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Physics

MEASUREMENT OF A PHASE POSITION OF ELECTRON BUNCHES

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Presented technique allowed to measure the phase position of electron bunch relative to accelerating wave.

***Keywords*:** magnet spectrometer, slit collimator, perturbation, phasemeter, oscillator.

The feasibility study of Terahertz Free Electron Lasers (THz FELs) on the basic of 20 *MeV* electron linac LUE-20 [1, 2] is developing in Yerevan Physics Institute. The special-purposed test-facilities will be created for experimental precheck of the adopted technical decisions. The important are the time-structure diagnostics of a train of relativistic electron bunches including the bunch phase position relative accelerating wave. There are many methods for phase position determination, but these methods are awkward and could not be used for on-line monitoring and adjustment of the linac. Some other approach is suggested in present paper.

The method is based on the known effect of disturbance of the field of an electromagnetic wave in a cavity by the field of electron bunch [3]. Measuring the exact phase of the disturbance makes it possible to define the phase of bunch relative to the wave.

Let us assume that at some point of an electrical circuit a harmonic signal $e(t)=E_0\cos(2\pi t/T_0)$ is disturbed by any given periodic signal $x(t)=x(t+m\,T_0)$, where T_0 is the period ($\omega_0=2\pi/T_0$) and $m=\pm1,\pm2,\pm3,...$ In this case the total signal can be written as

$$u(t)=u(t+mT_0)=u[e(t),\,x(t)]. \tag{1}$$

It is completely clear that two realizations of a signal $u(t)$ are possible: additive, if $u(t)=e(t)+x(t)$ and multiplicative $u(t)=e(t)*u(t)$. Without loss of generality we can limit our consideration to the additive case, assuming also that $\tau << T_0$. Our aim will be the definition of t_x (see Fig. 1).

If the signal $u(t)=e(t)+x(t)=E_0\cos\omega_0\,t+x(t)$, its spectrum will be equal to the sum of the spectra of components. Because $x(t)=x(t+mT_0)$ is a periodic function, we can write

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$$x(t) = A_0 + A_1 \cos(\omega_0 t - \theta_1) + \sum_{k=2}^{\infty} A_k \cos(k\omega_0 t - \theta_k)\,, \tag{2}$$

$$u(t) = A_0 + C_1 \cos(\omega_0 t - \varphi_1) + \sum_{k=2}^{\infty} A_k \cos(k\omega_0 t - \theta_k)\,, \tag{3}$$

where $C_1 = \sqrt{E_0^2 + A_1^2 + 2E_0 A_1 \cos\theta_1}$ and

$$\varphi_1 = \mathrm{arctg}\left[\frac{A_1}{E_0} \cdot \frac{\sin\theta_1}{1 + \frac{A_1}{E_0}\cos\theta_1}\right]. \tag{4}$$

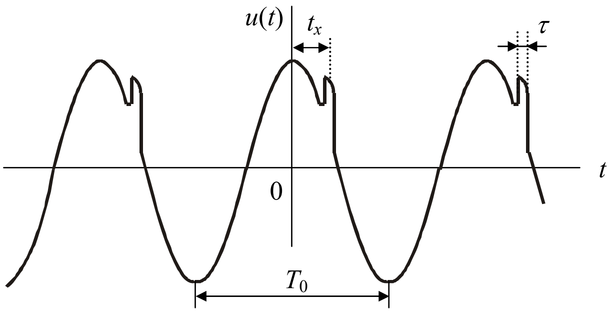

Fig. 1. Periodic perturbation of a harmonic signal.

Let us note that in the case of negative polarity of $x(t)$ it is necessary to change the variable $\theta_k \to (\theta_k + \pi)$ in eqs. (2)–(4). Generally the phase θ_k is determined by the expression

$$\theta_k = \mathrm{arctg}\left[-\frac{\int_0^{T_0} x(t)\sin k\omega_0 t dt}{\int_0^{T_0} x(t)\cos k\omega_0 t dt}\right]. \tag{5}$$

In the case of symmetric signal $\mathrm{tg}\theta_k = -\,\mathrm{tg}k\omega_0 t_x$. The definition of t_x in the case of an arbitrary form of the signal requires a refinement of the problem, as θ_k will depend not only on t_x, but also on the shape of $x(t)$. As follows from (5), the information on the moment of disturbance is contained with certain difficulties, because the phase φ_1 depends not only on θ_1, but also on the relation of the amplitudes A_1/E_0 (4). The following conclusion can be drawn from formula (4): the definition of the moment of perturbation on the first harmonic is inexpedient, since in view of the unknown value of A_1/E_0 it is impossible to define t_x measuring φ_1. Thus, we have to measure t_x using the higher harmonics of ω_0 ($k \geq 2$). Let us consider now how to choose the number of a harmonic by looking at the circuit given in Fig. 2.

