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AUTOMATIC PARAMETER MEASURING SYSTEMS AND CONTROL SYSTEMS FOR CYCLOTRONS

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Abstract. - The results of parameter measurements and computer control of cyclotrons at the Laboratory of Nuclear Problems (LNP), JINR, are given. Automatic systems for data aquisition and failure detection for the high current JINR phasotron, for beam phase control of the LNP electron cyclotron and of the isochronous cyclotron U-120M (Czechoslovakia), for optimal beam current adjustment of the LNP electron cyclotron are described. Technical data for the above mentioned systems are given.

The automation of accelerators of different systems based on extensive employment of computers enables to speed up significantly the process of constructing and utilizing these machines and to attain the design parameters within the minimum time.

At the stage of constructing modern cyclic accelerators much effort is given to the formation of magnetic fields of complex topography. The automation of the process of magnetic measurements enables to reduce significantly the time of field shaping. A number of such systems have been developed and utilized in the Laboratory of Nuclear Problems, JINR [1-7].

In the Laboratory there have been also developed and are being developed control systems for cyclic accelerators - isochronous cyclotrons and synchrocyclotrons.

The data aquisition system about the synchrocyclotron mode of operation. - The automatic system of synchrocyclotron control (ASSC) should deal with the following tasks [6,8]:

1. To give the operator on his request current information on the status of some accelerator unit.
2. To store-up in the long time memory (magnetic tapes, discs) the data on the accelerator parameter changes within a long period of time (a month, a year) and to give the operator a sample of these data on his request.
3. To warn the operator when the accelerator parameter is approaching the limit of the permitted value (ALARM-situation).
4. To set the necessary mode of accelerator operation.
5. To carry out the optimum adjustment of the accelerator basing on the following important beam parameters: external beam intensity, the extraction coefficient, beam dimensions in some point of its trajectory and etc. The ASSC is being also made in CAMAC standard.

Important problem is the provision of the ASSC with the necessary calculating power by means of selecting corresponding type and quantity of the control computers. The study of the list of problems solved by ASSC with taking into account the need for providing correspondence between the real ASSC speed of response, depending on the application of the CAMAC standard and of the given computer type, and the wanted ASSC speed of response has demonstrated that it is necessary to subdivide the information flow from the phasotron indicator field into several flows. Each of them will be processed by a separate micro-computer of "MERA-60" type joined to the central computer according to the radial principle.

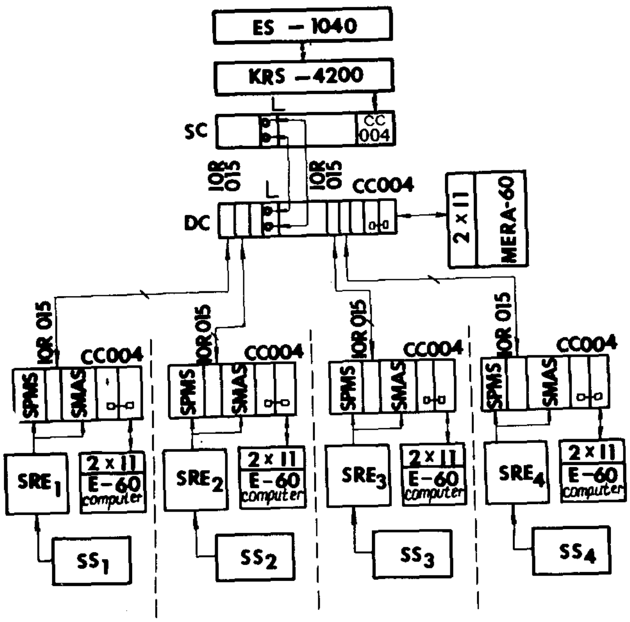
The task of accelerator optimum adjustment over some output parameter will be accomplished with using a link with ES-1040 computer. This link will be also used for exchanging data with the bank made on the ES-1040 computer.

Distribution of the necessary ASSC computing power between several computers will increase the speed of ASSC operation and will increase significantly its reliability and maintainability.

Figure 1 presents the block diagram of the ASSC. It is evident from the diagram that total information flow from the ASSC indicator field is subdivided into flows coming from the following accelerator subsystems: the system of magnetic field (shaping) and beam extraction (IF_1); high frequency subsystems (IF_2); vacuum, water cooling and radiation safety (IF_4); ion sources and probes subsystems (IF_3).

Information flow from each accelerator subsystem passes through the signal reduction equipment (SRE), the purpose of which is the reduction of signals from accelerator indicators, which differ by their characteristics, to the form necessary for CAMAC equipment.

