ON POSSIBILITIES OF DIAGNOSTICS AND FORMATION OF PICOSECOND ELECTRON BUNCHES IN THE LINEAR ACCELERATOR BY MEANS OF AN OPTICAL DEFLECTOR

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The possibilities for measuring the phase charge distribution in picosecond bunches of the electron linac without application of an electron-optical chamber are discussed. It is proposed to use the measurement scheme based on the spatial scanning of the transition radiation light pulse equivalent to the electron bunch by means of a traveling-wave optical deflector. The estimations of the sensitivity and resolution of the method are given. The picosecond optical pulse trains can also be obtained by using the microwave scanning of a laser ray across the adjustable diaphragm. After amplification, the pulses can be used in microwave photo-emission guns.

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ON POSSIBILITIES OF DIAGNOSTICS OF PICOSECOND ELECTRON BUNCHES

In paper [1] the offered measurement method based on the fast electron-optical scanning of a light pulse is discussed. However, this measurement method possesses some disadvantages caused by the fact that there observed is a significant angular electron beam spread during passage through the Cherenkov cell that significantly deteriorates the time characteristics of the bunch in the energy range of ten MeV. In this paper a variant of the method using a transition radiation being free of the above-mentioned disadvantage is considered. The diagram of measurement is shown in fig.1. When the electron bunch from the linac intersects the surface of the mirror metallic foil there formed is a pulse of transition optical radiation the envelope of which essentially repeats the shape of the electron bunch. This is related to the fact that the spectral density of transient radiation energy does not depend on the frequency up to the frequencies equal to the plasma frequency of electrons in metal (for copper $\omega_{pl} \approx 2.3 \cdot 10^{16}$ s^1) [2]. The foil is placed at an angle of 45° to the accelerator axis for the convenient radiation extraction outward (fig.1).

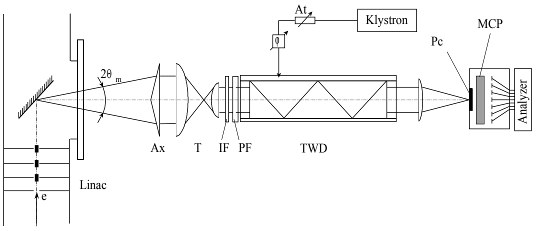

Fig. 1. *Diagram of measurement of picosecond electron bunches. LINAC - linear electron accelerator, Ax -* ***axicone,*** *T* **-** *telescope***,** *IF - interference filter, PF- polarization filter, TWD - traveling wave deflector, PC - photocathode, MCP - microchannel plates, φ - phase shifter, At - attenuator*

An optical system is designed for formation of a linearly-polarized light beam of 2.5 mm in diameter which arrives to the entrance of the traveling wave deflector (TWD). The interference filter (IF) having the wave length at the transmission maximum λ_0=5000 A and the transmission band width $\Delta\lambda$=100 A narrows the frequency band up to $\Delta\omega = 8 \cdot 10^{13}$ s^{-1} and decreases the light pulse spreading in TWD. The polarization filter (PF) releases a necessary light beam polarization $E_{optical}$ relatively to the electrical field strength vector E_{mw} and thereby it provides normal operation of the deflector based on ADP crystals the axes x(y) of which are directed along the field E_{mw}. The microwave signal of a frequency f=3 GHz is applied onto the deflector from the klystron via the phase shifter φ synchronically with the signal arriving to LINAC. The light pulse scanned in the space is focused by the lens L with the focal distance f=100 cm on the photocathode FC and is converted into the photocurrent pulse that is then amplified with the help of microchannel plates MCP. The amplified electron photocurrent comes onto the slotted collector from the lammellas of which the pulses enter into the multichannel amplitude analyzer and are memorized forming a hystogram of the electron bunch shape on the analyzer screen.

The traveling wave deflector (TWD) described in detail in [1] scans a transition radiation light pulse with a maximum deflection angle

$$\alpha_{дефл} = \frac{2 n_{ef}^3 r_{41} E_X l}{a}, \qquad (1)$$

where $n_{ef} \approx 1.5$ is the effective refraction index of the ADP crystal; r_{41} is the electro-optical coefficient, for ADP $r_{41} = 24.5 \cdot 10^{-10}$ cm/V; *l* and *a* are the ADP crystal set length and the TWD aperture, respectively; E_x is the traveling wave field strength in the resonant cavity.

If it is taken that *l*= 20 cm, *a*=0.4 cm, E_x=20 kV/cm, then we obtain α_{defl}=1°.

As it is shown in [2] to correlate the group velocity of light V_0 and the phase velocity of microwaves V_p it is necessary to increase the phase velocity of microwaves up to the value v_0=c/n. This velocity increase can be gained due to the choice of the transverse waveguide dimension at which the modulating microwave frequency is close to the cut-off frequency. According to [2] the transverse waveguide dimension *b* should be $b = c/2f_c\sqrt{\varepsilon} = 0{,}72 см$. When calculating *b* it was taken into account that for correlation of velocities in the waveguide filled with ADP crystal the conditions f/f_c=1.02 should be met.

