CONSTRUCTION AND SYSTEM TUNING OF CONTROL SYSTEM FOR THE RCNP RING CYCLOTRON AND BEAM LINES

T. Yamazaki, K. Tamura, A. Ando, K. Hosono, T. Itahashi,
M. Kibayashi, I. Miura, K. Nagayama, T. Saito, A. Shimizu, M. Uraki and H. Ogata
Research Center for Nuclear Physics, Osaka University,
Mihogaoka 10-1, Ibaraki, Osaka 567, Japan

and

M. Maruyama, S. Yamada, Y. Kimura, K. Aoki, K. Kodaira* and M. Tachibana
Quantum Equipment Division, Sumitomo Heavy Industries,
Soubiraki 5-2, Niihama, Ehime 792, Japan

ABSTRACT

The control system for the RCNP ring cyclotron and beam lines was designed in 1987, and the constructions of individual device control units and their softwares were completed in 1990. The control system was installed in the new ring cyclotron building in autumn of 1990, and final adjustments and operational tests were executed by using the softwares of control computers. After the accelerated proton beam from the injector AVF cyclotron was injected to the ring cyclotron, the computer control system has been used for the beam acceleration of the ring cyclotron. The software of this control system performs its basic facilities almost satisfactory under actual cyclotron operation.

1. INTRODUCTION

The control system consists of a computer network with a central computer (a system control unit SCU using microVAX 3500), four computers (group control units GCU using a microVAX II and three diskless rtVAX 1000's) and many control cabinet racks.[1)] The SCU computer has charge of a concentrated control of the total system, file managements and a man-machine interface. The RING-GCU subsystem (microVAX II) covers the controls of injection beam line, cyclotron magnets and injection-extraction system. The RF-GCU subsystem (rtVAX 1000) covers the covers the controls of RF system, vacuum system and cooling system. The BT-GCU subsystem (rtVAX 1000) covers the control of magnets of the beam lines. The DIAG-GCU subsystem (rtVAX 1000) covers the control of beam diagnostic devices. Each group control computer is also connected to many device controllers by an optical communication system.

The control cabinets located in the cyclotron vault, experimental halls and power supply areas, and contain universal device controllers (UDC's) which control component devices, associated local panels, the drivers of the stepping motors and AC motors, input signal multiplexers, analog-to-digital converters and interlock relays.

*Systems Engineering Development Department, Sumitomo Heavy Industries, Yato 2-4-15, Tanashi, Tokyo 188, Japan

2. POWER SUPPLIES OF MAGNET COILS

The UDC's and associated local control panels are installed within power supplies of the cyclotron coils, i.e., main coil, auxiliary coils, trim coils and magnetic-channel coils. The communication data between GCU computer and UDC are stored in the memories of UDC named a communication register (CRG).

The power supply of the ring cyclotron main coil uses a high precision digital-to-analog converter for the coil current setting, and its CRG has unique status bit corresponding to the GP-IB interface. The firmware of the power supply control for the main magnet coil consists of six tasks. Task1 starts at 200 ms intervals to initialize the GP-IB port, output a preset value, and read the current value. Task2 is a communication task, and uses the CRG as the communication area. Task3 starts at 10 ms intervals to calculate the output current value depending its cycling mode which set the ratio of the output value to the final preset value. Task4 starts at 10 ms intervals for the operation of the sequence control depending on the present status and setting commands. They are the startup and shutdown sequences, the polarity change of the output current, and the interlock and status monitorings and correspoding status transition operations. Task7 starts at 100 ms intervals for the local panel controls. Task8 starts at 100 ms intervals for the GP-IB input-output processings.

