WIDE RANGE ELECTRON ENERGY ADJUSTMENT AT TWO-SECTION RF LINAC

K.Yu. Kramarenko, V.A. Kushnir, V.V. Mytrochenko*, A.M. Opanasenko, S.O. Perezhogin

National Science Center "Kharkov Institute of Physics and Technology", 61108, Kharkov, Ukraine

(Received June 16, 2009)

The results of numerical electron energy adjustment simulation at the exit of two-section RF linac in a wide range are presented. It is shown that energy of particles can be varied at the range of 15...94 MeV. Other beam parameters vary within tolerance limits at beam energy adjustment due to keeping the bunches at the travelling wave crest of self-consistent field in the linac sections.

PACS: 41.75.Ht, 25.20.-x

1. INTRODUCTION

At present there's the lack of information on cross-sections of many-particle photonuclear reactions for most nuclei. The reactions on nuclei that are placed far from β stability band and have changed relation between coulomb and nuclear interaction are of particular interest. The serious problem at the modern stage of nuclear power engineering is to develop the subcritical nuclear reactors controlled by electron linacs. Obtaining experimental data on cross-sections as well as on neutron yield in multi-neutron photonuclear reactions on various isotopes are critical issue at solving the problem especially at γ-quantum energy in the range of 40...100 MeV where experimental data is almost absent while theoretical models are unreliable [1]. To carry out the experiments aimed to obtain experimental quantitative data it is necessary to have specific apparatuses, particularly electron linac with beam energy that can be smoothly adjusted in a wide range, preferably from 20 through 100 MeV. For this matter, an electron linac with maximum energy of 100 MeV and average current of 6 μA [2] has been created at NSC KIPT on the basis of the existed linac $LU-40$ with maximal beam energy of 40 MeV. The key elements of the linac are diode electron gun, injection system and two travelling wave accelerating sections. Increase of maximal beam energy has been obtained by replacing the old accelerating section with new ones that have higher shunt impedance (so called "Kharkov-85" section type [3]). At the reconstruction of $LU-40$ linac, besides maximal beam energy increase, it was necessary to solve the problem of wide range beam energy adjustment that is very important for nuclear-physical researches. Beam energy at the exit of the first section of the two-section linac is usually well relativistic. For example, at the reconstructed linac that energy in the nominal mode must be about 50 MeV. In such case, at the very short electron bunches, energy of particles can be changed by a few methods. In particular, the acceleration of electron bunches off-crest of travelling wave in the second section allows to change particle energies in a wide range [2]. Obviously, off-crest acceleration leads to energy spectrum widening at finite bunch length. Acceleration or deceleration of particles at the travelling wave crest with variable amplitude can be alternative method of beam energy adjustment. In our opinion this method is more acceptable concerning finite bunch length. In order to study this method efficiency, the simulation of self-consistent beam dynamics in the reconstructed linac has been carried out. Because of high shunt impedance of the "Kharkov-85" sections simulation of self-consistent beam dynamics is reasonable and can get more adequate results comparing with "given field" approach simulation. Preliminary analysis has shown that even at beam current about 100 mA beam loading effect causes significant influence on beam parameters.

2. SIMULATION OF BEAM DYNAMIC

The simulation has been carried out with the computer code developed by the authors [4], [5], [6] that is based on use of the SUPERFISH [7] and PARMELA [8] codes. The developed code simulates self-consistent dynamics of intense electron beam in linacs consisted of standing wave and traveling wave sections taking into account space charge effect and transients. Beam dynamics in electron source (thermionic diode gun) was simulated with the EGUN code [9].

