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Recording the synchrotron radiation by a picosecond streak camera for bunch diagnostics in cyclic accelerators

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Abstract. **A PS-1/S1 picosecond streak camera with a linear sweep is used to measure temporal characteristics of synchrotron radiation pulses on a damping ring (DR) at the Budker Institute of Nuclear Physics (BINP) of the Siberian Branch of the Russian Academy of Sciences (Novosibirsk). The data obtained allow a conclusion as to the formation processes of electron bunches and their 'quality' in the DR after injection from the linear accelerator. The expediency of employing the streak camera as a part of an optical diagnostic accelerator complex for adjusting the injection from a linear accelerator is shown. Discussed is the issue of designing a new-generation dissector with a time resolution up to a few picoseconds, which would allow implementation of a continuous bunch monitoring in the DR during mutual work with the electron-positron colliders at the BINP.**

Keywords: *streak camera, dissector, synchrotron radiation, optical diagnostics.*

1. Introduction

The traditional areas of image-converter camera (ICC) applications in physical experiments comprise physics of lasers, laser plasma diagnostics, laser spectroscopy, etc. [1]. At present, in the course of the development of cyclic accelerators, which allow a significant increase in synchrotron radiation (SR) brightness by reducing the bunch emittance, a necessity has appeared of perfection of the optical diagnostic complex for SR recording. This is associated both with measurements of spatial and temporal characteristics of particle bunches in cyclic accelerators and SR application in various problems of science and technology [2]. This task requires an increase in time resolution of picosecond dissectors used in optical diagnostics accelerator systems up to the units of picoseconds [3]. The ICC with a linear sweep have proven to be very promising for optical diagnostics of particle bunches at the stage of the formation of electron and positron bunches in collider boosters, storage rings and other cyclic accelerators. In particular, this has allowed us to optimise the damping ring (DR) operation of the injection complex at the BINP [4] and to improve the regime of particle injection into the DR from a linear accelerator (linac). Such a conclusion was made in the course of preliminary experiments on the DR, which were performed in the framework of a project aimed at the design of a new-generation dissector with a time resolution of a few picoseconds.

The SR recording in the optical range is widely used for the measurements of bunch parameters in cyclic accelerators of electrons and positrons. Optical diagnostics in accelerator technology is contactless and utilises either the self-radiation of the object under study or the probe radiation scattered on the object [5]. In this case the object characteristics are not distorted, and the diagnostic benches for the measurement of the SR parameters consist of a number of traditional elements, such as TV and CCD cameras, photodiodes and photomultiplier tubes, interferometers, etc. [3].

There has always been an interest in accelerator physics in studying the spatial distribution of the bunch particles, in particular, in measuring the parameters of the longitudinal profile of the bunch. For these purposes, an LI-602 dissector [6] has been designed at the BINP, representing a regular, reliable and permanently operating instrument, which, being part of the optical diagnostic complex in a variety of cyclic accelerators, is designated for monitoring the longitudinal bunch profile. This device has a time resolution of about 20 ps, which is no longer enough to measure the internal structure of electron bunches in modern cyclic accelerators. An advance in the time resolution of dissectors allows exploration of different types of quick instabilities, such as the 'meeting' effects, nonlinear dynamics of bunches, instabilities caused by a large number of electron bunches, etc. [7]. This requires monitoring of the SR temporal parameters with picosecond resolution, which corresponds to the longitudinal variation of the particle distribution in the bunch. It should be noted that nowadays there are virtually no accelerators in the world, in which the longitudinal bunch profile monitoring in the form of a regular, permanently acting diagnostic procedure would have been implemented. The exceptions are the installations at which the 20-ps dissectors developed at the BINP are used.

2. Experimental

The aim of the work on the DR of the injection complex at the BINP was to specify the parameters of the dissector which is being developed on the basis of the PS-1/S1 streak camera. In

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the course of these studies, the synchronisation regimes of external triggering of the dissector from the SR signals or from the electronic devices of an accelerator have been determined. Apart from that, we have measured the actual duration of electron bunches according to the SR signals for subsequent comparison of these data with the results of measurements to be obtained on the dissector designed. Only an ICC with a spiral sweep have been previously used in the experiments for SR recording in Russia [8]. As to the situation abroad, the streak cameras were present as part of the optical diagnostic complex of cyclic accelerators [9], but have not found regular use due to the complexity and high operational cost. Therefore, the use of the PS-1/S1 streak camera in the DR experiments is of undoubted interest for further research on the SR properties.

