THE MEASUREMENT AND MONITORING OF SPECTRUM AND WAVELENGTH OF COHERENT RADIATION AT NOVOSIBIRSK FREE ELECTRON LASER

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Abstract

This paper describes in detail the architecture and capabilities of the system for measurement of the free electron laser (FEL) radiation spectrum. The measurements are performed with a monochromator and a step-motor with a radiation power sensor. The measurements result in the transmission of the curve of the radiation spectrum to the control computer. As this subsystem is fully integrated into the common FEL control system, the results of the measurements – the spectrum graph, average wavelength, and radiation power calculated – can be transmitted to any other computer in the FEL control local area network, as well as to computers of the user stations.

INTRODUCTION

A high-power FEL based on a multiturn energy recovery linac (ERL) [1] is under construction now at Budker Institute of Nuclear Physics. The first and second phases of the project have already been commissioned and are currently in operation.

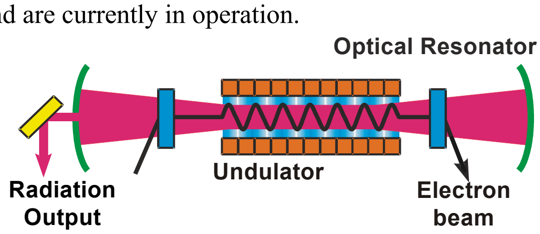

Figure 1: FEL Operation layout.

During its operation, the FEL generates coherent radiation (see Fig.1), which is used for various experiments. The wavelength of this radiation depends on some accelerator parameters and beam energy and is expressed with formula

$$\lambda = \frac{d}{2\gamma^2}\left(1 + \frac{k^2}{2}\right), \quad (1)$$

where λ is the radiation wavelength; d is the undulator period; γ is the relativistic factor of electrons; k is the undulator parameter; $k = k_0 \cdot I$, where I is the current in the coils of the electromagnetic undulator, and k_0 is the constant of proportionality.

As seen from Eq. (1), the radiation wavelength can be tuned via change in the beam energy or adjustment of the undulator current. Besides, the FEL radiation has a rather narrow spectrum, which depends on different FEL parameters. Therefore, the real-time monitoring of the spectrum, power and average wavelength of the FEL radiation is necessary for operators and FEL users throughout FEL operation. For this purpose, we created a separate system with a monochromator.

HARDWARE AND STRUCTURE OF RADIATION MONITORING SYSTEM

The layout of the system is presented in Fig.2. Its main device is the monochromator, which is used for measurement of the FEL radiation spectrum. The FEL radiation enters the entry window of the monochromator, and the radiation with transverse amplitude distribution corresponding to the input radiation spectrum goes out through the exit window. Thus, to obtain the radiation spectrum, one has to read out the intensity distribution at the exit of the monochromator and transmit it to the computer. That is done with the radiation sensor installed on a support, which is moved horizontally by a stepper motor. The stepper motor controller is connected to the IBM-PC via the RS-485 interface.

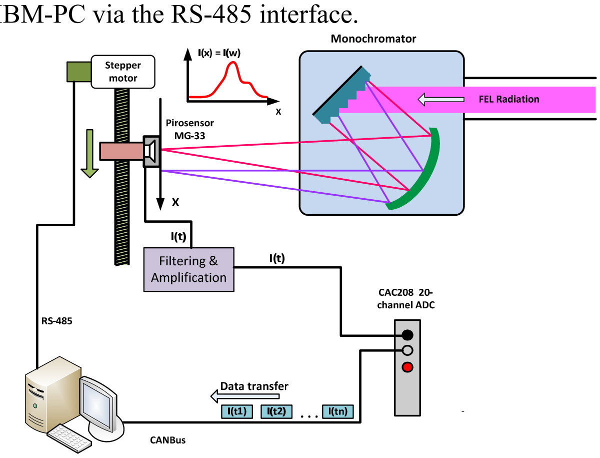

Figure 2: Layout of the system for measurement of the FEL radiation spectrum.

For proper measurement of the radiation power, the flux of measured radiation is modulated with a special rotating shutter. This procedure is necessary because the pyroelectric radiation sensor applied can measure only a variable signal. After some filtering and amplifying, the signal is measured with an ADC. The CAC208 device with CAN interface, developed at BINP [2], is used for

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this purpose. The CAN bus line is connected directly to the IBM-PC.

Having the obtained spectrum curve and using some calibration coefficients, one can calculate the power, maximum and average wavelength of the FEL radiation.

SPECTRUM MEASUREMENT AND PROCESSING OF RESULTS

The control software fully governs the process of spectrum measurement. A user command starts the process, after which the program executes the following steps:

1. The support with the radiation sensor is moved to the extreme left position.
2. The command "MOVE" with a specified constant speed is sent to the stepper motor controller, for the radiation sensor to run the entire horizontal range of output radiation from the monochromator.
3. A command is sent to the ADC to start repetitive single-channel measurements of the channel the signal from the radiation sensor arrives at. The time of one measurement is specified as 40 milliseconds. After this command, the ADC device begins measurements of the current channel and immediately sends the measured data to the central PC.
4. The measurement data are received and added to a dynamic array, until the signal "STOP MOVEMENT" arrives from the stepper motor controller. During this process, the control software plots the waveform of the data (see Fig 3.) received before the actual moment.
5. The signal "STOP MOVEMENT" informs that the radiation sensor has reached the extreme right point of the scanning area, the stepper motor has stopped, and the scanning process has been finished. Upon receiving this signal, the control application stops the current ADC operation and begins the processing of the obtained waveform of the spectrum.

