HYBRID ELECTRON LINAC BASED ON MAGNETIC COUPLED ACCELERATING STRUCTURE

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Abstract

This paper presents the design of a hybrid linac which consists of a standing wave buncher and a travelling wave accelerating part. Both electric and magnetic-coupled disk-loaded waveguide (DLW) could be used as accelerating structure. The last one has better electrodynamical parameters comparing to classical DLW. Such an accelerator possesses the advantages of both standing wave and travelling wave linacs and has better output beam parameters.

INTRODUCTION

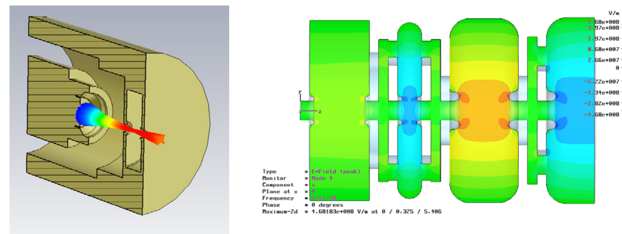
A disk-loaded waveguide (DLW) is the most common structure for compact linear accelerators working in a travelling wave (TW) regime. Among its advantages are high shunt impedance and manufacturing simplicity. The other popular structure is an on-axis coupled bi-periodical accelerating structure (BAS) that works in standing wave (SW) regime. Both the standing and the travelling wave regimes have their own advantages and disadvantages. The design of the hybrid accelerator with SW buncher and TW accelerating section presented in this paper unites the advantages of both regimes. For example, the buncher in the hybrid accelerator is shorter than in a pure TW accelerator, it requires no solenoid; this structure is more technologically convenient as it does not require a circulator.

The other way to combine the advantages of DLW and BAS is to design a magnetic coupled disk-loaded waveguide (DLW-M). The DLW-M accelerating structure design and optimization results were thoroughly described in work [1].

DYNAMICS SIMULATIONS

The results of the dynamics simulations of electrons in a hybrid accelerator are presented in this part. The simulations of the electron gun and the SW part have been done with the help of the *Parmela* code. The TW part was simulated and designed via the *Hellweg2D* [2] code.

This accelerator was designed as a substitution for the existing one [3] working in a pure SW regime. It should work in single energy (10 MeV) or dual energy (5 and 10 MeV) regimes at operating frequency of 5712 MHz with a pulse length of 10 µs and a repetition rate of 240 Hz. The output klystron power was chosen at level 4.5 MW to satisfy the following demands: the output current should be no less than 75 mA (preferably 100 mA) in a 10 MeV regime, while the length of the new accelerator should be about 75cm.



a) electron gun b) buncher

Figure 1: Initial part of the accelerator.

The beam injector represents a 50 keV 2-electrode electron gun with grid controlled cathode (Fig. 1a). The output current can be varied from 0 to 2 A. The SW-buncher consists of 3 BAS cells (see Fig. 1b). The electron beam was injected with initial energy 50 keV and 200 mA current. Phase velocity and field strength were optimized in order to achieve the maximal capture while having the minimal coupling holes size. Cells with phase velocitied 0.67, 0.42 and 0.78 allowed to capture 70.5% of particles, bunch them into a 26 degrees long beam with output kinetic energy of 630 keV and Twiss parameters α=-0.85, β=3.2 cm/rad, ε=5.2*10^{-4} cm*rad.

Forward Wave Accelerator (DLW)

Right after the SW part, the bunch comes to the acceleration section. The principles of a TW accelerator operation are fairly simple. An electromagnetic wave is coupled into the first accelerating cell and propagates along the accelerator. Particles are injected in the centre of the cells synchronously with the accelerating phase, so they can consume the wave power and gain energy. One of the most simple and reliable types of TW accelerators is a constant impedance structure as all its cells are identical. The energy of the electromagnetic field is consumed by the conducting walls and beam, so its amplitude decays along the accelerator. Spare energy transfers to the RF load in the end of the accelerating section. The cell parameters should be optimized in order to achieve the maximal efficiency, so the beam load is as high as possible. In DLW the aperture radius *a* affects on one hand the value of the on-axis electric field strength and on the other hand such important parameters as the coupling coefficient and the group velocity. So it is necessary to find a compromise between high accelerating gradient, operating regime stability and filling time.