The mean power loss in the crystal-filled resonant cavity is:

$$W_L = \frac{E_0^2 \omega \varepsilon \varepsilon_0 abl}{2QP}, \qquad (2)$$

where $E_0=2E_X$ is the standing wave field strength in the resonant cavity $E_0=4000$ kV/m.

$\omega=2\pi f$ is the microwave going-around frequency, f=3 GHz, $\varepsilon=58$ for the ADP crystal and $\varepsilon_0=8.85\cdot10^{-12}$Ф/m are the dielectric relative and absolute permeability constants respectively.

a, b, *l* are the waveguide resonant cavity dimensions.

$Q=1/\mathrm{tg}\delta$ is the quality factor. For the ADP Q =100 at a frequency of 3 GHz.

$P=(f\tau)^{-1}$ is the off-duty factor, f=10 Hz is the repetition rate, $\tau=0.3$ μs is the linac pulse duration.

In this case we obtain the power loss W_L =15 W being quite permissible for the crystal operation without overheating it.

To evaluate the sensitivity of the method let us represent the spectral energy density of the transition radiation from the one electron in the form [3]

$$dW(\omega) = \frac{e^2}{\pi c}\left[2\ln\gamma - 1\right]d\omega \qquad (3)$$

Taking that $\Delta\omega=8\cdot10^{13}$ for $\Delta\lambda$ =100 A and γ = 30 for E=15 MeV, we obtain $dW=15\cdot10^{-16}$ ergs.

For the visible part of the spectrum λ=5000 A ($h\nu$ =2.5 eV=$4\cdot10^{-12}$ ergs) the conversion coefficient is $n_\Phi=3\cdot10^{-4}$ photon/electron. Using the linac operating conditions with the pulse current I=0.5 A and the pulse duration $t_p=0.3$ μs we obtain the number of electrons in the pulse $N_e= 0.9\cdot10^{12}$ electron/pulse that gives, with taking into account the conversion, the number of photons $N_{ph}=n_{ph}N_e=2.7\cdot10^8$ photon/pulse.

Allowing that the coefficient of optical losses is $K_{opt}=0.01$ and the quantum efficiency of the photocathode is $\eta_{phc}=0.1$ and also that the spectrum analyzer is composed of 10 channels (lamellas) we obtain that for signal extraction on the lamella $U_{lam}=0.4$ B ($C_{lam}=10$ pF) one needs a microchannel amplifier with the amplification coefficient 10^4.

The resolution of the method related to the light beam diffraction is determined by the expression

$$\Delta\tau_d = \frac{T_p}{2\pi}\frac{\varepsilon}{\alpha_{deff}} = \frac{T_p}{2\pi}\frac{1}{N_p}, \qquad (4)$$

where $N_p=\alpha_{defl}/\varepsilon$ is the number of distinguished elements, $\varepsilon=5\cdot10^{-4}$ is the angular electron beam spread, $\alpha_{defl}=0.0174$ corresponds to 1°, T_p=360 ps is the scanning period.

For the given values $N_p=35$ and $\Delta\tau_d=1.5$ ps.

So, the offered method for diagnostics of a shape of microbunchs in the electron linac has a resolution not worse than that of electron-optical chambers and can be used for measuring the phase distribution of electron linac microbunch charges by the transition radiation.

FORMATION OF PICOSECOND ELECTRON BUNCHES IN THE LINEAR ACCELERATOR BY MEANS OF THE OPTICAL DEFLECTOR

The possibilities for forming the trains of microwave optical picosecond pulses with subsequent amplifying and converting them into electron bunches on the photocathode of the microwave gun were considered in /4/. A peculiarity of this work, as well as of all standard methods of optical pulse formation, is the following: the radiation from the preset optical oscillator is either modulated or scanned at a frequency $f_{scan}=f_{uhf}/n$, where usually n>10, and then, after amplification and multiplication of light pulses by means of a multiplexor by a factor of n, one can reach the frequency up to f_{uhf}.

In the present work the layout of the setup is very simplified due to scanning the laser beam at the klystron frequency f=3 GHz. The block-diagram of the setup is shown in fig.2.

