

Suppression and Enhancement of Coherent Synchrotron Radiation in Conducting Boundaries*

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Abstract

A suppression effect of coherent synchrotron radiation due to conducting boundaries was observed by using the Tohoku 300 MeV Linac. Electron bunches, whose energy was 50 MeV and longitudinal length was 1.65 mm, were bent by the magnetic field of 68.6 mT between a pair of finite parallel aluminum plates with a variable gap in a vacuum chamber.

As the shielding gap became narrow, the intensity of coherent synchrotron radiation was enhanced at first and then drastically suppressed. The results can be qualitatively explained by the theory of suppression effect obtained by Nodvick and Saxon and applicable to the intense and short-bunched accelerators.

I. INTRODUCTION

In early 1940's it was predicted that bunched electrons might radiate coherently at wavelengths comparable to or longer than the bunch length, and that the radiation loss from all the electrons would be proportional to the square of the number N of electrons in the bunch. According to this idea, the shorter the bunch length would be, the more serious the electron energy loss would become. However coherent radiation loss has not observed for long years.

It was considered that this reason was suppression effect due to metallic walls of the vacuum chamber. This idea was developed by Schwinger. After that Nodvick and Saxon [1] studied radiation in detail by an electron beam following a circular orbit midway between two conducting parallel plates of infinite extent. In order to examine the theory, coherent radiation loss needed to be observed.

In 1989 coherent synchrotron radiation from short electron bunches was observed by using the Tohoku 300 MeV

Linac [2] [3]. Hereby, it became possible to verify the suppression theory. The intensity of coherent synchrotron radiation was measured in the presence of finite parallel plane metallic shields while the distance of those was changing. In this paper experimental results are compared with the theory obtained by Nodvick and Saxon, and features of the suppression effect are shown.

The effect seems to be applicable to electron accelerators with high current and short bunch length, such as bunch compressors of high energy linear colliders or bending arcs of large storage rings.

II. THEORY

Here we account for the suppression theory discussed by Nodvick and Saxon for a beam circulating between two infinite parallel conducting plates. Assuming that these plates exist at $z = \pm a/2$ in three dimension (r, ϕ, z) and that an electron bunch moves in the $z = 0$ plane in a circular orbit of radius R with angular velocity ω_0 , the power P_{coh} coherently radiated by electrons can be expressed as

$$P_{coh} = N^2 \sum P_n f_n, \quad (1)$$

where N is the number of electrons in one bunch, f_n is the bunch form factor, and P_n is the power radiated in the n -th harmonic by an electron.

P_n obtained by Nodvick and Saxon, in MKSA unit, is approximated in the case of β approaching unity as

$$P_n = \frac{n\omega_0 e^2}{3\pi^2 \epsilon_0 a} \left\{ \sum_{j=1,3,\dots}^{j < na/\pi R} \left(\frac{\xi_j}{n} \right)^4 \times \left[\left\{ K_{1/3}^{(1)}(\xi_j^3/3n^2) \right\}^2 + \left\{ K_{2/3}^{(1)}(\xi_j^3/3n^2) \right\}^2 \right] \right\} \quad (2)$$

where $K_{1/3}^{(1)}$ and $K_{2/3}^{(1)}$ are the modified Bessel functions, and $\xi_j = j\pi R/a$. In order to convert P_n to $P(\omega)$ [Photons/electron/mrad/1%BW], replace the factor outside of the big braces by

$$\frac{4 \times 10^{-5} \omega R}{3\pi \omega_0 a} \alpha, \quad (3)$$

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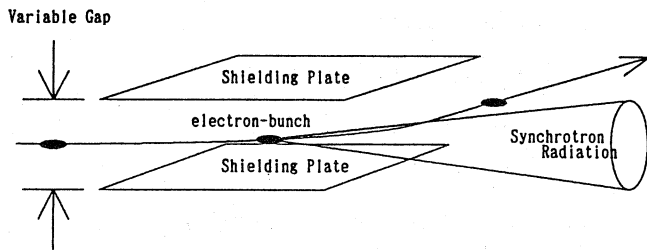


Figure 1: A conceptual drawing of the experiment. The luminous region of synchrotron radiation accepted in an optical system is covered with two parallel metallic shields. The distance between them is changed by remote control.

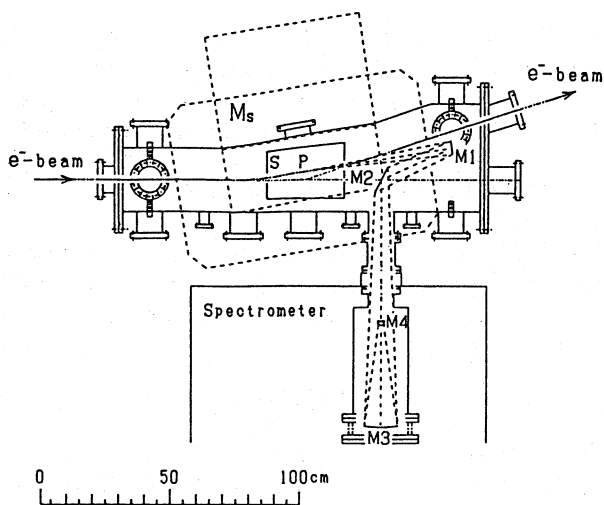


Figure 2: Schematic layout of the experimental setup. M_5 : bending magnet, S: shielding plates, P: luminous point, M_1 , M_2 and M_4 : plane mirrors, M_3 : spherical mirror.

where α is the fine structure constant.

