DESIGN OF LINEAR INDUCTION ELECTRON ACCELERATOR LIA-R

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A design of linear induction electron accelerator LIA-R meant for generation of bremsstrahlung pulse of duration ~ 50 ns at half maximum is presented. As well as a facility LIA-10M the accelerator consists of an injector and 16 standard acceleration modules. As an injector it is supposed to use a modification of STRAUS-R accelerator developed on the basis of five-cascade double stepped forming line (DSFL) of diameter 1.2 m with water insulation. Inductors will be made on the basis of four-cascade DSFL of diameter 1 m. It is expected to accelerate the electron beam up to the energy ~30 MeV at the acceleration rate ~1 MeV/m.

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INTRODUCTION

Recently in many countries (the USA, Great Britain, France, China, Russia) there have been conducted works on developing of electron accelerators of different type meant for X-ray imaging of fast processes and capable to generate powerful bremsstrahlung radiation pulses of length not more than 100 ns at focusing of electron beam on the target to a spot with a diameter of several mm and less. For this purpose accelerators of various types are used. (LIA on the base of inductors with ferromagnetic cores or metglass cores, accelerators with employment of technology of inductive voltage adder, linear high-frequency accelerators, direct-action pulsed accelerators, ironless betatrons). The results of works are covered in details in the scientific literature (see, for example, review [1] and references presented).

One should pay attention to the fact that each laboratory participating in creation of such accelerators directs its efforts, as a rule, to the facilities of special type. This is explained by the fact that development of each such accelerator is based upon employment of special technologies mastered in these laboratories whose practical realization takes a lot of years and requires large material expenses.

For several decades RFNC-VNIIEF has been accumulating a large experience of development and operation of ironless linear induction accelerators with inductors on the basis of transmission lines with water insulation [2,3]. The main units of accelerating system of such facilities are: an injector and a series of one-type acceleration modules (inductors) installed in turn, where an electron beam is formed and accelerated, a beam transportation track to the site of experiments, and, if necessary, a focusing unit. To prevent the beam radial expansion under the effect of volume charge forces in the near-axial area along the whole length of the accelerator a pulse uniform longitudinal magnetic field is created.

In the accelerators LIA-10, LIA-10M and LIA-30 there are formed annular electron beams of diameter 60…200 mm with current of 30…100 kA which at boundary acceleration energy of 14…40 MeV generate powerful pulses of bremsstrahlung radiation with relatively short duration of 10…20 ns. Magnetic field induction in the accelerating channel is 0.5…0.6 T.

Accelerators of such a type can be used for the purposes of fast processes studying. Below a design of powerful X-ray accelerator LIA-R is briefly described.

1. INDUCTOR LIA-R

As a result of analysis of results of a large series of calculations to form the pulses of accelerating voltage in the facility LIA-R there were selected inductors on the basis of stepped forming lines made with the use of cylindrical coaxial lines with water insulation [2,4]. The inductor is designed according to the circuit of four-cascade double stepped forming line (DSFL) presented in Fig.1.

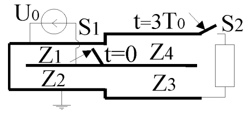

Fig.1. Circuit diagram of inductor LIA-R

When switch S_1 is closed at the output of inductor charged up to the voltage U_0 beginning from the time point T_0 there are formed voltage pulses of alternating polarity of $2T_0$ duration that have, ideally, a square shape. Here T_0 is an electric length of individual cascade. The second voltage pulse is a working one. At correlation of impedances Z_1:Z_2:Z_3:Z_4= 1:3:6:2 such a circuit possesses, ideally, 100% efficiency and in the matched mode of operation it provides a two-fold increase of the output voltage as compared to the charging voltage of the line and in the idle-running mode – a four-fold increase. The given circuit was earlier successfully used at development of 16 inductors of accelerator LIA-10M [4].

Fig.2 presents an inductor construction diagram. DSFL is formed by the coaxial cylindrical lines 1…4 with water insulation arranged subsequently over the radius in the case Ø1 m and 1.3 m in length. The output impedance of DSFL is 7 Ohm. On the outer diameter of DSFL a triggered multi-channel switch is mounted formed by 18 gas-filled spark gaps 5. Accelerating tube 8 is made as a polyethylene tube and a sectioned insulator mounted inside, between them a tubular layer of water solution NaCl is placed. The space between the accelerating tube, polyethylene diaphragm 6 and metallic cone 9 is filled by transformer oil. The full axial size of inductor is ~1.8 m.

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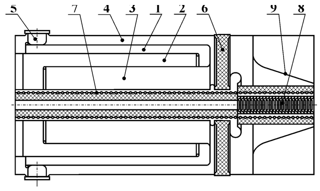

Fig.2. Construction diagram of inductor LIA-R

The electron beam with diameter ≤ 20 mm propagates in the paraxial vacuum channel Ø60 mm. With the aid of solenoid 7 in the vacuum channel when accelerating the beam there is formed a longitudinal field that is rather uniform by length with induction of 1.5…2 T. DSFL will be charged up to the voltage ~500 kV by a six-cascade Marx generator with output capacity 135 nF using in every cascade two condensers IEPM-100-0.4.