3. POWER SUPPLIES OF THE RF SYSTEMS

Power supplies of intermediate stage and final stage amplifiers were constructed since 1987 in the early stage of the construction of the ring cyclotron, the designs to control the power supplies by using UDC's were not in time. Therefore the control units including UDC's were connected externally to the power supplies already completed. On the contrary other power supplies were designed by considering the controls using UDC's together with associated local control panels, and control units containing UDC's and local control panel were included inside the power supply cabinets. The power supplies of the RF system amplifiers can be operated locally without using UDC, but other power supplies such as magnet coils of the ring cyclotron and the beam lines cannot be operated without UDC even in a local control mode.

The firmware of the power supply controls for the amplifiers of RF system consists of five tasks. They are input of actual values from an analog-to-digital converter, a communication task, output of preset value to a digital-to-analog converter, sequence controls including startup and shutdown of the power supply and checking functions of interlock and status signals, and local input-output controls.

The harmonic numbers of accelerations at the ring cyclotron are 6, 10, 12 and 18, and ratios of the RF frequencies of the ring cyclotron to the AVF cyclotron are 3 and 5.[2] These relations determine the RF phase differences between three accelerating cavities and a flat-topping cavity. The UDC for the phase adjustment of RF low level system reads the detected phase values and outputs new setting value for RF phase. The UDC for an automatic tuning of RF low level system reads an injected power from the final stage amplifier, a reflected power from a cavity, an amplitude and a phase of the input impedance to cavity.

Fig. 1. Central operator console.

4. CONTROLS OF STEPPING MOTORS AND AC SERVOMOTORS

The stepping motors are used for the open loop controls of the positions of electro-static channels, frequency tuning devices of RF power amplifiers and cavities, variable width slits and beam probes.

At power-on time, the UDC for the driving of stepping motor has no pulse value corresponding to the present position. Then a GCU subcomputer downloads the pulse value for the position at power-off time, or it sets new pulse value at either limit position used for a calibration. One UDC can control upto four stepping motors. When the UDC receives a drive command from the GCU subcomputer or a local control panel, the UDC controls the positions of a device by outputting control pulses to the driver module of a stepping motor. The UDC controls hold and brake functions and also interlock conditions if necessary.

Some position controls of RF cavities use AC servomotors with a closed loop control. One UDC can control upto four AC motors. After selecting motor number, the UDC reads the present position from a potentiometer through analog-to-digital converter, determines driving direction by comparing the present value with a preset value, and outputs driving signals until reaching to final preset position by checking interlocks relating the driving direction.

5. ADJUSTMENT OF DEVICE PARAMETERS AND DISPLAY OF DEVICE STATUS

Device states can be displayed on two twenty-inch CRT displays with touch panels of the central operator console.(Fig. 1) The screens for device status, not ready device list, fault device list and dynamic parameter value are prepared. These values are also displayed on the computer console terminals of GCU subcomputers, and are useful to check the control functions for not only maintenance aids but also daily operations.

In the early stage of the construction operational tests of the device control systems were performed at the local panels of the control units in the cabinet racks installed in and near the cyclotron vault and experimental halls. After completing installations and checks of the device control systems, their control functions were confirmed at GCU subcomputers and finally at SCU main computer.

All the control informations of each device is displayed on a memory of the UDC called communication register CRG. The subcomputers GCU's usually have updated copies of the CRG data of UDC's. According to the requests from the tasks of the SCU and the operator console, the main computer SCU gets necessary CRG data from the corresponding GCU. For each control information a proper name called operation name is assigned, the main computer and subcomputers can refer CRG data by using the operation name. After defining the operation names on SCU, the device control functions are checked from the computer console terminal of the GCU by using not bit images of the CRG but more familiar names based on the operation name. In this process the validity of the operation names can be checked. Next the control functions are checked from the operator console by using the main computer SCU. Twenty-nine processes run on the SCU with issuing mails between processes, and total software system is rather complicated. Therefore it is often to run a particular process with a debugging mode for checking purpose. After finishing these procedures, the control software itself becomes open to general operators of the ring cyclotron system in spring of 1991.