The disturbed harmonic signal $u(t) = e(t) + x(t)$ acts on the frequency filter $\mathrm{F}(k\omega_0)$ resulting in a signal $A_k \cos(k\omega_0 - k\omega_0 t_x)$ at the output, which then acts on the first input of phasemeter Φ. The signal $E_k \cos k\omega_0 t$, resulting from the multiplication of frequency ω_0 of the signal $e(t)$, acts on the second input of the phasemeter. Thus, the signal at the output of phasemeter will be $\theta_k = k\omega_0 t_x$, whence the moment of perturbation can be defined. If the phasemeter range for a unique measurement is limited to $\pm 180^{\circ}$, this means that $-180^{\circ} \le \theta_k \le 180^{\circ}$ and, hence for the measurement of the k-th harmonic, that the limits of a single valued definition of t_x are reduced by a factor k to $-T_0 / 2k \le t_x \le T_0 / 2k$. The narrowing of the single-valued definition of t_x means that any two other perturbations x_1 and x_2 at distance $T_0 / 2k$ of each other will give the same signal indication of phasemeter. Besides, with the growth of k the amplitude A_k decreases and for a small perturbation amplitude the measured signal can be below the threshold of sensitivity. At the same time, the more number of harmonics, the better the resolution of the t_x measurement. Based on this we can choose as an operating harmonic k=2 or k=3. Let us consider now a scheme that allows to expand the limits of the single valued definition of the moment of perturbation (Fig. 3).

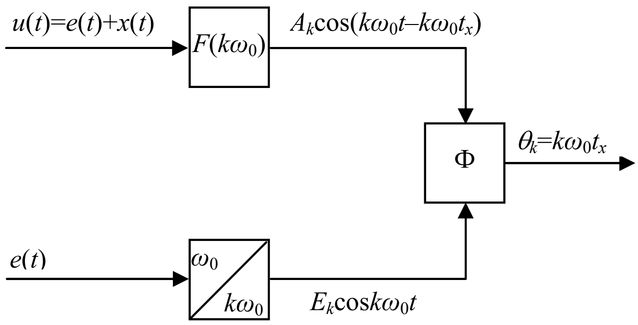

Fig. 2. The circuit for the measurement of the moment of perturbation on the k-th harmonic.

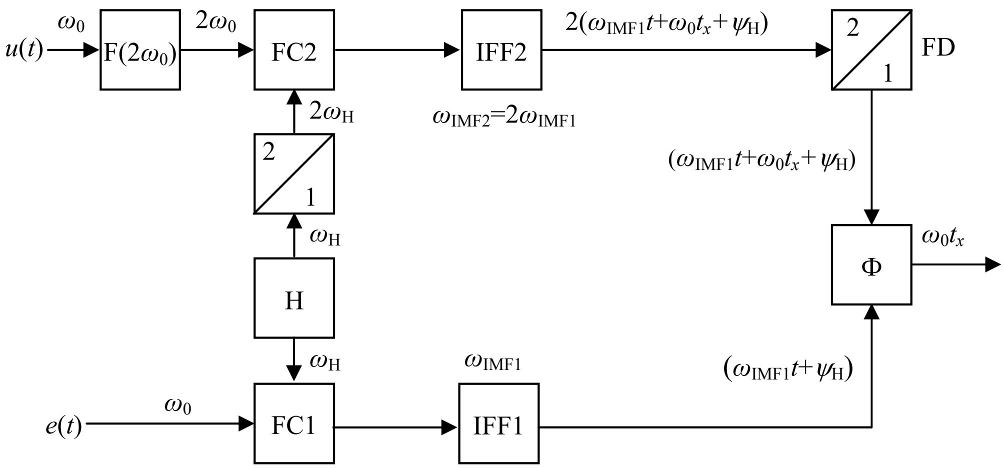

Fig. 3. The block-diagram of the device with expanded limits of the single-valued definition of the moment of perturbation. F($2\omega_0$) – frequency filter, FC – frequency converter, IFF – intermediate frequency filter, H – heterodyne oscillator, FD – frequency divider, Φ – phasemeter.

