INVESTIGATIONS ON NEW ACCELERATION SCHEMES IN DUBNA

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The direction in accelerators, based on the use of collective effects has been born and developed as efficiently alternative to synchrotrons and capable to assure high acceleration gradients by the more efficient way. It was relative to the accelerators of protons, heavy ions and electrons.

One of the collective method direction using dense electron rings for the ions acceleration and there keeping during the acceleration has been investigated in the last few years in Dubna. Initially such accelerator should be a protons linear accelerator with high acceleration gradient. Then, taking into account the JINR traditions and other reasons, as for example rapid development of superconductivity, that defined the priority of proton synchrotrons relatively to all of methods, the investigations have been run with heavy ions. The collective method investigations with electron rings accelerating heavy ions have shown that the maximum gradients on a full scale prototype accelerators (KUTI-20) of today are 4 MeV/nucl·m. The made calculations and experiments /1,2,3/ on possible variants of collective accelerator efficiency increase nave shown that due to the increase of the electron ring long time keeping in Adgezator chamber the ratio of the charge to the ions mass (Z/A) can be increased up to the value 1/2-1/3. The use of supplementary system of ring forming permits to improve geometrical characteristics of the ring. All this permits to hope to receive acceleration gradients 40 MeV/nucl·m. Comparing the expenses on the collective accelerator building and these on the heavy ions synchrotron we can say that they are comparable up to the particles energies 1 GeV/nucl. To produce heavy ions of higher energies the synchrotron remains always better.

As for the relativistic particles acceleration systems the last years a range of different directions of investigations has been born. It permits already now to think about the linear colliders with high efficiency. One of such directions foresees the transition in acceleration systems to higher frequencies (10 - 100 GHz). So, the top value of acceleration gradient in electrodynamic structure increases $1/\lambda$, where λ is the wave length of accelerating voltage.

If we take the accelerating structure as diaphragm wave guide, the accelerating tension wave length should be evidently $\lambda = 5 - 10$ mm. To produce high power levels of such a radiation the best is the use of high current induction accelerators to generate coherent electro-magnetic radiation /4,5/. Taking into account the JINR possibilities this direction hes been chosen for the investigations.

As a tesult of this investigations it is proposed to choose an optimal generation system, from the point of view of an induction accelerator (beam configuration, acceleratind gradient value) as well as the radiator type from the point of view of its efficiency.

Usually in schemes of two-beams acceleration a parallel scheme is discussed, it means that the high-current beam of small energy excites the electro-magnetic wave interacting with lowering structures, and this wave excites the acceleration structure with high gradient. After the interaction the high-current beam passes the acceleration region, where the radiation energy losses fill up, and prepares to the next interaction /6/. Fig.1.

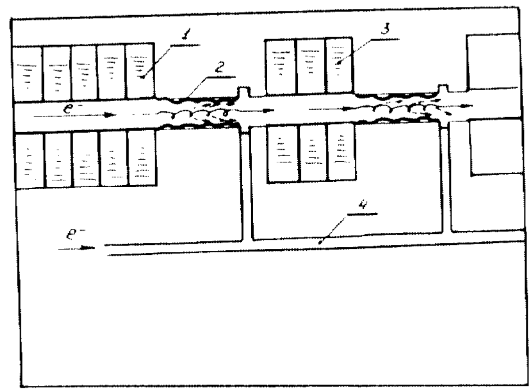

Fig.1. Two-beam acceleration scheme.

We will not discuss here the beam monochromatization questions after interaction and possibilities of the electron beam multiple use for the interaction.

To produce high accelerating gradients in accelerator, for example 250 MeV/m, a supply electro-magnetic wave power 1 Gw per meter of accelerating structure is needed.

If we take realized already today data on the generation system /5/ we can see that in these experiments with energy of electrons 3.5 MeV when interacting with 3 meter ondulator a necessary 1 Gw power has been produced with the efficiency 34 %. The filling up of the beam energy in such an induction system with mean accelerating gradient 5 - 10 kV/cm is possible on the length of 1-2 meters. It is seen that induction accelerator system requiere the increase of accelerating gradient, being diffisult to produce by a direct method, but possibleby the transition, for example on two parallel generating beams. As for the electro-dynamic structures, its linear efficiency should be increased in 5 times.