2. INJECTOR LIA-R

Selection of circuit and construction diagrams for the injector depended mostly on selection of corresponding diagrams for inductors of facility LIA-R. As a result of analysis of different variants for a high-voltage pulse shaping in the injector there was selected a circuit diagram of five-cascade DSFL (Fig.3) which possesses, ideally, 100% efficiency at correlation of impedances Z_1:Z_2:Z_3:Z_4:Z_5= 1:3:3.75:1.25:15.

In the matched mode of operation the voltage at the output of DSFL grows by a factor of three as compared to the charging line voltage, and in the idle-running mode – by a factor of six. The given circuit was earlier successfully used when developing accelerators STRAUS, STRAUS-2 and LIA-10M injector [4].

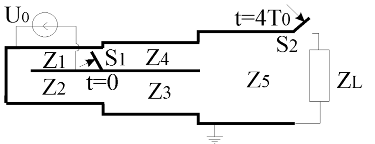

Fig. 3. Circuit diagram of inductor LIA-R

The simplified injector construction diagram is given in Fig.4. DSFL is formed by cylindrical coaxial lines with water insulation 1…5 placed in the case Ø1.2 m. The output impedance of DSFL is 18 Ohm. On the outer case diameter there was mounted a triggered multichannel switch formed by 20 gas-filled spark gaps 6. Accelerating tube 9 is similar in design to the accelerating inductor tube. The space between the accelerating tube, polyethylene diaphragm 7 and cone 12 is filled by transformer oil.

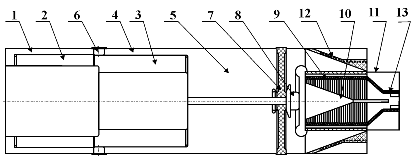

Fig.4. Construction diagram of injector LIA-R

In the inner vacuum volume of the accelerating tube there are located cathode support 10 and a cylindrical cathode, whose emitting edge is placed in output chamber 11. When triggering switch 6 at the output of DSFL there are formed pulses of altering polarity voltage. The second pulse is working and the first one is cut off from the accelerating tube by one-channel triggered prepulse gas-filled gap 8. The required distribution of the magnetic field in the area of vacuum diode is developed with the aid of pulse solenoids 12 and 13. The full axial size of injector is ~ 4.5 m.

DSFL will be charged up to the working voltage ≤ 650 kV for the time 0.8 μs by 8-cascade Marx generator with output capacity 100 nF using in every cascade two condensers IEPM-100-0.4.

3. ACCELERATING SYSTEM LIA-R

In the developed design the accelerating system LIA-R is to be made as a part of the injector, 16 standard accelerating modules, the electron beam transportation track and the output focusing unit. By its appearance and composition the accelerating system LIA-R will be closely similar to an analogous accelerator LIA-10M system, but it differs in increased axial dimensions of the injector and inductors.

A specific feature of accelerator LIA-R as compared to the earlier developed ironless LIA is the necessity to focus the beam at the output of the facility to a small-size spot. Taking into account a circuit (accepted in such type facilities) of injection, acceleration and transport of the beam in the uniform longitudinal magnetic field such an operating condition imposes limits on the maximum diameter of the injected beam and requires obtaining of electrons with minimum transverse impulse at the facility output. In LIA-R the beam diameter should not exceed 20 mm.

Besides, according to the terms of application LIA-R can have a much higher (up to 100 ns) pulse duration. It is shown that at accelerator implementation on the basis of above-named circuit designs the optimal half-height duration of bremsstrahlung radiation is 45…50 ns at current pulse duration of ~60 ns. This was a reason for refuse to employ the radial lines in inductors. A significant interest should be also paid to the growth of the facility operation reliability and to the accelerating system precise adjustment.

According to the results of numerical simulation the injector must provide formation of the electron beam with current of 10…20 kA at the outer diameter 10…20 mm and the boundary electron energy of 3…3.3 MeV (Fig.5,a). Accelerating voltage pulse duration on the level of 0.5 from the amplitude value is 60 ns, on the level of 0.9…50 ns [5].

The beam formed in the injector will be accelerated in the vacuum channel of diameter 60 mm at induction of longitudinal magnetic field of 1.5…2 T. At the output of each inductor there should be generated a pulse of accelerating voltage of the amplitude of 1.75…1.65 MV (at current of 10…20 kA) with duration on the level 0.5 from the amplitude value of 63 ns, on the level 0.9…43 ns (Fig.5,b). A possibility exists for changing the amplitude of the accelerating voltage (within certain limits) through varying the inductor charging voltage and resistance of electrolytic load of the accelerating tube.

At the accelerator output the diameter of the electron beam with the maximum energy of particles of about 30 MeV will decrease ~4 times at the length of ~1 m through the use of intensively growing magnetic field

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with maximum induction of ~30 T. According to the calculations the bremsstrahlung dose at a distance of 1 m from the target should be from 2000 to 4000 R.

