MEASUREMENT OF PHASE-ENERGY ELECTRON DISTRIBUTION AT THE RF GUN EXIT USING ALFA-MAGNET

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The paper presents the results of measuring the electron phase-energy distribution at the exit of the S-band nanosecond photo RF gun. The RF gun is the electron source of the injector system of linac LU-60. The main bunching and selection of longitudinal moments occur in the nonisochronal magnetic system named as α-magnet. The method of measuring the phase-energy distribution is based on selection of properties of a bunching system.

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1. INTRODUCTION

Besides the knowledge of transverse emittance of the beam, in some cases for injectors the information about the projection of phase volume onto the (z - p_z) plane is of great interest. Instead of the z, p_z canonical phase space, usually the φ, W coordinates (φ is the phase of RF field, W is the energy of electrons) are used. The distribution of particles on this plane is the phase-energy distribution. The information on the (φ - W) distribution is very important for development of systems for energy spread compression or phase spread compression (see, for example [1]). During recent years the systems for obtaining short electron bunches and bunch compression with RF guns [2] have been widely used. The transformation of the (φ - W) distribution in nonisohronal magnetic system gives the possibility to shorten significantly an electron bunch [3, 4]. The design of these bunching systems, particularly the definition of the value and sign of longitudinal dispersion R_{56} is based on the information about phase-energy distribution of particles. On the other hand, it is necessary to have opportunities to exercise the control and check the optimum mode of the magnetic buncher operation during the change of beam parameters at the RF gun exit. In the presented paper we study the method based on the use of properties of the magnetic bunching system and accelerating section. The measurements were carried out on the injector system of the linac LU-60 [5]. The injector contains a one-cavity RF gun that operates in photoemission mode [6], and a α-magnet [7].

2. METHOD OF PHASE-ENERGY DISTRIBUTION MEASUREMENT

For the experimental study of phase-energy distribution at least two elements are needed: analyzers of phase and energy particles. These elements can be made as different devices or be joined in one module (see, for example [8]). In our case we used the magnetic buncher as an energy analyzer. For phase determination the accelerator structure with the energy analyzer of accelerated electrons was utilized. The experimental facility is shown schematically in Fig.1.

The electrons with the energy $W_i \pm \Delta W_i$ are separated by the α-magnet. Then difference in phase between the RF gun and the accelerating section is measured and the phase φ_i, corresponding to the maximum of the energy rate in the structure is determined. It is clear, that this value corresponds to the phase of bunch centre of gravity. This bunch contains the particles with the energy $W_i \pm \Delta W_i$.

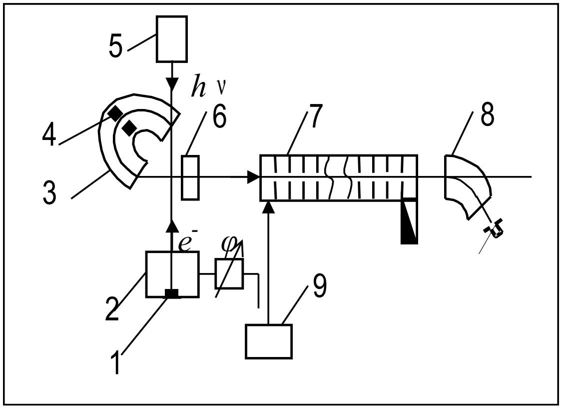

Fig 1. Experimental facility. 1-cathode, 2-cavity of RF gun, 3-α-magnet, 4- collimator, 5-laser system, 6 – beam current monitor, 7 – accelerating section, 8 – energy analyzer, 9 – klystron

