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ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ

ЕФИ-554(41)-82

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COHERENT ADDITION OF ELECTROMAGNETIC FIELDS OF ULTRARELATIVISTIC PARTICLES MOVING IN EXTERNAL FIELD

ԵՐԵՎԱՆ 1982 ЕРЕВАН

An equal-time pattern of the field near a curvilinearly moving particle based on the Lienard-Vichert potential analysis contains a region with strong γ -dependence of field (γ -region), where γ is the particle Lorentz factor. A characteristic width of the γ -region is of order of R/γ^3 , where R is the radius of curvature of the motion trajectory [1-3] . The value of the electric $\vec{E}$ and magnetic $\vec{H}$ fields in the γ -region is of order of

$$E \sim H \sim \frac{2\sqrt{2}\, e}{R^2} \gamma^4 \sqrt{\frac{R}{x}} \; ; \tag{1}$$

where x is the distance from the particle up to the observation point, $0 < x << R$.

Find out the field energy $\mathcal{E}$ within the γ -region. Taking into account the fact that the vertical sizes $Z_W(x)$ of this region

$$Z_W \approx \sqrt{2x/R}\; R\gamma^{-1} \tag{2}$$

we find out

$$\mathcal{E} \approx \frac{2e^2}{\pi R} \sqrt{\frac{2x}{R}}\, \gamma^4 . \tag{3}$$

This energy is generated by charge during the time of passage τ of the sector with angle $\sqrt{2x/R}$. Write down the ratio $I = \mathcal{E}/\tau$ as

$$I = \frac{2}{\pi} \frac{e^4 H_\beta^2 \gamma^2}{m^2 c^3} , \tag{4}$$

where $H_\beta = mc^2\gamma / eR$ is an external magnetic field.

One can see that the obtained expression is of order of the total intensity of synchrotron radiation . Taking into account the fact that the γ -region width is the wavelength corresponding to the synchrotron radiation spectrum edge we come to the conclusion that the synchrotron radiation of the particle is formed into the γ -region.

In this work we consider the conditions of the coherent addition of fields of γ -regions of N particles moving along circular trajectories as well as the quantity and time of such superposition existence. A maximally possible energy transferred to a motionless particle by the coherent field is calculated. The application of these fields is discussed, particularly, to: the enhancement of the action of the synchrotron radiation on different objects of the related investigations, experimental demonstration of the field pattern in the γ -region, thermonuclear fusions purposes.

γ -Region Geometry

Due to small width and height of γ -region it is convenient to describe the latter relative to some line entirely being in it.

This line is γ -helicity, i.e. the geometrical locality of points of simultaneous arrival of signals emitted by the particle along the tangent to the circular trajectory.

In the cylindrical coordinate frame with the Z axis passing through the centre of the circle the γ -helicity can be given parametrically through the delayed angle θ :

$$x = R\left(\sqrt{1+\theta^2/\beta^2} - 1\right), \tag{5}$$

$$\varphi = -\theta + \operatorname{arctg}(\theta/\beta),$$

where βc is the particle velocity, angle φ is referenced from the radius connected with the particle at a given time moment in the direction of the particle rotation (see Fig.1).

By formulae (5) one can find out the positive angle $\varkappa$ between the tangent to the γ -helicity and radius-vector of the delayed point of trajectory A :

$$\varkappa = \arccos\left(1 + R^2/(\beta^2(1+\beta)^2\gamma^4 \ell^2)\right)^{-1/2}, \tag{6}$$

where $\ell = R\theta/\beta$.

The γ -helicity curvature radius at 0 point is equal to

$$R_0(\ell) = \frac{2\ell}{(1+\beta)\gamma^2} \cdot \frac{[1 + R/\beta^2(1+\beta)^2\gamma^4 \ell^2]^{1/2}}{2 - \beta - [1 + R^2/(\beta^2(1+\beta)^2\gamma^4 \ell^2)]^{-1}} . \tag{7}$$

The part of γ -helicity we are interested in corresponds to the values of

$$R\gamma^{-2} \ll \ell \ll R \tag{8}$$

Here

$$\varkappa \approx R/(2\ell\gamma^2), \quad R_0(\ell) \approx 2\ell(1+R^2/(2\ell^2\gamma^2))^{-1}. \tag{9}$$

The Coherence Conditions

The conditions of obtaining coherent radiation of several particles in a small spatial region are as follows:

a) γ -helicities intersect in the observation region,

b) they have the same tangent,

c) the signals from different particles reach the observation region simultaneously.

