Radiation of superluminal sources in vacuum

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Mach investigated acoustical waves generated by a projectile moving in the air with supersound velocity. Mach showed that the sound waves are emitted under the angle θ to the projectile velocity, and $\cos\theta$ satisfies to the equation

$$\cos\theta = u/v, \tag{1}$$

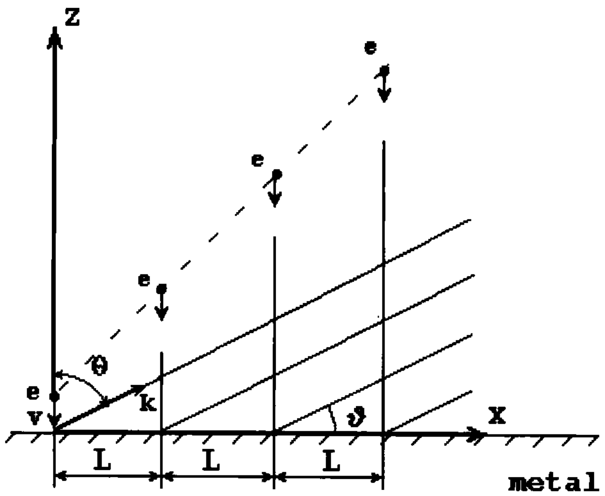
where u - sound velocity and v - projectile velocity.

The same nature has the Vavilov – Cherenkov effect. If a charged particle moves in medium with velocity v anf if v exceeds the light velocity $c/\sqrt{\epsilon}$ in the medium, then the moving particle emits directed electromagnetic waves propagating under the angle θ to the velocity, and

$$\cos\theta = \frac{c}{\sqrt{\epsilon}v} \tag{2}$$

where c is light velocity in vacuum, ϵ is dielectric constant.

Consider one more model of superluminal source.



At the time instant t=0 the electron intersects the surface at the point x=0. The field $\mathbf{E}_1$ of TR at large distances from the point x=0 can be represented in the form

$$\mathbf{E}_1 = \mathbf{E}(\mathbf{k})e^{i\mathbf{kr}-i\omega t} \tag{3}$$

After the time T another electron having the same velocity v hits the surface at the point $x = L$. Another flash of TR is generated, and its field at large distances from the point $x = L$ is

$$\mathbf{E}_2 = \mathbf{E}(\mathbf{k})e^{i\mathbf{k}(\mathbf{r}-\mathbf{L})-i\omega(t-T)} \tag{4}$$

Full radiation field is equal to the sum of fields $\mathbf{E}_1, \mathbf{E}_2, .., \mathbf{E}_n$. If the number of particles is infinite, we get after summation

$$\mathbf{E} = \sum \mathbf{E}(\mathbf{k}) = \mathbf{E}(\mathbf{k})e^{i\mathbf{kr}-i\omega t}[1 + e^{i(\mathbf{kL}-\omega T)} + e^{2i(\mathbf{kL}-\omega T)} + ...] = \tag{5}$$
$$= 2\pi\mathbf{E}(\mathbf{k})e^{i\mathbf{kr}-i\omega t}\delta(\mathbf{kL} - \omega T - 2\pi m)$$

where m is an arbitrary integer, the Dirac's delta function.

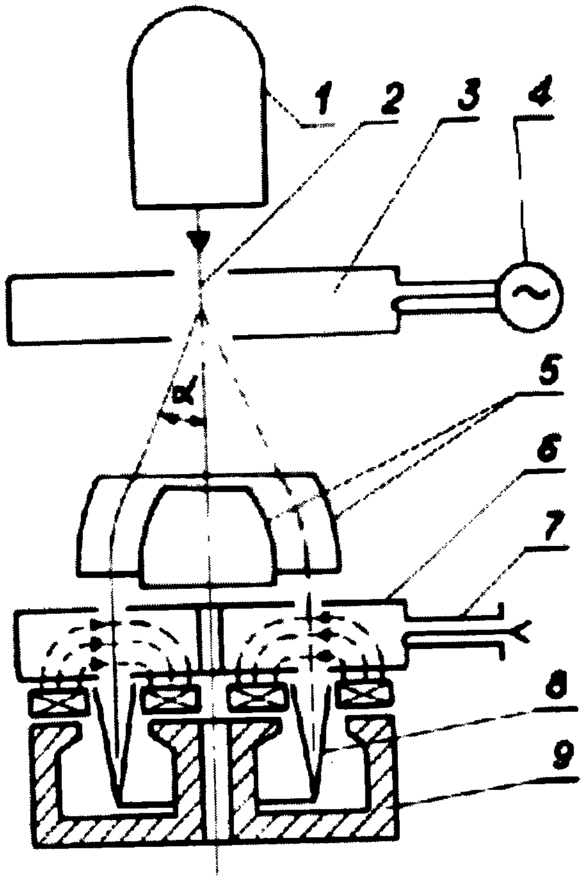
The total TR field differs from the field produced by a single charge by the factor $\delta(\mathbf{kL} - \omega T - 2\pi m)$. The TR contains only those waves satisfying the condition $\omega T - \mathbf{kL} = 2\pi m$. Taking into account the geometry of the problem, this condition can be recast in the form

