MEASUREMENT AND CONTROL SYSTEMS OF TRITIUM FACILITIES FOR SCIENTIFIC RESEACH

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ABSTRACT

The technical approach, equipment and software developed during the creation of measurement and control systems for two complexes are described. The first one is a complex that prepares the gas mixture and targets of the "TRITON" facility. The "TRITON" facility is designed for studying muon catalyzed fusion reactions in triple mixtures of H/D/T hydrogen isotopes over wide ranges of temperature and pressure. The second one is "ACCULINNA" - the liquid tritium target designed to investigate the neutron overloaded hydrogen and helium nuclei. These neutron-overloaded nuclei are produced in reactions of tritium beams on a heavy hydrogen and tritium target.

I. INTRODUCTION

Within the framework of collaboration with the Joint Institute for Nuclear Research in the RFNC-VNIIEF there were developed tritium complexes and targets for muon catalyzed fusion experiments. The experiments are also conducted to study into exotic neutron-overloaded hydrogen and helium nuclei.

For studying the dependence of muon catalyzed fusion parameters in a H/D/T mixture on temperature, mixture density, and isotope concentrations the complex for gas mixture preparation (CGMP) [1] was created. Also the replaceable targets of several types were created: the liquid tritium target [2], high-pressure tritium target [3], high-pressure deuterium target [4]. CGMP and targets allow in conditions of unspecialized laboratory the work to be conducted with tritium of activity up to 10 kKi, which is in free state under the pressure of up to 160 MPa and within the temperature range of 20÷800 K and with activity in the bound state of up to 100 kKi. The complex allows the mixture of hydrogen isotopes with a required concentration to be prepared. It also purifies the mixture up to the level of 10^{-7} of admixture volume content, carries out radio chromatographic analysis of molecular and isotope composition of the mixture. The equipment developed has been used since 1997 in experiments on muon catalyzed fusion studies, and ensures the radiation safety of this work.

For investigation of light nuclei and nuclear systems on the boundary of neutron stability the reactions of radioactive beams are very promising. For such kind of experiments a unique tritium target was created that included a complex of equipment designed for tritium safe storage, infilling the target with liquid or gaseous tritium, the target temperature stabilization during the experiment and tritium utilization [5].

From the point of view of complicated experiments organization in the hydrogen and tritium technology area the described complexes are ordinary. In the experiments of such kind a wide spectrum of measurement and control techniques is used, and various devices, as well. The equipment includes both the production run equipment and the unique devices created at VNIIEF. Essential parts of those complicated complexes are the control and measurement systems and the systems of radioactive safety.

II. MEASUREMENT AND CONTROL SYSTEMS OF THE TRITON FACILITY AND THE LIQUID TRITIUM TARGET

The complex facilities described above require a large number of physical and technological parameters to be measured and must be controlled during the experiment preparation, throughout the experiment and within some time after the experiment completion. In line with the technical requirements, the measurement and control processes must be continuous during the whole operation period (up to several months). The parameters of these facilities to be monitored and controlled, measurement techniques, sensors and instrumentation applied are multiple and heterogeneous. For providing radiation safety of the performed work the radiometric monitoring of tritium volumetric activity in the atmosphere of the working zone and gas lines of the facility is of particular importance. Also a blocking system is needed to avoid dangerous situations.

The measurement and control system of TRITON includes over 40 analog and 100 digital monitor and control channels. Among them there are temperature sensors (thermocouples, thermoresistors and cryogenic thermodiodes), high pressure (strain-gauge) sensors, vacuum sensors, heater control, power relay control, electromagnetic valves status monitoring and control, mass spectrometers, monitoring of tritium volumetric activity in air, etc. The configuration of ACCULINA measurement and control system is similar.

Despite the different destination of these facilities, their measurement and control systems have much in common in their structure, executed operations, hardware, and software.

The systems for control and operational parameters maintenance of the complexes and targets [5,6] constitute a distributed network based on the main computer and on a set of autonomous modules of analog and digital input/output. Those modules communicate with host computer through RS-485, RS-232 serial interfaces.

