Diagnostics of local electron beam losses in microtron-recuperator on Novosibirsk Free electron Laser beamline via detection of induced X-rays

E.N. Dementiev\textsuperscript{a,b}, Yu.I. Mondich, S.S. Serednyakov\textsuperscript{a,b,*}, M.A. Scheglov\textsuperscript{a}

\textsuperscript{a} Budker Institute of Nuclear Physics SB RAS, 11, Akademika Lavrentieva Prospect, Novosibirsk 630090, Russia
\textsuperscript{b} Novosibirsk State University, 2, Pirogova Street, Novosibirsk 630090, Russia

Abstract

The Novosibirsk Free Electron Laser (NovoFEL) is based on a four-turn microtron-recuperator. To ensure its stable operation and radiation generation, it is necessary to provide a stable mode of electron beam recirculation and minimize beam losses on the vacuum chamber wall on all the beam way in the accelerator beamline. To this end it is necessary to know the longitudinal distribution of these losses along the beamline.

A system for registration of beam losses was created. The system applies optical fibers placed along the vacuum chamber and nearby it. If local electron beam losses occur somewhere in the vacuum chamber, electrons falling to the vacuum chamber wall cause generation of X- and gamma rays. This radiation in turn originates optical emission in an optical fiber nearby the region of electron “precipitation” on the chamber wall. Then, executing some transformation and processing of the time dependencies of signals from these optical fibers, one can obtain the longitudinal distribution of electron beam losses along the accelerator line in all its four turns.

Keywords: Free electron laser; particle accelerators; microtron-recuperator; beamline; X-rays

* Corresponding author. Tel.: 7-383-329-4859; fax: +7-383-330-71-63.
E-mail address: S.S.Serednyakov@inp.nsk.su
1. Introduction

The construction of the third stage of the Novosibirsk Free Electron Laser (FEL) is now close to completion [1]. The generation of coherent radiation in the wavelength range of 8-11 μm has been attained.

The facility of the third stage includes the four-turn microtron-recuparator, which makes a basis for the third stage FEL operation. The mode of electron beam recirculation in the microtron-recuparator line has the following features:

- High average electron beam current – up to 3 mA.
- Simultaneous presence of two different (accelerated and decelerated) beams in the accelerator line.
- Variable transverse size of the vacuum chamber in some regions of electron beam propagation.

These and some another factors enable large electron beam losses on the walls of the vacuum chamber. This may in turn cause overheating and even burning of the chamber by the electron beam. This circumstance necessitates the development of a system for diagnostics of electron beam losses along the beam propagation.

The current diagnostics systems of the facility enable only indirect and very rough determination of the beam losses. For example, the beam position measurement system is only able to detect the change in the electron beam current from one BPM station to another. The accuracy of this method is very low. Another system – control of the temperature – has a very large time of response. Besides, this system is able to show a local overheating only in an immediate proximity of temperature sensor.

On the other hand, the method of beam loss detection by induced radiation is free from the above disadvantages: it is quite fast and enables rather accurate (within 1 meter) detection of the place of beam losses. This method is described in the current article.

2. Brief description of the system

As known, single electrons from an electron bunch hitting the vacuum chamber wall and penetrating into it may initiate Gamma or X-rays. These rays, freely passing through the chamber wall and propagating further, produce the background radiation in the accelerator hall. Permeating into an optical fiber placed not far from the vacuum chamber, these rays in turn induce light flashes, which propagate in this fiber in both directions (Fig.1).

![Diagram of the system](image)

Accordingly, the intensity of the light induced in these fibers will be proportional to the intensity of the penetrating Gamma and X-rays and thus proportional to the electron beam losses in the chamber wall in this region.

If an optical fiber is laid along the accelerator line, the temporal distribution of the light intensity in this fiber will reflect the temporal distribution of electron beam losses during the beam flight in this line. If this signal is properly
synchronized with the beam pass in the accelerator, the distribution of local beam losses in time can be re-calculated easily to the distribution over the optical fiber length. Thus any time period in this signal can be bound to a certain place in the accelerator line.

The above approach was applied to the development of the present diagnostics system. The optical fibers were laid along each track of the microtron-recuperator (see Fig. 2). The light signal outgoing form the optical fiber was converted to an electric one using a standard photoelectron multiplier. The latter was fed by a controlled power supply, and thus the amplification factor was also under control. This power supply was regulated from the control PC via a CAMAC interface.

