ISSN 1547-4771, Physics of Particles and Nuclei Letters, 2023, Vol. 20, No. 4, pp. 809–813. © Pleiades Publishing, Ltd., 2023.
Russian Text © The Author(s), 2023, published in Pis'ma v Zhurnal Fizika Elementarnykh Chastits i Atomnogo Yadra, 2023.

PHYSICS AND TECHNIQUE OF ACCELERATORS

Development and Implementation of an Automation System for an Accelerator-Based Neutron Source for Neutron Capture Therapy

A. M. Koshkarev[a, b, *] and S. Yu. Taskaev[a, b]

[a] *Novosibirsk State University, Novosibirsk, Russia*
[b] *Budker Institute of Nuclear Physics, Siberian Branch, Russian Academy of Scences, Novosibirsk, Russia*
**e-mail: koshi8bit@mail.ru*

Received November 18, 2022; revised December 16, 2022; accepted January 23, 2023

Abstract—This paper describes a method for automating the facility and a method for online data processing that allows an operator and analytical physicists to quickly process information during an experiment without the need for the manual postprocessing of data. The architecture of the automation system was proposed and software was developed for (1) an analysis of signals at the installation with the ability to filter according to user-defined conditions and the ability to display on real-time graphs and (2) displaying the values of various diagnostics with general real-time availability.

DOI: 10.1134/S1547477123040404

INTRODUCTION

An accelerator source of neutrons, including an electrostatic tandem accelerator of an original design (a vacuum-insulated tandem accelerator), a lithium target, and a system for forming a neutron beam, were proposed and developed at the Budker Institute of Nuclear Physics, Siberian Branch, Russian Academy of Sciences [1], for the development of boron neutron capture therapy [2] (a promising method for treating tumors) and other applications.

To carry out a number of experiments using the accelerator, it was necessary to create an automation system. The specificity of the experimental accelerator being developed is its constant modernization and the introduction of new diagnostics, which must be promptly integrated into the automation system. The absence of single scalable automation systems make it difficult to analyze the experimental data in real time. The solution to this problem is described in this paper.

One of the most important and time-consuming parts of a researcher's life is the processing of experimental data. Sometimes it takes more than three hours, but some experiments require the real-time processing of results, for example, the visualization of the beam position by thermocouples or the calculation of average beam currents only at those moments when energy is within the specified range.

SUGGESTED CONFIGURATION

The architecture of the developed complex is shown in the Fig. 1. The level of controllers is shown on the left: these can be either I/O devices without internal logic or controllers with programmed algorithms. In the middle is a server with a database and a printer for printing a log at the end of the experiment. On the right are all programs that can use the server API to display data or set values on controllers through the server.

To simplify the structure of the server program, a three-level architecture has been developed consisting of the following levels: device, channels, and modules. Each level implements its own abstraction layer. Consider the proposed system using the example of a power meter. Its scheme is shown in Fig. 2.

In this example, a device is a set of channels combined into one logical group to calculate the power taken from the cooled device. The power calculation algorithm is configured at the power channel level, which is calculated based on temperatures and flow according to a given formula.

The channel level is needed to convert from the "raw" value of the ADC to a physical value. At this level, the name and physical value are configured for display and storage in the database. The channel also serves as an interface for interaction between the developed utilities.

The module layer serves to abstract the process of collecting data from I/O devices. In some cases, in order to get a particular value from the periphery, you