The PS-1/S1 streak camera operates in the linear sweep regime in a wide range of sweep durations (from hundreds of picoseconds to hundreds of nanoseconds) and provides recording of ultrafast processes in the spectral range of 115–1550 nm. The main camera characteristics are given in [10]. In the DR accelerator complex, this streak camera was positioned on the optical bench, the schematic of which is shown in Fig. 1. The camera records the SR in the spectral range of 400–900 nm at the stage of formation of electron bunches, which occurs in the course of the bunch extinction in the DR after injection from the linear accelerator. By means of the objective lens, the SR was focused directly onto the camera photocathode, since the purpose of experiments was to measure only the longitudinal (temporal) bunch profile.

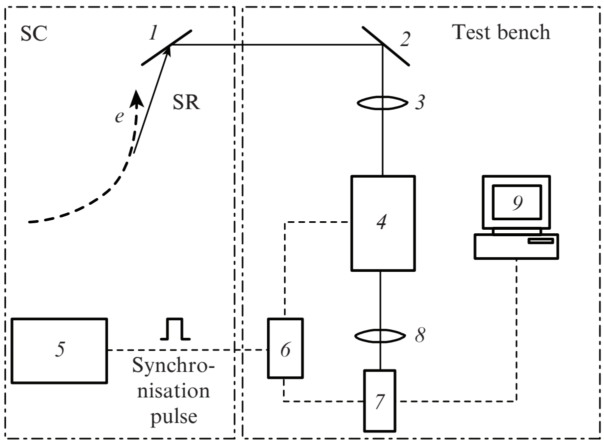

Figure 1. Experimental setup: (*1*, *2*) rotating mirrors; (*3*, *8*) objective lenses; (*4*) image-converter camera; (*5*) control unit; (*6*) delay generator; (*7*) readout system; (*9*) PC.

The DR VEPP-5 injection complex represents an accelerator of electrons and positrons for the energy up to 510 MeV. Its circumference is 27 m; the revolution frequency is 11 MHz. The bunch trajectory radius in the bending magnet is 112 cm. The bunch length in the accelerator is 2.5 cm at an accelerating voltage on the resonator of 200 kV, which corresponds to SR pulse duration σ = 80 ps. The bunch is injected into the accelerator ring at a frequency of 1 Hz.

The injection can be stopped; in this case, the bunch accumulated inside the ring will live in it about 1000 s. The SR radiated from the bending magnet is coupled out of the vacuum chamber through the optical window and by means of mirrors is introduced into the diagnostics hopper through a biosecurity channel. The SR shape was close to a circle with a diameter of ~10 cm. The SR spectrum is presented in Fig. 2. A single SR pulse contains no more than 10^6 emitted photons in the wavelength range of 400–900 nm. It is worth emphasising that reliable detection of such a small number of photons is only possible if the streak camera operates in the point-like linear sweep regime, with focusing of the entire SR bunch onto the camera photocathode by means of objective lens.

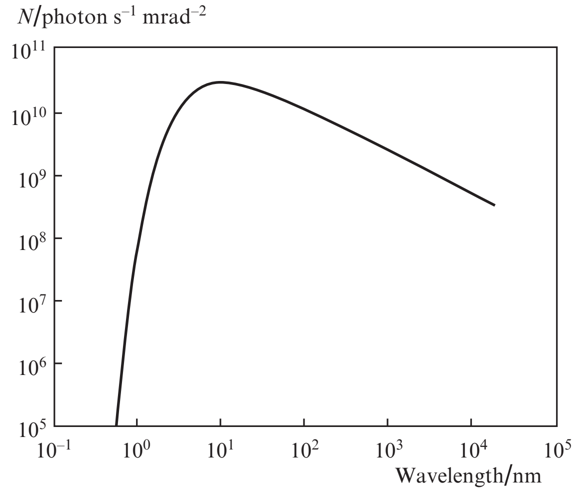

Figure 2. SR spectrum at the electron energy E = 410 MeV and bunch current of 10 mA.

In the hopper, the time moment of the beam injection from the linac into the DR was synchronised with the bunch turn in that ring. In the framework of experiments using the PS-1/S1 streak camera, the dynamics of electron bunches in the DR was monitored during about 1000 turns in the process of the bunch extinction. This process can be well described analytically, and the experimental data can be compared with the calculated values, which provides a basis for the theory refinement and optimisation of the DR operating parameters. Apart from that, we have explored the bunch length dependence in equilibrium state on the accelerating cavity voltage and studied the reasons for spreading the bunch between several neighbouring DR separatrices.

