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The Technique of Measuring Coherent Radiation on the MT-25 Microtron

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Abstract—The article presents a method for measuring coherent transition radiation at one of the basic FLNR JINR installations, the MT-25 microtron, with ultra-high spectral resolution. The presented technique makes it possible to estimate the electron bunch length from measured spectra, demonstrating an effective tool for longitudinal diagnostics of charged particle beams with bunch length from a few tens of femtoseconds to a few tens of picoseconds have been demonstrated.

INTRODUCTION

Transition radiation (TR) appearing when a fast charged particle crosses a boundary between two media with different dielectric properties has widely been used for charged particle beam diagnostics [1]. Coherent transition radiation (CTR) is produced when the wavelength of the emitted radiation is equal to or greater than the length of a charged particle bunch [2]. These days there are methods for measuring coherent radiation that allow determining the bunch lengths from a few tens of femtoseconds [3] to a few tens of picoseconds [4].

The paper presents a technique for measuring CTR spectra, which allows longitudinal diagnostics of charged particle beams. Based on the experimental data obtained, it was possible to estimate the duration of the electron bunch.

EXPERIMENTAL SETUP

The experimental part of the research was carried out at the installation of the Flerov Laboratory of Nuclear Reactions of Joint Institute for Nuclear Research (Dubna, Russia)—the MT-25 microtron. In the experiment the following parameters were used: the energy of accelerated electrons is 10 MeV, the

beam current is about 10 µA, the pulse repetition rate is 380 Hz and the acceleration frequency corresponding to the fixed frequency of the magnetron generator is 2.794 GHz.

