ELECTRON RECIRCULATOR AS HIGH EFFICIENCY SOURCE OF HARD RADIATION

V.Grishin, B.Ishkhanov, S.Lichachev, V.Petukhov
INP of MSU, Moscow 119899, Russia

Abstract

The new physical scheme of an X- and gamma- ray source is considered, in which one the process of an emission of bremsstrahlung photons is accompanied by acceleration of electrons. The computer modeling confirms high efficiency of proposed scheme enhancing the yield of soft and hard bremsstrahlung photons at maintenance of the compact sizes of all devices.

1 INTRODUCTION

The X-ray and gamma bremsstrahlung radiation sources discover extremely broad applications in fundamental and applied researches. Therefore it is rather important to raise efficiency of these devices, which one in practice does not exceed 5-10 % [1,2]. The optimization of similar devices is reached as the compromise of conflicting objective. For pinch of a photon output it is required to increase thickness of the target, but thus will increase uptake of generated photons in the target body. Besides as in the thick target (optimum is a thickness about half of electron range in matter of the target) electrons on the average radiate at energy, smaller initial one. In result a radiation yield of not only soft, but also hard photons is reduced, and the ultimate yield does not exceed third of their generated quantity.

In paper of the authors [3] it was offered to utilize the scheme with the thin target located in a special focusing magnetic field. The electrons circulating in a magnetic field multiple cross the target and generate in the total as much of photons, as well as in the target matter of conventional device, but thus practically all photons leave from the target. The subsequent computer modeling has confirmed this prognosis: The energy efficiency of radiation is increased approximately in 3 times [4]. The truth as it also was necessary to expect the basic increase in a radiation spectrum is a share of soft photons.

Therefore it is important to estimate efficiency indicated in [3] other scheme with the prolonged cycle of radiation with compensation of electron energy lost at passage of the thin target. Here circuital mode gains the relevant peculiarities. Due to regular compensation, the radiation now happens at electron energies closed to maximal (in the thin target the energy of electrons for one pass varies a little). Owing to this the bremsstrahlung spectrum is enriched by photons with the greatest energies. Thus will increase also ultimate yield of radiation because the power transmission of electrons in radiation is proportional to magnitude of particle energy [2].

2 RECIRCULATOR AS RADIATION SOURCE

The modern methods of a beam acceleration allow to realize the scheme of a recirculation source by different ways. One of the possible simple schemes - electronic cyclotron with an induction beam acceleration (see fig.1).

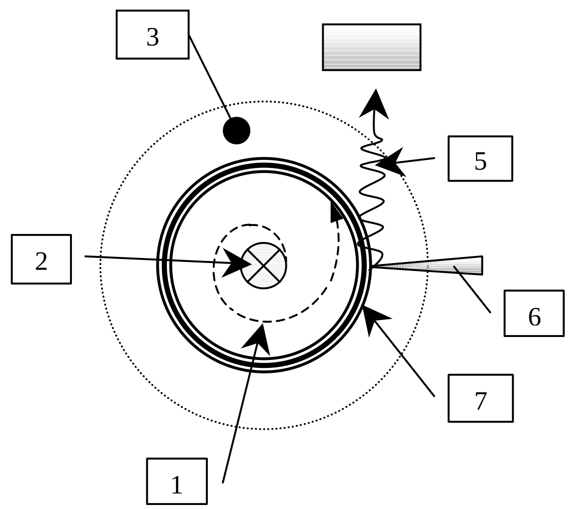

Figure1: Recirculator as source of hard radiation. 1-Electron acceleration, 2-Induction magnetic core, 3-Magnetic poles, 4-Detector, 5-Gamma-rays, 6-The bremstrahlung cuneiform target, 7- Trajectories of electrons near of a radiation orbit.

The system consists of two flat magnetic poles creating a constant magnetic field (can be utilized permanent magnets) and induction core, passed through poles, by which one accelerating electric field is excited. During acceleration the electrons will displace from an interior initial orbit of injection up to some final trajectory. Here the radiation target having a wedge form with pearhead directed inside is disposed. The system is calculated so, that on electron reaching of an outer orbit the accelerating cycle is prolonged. Then the electrons will displace out, crossing the target, losing energy and radiating photons. As the target thickness grows with radius of an orbit, the dynamic balance between power losses of a particle and its acceleration is automatically erected on some radius, and this balance will be supported up to an end of an accelerating cycle. Further electrons are dropped on the supplementary target, radiating the last portion of photons, and the cycle is iterated.

From the practical point of view it is necessary, that the system ensured a sufficient stability of electrons. It is successfully solved if to follow to the prescriptions of construction of modern accelerators. So, in the cyclotron the stability of particles at acceleration up to radiation orbit is ensured by natural dispersion of a magnetic field on a rim of poles. By the data [4], the circulation should be stable though in an radiation mode the electrons experience a dispersion in targets deflecting their trajectories (these confirm also by results of modeling in paper [5] where, the truth, was considered more simple problem).

3 COMPUTER MODELING

The expressed above conclusions and prognoses were tested by means of computer modeling. The modeling was conducted on the basis of the software package GEANT [6], specially adapted for motion study of particles in different electromagnetic fields [4].

So, model of a source of a cyclotron type discussed with induction acceleration is picked. The electrons with final energy E_0 by turns was injected on an intermediate stable orbit in axial - symmetric, slow reduced at removal from center a magnetic field (initial stage of a beam acceleration, as not representing of special interest, was eliminated). The induction acceleration was imitated by resonator transferring to electrons on each their revolution the portion δE of energy. The electrons, gathering energy, enlarged a radius of rotation and started to “mesh” the wedge target (its thickness accrued with a radius) losing energy, and radiating photons. Through some electron circulations the dynamic balance was erected, and the electrons were prolonging to radiate, making spatial oscillations near to some medial stable orbit. On reaching a circulation quantity of radiation, the process was stopped.