The reference signal $e(t)$ acts on the input of the frequency-converter FC2, where it mixes with the heterodyne signal. At the output of the intermediate frequency filter IFF2 the signal $E_0\cos(\omega_{\mathrm{IMF1}}+\psi_{\mathrm{H}})$ will be received, where $\omega_{\mathrm{IMF1}}=$

$=\omega_0-\omega_H$ and ψ_H is the phase of the heterodyne oscillations. This signal acts on one of the inputs of a phasemeter Φ. The disturbed harmonic signal $u(t)$ acts on the input of the frequency filter $F(2\omega_0)$, at the output of which the signal with frequency $2\omega_0$ is received. This signal in the frequency converter FC2 mixes with oscillations of frequency $2\omega_H$, i.e. twice the heterodyne frequency. The difference frequency signal $A_2(2\omega_{IMF1}-2\omega_0 t_x-2\psi_H)$, selected by the intermediate frequency filter IFF2, acts on frequency divider FD, at the output of which we get the signal, acting on the second input of the phasemeter. After calibration of the phasemeter its indication will be equal to $\omega_0 t_x$. Thus, if the phasemeter has limits for the single valued definition of a phase $\pm 180^0$, the complete interval of the single valued definition of t_x will be T_0.

The experimental layout of the proposed scheme is given on Fig. 4.

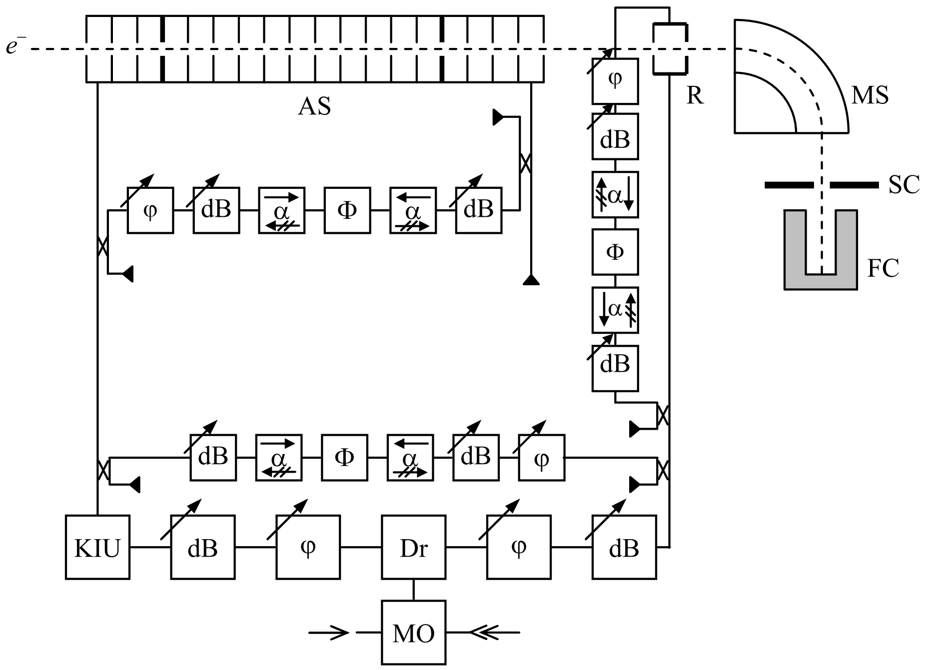

Fig. 4. Experimental layout. AS – accelerating section, R – RF-resonator, Dr – RF-preamplifier, KIU – 20 MW S-band klystron , MS – magnet spectrometer, SC – slit collimator, FC – Faraday cup.

The proposed scheme considerably facilitates the construction of phasometric part has high sensitivity and allows to make easy necessary transformations of signals in RF-channels.

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Մ.Լ. Մովսիսյան, Է.Հ. Ալեքսանյան

Էլեկտրոնային թանձրուկների փուլային դիրքի չափումը
արագացնող ալիքի դաշտում

Առաջարկված է մեթոդ, որը թույլ է տալիս հարմոնիկ ազդանշանի խոտորման փուլային դիրքի միարժեքության սահմանների ընդլայնում:

М.Л. Мовсисян, Э.О. Алексанян.

Измерение фазового положения электронных сгустков
в поле ускоряющей волны

Предложен метод, позволяющий расширить пределы однозначности фазового положения возмущения гармонического сигнала.