NEW CONTROL SYSTEM FOR THE ISOCHRONOUS CYCLOTRON U-120M

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The new control system based on the ISOLDE control system developed at CERN together with an on-line mathematical model is presented. An operator console as a client controls remote subsystems (various devices) in a function of servers via the Ethernet LAN. This way, fast and flexible tuning and monitoring of cyclotron operational parameters is enabled. Subsystems work upon the DOS OS while the operator console runs upon the MS Windows OS. The cyclotron tuning is supported by the on-line mathematical model which provides calculations of the main and trim magnet coil currents for any accelerated regime. The optimalization of beam phase radial dependencies as well as of the radial and azimutal free oscillations and the trim coils power consumption is performed. The well tuned cyclotron regimes are stored in the database.

1. Control system

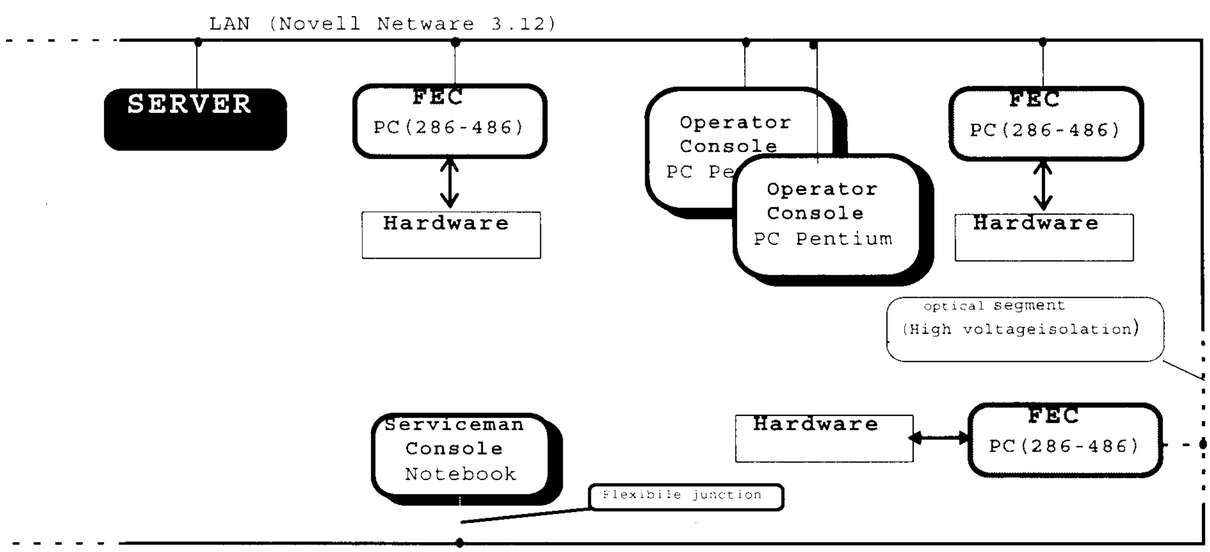

Figure 1. Structure of the ISOLDE-based control system

The system is based on the ISOLDE control system developed at CERN. Its architecture is well known as has been presented many times [1].
The system is distributed on the NOVELL network with the structure shown in Figure 1.
The FECs (Front End Computers) as DOS Servers control the HW whereas the operator consoles work as clients. The consoles run upon the OS MS Windows; one can thus experience all advantages and disadvantages of the widely distributed and used software running under this system. The main reasons to use the ISOLDE-based software were the fast implementation to our applications and relatively cheap solution. The system is also very flexible and widely opened.

1.1 System description

The RPCSRV (Remote Procedure Call SeRVer written in C++) runs on the operator's console and communicates via network with NODAL programs running on the particular FECs. By means of the DDE it can access the application programs of the control system (Visual Basic, VC++, Delphi, Excel, Word etc.). The NODAL programs serve the concrete HW via the external function (EQuiPmentMODule), which controls the particular type of equipments (Quick C).
During the system implementation, it was necessary to make some corrections in the RPCSRV and NODAL programs and write the Equipment Modules for the HW used in our

system. The language localization of the operator interface had to be accomplished and application programs for operator the console were created, as well. To take all these steps one has to be familiar with the programs i.e. VC++, QC, Excel VB or Delphi, C++Builder etc.
The system requires also implemented LAN (Novell Netware or any LAN with TCP/IP protocol).

