

# TEMPERATURE MEASUREMENT SYSTEM OF NOVOSIBIRSK FREE ELECTRON LASER

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## Abstract

This paper describes the temperature-monitoring system of Novosibirsk FEL. The main task of this system is to prevent the FEL from overheating and its individual components from damage. The system accumulates information from a large number of temperature sensors installed on different parts of the FEL facility, which allows measuring the temperature of the vacuum chamber, cooling water, and windings of the magnetic elements. Since the architecture of this system allows processing information not only from temperature sensors, it is also used to measure, for instance, vacuum parameters and some parameters of the cooling water. The software part of this system is integrated into the FEL control system, so measurements from all sensors are recorded to the database every 30 seconds.

## INTRODUCTION

A high-power free electron laser (FEL), based on the microtron-recuperator[1], is under construction now at Budker Institute of Nuclear Physics. The first and second phases of the project were commissioned recently. The system for monitoring of the temperature of FEL components during its operation takes a very important place among other diagnostic systems of the FEL. The system consists of a large amount of temperature sensors installed on different parts of the FEL facility, including the vacuum chamber of the microtron-recuperator, the windings of the magnetic elements, and the elements of the water cooling system. The sensors are installed mainly at places with a hazard of overheating. They are also installed at places where temperature measured can give some useful information about the FEL operation, e.g. places of possible beam losses.

## MEASUREMENT HARDWARE

The measuring part of this system consists of a few types of sensors (or some measuring devices) installed on different parts of the microtron-recuperator. Let us enumerate all these types and briefly describe the principles of their operation:

1. Temperature sensors. This is a small winding of copper wire enclosed in a metal case and toughly connected to the place the temperature of which is to be measured. The leads of this winding are connected to a special electric circuit. The output voltage of this circuit depends on the resistance of the winding. As the resistance of copper wire depends on its temperature and this temperature is actually equal to the temperature of the

surface this sensor is connected to, the temperature could be calculated from the output voltage value. The calculation formula is as follows:

$$T = A * U + B \quad (1)$$

where  $A$  and  $B$  are constant coefficients and  $U$  is the output voltage.

2. Water sensors. These sensors are very similar to the temperature sensors, two large metal plates with a very small spacing used instead of a copper-wire winding. These sensors are installed on the floor of the accelerator hall. If water gets between these plates, the resistance of this circuit decreases noticeably, and the output voltage of the circuit also changes much. So, if the output voltage exceeds a certain value, one can suppose that there is water on the floor of the accelerator hall.

3. Vacuum "sensors". These sensors are actually control devices for vacuum pumps. These devices measure the current of a vacuum pump; convert it to the output voltage, which could be measured by an ADC. These pumps are installed on different parts of the vacuum chamber of the microtron-recuperator, so collecting values of their currents could give information about the vacuum state of the accelerator chamber. The calculation formula for the pump current is as follows:

$$I = A * e^{B*U+C} \quad (2)$$

where  $A$ ,  $B$  and  $C$  are constant coefficients, and  $U$  is the output voltage.

The output voltages from sensors of all the three types are measured by a few identical multi-channel ADCs connected to one CAN line and working in the same measurement mode. Thus, all the sensors of these three types are united into one subsystem of the common control system. The quantities of sensors for different stages of the FEL are shown in table 1.

Table 1: Quantity of Sensors for the 1st, 2nd and 3rd Stages of the FEL

Sensor type	FEL Stage		
	1st	2nd	3rd
Temperature	98	112	165
Water	3	3	3
Vacuum	14	19	25

The total scheme of this system is presented in Figure 1.

### CONTROL HARDWARE

The choice of measurement devices is influenced by the following factors:

1. The accuracy of value to measure. Temperature sensors impose the highest requirements on the measurement accuracy. The measurement error of these sensors must not exceed 0.3 degree of Celsius. Since the coefficient  $A$  in formula 1 equals 300.0, the output voltage must be measured with an accuracy of 1.0 millivolt. So, the measuring device must have a less resolution.
2. The large quantity of identical sensors with readings to process. This factor makes one use devices with as many

input channels as possible. It is also desirable that the device should support the multi-channel measurement regime. Application of devices with such characteristics would reduce the required number of devices and consequently the cost of the system.