Simultaneously the beam current at the exit of α-magnet was measured for each energy value (the energy spectrum was determined). Then, we make a correction to φ_i: $\delta\varphi_i = \varphi_0 - \varphi_i = \frac{\omega \cdot L}{c}\left(\frac{1}{\beta_0} - \frac{1}{\beta_i}\right)$, where $\omega=2\pi f_0$, $\beta_0=V_0/c$, $\beta_i=V_i/c$, f_0 is the operating frequency; V_0 *and* V_i are the velocities of electrons with energy W_0 and W_i respectively, c is the velocity of the light, L is the distance between the gun exit and the entrance of the section. In this manner as a result of measurements the dependence of the phase of selected bunches and the beam current v.s. electrons energy at the RF gun exit was determined. Suppose, that the phase spread of electrons in the energy band ΔW_i is more less than the phase length of the whole bunch. In this case the dependences obtained allow one to determine the phase spectrum and to characterize the phase-energy distribution. This supposal is acceptable for RF electron guns. In contrast to the other injectors for linac, unique strong correlation between phase of RF oscillations and energy of electrons is observed for the beams generated in the RF gun. In this context the dependence of electron energy v.s. phase is a "thin line". This feature allows to produce sub picosecond electron bunches using S-band RF gun (see, for example [4]). The form of phase-energy distribution is determined by be features of RF gun operation – electrons are emitted in the strong RF field (>10^7 V/m). Therefore their motion is radically connected with a phase of RF oscillations. Under such conditions electrons become relativistic at the distance less than the wavelength. There are factors, which make the phase-energy correlation less: the initial spread of electrons on the longitudinal momentum on the cathode and the influence of space charge forces. However, as calculations show, these factors do not significantly influence on the phase-energy correlation. For instant, an initial thermal energy spread for typical thermionic cathodes is of about 0.1 eV. If the beam energy at the RF gun exit is ≈ 1 MeV and L ≈ 1 m, this energy spread is the cause of phase variation less than 10^{-4} degree. The influence of the space charge is more essential. Thus, for a bunch with ≈0.3 nC charge and ≈ 10 mm bunch length, the addition energy spread due to the space charge is ~10^3 eV. This spread causes the addition phase spread and phase-energy distribution deformation. For peripheral particles in a bunch the value of phase shift at L ≈ 1 m can reach a few degrees. In a thermionic RF gun a part of electrons executes a complicated motion - stop and oscillations during the time exceeding the RF period. The phase-energy distribution of these electrons has not strong correlation. However simulation shows this amount of "noncorrelated" electrons does not exceed a few per cents and they do not make a significant contribution on a whole phase-energy distribution. The monotonic phase-energy correlation electrons being generated in the thermionic RF gun and nanosecond photo RF gun is the well-known fact that is confirmed by numerical simulations and experiments. Fig.2., for example, shows the simulation results for the nanosecond photo one-cavity RF gun with a maximum field on axes of 47 MV/m

Further, let us consider the causes of phase-energy distribution measurement error.

1. The phase measurement error is determined basically by the energy resolution of the magnetic analyzer installed at the exit of the accelerating section. It is easy to show that the accuracy of phase φ_i measurement based on the search for a maximum of energy at the section exit W_{out} is $\pm\sqrt{\frac{2\cdot\delta W}{W_{out}}}$, where δW is the energy resolution of the analyzer.
2. It is evident, that the energy measurement error is caused by the energy resolution of the selected device – in our case it is the α-magnet.
3. The "thin line" approximation is correct for one bunch. The proposed method does not allow one to make the measurement of the phase-energy distribution during one RF period. Therefore we suppose that the phase-energy distribution of electrons does not change during the time of measurement. The pulse-to-pulse stability of beam parameters depends on the stability of the main RF supply system parameters (frequency f, amplitude E, difference phase between the RF gun and the accelerating section φ), and emission current I. The current stability depends also on the laser energy (for the photo RF gun) and cathode temperature (for the thermionic RF gun). It is easy to obtain ($\Delta f/f<10^{-6}$, $\Delta E/E<10^{-2}$, $\Delta\varphi<1°$, $\Delta I/I\sim10^{-2}$) using the stabilization systems ordinary for linacs. Estimations shows, that under this conditions the changes of a phase length and an energy spectrum during the time measurement are negligible for measured phase length 10-20°.

Thus, the above-described method can be used for determination of the bunch length at the exit of a the thermionic RF gun and the nanosecond photo RF gun with a typical value of the phase length of tens degree.

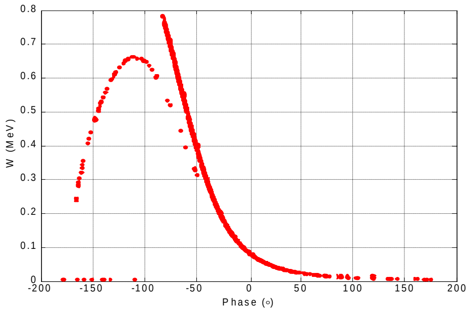

Fig.2. Phase-energy distribution of electrons at the nanosecond photo RF gun exit

3. EXPERIMENTAL FACILITY AND RESULTS OF MEASUREMENTS

As a subject of study (see Fig.1) we used the one-cavity RF gun with operating frequency 2797.15 MHz. The maximum RF electric field strength on the cavity axis and on the cathode was 55 MV/m and 48 MV/m, respectively, at the input RF power of 1 MW. The oxide nickel pressed cathode [9] with diameter of 4.5 mm was used as photocathode. The cathode was irradiated by the Nd-YAG laser system (wave length of 355 nm, pulse duration of 6 ns, energy of 0.08 mJ). The pulse current at the gun exit was of 0.7 - 0.8 A. The results of this RF gun study are described in detail in [6].

