KnE Engineering

AtomFuture-2017
XIII International Youth Scientific and Practical Conference
“FUTURE OF ATOMIC ENERGY - AtomFuture 2017”
Volume 2017

Conference Paper

Modernization of the Data Processing Device for the Boron Concentration Meter

Kryukov I. S., Kozyr D. V., and Mukhamedov K. A.

JSC “Scientific Research Institute of Technical Physics and Automatization”, Varshavskoe shosse 46, 115230, Moscow, Russia

Abstract

Currently all nuclear power plants with VVER-reactors used data measuring systems called a Boron Concentration Meter (NAR). They are necessary for the boron control implementation. NAR consists of sensors and auxiliary devices, and it includes the device of storage and data processing (UNO). Both the rapid evolution of computer architectures, and associated microprocessor hardware updates in the electronics market create a necessity of a new device development. The main design goals both are to optimize the hardware solutions and to use a new software and algorithmic capabilities. However, another development goal is not only the upgrading of circuitry and software, but the optimization of calibration process in the NAR and testing it.

Keywords: boracic acid, boron shim, ex-core detector, concentration meter

Corresponding Author:
Kryukov I. S.
Iwan.Kryukow@yandex.ru

Received: 23 December 2017
Accepted: 15 January 2018
Published: 21 February 2018

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the AtomFuture Conference Committee.

1. Introduction

Most of nuclear power plants (NPP) in Russia are equipped with VVER-reactors [1]. The concentration of the isotope ^{10}B in the nuclear plant primary system is one of the most important parameters out-of-pile control in reactors of this type. Due to the high thermal-neutron-absorption cross section, the change in the concentration of boracic acid leads to the change of reactor reactivity in VVER-reactors. Thus, the boron control system features to compensate for slow changes of reactor reactivity and maintain the reactor in a critical state [2].

All Russian and foreign nuclear power plants, which have VVER-reactors, are equipped with a boron concentration meter. The development of this system is carried out in NIITFA. NAR includes a sensor, the data-preprocessing device located in the immediate vicinity of the primary system pipe and the device for storage and data processing.

How to cite this article: Kryukov I. S., Kozyr D. V., and Mukhamedov K. A., (2017), “Modernization of the Data Processing Device for the Boron Concentration Meter” in *XIII International Youth Scientific and Practical Conference “FUTURE OF ATOMIC ENERGY - AtomFuture 2017”*, KnE Engineering, pages 70–79. DOI 10.18502/keg.v3i3.1607

Significant disadvantages of currently used devices is both the outdated facilities of NAR and the inability to refresh some electronic parts due to the reduction of their numbers in the electronics market. In addition, the use of the legacy operating system does not allow to use fully modern tools and to use new algorithms. Thus there is a need to create a new instrument, the development of which is conducted in NIITFA.

2. The concentration meter principles

The operation principle of boron concentration meter based on the measurement of thermal neutrons flux transmitted through the medium and have the back coupling on concentration of 10B (this isotope have abnormally high value of the effective absorption cross-sections σ = 3838 barn) with cores of isotope ^{10}B thermal neutrons according to the reaction ^{10}B(n,α)^{7}Li [6, 9]. Radionuclide Pu-Be fast neutron source (IBN type) with the flow (1-5) 106 s^{-1} is the neutron emitter. Moderation of neutrons happens by means of their nuclear scattering on hydrogen nuclei. Helium neutron counter SI-19N [10] records the flux of thermal neutrons after their interaction with the filler by the reaction ^{3}He(n,p)T. The pulses from the pulse detection unit (BDIN) come to the microprocessor system (UNO) designed for storage and data processing.

The essence of boron concentration meter used in the neutron-absorption method of analysis by thermal neutrons is as follows. Considering the irradiation of the analyzed medium flux monochromatic neutron radiation on the basis of the exponential law of primary radiation attenuation and the properties of cross sections additivity of nuclear reactions [6], it can write the expression for the flow past radiation:

$$N = N_0 \exp \left[-\rho d \sum_{i=1}^{n} \sigma_i C_i \right], \tag{1}$$

where N_0 and N – stream primary and the last neutron radiation, respectively; σ_i – the complete macroscopic cross section attenuation; $\sigma_i = \sigma_{ic} + \sigma_{is}$; σ_{ic} and σ_{is} – absorption cross-section and scattering cross-section, respectively, for the i-th element of the environment; d and ρ is the thickness and density of the medium; C_i– mass concentration; n is the number of elements.

