PC BASED RF CONTROL SYSTEM FOR THE VINCY CYCLOTRON

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The concept and design procedure for the RF control system of the VINCY cyclotron are described. Special attention has been paid to the choice of computer support of this system. The merits and limitations of the chosen solution have been analyzed. A PC type computer has been selected as the platform for performing the functions of initiation, control, and supervision of the RF system. The integration of the hardware is carried out by direct connection to the PC bus and via standard communication interfaces. The system software operates under a graphic oriented Windows operating system applying the modern concept of virtual instrumentation. The application of this concept allowed considerable simplification of the operator-RF system interaction and resulted in additional flexibility of the software to further extensions or modifications of the system. The selected open architecture of the computer platform allows a simple and economic upgrading of the realized system in accordance with future requirements. Tests of the realized RF control system prototype are in progress.

1 Introduction

The radiofrequency (RF) system is a key part of a cyclotron. A quality beam of accelerated particles requires a high stability of the RF system. In order to achieve this requirement the RF system control should ensure a dynamic control of the amplitude and phase of the accelerating voltage and the control of the resonant frequency of the resonator. In addition to this basic requirement, the control subsystem of the RF system should provide the control and indication of all operating parameters of the control mechanisms significant for a good operation of the RF system.

The control of the amplitude and phase is, as a rule, accomplished by fast analogue RF circuitry [1]. A digital wideband control of the amplitude and phase of the accelerating voltage implies digitalization of the RF signal, processing by a suitable algorithm, and D/A conversion to an analogue form. The capacities of modern digital signal processors are still inadequate for a real-time control of this procedure.

In the areas of control of the amplitude and phase modulators and tuning of the resonant frequencies of resonators the solutions based on digital signal processors are present [2].

Modern systems for control of RF systems are mainly realized in accordance with the standard model of accelerator control systems [3] irrespective of specific requirements that may arise in the course of implementation.

The computer support of the control subsystem of the RF system of cyclotron VINCY is used for tuning and monitoring operating parameters of the RF system. The core of this system is an industrial PC offering the merits of an open software and hardware architecture.

2 RF Control System Design

The RF system of VINCY cyclotron consists of: two $\lambda/4$ resonators, two amplifier chains, coupling lines, control subsystem, and safety subsystem [4]. The control of the amplitude and phase of the RF signal applied to the accelerating electrodes and control of the resonant frequency of the resonator are effected by the respective feedback systems. Putting into operation, setting the operating parameters of control mechanisms, and monitoring the operating regime of the RF system are performed by the industrial PC extended by the standard I/O and acquisition control cards. The parameters set and monitored by this computer are: frequency of the RF synthesizer, amplifications of the programmable amplifiers/attenuators, signal amplitude, signal phase, resonant frequencies of the resonators, positions of sliding shorts, and delay times of the delay lines.

The basic components of the control subsystems of VINCY cyclotron are:

- computer console which enables interaction of the operator and the RF system; it also realizes the connection between the RF system and the control system of the whole installation;
- instrumentation rack containing RF modules (amplitude and phase detectors and modulators, delay lines, and programmable amplifiers/attenuators);
- termination chassis accommodating analogue and digital input/output termination panels used for interconnections, conditioning of signals, galvanic separation of signals of RF amplifiers and resonators.

The control of the RF system of cyclotron VINCY is based on an industrial PC ADVANTECH PCA-6147 which unites the functions of the RF console and the instrumentation rack containing RF modules. Fig. 1 shows block diagram containing interconnections between components of the control subsystem and the industrial PC via a PC bus and standard communication interfaces. The available slots, extending the capacity of the industrial PC are used to mount acquisition cards used for acquisition of analogue and digital signals and adjustment of digital and analogue control signals. For the purpose of digital control of the programmable RF modules, a 16-bit extended bus has been designed. The signals from acquisition cards are connected to the corresponding termination panels accommodated by the termination chassis.

