DEVELOPMENT OF AN AUTOMATED RADIATION CONTROL SYSTEM BASED ON SEMICONDUCTOR IONIZING RADIATION DETECTORS

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An automated radiation monitoring system for experimental setups with electromagnetic retention of plasma is presented. It is based on a real-time X-ray measuring device made from available elements. It includes a high-speed integrated microcontroller. The sensor is a semiconductor detector of ionizing radiation with a unit of thermal stabilization.

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INTRODUCTION

On powerful experimental physical setups, where magnetic plasma retention systems are used, with a sharp decrease in the current in the windings (currents in windings – up to 16 000 A), a sharp uncontrolled surge of electric fields arises that provokes hard X-ray radiation.

This transitional process takes a small time interval of several tens or hundreds of milliseconds. It becomes necessary to measure the dependence of the radiation intensity on the magnitude of the magnetic field, especially during it falls. Since the process of ionizing radiation in pulsed setups with electromagnetic retention of plasma occurs quickly enough, it is necessary to use automated equipment (a system, a special device or a set of devises for radiation monitoring devices) that makes it possible to measure the intensity of ionizing radiation in real time. Due to the lack of such technical means in the arsenal of the Institute of Plasma Physics and the inaccessibility of expensive imported equipment, it was decided to develop independently a corresponding automated system.

The Institute of Plasma Physics of the NSC KIPT carries out a long-term program for scientific research in the field of controlled thermonuclear fusion. Stellarators "Uragan-2M" and "Uragan-3M" serve as an experimental base. Experimental researches are accompanied by the appearance of ionizing radiation in the form of a hard X-ray at each operating pulse of the stellarator. To register the intensity of X-ray radiation, an automated radiation monitoring system was designed and manufactured by the staff of the Institute of Plasma Physics.

MAIN PART

The automated system of radiation monitoring is a distributed hardware-software complex (Fig. 1) of persistent registration of X-ray signals in this zone at each operating impulse of setup. The device uses a volumetric CdZnTe crystal detector with dimensions of 5x5x2 mm. The remote sensor includes an electronic unit that allows receiving weak current pulses from a semiconductor detector with a short edge and an exponential falling, converting them into voltage pulses and pre-amplifying for subsequent processing. In order to improve the signal-to-noise ratio in a wide bandwidth for weak signals from the detector and to increase the measurement accuracy, the remote sensor unit is equipped with a software-controlled device for the thermostabilization mode based on Peltier element.

The signal from the preamplifier is fed to the input of the preprocessing unit (Fig. 2).

The complex includes:
- remote ionization radiation sensor;
- ionization radiation meter – X-Meter;
- interfaces's converter;
- computer data collection(laptop);
- ethernet switch;
- local computer network(segment);
- graphic monitor.

The remote sensor is designed on base of a semiconductor detector and is intended to receive ionizing radiation [1, 2]. Constructively it is a metal cylinder, which is placed directly near the wall of the vacuum chamber of the experimental setup. Sensor is connected with next part of the measuring equipment by a cable. Previous researches have shown the existence