2. Mathematical Model of Cyclotron

2.1 Principle of Operation

The mathematical model is performed as an interactive program, the simplified scheme of which is shown in Figure 2. The Mathematical description of the cyclotron enables calculation of average values of the magnetic induction Bs(r) at 61 radii for arbitrarily chosen currents in the main coil and 14 trim coils of the cyclotron magnet. The description is based on the measurement of the magnetic field topography performed on 12 basic levels

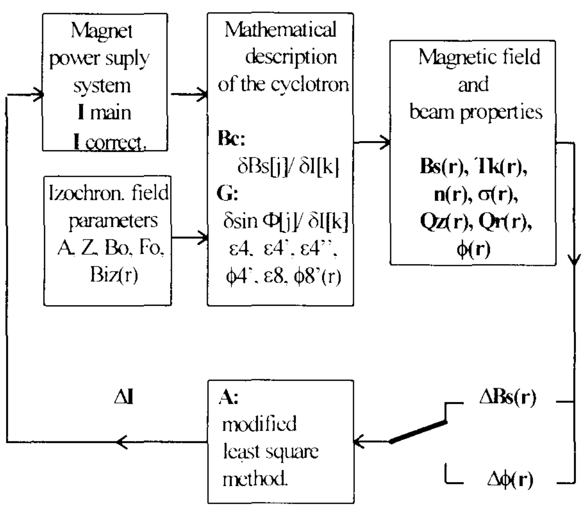

Figure 2. Simplified scheme of the mathematical model.

The U120-M cyclotron was projected for a wide range of accelerating regimes and, generally, the field of iron considerably differs from isochronous ones. Therefore, the fields for protons, deuterons and He2/3 were formed already close to isochronous ones during measuring the magnetic fields.
The contributions of the trim coils were measured on 4 levels of the main magnetic field. Four coefficients were then calculated in order to enable a cubic interpolation for any radius and any basic level of the main magnetic field [2].
The mathematical description of any isochronous field is formed using the closest level measured together with the two neighbouring ones. There within the tree levels, the trim coil contributions are considered constant, while the main coil contribution is parabolically interpolated in order to get the final magnetic field of both neighbouring levels equal to the measured field values [2]. This procedure resulted in higher accuracy for the whole region defined by these neighbouring basic fields. The **Bc** matrix [61x17] consists of 14 columns of the trim coil contribution coefficients and 3 columns for the main coil. The matrix elements for k-th trim coil and j-th radius are

$$Bc[j,k] = \Delta Bs[j] / \Delta I[k]. \qquad (1)$$

The main coil linear Bc[j,15], quadratic Bc[j,16] and absolute Bc[j,17] coefficients are then calculated. The average field values Bs on j-th radius are then as follows:

$$Bs[j] = Bc[j,17] + Bc[j,16] * \Delta I[15]^2 + \sum_{k=1}^{15} Bc[j,k] * \Delta I[k], \qquad (2)$$

where ΔI[k] are deviations of the actual currents from the values of their basic level. The **Bc** matrix elements are then used to get **A**[15x15] matrix applied to the optimalization of the accelerating regime. The main coil elements are calculated with the use of linearization of its contribution in the points of the actual working level Bs. The optimalization of parameters for the given regime uses a modified least square method [5], where the functional

$$F = \sum_{j=1}^{61} \omega_j \left(\sum_{k=1}^{15} Bc_{jk} * \Delta I_k - \Delta Bs_j\right)^2 + \sum_{k=1}^{15} \alpha_k^2 (I_k - Iz_k)^2 \qquad (3)$$

is minimized. There ω_j are coefficients which affect the efficiency of the optimalization at the i-th radius while the α_k affects the k-th coil participation in it. Resultant currents I_k for non-zero α_k will converge to I_{zk} values. Thus the final solution for $I_{zk} = 0$ will aim at the minimum of energy consumption at the trim coils. Of course, coefficient α_{15} for the main coil always equals zero.

The optimalization of the beam transit phase Δϕj uses matrix **G**[61x15] instead of **Bc,** where matrix elements

$$G[j,k] = \Delta \sin(\Phi[j]) / \Delta I[k] \qquad (4)$$

are calculated using the integration of (Bs(r)-Biz(r))s(r) functions [3]. The radial dependence of the average magnetic induction and the beam transit phase are calculated after each change of parameters as well as field index n(r). Free oscillation frequencies Qr(r), Qz(r) and σ(r) are obtained by using formulas [5,4], where the products of harmonic analysis of magnetic fields ε4, ε4 ', ε4 ' ', ϕ4 ', ε8, ϕ8 ' measured beforehand are used. The beam energy Tk for each radius is calculated, as well. Graphs of beam properties are then renewed on the screen according to the operator's needs.

