AUTOMATIC CONTROL SYSTEM OF MAGNETIC SEPARATOR FOR KURCHATOV IAE CYCLOTRON

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ABSTRACT

An automatic control system for a magnetic achromatic separator of exotics (MASE) designed to investigate with a cyclotron the neutron-physical processes of small cross-section as well as to produce beams of radioactive nuclei is described. The characteristics of the MASE installation are given; hardware and software ensuring automation of its control are described. The automation system was developed on the basis of CAMAC modules controlled by a personal computer IBM PC/AT. The fibre-optics data exchange systems are used to connect the hardware with controlled objects. The system makes it possible to adjust automatically the magnetic field for the standard operation modes of the MASE installation, to detect the failures of individual units as well as to calculate and select new operation modes. Automation of the MASE installation allows a physicist-experimenter to change over the installation directly during experiment. The system considered can be used in other electrophysical installations.

1. INTRODUCTION

A magnetic achromatic separator of exotic nuclei (MASE) was proposed and implemented for the first time in I.V.Kurchatov IAE [1]. The separator is designed to perform the following experiments:

-investigation of processes running with a small cross-section, study of the properties of exotic nuclei;

- production of secondary radioactive beams;

- correlation measurements in investigating the decay modes of giant resonances and other nuclear states.

The schematic diagram of the installation is presented in Fig.1. A beam of charged particles with various masses in the whole energy range which exits from a target along the MASE longitudinal axis is formed by an aperture diaphragm within a required angular interval. The required dimensions of the beam at the target (an optical source) are ensured in an ion-optical system of cyclotron beam transport to be $X \leq 3$ mm and $ZY \leq 2$ mm. A crossover in the horizontal plane is formed at the MASE center in the area of an analyzing diaphragm to separate in the best way the beam of a given energy range. The formation is performed by a doublet of quadruple lenses and a dipole magnet. This magnet is involved in analyzing the particles for momenta (the turning angle of the axial trajectory in it is 30°). The effect of the achromatic aberration of the separator on its energy resolution is eliminated by the analyzing diaphragm placed at an angle of 6° with the beam axis.

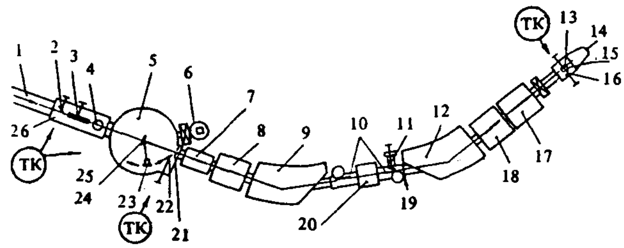

Fig.1. The schematic diagram of the MASE installation: 1 - ion guide; 2, 11, 16, 22, 25 - scintillators; 3 - collimator; 4 - profilometer; 5,14 - target chambers; 6 - lock; 7,8,17,18 - quadruple doublets; 9 - analyzing magnet; 10 - analyzing diaphragm; 12 - collecting magnet; 13, 23 - telescopes ΔE-E; 15,26 - diagnostic units; 19 - foil; 20 - quadruple singled - symmetrizing lens; 21 - aperture diaphragm; 24 - target.

The beam trajectories are symmetrized relative to the MASE center (energy focusing) by a symmetrizing lens representing a quadruple magnet focusing in a plane of analysis (horizontally).

The second part of the MASE ion-optical system is reflection-symmetrical to the first one and intended for collection of particles having been analyzed and their transport to the second target (or a detector).

The character of experiments to be made in the MASE sets high requirements to its reliability, stability of operation, operative, change-over efficiently of diagnostics and quality of operator's work. One of the ways for improving the above characteristics of the cyclotron and the MASE installation consists in development of an automatic control system.

2. THE CONTROLLED OBJECTS

The controlled components of the MASE installation include the power supply devices for the magnets of its ion-optical system. To compact quadruple magnets having a high field gradient invariable over the whole aperture better than within 1% guarantee good conservation of the phase volume of the beam during its transport through the installation.

The parameters of these magnets are listed in Table 1.