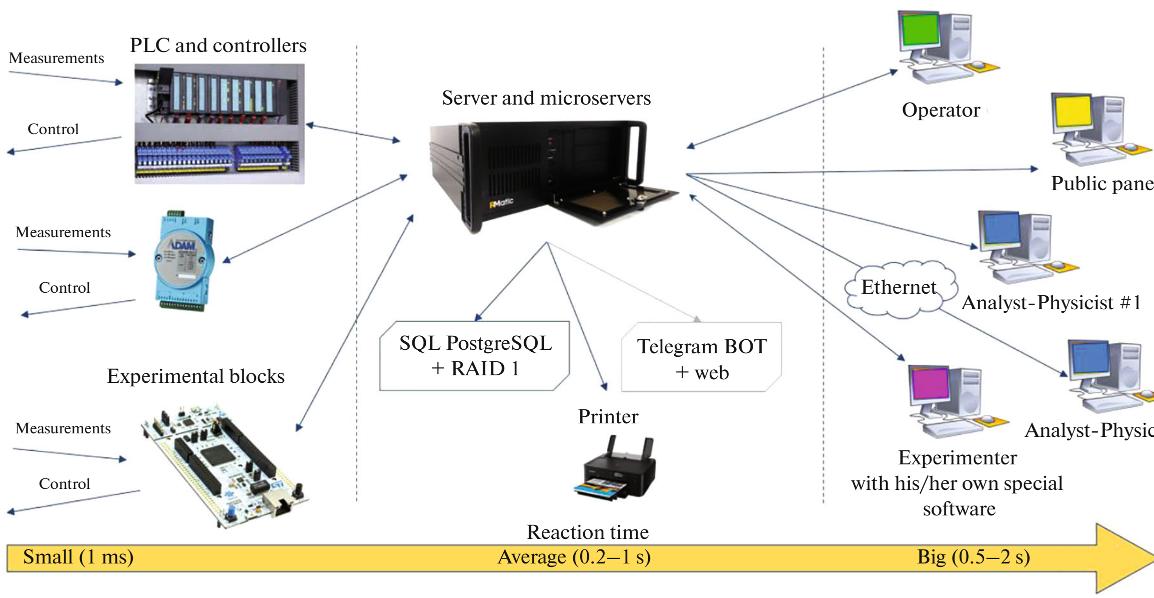

Fig. 1. Architecture of the developed automation system.

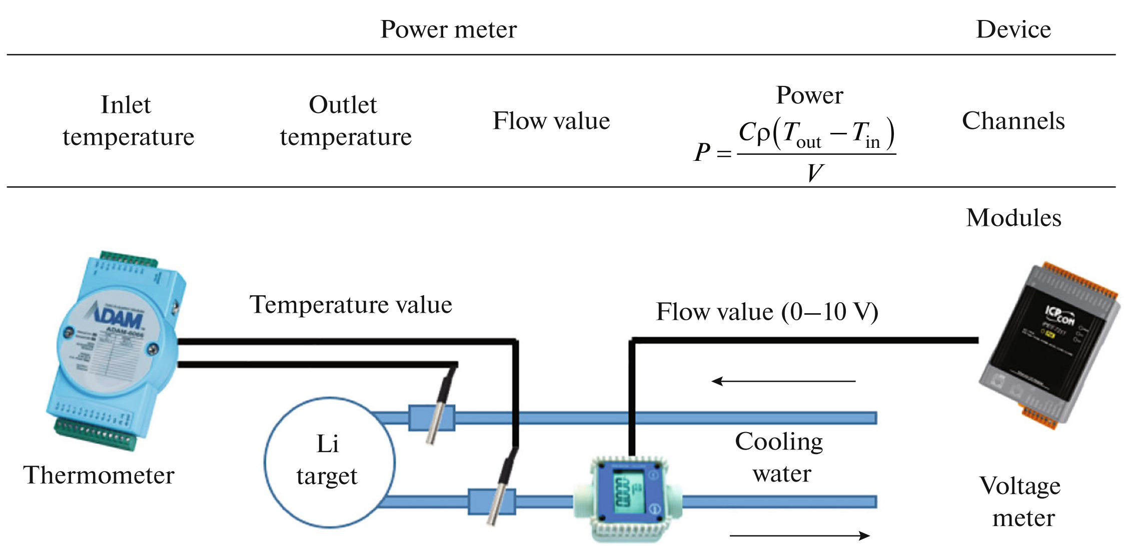

Fig. 2. Server architecture using the example of a power meter.

need to connect to the device, read data from the desired register, and process it; only then the voltage value will be available (in the case of an ADC). It is also necessary to monitor the lack of connection and automatically restore communication in the case of loss of communication. All used modules are implemented as classes for code reuse. When signaling the readiness of the collected data from the device, a "raw" value from the ADC can be written to the channel, which is converted into a physical value at the channel level.

To transfer information between the server and clients, it was necessary to develop a mechanism that involves a minimum set of actions for synchronizing values. Therefore, a network variable mechanism is implemented at the channel level, which allows one to synchronize values in different programs.