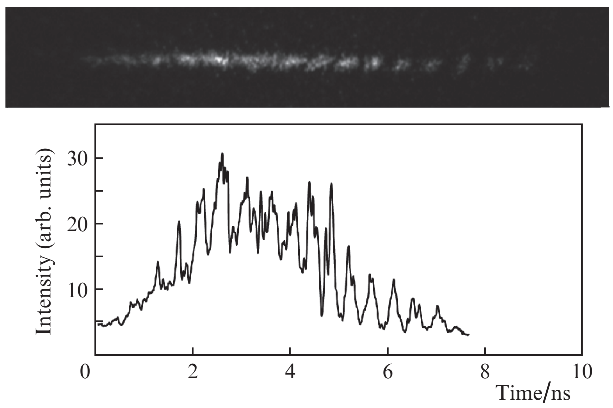

Figure 3. Particle distribution in the beam from the linac, which has performed 5 turns in the DR after injection.

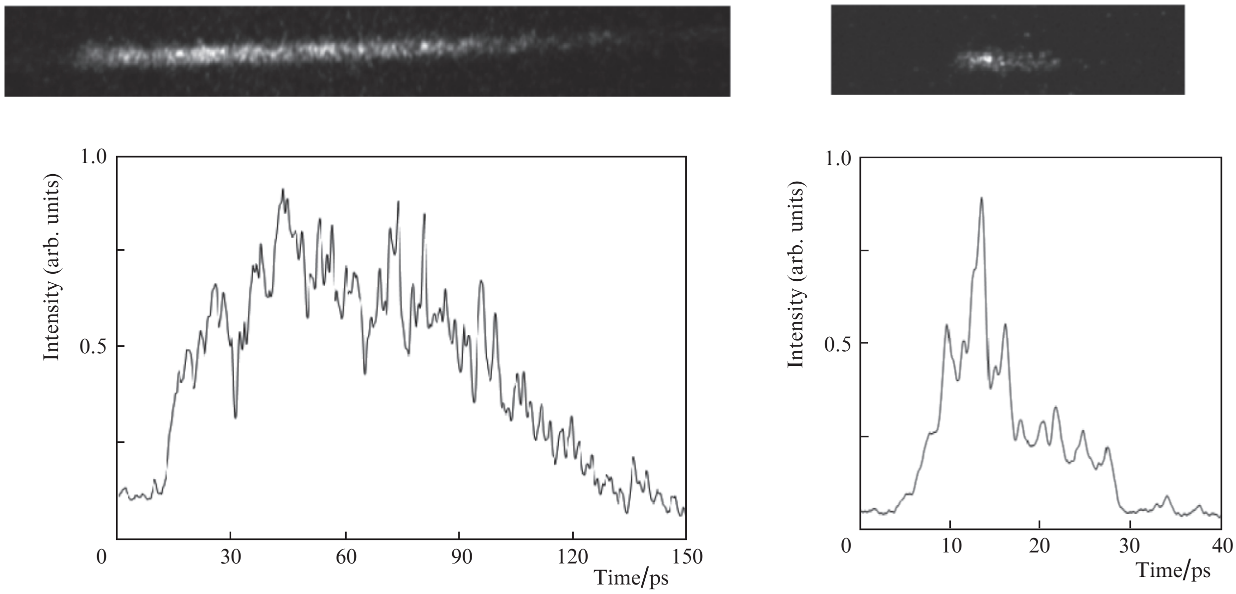

Figure 4. Structures of two bunches generated by the linac.

The recorded structure of the beam injected from the linac into the DR (Fig. 3) shows that the beam with a total duration of about 7 ns consists of more than ten bunches, the distance between them being equal to the period of the linac accelerating frequency (v_{linac} = 2.856 GHz). The duration of a single bunch in the beam can vary in a wide range (Fig. 4).

The accelerating voltage frequency in the DR is v_{AC} = 700 MHz; therefore, only those particles of the beam injected from the linac will be captured on a stable orbit, which fall on the DR separatrices. In other words, the linac beam will be 'thinned' with a frequency of 700 MHz, and only those particles of the beam will be captured into the DR, the distance between which is determined by the v_{AC} frequency. After 10 turns of the beam, its modulation becomes clearly visible (Fig. 5) due to extinction of the particles caught into the non-equilibrium phase region during their passage through the DR accelerating cavity.

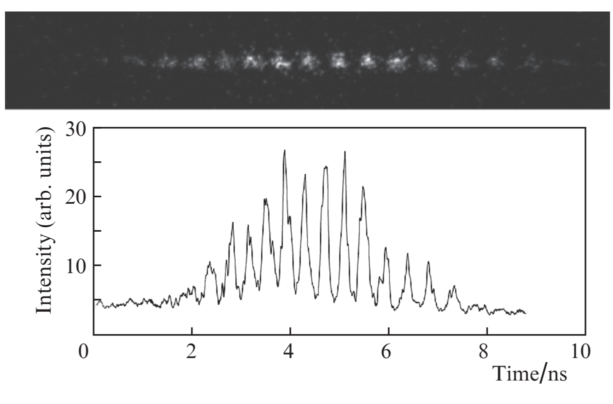

Figure 5. Structure of the bunch, which performed 10 turns in the DR after a single injection.

