COMPACT STANDING WAVE ELECTRON LINAC WITH THE HYBRID ACCELERATING AND POWER GENERATING CELL

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Abstract

Compact electron linear accelerators for small energies are now found their place in the industrial market. Such accelerators are used for cancer treatment, cargo inspection, when one needs higher dose that X-ray source can produce, food and medicaments irradiation etc. Acceleration structures themselves are already developed very well, so the most important issue now – is to make the whole installation with power supply, RF tracts, cooling system – as smaller as possible to provide the structure mobility. In this article we present the development how to combine a power supply (usually it is a klystron, IOT, magnetron or solid state amplifier) with the accelerating cell itself, that can decrease installation size at least twice. No RF tracts needed, no reflected power will occur, so no circulator needed. Different power input combinations have been studied, but the smallest and the most efficient one has been manufactured for cold tests at S-band frequency range. In this structure it is very easy to vary accelerating voltage simply changing the generator beam current or the generator beam accelerating voltage.

ACCELERATING STRUCTURE

Biperiodic accelerating structure (BAS) (Fig. 1) [1] has been used for the accelerating structure. It is magnetically coupled compensated standing wave accelerating structure. Standing wave allows to bunch electrons without applying the external magnetic field, compensation increases the coupling coefficient i.e. geometry tolerances. Magnetic coupling allows to tune the accelerating field ratio in different cells without changing the beam tube radius.

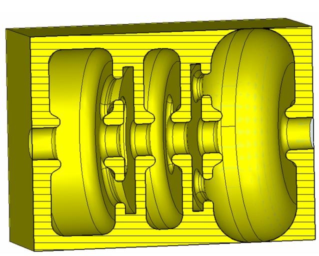

Figure 1: Three cells BAS designed geometry.

The field ratio and phase velocities have been designed to get the maximum capture and the minimum energy spread for the 30 KeV injected electron beam with 0.5 W pulsed input RF power (Fig. 2, Table 1)

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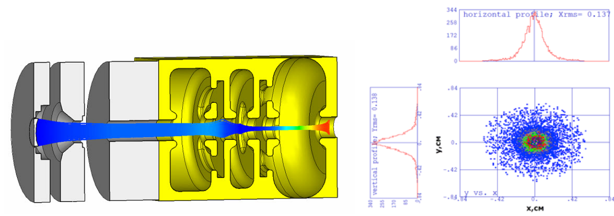

Figure 2: Three electron beam dynamics and electron beam profile at the accelerator exit.

Table 1: Beam Parameters at the Accelerator Exit

Parameter	Value
Beam current, A	0.3
Maximum energy, MeV	1.7
Capture, %	85

GENERATOR PART DESIGN

For the generator cell IOT [2] concept has been applied. To achieve 0.5 MW input power one can use a multi-bunch decelerating cavity coupled to the accelerator. To allow this generator cavity to operate in a multi-bunch regime in has been designed to operate at TH020 mode (Fig.3). Six high current modulated with the operating frequency electron bunches are injected to 6 beam channels. Each beam gives its energy to the RF oscillations in the cavity thus the output power for the optimized geometry and 5 A current can reach 1 MW. Efficiency of this structure can reach 50 % depending of the input parameters.

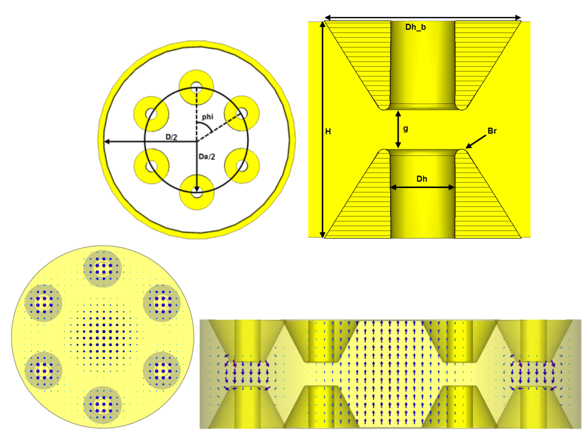

Figure 3: Generating cell geometry and electric field in it.

Unfortunately, modulation can be performed by the cathode grid only at frequencies lower than 1.3 GHz [2]. But for the research purposes the model has been designed to 2856 MHz and can be easily redesigned for any required frequency.