PHYSICS–ANALYTICS SOFTWARE

To analyze the results of an experiment, physicists have to process significant amounts of data. To ana-

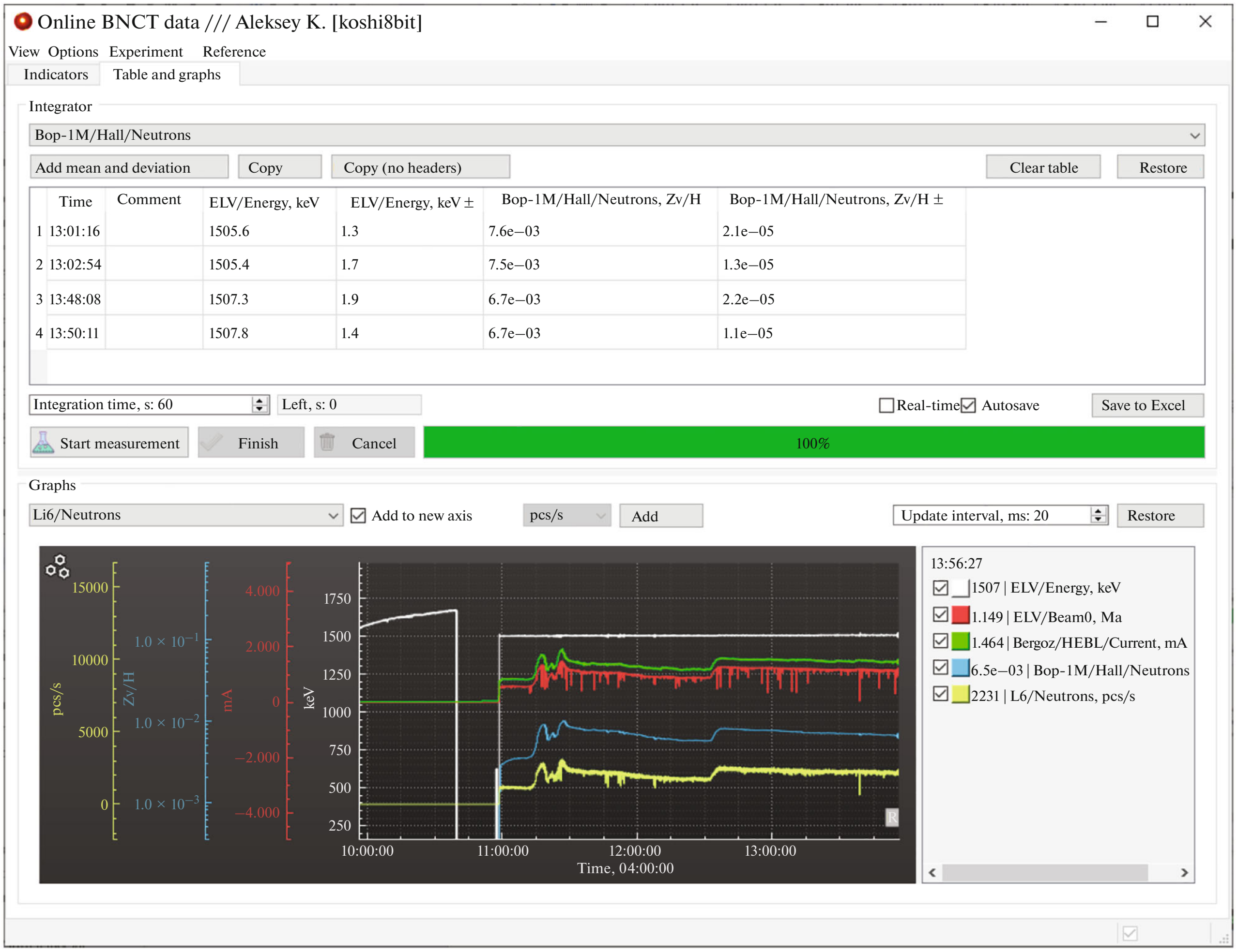

Fig. 3. Physics–analytics software. The averaging area and the real-time data display area are shown.

lyze all the data, before the implementation of the developed system, the analyst had to do the following:

(i) collect files with data from various diagnostic software;

(ii) combine all collected data in one Excel spreadsheet;

(iii) synchronize different diagnostics in time;

(iv) reconstruct the sequence of events during the experiment.

Usually, the analysis is reduced to the same type of actions: a calculation of the average value with the display of the average deviation, filtering data according to certain conditions, and displaying data on a graph. Usually, such routine work took a physicist–analyst from two to four hours, and the data on the experiment could be obtained only the next day after the end of the experiment in the evening and processing of the files.

A manual compilation of a large amount of experimental data from different programs is fraught with errors during processing. To automate this procedure, all diagnostics requiring data processing were introduced into the server software and special software was developed and implemented, as is shown in Fig. 3.

The program makes it possible to do the following:

(i) display real-time values with the ability to add any number of graphs and link to different axes;

(ii) build the dependence of one measurement channel on another and display the error in the form of a “whisker” (Fig. 4);

(iii) average the channel values over time according to the specified conditions, followed by a graphical representation that takes into account the error of the change;

(iv) perform distributed logging with automatic printing of the log at the end of the experiment.