Let us choose a cylindrical coordinate frame with the reference point being at the point of intercept of γ -helicities, the polar axis being orthogonal to their common tangent. Define the auxiliary curve g in order to determine the coherent trajectories as the geometrical locality of points which emit signals along tangents to the motion trajectories satisfying the coherence conditions. One can readily see that the curve g is described by the equation

$$\ell = \frac{R}{\beta(1+\beta)\gamma^2} \operatorname{ctg} \varphi, \tag{10}$$

where φ is the polar angle.

The coherent trajectories of motion are radius R circles contacting OA in point A, where A is an arbitrary point of curve g. It is suitable to give this circle parametrically by ψ, i.e. the angle of deflection of the circle point from the A point (see Fig.2)

$$\rho = (\ell^2 + 2R^2(1-\cos\psi) - 2\ell R\sin\psi)^{1/2},$$
$$\theta = \varphi + \arcsin[R(1-\cos\psi)/\rho]. \tag{11}$$

The particles position at an observation moment is determined by the angles $\psi = \beta\ell/R$. For ℓ satisfying the condition (8) we find out

$$x \approx \rho \approx \ell^2/2R,$$
$$\theta \approx \pi/2. \tag{12}$$

Let at an observation time moment on this curve there are situated N particles that move along coherent trajectories. We denote the distances from the first and the N -th particles to the intercept of γ -helicities, respectively, by ρ_1 and ρ_N, $\rho_1 < \rho_N$. Then the field in the coherence region defined as the intercept of γ -regions of all the particles has the form:

$$E \approx \frac{2\sqrt{2}e}{R^2}\gamma^4\sqrt{\frac{R}{x}}N \tag{13}$$

In case when

$$R\gamma^{-2} \ll \rho_1, \quad \rho_N \ll R, \tag{14}$$

the extension X of the coherence region in the plane of orbits is determined by the intercept of two circular regions with the widths R/γ^3 and radii $2\sqrt{2R\rho_1}$ and $2\sqrt{2R\rho_N}$:

$$X = \frac{R^{3/4}\,\rho_1^{1/4}\,\rho_N^{1/4}\,\gamma^{-3/2}}{(\rho_N^{1/2} - \rho_1^{1/2})^{1/2}} \quad (15)$$

The coherence region width $\sim R/\gamma^3$, vertical dimensions are defined by formula (2), where x should be replaced by ρ_1.

The field energy in the coherence region is

$$\mathcal{E}_{coh} = \frac{4\sqrt{2}}{\pi}\,\frac{e^2}{R}\,\gamma^{5/4}\left(\frac{\rho_1}{\rho_N}\right)^{3/4}\frac{R^{1/4}\,N^2}{(\rho_N^{1/2} - \rho_1^{1/2})^{1/2}}, \quad (16)$$

we mean here that the region of the parameters variation is limited by the obvious condition $\mathcal{E}_{coh} < N\gamma mc^2$.

We also estimate the lifetime of this region which is determined by a maximum time of coherent superposition of γ -regions of the first and the -th particles. Taking into account the fact that an equal-time pattern of the field for one particle at different time moments is determined by the angle rotation equal to the time difference divided by the angular velocity of motion one can find out that the time t_{coh} of the coherence region lifetime is equal to

$$t_{coh} \approx \frac{R}{c}\,\frac{R^{1/4}}{(\rho_N^{1/2} - \rho_1^{1/2})^{1/2}}\,\gamma^{-3/2} \quad (17)$$

During the time t_{coh} the coherence region "bastes" the volume with with dimensions of order of $\left(X\,c\,t_{coh}\,\sqrt{2\rho_1 R}\,\gamma^{-1}\right)^{1/3}$.

Application of Coherent Fields

The suggested method of coherent superposition of the γ -regions fields allows one to increase the bunch radial dimensions N times as compared with the same dimensions necessary to obtain the coherent synchrotron radiation in the whole space. The requirement for the particles density thus reduces. Besides the radiation intensity of the bunch of N particles moving along coherent trajectories is N times as higher as the non-coherent synchrotron radiation. Such an increase can be checked up experimentally to confirm the field pattern in γ -region. This increase, besides being used in traditional spheres of synchrotron radiation application, allows one to obtain the coherent classical field with a wavelength R/γ^3. Note that in this wavelength a low-energy particle with mass gains the energy

$$\mathcal{E}_M = \frac{4e^2}{\rho_N}\,\gamma N^2 q_M \quad (18)$$

where $q_M = eH_g\tau_M/mc^2$, $\tau_M = e^2/Mc^2$. In substance the particle is affected also by the coherent radiation field of the substance electrons the quantity of which is comparable with that of the fall field. Nevertheless to estimate roughly the energy transfer to a low-energy particle we shall use formula (18). The measurement of this energy would confirm experimentally the γ -region field pattern.