Figure 1a shows the scheme of the experiment. A beam of accelerated electrons was extracted from the magneto-optical channel and directed towards the target (*2*) through a 200 µm thick beryllium window (*1*). The target (*2*) was mounted on a motorized rotary platform (*3*), with rotation accuracy of ±0.01°. The target was a 360 µm thick silicon plate coated with a 0.5 µm aluminum foil. The radiation from the target was received by a pyramidal horn antenna (*4*) designed for the frequency range from 6.5 to 18 GHz. The high frequency signal from the horn antenna was transported by a 16 m long phase-stable coaxial cable (*5*), RG-405SS, with K-type connectors (2.92 mm) at both ends. The cable connected the horn antenna to the spectrum analyzer of the Ceyear 4052 series produced by Ceyear Technologies (*6*). The spectrum analyzer was located in a specially designed box that protected it from electromagnetic interference and external radiation (*7*). The analyzer had the following characteristics: operating range from 2 Hz to 40 GHz, minimum noise level −171 dBm, analysis bandwidth from 10 MHz to 1.2 GHz, video bandwidth from 1 Hz to 40 MHz. To normalize the received signal, the
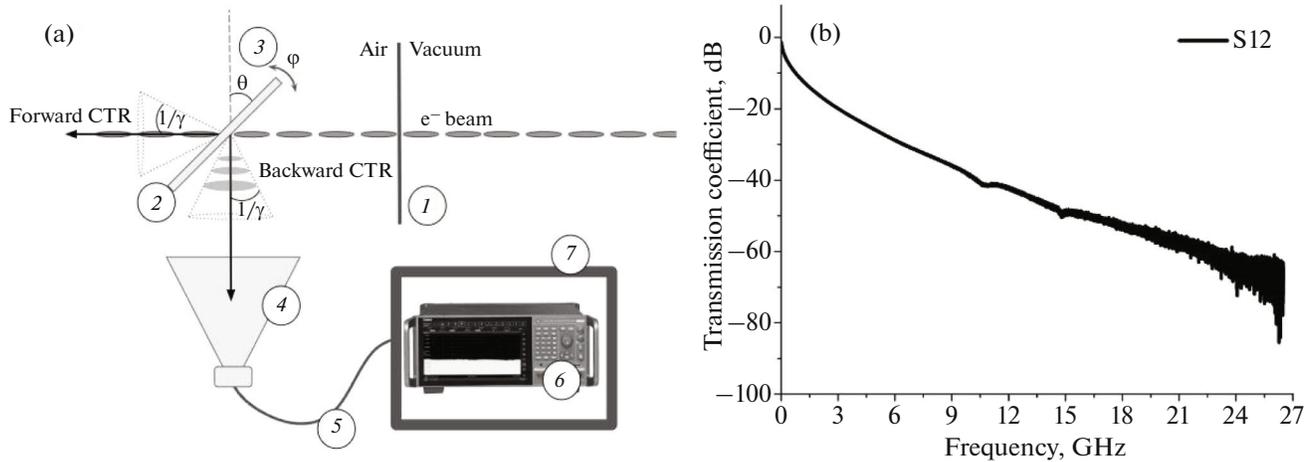
Fig. 1. (a) The scheme of the experiment: (*1*) output window; (*2*) target; (*3*) motorized rotary platform; (*4*) horn antenna; (*5*) cable; (*6*) spectrum analyzer; (*7*) radiation shield; (b) The transmission coefficient of RG-405SS cable.
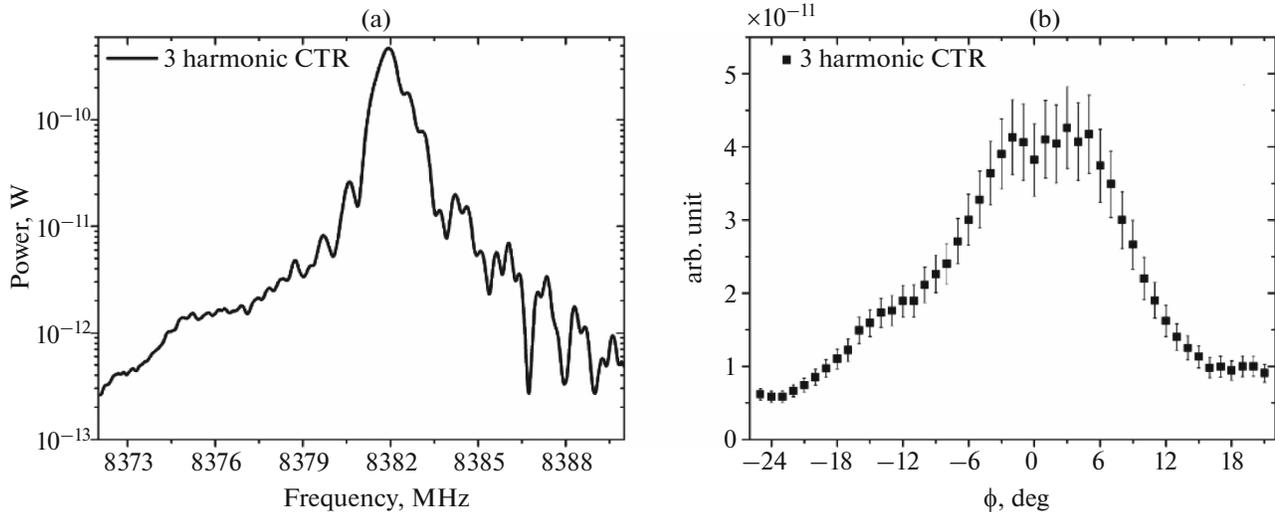

Fig. 2. (a) The spectrum of the 3rd harmonic CTR; (b) The orientation dependence of the 3rd harmonic CTR.

transmission coefficient (S12 parameter) was measured for the frequency range from 0.01 to 26.5 GHz used by the cable assembly using the Keysight PNA-X circuit analyzer. The results are shown in Fig. 1b.

RESULTS AND DISCUSSION

The CTR spectra from the 3rd to 8th harmonics of the fundamental RF frequency of 2.794 GHz were measured. The signal from the first and second harmonics is significantly overlaid by the background microwave signal from the magnetron. Our antenna sensitivity begins from 6.5 GHz and, therefore, does not detect the first two harmonics. Further, data for

the 3-8 harmonics were studied. Figure 2a shows the measured example CTR spectrum of the 3rd harmonic. It can be seen that the intensity of the useful signal is more than a thousand times higher than the noise level.