Since the speed of the support movement along horizontal axis can be determined easily, the speed of ADC measurements is specified by the user, and the constant of proportionality between the scale on the horizontal axis of the output radiation and the wavelength of the radiation is also well known, it is easy to apply the obtained waveform to the frequency axis.

After executing this sequence, the application changes to the idle state or, if the repetitive mode was set, the application starts a new scanning cycle, i.e. steps 2-4 are repeated. The only difference is that the direction of the movement of the support with the radiation sensor changes to the opposite one, so the control application has to change the initial point on the frequency axis from which the measurement starts and the order of adding of the incoming data from the ADC. The total time of the movement of the support throughout the range of interest is approximately 50 seconds.

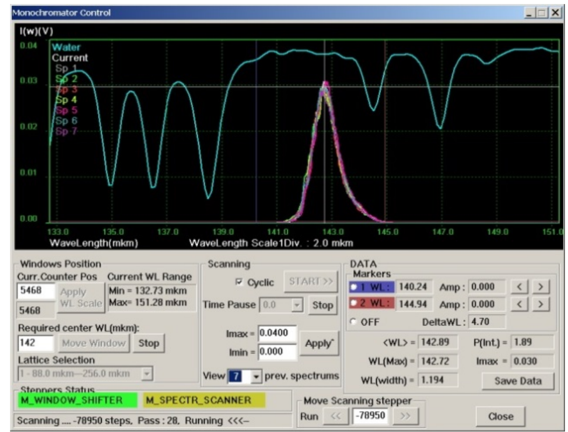

Figure 3: Plot of measured FEL radiation spectrum.

Thus, in the repetitive mode, the control application continuously sends commands for the support to move by turns in opposite directions, receives measurement data from the ADC, and processes and displays these data as the spectrum of the FEL radiation.

In this mode, the application also allows setting the delay time between the completion of the actual support pass (spectrum scan) and beginning of next one. It is possible to set a delay time of up to 120 seconds. This feature allows one to reduce the mechanical wear of support and is used during stable operation of the FEL, when the operator does not modify the radiation wavelength.

After receiving the entire spectrum waveform, the application performs the following processing:

1. Calculation of the total power of the FEL radiation from the spectrum curve with application of calibration coefficients.
2. Calculation of the "average" wavelength of the radiation using the following formula:

$$\langle \lambda \rangle = \frac{\sum_i (A_i - A_{\min}) \times \lambda_i}{\sum_i (A_i - A_{\min})}, \quad (2)$$

where λ_i is the wavelength corresponding to the ith element in the measured waveform; A_i is the value of the ith element in the measured waveform; $A_{\min}$ - minimum value of the radiation intensity in the waveform of the obtained spectrum.

3. Calculation of the width of the spectral line of the radiation using the following formula:

$$\Delta \lambda = \frac{d\lambda \times \sum_i (A_i - A_{\min})}{A_{\max}}, \quad (3)$$

where $d\lambda$ is the step in the wavelength between two measurements with the ADC during the support

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movement; A_{max} - the maximum value of the radiation intensity in the waveform of the obtained spectrum.

Retrieval of the wavelength corresponding to the maximum intensity.

TRANSFER AND DISPLAY OF DATA OBTAINED

Since the default communication protocol in all the applications of the FEL control system is the EPICS Channel Access, it is also used for the transfer of the obtained and calculated spectrum data to other FEL control PCs and user station computers. The spectrum curve itself, total radiation power, average and maximum wavelengths, and spectral line width are represented as process variables both in the FEL control network and user station network (see Fig.4). The computer with the FEL radiation control application is connected to both these networks.

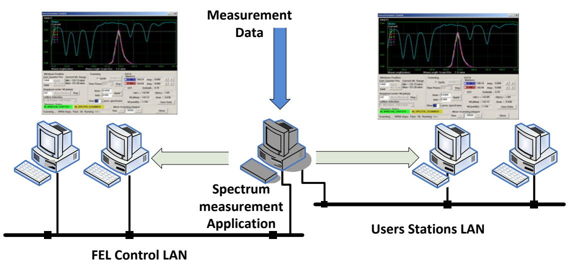

Figure 4: Connection of the control PCs and data transfer layout.

The application that controls the process of spectrum scanning is executed as a module inside the application that controls and monitors all other parameters of the FEL radiation system and described in detail in [3]. This application can run in two modes – client and server ones. The server-mode application runs on the computer connected to all the control and measurement hardware, while the client-mode application runs on other computers in the FEL control or user Local Area Networks. The client-mode application only displays data obtained by the server-mode application and transmitted by means of the Channel Access Server.

In case of the scanning spectrum application, this division into the client and server modes is also used. All operations regarding the scanning process control and interaction with the hardware (CAN ADC and stepper motor controller) are carried out in the server-mode application. After obtaining the new spectrum waveform and its processing, the Channel Access server updates all the corresponding PVs. The client-mode applications are only waiting for new values to appear, whereupon these values are displayed. Applications in both modes have the same user interface, therefore the FEL operators and users work with the same spectrum graph and window and are able to implement the same actions with the spectrum graph, its data and calculated values.

CONCLUSION

The system of real-time measurement of the FEL radiation spectrum has been successfully used for several years, during all time of the FEL operation, demonstrating high stability and reliability. The measurement data allows obtaining not only the radiation spectrum, but also the total power, average wavelength and spectral line width. With the EPICS Channel Access protocol, all the obtained data can be displayed on any computer both in the FEL control and user station local area networks.

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