Three types of cells with different aperture radius to wavelength ratio a/λ were considered. Though the best output parameters are achieved using a/λ = 0.08 cells, it is necessary to consider a very high sensitivity of such a structure to frequency deviations due to low coupling coefficient. From this point of view the optimal DLW cell is a/λ = 0.1 as it provides almost similar output results compared to those of a/λ = 0.08 while having reasonable coupling.

Nevertheless, such an accelerator is not effective due to the fact that in the end of a waveguide the field strength decays a result of the minor electrons energy gain in this part. Unfortunately, this part of a waveguide is quite long. Almost 80% of energy is gained by electrons in the first 40-60% of constant impedance accelerator length. To avoid this effect, it is necessary to modify the geometry of the cells so that the field amplitude remains constant along the accelerator. Such a structure is referred to as a constant gradient. Table 1 presents the result of beam dynamics simulations in a constant gradient accelerator. The limit of ending cell a/λ value is 0.08, as lesser values lead to problems with coupling and RF instabilities.

Table 1: Output DLW Based Linac Parameters

Parameter	Value
Number of cells / Structure Length, cm	28 / 48.9
a/ λ in first / last cell	0.105 / 0.083
Average / maximal Energy, MeV	10.0 / 10.3
Field strength on axis / at aperture, MV/m	19.3 / 38.6
Output current, mA	95
Particles captured, %	65
Energy spectrum, %	2.0
Efficiency, %	21

This accelerator allows to achieve output beam parameters similar to an a/λ =0.1 constant impedance structure on the shorter length. Also, it can be designed for the higher beam currents or higher energies to increase the efficiency without dramatic beam parameters degradation.

Backward Wave Accelerator (DLW-M)

DLW-M cells can also be used as an accelerating structure in a hybrid linac. Its dispersion on the operating wave is negative due to the coupling by magnetic field. Thus, the wave in this section would be backward (BW).

The results of dynamics simulations of the hybrid linac with the BW constant impedance DLW-M cells are presented in Table 2. Since the RF power is input in the end of the structure and decays through the structure, the field level of the buncher depends on the line attenuation of the structure and on the beam loading. Low field strength in the beginning of the TW section where beam energy is less than 1 MeV, can result in energy and phase spectra degradation. On the other hand field level grows along the accelerator, which is positive for beam dynamics.

Table 2: Output DLW-M Based Linac Parameters

Parameter	Value
Number of cells / Structure Length, cm	28 / 48.9
a/λ / coupling coefficient, %	0.08 / 1.0
Average / maximal Energy, MeV	10.0 / 10.5
Field strength in first / last cell, MV/m	14.8 / 25.6
Output current, mA	93
Particles captured, %	65
Energy spectrum, %	5.0
Efficiency, %	21

The DLW-M based accelerator parameters are similar to those of a constant gradient DLW accelerator. But the cells in the first case are identical, which is more technologically convenient for an industrial linac. Also, the coupling coefficient in this linac is equal to 1.0% versus 0.6% in the end of a DLW-based one. Another advantage of DLW-M is its flexibility: if a lesser energy spectrum is needed, a lower aperture radius can be used, If more particles should be captured or high currents are accelerated, a bigger aperture size is more continent. A necessary coupling coefficient or field gradient can be achieved by adjusting the side coupling holes. Unfortunately, due to the low field strength in the beginning of such an accelerator, the dual energy regime is disadvantageous for this structure. The beam loading field level dropped to critically low values resulting in a disastrous energy spectrum growth.

INPUT COUPLER DESIGN

The RF power input coupler design (Fig. 2) has been developed for a hybrid accelerator with an a/l =0.08 DLW-M based hybrid linac with constant impedance. The RF power is brought to the accelerator via the 40x20mm rectangular waveguides WR187. As the DLW-M structure is working in a backward wave regime, the power is input into the last TW cell and is output from the first TW cell. Thus the phase would propagate from the first TW-cell to the last TW-cell while in 3 cells before the RF output, the SW regime will be set due to the short-circuit at the beginning of the accelerator.

To ensure symmetry of the field in input and output cells, opposing rectangular waveguides are connected. This waveguide should be short circuited for RF power either by a metal pin or by a waveguide with a cut-off frequency above operating frequency. The simulations of these 2 shorting schemes show [4] that in the first case resonances in cavities between a metal pin and other metal parts of the accelerating structure, such as irises or input windows, can have a lot of influence on the stability of the accelerator. Thus, the waveguide with section a 22x20mm section have been chosen to ensure the symmetry of the field in coupled cells. These waveguide are also use used for pumping-out.