Highlighting member for the designated element, the expression (1) will appear in the form:

$$N = N_0 \exp\left[-\sigma C d \rho\right] \exp \left[- \left(\sum_{i=2}^{n} \sigma_i C_i \right) d\rho \right], \tag{2}$$

which implies that when abnormally high value of $\sigma \gg \sigma_i$ (i=2, 3,..., n) and the absence of other elements with high absorption cross-section and the scattering cross-section of thermal neutrons it takes place almost unique dependence of the detected radiation flux on the concentration of the element.

In the general case on the basis of expression (2) we can obtain analytical expression for the concentration of a specific element depending on the flow of the last neutron radiation in the following form:

$$C = a_j - b_j \ln A_j, \quad (3)$$

where C is the volumetric or mass concentration; A_j analytical parameter; a_j and b_j is the coefficients dependent on the absorption properties of the analyzed medium and geometric conditions of measurement; j – type measurement techniques listed in table 1 in accordance with the form of an analytical parameter.

Table 1: Methods neutron-absorption analysis, depending on the type of analytical parameter.

Analysis method	Analytical parameter	Realization of method
Direct method of measurements	N	NAR-12M
Relative measurements	N/N_0	-
Measurement with standard sample	$N \cdot (N_{co}/N_{co})$	OKB-10

The direct method of measurements is the most simple in practical implementation, and has the lowest statistical error. However instrumental means of its use have significant instrumental error. The technique of relative measurements is more resistant to the destabilizing factors of the analysis. The method of measurement with a standard sample allows to correct the measured analytical parameter compared to the calibration value [7]. In Table 1 the following notation: and N_0 is a set of pulses of the measured sample, including in the absence of the designated element; and N_c and N_c– a set of pulses from the standard sample at the current measurement and the calibration, respectively. Determination of the concentration of NAR-12M is carried out according to the method of direct measurements. To reduce the error of analysis of the concentration meter of OKB-10 (exemplary boron concentration meter) methodology used for relative measurements with a standard sample.

A graphical illustration of analytical expressions to determine the concentration of elements with high absorption cross section for thermal neutrons taking into account the background component is shown in Fig. 3.

In the analysis of technology products in industrial conditions the results can influence a number of confounding factors, such as the matrix effect of the filler, the scattering of neutrons, the change in the temperature and density of the analyzed medium, denominational radiation, the influence of intermediate media, background

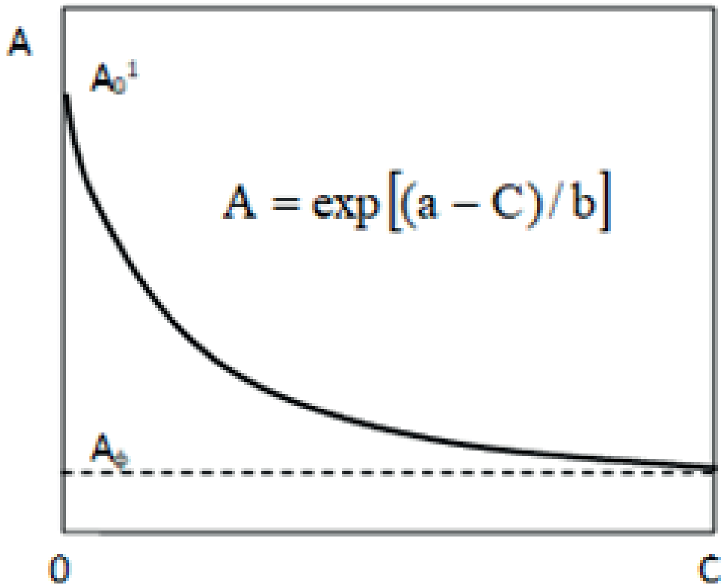

Figure 1: The calibration dependence for neutron absorption measurements of concentration of elements by thermal neutrons: [C] – g/dm^3, g/kg; [A] – pulse/s, relative unit; $A_0^1 = A_0 + A$; $A_0 = \exp(a/b)$; A – background rate.

radiation. Due to the fact that the experimental calibration dependence for these reasons different from the analytical form (3) proposed methods of its mathematical approximation [8].