The signals from the optical cables arrive at the entry of a four-channel digital oscilloscope, from which the digitized waveforms are delivered to the computer.

![Figure 2. Location of optical fibers in immediate proximity of accelerator vacuum chamber.](image)

3. Whole system and synchronization structure

As discussed above, the optical fibers are laid along all the four tracks of the microtron-recuperator. Gamma- and X-rays appearing in a particular track may influence the optical fibers of the other tracks but with smaller amplitude. Moreover, in every accelerator track, except the last one, there are two different beams – the accelerated and...
decelerated ones. These beams have different trajectories and therefore may have different losses at the same place of the accelerator track. Furthermore, to detect the local electron beam losses, one needs a precise binding of the temporal scale of waveforms from the optical fibers to the time intervals of the beam pass in the different tracks of the microtron-recuperator.

To provide such binding and proper synchronization, we realized the following features in this system:

- A signal to start the digitization using the digital oscilloscope arrives from the beam current sensor installed in injection line of the accelerator.
- The signal from the plate of the BPM station that is situated in the middle of the acceleration section is added to the signal from the optical fiber of the fourth turn of the microtron-recuperator (see Fig. 3). Since the electron beam passes this acceleration section every time before starting a flight by the next track of the accelerator, the electric pulse from this BPM station corresponds to the beginning of the beam movement on this track, and the time interval after this pulse corresponds to the time of beam flight by this track (see Fig. 3). As a result, the signal from the fourth track contains, in addition to information on local beam losses, eight pulses from the BPM station, which correspond to four turns of beam acceleration and four turns of beam deceleration.
- The lengths of all the four optical fibers and the measurement trigger cable are selected so that signals from all the optical fibers arrive at the entry of the digital oscilloscope simultaneously and the moment of starting the digitization process enables observation of these signals from the very beginning.

Due to this synchronization scheme, the digital oscilloscope outputs digitized temporal dependencies of induced radiation background in the accelerator hall, from which one can easily reconstruct the distribution of local electron beam losses throughout the beam way in all the four tracks of the microtron-recuperator.

4. Control application

As mentioned above, digitized signals from the four optical fibers are passed to the control program for their further processing and displaying of the results. The control program performs the following main functions:

- **Control of the power supplies of the photoelectron multipliers.** To obtain the required level of signals from the optical fibers, it is necessary to select a proper voltage of the power supply of photoelectron multiplier (PEM), which in turn specifies the amplification coefficient of this PEM. This operation is executed by the control program. The resulting values are stored and set for the power supplies in the next start of the program.
Displaying of electron beam presence in each of the four tracks of the accelerator. As mentioned above, the signal from the BPM station in the middle of the accelerating section is passed to the output of the optical fiber from the fourth track of the accelerator. Since the electron beam passes this BPM station before each next turn and induces a current pulse on the BPM electrodes, the control program can detect beam existence in any accelerator track from the presence and quantity of electric pulses from a certain station. The program outputs the results of the processing to the main window (see Fig.4).

Processing of resulting waveforms and visualization of local electron beam losses in the scheme of the microtron-recuperator. As every electric pulse from a selected BPM station indicates the beginning of flight in the relevant track, the time range from the pulse in question to the next one corresponds to the time of the beam passage of this track (see Fig.3). The control program uses these pulses to determine the time range corresponding to this accelerator track.

The main window of the control program is shown in Fig. 4. During the processing of the measured digitized waveforms, the program divides each time range corresponding to a certain accelerator turn into 10-ns intervals. Every such interval corresponds to an accelerator line region 3 m long. Then, after calculation of the average signal amplitude in this interval, the program outputs this value in color in a small elliptic icon at a place in the scheme that corresponds to this interval. This value also represents the electron losses in this region of the accelerator track. This value is also output in the form of vertical bar. The sampling of the measured waveforms, processing of the data and output of the results are realized once per second.

5. Conclusion

The above system has been completed and is ready for use. The control program regulates the level of signals from the optical fibers and calculates the levels of local electron beam losses throughout the beam flight. The resulting beam losses values are displayed in the scheme of the microtron-recuperator. The usage of this system may greatly facilitate the tuning of the electron beam recirculation regime in all the four tracks of the accelerator and give information about the regions of occurrence of electron beam losses.

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