$$\omega = \frac{2\pi m}{T(1 - \frac{L}{cT}\cos\vartheta)} \tag{6}$$

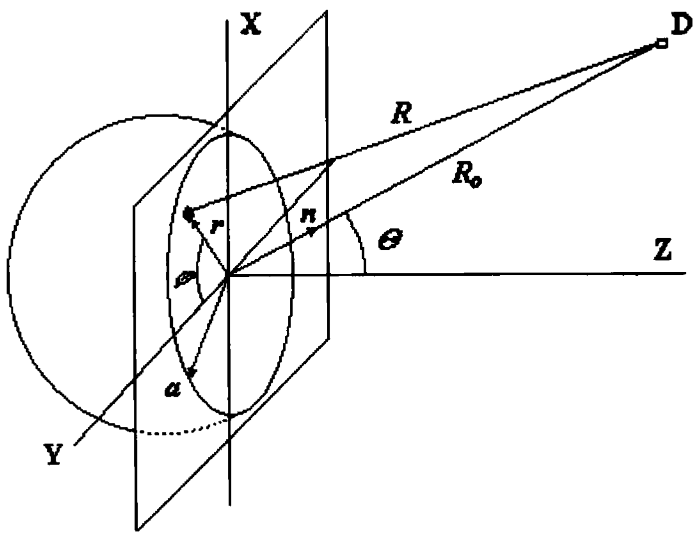
where ϑ is the angle between the x-axis and the direction of radiation.

The emitted radiation may be considered as radiation generated by the blinking source which moves along the x-axis with the velocity $v = L/T$ and produces flashes with the period T.

Using the above mentioned system of colliding particles it is possible to create the source of the Vavilov-Cherenkov radiation in waveguide. Source of radiation in waveguide can also be got with the help of continuous current of charged particles if the current intersects the waveguide in such a way that the point of intersection moves along waveguide. Under synchronism condition this current generates the corresponding proper wave. Gyrocon is the example of such kind of generator. Scheme of gyrocon is shown at picture.



It is necessary to mention that the properties of radiation depend not only on the low of bunch movement but also on size and form of the electron bunch. As an example, we considered TR from a spherical bunch with a uniform charge density over the volume.



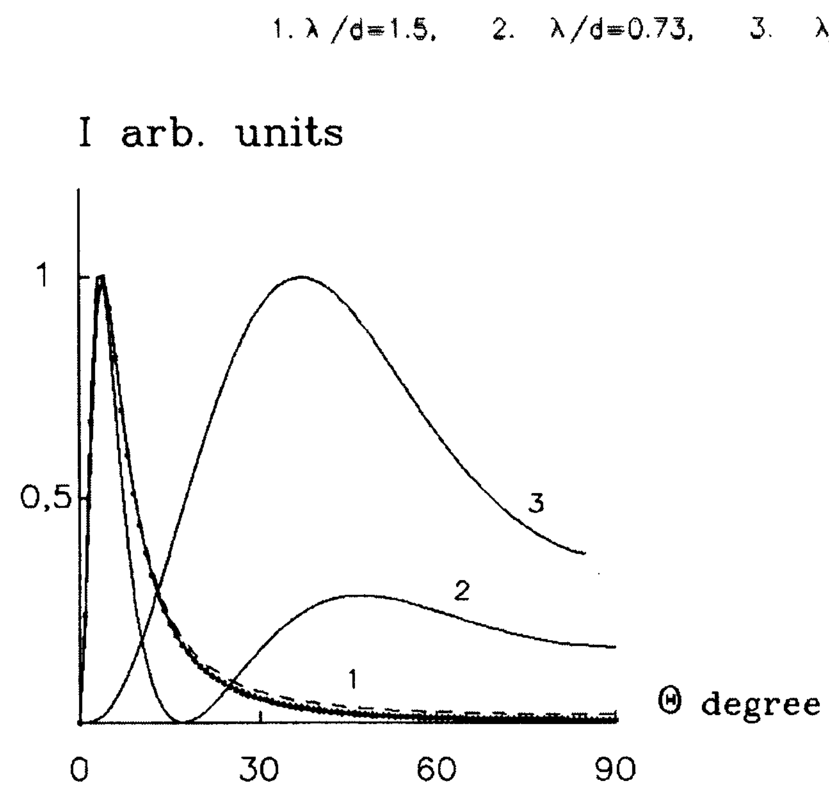
Suppose that the volume of the bunch is divided into thin layers parallel to the boundary. The interference of the waves emitted by every layer gives TR from the whole bunch. Every layer is a circle with a uniform charge density. The radius $a(t)$ of the circular layer situated on the boundary at the time t, changes during the passage of the bunch. At initial instant of time the radius of the circle is zero. At the time t the radius is given by the formula