The advantage of the proposed variant of radiography accelerator is a possibility to obtain rather large pulse currents and bremsstrahlung doses and, what is more important for installation of LIA-R, a weak dependence of the sizes of focus spot on the electron energy at the accelerator output. Disadvantages are a relatively large energy store of the capacitor bank used for development of pulsed magnetic field in the accelerator.

a

b

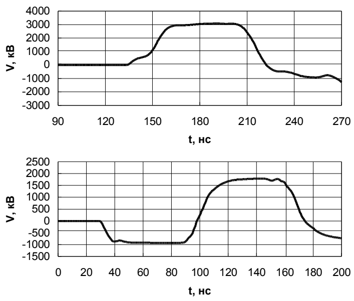

Fig.5. Calculation pulse shapes of the accelerating voltage of injector (a) and inductor (b)

The developed design is realized by several stages. At the first stage in 2003 an injector prototype – STRAUS-R pulse electron accelerator was created [6]. It is used as an independent radiography accelerator and provides for a focus spot ≤ 4 mm in diameter on the target at the maximum X-ray dose of 27 R at a distance of 1m from the output flange. The boundary electron energy is 3.0…3.5 MeV, the beam current is ≤ 60 kA and the bremsstrahlung radiation pulse duration is ≤50 ns. Experimentally determined accelerator characteristics correspond to the design parameters.

At present the development of LIA-R mock-up with acceleration energy of ~10 MeV as a part of the injector, four acceleration modules, the beam transportation track and the output focusing is being finished. Experimental results obtained here will be taken into account when creating a full-scale accelerator LIA-R with acceleration energy of ~30 MeV.

REFERENCES

1. C. Ekdahl. Modern Electron Accelerators for Radiography // *IEEE Trans. on Plasma Science*. 2002, v.30, №1, p.254-261.
2. V.S. Bosamykin, A.I. Gerasimov, V.S. Gordeev. *Ironless linear induction electron accelerators – powerful generators of bremsstrahlung short pulses*. High Energy Densities. Collection of Proc. RFNC-VNIIEF. Sarov. 1997, p.107-133.
3. M.A. Voinov, A.I. Gerasimov, V.S. Gordeev et al. Complexes on the Basis of High-Current Linear Induction Accelerators and Pulsed Nuclear Reactors// *Problems of Atomic Science and Technology. Series: Nuclear Physics Investigations*. 1999, №3(32), p.82-84.
4. V.S. Gordeev, V.F. Basmanov, G.A. Myskov et al. High-current pulsed electron accelerators based on step-like forming lines // *Problems of Atomic Science and Technology. Series: Nuclear Physics Investigations*. 2001, №3(38), p.50-52.
5. V.S. Gordeev, E.S. Mikhailov, G.A. Myskov, D.V. Laptev. Numerical simulation of the processes of small-diameter high-current electron beam shaping and injection // *Problems of Atomic Science and Technology. Series: Nuclear Physics Investigations*. 2001, №5(39), p.33-35.
6. V.S. Gordeev, G.A. Myskov, V.F. Basmanov et al. *Pulsed Electron Accelerator STRAUS-R*. Proc. of the 15th Intern. Conf. on High-Power Particle Beams, BEAMS'2004. 2004, Saint-Petersburg, p.323-326.

ПРОЕКТ ЛИНЕЙНОГО ИНДУКЦИОННОГО УСКОРИТЕЛЯ ЭЛЕКТРОНОВ ЛИУ-Р

В.С. Гордеев, Г.А. Мысков, Е.С. Михайлов

Представлен проект линейного индукционного ускорителя электронов ЛИУ-Р, предназначенного для генерации импульса тормозного излучения длительностью ~ 50 нс. Как и установка ЛИУ-10М ускоритель состоит из инжектора и 16 типовых ускорительных модулей. В качестве инжектора предполагается использовать модификацию ускорителя СТРАУС-Р, разработанного на базе пятикаскадной двойной ступенчатой формирующей линии (ДСФЛ) диаметром 1.2 м с водяной изоляцией. Индукторы будут выполнены на базе четырехкаскадной ДСФЛ диаметром 1 м. Электронный пучок предполагается ускорять до энергии ~30 МэВ при темпе ускорения ~ 1 МэВ/м.

ПРОЕКТ ЛІНІЙНОГО ІНДУКЦІЙНОГО ПРИСКОРЮВАЧА ЕЛЕКТРОНІВ ЛІП-Р

В.С. Гордєєв, Г.А. Мисков, Є.С. Михайлов

Представлено проект лінійного індукційного прискорювача електронів ЛІП-Р, призначеного для генерації імпульсу гальмового випромінювання тривалістю ~ 50 нс. Як і установка ЛІП-10М прискорювач складається з інжектора і 16 типових прискорювальних модулів. Як інжектор передбачається використати модифікацію прискорювача СТРАУС-Р, розробленого на базі п'ятикаскадної подвійної східчастої формуючої лінії (ПСФЛ) діаметром 1,2 м з водяною ізоляцією. Індуктори будуть виконані на базі чотирьохкаскадної ПСФЛ діаметром 1 м. Електронний пучок передбачається прискорювати до енергії 30 МеВ при темпі прискорення 1 МеВ/м.