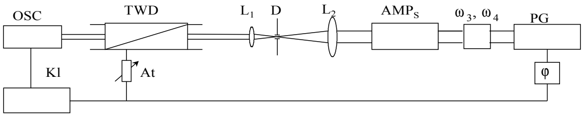

Fig.2. *Block-diagram of the setup for forming picosecond electron bunches in the electron linac. OSC - master oscillator, TWD - traveling wave deflector, L_1, L_2 – telescope1: 2, D – adjustable diaphragm, AMP_s – amplifiers, ω_3, ω_4 – converter into 3d or 4th harmonics, PG – photogun, Kl – klystron, At – attenuator, φ - phase shifter*

As a master oscillator OSC one can use a pulsed Q-switched laser with an active element Nd:YLF or Nd:YAG, being triggered with a repetition rate ν =10 Hz synchronically with a klystron and generating optical pulses of a duration τ=7 ns and an energy of 0.03 J at a wavelength λ=1047 or 1064 nm. An optical ray from the master oscillator comes into the traveling wave deflector TWD being energized via the attenuator from the klystron. TWD scans the ray with a frequency 3 Ghz across the adjustable slotted diaphragm. The lens L_1 with a focal distance of ~30 cm converts light beams scanned by the deflector into ones being parallel to the optical axis of the system and convergent into the plane of the diagram D. The laser beam after going through the diagram D is collimated by the lens L_2 with a focal distance of 60 cm and comes onto the amplifiers AMP and the converter of the frequency ω_3 or ω_4 triplicating or multiplying by a factor of 4 the master oscillator frequency depending on the cathode type of the microwave gun.

The phase shifter φ is used for displacing the phase of microwave radiation taken from the klystron. The phase is selected so that the maximum of microwave power be coincident by the phase with the photocurrent pulse on the photocathode of the gun. In this case the photocathode pulse generated due to the reverse run of the laser beam over the diaphragm will be in the opposite phase with a maximum value of the microwave field and will be not captured by this field.

The light pulse duration τ depends on the relation between the laser beam diameter in the focal plane of the lens L_1 and the width δ of the slotted diagram /4/.

$$\tau = \frac{T_{scan}}{2\pi N}\frac{\delta + d}{d} \qquad (5)$$

where $N=\alpha_{defl}/\alpha_{diverg}$, a α_{diverg} and α_{defl} are the divergence angle and deflection angle of the laser ray, respectively.

If we select the TWD length l=40 cm and δ

=2d=0.3 mm, taking into account that F=30 cm and α_{diverg}=0.0005 rad, and α_{defl}=2°, then τ=2,5 ps can be obtained. At a macropulse duration of 7 ns and a micropulse repetition frequency of 3 GHz, after the diaphragm 20 light micropulses of an energy ~ 10 μJ every will recur. At the exit of the amplifier AMP comprising four amplification stages the micropulse energy up to 1 mJ (K_{ampl} =100) can be reached. After conversion of the optical radiation into 3d or 4th harmonic one can obtain the light pulse energy on the photocathode of the order of 10 μJ. It allows one to obtain the electron bunch charge of ~0,25 ncoul at a quantum efficiency of a coper photocathode η =10^{-4} on the wavelength of 266 nm.

The advantages of the diagram for optical pulse formation being offered are:

1) possibility of forming micropulses of any required duration in the wide range from subpicosecond to tens of picoseconds;

2) possibility for two or more number of pulses during the microwave period due to the position of several diaphragms in the plane D.

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О ВОЗМОЖНОСТИ ДИАГНОСТИКИ И ФОРМИРОВАНИЯ ПИКОСЕКУНДНЫХ ЭЛЕКТРОННЫХ СГУСТКОВ В ЛИНЕЙНОМ УСКОРИТЕЛЕ С ПОМОЩЬЮ ОПТИЧЕСКОГО ДЕФЛЕКТОРА

В.С. Демин, Л.В. Репринцев, В.А. Шендрик

Обсуждаются возможности применения оптического дефлектора бегущей волны для измерения фазового распределения заряда в сгустках пикосекундной длительности ЛУЭ. Для получения временного разрешения ~1 пс предлагается использовать переходное оптическое излучение сгустков и синхронную с ЛУЭ СВЧ развертку в дефлекторе. Возможно также получение серий пикосекундных оптических импульсов, используя СВЧ сканирование лазерного луча по регулируемой диафрагме. После усиления эти импульсы могут быть использованы в СВЧ пушках с фотоэмиссией.

ПРО МОЖЛИВІСТЬ ДІАГНОСТИКИ ТА ФОРМУВАННЯ ПІКОСЕКУНДНИХ ЕЛЕКТРОННИХ ЗГУСТКІВ В ЛІНІЙНОМУ ПРИСКОРЮВАЧІ ЗА ДОПОМОГОЮ ОПТИЧНОГО ДЕФЛЕКТОРА

В.С. Дьомін, Л.В. Репринцев, В.А. Шендрик

Обговорюються можливості застосування оптичного дефлектора бігучої хвилі для вимірювання фазового розподілу заряду в згустках пікосекундної тривалості ЛПЕ. Для одержання часового розділення ~1 пс пропонується використовувати перехідне оптичне випромінювання згустків та синхронну з ЛПЕ НВЧ розгортку в дефлекторі. Можливо також одержання серії пікосекундних оптичних імпульсів, використовуючи НВЧ сканування лазерного променя за діафрагмою, що регулюється. Після підсилення ці імпульси можна використати у НВЧ гарматах з фотоемісією.