(a)

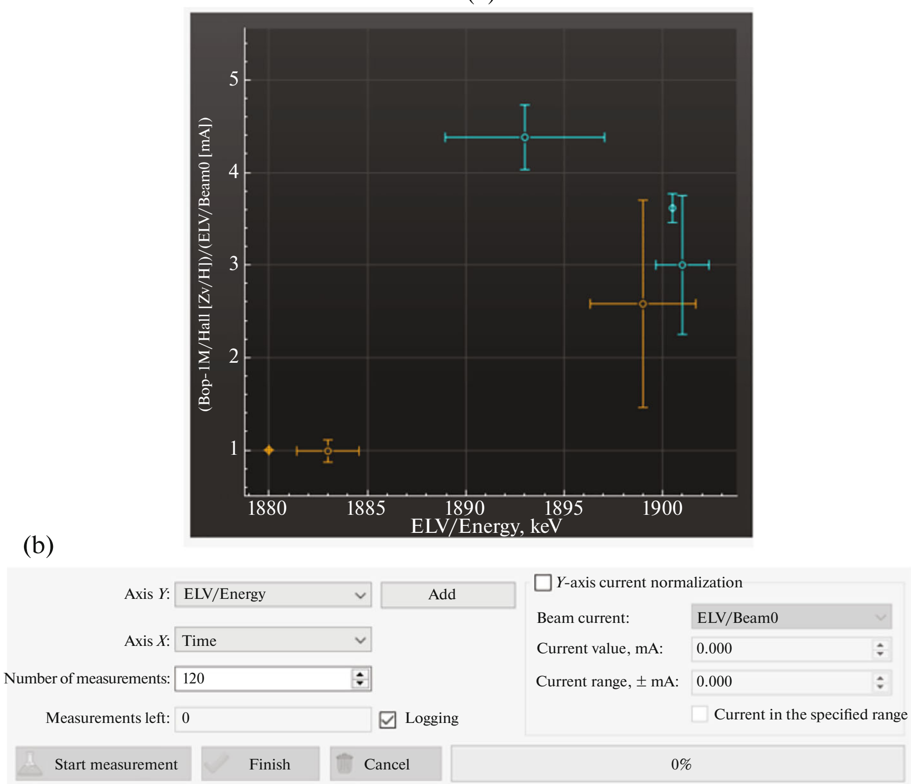

Fig. 4. Dependency building panel: (a) dependence of the readings of the gamma detector (divided by the beam current) on the beam energy; (b) settings panel.

In some experiments [3–7], it was required to analyze the data only according to a certain condition. For example, to read the average value of gamma radiation, if the energy is in acceptable ranges. It is regularly required to normalize the reading of the device to the beam current and only then display it on the graph. For this, an appropriate mechanism has been implemented, the chart and settings panel of which is shown in Fig. 4.

PUBLIC PANEL

The facility is used to conduct international experiments in which colleagues from different countries participate. Most often, guests are interested in knowing the current parameters of the accelerator.

To inform all participants in the experiment, a program has been developed that consists of three windows and displays all the basic information about the experiment on three LCD monitors with a diagonal of 50 in. The panel of common use and the view of the panel in the control room are presented in Fig. 5.

The panel is divided into three areas, which display information in different formats. The upper left monitor displays two of the most important parameters of the setup, energy, and beam current. Graphs that show changes in values over time and several diagnostics are on the lower monitor. The real-time graph component was developed by the author.

The right monitor displays many standby values that are most often of interest in a number of different experiments, such as

(i) beam currents in different places;

(ii) accumulated integrals of values for currents and radiation;

(iii) stripping efficiency;

(iv) server date and time that are used throughout the complex;

(v) recent entries in the experiment log;

(vi) levels of gamma and neutron radiation at different installation locations.

The public-use program is already being used in international experiments; with its help, guests understand the current status of the experiment. The last guests were teams from CERN and ITER.