Figure 1



KEY TO THE CHART

IOR – input-output register
SRE – signal reduction equipment
SC – system crate
DC – distribution crate
CC – controlling crate
SPMS – signal precise measurement system
SMAS – system of signal measurement in alarm situation
SS – subsystem

Central Computer is connected with the ES-1040-computer through a system crate (SC). The completely realized ALARM-system has the following functions:

1. Informs the operator on the accelerator parameter deviation from permissible values. Alongside with this the operator obtains information on the time a failure has occured, on the source of the failure and the list of erroneous parameters.
2. By consecutive registering in time of ALARM information it defines the tendency of ALARM-situation development. The operator gets on the print or on the monitor screen information on the time sequence of ALARM-events.
3. Gives an advice to the operator on the possible ways of elimination of the occurred failures, indicates the necessary operations and the most advantageous sequence for carring them out, informs the operator on the time within which he could correct the deviation, and on the list of units which should be switched off by the operator.
4. Switches off automatically the erroneous subsystem or its part by means of special switch-off electronics.
5. Analyses the ALARM situation and perform the self correction of parameter deviations by means of a self-instruction system. The ALARM-system of the ASSC receives normalized signals from the accelerator indicators through the SRE of the ALARM-system.

The system of information representation (SIR) supplies the accelerator operator with information in a compact and easy for understanding form on the change in the accelerator parameters with time.

SIR includes: microcomputer "MERA-6040", accelerator monitoring and control board and a CAMAC-crate with a set of units (blocks).

The system controlling the magnetic field structure over the drift phase for isochronous cyclotrons. – Another important characteristic of acceleration mode is the dependence of the radius on the phase of the accelerated bunch transit through the dee edge with respect to the accelerating high frequency voltage. This dependence reflects the state of the magnetic system, the degree of conformity of the real average magnetic field and the necessary isochronous field. It can be used for field correction aimed at achieving the necessary acceleration mode.

Similar phase correction systems have been constructed and successfully operates on the electron cyclotron of the Laboratory of Nuclear Problems, JINR [9] and on the isochronous cyclotron U-120M [10].

A M-6000 computer is used in the system controlling the magnetic field of U-120M cyclotron. The system performs automatic measurement and correction of the transit phase with an accuracy of $\pm 2^{\circ}$.

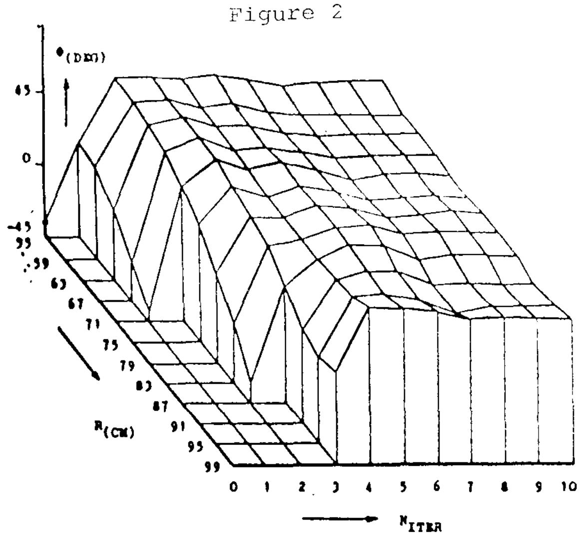
This accuracy is provided for α-particle beams with mean current of 1 μA and proton current 0.1 μA when the ratio of particle bunch length to the transit time is 20. In the system installed on the electron cyclotron of the Laboratory of Nuclear Problems, JINR, a ES-1010-computer is used.

The problem of phase correction can be solved by means of the random search method [11]. This method is especially effective for the cases of phase dependence correction when they have small deviations from the necessary law (the order of ± 15-20°). In this case the mean time of defining the current additions is several time shorter than the time of finding them by the matrix reversal method which is of interest for the operation of the system controlling the transit phase in the mode of stabilizing the assigned phase values in different points along the radius.

The use of similar systems is most effective with accelerators the particle energy of which can be smoothly changed in a wide range. Thus, the conduit of the beam to the extraction system takes place on reaching the first indicator during three-four cycles of magnetic field correction (Fig. 2).

Current controlling at the injector output in a ring electron cyclotron. – The task to be solved most frequently by an operator is the optimization of beam parameters in the given

Figure 2



points of its trajectory by means of changing some definite accelerator parameters.

The time for solving this problem depends essentially on the operator experience and on the complexity of the binding function. The choice of a method for solving the optimization problem with a computer depends on the following factors: the characteristics of the used computer, time and accuracy characteristics for the system of interrogation and adjustment of accelerator parameters.

The optimization method which we suggest in this paper has been tested at the injector of the ring electron cyclotron of the Laboratory of Nuclear Problems, JINR [12]. Vertical type electron injector consists of an electron gun, focussing beam line and the rotary unit which brings the beam into the horizontal plane.