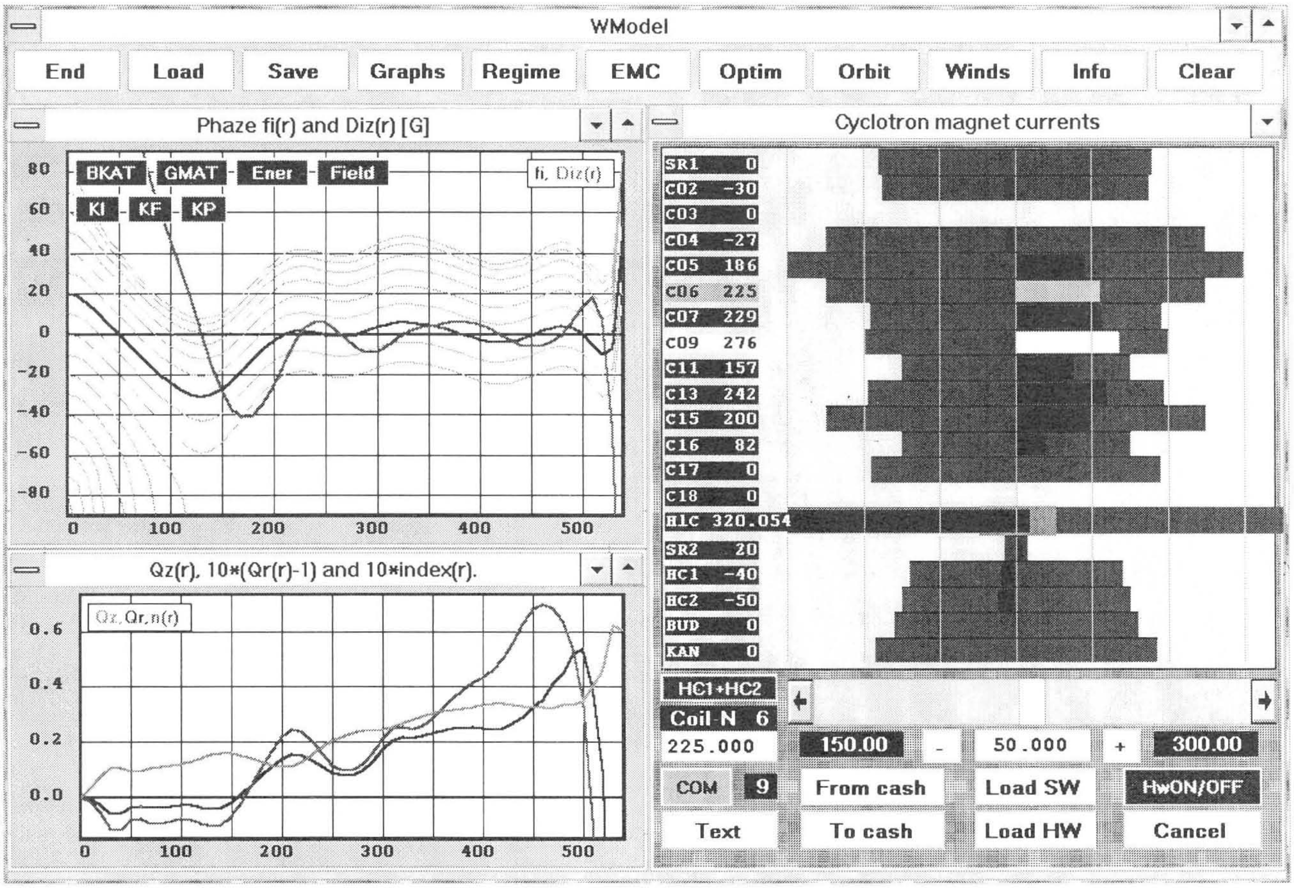

Figure 2. Main window for the cyclotron accelerating regime on-line control.

