MEASUREMENT OF DISTRIBUTION FUNCTION OF REB, USED IN COLLECTIVE ION ACCELERATOR

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The parameters of the intense relativistic electron beam (REB), being a base element of the ion accelerator concept, were measured at the exit of the first section of a collective ion accelerator. The experimental studies of a REB current passing through metal foils of a different thickness were carried out. Using the obtained dependence of beam current attenuation on the foil thickness and the calibration curves (tables) of the dependence of penetration lengths on the particle energy, the energy distribution function of REB electrons was determined and it is represented as a histogram. The kind of plasma resulting in a short circuit of the magnetically-insulated diode was determined.

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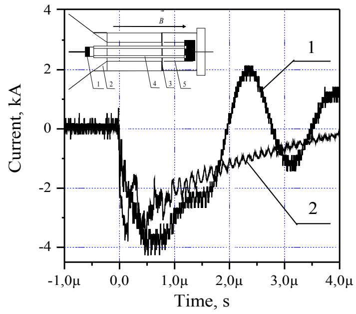
The purpose of investigations is the determination of the energy distribution function of electrons of REB used in the collective ion accelerator. It was made by measuring the REB current decreasing with metal foil thickness increasing. Along with cutting off the plasma from REB by means of metal foils we clarified the origin of plasma that carried out a short circuit of magnetically-insulated diode and caused a long duration signal of the electron current observed at the collector.

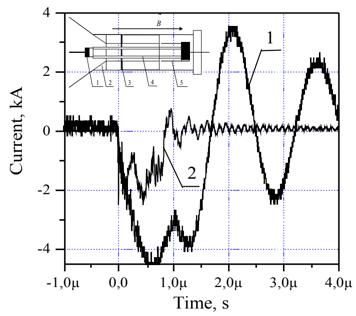
1. DETERMINATION OF PLASMA ORIGIN

In the course of the REB current registration by means of the Faraday cup (FC) and Rogovsky coil a negative unidirectional signal of long duration τ ≈ 5 μs (tail) is observed. Its duration considerably exceeds the time of a short circuit of the anode-cathode gap rated by the plasma extension velocity v_T=(2…5)·10^6 cm/s [1] and value of gap d=11 mm and, therefore, it is much more than the pulse duration of REB. On this time interval the oscillogram of a current from the Marx generator through the short circuitited diode looks like a damped sinusoid unlike the unidirectional signal from FC (Fig.1,a). It means that the signal from FC has not relation with circuit currents of the Marx generator. For explanation of such a signal, the hypothesis about presence of plasma in the REB drift liner is natural. This plasma causes the negative FC signal corresponding to the electron current $I = env_TS$ with thermal velocity v_T. Here n is the plasma density, S is the receiving square of FC. For available plasma parameters ($n \approx$ 10^{13} cm^{-3}) and FC (diameter 4.5 cm) the electron FC current is $I \approx$3 kA that is comparable to the REB current and corresponds to the amplitude of the tail of signal. In addition to the plasma with a density n_d that is formed at a breakdown of the diode gap and propagates freely along the external magnetic field, the plasma with a density n_g can be generated because of poor vacuum at ionization of residual gas by REB.

With the purpose for cutting off the plasma from REB and receiving of the FC signal corresponding only to the REB current the aluminum foils were used. To determine which of the indicated plasmas is present in the plant and forms the FC signal, the foils were placed in different places: immediately after the diode (for overlapping only the diode plasma n_d) or at the end of drift channel before FC (for cutting off both the diode plasma n_d and the plasma of the ionized gas n_g).



a - 8 μm foil at the exit of the chamber



b - 40 μm foil at the entrance of the chamber

Fig.1. The oscillograms of the input current of the magnetically-isolated diode (1) and the current of the electron beam on the Faraday cup passing through the foil (2). The denotations on the transporting scheme of electron flow: 1 - cathode; 2 - anode; 3 - foil; 4 – electron beam; 5 - Faraday cup

In addition for definition of the presence and role of the plasma of ionized gas we have made experiments with finer vacuum obtained using the trap with liquid nitrogen. The coincidence of results for poor and fine vacuum demonstrated the absence of the plasma of ionized residual gas.

When realizing these experiments it turned out that the foils being evaporated and ionized by REB generate the plasma with a density n_f and cause the FC signal-tail. This phenomenon depends on the foil thickness and REB energy. The outbreak of plasma is not also excluded if the time of foil combustion is not enough.