During the checking procedures of the control functions it is often to use the displays of GCU and the operator console simultaneously. A device control is initiated from the operation screen of the operator console by selecting particular cell. Then the following control result is displayed on the display of GCU, and the control function can be confirmed. They are performed by comparing device states, preset values and measured actual values on both GCU and SCU (operator console).

6. INTERLOCK SYSTEM

Device status signals used for external interlocks to other devices are collected in an interlock control unit through a signal distributer box with terminal boards and status display lights. The control unit contains a UDC and relays to output the signals for an interlock circuit. The interlock system for power supplies, a beam handling and an interface to the radiation protection system and the injector cyclotron are constructed by using hardwiring and conservative relays. Software interlocks using sequence programs, written by a basiclike interpreter-type language, are also supplementarily executed on GCU subcomputers. Processes of SCU main computer also contain software interlock facility.

Devices are controlled by UDC, and hardwired interlock signals are also connected to UDC's in an interlock unit. Many interlock units are distributed to control cabinet racks: two units for cyclotron magnet coils, eight units for RF cavities and amplifiers, two units for injection and extraction devices, six units for beam lines, and also for beam diagnostic devices and radiation protection system. The UDC for interlock handles 48 digital input signals and 16 digital output signals. Interlock signals such as flow switches of magnet coils are inputed to digital input port of the UDC in addition to the hardwired interlock circuits. These signal data are sent to GCU subcomputers and the SCU main computer. The digital output port of the UDC is an interface between the hardware interface and the software interface.

The software interlock conditions are created in GCU computers and the SCU main computer. Each digital output signal of the UDC has operation name correspondig to its function, and the software interlock conditions are outputed to UDC's by referring operation names. The digital outputs are taken into hardware interlock relay circuits. Excess beam current on slits at beam lines and in the ring cyclotron will stop beam before acceleration by using this software interlock function. After this interlock system sends an information on a selected beam line to the radiation protection system, the control system receives additional interlock data concerning a safety condition on transporting beam to the specific beam course in experimental hall. The degree of vacuum data can be also used as software interlock. Compared with the hardware interlocks the flexibility of the software interlock function is very useful for the dynamic change of interlock threshold values to actual parameters.

Another type of the software interlocks is a direct output of the interlock conditions to the UDC of power supplies and motor drives. Fault sequence programs in GCU subcomputers can control the status of power supplies and other devices by using their operation names.

7. SEQUENTIAL STARTUP AND SHUTDOWN

Operations of the ring cyclotron and beam lines consist of parameter setting to devices according to a beam condition, device startups, parameter adjustments, shutdowns and fault status handlings. For realizing an automatic sequential operation it is convenient to grouping many devices. Considering an operation unit of the ring cyclotron and beam lines, control facilities are divided to a few groups. Individual group consists of a few blocks, and each device belongs to one block. Startup and shutdown procedures of the system can be performed by three methods: operations in unit of group, operations in unit of block and operations in unit of device.

The RING-GCU subcomputer covers the controls of injection beam line, cyclotron magnets and injection-extraction system. Devices connected to the RING-GCU subcomputer belong to INJBT group or RING group. The INJBT group consists of INJBT1 block and INJBT2 block. Power supplies in the upperstream part of the injector beam line belong to the INJBT1 block, and power supplies in the downstream part of the injector beam line belong to the INJBT2 block. The RING group consists of MAINC block (power supply of main coil), AUXC block (power supplies of auxiliary coils), TRIMC block (power supplies of trim coils), MICMEC block (power supplies of injection and extraction magnetic channels), EIC block (injection electrostatic channels) and EEC block (extraction electrostatic channels).

During the coil current setting a cycling function of the coil current has been introduced as a firmware of the UDC's. In the case of the RING group startup, at first the startup sequence (ON sequence) of the MAINC block runs. When the cycling state of the main coil becomes the third state, the ON sequences of remaining AUXC and other blocks begin to run. Then the field distributions of the sector magnets of the ring cyclotron become to the desired distributions. A fault state processing procedure for discharges in the electrostatic channels is included in the UDC firmwares.