The extinction process leads to the fact that, after 15 turns in the DR, the beam is disintegrated into separate bunches (Fig. 6), and the particle concentration within the limits of the SR separatrices becomes noticeable. Thus, it is very likely that the temporal distribution of particles in the beam (see Fig. 3) becomes distorted by the losses already in the course of the first five turns in the DR. Finally, the particles captured into the DR separatrices survive (Fig.7). These data allow merely qualitative assessment of the injection efficiency from the linac into the DR.

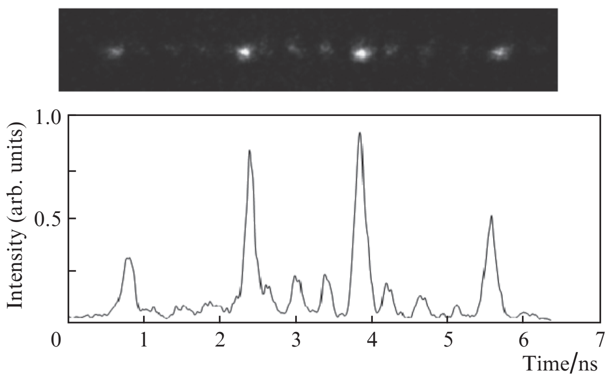

Figure 6. Structure of the bunch, which performed 15 turns in the DR after injection.

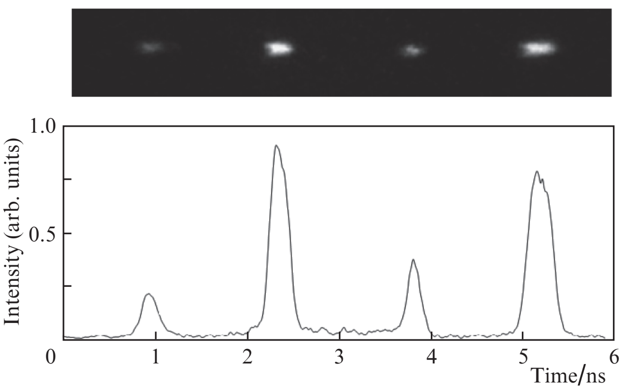

Figure 7. Structure of the bunch accumulated in four separatrices after several hundred turns in the DR.

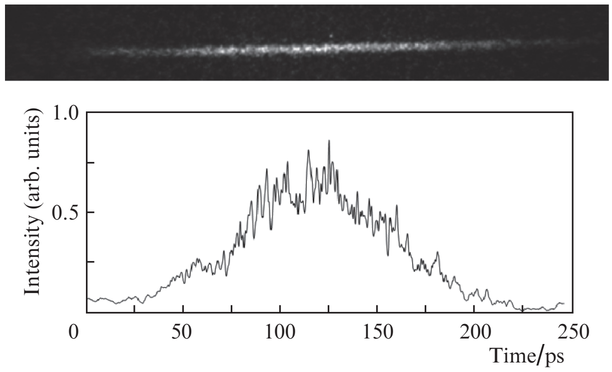

Figure 8. Longitudinal profile of a single bunch accumulated in the DR. The accelerating cavity voltage is 55 kV.

Measuring the profile of a bunch captured into a separate separatrix in the DR shows that its shape is similar to the Gaussian one and corresponds to the calculated duration of $\sigma \approx 80$ ps at a given voltage $U_{\mathrm{RF}} = 55$ kW on the accelerating cavity (Fig. 8).

3. Conclusions

Measurements of the duration of SR pulses corresponding to the length of electron bunches have shown that the ICC allows recording both a train of electron bunches inside a beam of ~5 ns duration (Figs 3, 5) and a structure of bunches inside a train (Figs 6, 7). Apart from that, the ICC records the distance between the bunches (~1.5 ns) and their amplitude related to the number of particles in the bunch. It is found that the length of a single electron bunch may lie in the range of 20–100 ps. The internal structure of a single bunch varies greatly depending on the linac operation parameters.

The use of the ICC in the diagnostic accelerator complex allows monitoring the formation process of electron (in the future–positron) beams, which is of great practical importance, since it makes it possible to increase the efficiency of capturing the particles from the linear accelerator into the storage–cooler. Improving the capture efficiency is directly related to an increase in the average luminosity of the VEPP 2000 and VEPP-4M electron–positron colliders [3, 11] for which the DR should become a particle source.

A small jitter of the ICC synchronisation pulses (up to a few picoseconds) and their good synchronisation with the SR pulses allows a hope for gaining a high time resolution in the regime of long-term accumulation of repetitive signals, which is fundamentally important for a new generation of picosecond dissectors.

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