$$a(t) = \sqrt{r_o^2 - (r_o - vt)^2} \tag{7}$$

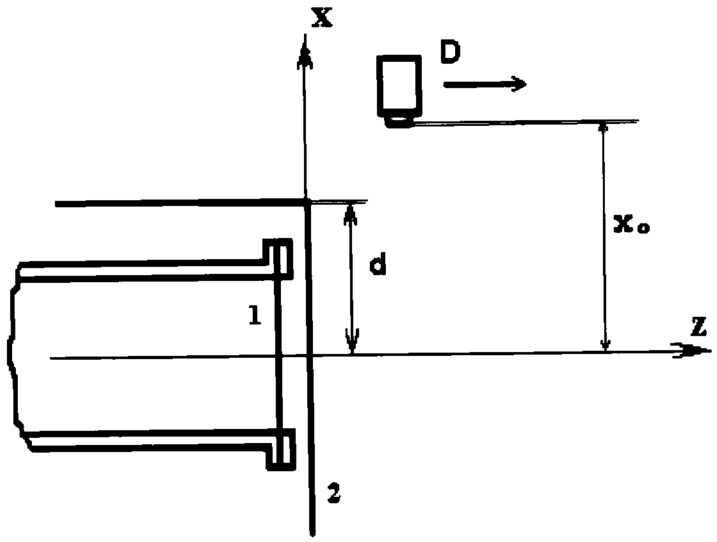
The evolution of radiating area is determined by a change of the circle radius with time. During the passage of the spherical bunch through the plane x=0, the radius of radiating circle changes from zero up to the radius of the bunch, and then decreases to zero. The velocity which describes the expansion (and subsequent diminution) of radiating area follows from Eq. (7):

$$\frac{da}{dt} = v \, \frac{r_o - vt}{\sqrt{2r_o vt - v^2t^2}} \tag{8}$$

It is seen that at some intervals of time the velocity of expansion exceeds that of light. Radiation connected with superluminal expansion has some characteristic features of Vavilov-Cherenkov radiation. Angular distribution of TR for different values λ/d are shown on the fig. It can be seen that for λ bigger than d angular distribution is close to that for radiation of point charge. For λ smaller than d, angular distribution differs from that of point charge, the difference grows as the wavelength becomes smaller.

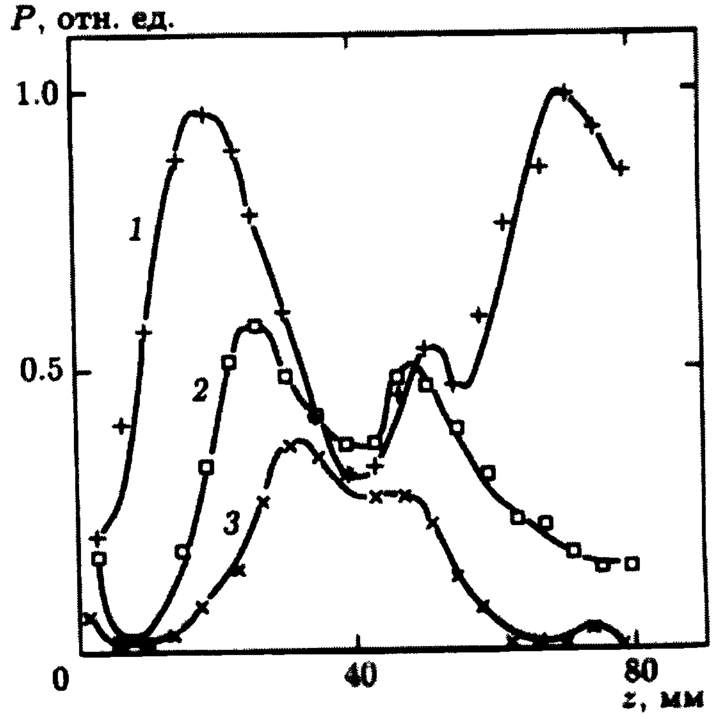


In our experiments on TR of extended bunches we observed another case of superluminal source. Angular ditribution was measured of TR for bunches accelarated in microtron. The maxima under large angles were found ($\sim$ 70 degree) whereas angular distribution for single electron is sharply directed within the angle 3,5 degrees.