All magnets are energized from commercial reversible thyristor converters (RTCs) with a specially-developed stabilization system [2]. The converters are about 100 m distant from a control room. Water-cooled manganin instrument shunts are disposed near the RTCs.

Parameter of magnet	Magnet index		
	56k2	38k21	38k13
Diameter of aperture, mm	56	38	38
Length of pole, mm	210	210	130
Supply current, A	1000	1000	1000
Voltage, V	60	85	100
Magnet weight, kg	48	24	15
Magnetic field gradient, T/m	25	35	23

Table 1. Parameters of MASE magnets.

All devices for the control of the magnet current have the conventional negative-feedback stabilization scheme. The voltage from the instrument shunt is applied to the input of an error amplifier through an MDM converter to decouple conductively the power supply and the measuring circuits. Program-controlled digital-to-analog converters (DACs) ensure the control over the reference voltage at the input of the error amplifier and, therefore, the current in the windings within $2\cdot10^{-5}$.

3. THE STRUCTURE OF THE AUTOMATIC CONTROL SYSTEM

The Kurchatov IAE cyclotron uses a structure of automatic control with the control functions distributed among individual subsystems. The control system of the MASE installation is a constituent part of the cyclotron complex.

A standard control station was developed on the basis of the CAMAC modules [4]. The station includes measuring equipment to record analog signals in a range of -10 V to +10V and to control analog parameters within 10^{-3}, units for control over discrete parameters and interface modules connecting the equipment with a control computer and peripherals used for operator-system interaction.

Wide use of commercial fiber-optics data-exchange systems is the important feature of the station [5]. The hardware comprise a digital data transmission systems "Elektronika MS-4101", an analog data collection systems "Elektronika MS-8201" and an analog data distribution systems "Elektronika MS-8401". Each system consists of a transmitter and a receiver connected by a fiber-optics line (FOL) up to 300 m long and ensuring the transfer of information with a rate of up to 8 Mbit/s.

Use of such multichannel devices connected through the input and output registers evidently allows one to eliminate the conductive coupling between the control equipment and the controlled objects, to guarantee reliable protection of the communication lines from electromagnetic fields, to increase considerably their reliability and to bring ADCs and DACs nearer to the controlled objects, which essentially improves the performance of the system in terms of error probability.

An IBM PC/AT computer controlled by an MS-DOS 3.31 operation system is used as a control computer. The complex of control and checking programs is written in Turbo-Pascal 5.5 and occupies about 200 kbite in the main memory. The structure of the system is shown in Fig.2.

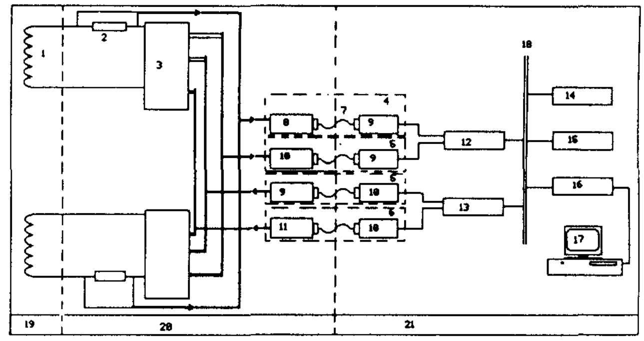

Fig.2. The structure of the automatic control system for the cyclotron and MASE magnets: 1 - magnet; 2 - shunt; 3 - RTC; 4 - analog data collection system; 5 - digital data transmitting system; 6 - analog data distribution system; 7 - fiber optic line; 8 - collection module; 9 - receiver; 10 - transmitter; 11 - distribution module; 12 - input register; 13 -output register; 14,15 - functional CAMAC modules; 16 - crate controller; 17 - computer; 18 - CAMAC bus; 19 - cyclotron hall; 20 - electrotechnical hall; 21 - control room.

The control computer, the CAMAC equipment as well as the digital receivers and transmitters of the fiber-optics systems are in the control room. The FOLs are laid from the systems to an electrotechnical hall 100 m distant from the control room. The response parts of the fiber-optics systems connected directly to the controlled objects and transducers are in this hall.