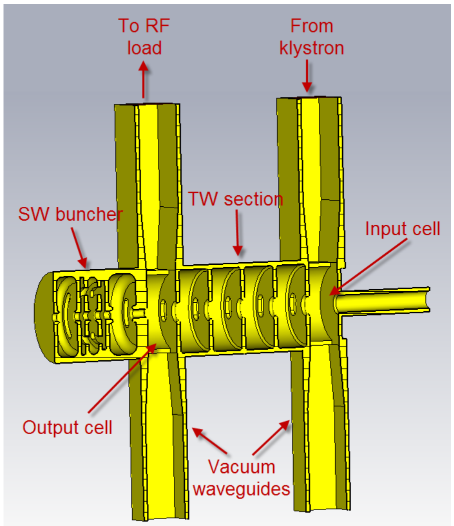
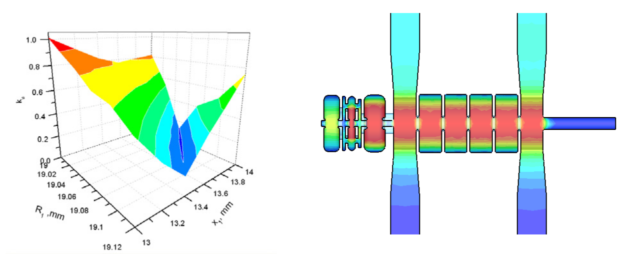


Figure 2: RF input coupler design.

The tuning process of the RF coupler consisted of several steps. First, the radii of all cells, including coupler cells in the SW buncher and coupling holes dimensions, have been adjusted in such a way that the resonant frequency of the structure was equal to 5712 MHz and the ratios between the amplitudes in each cell were close to design.

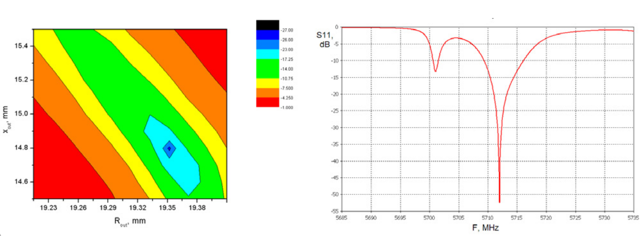


a) field uniformity optimization

b) field amplitude distribution in accelerator

Figure 3: Output cell tuning.

Then, the output cell dimensions (radius and RF window width) have been tuned to achieve the uniform distribution of an E-field complex amplitude inside the TW part (Fig. 3).

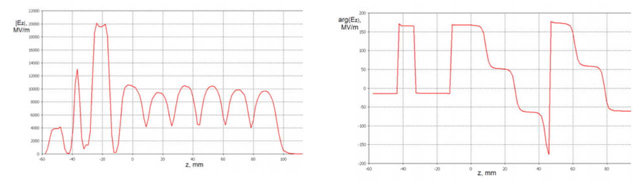


a) Reflection optimization

b) S_{11}vs frequency

Figure 4: Input cell tuning.

Finally, as the input and output cells are not equal the following tuning of input cell is necessary to achieve the minimum reflection of RF power (Fig. 4). Fig. 5 presents the on-axis field amplitude and phase distributions along the structure. These charts prove that the input coupler has been tuned well. The E-field complex amplitude distribution is uniform and equal to the designed. The phase chart shows that the phase shift between cells in the TW section equals to 120 degrees or $2\pi/3$ and to 180 degrees in the SW section.



a) complex amplitude

b) phase

Figure 5: On-axis field distributions along structure.

CONCLUSIONS

A C-band hybrid linear accelerator with an SW buncher and a TW accelerating section has been designed. Two types of TW accelerating structure have been proposed: DLW and DLW-M. The latter has better electrodynamical parameters than those of the classical DLW.

Dynamics simulations show that the constant impedance structure of DLW-M can provide almost the same results as the constant gradient structure of DLW which is a further technological simplification of a linac. A common RF input coupler for the TW and the SW sections can be successfully used to provide the necessary regimes and field levels.

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