8. TREND DISPLAY

Variations of coil currents, degrees of vacuum and temperatures of cooling water can be displayed graphically on the trend display screen of twenty-inch CRT display. Three screens for the trend displays are prepared and each display shows eight parameters.

For the startup procedure of the power supplies of the ring cyclotron magnet coils, one can use the ON sequence operation of the RING group and the trend display of magnet coils. A cycling pattern of the main coil current together with auxiliary and trim coil currents can be recorded on this trend display. On the operations of electrostatic channels and RF systems one can use the trend display to show the relation between the degree of vacuum, high voltages and leakage currents for a diagnostic purpose.

9. COMMUNICATION WITH CONTROL SYSTEM FOR EXPERIMENTAL INSTRUMENTS

By using a power-line connection system one power supply can change its connection to magnet coils in beam lines and experimental instruments. Many devices in the beam lines are controlled by the SCU main computer. However it is also necessary to control some devices that are connected to SCU from experimental side for some specific precesses such as a dispersion matching beam handling.

The communication function between the SCU main computer and a control computer for experimental instruments is realized by a process named PCP (communication process with personal computers and VAX computer by DECnet). This process opens a link to other computers with a name of PCP-PORT, and it is necessary that the control computer for experimental instruments establishes a logical link to this port.

The PCP process treats functions such as connection-disconnection of the communication, conversion from operation names to operation name numbers for the speedup of data access, device parameter transmission and adjustment, device on/off operation, device status monitoring and operation and data transmission of beam profile monitors.

A VAX computer in the counting room performs the man-machine interface of the control system for experimental instruments and is connected with intelligent VME crates for the control of experimental instruments and the SCU computer. The uses of control functions by this remote VAX computer are now open to users of experimental instruments.

10. INITIAL OPERATIONS OF THE RING CYCLOTRON

Software of the control system has been constructed assuming the usage at final stage of the particle acceleration. For example, the interlock checks is to be executed from beam injection to beam dumps in the experimental halls. However an initial beam test of the ring cyclotron was restricted to the beam injection part, and it is necessary to modify both hardware and software interlock sequences depending on particular test purpose.

The group and block start/stop facilities have been used partly at initial beam acceleration period. The start and stop sequences of injection beam line group and cyclotron magnet group have been executed several times upto now, but the startup procedure of devices for RF system is executed manually one by one. The data of accelerated particles and their energies are limited to a few cases for the present and the data on frequency and position relations of cavities and relating devices have not been included in the software properly. Therfore an automatic frequency tuning procedure for RF system is not yet completed now.

During the initial startup procedures the use of a trend display is very useful for the checks of operation itself and firmware contents of the UDC's such as cycling procedure at startup time of the power supplies of magnet coils. For the startup procedure of high voltages of RF cavities and electrostatic channels rather complicated time sequences are considered, and their operations were confirmed together with the variation of degree of vacuum in the cyclotron chamber and also leakage currents.

Interlock system concerning with beam stopper and radiation protection system was tested for hardware wiring only using actual ring cyclotron operation, and the tests for software interlocks is left for future beam acceleration. Trivial troubles on the operations at the central operator console were temporarily fixed by using the console terminals of the GCU subcomputers, and the softwares of the SCU computer are updated later by including this operational experience.

During a beam injection process of the ring cyclotron many beam diagnostic devices such as slits, beam profile monitors and beam viewers have been applied, and many checks on device position and beam current measurement including noise current observation were done. For slight beam current the lack of beam viewers in injection part of the cyclotron made the beam tranport procedure to be difficult. Continuous measurements on reliability and reproducibility of the control system are necessary for the present particle accerelation period.

11. CONCLUSION

The accerelated proton beam from the injector AVF cyclotron has been injected to the ring cyclotron and the computer control system is used for the beam accereration of the ring cyclotron. The software of this control system performs its basic facilities almost satisfactory under actual cyclotron operation.

12. REFERENCES

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