3. Development of the device for the storage and data processing

Functional diagram of the boron concentration meter version developed is shown at Fig. 2. Depending on the location of the sensor, there are several variants of its execution. They are the primary transducers of the physical value. The information is transmitted to the preprocessing block, which makes signal amplification. Further the storage and data processing device (UNO) accepts the pre-prepared information. Calculated parameters of the concentration of 10B goes to PC operator.

The UNO architecture using currently is based on the industrial modules. The processor in the central unit uses the operating system DOS, which is outdated and restricts possibilities of application of modern development tools, tools used for programming languages. Also some features of the central unit and the processor does not allow for debugging and testing perform any additional actions related to the recording files on the device status and perform operations. As a result, not only software, but also hardware limitations do not allow you to add some necessary changes in the algorithm.

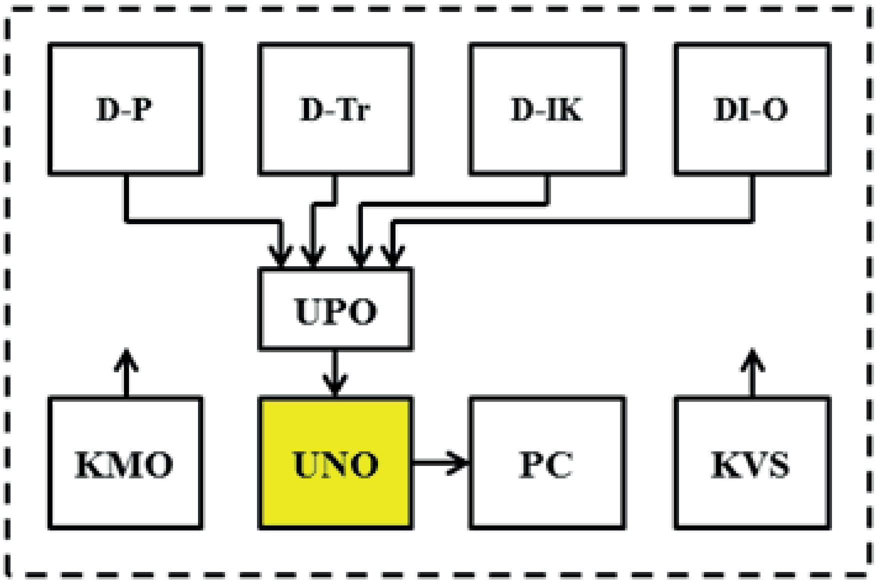

Figure 2: Functional diagram of boron concentration meterD-P – submersible sensor; D-Tr – pipe sensor; D-IK – ensor with measurement chamber; DI-O – exemplary measuring sensor; UPO – pre-processing device; UNO – storage and data processing device; PC – personal computer; KMO – metrological assurance set; KVS – auxiliary tools set.

Hardware architecture of the device shown in Fig. 3.

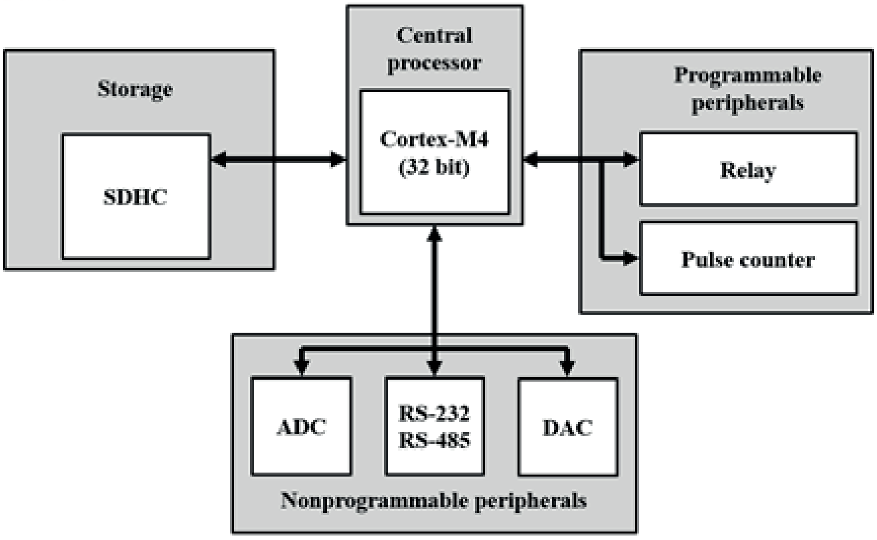

Figure 3: Hardware architecture of UNO.