The systems have been developed on the basis of personal computers connected to a distributed local RS-485 network of I-7000 series (ICP DAS) intelligent modules of analog and digital input/output. I-7000 modules are certified in Russian Federation for industrial measurement and control systems. These modules help to measure analog and digital electric signals and to generate analog and digital control signals. Some special equipment (for example Balzers vacuum sensors) is connected via RS-232 interface. The distributed control and data acquisition systems have the following advantages:

- Distribution of the computational capacities improves the operational stability of the entire system, making it possible to temporarily exclude failed elements from the network and easily double the most important units.
- Blocking systems based on autonomous modules guarantee safe operation even if the host computer is hanging or network connection is lost.
- It becomes less expensive to update the system, its capabilities rapidly expand and grow, and newly developed subsystems are easily incorporated into the general measurement and control system.
- The computing units are closer to the sensors and control devices, what appreciably reduces the costs for cable communications. And short signal cables allow also the noise to be reduced.

While selecting the modular equipment the requirements were naturally taken into account to the analog-signal measurement accuracy and sensor sampling rate, the conditions under which measurements were performed, sources of industrial noises, etc. As a result the modules of I-7000 (ICP DAS firm) series were chosen. Those modules are combined in an asynchronous half-duplex RS-485-standard two-wire network which data-transfer is 115200 Baud. I-7000 modules offer an inexpensive, flexible, and efficient solution to a wide range of problems in measurement and control automation. Processor modules (controllers), communication modules, analog and digital input/output modules, and timer–counters are among the devices produced. The insulation voltage of the module input and output circuits is >3000 V, and there is a built-in noise filter. A no stabilized dc voltage of +10 to +30 V powers the modules. There serviceability is ensured over a temperature range of –20 to +75°C.

Significant advantages of the modules of I-7000 series are the possibility of replacing any module without turning off the system's power supply and the presence of a double (hardware and software) watchdog timer in each module. The first watchdog timer is a device that restarts the module in the event of its hang-up and does not allow the control over the system to be lost. The second watchdog timer is of a software nature and continuously monitors the presence of a data transfer in the RS-485 network. If no data transfer occurs during a given time interval, a conclusion is made about the failure of the control computer or a disconnection in the communication lines. In this case, all the module's outputs are switched to special predefined states provided beforehand for this occasion. As a result, in the event of an emergency situation, it becomes possible to maintain the parameters of the facility within acceptable limits until the failure is eliminated.

The automatic systems of the facilities work under control of computer's programs. The stability, robustness and predictability of data acquisition and control software have the vital importance for potentially dangerous facilities. In order to have predictable programs, open program code is very advisable. Open code is of particular importance for development of real-time systems, because a lot of code details, like unexpected delays or resource locking, may cause problems with timing. Open code is also the best way to understand how the program works. Moreover, open code gives full control over the data acquisition system.

Program code is not usually available for commercial software. In order to have full control over the data acquisition system and to have open program code available, the own special software package CRW-DAQ [7] for the automation of research physical facilities was developed since 1997 for Windows-95/98/NT/2K/XP platform. The package development was based on the following principles.

The basic software (CRW-DAQ package itself) that is a common core for all facilities provides a graphic interface, programming languages, mathematic utilities and other tools for application software development and other common services. The application software of specific facilities that includes configuration files and application programs developed in built-in languages uses the tools that CRW-DAQ package provides for solving the specific problem.

CRW-DAQ package uses a single-process, multi-thread model. This choice was done because inter-thread communications are much faster and easier as compared to inter-process communications. All threads have full access to the real-time database (see below). Multi-process model is also partly supported. In multi-process configuration CRW-DAQ process works as a parent supervisory process which may start, terminate and control child processes. But child processes have no direct access to real-time database. Low-level inter-process communications, like pipes or shared memory, is the only way to communicate with child processes. Usually anonymous pipes are used.

CRW-DAQ data acquisition runtime engine have three general components: real-time database, window manager and device manager. The real-time database includes a set of named variables, which is available to the window manager and to device manager. Window manager includes a set of user-defined windows to organize user input, to indicate actual real-time database content, etc. The device manager includes a set of devices, connected to real-time database to produce or process data. The window manager and the device manager are both connected to the real-time database, but have no direct access to each other. They can only modify the database content or send asynchronous messages through the real-time database.

The real-time database may have two kinds of data elements: scalar variables (named tags) and dynamic arrays for historical data (named curves). Database engine guarantees data integrity in multithread environment and is optimized to have minimal data access time. Each element of the database has a unique name and integer reference for fast access. Element name is a permanent attribute, while integer reference may vary from one session to another. When window manager or device connects to the database, first operation is to get data element reference by given element name, because all data access functions use data element reference to make the access faster.

