INFRARED SYNCHROTRON DIAGNOSTICS AS A NEW PERSPECTIVE DIRECTION IN THE PHYSICS AND TECHNOLOGY OF ACCELERATOR AND APPLIED EXPERIMENTS

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Infrared synchrotron diagnostics of relativistic charged particles is a well-known effect observed in ring accelerators and storage systems and is widely used in various experiments and investigations, in particular, for passive, nondestructive diagnostics of charged-particles bunches.
during their formation and acceleration. Synchrotron infrared radiation (SIR) can be used to measure the current, energy, and geometrical of electron and proton beams and bunches without affecting the accelerated particles, as well as for nondestructive studies of fast processes [1].

Analysis of the SIR spectra of proton ring accelerators at the leading accelerator laboratories around the world shows that the bulk of the spectral distribution of the radiation for protons with energies of up to 1 TeV lies in the infrared region [2]. Estimating the intensity of the proton radiation and comparing it with that of the SIR of low-energy electrons at, for example, the JINR accelerator - compressor electron-ring bunch, we find that the techniques and systems of infrared synchrotron diagnostics developed for the JINR accelerator and later used in accelerator experiments may be also useful for the diagnostics of proton beams with energies above 100 GeV. So far there are no cases of diagnostics of proton beams with energies above 400 GeV. The calculation of the SIR characteristics and the choice of techniques and diagnostics systems have been made and demonstrated for the ring-shaped bunches during bunch compression in the high-current low-energy accelerator - compressor of ring-shaped electron (electron-ion) bunches and are based on the measurements of SIR. Based on these methods there were elaborated measurement systems for the diagnostics of bunch parameters [3].

**NUMBER OF CHARGED-PARTICLES**

The electron number measurement method is based on the direct dependence of the SIR intensity on the electrons number and the SIR registration is made in the spectral region \( \lambda > \lambda_c \) (\( \lambda_c \) is the critical wavelength) when the radiation intensity is independent of the energy of electrons. If the total power \( W \) of the radiation of the e-bunch is proportional to the number \( N_e \) of electrons in the bunch, for a given number of electrons the total power of the radiation is \( W = N_e \cdot w \). The electrons number \( N_e \) in the bunch can be calculated if one-electron SIR power \( w \) is known and SIR total power \( W \) is measured. The total SIR power can be determined if we know: the signal on the radiation detector \( U_{sir} \); the calibration constant of the detector \( S \); the energy of electrons \( E \); the orbit radius \( R \); the coefficient of SIR flow using from \( G \) – geometrical factor determined by solid angle of the SIR detector; relative spectral characteristic \( \varepsilon(\lambda) \) of the detector; the coefficient of spectral passing \( \tau(\lambda) \) of interval pass limits environment (window, filters, optics) and the SIR polarization properties.

**GEOMETRICAL PARAMETERS**

Since a bunch of charged particles in an accelerator can be considered as an ensemble of oscillators with three degrees of freedom (longitudinal (synchrotron) and two transverse (betatron)-radial and axial ones), the diagnostic set must provide the measurements of the corresponding geometrical parameters of the bunch and possibility of observing the bunch dynamics. The method of measuring the sizes of the bunch and its location inside the accelerator, as well as studies of the bunch dynamics during the compression involves the facilities for extraction of SIR from the accelerator chamber, its transportation, and detection. The appropriately reduced image of the bunch cross section is focused on and recorded by a detector unit with sensitive elements arranged in line.