3. The very low frequency of measurement. All above values – temperature, vacuum pump current, water presence – are parameters that change very slowly. For example, temperature changes noticeably only in tens of seconds. Therefore, a period for processing of readings of all sensors of five to ten seconds would be enough.

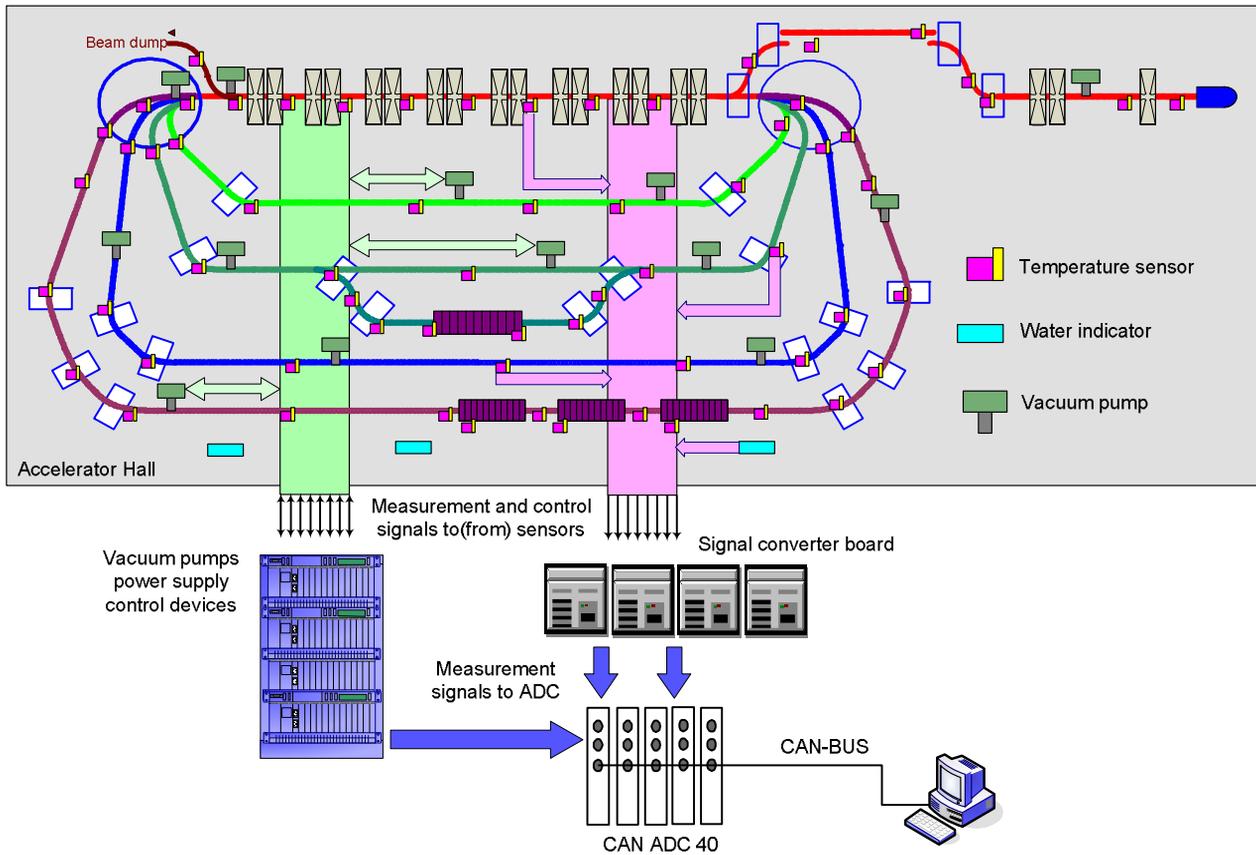


Figure 1: Main scheme of the system.

CANADC40 devices have been chosen for this system. These devices are 40-channel ADCs with the CAN-BUS[2] interface. They were designed and manufactured at BINP [3]. They meet all the above requirements.

Since different quantities of sensors are used for different FEL stages, the number of CANADC40 devices also varies (see Table 2).