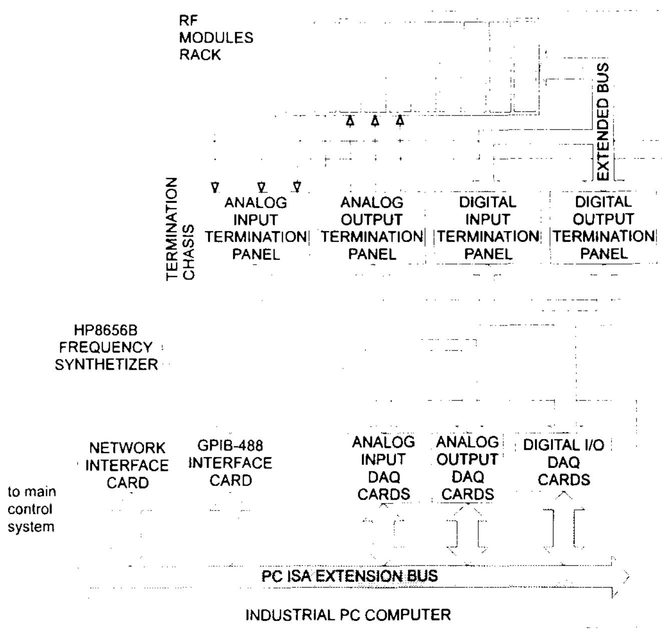

Figure 1: Interconnections between components of the RF control system and the industrial PC

The connection of the PC to the signal generator HP8656B is realized by a PC compatible IEEE-488 communication interface. The communication of the computer console to the control system of the installation is provided by adding a Ethernet network adapter to the PC. In this way the control of the RF system is included in the structure of the global control of the cyclotron.

3 The Software

3.1 Operating System

The choice of the operating system (O.S.) in real time systems is of considerable importance. Such an O.S. implies that it responds within an envisaged time to an unpredictable external stimulus. This means that upon a request is addressed to the processor, the O.S. should react within a specified time interval even if several events occur simultaneously. This requirement could be met if the O.S. allows simultaneous multitasking, assigns task priorities, and that it can interrupt a running task and allocates the processor another task. The evaluation of the ability of the O.S. for real time operation requires that the delay in processing an interrupt, the delay caused by any system call, and the maximum time during which the O.S. can mask an external interrupt are known.

Windows NT is an O.S. which supports multitasking and preemptive scheduling. The priorities of tasks have been resolved by introducing two classes of tasks: real-time class and dynamic class. The mechanism of interrupt processing by Windows NT is split to two phases. During the service phase of the interrupt routine the most critical operations are processed (e.g. write/read of hardware registers) and the postponed procedure is called. During the phase of the postponed procedure most of the operations related to interrupt processing are performed. The postponed procedures of all interrupts coexist in a sole queue waiting for the processor; this is the main reason that the length of a system call can not be envisaged. Some of the postponed procedures (therefore system calls) in Windows NT may require milliseconds. An example is that the length of system call MUTEX in a 100 MHz Pentium may last from 35 μs (95%) up to 1 ms (10^{-4} probability) [5].

The preceding analysis leads to the conclusion that Windows NT could be used in real-time systems involving weak time restrictions (soft real-time systems) whereas its use in systems involving strict time restrictions (hard real-time systems) is debatable.

The use of Windows NT graphical operative system could offer many merits. For Windows Application Programming Interface there are numerous good quality, commercially available, and cost effective development tools. A number of software engineers are using Win32 API, therefore the practical experiences are considerable. A graphical operating system offers a possibility to realize a classical user interface in a modern way by using the concept of virtual instrumentation. This means that toggles, switches, pots, analogue indicating instruments, and other hardware elements of a classical user interface could be realized on the console monitor in a clear and graphically acceptable manner. The merits of this concept are flexibility in organizing a user interface and economic modifications or extensions.

3.2 Software design

The application software of the control subsystem of the RF system of cyclotron VINCY covers the following functions: initialization, control, and monitoring. The realized software allows that these functions are performed either via the central control system of the whole installation or locally in an entirely autonomous mode. The concept of the autonomous operation of the RF system is significant for initial start-up of the installation, for testing parts of the equipment, for servicing parts of the RF system, etc.

The developed software application is carried out by an industrial PC under Windows NT operative system. The computer support of the RF system control belongs to the class of so called soft real-time systems where the response time to an external stimulus is not critical. The nature of the application is such that the emulation of the complete user interface serving for operator control of the RF system is done by the computer console. Operator's requests for changing the value of a parameter or for updating the indication of a system parameter are not timewise strict activities. In addition, the number of different events treated by the application is relatively small (acquisition and setting of approximately 50 parameters).