The beam from the gun exit is transmitted into the α-magnet through the beamline with the magnetic lens, beam current monitor and deflector system (they are not shown in Fig.1). The particle loss in those elements is about 50% and therefore the beam current at the α-magnet entrance does not exceed 0.4 A. The split collimator for electron selection in accordance with longitudinal moments was installed into the α-magnet in the place where the transverse dispersion has a maximum value. (≈ 135°). The width of the split can be changed in limits of 4-22 mm. Besides, we had the possibility to change the collimator in a range ± 7 mm relatively the main radius r_0 = 100 mm. It allows one to select the linear part of phase-energy distribution and achieve the maximal bunch compression. The energy resolution of system at 4 mm slit width was 13%. After the α-magnet the beam was accelerated in the accelerating section with the energy rate of 20 MeV/m. The energy analyzer at the exit of the accelerator has the energy resolution of 0.5%. The phase difference between the RF gun and the accelerating section can be changed in a range of 360°. The accuracy of phase reading was ± 2°.

The results of measurements, given in Fig.3, show that the phase-energy distribution in the error bound is linear for the better part of particles at the RF gun exit. It makes possible to realize a good bunch compression in the magnetic nonisochronal buncher.

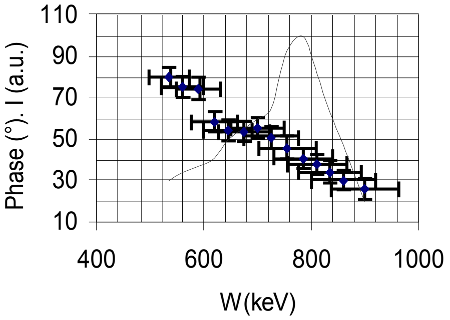

Fig.3. Solid line –energy spectrum, points – phase-energy distribution

From the measurement results we determine a width of energy and phase spectrums. These FWHM values are of 25±7% and 24±5° respectively. It is in a good correspondence with the simulations results – for 35% of whole particles generated in the RF gun (it corresponds to experimental conditions) the phase spectrum has FWHM of 23°.

CONCLUSIONS

The described method allows one to measure a phase length and a phase-energy distribution of electrons generated in the RF gun without additional equipment. We successfully used this method for adjustment of injectors containing the thermionic and photo RF gun and bunching magnet system. The authors would like to thank the specialists from "Accelerator" the help of which have made possible our experiment.

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ИЗМЕРЕНИЕ ФАЗО-ЭНЕРГЕТИЧЕСКОГО РАСПРЕДЕЛЕНИЯ ЭЛЕКТРОНОВ НА ВЫХОДЕ ВЧ ПУШКИ С ИСПОЛЬЗОВАНИЕМ АЛЬФА-МАГНИТА

В.А. Кушнир, В.В. Митроченко

В работе приведены результаты измерения фазо-энергетического распределения электронов на выходе наносекундной фотоэмиссионной ВЧ пушки десятисантиметрового диапазона. Предложенный метод измерения фазо-энергетического распределения базируется на селектирующих свойствах неизохронного магнитного группирователя – альфа-магнита.

ВИМІРЮВАННЯ ФАЗО-ЕНЕРГЕТИЧНОГО РАСПОДІЛУ ЕЛЕКТРОНІВ НА ВИХОДІ ВЧ ГАРМАТИ ІЗ ЗАСТОСУВАННЯМ АЛЬФА-МАГНИТА

В.А. Кушнір, В.В. Митроченко

В роботі приведено результати вимірювання фазо-енергетичного расподілу електронів на виході наносекундної ВЧ гармати десятисантиметрового диапазону. Метод вимірювання базується на селектуючих властивостях неїзохронного магнітного группирователя – альфа-магніту.