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Generator and Accelerator Coupling Different Solutions

Different types of coupling between the generating and accelerating cavities have been researched and compared (Fig. 4). Fig.4a shows the easiest way to extract power for generating cells: it is adding an overcoupled rectangular waveguide connected to the accelerating structure. In this case one can obtain up to 1 MW input power, but this geometry leads to the power reflections back to the source from the accelerating cavity during the transient processes, so the circulator can be applied. Fig. 4b and 4c show ways to increase the generating cell efficiency by inserting the coaxial rod in the area of the maximum on-axis electric field to increase the field on the generating beams lines. One rod can be changed to many smaller rods, which reducing the amount of copper in the structure. Fig. 4d shows that it is possible to "wrap" coaxial generating cell around the accelerating structure and connect both cavities by rectangular windows. The problem of this idea is that for the such windows it is impossible do design couplings, so the field ratio between generating and accelerating beam lines is not designable. That's why in Fig. 4e the short coupling waveguide between two cavities is presented. It allows to separately change coupling coefficient between the generating cell and the waveguide and between the accelerating cell and the waveguide. The main problem of this geometry – it is non uniform electric field (high field near the coupling waveguides and low field in the other beam lines). The solution – is to decrease the number of generating beams channels and to insert three coupling waveguides. Electric field profiles in a such structure are shown in Fig. 5.

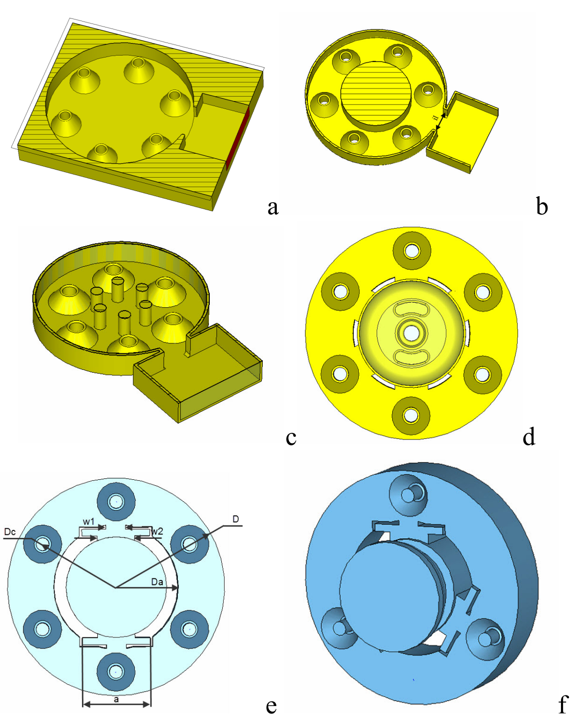

Figure 4: Different coupling solutions between the generating and accelerating structures.

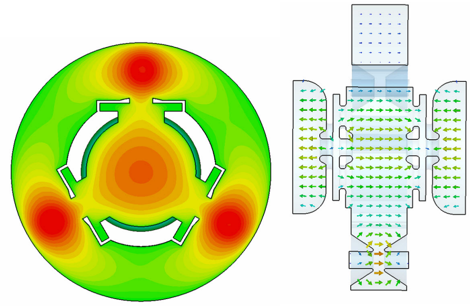

Figure 5: Three waveguide coupled scheme.

The Final Coupling Design

To avoid problems connected with the coupling waveguides and transient regimes power reflection, the model, where 3rd accelerating cell operates at the TM020 [1] mode is proposed (Fig.6). Here, both decelerating and accelerating voltages are exited in the same time and its ration depends only on the hybrid cell geometry. In the Fig.6 this ratio is 1:1. By changing the decelerating gap this ratio can be changed (Fig.7, where k – is the ratio between maximum electric field on decelerating axis to the accelerating axis).

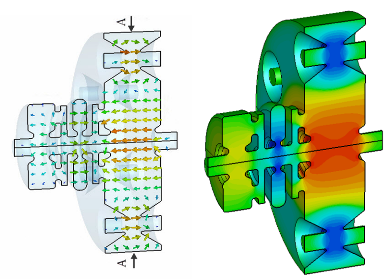

Figure 6: Electric field in the combined structure.

