ACCELERATING STRUCTURE OF 10 MeV ELECTRON LINAC

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The calculation of the on-axis coupled the biperiodic 10 MeV electron accelerating structure is represented. The one-meter structure includes 19 accelerating cells, two of which are bunching cells. Two versions of RF feeding of accelerating structure 2.5 and 4.5 MW are considered. The peak beam current is 0.14 and 0.3 A for these versions. 44…49% of the injected current is accelerated. Shunt impedance is 74 MOhm/m with the 8 mm aperture diameter.

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1. INPUT DATA

High beam power electron linacs with theenergy up to 10 MeV found more and more various industry applications. A variant of a pulse mode normal conductivity electron linac with an on-axis coupled biperiodic accelerating structure is considered.

The 2856 MHz klystron is used as a RF- power source for the accelerating structure. Two versions of RF feeding of the accelerating structure are considered: peak RF power is up to 2.5 MW in Version 1 and up to 4.5 MW in Version 2. The maximum RF pulse width of the klystron is 20 μ sec. But the operating RF pulse width will be chosen in the range 10...20 μsec (13.5 μsec nominal) to decrease the RF breakdown possibility. Maximum average RF power is 22.5 kW. Nominal beam power is 4.6 kW.

Two variants of a 40 kV three-electrode electron gun are considered as an electron source. Variant #1 is an injector with a concave cathode and a focusing electrode. Applying an additional negative voltage to the focusing electrode, we can cut off the injected current. Calculated beam diameter in crossover is d_i=0.7...1.0 mm. Variant #2 is an injector with a flat grid controlled cathode and a focusing electrode at the grid voltage. Changing the grid voltage, we can control the injected current I_i in the range from 0 to maximum value and therefore control the accelerated beam current I_b. The calculated beam diameter in crossover is d_i=1.0...1.4 mm.

The RF field of the accelerating structure focuses the electron beam. An external solenoid is not required. The electric field, accelerating and drift spaces in the bunching part of the structure were optimized to get a maximum capture ratio $k_c=I_b/I_i$ and requid accelerated beam parameters.

2. CHOICE OF OPTIMUM VARIANT

The electron linac was calculated in four main steps.

Step #1: the accelerating cell form is compromised using the SUPERFISH computer program to get a maximum shunt impedance and satisfied maximum surface electric field.

Step #2: main required parameters of the structure are calculated using analytic relations [1] and data calculated during Step #1.

Step #3: electric field, accelerating and drift gaps in the bunching part of the structure are optimized using the PARMELA program to get a maximum k_c and satisfied energy spectrum.

Step #4: variational parameters are calculated (accelerated electron beam parameters depending on RF power P, injected current I_i, injector voltage U_i).

Accelerating structure includes 2 bunching cells, 17 regular accelerating cells, 18 coupling cells and input waveguide coupler. Input coupler is connected to the last (#19) accelerating cell as it is shown in Fig.1. Aperture diameter is 8 mm. Length of drift tube nose is 3 mm for bunching cells and 4 mm for the rest cells. Diaphragm thickness is 4 mm. Radius of the cells is chosen to get operating frequency 2856 MHz.

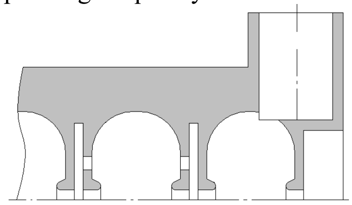

Fig.1. Form of the structure

Calculated values of effective shunt impedance ZT^2 and unloaded Q-factor Q_0 are represented in Table 1.

Table 1. Accelerating cell parameters

Cell No.	Q_0	ZT^2, MOm/m
1	12045	50.3
2	13269	53.2
3-19	17950	74.1

The bunching part of the structure was optimized to get a maximum k_c, required most probable E_m and average E_a energies and energy spectrum. Following parameters of the bunching part of the structure were changed during this optimization: cell length, accelerating gap length, drift gap length and electric field in the cell.

Table 2. Beam dynamic calculation results

Parameter	Version 1	Version 2
RF power, MW	2.5	4.5
Field in cell #1, MV/m	5.80	
Field in cell #2, MV/m	14.40	
Field in cell #3-19, MV/m	15.00	
Injection current, A	0.225	0.5
Accelerated current, A	0.108	0.22
Capture ratio, %	48.1	44.4
Average energy, MeV	9.36	10.56
Most probable energy, MeV	10.28	11.82
Beam power, MW	1.01	2.32
RF loss in the structure, MW	1.45	2.02
Lost beam loss power, MW	0.105	0.12

Following model was used during calculation of the bunching part with PARMELA program: accelerating cell #1, coupling cell, accelerating cell #2, coupling cell and accelerating cell #3.

Main results of the beam dynamics calculation for two RF power levels are represented in Table 2 and in Fig.2.

The typical energy spectrum and beam cross-section are shown in Fig.3.