The modeling has confirmed a dynamic stability of electrons, the trajectories which ones did not fall outside the limits of some tube of a beam current, in spite of the fact that the scattering of orbits on each revolution were noticeable, as the portion of swapping of energy and its losses at cross of the target were major enough. Therefor the dynamic balance was fulfilled only on the average (last circumstance reflects accidental character of physical processes of a dispersion and radiation of electrons in matter; the program imitated this phenomenon by Monte Carlo method). The quantity of traced circulations reached from several tens up to hundreds turnovers, and the extinction of a cycle of rotation for separate particles was caused in the basic poor operation proving of modeling. This circumstance has induced us to convert to not too most advantageous and technically not to the simple prototype of a source with a rather major level of compensation of energy δE about several tenth MeV for a turnover.

4 RESULT DISCUSSION

Stop on the data of one of variants of modeling with parameters: initial energy of electrons E_0 = 10 MeV, δE = 0.2 MeV/turnovers. In the total a mean value of total compensation of energy $\Delta E = N\, \delta E$, where N - an average of turnovers, has compounded 8 MeV, and N = 40, though the some particles were traced up to hundreds turnovers. The results of modeling represented on four spectrums (obtained at equal quantity tested particles at 4000), the data which ones allow judging about efficiency of the proposed scheme:

A spectrum S (10) of intensity of a conventional (direct) bremsstrahlung radiation of electrons with energy 10 MeV on the target optimized for this energy.

A spectrum S (18) of intensity of a conventional (direct) bremsstrahlung radiation of electrons with energy 18 MeV on the target optimized for this energy.

A spectrum S (8) of bremsstrahlung radiation of electrons on the cuneiform target at circulation mode obtaining and losing supplementary energy at 8 MeV.

A total spectrum S (10+8) = S (10) + S (8), as in the total after the termination of recycling the electrons are dropped on the supplementary target.

The spectrums S (8) and S (10), presented in a fig. 2, visually represent peculiarities of active circuital and conventional modes of radiation, demonstrating advantages first on quality of a spectrum, and on total energy of radiation (despite of that the spectrum S (8) is obtained at smaller energy lost by particles during brake action).

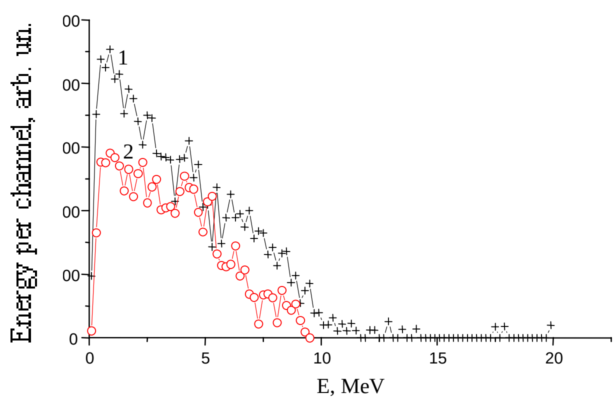

Figure 2: A distribution of photon energy radiated by electrons with energy 10 MeV. 1. - spectrum S (8), radiated at quasi-stationary value of energy 10 MeV, by electrons obtained and lost the recycling energy at 8 MeV; 2 - spectrum S (10) of direct bremsstrahlung radiation with initial energy 10 MeV.

The total energy of photons of S (8) is more than total energy of photons of S (10) approximately in 1.6 times.

A fig. 3 allows to judge, what advantages there is an active mode as contrasted to conventional in a case, when the particles gain is equal energies from accelerating system.

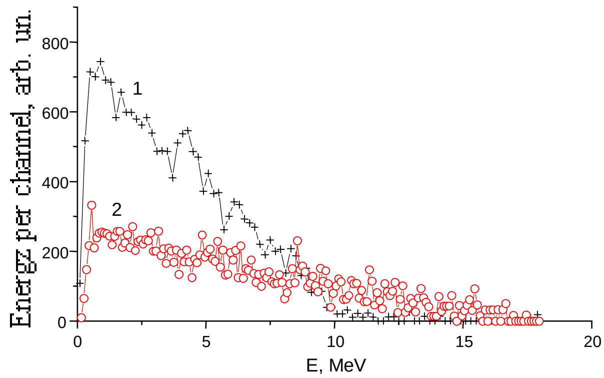

Figure 3: A distribution of photon energy radiated by electrons with the energy loss 18 MeV. 1 - spectrum S (10+8), radiated on a quasi-stationary value of energy at 10 MeV by electrons, obtained and lost the recycling energy at 8 MeV, and then dropped on the supplementary target; 2 - spectrum S (18) of direct bemsstrahlung radiation of electrons with initial energy 18 MeV.

The total energy of photons in S (10+8) is more than the energy of photons S (18) approximately in 2 times. The essential raise of a photon yield confirms, especially in the range of photons energy up to the order 9 MeV. Only in an energy range more than 10 MeV, the conventional radiation mode gives the greater number of photons which one however is not enough here. It is curious, that some photons also generated in a prolonged mode (see above) here are observed also.

At last, it is necessary to take into account, that here sizes of an source-recirculator approximately twice are less than the accelerator on a total energy (and accordingly in the cost relation), and this advantage promptly raises in accordance with extension of a cycle of radiation. Said once again confirms expediency of careful study of the practical scheme.

5 CONCLUSION

Computer modeling confirms high efficiency offered scheme of source of hard photons on base of electron recirculator with prolonged radiation mode. Thus the spectrum of radiation is essentially enriched by soft and hard photons.

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