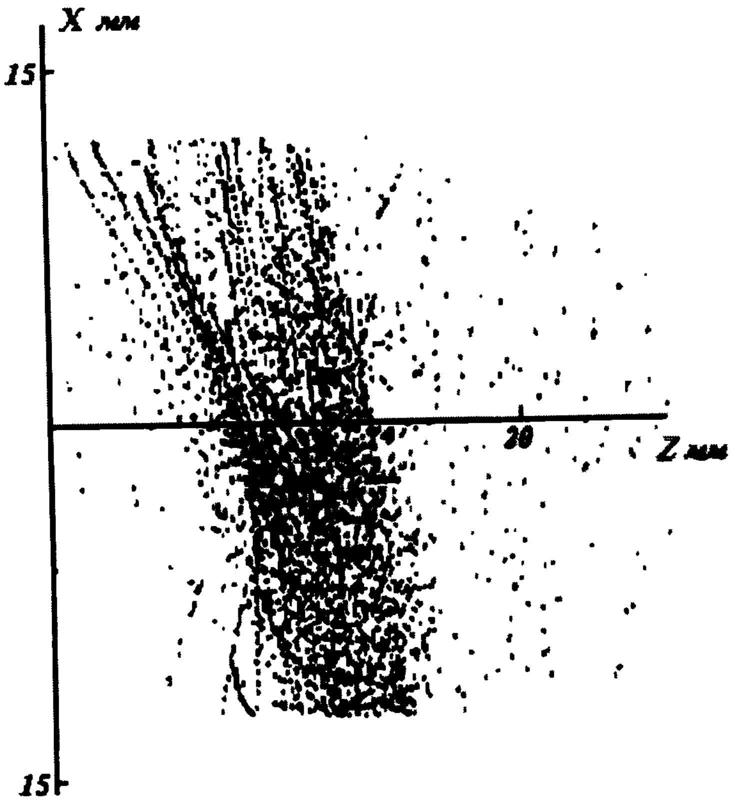
Experimental setup is shown in the fig. The source of the relativistic electron was microtron. Accelerated electrons had energy og 7.4 Mev. Then the bunch passed through interspace of length 1.5m and was extracted through the foil of thickness 100 μm. The detector D could be positioned at various distances from the beam axis z and moved parallel to this axis.

The experimentally measured dependency of the radiation intensity of the longitudinal coordinate of detector z is shown in fig.

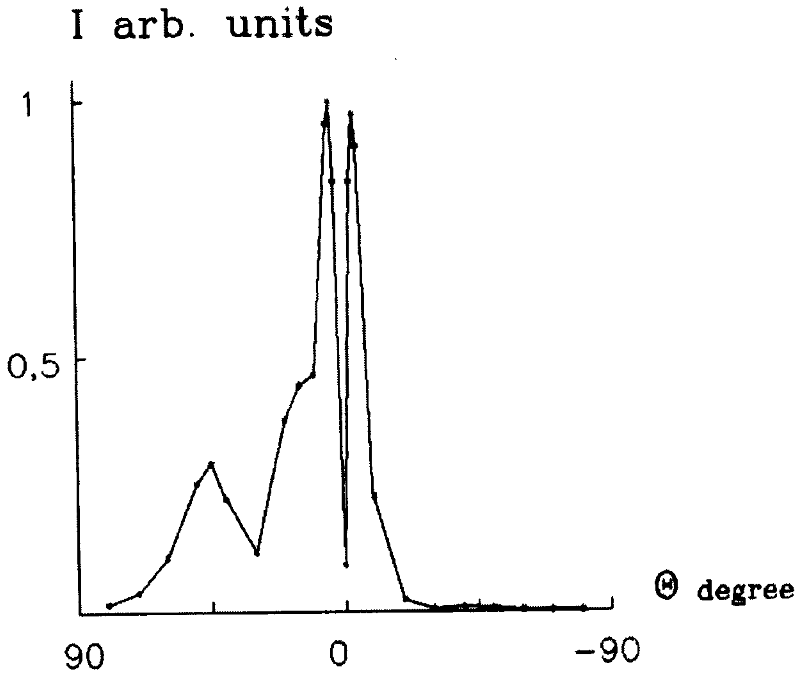


Different curves correspond to the different values of coordinate of the detector x. Measurements showed that there is more essential difference of TR emitted by bunch in comparison with the radiation emitted by singl electron. Under the large angles angular distribution of radiation is asymmetrical relative to the z axis.

To explain the experimental data, numerical calculations of charge distribution in the bunch accelerated in the microtron and angular distribution of TR generated by this bunch were carried. The spartial distribution of the bunch particles before the crossing foil is shown in the fig.



The angular dependence of radiation intensity I in the plane xz is shown in the fig.



In interpreting the results, an important circumstance is that the bunch front is sloped with respect to the velocity vector. In other words, the normal to the front is not parallel to the velocity vector, the angle between these directions about 10 degree. Therefore, various points of the front cross the foil surface at various time instants. Superluminous motion of the radiating spot on boundary surface results in that emitted radiation has qualities of Vavilov–Cherenkov radiation.