Within CRW-DAQ package, device is any user-defined program, connected to real-time database to produce or process data. In particular case the device may readout data from real physical device (that is why it named device). For example, one device may readout thermocouple voltage from ADC to write value into the real-time database, while another device may read thermocouple voltage from the database, convert to degrees and write degrees into the database. Device program code is usually designed using integrated programming language and executed in a separate thread. Devices are executed concurrently and may have different priorities. Being used correctly the priority system can guarantee the fixed time slice for critical threads despite the high processor loading.

The multiwindowing real-time graphics environment, controlled by the window manager, allows the measurement process to be watched and controlled during the measurement at the same time. Observable values are represented in the widows as symbolic circuits, graphics, texts and spectra or as three-dimensional surfaces. Graphic interface is executed in a separate program thread with low priority relative to device threads. Each visual element of the graphic interface is connected to the real-time database. The window manager automatically updates visual elements by timer if the corresponding database element changes. User programs never draw any data directly, they only work with database elements and don't care about how it will be presented on the screen. Such scheme has been chosen in order to minimize the influence of data drawing (which may not be strict real-time) on real-time data processing.

The CRW-DAQ package includes a three integrated program languages to design user programs. One of them is the expression interpreter Daq Script, which is something like a simplified C interpreter. That simple interpreter serves for the case when the program couldn't be formalized at the compilation stage. For example, if user needs to input some formula expression via dialog at runtime and then execute this expression, he uses Daq Script interpreter. The second one is Daq Pascal which is a compiler of simplified Pascal language generating a code for some virtual machine. The produced code is well protected due to virtual machine code interpreter though its executing rate is somewhat lower than the native machine code. The third one is Object Pascal (Delphi 5.0), which is a compiler of an object-oriented language into native code for the present machine. This commercial compiler can be integrated with CRW-DAQ and allows subprograms writing in the form of DLL-libraries which provide full access to all of the machine capabilities. The DLL-libraries could be edited, compiled and executed within CRW-DAQ without program restart. The programmer need not even stop the data acquisition to edit and compile user program code. It is possible because each device is executed in a separate program thread and may continue data processing while another device can be stopped, compiled and restarted.

The CRW-DAQ system combines the design-time and runtime environment that allows application programs to be developed and debugged without interrupting the measurement process. The package has about 20 MB of zip-compressed volume size and allows the whole cycle of measurement systems development to be entirely realized. This cycle of development includes the interface design, program coding, database configuration, calibrations, help system design, etc. All these stages are supported by built-in tools.

The package includes a well thought-out set of measurement-channel calibration facilities and an easily supplemented calibration database for standard sensors (e.g., thermocouples, resistive temperature sensors, etc.).

To save the data that come in during the measurements the internal binary archiving format is used. The measured data can be exported to other applications through the text tables. The user may also write a special program to produce desired data file format during or after measurements. The package includes a wide set of mathematical utilities for measured signals primary processing, such as smoothing, digital filtering, sorting, etc.

Great efforts have been undertaken to make program code of CRW-DAQ package more robust and safe. Following features have been implemented: exception handling technique, shared resource locking, memory leak monitoring, resource usage monitoring, program watchdog to detect thread hanging, etc. Most part of user programs is written in integrated language tools like Daq Script or Daq Pascal. These user programs are highly protected, because the virtual machine interpreter itself is very safe. The practice shows that CRW-DAQ system is stable enough.

III. CONCLUSIONS

The measurement and control systems of the tritium facilities and targets have been operated successfully for a number of years since 1997. In the course of their development a great deal of methodological experience has been acquired, and special electronic and radiometric instruments and CRW-DAQ software package have been developed. The last one facilitates significantly the applied software elaboration for such facilities. The operation experience has proved high stability and safety of the developed software.

The experience gained, and the developed hardware and software, as well, were successfully applied to automate some other experimental setups. To study the phenomenon of hydrogen isotopes (including tritium) retention in and permeation through metals and constructional materials at RFNC-VNIIEF a high-vacuum setup “Prometheus” was designed [8]. Experiments at this setup should answer the questions about the resource of constructional materials operating in tritium-containing media, protective covering selection to effectively decrease hydrogen isotopes penetration through constructional materials, possibility for the phenomenon of hydrogen isotopes superpermeation through metals to be applied to recycling treatment of thermonuclear reactor composite fuel.

Also at the design stage now is a multichannel cooled electromagnetic photon spectrometer PHOS for quark-gluon plasma investigation at the large hadronic collider LHC (ALICE experiment) at CERN [9]. To test the spectrometer prototypes there was created a system for thermostabilization and precise temperature measurement in the crystal matrix, which was successfully used in a series of test experiments [10].

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