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THE CONTROL SYSTEM OF NOVOSIBIRSK FREE ELECTRON LASER

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Abstract

Novosibirsk Free electron Laser (FEL) based on multi-turn energy recovery linac is the source of coherent radiation with ability of wavelength tuning. It involves one single-turn and one 4-turn microtron-recuperator, which are have general injection channel and acceleration section. There are three different free electron lasers, mounted on different tracks of these accelerators, and operating on different electron beam energy and have different wavelength range and power of generated radiation.

Whole FEL facility is a complex physics installation, controlled by large amount of equipment of different types. Therefore, for effective control and monitor of FEL operation state and its parameters, the particularized control system was developed. In this paper the architecture, hardware, software compound parts of this control system are considered. In addition, main abilities, characteristics of this system and examples of its usage are presented.

INTRODUCTION

A Novosibirsk Free Electron Laser (FEL), on the base of microtron-recuperator [1] is operating now at Budker Institute of Nuclear Physics. This FEL involves three different configurations (operation modes), which are differ in electron beam energy, which is used for radiation generation and range of wavelengths of this radiation.

Certain number of accelerator turns and separated free electron laser is corresponds to each of these operation modes.

Moreover, the structure of whole facility is such, that some of its parts are used in all three operation modes, whereas other parts are used for operation of only one mode (see Fig.1)

All these three FEL configurations both separately and all together, are represents complex physical facility with large quantity of control and diagnostics parameters. Therefore, for full-functional operation of FEL, the specialized and distributed control system, containing specialized control equipment and corresponding software, was developed.

THE PRINCIPLES OF OPERATION AND FEATURES OF NOVOSIBIRSK FEL

The free electron laser is represents the source of coherent radiation, where the accelerated electron beam, moving through special magnetic structure – undulator, is act as working environment. The undulator is generates magnetic field, which is perpendicular to beam movement, constant in time, and harmonically changing along the beam propagation.

Accumulation and amplification of radiation is take place in optical resonator, which is installed on main axis of beam propagation (see Fig. 2). The wavelength of radiation is expressed by formula(1).

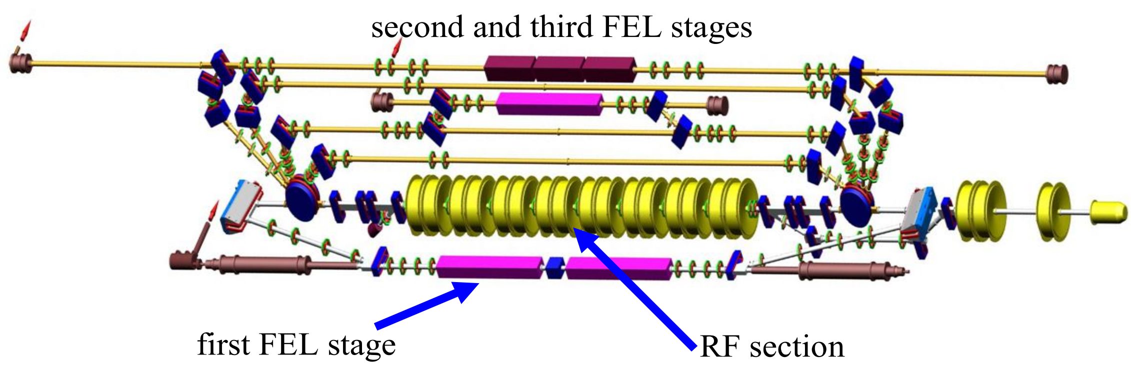

Figure 1: Multi-turn accelerator-recuperator of Novosibirsk FEL scheme.

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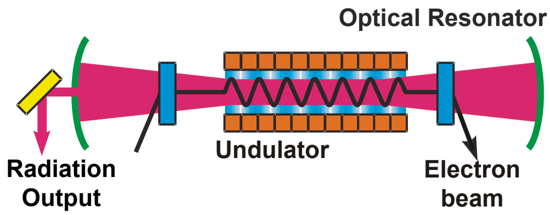

Figure 2: FEL operation principle.

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

where λ – wavelength of radiation, d – undulator period, γ – relativictic factor of electron beam, $K = K_0 I$ – undulator parameter, I – current in undulator coils.

It is shown from this formula, that it is possible to vary the wavelength value in large enough limits by either changing amplitude of magnetic field in undulator, or by changing the energy of electron beam.