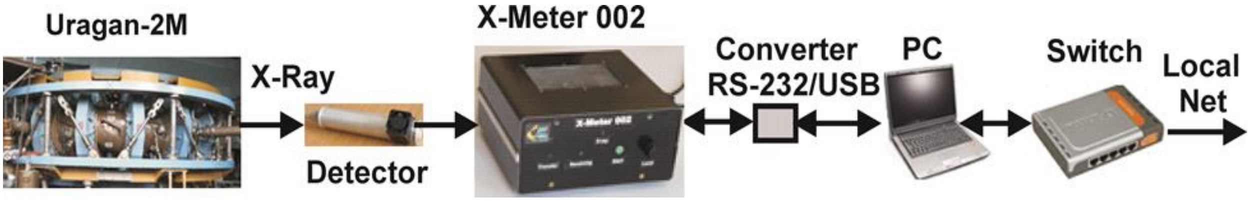

Fig. 1. Hardware-software complex radiation detectors

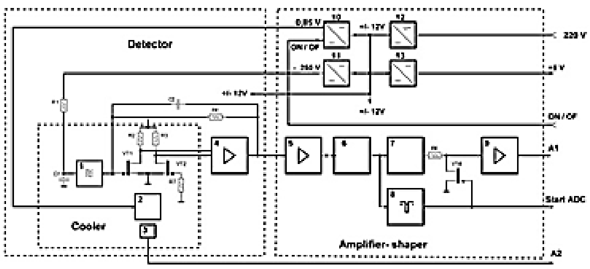

Fig. 2. Signal preprocessing block

1 – X-ray sensor; 2 – Peltier element; 3 – Temperature sensor; 4 – Preamplifier; 5 – Amplifier; 6 – Shaper; 7 – Peak detector;8 – Comparator; 9 – Scale amplifier; 10 – Peltier power source; 11 – Offset source; 12 – Power supply +/- 12 V; 13 – Power supply + 5 V.

To increase the resolving power of the measuring path, each input signal is converted into short pulses. This reduces the error of registration with the possible partial overlap of exponential input signals (Fig. 3).

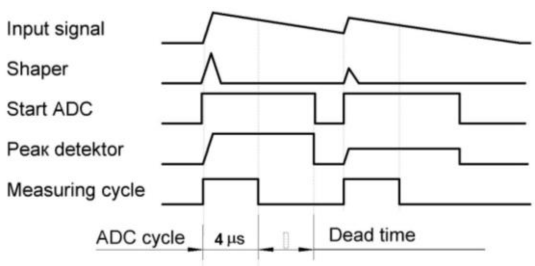

Fig. 3. Formation of the input signal

Constructively, the signal pre-processing unit (SPPU) is located in the meter shell. The developed ionizing radiation meter X-Meter 002 is shown in Fig. 4.

Fig. 4. Appearance of the meter X-Meter

The meter also includes: – microprocessor controller; – the control unit of the thermal stabilization circuit with the power supply device of the Peltier element; – remote sensor power supply unit; – common power supply; – display, control and adjustment panel. On the rear panel of the devise there are ports for connecting a remote sensor, serial interface RS-232, a start synchronization signal for the measuring mode and a power switch trigger.

The following experimental parameters were taken into account during structure developing of the measuring instrument for an automated radiation monitoring system, specifically for the "Uragan-2M" stellarator:

- the lifetime of the electromagnetic field - 4 seconds (of which the field increase is 0.5, the field decay is 0.5 sec);
- duration of the pulses of the equipment for detecting hard ionizing radiation – ≥ 5 μs;
- the expected maximum of hard X-ray radiation in the region of the magnetic field falling (0.5 s).

Also, the developed device should provide a communication channel with the computer for controlling the operating modes and transferring the registered data for the purpose of following processing, archiving and visualization.

The listed requirements in an inexpensive design can be realized by using a powerful integrated single-chip microcontroller as the basis for the developed radiation monitoring device

This includes products of world leaders in the production of integrated microcontrollers under the trademark STM (European Union) and the company's microcircuits Microchip (USA, California).

A criterion of choice for suitable option was:

- advantageous elements in the technical characteristics;
- accumulated experience in the development prototyping and manufacturing of devices based on microcontrollers;
- availability of programming tools and debugging of a certain type of microcontrollers (ICD-3, PicKit-2, PicKit-3, PICDEM-2 +);
- the existence of a significant amount of developments in the field of software.

As a result, preference was given to microchips of Microchip production with an equally high evaluation of STM 32 samples.

With ultra-compact controllers (9x9x1 mm), the manufacturer placed a high-speed, powerful processor with graphics, memory, and a large number of peripheral modules in a single chip (fractions of melimmeter). It is necessary to take into account the possibility of providing the above critical parameters choosing specific controller chip:

- channel speed of the analog-to-digital converter module of the ADC (sampling period) – ≤ 5 μs;
- ADC resolution – at least 10 bits;
- presence of the timer module of the big capacity;
- a sufficiently large capacity of internal data memory > 128 000 bytes.