Figure 2b shows the CTR orientation dependence measured at the 3rd harmonics by rotating the CTR target. The scanning was performed when the angle φ changed from $-26°$ to $23°$, where $0°$ corresponds to direction of specular reflection and is $45°$ with respect to the beam trajectory. Classic CTR distribution has a minimum in the direction of specular reflection. However, due to a very large aperture (78×65.5 mm) of the horn antenna, the minimum is smeared out.
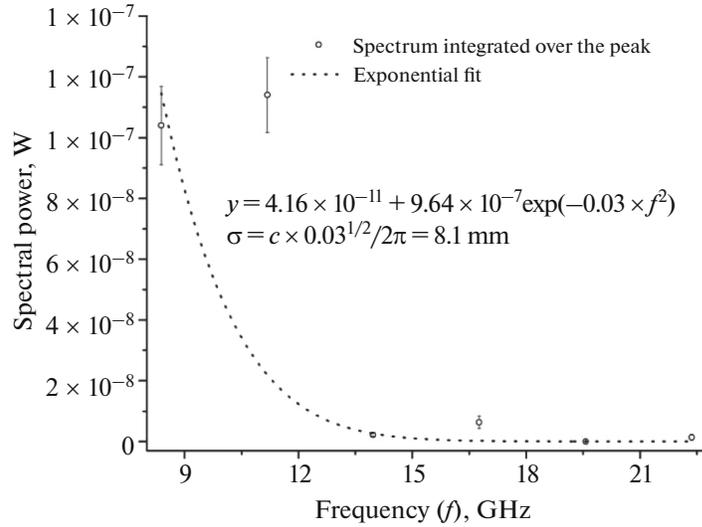
Fig. 3. Determination of the length of the electron bunch: points are the frequency spectrum for 3rd to 8th harmonics; the dashed curve is an exponential fit function.

To estimate the length of a bunch, we use a formula for the form factor of a Gaussian electron bunch. This formula is described as follows [4]:

$$F_b(\omega,\sigma) = \left| \int_{-\infty}^{+\infty} \rho(z,\sigma) e^{-i\frac{\omega z}{c}} dz \right|^2 = e^{-\frac{\omega^2 \sigma_s^2}{c^2}}, \quad (1)$$

where, σ_s—rms length of the bunch, c—speed of light, ω—frequency of radiation.

To estimate the length of the bunch using the formula (1), the CTR frequency spectrum from 3rd to 8th harmonics was constructed at the angle $\varphi = 5°$ corresponding to the maximum of the angular distribution. The result obtained, considering the transmission coefficient of the cable, is illustrated in Fig. 3. The resulting frequency spectrum was fit using the exponential function in Eq. (1).

From the data obtained, the length of the electron bunch was found to be $\sigma_s = 8.2$ mm ± 1.1 mm. The obtained value is close to the value obtained at the microtron accelerator facility in Tomsk, which is similar to MT-25 [4]. This estimation assumes that the single electron spectrum is constant and does not contribute to the spectral intensity variation. Ideally the single electron spectrum must be calculated and used to normalize the data. Nevertheless, the CTR intensity generated by a single electron is a slow function of frequency and will not change the bunch length estimate much.

CONCLUSIONS

An experimental setup was created and a technique for measuring coherent radiation on the MT-25 microtron was tested. Using the described measuring system, it was possible to obtain the spectral-angular distribution of CTR and register the spectra of six CTR harmonics. This technique made it possible to estimate the length of the electron bunch, which was $\sigma_s = 8.2$ mm ± 1.1 mm. In future we plan to continue the data analysis and experimental activity in the framework of the FLAP Collaboration. It is planned to conduct additional tests of the above-described technique on the "LINAC-200" linear electron accelerator (Dzhelepov Laboratory of Nuclear Problems of Joint Institute for Nuclear Research, Dubna, Russia) [5] and at the Röntgen-1 setup [6] of the "Pakhra" accelerator complex of the P.N. Lebedev Physical Institute (Moscow, Russia).

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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