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Abstract

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PHYSICS

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EXPERIMENTAL PRODUCTION OF SUBMILLIMETER-RANGE POWER IN A MAGNETIC UNDULATOR

(Presented by Academician M. A. Leontovich, 16 IX 1959)

The paper describes preliminary results on obtaining the total average power of electromagnetic oscillations in the submillimeter range, emitted by relativistic electrons with an energy of 17 MeV in a magnetic undulator. An average power level of $\sim 10^{-7}$ W was obtained at an average electron current of $4\,\mu$A.

In experiments on the generation of electromagnetic oscillations by relativistic electrons in magnetic undulators ([1–3]), electromagnetic oscillations have so far been obtained with wavelengths lying in the range 0.5–8 mm, from electrons with an energy of ~ 2 MeV, and in the visible part of the electromagnetic spectrum from electrons with an energy of ~ 100 MeV. Of great practical interest is the production of radiation lying in the range of tenths of a millimeter and in the submillimeter region. Among the existing methods for generating electromagnetic oscillations lying in this region, only spark generators and heated bodies can be used. However, the power levels generated by these methods are very small. The undulator method of generating superhigh frequencies, based on the use of the double Doppler effect of frequency transformation, makes it possible to cover the entire range of electromagnetic oscillations from 1 mm to visible light; in this case the level of the radiated power can realistically be made sufficiently high even for incoherent radiation.

The radiation frequency in a magnetic undulator for free space is determined by the expression

$$\nu = v/[l_0(1 - \beta \cos \vartheta)],$$

where v is the electron velocity; l_0 is the period of the magnetic structure; $\beta = v/c$; ϑ is the angle between the direction of motion and the direction to the

Fig. 1.

Figure 1: Fig. 1.

observer.

It is seen from this that the generation of electromagnetic oscillations in a sufficiently broad frequency range can be carried out by varying the electron energy (at constant l_0). At an electron energy of 17 MeV, in an undulator with a magnetic-field period of 10 cm, a spectrum of electromagnetic oscillations with a power maximum lying in the region of $42\,\mu$ should be generated. The level of radiation power generated by the electrons depends on the magnitude of the electron current that has passed through the undulator. The use of an undulator with common magnetic cores ([1]) leads to the result that 90% of the current is lost in the first 15 cm of path because of the action of a harmful component of the magnetic field that deflects the beam from the axis.

In the present work an undulator was used, consisting of separate electromagnets, in which it proved possible to eliminate completely the harmful component —

of the magnetic field. As a result, 90% of the current supplied to the input passed through the entire undulator along a waveguide of dimensions 10×23 mm at the maximum magnetic field, which reached 1500 oersteds. The dimensions of the waveguide were chosen with a view to good transmission of the electron beam. With these waveguide dimensions, owing to interference of the excited oscillations, a discrete spectrum of electromagnetic oscillations is obtained, which is divided into two main regions: from 100 to $250\,\mu$ and from 50 to $67\,\mu$. The principal part of the generated lines falls in the region from 50 to $67\,\mu$; the main radiation power is also concentrated in this region.

Fig. 1.

At present, measurements have been made of the total radiation power of the entire generated spectrum, and preparatory work is under way to record the spectrum.

Figure 1 shows a schematic of the setup. The radiation from the open end of the waveguide was deflected from the undulator axis by means of an optical system consisting of metal mirrors and was focused on the indicator. A thermocouple connected directly to a galvanometer was used as the indicator; the scale of the galvanometer had been calibrated in watts.

During the measurements, the background level from the accelerator, while remaining constant in time, increased relative to the background against which the thermocouple calibration was performed, which led to a shift of the zero of the scale. In connection with this, a method was used that made it possible to exclude the background.

In all measurements, the conditions for injecting the beam into the undulator were chosen so that, at different values of the magnetic field, an electron current of the same magnitude passed through the undulator; this ensured constancy of the background level. To eliminate the background, the difference in radiation levels was determined at different values of the magnetic field,

$$P(H_1) - P(H_2) = \Delta P. \tag{1}$$

The radiation power of the electrons in the undulator is proportional to H^2; in connection with this,

$$\frac{P(H_1)}{P(H_2)} = \frac{H_1^2}{H_2^2}. \tag{2}$$

Solving (1) and (2) simultaneously, one can determine the absolute value of the radiation intensity at the given value of the magnetic field. The results

Table 1

Calculated and measured values of the radiation power (in watts)

Electron current I_{av}, μa	Calculation $H = 1000$ oerst.	Calculation $H = 1500$ oerst.	Measurement $H = 1000$ oerst.	Measurement $H = 1500$ oerst.
1.6–1.8	$3.3 \cdot 10^{-9}$	$7.6 \cdot 10^{-9}$	$6.6 \cdot 10^{-8}$	$14.8 \cdot 10^{-8}$
3.8–4.0	$8.5 \cdot 10^{-9}$	$19.2 \cdot 10^{-9}$	$10.4 \cdot 10^{-8}$	$33.5 \cdot 10^{-8}$

measurements are summarized in Table 1. The calculated data in the table refer to free space.

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Note: Figure translations are in progress. See original paper for figures.