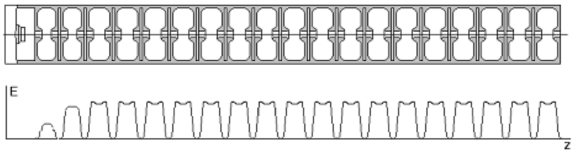

Fig.2. Accelerating field distribution

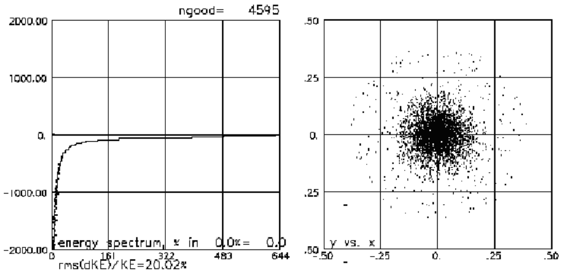

Fig.3. Typical energy spectrum (keV) and beam cross-section (cm)

3. VARIATIONAL PARAMETERS

Dependence of accelerated beam parameters on injection voltage, injected current and klystron RF power were investigated. The results of calculation are represented in Table 3, Fig.4 and 5.

Table 3. Injection voltage variation

Ver.	U_i, kV	k_c, %	I_b, A	E_m, MeV	E_a, MeV
1	30	45.5	0.11	10.26	9.27
	40	48.1	0.11	10.28	9.36
	50	49.9	0.11	10.30	9.30
2	30	39.9	0.24	11.68	10.19
	40	44.4	0.22	11.82	10.56
	50	47.4	0.21	11.88	10.75

The beam current changes in 2% range at RF power changing in 2.25...2.90 MW range for Version 1 and in 4.5% range at RF power changing in 4.0...4.75 MW range for Version 2. Analysis of variational parameters allows us to conclude:

- Injection voltage influences on accelerated beam parameters very weakly in the range 30...50 kV. Injection voltage can be chosen in this range taking into account high-voltage power supply aspects.
- Changing the peak RF power and injected beam current we can choose the operating mode in wide range of beam parameters, namely for Version 1: P=2.5 MW, I_i=0.25 A, U_i=40 kV, E_m=9 MeV, E_a=8.1 MeV, I_b=0.14 A and for Version 2: P=4 MW, I_i=0.68 A, U_i=40 kV, E_m=9.0 MeV, E_a=8.1 MeV, I_b=0.3 A. As an experience shows there are unaccounted power losses subsequent upon not ideal tuning of the units in real accelerator. In this case the klystron power reserve will be used.

4. CALCULATION OF ACCELERATING STRUCTURE SIZES

The computer program MICROWAVE STUDIO was used for these calculations with method, described in [2]. The structure sizes were calculated in three main steps.

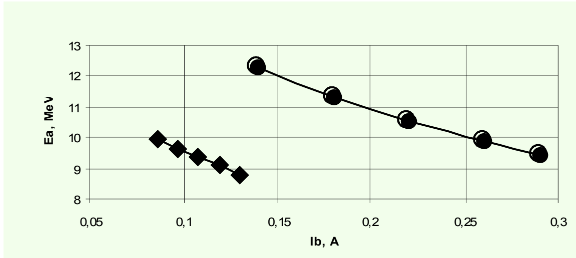

Fig.4. Beam load at injection voltage U_i=40 kV and RF power 2.5 (♦) and 4.5 (•) MW

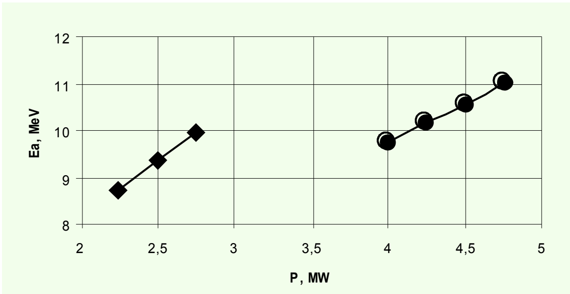

Fig.5. Average energy dependence on RF power at injection voltage U_i=40 kV and injected current I_i 0.225 (♦) and 0.5 (•) A

Step #1: calculation of frequency of accelerating and coupling cells using model including two accelerating half cells and coupling cell between them.

Step #2: correction of calculation of Step #1 for first part of the structure using model, including full accelerating cell #1, accelerating half cell #2 and coupling cell between them.

Step #3: calculation of accelerating cell #19 and input coupler using model including accelerating half cell #18, full accelerating cell #19, coupling the cell between them and the input waveguide coupled with accelerating cell #19.

The accelerating field in the model of regular part of accelerating structure is shown in Fig.6.

Designed value of coupling coefficient of the input coupler is 2.1 for Version 1 and 3.4 for Version 2. The input waveguide is coupled with the structure through rectangular coupling window. The calculation model includes: accelerating half cell #18, full accelerating cell #19, coupling cell between them and input waveguide coupled with accelerating cell #19 through rectangular window. The window width (parallel to structure axis) is equal to 13.2 mm. The coupling coefficient $\beta_{1.5}$ of this model (1.5 accelerating cells) relates with coupling coefficient of the whole structure β_{19} (19 accelerating cells) with the same coupling window by following relation: $\beta_{1.5} = \beta_{19} \dfrac{L_{19}}{L_{1.5}}$,

where L_{19} and $L_{1.5}$ are the lengths of the whole structure and the model.