As mentioned before, Novosibirsk FEL is based on multi-turn accelerator-recuperator, and able to operate in three different modes. All three modes of operation are vary in number of turns of electron beam in accelerator, and, therefore operate in different beam energy.(see. Fig.1)

Table 1: FEL Operation Modes

FEL operation mode	1	2	3
Turns number	1	2	4
Electron beam energy, MeV	12	20	40
Radiation wavelengths range, mkm	110-240	40-80	5-30

Thus, every FEL operation mode has its wavelength range and average power of radiation. The common table of main parameters of all three operation modes is presented in Table 1.

THE STRUCTURE OF FEL AS CONTROL OBJECT

The Novosibirsk FEL, based on multi-turn accelerator-recuperator is involves the following main susbsystems:

1. Electron gun, producing electron bunches with frequency up to 22.5 MHz and charge in bunch up to 1.4 nano-Coulomb.
2. RF-system, involving 16 acceleration resonators, and 3 resonators in injection channel.
3. Magnetic system. Consists of hundreds of magnetic elements of different types – focusing solenoids, quadrupole lenses, bending magnets, correctors.
4. Beam diagnostic system. Involves beam position monitors, installed on all tracks of accelerator-recuperator.
5. System of monitoring of “Engineering” parameters of FEL. This system controls temperature, vacuum, state of electrical power system and so on.
6. Optical system of FEL. Involving equipment, required for generation, storing and transfer of coherent radiation – optical resonator, radiation output channel, system of deliver of radiation to users station.

Every of these subsystems is require great amount of corresponding electrical equipment. This is power supplies for magnetic elements, RF generators, various signal converters, step motor drivers and so on. For control of this equipment, special control and diagnostics electronics is required. With the help of control software, this electronics is implements control over whole FEL facility.

The structure of all FEL subsystems and their electrical equipment is presented on Table 2.

Table 2: Main FEL Subsystems and Equipment Used

FEL subsystem	Subsystem componentry	Control equipment
Electron Gun	Cathode-mesh unit and high-voltage rectifier	Devices for control of cathode mesh unit and rectifier
RF-system	19 RF resonators	4-cascade RF-generators
Magnetic system	390 magnetic elements	DC power supplies
Beam diagnostic system	70 BPM stations	Signal converters
System of monitoring of “Engineering” parameters	290 temperature sensors, water sensors 20 vacuum pumps	Signal converters from sensors, vacuum pumps power supplies
Optical system	3 optical resonators, channels for output and transportation of radiation	Step motor controllers, ADC for measure of coherent radiation parameters

During FEL operation, some of these subsystems are weakly interact with each other.

Besides, Novosibirsk FEL has a few features, which are distinguish it from other similar facilities:

1. High consumption power (up to 3 MW)
2. High maximum average electron beam current(up to 30 mA)
3. Necessity of operation alternately in three different modes.
4. “Combined” architecture of whole FEL facility – some parts are used in all three operation modes, whereas other parts are used only in one or two modes.

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These and some other factors are influenced on choice of control equipment and final architecture of control system.

HARDWARE OF FEL CONTROL SYSTEM

Step-by-step construction of facility has influenced on control hardware, used in control system. For example, control system of RF-subsystem is based on devices, made in standard CAMAC. Well known disadvantages of CAMAC based systems and great technological progress in electronics development are initiated the search of another approaches to design of control system of FEL facility. As result, in conjunction with using outmoded CAMAC systems, the set of unified controllers with CANbus interface [2] was developed and integrated into different FEL subsystems (control of power supplies, temperature measurement and so on).

The list of controllers, developed specially for FEL control system and used now, is shown on Table 3.

Uniform set of channels, used for control required equipment has provides easy integration of these controllers with different analog devices, while uniform set of commands of these controllers has greatly simplified control software development.

The typical resources, provided by these controllers, are represents precise analog-digital channels with about 20 bit resolution, digital-analog channels of different accuracy and set of digital input/output channels.

Table 3: Controllers with CANbus Interface

Controller	ADC channels	DAC channels	Digital input and output channels
CANADC40	40	-	8+8
CANDAC16	-	16	8+8
CANDAC20	5	1	8+8
CEDAC20	6	1	8+8
CAC208	20	8	8+8
CEAC124	12	4	4+4
CIR8	-	-	16+8
SLIO24	-	-	24+24

This set of devices has allowed to universally automate all FEL subsystem with low communication traffic and eliminate a large amount of connection cables between control devices installed in CAMAC crate and controlled equipment.