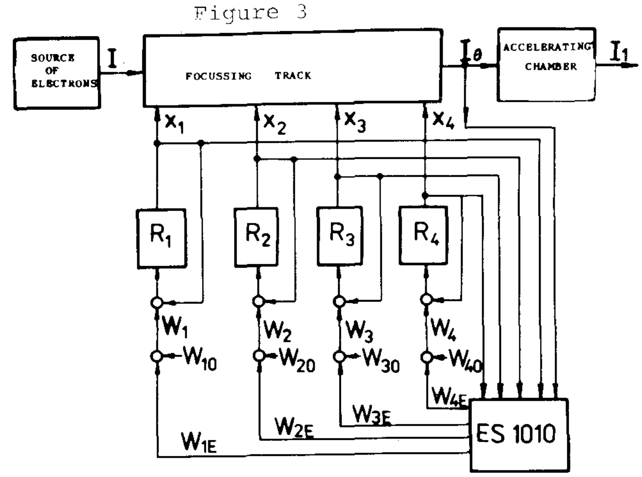
In the injector a beam of electrons is modulated at a frequency of f = 100 Ghz by 100 μA long pulses and on passing the rotary unit it is indicated on the pick-up electrode, which transmits the signal to the single pulse integrator. The mean value based on 8 integrator indications is accepted as the current value of the electron beam.

Current value at the output of the rotary unit - I_θ has been optimized by means of 4-parameters : focussing coil current - I_f; electrostatic track voltages - U_{tr}; rotary condenser voltage - $U^{\oplus}_{r.c.}$; rotary condenser voltage - $U^{\ominus}_{r.c.}$.

The selected optimization method is a method of step-by-step approach to the optimum of the wanted accelerator parameter with a constant step length in time of the search. The method does not require the knowledge of the optimized process mathematical model and by its algorithm it is similar to the method used by the accelerator operator at the setting of the optimum mode of accelerator operation.

The block scheme of the communication unit binding the ES-1010 computer with the electron injector is presented in Fig. 3, where R_i - the adjusted elements, in our case - the power sources of some elements of the injector, W_i - controlling operation; W_{io} - the given value; W_{ie} - the change introduced

Figure 3



into the given value by the computer, x_i - adjustable parameters of the injector (I_f, $U_{tr.}$, $U^{\oplus}_{r.c.}$, $U^{\ominus}_{r.c.}$) I_k - the current of cathode source emission; I_θ - beam current at the output of the rotary unit (optimized parameter).

Index i = I - corresponds to the regulation circuit I_f and i = 2 - the circuit of electrostatic track power regulation - U_{tr}, i = 3 - power supply regulation circuit - $U^{\oplus}_{r.c.}$, i = 4 - power supply regulation circuit - $U^{\ominus}_{r.c.}$.

When the power supply of the injector is switched on the operator adjusts it until there appears a beam at the output of the rotary unit and sets the necessary operation mode for the electronic gun, which remain unchanged during optimization. In this case the injector adjusted parameters equal the following given values:

$$W_i = c_i x_i = W_{io}$$

where c_i is the coefficient of the bond between W_i and x_i.

During current I_θ optimization the adjusted parameters are changed consecutively by adding constant steps ΔW_{iE}. The initial step is always made in the positive direction of adjusted parameter x_i change. The direction of later steps coincide in their sign of difference $(x_i^2 - x_i^1)$ where x_i^1 is the "i"-th value of the adjusted parameter in some intermediate point I, x_1^2 - the "i"-th value of the adjusted parameter in the point distanced by a step ΔW_{iE} from point I. Note that here $W_{iE} = \Sigma \Delta W_{iE} \neq 0$. Maximum I_θ is further searched for in the corridor $2\Delta W_{iE}$, which is located in the direction opposite to the direction of the last step which has spotted the appearance of the maximum. The search step in the indicated corridor has been

$$\Delta W'_{iE} = \frac{\Delta W_{iE}}{4}$$

The I_θ maximum in the corridor $2\Delta W_{iE}$ is searched for through simple scanning with a step of $\Delta W'_{iE}$ and remembering the maximum value I_θ which will be found as a result of it. If $\Delta I_\theta / \Delta W'_{iE} < G$ (where G is the given value, selected experimentally for each optimization track, and ΔI_θ is the I_θ current increase at the increase of W_{iE} by one step ΔW_{iE}) then the scanning is finished. Quantity x_i corresponding to the obtained maximum I_θ is established with a computer at the i-th injector power supply source.

Maximum values I_θ are compared before (I') and after (I") completing each full optimization cycles over each of four parameters. If $\frac{I'' - I'}{I'} < E$ where E is the given quantity, then the process is completed. In the opposite case the cycle is renewed.

In 50% of cases the maximum I_θ, obtained by means of an automatic system was not less than the maximum obtained by the operator at manual adjustment. Note that the number of optimization cycles until the maximum varied from 2 to 5 with mean cycle duration of 2 min.

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