In view of mentioned considerations, a series of experiments was made for explanation of the origin of the signal-tail on FC and the problem – which plasma of considered ones is responsible for such kind of signal? The experiments performed and shown in Fig.1 representing the diode current (1) and FC current (2) in dependence on the foil location (at entrance and at exit of the drift tube or at both places simultaneously) and its thickness (8 and 40 μm), are gathered in the Table. In the Table the results of the experiment taken from Fig.1 are given together with answers: i) is or is not there the signal-tail, and ii) logical conclusion about the presence and role of corresponding plasma.

experimentNumber of	Foil thickness, μm	Place of foil (before or after drift liner)	Experiment result. Is there a signal tail? (Yes or No)	Possible plasma	Conclusion
1	8	before	Yes	n_g, n_f	n_f
2	8	after	Yes	n_f	n_f
3	8+8	before and after	Yes	n_f	n_f
4	40	before	No	n_g, n_f	none
5	40	after	Yes	n_f	n_f
6	40+40	before and after	No	n_f	none
7	40+8	before and after	Yes	n_f	n_f

As it follows from the Table and taking into account that the high vacuum has eliminated the presence of n_g, in experiment №1 from two possible kinds of plasmas (n_g and n_f), it is necessary to conclude that the signal-tail is caused by only foil plasma with n_f density. In experiment №2 the signal-tail on FC is caused by only foil plasma (n_f). From experiment №3 it follows that the plasma of the evaporated and ionized foil (n_f) is only responsible for the tail of a signal on FC, and others are separated. And two foils have noticeably attenuated the REB current. In experiments №4 and 6 the foil thick of 40 μm in thick (or two thin ones) cuts off the plasmas with a density of n_d and n_g and does not produce a foil plasma (n_f). In these cases, the REB current is noticeably decreased that is naturally. In experiment №5 with the thick foil after the drift tube the observable signal-tail is probably caused by the plasma with n_f density in the case of sputtering the thick foil by REB which is not decelerated, as it takes place in experiment №6. In experiment №4 unlike №5 the foil is at a large distance from FC and the foil plasma (n_f) reaches FC with a large delay that is not registered at a working scan of the oscilloscope. And at last, in experiment №7 the foil plasma (n_f) arises since the second foil is thin as compared with experiment № 6.

It should be noted that in experiments № 4 and 6 the duration of the collector current pulse corresponded to the duration of the REB pulse that was confirmed by measurements of X-radiation.

Summarizing the analysis performed it is possible to conclude that in all versions the foils either the signal-tail is eliminated, or such a signal is produce only by the foil plasma with n_f density. Thus, as the plasma of ionized residual gas is absent that is shown in experiments with the high vacuum, it is possible to declare that at the absence of foils the signal-tail on FC is caused only by the diode plasma with n_d density.

2. ENERGY DISTRIBUTION FUNCTION OF RELATIVISTIC ELECTRON BEAM

The experimental studies with using the aluminum foils allowed us to determine the electron energy distribution function of REB. The method basing on attenuation of the electron flow by metal foils of a different thickness was used for this purpose [2].

According to the technique introduced in paper [2] the current value I_j of REB, registered by the Faraday cup after REB passing the foil with a thickness $\delta_j = \sigma_j / \rho$, where σ_j is normalized foil thickness in g/cm^2 and ρ is the foil density in g/cm^3, is determined by the expression

$$I_j = I_0 \sum_{i=1}^{n} K_{ji} \varphi_i (E_i), \; j = 1,...,n \, . \quad (1)$$

Here n is the number of foils with different thickness δ_j; I_0 is the electron beam current at the entrance in the foil; $\varphi_i (E_i)$ is the value of a distribution function of electrons with energy $E_i \in [E_{i-1}, E_i]$. An energy interval $[0, E_0]$ under consideration, where E_0 is the upper bound of the energy interval of REB (in our experiments it is determined by the maximum value of voltage between the cathode and anode), is divided on equal intervals n so the energy width of each interval is equal to $\Delta E = E_i - E_{i-1} = E_0 / n$. The value of $E_i = (2i-1)E_0 / 2n$ is the energy in the middle of i-th interval. The K_{ji} factors are determined as $K_{ji} \approx K(\delta_j / R(E_i)) \Delta E$, where $K(\delta_j / R(E_i))$ is the transmission factor of electrons with E_i energy that passed through the foil with δ_j thickness. The transmission factor is determined from the universal curve for relativistic electrons passed through aluminum [2, 3]. The $R(E_i)$ is the penetration depth of electrons with E_i energy in aluminum media (up to total absorption) that is determined by the formula [2, 4]