Hardware architecture consists of central and peripheral blocks. The peripherals consists of programmable and non-programmable blocks. Memory device is particular function unit. The basis for the central unit is the microcontroller based on the architecture Cortex-M4 (ARM) [11] due to the fact that in comparison with other families of microcontrollers Cortex-M (tab. 2), it supports computation with floating point numbers, has a higher clock speed operations, has sufficient memory to accommodate the program.

Table 2: Some comparative characteristics of the Cortex-M families.

Cortex-M family	Cortex-M0	Cortex-M3	Cortex-M4
Architecture	v6M	v7M	v7ME
DMIPS/MHz	0.9	1.25	1.25
Bus interfaces	1	3	3
Bus protocol	AHB Lite	AHB Lite, APB	AHB Lite, APB
Single cycle DSP/SIMD	No	No	Yes
Floating point hardware	No	No	Yes

A wide functionality allows the processor to perform some of the functions of digital signal processor (DSP), such as high-speed data processing [11]. However it requires a large microcontroller capacity to perform the main function such as calculation of concentration, various parameters storage, file I/O. All the intermediate functions for working with analog and discrete signals were passed on to peripheral blocks. So the central unit makes high-speed scanning and management for peripherals via the data exchange interface SPI [12]. The distributed hardware architecture of the device provides to free the CPU from the intermediate signal processing.

AVR based microcontroller is the main processor for programmable peripherals. It performs some simple auxiliary function and sends data to the central unit by force of simplicity and lightweight capabilities [15]. Programmable logic is used in some peripheral blocks because that solution is more flexible and more available to change during the test. Such changes are not possible when using non-programmable solutions.

Computing of concentration processing requires either enough memory allocation or its optimal distribution. The developed device architecture is shown at Fig. 4.

As we can see from the diagram, the central unit software is based on the real-time operating system (RTOS). It optimizes the process time allocation and memory resources. The standard central unit software included both the main loop and interrupts, does not provide for the resource allocation of CPU. So there are errors of program execution associated with both data integrity and the execution delay of the program. Comparison of the above-described architectures is shown in Fig. 5.

Above diagrams shows the main differences of the architectures, therefore, some of the details of each of them are omitted.

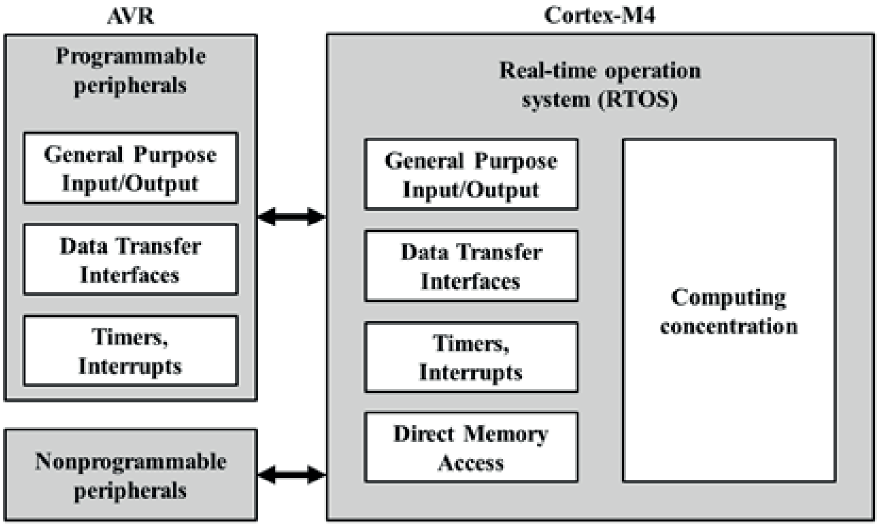

Figure 4: Software architecture of UNO.