4. SOFTWARE FEATURES

The automatic control program for the power supply of the isochronic cyclotron and MASE installation magnetic circuits realizes the interaction with the RTCs setting the current in the windings of the magnets. The controlled parameters involve the voltages of the outer reference-voltage sources, "ION", and the signal of current polarity and energizing of the converters "REVERS". The checked parameters are the voltages across the RTC shunts "SHUNT" and a signal "STATUS" showing the presence of the RTC outer control authorization "STATUS". The values of the parameter "SHUNT" determining unambiguously the magnetic field configuration can be set by an operator or automatically in accordance with data stored in the computer.

The whole complex of programs is controlled by a menu system (Fig.3) which fixes a certain current state of the dialog environment and offers several alternative paths of transition from this state. The main menu allows one

- to start the program of setting the magnet currents;

- to calculate a new mode of magnet operation;
- to select a precalculated mode from the mode database;
- to start a program changing the channel display form;
- to exit from the program.

The example presented shows the graphical copy of the display screen - the case when the

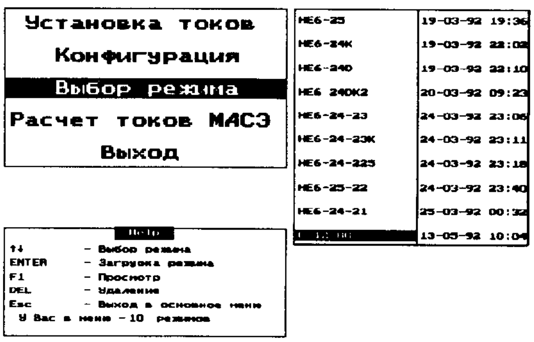

Fig.3. The fragment of the operator menu system.

operator selects the mode of 77-MeV ^{7}Be beam production by the MASE installation. The CTCs are controlled by a program "Setting of current". The character of interaction of the operator with the controlled devices is determined by three basic operation modes of the system: (1) monitoring and automatic adjustment, (2) general control and (3) channel control. Each RTC has a cell on the monitor screen, "a channel window", to display the RTC and its magnet numbers, the RTC purpose and the status signals in the form of colored pictograms. The analogous variables are represented in the following way: the signals "SHUNT" and "ION" by colored columns with a length proportional to the magnitude of the signal, the stored values by colored marks on the scale. Figure 4 shows an example of representing the status of the controlled and adjusted parameters corresponding to one of the real operation modes of the cyclotron magnetic systems. The MASE magnets work in the computer-controlled mode, all other magnets are only diagnosed.

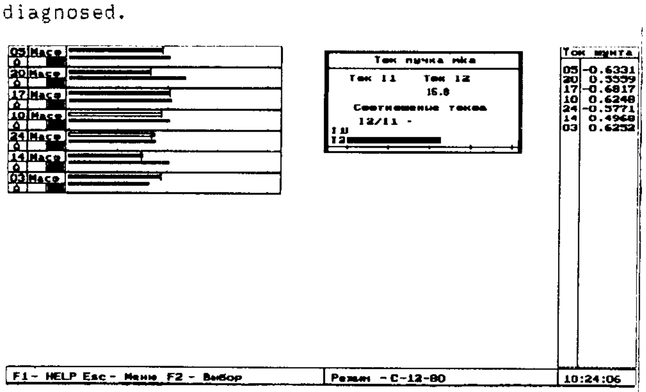

Fig.4. The information to be output onto the monitor screen in the mode of automatic adjustment of currents (example of representation).

The mode of monitoring and automatic adjustment ensures successive measurement of voltages across the shunts in all controlled channels and automatic fine adjustment of the voltages in accordance with their set values as well as indication of the most important status information. The 0.1% deviations of the measured parameter from its set value after being stored attract the operator's attention because of the change in color of the "SHUNT" column from blue to red-framed blue; the 1% deviation changes the blue color to the red one. When the deviation is 0.5%, automatic adjustment of the changed parameter is initiated. If the system is not able for any reasons to correct the changed parameter, it attracts the operator's attention by a sound signal. In mode (1) the system works without operator's intervention, the keyboard is blocked to protect from stray keystrokes. An encapsulated directive is provided for the system change-over in the general control mode.