First experiments on the beam interaction from the induction accelerator with different electro-dynamic structures have been run in Dubna.

a) First serie of investigations concerns only well examined structures with periodic magnet-static field. The block-sheme of the experimental set-up is given in fig.2. The old induction ac-

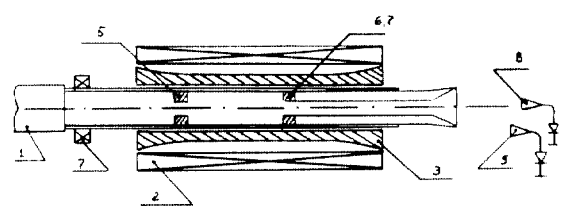

Fig.2. Beam and ondulator interaction scheme.

celerator LIU-3000, used earlear in the model of the collective accelerator /1/ is used as the electron accelerator. This accelerator permits to produce the electron beam with 200 A current and 1.5 MeV energy. The energy spread in the beam is $\leqslant 2$ %, beam radius in the accelerator exit = 0.3 cm.

The interaction region represents a wave-guide/4/ forming a thin-wall tube of stainless steel with 2.9 cm diameter. The interaction region magnetic field is the superposition of guiding longitudinal magnetic field $H_o \leqslant 10$ kG, creating by the solenoid /2/ and transversal one periodically rightpolarizated wiggler field /3/ with amplitude 5 kG. Due to the smooth increase of the field vale from zero to the maximum value (on the first five wiggler periods) (wiggler period length was 7.2 cm) the adiabatic beam enter in the wiggler field has been assured. The interaction region from both sides was limited by the mirrors /5,6/. The distance betweem them could vary in limits from 0 to 250 cm. The electron current passing through the interaction region was controlled by the meters /6,7/. The spectral constitution of radiation was determined with the help of semiconductor detector /8/ and assembly of wave-guides, permitting to change the wave length cutt in the limits 3.4 mm $\leqslant \lambda_s \leqslant 11.9$ mm. To increase the detector measurements accuracy we based on the data of supporting detector/9/.

In these experiments a large region of parameters of H_o and H_w has been investigated and we think that two regions are the most interesting. In fig.3 a rating

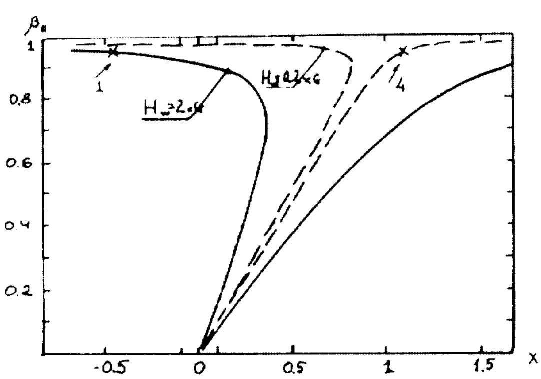

Fig.3. Longitudinal beam velocity, dependding on the interaction region fields.

longitudinal velocity depending on the $X = \frac{\omega_H}{\gamma k v c}$ with fixed Hw value is given. Zones 1 and 4 in fig.3 were realized in the experiment. For the zone 1 when $H_W = 2.2$ kG and $H_O = -2.7$ kG (H_O field direction is opposed to the electron velocity direction) radiation pulses lating from the electron current pulse to 50-80 ns with duration (100-120 ns) were observed. A characteristic spectrum of generated radiation is given in fig.4, curve 1. The radiation is observed in a large range of wiggler field values 1.5 kG - 3 kG with a maximum when H_W - 2 - 2.4 kG.

Another generation regime was observed when the driving field direction coincided with longitudinal movement direction of electrons. The pulse generation duration coincided with a beam current pulse of electrons. The characteristic peculiarity of such a resonance radiation depending on the wiggler field intencity and the solenoid. For example when the wiggler field optimum value of 300 G (H_O=5 kG) decayed on 50-80 G, the power of generation decreased up to zero. But we could renew the genera-

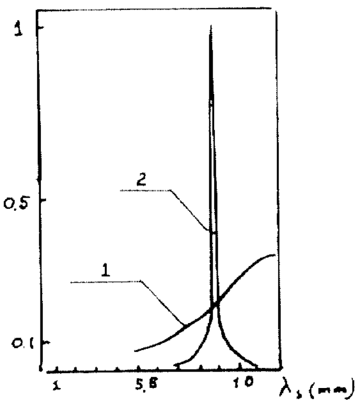

Fig.4. Radiation spectra.

tion approximately with the same power and the same spectrum character by the H_O guiding field reforming. The generation band (zone 4, fig.3) was H_W = 200 - 1000 G and respectively by H_O - 6 -7.6 kG. Total powers of radiation in both generation regimes were approximately equal. It seems to be necessary to examine the first region in a regime of independant signal increase, because of the possibility of considerable ondulator length decrease by the transition to lesser wiggler periods when H_W values are bigger.

b) Another serie of works concerns the investigations of differ mecanisms of particles stimulated radiation. Test experiments were run, where the stimulated Cerenkov and cyclotron radiation was produced.