As one of the possible practical applications, estimate, for example, the possibility of initiating the deuterium-tritium (DT) fusion in coherent fields under consideration. The DT-fusion with inertial keeping can be realized if the target ionic component temperature $\gtrsim kT \sim 10^4_e V$ and the target size $> \ell_p$ (nuclear free length). The energy ϵ_e transferred to one electron of the target must be $\sim kT$, ϵ_e is to be found from formula (18) with the replacement $M \to m$. It is obvious beforehand that the use of coherent fields for DT-fusion purposes makes sense only in case when the field energy in the coherence region $\mathcal{E}_{coh} \sim N\gamma mc^2$ beam energy. Having calculated by formulae for the coherence region dimensions $\mathcal{E}_{coh}$ and taking into account the relation $\epsilon_e \sim kT$ one can express the beam particles number through the geometrical parameters ρ_1 and and temperature kT :

$$N = \frac{4}{\pi^2} \frac{\rho_1^{3/2}}{r_e \rho_N^{1/2} (1-\sqrt{\rho_1/\rho_N})} \left(\frac{kT}{mc^2}\right)^{3/2}. \tag{19}$$

It is seen that at $\rho_1 \sim \rho_N$ the mean distance between the beam particles $\Delta\rho = (\rho_N - \rho_1)/N \sim 10^{-10}$ cm. The ratio $\mathcal{E}_{coh}/kT$ gives N_e - the number of heated electrons of the target. Introducing the atomic density n we obtain the volume of heated electrons region $V_e = N_e/n$. Here formula (17) shows that the lifetime t_{coh} of the fields at $\rho_N \sim \rho_1 \sim 100$ cm is sufficient to heat N_e electrons. Having chosen the target of volume V_e from the requirement $\sqrt[3]{V_e} > \ell_p$ we shall obtain the condition for the γ -factor of the beam particles in the form

$$\gamma \gtrsim \frac{\pi^2}{4} n\ell_p^3 \frac{r_e \rho_N^{1/2}}{\rho_1^{3/2}} \left(1-\sqrt{\frac{\rho_1}{\rho_N}}\right)\left(\frac{mc^2}{kT}\right)^{1/2}. \tag{20}$$

For $\rho_1 = 1$ cm, $\rho_N = 2$ cm, $n = 10^{24}$ cm^{-3} and $\ell_p = 10^{-2}$ cm, which

corresponds to preliminary compression of the target [4] , we shall find out $\{N, \gamma, \Delta\rho\} \sim \{10^{10}, 2\cdot 10^6, 10^{-10}\text{ cm}\}$. Notice that for these parameters the field in the coherence region is classical.

The authors should like to express their deep gratitude to A.Ts.Amatuni for the attention to the work and many valuable remarks.

REFERENCES

1. Арутюнян С.Г., Нагорский Г.А. Нелинейная зависимость эффектов интенсивности от числа частиц в кольцевом токе. - АЭ, 1980, т.48, с.318-321.
2. Арутюнян С.Г., Нагорский Г.А. Искажение кулоновских полей частиц в кольцевых пучках.- Труды конференции молодых ученых ЕрФИ (Нор-Амберд, 25-27 сентября 1979 г.),Ереван, 1980, с.237-238.
3. Арутюнян С.Г. Одновременная картина поля вблизи движущейся по кругу ультрарелятивистской заряженной частицы.-Препринт ЕФИ-367(45)-79, Ереван, 1979.
4. Ковальский Н.Г. Лазерный термоядерный синтез.- В кн:Итоги науки и техники. Физика плазмы т.I, М: ВИНИТИ, 1980.

The manuscript was received 22 February 1982

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КОГЕРЕНТНОЕ СЛОЖЕНИЕ ЭЛЕКТРОМАГНИТНЫХ
ПОЛЕЙ УЛЬТРАРЕЛЯТИВИСТСКИХ ЧАСТИЦ,
ДВИЖУЩИХСЯ ВО ВНЕШНЕМ ПОЛЕ

(на английском языке, перевод З.Н.Асланян)

Ереванский физический институт

Редактор Л.П.Мукаян

Тех.редактор А.С.Абрамян

Заказ 270 ВФ-03874 Тираж 299

Препринт ЕФИ Формат издания 60x84/I6
Подписано к печати I6/УП-82г. 0,7 уч.-изд.л. Ц. I0 к.

Издано Отделом научно-технической информации
Ереванского физического института, Ереван 36, Маркаряна 2