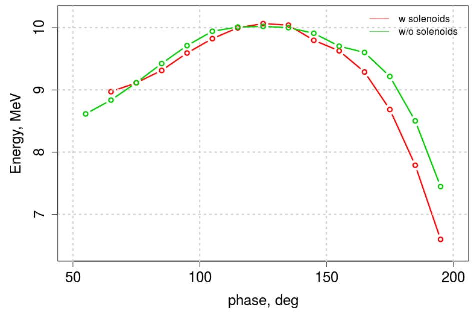


Figure 9: Average output energy of the accelerator over phase difference between the SW and the TW parts with and without magnetic focusing

CONCLUSION

The new scheme of the hybrid linear accelerator with use of bi-periodic accelerating structure cell section instead of the absorbing load was investigated. Results of the particle dynamics calculations in 10 MeV accelerator with and without focusing magnetic field were presented, capture coefficient of 71 % was obtained with use of a four-cell BAS buncher. Capture coefficient of 81 % was obtained with introduction of the focusing magnetic field. Impedance characteristic for the accelerator sections, as well as for a whole accelerating structure were calculated using the equivalent circuit method. It was shown that output energy adjustment is possible by inserting a phase shifter between the travelling and the standing sections of the accelerator. Further investigations are planned.

REFERENCES

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