$$R(E_i) = 0.661E_i[1 - 0.9878/(1 + 3.83E_i)]$$

or by the tables of [5]. The values of $\varphi_i(E_i)$ are the solution of the system of simple equations (1). The energy distribution function of electrons $\varphi(E)$ is represented as the histogram $\varphi_i(E_i)$.

In our experiments I_0=4.4 kA and maximum voltage value between the cathode and anode of the accelerator was equal to 280 kV.

In Fig. 2 the experimental dependence of electron current passed through an aluminum foil upon normalized foil thickness (σ_j) is shown. The experimental points are corresponding to maximum values of the pulsed electron beam current on the Faraday cup.

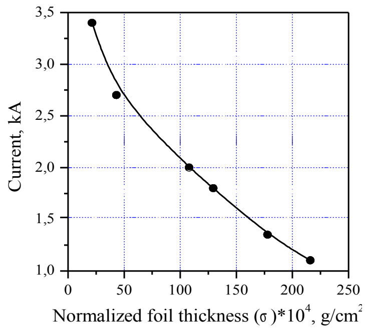


Fig. 2 Experimental collector current dependence upon foil thickness

Using measured currents of electron beam passed through foils of different thickness and above mentioned technique the energy distribution function of electrons was determined that is shown as a histogram in Fig.3. It is seen that almost 50% of electrons has a value of (210±30) keV. Energy of the main quantity of electrons is distributed within 60...240 keV.

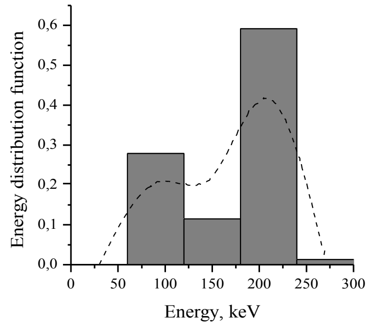


Fig.3 The histogram of electron energy distribution

Thus, the technique for measuring the energy distribution function of relativistic electrons based on passing REB through aluminum foils of different thickness was perfected. In our experiment, the measurements of the REB energy distribution function by this technique are satisfactorily coincident with the earlier obtained results based on determination of the voltage on the diode [6].

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ИЗМЕРЕНИЕ ФУНКЦИИ РАСПРЕДЕЛЕНИЯ РЭП, ИСПОЛЬЗУЕМОГО В КОЛЛЕКТИВНОМ УСКОРИТЕЛЕ ИОНОВ

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В первой секции двухсекционного коллективного ускорителя ионов проведены измерения параметров сильноточного релятивистского электронного пучка (РЭП), являющегося главным элементом концепции ускорителя ионов. Проведены экспериментальные исследования прохождения тока РЭП через металлические фольги различной толщины. По полученной зависимости ослабления тока пучка от толщины фольги и калибровочных кривых (таблиц) зависимости длин торможения от энергии частиц, определена функция распределения электронов РЭП по энергии в виде гистограммы. Определен вид плазмы, приводящей к закорачиванию магнитно-изолированного диода.

ВИМІРЮВАННЯ ФУНКЦІЇ РОЗПОДІЛУ РЕП, ЯКИЙ ВИКОРИСТОВУЄТЬСЯ В КОЛЕКТИВНОМУ ПРИСКОРЮВАЧІ ІОНІВ

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В першій секції двохсекційного колективного прискорювача іонів проведені вимірювання параметрів сильнострумового релятивістського електронного пучка (РЕП), який є головним елементом концепції прискорення іонів. Проведені експериментальні дослідження проходження струму РЕП через металеві

фольги різної товщини. По отриманій залежності ослаблення струму пучка від товщини фольги і каліброваним кривим (таблицям) залежності довжини гальмування від енергії часток, виявлена функція розподілу електронів РЕП по енергії в вигляді гістограми. Вияснений вид плазми, яка приводить до закорачення магнітно-ізольованого діода.

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