III. EXPERIMENTAL METHOD

A conceptual drawing of this experiment is shown in Figure 1. There are finite parallel shields (Aluminum, 1 mm in thick) in the field of a dipole magnet, where synchrotron radiation is produced by an electron beam. The distance between those can be varied from 81 mm to 14 mm. The shape of shields are trapezoidal, of which the transverse size to the beam axis is 180 mm (upstream) and 200 mm (downstream), and the longitudinal size is 300 mm.

The experimental setup is shown in Figure 2. Electron beam accelerated by the linac was injected from left to bending magnet. The beam energy was 50 MeV with an energy spread of 0.2 % and the field strength of the bending magnet was 68.6 mT. A duration of the beam pulse was 2 μ sec and its repetition rate was 300 pulses/sec. One pulse was made up of about 5700 electron bunches. One bunch consisted of 3.6×10^6 electrons and its longitudinal

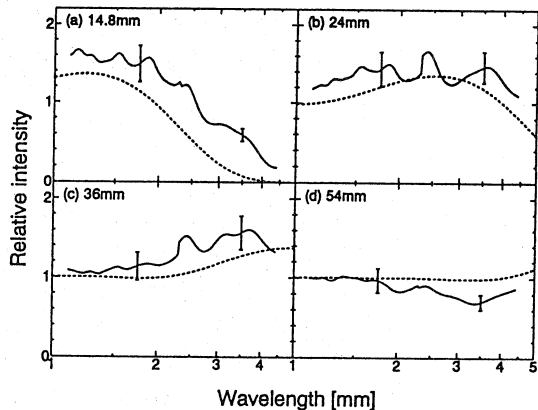


Figure 3: Relative spectra obtained by using a polarizing interferometer at fixed distance between the shielding plates. Panel (a), (b), (c) and (d) show spectra at the distance of 14.8, 24, 36 and 54 mm, respectively. Spectra were normalized by those at the distance of 81 mm. Solid lines show measured values with a slit to block stray light. Dashed lines show theoretical values calculated by formula by Nodvick and Saxon.

length was about 1.65 mm which corresponded to 5.5° in the phase of 2856 MHz accelerating rf.

Synchrotron radiation was condensed by a round spherical mirror with an acceptance angle of 70 mrad and was led to spectrometers. A grating-type far-infrared spectrometer [4] was used at a fixed wavelength with scanning the distance between the shielding plates. A polarizing interferometer [5] was used at the fixed distance between those to measure the spectrum of synchrotron radiation.

In order to block the stray light reflected by the shielding plates, a slit was set at a focal point just at the entrance of the spectrometer.

The radiation was detected by liquid-helium-cooled silicon bolometers [6].

IV. EXPERIMENTAL RESULTS

As is shown in Figure 3, relative spectra at the distance between the shields of 14.8, 24, 36 and 54 mm were obtained by using the polarizing interferometer. Spectra in the wavelength regions of 1.1 ~ 2.3 mm and 2.3 ~ 4.4 mm were measured by using 1 mm and 2 mm low-pass filters, respectively. If suppression effect does not exist, relative spectra must be unity. The observed results show the existence of this effect.

The relation between the intensity of coherent synchrotron radiation and the distance of the shield gap, which is shown in Figure 4, was obtained by using the grating-type spectrometer at fixed wavelength 1.6, 3, 4, 4.5 and 5 mm. The results show a tendency comparable with theoretical values by the formula (2) and can be qualitatively explained by the theory by Nodvick and Saxon.

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VII. REFERENCES

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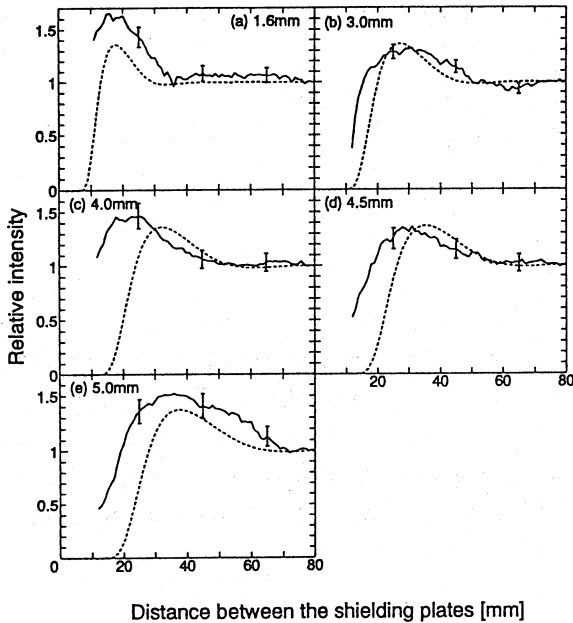


Figure 4: The relation between the intensity of coherent synchrotron radiation and the distance of the shield gap. Panel (a), (b), (c), (d) and (e) show the intensity at fixed wavelength 1.6, 3.0, 4.0, 4.5 and 5.0 mm, respectively. The intensity was normalized by those at the distance of 80 mm. Solid lines show measured values with a slit to block stray light. Dashed lines show theoretical values calculated by formula of Nodvick and Saxon.

Moreover, it is obvious that the shielding effect enhances the intensity of synchrotron radiation at the wavelengths just shorter than suppression region. Furthermore, by comparing the theoretical spectrum calculated by formula by Nodvick and Saxon with that by Schwinger [7], it has been found that the suppressed power due to the shielding plates is equal to the enhanced power, and that total energy of incoherent synchrotron radiation does not change due to conducting boundaries.

V. CONCLUSION

The following important results were obtained by these experiments.

1. Suppression and enhancement effect of coherent synchrotron radiation in conducting boundaries was observed.
2. The intensity of coherent synchrotron radiation which is suppressed and enhanced by conducting boundaries can be qualitatively explained by the theory derived by Nodvick and Saxon.
3. Total energy of incoherent synchrotron radiation does not change due to conducting boundaries.