The following parameters have been used at simulation: pulse current at the injector exit 66 mA; current pulse duration 1.6 μs; pulse duration of RF power supply 3 μs. Values of RF power supply at kly-

*Corresponding author E-mail address: mitvic@kipt.kharkov.ua

stron outputs can be varied in a range from 0 through 16 MW by adjusting amplitude of high voltage pulses at outputs of klystron modulators. The reconstructed linac has been configured so that the injector system and the first accelerating section are supplied with RF power from the same klystron. Part of klystron output power canalized to the injector through directional coupler with minimal attenuation of 11 dB. The simulation has shown that optimal RF power supply of the injector is 0.75 MW. Therefore minimal RF power that can be used to supply the first accelerating section is 9.4 MW. Maximal beam energy at the linac exit can be obtained when RF power supply of each section are 16 MW (see second column of Table 1 and Fig.1). In this case beam energy is 94 MeV. It is necessary to note that energy spread width substantially depends on beam loading influence. The field amplitude excited in the sections by accelerated particles is substantial to the total accelerating field. Steady state acceleration is set after accelerating sections are filled with fields associated both with RF generator and particles (filling time is 0.92 μs in our case). To diminish influence of beam loading on beam energy, so called ΔT scheme was used. It means that current pulses have been injected into acceleration section at the moment of time when the section is not yet filled with RF power from the klystron. Despite simulation has shown that optimal time delay between RF and current pulses is 0.8 μs or 0.87 μs fraction of the section filling time, full beam loading compensation has not been obtained. For further diminishing influence of beam loading onto beam energy it is necessary to decrease the beam current. At constant RF power supply of the first section (16 MW) beam energy at the linac exit can be smoothly changed by gradual decreasing of RF power supply of the second section with simultaneous adjustment of it phase to provide about on-crest acceleration. At zero RF power supply of the second section its wave phase velocity needs to be changed from the velocity of light, for example by changing section temperature far away from operation temperature, to diminish excitation of RF fields by particles traveled through the section. In this case it is possible to expect that energy parameters of beam at the linac exit are the same as that at the exit of the first section. As simulation has shown (see third column in Table 1) the minimal beam energy that can be obtained with this approach is 48 MeV.

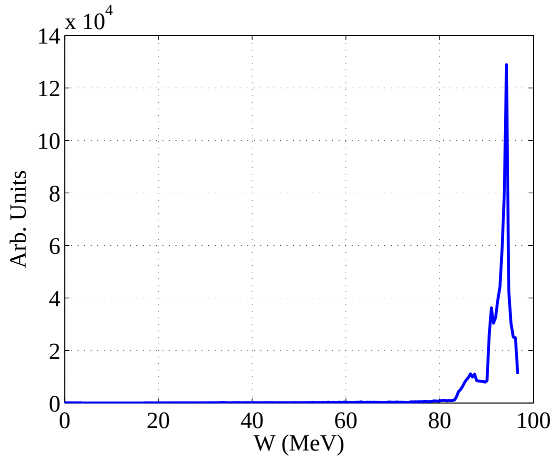

Fig.1. *Beam energy spectrum at maximal energy*

Table 1. *Beam parameters at the linac exit*

RF power supply (MW)	16+16	16	9.4*	9.4**
Beam current (mA)	63	63	61.5	61.3
Mean energy (MeV)	89.3	45	34.6	32.2
Peak energy (MeV)	94.3	48	36.1	32.6
Energy spread width for 70 % of particules (%)	5.4	8.2	5.9	8.9
Energy spread width at the half of spectrum maximum ($FWHM$) (%)	0.5	2.4	0.5	0.5
Bunch phase length for 70 % of particules ($deg.$)	17.1	17.6	17,1	17.1
Rms beam radius (mm)	0.71	0.73	0.76	1.2
Normalized emittance ($mm \cdot mrad$)	6	6	5	5

* second section is detuned (wave phase velocity is not equal to the light velocity)
** second section is tuned