The realized solution, based on a 486DX-66 PC and the graphical operative system Windows NT, offers a good performance for monitoring and setting the parameters of the RF system. The currently accomplished performance warrants that all signals will be read and all parameters will be set 10 times per second. Owing to non-deterministic nature of Ethernet, the response time is not critical during data exchange with the global control system.

The software of the control subsystem of the RF system of cyclotron VINCY has been developed using Lab Windows CVI [6]. The development of the software in C language has been combined with the concept of virtual instrumentation.

Programming in ANSI C language allows complete flexibility and portability in the course of software development. Thanks to these properties, the PC compatible acquisition hardware has successfully been incorporated in the RF system of cyclotron VINCY. For this hardware the drivers for Windows environment have been realized using C language. In addition to standard ANSI C libraries, Lab Windows CVI also contains libraries supporting standard communication interfaces and protocols (e.g. IEEE-488 and TCP/IP).

The concept of virtual instrumentation has the advantage that it is programmed in an environment possessing ready-to-use elements of the graphical user interface, so the process of software development is considerably accelerated and the extent of source code is considerably reduced in comparison with classic compilers for Windows.

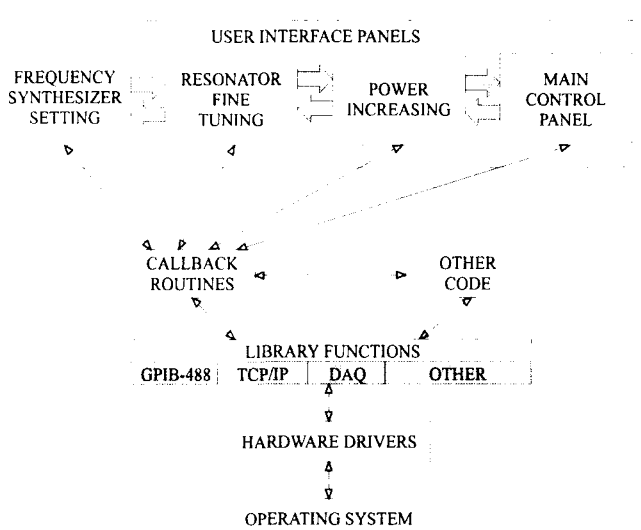

Figure 2: The RF Control System software architecture

The development and testing of the complete application for control of the RF system of cyclotron VINCY has taken six man-months. The source code of the application in C language contains 5000 source code lines.

The structure of the application programs developed in the Lab Windows development tool is multilayer (Fig. 2). The highest level makes the user interface performing the communication to the user. Upon detection of an action directed toward an element of the user interface, the call is made to the code representing the reaction (the so called call-back function). In the software hierarchy below the call-back routines the layer of libraries performing standard tasks is placed. This layer contains TCP/IP libraries, GP-IB communication, and the specific drivers developed for the add-on acquisition hardware. The lowest level is the level of the operative system.

The procedure of the realization of the application software can be split in two phases. The first phase comprises detailed specifications of the user interface in accordance with the concept of virtual instrumentation. The designed user interface is realized by means of the different ready and adjustable elements (panels, digital and analogue instruments, switches, toggles, etc.). The second phase is allocating and coding the corresponding call-back functions to the elements of the user interface in accordance with the event-driven programming.

3.3 Graphical User Interface

The user interface of the application program for control of the RF system is organized as a set of panel-screens (top layer identified on Fig. 2). Each panel contains information of interest for the corresponding phase of adjustment of operating parameters of the RF system of cyclotron VINCY.

At the outset, an automatic initialization of all RF system resources is carried out. A user is then supplied with a panel for adjusting the operating frequency of the RF system. According to the selected frequency, a whole series of static parameters is adjusted (the positions of sliding shorts, delays of the programmable delay lines, and the programmable attenuators). The next step in the start-up of the RF system is the fine, manual adjustment of the resonant frequency and of signal phases on duants. When the values of these parameters are brought to the dynamic ranges of the regulation mechanisms, the user is allowed to switch to the panel for increasing the amplitude of the accelerating voltage (the power of the RF amplifier). A manual increasing of the power applied to the resonators is monitored on the panel by the corresponding indicators of the resonator powers. On appearance of a spark the input signal of the RF amplifier is inhibited until the state of the system is stable again. When the desired power on the resonators is reached, the main operating screen appears on the console screen (Fig. 3) and this screen allows switching to automatic operation of the mechanisms for control of phase, amplitude, and resonant frequency.