Subsystems with high communication traffic, such as beam diagnostic systems, are still controlled by devices, compatible with CAMAC standard.

The total information about quantity of control devices, interface used, and total amount control and diagnostic channels for all FEL subsystems are presented in Table 4.

Table 4: Interfaces Used and Amount of Channels for all FEL Subsystems

Subsystem	Interface	Devices	Control channels	Diagnostics channels
Electron GUN	CAMAC, CANbus	7	10	10
RF-system	CAMAC	28	50	200
Magnetic system	CANbus	61	400	800
Beam diagnostic system	CAMAC	75	0	280
"Technological" parameters control system	CANbus	16	20	330
Optical system	CANbus, RS-485	10	10	20
Total	-	164	490	1640

All control devices are connected to IBM-PC computers using interface devices, which are either IBM-PC extension cards, or external devices, connected to computers through standard buses (USB, Ethernet). Total layout of control system hardware connections with IBM-PC computers is shown on Fig. 3.

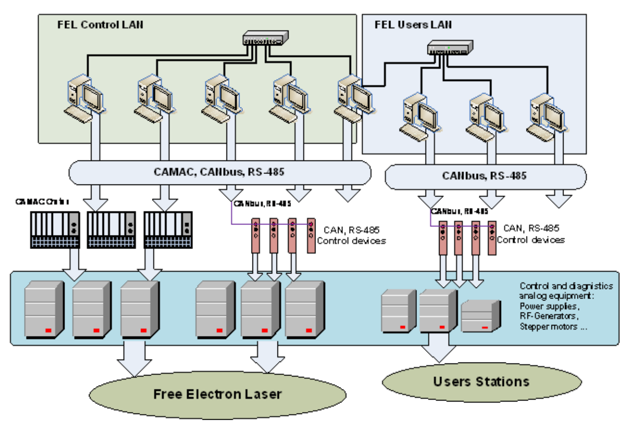

Figure 3: FEL control system hardware.

FEL CONTROL SYSTEM SOFTWARE

Software of FEL control system is organized as a set of separated applications, running on IBM-PC computers. Each application implements the control over one of FEL subsystem. Access to control equipment is executed through interface devices by means of device drivers and high-level libraries. Structural scheme of FEL control software is presented on Fig. 4.

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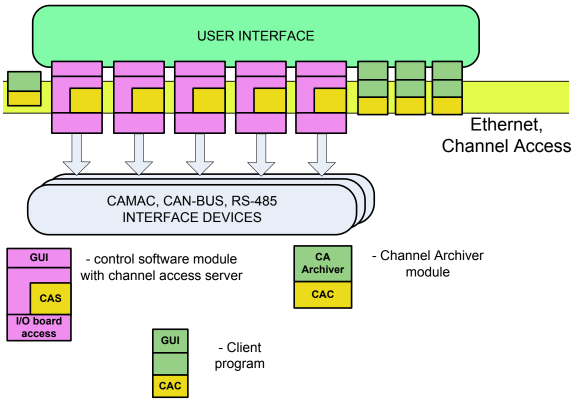

Figure 4: Architecture of FEL control software.

Each control application containing remote control server Channel Access from EPICS framework[3]. Server maintain set of Process Variables (PV), which are bound with corresponding control and measured values of current subsystem, which this application is serve. Thus, with help of this server it is possible to implement control of parameters of subsystem "remotely" that is from any other application on any other computer, connected to FEL control local area network.

Channel Access protocol [3] allows to develop high-level client applications, which may control parameters, situated on different subsystems and controlled by different applications.

On the other hand, each control application containing advanced user interface (GUI), which is allow to control this subsystem from operator console.

Let's enumerate main FEL subsystems and main functions of their control applications:

1. **Magnetic system –** implements the control over magnetic elements power supplies, and monitoring of stability of output current and current ripples detection as well.

2. **Beam position measurement system** – measurement and output of transverse coordinates of electron beam. Study and monitoring of time stability of position and average current electron beam.

3. **System of monitoring of "Engineering" parameters** – readout and output values from temperature sensors and vacuum pumps control devices. In case of temperature value exceeding allowed maximum value, application sends prohibition on electron beam switching on.

4. **RF system** – control over RF-generators, feeding RF-system of FEL, consisting of 19 RF cavities. Control and diagnostics of RF cavities.