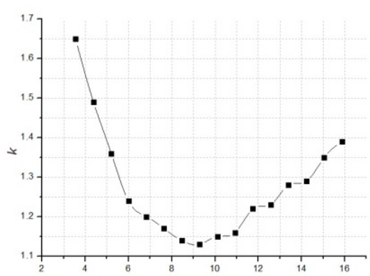

Figure 7: Field ratio vs decelerating gap.

Beam Dynamics

Designed model has been simulated with electron beams, Fig.8 (left) shows the beginning of a transient process. The DC 30 KeV beam with 0.3 A current (blue) has been injected in the accelerating structure without RF field in it. At the same time generating bunches (red) with 5 A current and 100 KeV energy have been injected in the opposite direction in the generating channels. Length of the generating beam is equal to the half of the RF oscillation period in the structure. After 190 ns (Fig.8 right) one can see that accelerating cells have some amount of the RF power in it and witness beam is accelerated to the 0.6 MeV energy.

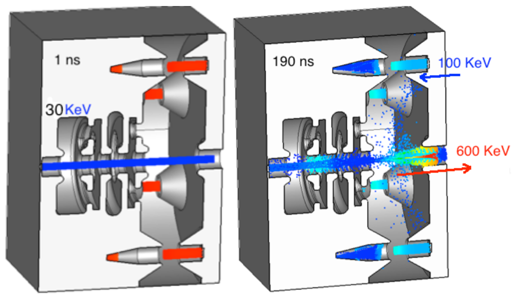

Figure 8: Electrons trajectories in a different time moments.

TEST STRUCTURE MANUFACTURING AND MEASURING

Final model of the geometry has been designed for the manufacturing (Fig.9). It consists from the copper plates screwed between each other. RF field is excited by the antenna in the maximum electric field area. Second antenna also has been designed to measure S21 [4] coefficient. Manufactured cells geometry, screwed assembly and the measurement stand are shown in Fig. 10. The structure has been excited by the antenna, by changing the cells radiuses and couplings, frequency has been tuned to the designed 2856 MHz and at this frequency accelerating field and generating channels field have been measured using the bead pull method [3] (Fig.11).

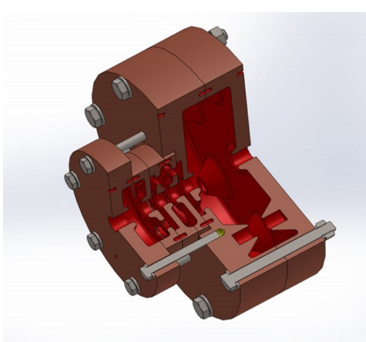

Figure 9: CAD model of the structure.

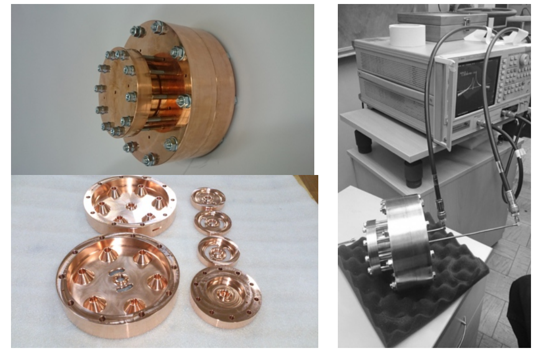

Figure 10: Manufactured cells and the measurement procedure.

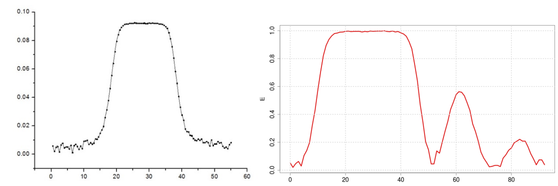

Figure 11: Measured field profile in the generating channel (left) and in the accelerating channel (right) x-axis is the length and y-axis is the normalized electric field.

CONCLUSIONS

The research work presented in this article shows the possibility of constructing a compact hybrid structure which combines a small electron linac and an IOT-based power source. The frequency range and accelerating structure can be chosen depending on the desired purposes of the accelerator.

ACKNOWLEDGEMENT

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REFERENCES

[1] O.S. Milovanov, N.P. Sobenin, *RF Technique*, Atomizdat, 1980

[2] R. Seviour, *Comparative Overview of Inductive Output Tubes*, ESS report, 2011

[3] T.Wangler. *RF Linear Accelerators*, Physics Textbook, 2008