Table 2: Quantity of CANADC40s and Channels Used for all FEL Stages

FEL Stage	CANADC40 Qty	Total channels	Used channels
1	4	160	115
2	8	320	144
3	8	320	193

## CONTROL SOFTWARE

The control software for this system is a single application running on the IBM-PC computer. Communication with the CAN-BUS is realized with a CAN-to-Ethernet gateway developed at Budker INP. The main features of this application are as follows:

1. Representation of all sensors on a mnemonic scheme of the microtron-recuperator, which is displayed in the main window of the application. The position of the sensor in the scheme approximately corresponds to its position in the accelerator chamber. Every sensor is a small picture, which varies for different types of sensors. The color of the picture reflects the actual state of a sensor – *Normal*, *Not Connected*, *Warning*, and *Alarm*. The mnemonic scheme with sensors is shown in Figure 2.

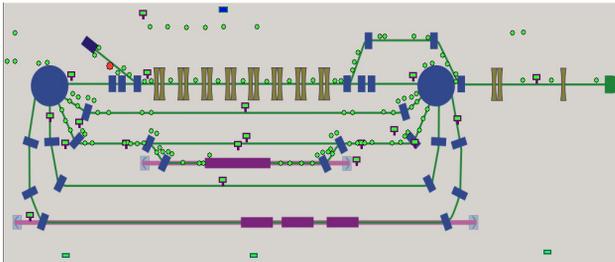


Figure 2: The mnemonic scheme of the microtron-recuperator.

2. Representation of values from all sensors as a row of vertical columns. In addition to the row of values, the second row contains the columns of time derivatives of the values of the sensors. The column height depends on the value of sensor or its derivative, correspondingly. Besides, the color of column reflects the state of sensor, as in the case of the sensor picture in the mnemonic scheme. A fragment of these rows is presented in Figure 3.

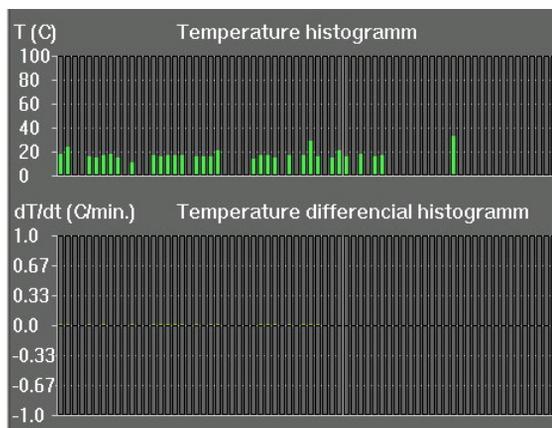


Figure 3: Temperature and derivative columns.

3. Flexible tuning of the configuration of the application. Using external configuration files, the user can specify a few different regimes of operation, which include different sets of sensors, different numbers of CANADC40 devices to be used, different pictures of

mnemonic schemes and so on. This allows using one control application for all three stages of FEL operation. Depending on content of the configuration file and command-line parameter, the application operates in a corresponding FEL stage.

4. The Epics Channel Access Server. The server is built-in inside the application and runs in a separated thread. In the server, the Process Variables (PVs) represent the values and status of all sensors, processed in the actual operation mode. The PV name is connected with the name and type of a sensor in the application. The content of the Process Variables is used in a few high-level client applications. Besides, the Channel Archiver application writes down all values of Process Variables on the hard drive every 30 seconds. The stored history of the values of all sensors can be extracted for further analysis (see Figure 4).

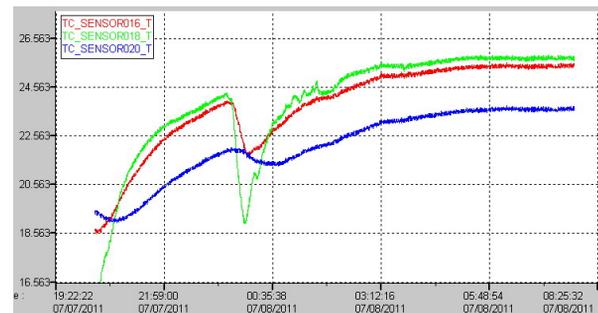


Figure 4: History of the values of a few temperature sensors.

## CONCLUSION

The above-described system has been under operation for the first and second stages of the FEL for about 8 years. During the operation, the temperature measurement system demonstrated high reliability and ease of usage. The large quantity of sensors of different types and intelligent visualization of the collected information – values and their derivatives – give much information on the actual state of the FEL facility. The Epics Channel Access server in the program allows transferring data measured to any client application in the FEL control LAN.

## REFERENCES

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