To implement the necessary functions of the developed device, one of the most modern high-performance 32-bit microcontrollers were chosen - the integrated microcontroller PIC32MX795F512H. At a clock frequency of 80 MHz, each 10-bit ADC conversion is performed at a frequency of 1 MHz, the program memory is 1 Mb, the data RAM is 128 Kb. Microprocessor controller provides conversion of analog signals into digital codes, synchronization and operation control of the whole device, exchange of registered data with computers of the local network. The structural scheme of the controller is given in Fig. 5.

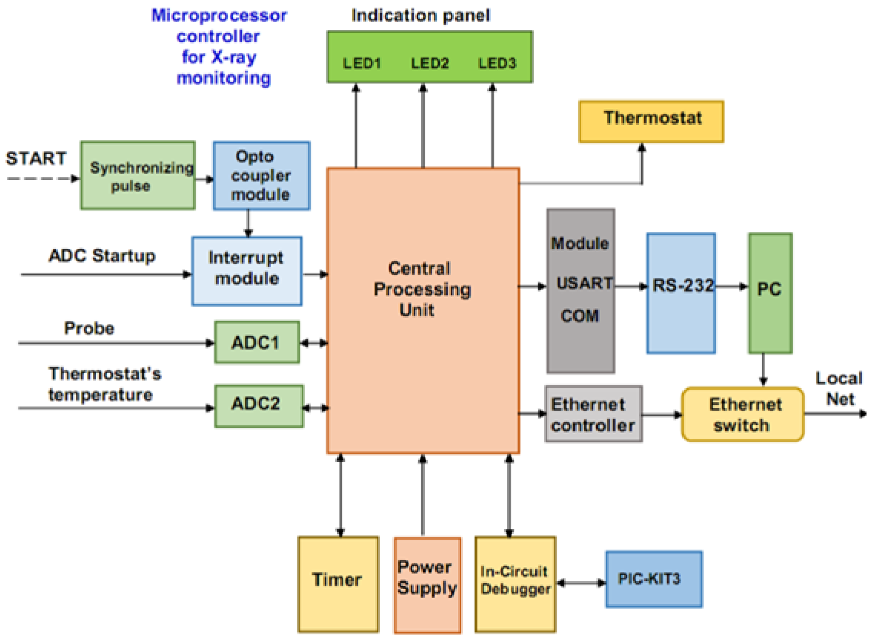

Fig. 5. Structural scheme of the controller

The power of the measuring device is carried out from a network of an alternating current with a voltage of 220 V, 50 Hz. Power consumption is 10 W. The overall dimensions of the device are 200x100x187 mm. The weight of the device is 1.9 kg. To ensure the functioning of the hardware and software complex, a package of original programs was developed. Each of the programs of the package performs the mode tuning and controls the operation of specific units and peripheral modules presented in the structural scheme.

The subroutine for controlling the ADC module operates in 2-channel mode. The first ADC channel receives data equivalent to ionizing radiation. The second ADC channel measures the temperature of the thermostat. The subroutine compares the measured temperature value with the programmed set point and ensures the stabilization of the thermostatting mode by controlling the operation of the Peltier module. Sampling and conversion of the analog signal for each channel is triggered individually. Sampling is started programmatically, the conversion is automatic. The timer records the start time of the analog signal conversion. Each conversion result and the start time of the ADC are stored in the microcontroller data memory.

The program provides data exchange with an external computer via the local network. With the EUSART microcontroller unit and the MAX232 serial integrated driver, a COM port supporting the communication protocol and RS-232 interface is implemented.

The software package is written in C32 [3] to work in the MPLAB X environment running the Windows operating system.

The registered experimental data via a serial interface RS-232 (COM-port) is transferred to the computer of the local network for further processing. Visualization of the obtained results is carried out with the help of packages Spectrum, Origin 9, which allow you to plot the graphics immediately after processing the experimental data.

When a START signal is received from the experimental setup synchronizing unit via the developed optical galvanic isolation unit to the external controller interrupt module, the normalized analog signals from the BPSS module are cyclically converted into digital codes using an analog-to-digital converter (ADC). The ADC conversion starts at an arbitrary time point corresponding to the occurrence of each single signal from the X-ray detector. Each conversion result and its acquisition time are fixed and stored in the controller memory, forming a corresponding array of data registered in real time.