2.2 The operator - system interface

A typical configuration of the main window is shown in Figure 2. Windows with corresponding information and additional control elements can be opened by clicking on the main menu buttons. Regime' button opens the window with isochronous field parameters (see Figure 3.). A and Z values of an accelerated ion, as well as the final energy E50, Fo frequency and corresponding central synchronous field Hso are entered numerically. The isochronous field is then calculated for these parameters. The amplitude of the dee voltage Ud and Nharm affect the beam phase history. The 'GENERATING' button then starts generatign the full description for entered isochronous field.

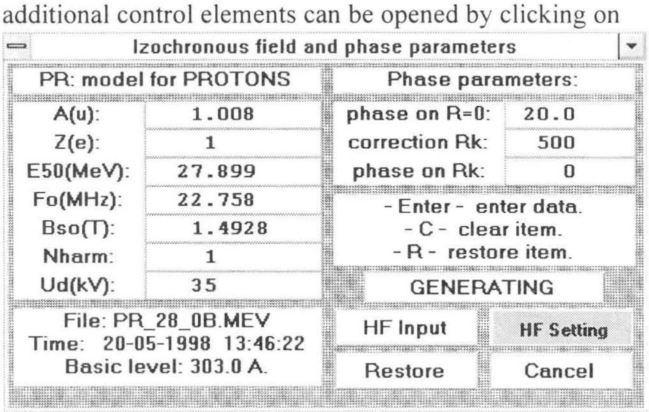

Figure 3. Window for the set-up of parameters of the accelerating regime.

The 'Optim' button initiates the parameters´ optimalization to minimize either the magnetic field or beam phase deviations. Aplying the equation (3) in some cases at some radii enables getting particularly Qr(r) near or equal to its resonance value. An acceptable compromise between the phase and free frequencies history can be always achieved by the means of manual corrections of the current in chosen coils together with a simultaneous monitoring of the beam properties behaviour.

The 'Cyclotron magnet currents' window (Figure 2.) consists of various control elements enabling a manual control. The magnet coil currents can be set in either defined by a numerical input, by discrete increments or by the usage of any scroll bar function. The choice of a coil, which can compensate for the influence of any other coil on the beam phase at the defined radius, makes tuning much easier. This enables a local modification of radial gradients of the average magnetic field without any loss of the beam. After each change, currents are reset at power supplies and thus the character of calculated properties of the beam can be compared at any time to its real behaviour. New accelerating regimes can be also prepared in OF LINE mode, completely independently on the cyclotron.

'Text' function opens the window of a notepad which contains the complete numeric description of the accelerating regime. Its extract can be either printed out or saved on a disk. 'To cash' and 'From cash' buttons serve for a temporary saving of set up currents.

"Graphs" function opens windows of the phase and frequency of free oscillations. The graph of the phase shows radial history of the central particle's phase and of injected particles with phases gradually differing by 10^0. The relation between the deviation of the calculated field Bs and the isochronous field is shown there as well. The window of the phase further offers buttons opening other windows for radial dependence of trim coils contributions (BKAT) and their influence on the transit phase (GMAT). Windows with graphs of the full magnetic fields and the beam energy can be opened there, as well. Three other buttons can start the correction of the phase at a defined radius by the mean of a calculation of a corresponding change of the main coil's current (KI) or frequency (KF). When the accelerated beam is gained, KP button can eliminate the influence of the hysteresis of the magnetisation curve of the magnet on its correct mathematical description. The window of frequencies of free oscillations shows not only Qz and Qr but also the index of magnetic field n.

'Save' button opens a dialogue window which enables storage of the well set up regime into the database. Repeated download is possible with the use of a "Load" function at any time. This enables a very fast set up of an accelerating regime of the cyclotron.

3. Conclusions

The biggest advantage of the ISOLDE-based system is the openness and the flexibility under the condition that the implementation of the system has been completed. There are two main disadvantages:

- the pure structure Client - Server
- the access to different equipments is connected with scanning of configuration database (though in the memory).

The system has been running on the cyclotron U-120M since 1995 with any severe problem. Even if the operator console is running under the OS Windows for Workgroups, no system collapse or instability has occurred. Due to the power supply backup of the server and separation of the control and application part of the network, its stability is considered to be very good.
For the main applications as the FECs we use the shut down PCs, which were replaced by the upgraded ones.

The mathematical model has been used for many years. Measuring of the real accelerated beam and the comparison of calculations for dynamics of the beam in the actual magnetic field and in an electric field have proven that the model like this works with acceptable accuracy within the working regime and that the high speed of calculations makes it an effective tool of an operator during a routine operation of the cyclotron.

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