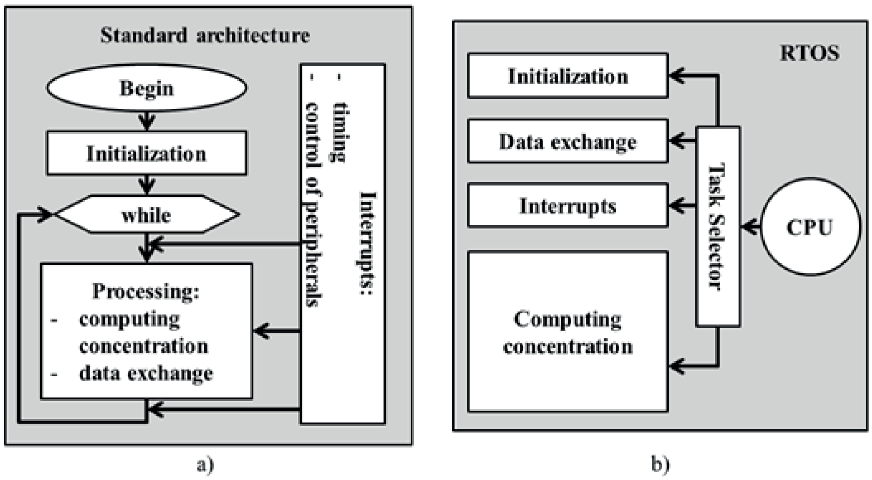

Figure 5: General software architectures for central unit a) standard software architecture; b) software architecture with RTOS.

Using an RTOS [13] all processes are independent functions. The execution time of these functions depends on the developer defined priority. In the case of switching execution from one function to another by task manager the system ensures that all the data was written without errors during transients.

As mentioned earlier, the underlying processor family the Cortex-M4 supports functions such as operations, floating point, matrix operations, and other necessary for the calculation of boron concentration. These functions are necessary for processing of experimental data, which uses piecewise-hyperbolic approximation of the three subbands for NAR-12M. Design expressions for determining the concentration of NAR-12M are:

$$C = C_{0k} + K_k (N - N_{0k})^{-1} \quad (4)$$

C_0, N_0, K – calibration coefficients for hyperbolic dependence, respectively; N – corrected count rate; k is the number of sub – bands. All the above factors are fractional numbers. To perform mathematical operations such numbers will be written in the form of floating pointing number with single precision. They are supported by an integrated module of the floating-point Cortex-M4 FPU providing a significant gain compared to custom software implementation.

4. Conclusion

Test circuit design of the developed device for the accumulation and processing of information is shown in Fig. 6.

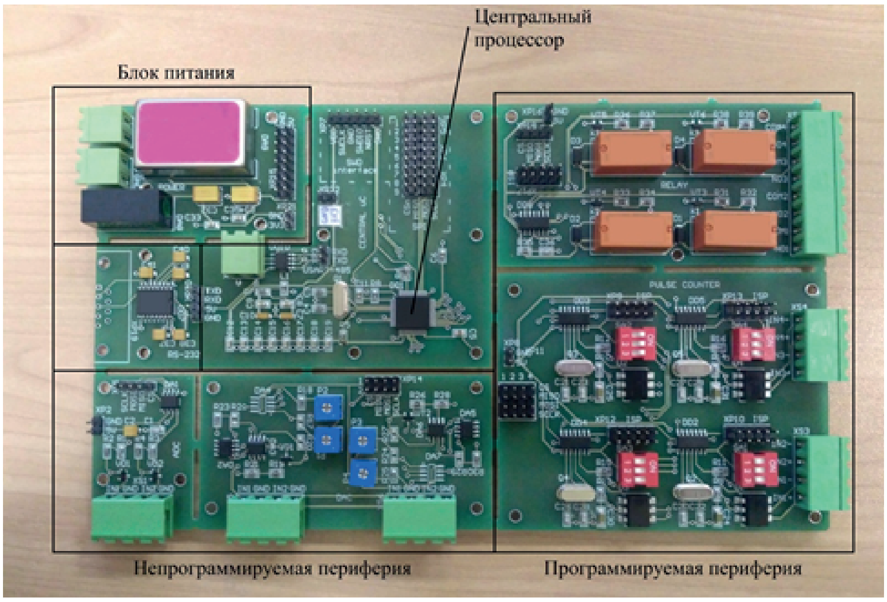

Figure 6: Image of testing version of UNO.