The operation of the ADC is synchronized by the program-configurable timer module. With the maximum speed of operation of the signal pre-processing unit and the corresponding performance of the PIC32MX795F512H microcontroller, it is possible to register the ionizing radiation in detail for a period of time not less than 200 μs. In this case, 20.000 intensity measurement results and 20.000 time values are recorded in the controller memory.

To ensure high accuracy of fixing the time of measurement of each signal from the detector, a 32-bit timer module with a clock frequency of 80 MHz was used. The timer starts with the START signal and ends with its overflow (at high X-ray intensity for a sufficiently long time) or with the removal of the stellarator pulse magnetic field. Reading of each current fixed time value is carried out without stopping the timer.

At the end of the measurement process, the data array of intensity distribution of hard x-ray radiation during the operating pulse of the "Uragan-2M" stellarator through the serial RS-232 channel through the interface converter is transferred to the computer of the local computer network.

The registered array is displayed on the network graphic monitors in the form of a histogram tied to the real-time registration axis (Fig. 6).

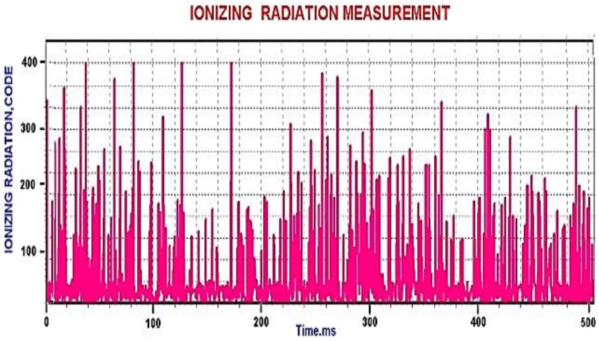

Fig. 6. Distribution of radiation intensity

Plans for the further development of work on radiation monitoring provide for the calibration of measurements using standard sources of ionizing radiation. The calibration results will be entered in the radiation intensity calculation program and in the graphical display program of the recorded data.

CONCLUSIONS

The Institute of Plasma Physics of the NSC KIPT developed an inexpensive automated radiation monitoring system. It is based on a real-time X-ray measuring device made from available elements. It includes a high-speed integrated microcontroller. Designed system makes it possible to monitor the intensity of electromagnetic radiation during applied research on promising areas of controlled thermonuclear fusion. Thus, the application of this system is a significant measure / contribution to improve the safety of the personnel in the experimental zone.

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РАЗРАБОТКА АВТОМАТИЗИРОВАННОЙ СИСТЕМЫ РАДИАЦИОННОГО КОНТРОЛЯ НА ОСНОВЕ ПОЛУПРОВОДНИКОВЫХ ДЕТЕКТОРОВ ИОНИЗИРУЮЩЕГО ИЗЛУЧЕНИЯ

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Представлена автоматизированная система радиационного контроля для экспериментальных установок с электромагнитным удержанием плазмы. Основой её является прибор для измерения рентгеновского излучения в реальном масштабе времени, изготовленный из доступных элементов. Он включает в себя быстродействующий интегральный микроконтроллер. Датчиком является полупроводниковый детектор ионизирующего излучения с узлом термостабилизации.

РОЗРОБКА АВТОМАТИЗОВАНОЇ СИСТЕМИ РАДІАЦІЙНОГО КОНТРОЛЮ НА ОСНОВІ НАПІВПРОВІДНИКОВИХ ДЕТЕКТОРІВ ІОНІЗУЮЧОГО ВИПРОМІНЮВАННЯ

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Представлена автоматизована система радіаційного контролю для експериментальних установок з електромагнітним утриманням плазми. Основою її є прилад для вимірювання рентгенівського випромінювання в реальному масштабі часу, виготовлений з доступних елементів. Він включає в себе швидкодіючий інтегральний мікроконтролер. Датчиком є напівпровідниковий детектор іонізуючого випромінювання з вузлом термостабілізації.