Further beam energy decreasing can be obtained by decreasing RF power supply of the first section. Simulating results of beam dynamics at minimal RF power of 9.4 MW are presented in the forth column of Table 1. Simulation also has been performed for the similar case but when phase velocity of accelerating wave in the second section was equal to velocity of the light. The results are presented in the fifth column of Table 1. Beam energy is lower in this case because of particles interaction with the section (influence of beam loading). Thus, the simulation has shown that beam energy can be changed in a range from 33 through 94 MeV by level adjusting of RF power supply keeping bunches at the travelling wave crest in the second section and manipulating with wave phase velocity in that section. It is important to note that changes of beam performances excluding beam energy are not significant. To provide lower beam energy compared with 33 MeV it is necessary to inject bunches into the second section at decelerated phase of travelling wave generated by RF power supply. Simulation has been performed for two levels of RF power supply of the second section $2\,MW$ and $1\,MW$ at several values of time delay between RF and current pulses. The simulation has shown that beam loading in the second "decelerated" section is the essential cause of beam energy spread. Optimal delays between RF and current pulses for cases of maximal beam acceleration in both sections and substantial beam deceleration in the second section are quite different. It can be seen from Table 2 that change of the time delay from $0.8\,\mu s$ to $0.6\,\mu s$ causes marked improvement of energy spread width from 24 % to 12 % while other beam parameters, for example, beam size and bunch phase length vary within tolerance limits. Possible explanation of this feature is following. Beam loading is the particle deceleration in self-excited field, so if we decelerate the particles in the field excited by the external RF generator both fields act in the same direction and influence of transient is higher. To partially compensate this influence it is necessary to have lower energy of particles at the exit of the first section at the beginning of a current pulse compared with the case of maximal acceleration, because shorter time delay causes lower energy of particles at the beginning of current pulse. Fig.2 and Fig.3 show energy spreads at the linac exit at the time delay of $0.6\,\mu s$. Curve features at energies that are higher than energy of peaks (additional peak in Fig.2 and step in Fig.3) are caused by the influence of transient.

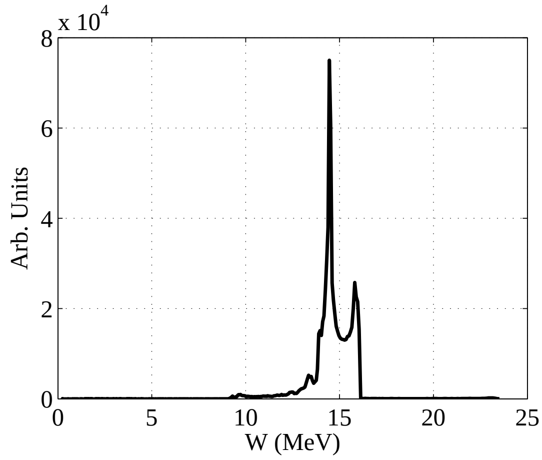

Fig.2. *Beam energy spread at deceleration in the second section with RF power supply of* $2\,MW$

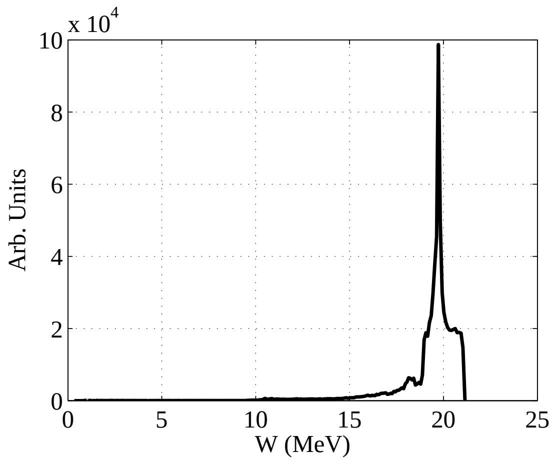

Fig.3. *Beam energy spread at deceleration in the second section with RF power supply of* $1\,MW$

Table 2. *Beam parameters at the linac exit*

RF power supply of the second section (MW)	2	2	1
Time delay (μs)	0.8	0.6	0.6
Beam current (mA)	61.2	61.6	61.7
Mean energy (MeV)	15.4	14.5	19.2
Peak energy (MeV)	14.5	14.5	19.7
Energy spread width for 70 % of particules (%)	24.2	12.2	8.5
$FWHM$ energy spread (%)	0.5	1.0	0.5
Bunch phase length for 70 % of particules ($deg.$)	17.7	19.5	19.4
Rms beam radius (mm)	1.76	2.06	1.84
Normalized emittance ($mm \cdot mrad$)	6	6	6

3. THE CONCLUSION

The simulation carried out has shown that the reconstructed linac can provide electrons energy in a range of $15...94\,MeV$. Other beam parameters vary within tolerance limits at beam energy adjustment due to keeping bunches on-crest of self-consistent field of travelling wave in the linac sections. The results obtained are of great value to carry out the experiments on wide electron beam energy adjustment at the exit of $LU-40$ which is is the base for obtaining experimental data on cross-sections as well as on neutron yield in multi-neutron photonuclear reactions on various isotopes.