Developed circuitry is currently testing on the performance and efficiency; the software solutions for the interaction of the CPU with the peripherals is currently debug. Structure of programs priorities hierarchy is defined for using in RTOS.

The developed software will allow implementing the following automatic on-line measurement modes: averaging, determination of the jump of the concentration, the subtraction of external background temperature compensation [14], adjustment of the calibration dependence and testing.

References

[1] Official website of ROSATOM State Atomic Energy Corporation. About us. URL: http://www.rosatom.ru/en/about-us/

[2] V.A. Sidorenko. Voprosy bezopasnosti raboty reactorov VVER. – M.: Atomizdat, 1977.

[3] N.P. Kuzelev, G.I. Kiryanov, A.G. Chuev, S.V. Shagov, A.S. Shtan etc.. Konceptsiya monitoringa I apparatura dlya izmereniya koncentracii izotopa ^{10}B v teplonositele I technologicheskikh rastvorakh VVER-reactorov s tseliyu povyshenija jadernoy bezopasnosti I nadyozhnosti AES. – Tyazheloye mashinostroenije, №9, 2005, p. 13-16.

[4] V.P. Bovin, V.L. Chulkin, S.V. Shagov. Neitronno-absorbtsionny analizator borav teplonositele pervogo kontura VVER. – Atomnaya energiya, т. 38, vyp. 5, 1975, p. 283-286.

[5] D. Foreman., P. Stockwell. Automatic Chemical Analysis. Per. s angl. – M.: Mir, 1978.

[6] K. H. Beckurts, K. Wirtz. Neutron physics. Per. s. angl. – M.: Atomizdat, 1968.

[7] B.I. Krasnov, E.P. Minaikin, E.G. Ponomarev, A.G. Chuev. K voprosu vybora mwtodiki opredeleniya soderzhaniya khimicheskikh elementov i ikh izotopov pri neitronno-absorbtsionnom analize tekhnologicheskikh produktov. – Nauchnaya sessiya MEPhI-2002. Sbornik nauchnykh trudov, T. 5. – M.: MEPhI, 2002.

[8] L. Yanosh. Teoriya i praktika obrabotki rezultatov izmerenij. Per. s angl. pod red. A.P. Kleshkova. – M.: Mir, 1968.

[9] Tablitsy fizicheskikh velichin. Spravochnik pod red. akad. I.K. Kikoina. – M.: Atomizdat, 1976.

[10] V.I. Kalashnikova, M.S. Kozodaev. Detektory elementrnykh chastits. – M.: Nauka, 1966.

[11] R. Popov. Obzor yadra ARM Cortex-M4. Compel. URL: https://www.compel.ru/wordpress/wp-content/uploads/2012/10/STM32F4-YAdro-Cortex-M4.pdf

[12] V.I. Bugaev, M.P. Musienko, Ya.M. Krainykh. Laboratorny praktikum po izucheniyu mikrokontrollerov STM32 na baze otladochnykh modulej STM32F3 Discovery и STM32F4 Discovery Mockav – Nikolaev: MIPT-ChGU, 2014. – 26 p.

[13] I.B. Burdonov, A.S. Kosachev, V.N. Ponomarenko. Operatsionnie sistamy realnogo vremeni – Preprinty instituta sistemnogo programmirovaniya RAN, Preprint 14, 2006, P. 1-98.

[14] A.S. Batuev, B.I. Krasnov, E.G. Ponomarev, A.G. Chuev. Issledovanie vliyaniya temperatury rastvora bornoy kisloty na rezultaty analiza neitronno-absobtsionnym

metodom. – VANT. Ser. Tekhnicheskaya fizika I avtomatizatsiya. Vyp. 56, TsNIIAI, 2002, P. 16-22.

[15] ATtiny24/44/84 8-bit Microcontroller with 2/4/8K Bytes In-System Programmable Flash. Datasheet. URL: http://www.atmel.com/images/doc8006.pdf