The general control mode ensures the control over a selected group of channels which can be used to execute the following operations: setting of voltages, reset write-in, storage-to-mode menu writing, transition to the channel scan mode, output to the main menu, prompt call. In the pauses between the directives specified by the operator and after the execution of each directive the systems scans in turn the channels representing the information about their status and the voltage across the shunts. The general control mode is intermediate between modes (1) and (3).

The channel control mode ensures the control of any selected individual channel. This mode makes it possible:

- to activate or deactivate the mode of automatic adjustment of currents;
- to correct the currents coarsely or finely;
- to write in the values of current;
- to set the current in accordance with its stored value;
- to select other channel;
- to go over into the mode of successive call of channels.

All above operations are executed by pressing so-called "operative intervention key".

Simultaneously with the main modes the logic pickups are tested for status of locking. In the case of disconnection in the locking circuit the display indicates both the channel number where the locking has operated and the concrete reason. Moreover, the sound signal from the display will attract the operator's attention to the information about the failure.

5. CALCULATION OF THE MASE MODES

A program of automatic mode change was developed to automate some experiments to be made with the cyclotron and the MASE installation. The results of magnetic measurements were used as a basis to derive the analytical dependences of the quadruple lens gradients and the dipole magnet induction on the currents in the excitation windings, G(I) and B(I), and the inverse functions I1=f(G) and I2=f(B), where I1 and I2 are the currents in the MASE windings. Using the well-known relationships between the field gradient and the magnetic rigidity of focused particles (depending on their type and energy) we obtain the expressions:

$$G = \omega^2 \sqrt{(E^2 + 2EE_0)} \;/\; q\cdot c \quad ,$$

$$B = \rho^2 \sqrt{(E^2 + 2EE_0)} \;/\; q\cdot c$$

where ρ is the radius of turning in the dipole magnet; ω is the focusing force of the lens; E is the kinetic energy of an ion; E_0 is the ion rest energy; q is the ion charge; c is the velocity of light.

It is convenient to express the ion rest energy through the parameters:

$$E \simeq (A + [0{,}01\cdot(A-100)^2 - 64]\cdot 10^{-3})\cdot 931{,}141 - (Z-N)\cdot 0{,}51$$

where A is the mass number; Z is the number of protons in the nucleus; N is the multiplicity of the ion charge. Substituting the calculated values of R and B into the derived dependences of the excitation currents it is not difficult to obtain their values for setting the specified operation mode of the MASE installation. The results of the calculations are written by the operator's command in the MASE mode menu. After this corresponding currents are automatically set.

To identify the spectrum of nuclear reaction products separated by the MASE installation during experiment it is essential to know the range of their energies. Such calculations are mode operatively during the setting of the magnet currents. For this purpose a certain feature of magnetic rigidity separation of wanted ($B\rho_1$) and accompanying ($B\rho_i$), particles is used. Using the known dependence $B\rho = f(A,Q,N,E)$ (where A is the number of nucleons of the particle; Q is the ion charge; N is the nuclear charge; E is the kinetic energy of the particle) we obtain the equation with a single unknown quantity

$$f\,(A_1,Q_1,N_1,E_1) - f\,(A_i,Q_i,N_i,E_i) = 0$$

The prepared program allows the solution of this equation for a particle of any type and the representation of the calculated data as a table of possible energy ranges of transmission in the MASE for given types of particles.

The automation of the MASE allows a physicist-experimenter to change over the installation directly during experiment without intervention of a cyclotron.

6. CONCLUSION

At present the automatic control system for the magnetic circuits of the cyclotron and the MASE installation ensures on-line control and monitoring of the analog variables within $2\cdot 10^{-5}$, check of the pickups of served equipment logic state, automatic change-over to the standard operation modes, acquisition of data on the operation time of the power supply systems and their stability, etc. The considered automation system is being operated successfully in I.V.Kurchatov Institute of Atomic Energy and can be used for other electrophysical installations. In particular, a modification of the developed hardware and software complex will be used to create a control system for a mini-cyclotron being developed now for medical research [6].

7. REFERENCES

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