4. NOTES

This research work is supported by NAS of Ukraine (Grant range beam energy adjustment at the $LU-40$ linac $No.\, X-9-242$).

References

1. A.N. Vodin. High-threshold photonuclear reactions beyond the energy of giant resonance // *Conference on High Energy Physics, Nuclear Physics and Accelerators.* Kharkov, Ukraine, 2009, p.42 (in Russian).
2. K.I. Antipov, M.I. Ayzatsky, Yu.I. Akchurin, et al. S-Band Electron Linac with Beam Energy of 30...100 MeV // *Problems of Atomic Science and Technology, Ser. "Nuclear Physics Investigation".* 2004, 5, p.135-138.
3. E.Z. Biller, A.N. Dovbhya, V.A. Kushnir, et al. Beam current enhancement in Kharkov electron linac // *Part. Accel.* 1990, v.27, p.119.
4. V.A. Kushnir, V.V. Mytrochenko, A.N. Opanasenko. Simulations of Transient Phenomena in Thermionic RF Guns // *European Particle Accelerator Conference.* Paris, France, 2002, p.1649.
5. V.V. Mytrochenko, A.N. Opanasenko. Simulation Technique for Study of Transient Self-consistent Beam Dynamics in RF Linacs // *European Particle Accelerator Conference.* Lucerne, Switzerland, 2004, p.2762.
6. V.V. Mytrochenko, A.N. Opanasenko. Study of transient self-consistent beam dynamics in RF linacs using a particle tracing code // *NIM.* 2006, A558, p.235-239.
7. J.H. Billen, L.M. Young. POISSON/ SUPERFISH on PC compatibles // *Particle Accelerator Conference.* Washington, USA, 1993, p.790.
8. L.M. Young. *PARMELA* Preprint. LANL, LA-UR-96-1835, 1996, 93p.
9. W.B. Herrmannsfeldt. *EGUN: Electron Optics Program* Preprint. SLAC, SLAC-PUB-6729, 1994, 140p.

РЕГУЛИРОВАНИЕ ЭНЕРГИИ ЭЛЕКТРОНОВ НА ВЫХОДЕ ДВУХСЕКЦИОННОГО РЕЗОНАНСНОГО УСКОРИТЕЛЯ

К.Ю. Крамаренко, В.А. Кушнир, В.В. Митроченко, А.Н. Опанасенко, С.А. Пережогин

Представлены результаты численного моделирования процесса регулирования энергии электронов на выходе двухсекционного резонансного ускорителя в широких пределах. Показано, что энергия частиц может изменяться в пределах 15...94 МэВ, тогда как остальные параметры пучка изменяются в допустимых пределах благодаря поддержанию сгустков на гребне волны самосогласованного поля.

РЕГУЛЮВАННЯ ЕНЕРГІЇ ЕЛЕКТРОНІВ НА ВИХОДІ ДВОХСЕКЦІЙНОГО РЕЗОНАНСНОГО ПРИСКОРЮВАЧА

К.Ю. Крамаренко, В.А. Кушнір, В.В. Митроченко, А.М. Опанасенко, С.О. Пережогін

Представлені результати чисельного моделювання процесу регулювання енергії електронів на виході двохсекційного резонансного прискорювача в широких межах. Показано, що енергія частинок може змінюватися в межах 15...94 МэВ, тоді як решта параметрів пучка змінюється в допустимих межах завдяки підтримці згустків на гребені хвилі самоузгодженого поля.