The coupling coefficient dependence on the coupling window length (perpendicular to the structure axis) is shown in Fig.7. The accelerating field distribution in input coupler is shown in Fig.8.

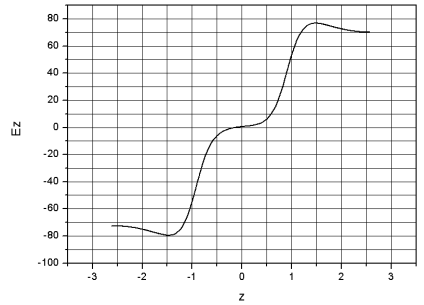

Fig.6. The accelerating field in the model of regular part of accelerating structure

Fig.7. Input coupler tuning

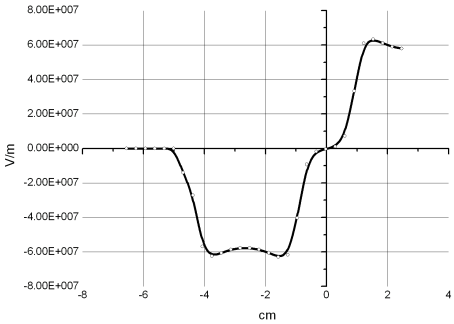

Fig.8. Field distribution in the input coupler

5. AVERAGE THERMAL CONDITION

A maximum average RF power is 22.5 kW. The power dissipated in the structure in this case is equal to 11.3 kW in Version 1 and 7.7 kW in Version 2. The cooling of the structure is realized by the water flow through 16 channels in the cell body as this is shown in Fig.9.

Four channels are connected in parallel so that the water flows four times through the structure in opposite directions in turn as this is shown in Fig.10.

The thermal calculation results are: water flow is 38 dm^3/min, outlet-inlet temperature difference is 0.2^{0}C, water-copper temperature difference is 6.5^{0}C, water speed is 2 m/sec for maximum power 11 kW dissipated in the structure.

Fig.9. Detail of accelerating structure

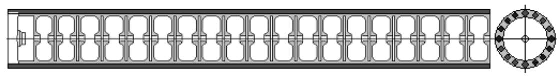

Fig.10. Water channels in the accelerating structure

6. SUMMARY

The calculated parameters of the accelerator operated in two modes at maximum klystron average power and in nominal beam power mode, corresponding to Version 1 and Version 2, are represented in Table 4.

Table 4. Facility parameters

Parameter	Version 1	Version 2
Peak RF power, MW	2.5	4.0
Average RF power (max/nom), kW	22.5/15	22.5/9
Most probable energy, MeV	9	9
Average energy, MeV	8.1	8.1
Beam current width, μsec	12	12
Frequency repetition (max/nom), Hz	600/430	400/160
Average structure loss (max/nom), kW	11.3/8.3	7.7/3.1
Average beam power (max/nom), kW	7.8/4.6	11.6/4.6

Taking into account unaccounted power losses, one may conclude, that the nominal total beam power of the facility is up to 7.5 kW for Version 1 and up to 10 kW for Version 2. Nominal beam power is 4.6 kW in both Versions.

REFERENCES

1. B.V.Zverev, N.P.Sobenin, *Electrodynamic Characteristics of Accelerating Cavities*, Moscow: Energoatomizdat, 1993.
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УСКОРЯЮЩАЯ СТРУКТУРА ЛИНЕЙНОГО ЭЛЕКТРОННОГО УСКОРИТЕЛЯ НА ЭНЕРГИЮ 10 МэВ

А.А. Завадцев, А.А. Краснов, И.С. Кузьмин, Н.П. Собенин, А.И. Фадин

Приведены результаты расчета бипериодической ускоряющей структуры электронного ускорителя на энергию 10 МэВ со связью по оси. Метровая структура имеет 19 ускоряющих ячеек, две из которых группирующие. Рассмотрены два варианта ВЧ-питания ускоряющей структуры мощностью 2,5 и 4,5 МВт. Амплитудные значения тока для этих вариантов равны 0.14 и 0.3 А, что обеспечивает захват в процесс ускорения 44…49% электронов. Структура с апертурой 8 мм имеет эффективное шунтовое сопротивление 74 МОм/м.

ПРИСКОРЮЮЧА СТРУКТУРА ЛІНІЙНОГО ЕЛЕКТРОННОГО ПРИСКОРЮВАЧА НА ЕНЕРГІЮ 10 МеВ

А.А. Завадцев, А.А. Краснов, И.С. Кузьмін, Н.П. Собенин, А.И. Фадин

Приведено результати розрахунку біперіодичної структури електронного прискорювача на енергію 10 МеВ зі зв'язком по осі. Метрова структура має 19 прискорюючих осередків, два з яких такі, що групують. Розглянуто два варіанти ВЧ-живлення структури потужністю 2,5 і 4,5 МВт. Амплітудне значення струму для цих варіантів дорівнюють

0.14 і 0.3 А, що забезпечує захоплення в процес прискорення 44...49% електронів. Структура з апертурою 8 мм має ефективний шунтовий опір 74 МОм/м.