CONCLUSIONS

The real-time data processing system has shown its effectiveness and has become an integral part of the system for controlling, collecting, and storing data of

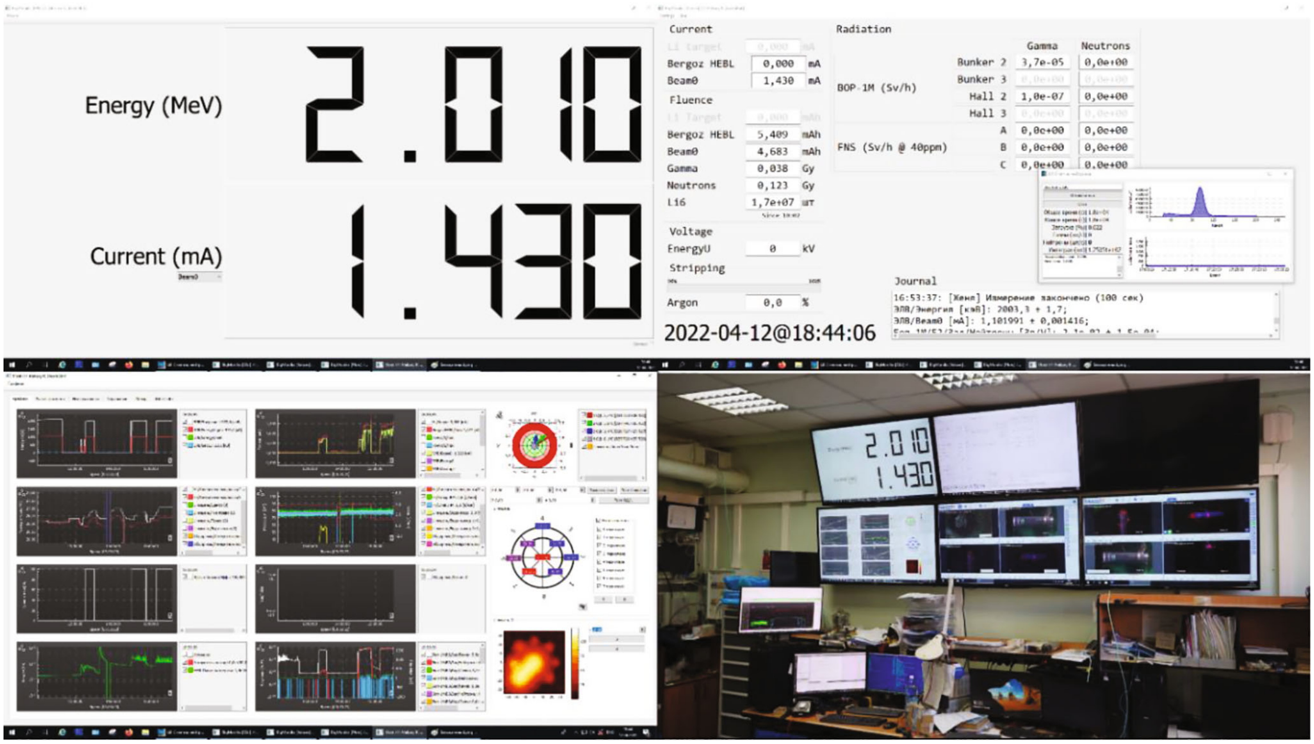

Fig. 5. Public panel with a general view of the control room.

the accelerator neutron source. As a result of the introduction of these tools, the performance of the analysis of experimental data and the refinement of the experimental log increased.

FUNDING

This study was supported by the Russian Science Foundation, project no 19-72-30005.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

1. *Neutron Capture Therapy: Principles and Applications*, Ed. by W. Sauerwein, A. Wittig, R. Moss, and Y. Nakagawa (Springer, 2012). https://doi.org/10.1007/978-3-642-31334-9
2. S. Taskaev et al., "Neutron source based on vacuum insulated tandem accelerator and lithium target," Biology **10**, 350 (2021). https://doi.org/10.3390/biology10050350
3. T. A. Bykov et al., "High flux accelerator-based neutron source," Vopr. At. Nauki Tekh., Ser.: Termoyad. Sint. **44**, 145–147 (2021).
4. T. Bykov et al., "In situ study of the blistering effect of copper with a thin lithium layer on the neutron yield in the ^{7}Li $(p, n)^{7}$Be reaction," Nucl. Instrum. Methods Phys. Res., Sect. B **481**, 62–81 (2020).
5. T. Bykov et al., "Measurement of the space charge effect of a negative hydrogen ion beam," AIP Conf. Proc. **2052**, 070004 (2018).
6. D. Kasatov et al., "New feedthrough insulator of the compact tandem-accelerator with vacuum insulation," in *Proceedings of 28th International Symposium on Discharges and Electrical Insulation in Vacuum (ISDEIV), 2018* (IEEE, 2018), Vol. 2, pp. 761–764.
7. T. A. Bykov et al., "Use of a wire scanner for measuring a negative hydrogen ion beam injected in a tandem accelerator with vacuum insulation," Instrum. Exp. Tech. **61**, 713–718 (2018).