**ANGULAR DIVERGENCE**

An important parameter for the diagnostics of the bunch is in the angular divergence of the SIR in the direction perpendicular to the median plane of the bunch. Measurement of this quantity gives information about the electron energy and angular distribution (axial betatron oscillations). A method has been developed to measure the divergence of the radiation beam and the characteristics related to this divergence. This method is based on repeated (throughout the acceleration cycle) measurement of the intensity of the SIR as it exits the accelerator chamber by means of an infrared detector whose length covers most of the SIR flux in the direction perpendicular to the charged particles rotation plane.
The diagnostics of the parameters of the ring-shaped bunch are performed simultaneously by several information-measuring systems [3] which realize the various methods listed in the preceding section. SIR from the electron bunch is extracted through an infrared window of the vacuum chamber of the accelerator, then it is transported along the optical channel over the given distance and is received by a detectors unit with a power sources. The detector signals are registered and processed by an electronic facility, and then transferred to a computer for the real-time processing. In the immediate vicinity of the accelerator, there are only detector units, which include a single-element and multi-element coordinate infrared detectors with a preamplifier in each of the recording channels, a cryogenic system (in case when the detector is cooled to the temperature of the liquid nitrogen), and power sources. The detectors unit can be moved in the image plane by electric motors, which is remotely controlled by a unit. The processing facilities are outside the region of radiation damage. The synchrotron radiation is extracted from the accelerator through windows made of various optical materials. Optical channel designed for the extraction and transportation of SIR includes an output window and a long-focus wide-band optical mirror channel; at the output of the channel, radiation is focused on the sensitive surface of the coordinate detector. The SIR extracted from the accelerator is recorded by three independent infrared detection systems forming a single information-measuring complex. Each system performs a specific task, operating synchronously on a common time scale. The device with a single-element detector is designed for measuring the absolute number of electrons. The geometrical parameters of the bunch are measured using a system containing a multi-element coordinate detector system located at the focus of the optical channel. The angular divergence of the SIR and its intensity are measured by an infrared coordinate detector with linear arrangement of the elements. The information obtained from the measuring systems is collected and processed in the units, which incorporate a computer. This information significantly raises the overall accuracy and information content of the measurements. The choice of detectors for the diagnostics systems is determined by the intensity and spectral characteristics of the recorded synchrotron radiation, and by the conditions of operation of the accelerator. The main requirements in choosing the detectors were the following:

1. High spectral sensitivity in the wavelength range $\lambda \approx 0.3 \div 40 \mu m$.
2. Time resolution (speed of response) $t = 0.1 \div 5 \cdot 10^{-6} \text{s}$.

Various types of infrared collectors were considered. Five types of photocollectors sensitive to the given region of the infrared spectrum were proposed to conform to the above requirements. The main characteristics of these photocollectors are listed in Ref. [1].

The SIR of the electrons can be recorded either by all the measuring systems simultaneously or by each separately. The radiation intensity is recorded by detectors and output as an analog signal, which is preamplified to the required amplitude and fed via a cable to the control panel of the accelerator, where it is transformed into digital form and processed by computer. The measurement channels allow repeated (up to 10 times) recording of a ring compression cycle in the compressor of the accelerator. The duration of the data measurement is 0.1 $\mu$s. The time interval between successive measurements can be varied from 100 $\mu$s and more for a total duration of the synchrotron radiation pulse of about one millisecond.

Methods for measuring the current and geometrical parameters and estimating the energy parameters of bunch in accelerator rings using synchrotron radiation in the infrared region are reviewed, together with the information-measuring systems designed to detect SIR and realize these methods. The detection systems incorporate specially designed infrared-optical elements (a high-vacuum window of optical ceramics and broad-band long-focus optical channels). The radiation is detected in the spectral region of $\Delta \lambda = 0.3 \div 40 \mu m$ by infrared detectors operating at low temperature or room temperature. It should be noted that the range of applicability of these results is fairly broad. Most of the techniques and information-measuring systems described here can be used in the same or slightly altered form at other electron and proton ring accelerators.
which generate synchrotron radiation, for example, LHC - SPS [4], the synchrotron radiation spectrum at which lies mainly in the infrared region. They are useful both for the diagnostics of bunches and beams during their dynamical development, and for carrying out various types of scientific research and solving applied problems based on the use of infrared synchrotron radiation, including beam diagnostics and research at electron-positron storage rings [5]. The objectives of this work are as follows:

1. We present the methods and systems of nondestructive diagnostics and study of charged-particle (electron, electron-ion, and proton) bunches and beams based on the use of their magnetic-bremsstrahlung (synchrotron) radiation in a wide spectral range, from the ultraviolet to the far long-wave infrared region.

2. We draw attention to the great diversity of problems, both in accelerator experiments (for example, the study of the coherence of synchrotron radiation or of the coherent processes at colliders) and in other, sometimes quite unrelated fields, such as metrology, high-temperature superconductivity, biology, etc., which might be solved by means of infrared synchrotron diagnostics, covering the interval of wavelengths $\Delta \lambda \approx 0.3 \div 40 \mu m$, which is much larger than the spectral range that is widely used at present (basically, the range of $\Delta \lambda \approx 0.3 \div 1.1 \mu m$) in various experiments and investigations. The extension of the spectral range of positively diagnosed SIR opens up new possibilities and prospects for solving scientific and applied problems.

REFERENCES