5. **Electron gun** - control over cathode-mesh unit – voltage of filament, cathode and acceleration tube. Specifying the frequency of electron bunches. Continuous monitoring of losses of electron beam in accelerator channel.

6. **Optical system** - tuning of positions of mirrors of optical resonator, measuring and output of values of radiation power. Spectrum of radiation measurement with help of monochromator.

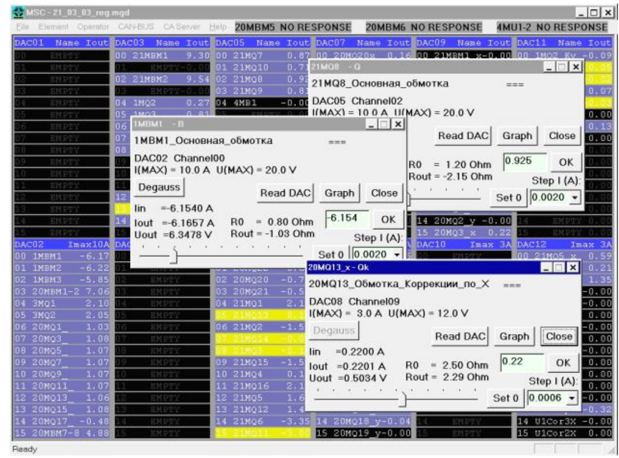

Figure 5: FEL magnetic system control application.

The screenshots of some control applications are presented in Figures 5-6.

Application mentioned above, are used mainly by operators during regular FEL operation.

In addition to these application modules, which are interact with control hardware "directly", the set of high-level client application was developed (see pic. 4). These applications are interact with required parameters with the help of Channel Access protocol through corresponding PVs, located in Channel Access servers embedded into control applications. At that, one client application may work with parameters, belongs to different FEL subsystems, and served by different application.

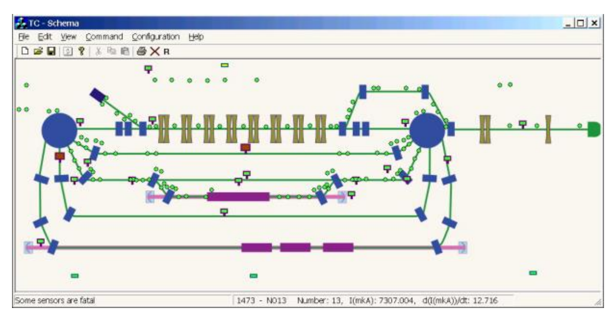

Figure 6: Monitoring of "Engineering" parameters application.

For archiving of all FEL parameters, standard software module Channel Archiver from EPICS Extension set is used. All FEL parameters are storing in common archive during all time of FEL operation. The interval of data archiving is 30 seconds.

In addition to standard variants of using of Channel Access protocol (client-server), several control application are apply its combined structure, that is containing server and client part at the same time. Such approach used, to realize application-to-application connection, then for some control application, it is necessary to obtain parameter from other subsystem. Such method is used most frequently in control application of optical FEL system [4]. To calculate theoretical value of radia-

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tion wavelength, application is "collect" required parameters (RF-system parameters, undulator current and so on), calculate wavelength value and pass it to over computers in FEL control system LAN and to users stations.

CONCLUSION

Developed FEL control system allow to implement full-function control over FEL facility both in tuning mode and in standard operation mode. Uniform interface and control algorithms are realized for all three FEL operation modes. This feature allows to easy switch between operation modes and simplifying work of operators. The experience of FEL operation during all period of it functionality and successful start of third FEL operation mode are confirmed accuracy of approaches, selected at control system design and development.

REFERENCES

[1] N.A. Vinokurov *et al.*, "Novosibirsk Free Electron Laser Facility: Two-orbit ERL Operation with Two FELs", *Proceedings of FEL2009*, Liverpool, UK, Aug. 2009, TUOD01

[2] V.R. Kozak, "Embedded device set for control systems. Implementation and applications", *Proceedings of RuPAC 2006*, Novosibirsk, Russia, Sept. 2006, THDO05

[3] Jeffrey O.Hill, http://www.aps.anl.gov/epics/base/R3-14/12-docs/CAref.html

[4] V.V. Kubarev, E.V. Makashov, K.S. Palagin, S.S. Serednyakov, "Control and Diagnostic System of Novosibirsk FEL Radiation", *Proceedings of FEL2007*, Novosibirsk, Russia, Aug. 2007, MOPPH043