To make these experiments , one of the induction accelerator sections was completed to produce a tube-electron beam (fig.5).

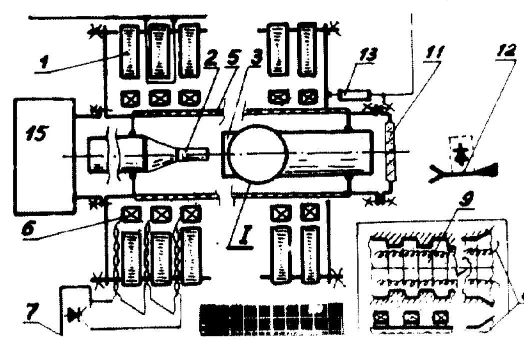

Fig.5. Scheme of experiments on the investigation of stimulated Cerenkov and cyclotron radiation of electrons.

The diode cathod and anode were made of thin-wall metal tubes, placed on a variable distance. The voltage between them was recieved by 24 inductors voltage summaring. The particles energy could vary in the limits 200-500 keV by changing the modulator voltage and anod-cathod distance.

The longitudinal magnetic field, focusing the particles and having intencity up to 20 kG was created by current bobbins. The field nonhomogeneity in the operating region did not exeed 3 %. The value of electron current passed through the interaction zone was measured by the shunt of reverse current. In the experiment the electron current value changed in the limits 0.4 - 1.2 kA. Current pulse duration was near 200 ns. But the beam trace on different materials we could determine that the beam had a tube structure with a tube diameter equal to the diameter of cathod and the wall thickness $\lesssim$ 1 mm. Two generators, based on different mecanisms of electron stimulation radiation have been chosen: on the base of Cerenkov radiation of rectilinear beams, another one - on the base of cyclotron radiation in the homogeneous magnetic field. The axial-symmetric resonators representing the fragments of weak-nonregular wave-guides were used in both generators (fig.5.From the cathod end they were limitted by narrowing, out of limits for thw operating mode, from the exit one - by the horn for the radiation taking out. The resonators difference was following: for the Cerenkov radiation excitation the wall of the resonator was corrugated with the depth $\lambda/4$, serving for the creation of slow space harmonic of resonance oscillation, synchronous with electrons. The lateral surface of gyrotron rasonator was smooth /8/. The E_{121} mode with 8.5 mm wavelength has been chosen as the operating mode of Cerenkov radoator. The mode selection has been done as in /7/ through longitudinal cuts in the resonator wall. The value of start current of electrons in the generation regime was 200 A. When the current was 600 A we recieved a stable generation with the efficiency η =5-7%. The mode type was well fixed by the characteristic radiation distribution. The radiation power was 15-20 Mw when the SHF pulse duration - 50 ns. The Cerenkov generation passed practically always near the current pulse front.

When the electron beam energy decreased, we observed the generation frustration at the mode E_{12} and its appearance at the mode E_{21} with the wavelength 11.5 mm. When the beam energy was 250 KeV and the current - 400 A, the generation power was 10 - 15 Mw, corresponding to the efficiency η = 10 - 15 %.

To produce transversal electron beam velocity, necessary for the cyclotron radiation, before the resonator a short ondulator was placed, formed by three cupper rings, modulating the field of pulse solenoid. The distance between the rings was chosen near the lermor particles step. The oscillation mode H_{311} with the wavelength 12 mm was chosen as an operating one. The transversal particles velocity $\beta_\perp$ = 0.15 corresponds to the starting regime when the calculation values of particles energy are 300 KeV, current - 600 A, magnetic field - 13 kG. In the experiment when $\beta_\perp$ = 0.1 - 0.15 the generation was absent. When $\beta_\perp$ = 0.3 - 0.4 the stable generation power 7 - 10 Mw and efficiency η = 3 - 5 % was observed. So, when we use the tube beam, we can have geometrical characteristics , necessary for the effective use in generation systems. The Cerenkov radiators assure one-mode generation (70 % of total radiation power) when interacting with such a beam, and when interaction lengths are small ($\sim$ 30 cm).

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