During a normal operating regime all important parameters of the installation are available to the operator subject to his minimal interventions. The normal shut-down procedure for the RF system is the opposite of the switch-on procedure. In case of an emergency shut-down by the autonomous safety system, the operator is given the corresponding warning and until the cause of this emergency is eliminated the operation of the system is disabled.

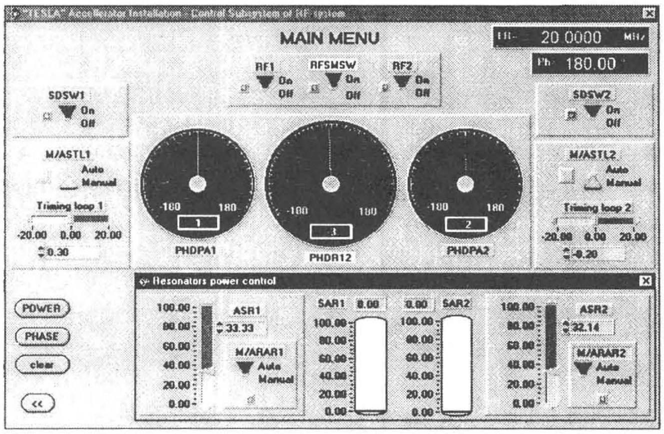

Figure 3: The Main control panel

The switch-on of the RF system and its control in a normal operating regime is possible either in the local or the remote mode of control. In the local mode of control the PC operates autonomously and processes the graphical user interface. In the centralized mode of control, the PC inhibits all possible actions from its keyboard or mouse and the PC only monitors the state of the RF system. All operating parameters of the RF system are adjusted and monitored by the central control console of the installation. A dedicated LAN enables communication to the local computer serving for direct adjustment of the RF system parameters.

4. Conclusions

The paper presents a practically realized computer support of the RF system of cyclotron VINCY and could have some significance for considerations of practical realizations of new RF systems or modernization of the existing ones.

The realized solution offers the possibility of choosing commercially available software and hardware platforms, thus it is very flexible as regards the software and hardware maintenance, modification, or specific adaptation. The user interface, realized by applying the concept of virtual instrumentation, allows intuitive and simple operation reducing the length of training of the operators of the RF system. A massive use of PC's and the investments in the corresponding PC support industry make the realized solution economic and cost-effective.

Further improvements of the performance of the realized system are possible by decoupling the function of presenting the state of the RF system and interacting with the operator from the function of monitoring the parts of the RF system.

The existing industrial PC could be used for performing a part of activities is does now: the support of the graphical user interface and the communication to the global computer of the central control system.

A separate, PC based, embedded computer devoted to monitoring the parts of the RF system could be provided with a real-time operative system. In this way the RF control would be made more suitable for use in the central control of the accelerator which is based on adaptive techniques of the production of beams of accelerated particles.

An improvement of the performance of the graphical presentation of the state of the RF system and communication to the operator would be accomplished by replacing the motherboard of the 486DX-66 PC by a commercially available singleboard computer including a processor of class PENTIUM and a PCI bus.

A possible shortcomings of the realized solution caused by the centralized architecture of RF system control are to a great deal overcome by choosing high quality, reliable components of the industrial PC.

References

[1] A. Bosotti et al., *CERN Library*, INFN/TC-89/12, (1989).

[2] K. Fong et al., *1995. Particle Accelerator Conference*, Dallas, TRI-PP-95-27, (1995).

[3] Pak C.O. et al., *Proceedings of ICALEPS*, Tsukuba, KEK Proc. 92-15., (1991).

[4] V. Drndarević et al. , *Proceedings of the Eighth Information Meeting on the TESLA Accelerator Installation*, Belgrade, 55 (1996).

[5] M. Timmerman, J.C. Monfret, *Real-Time Magazine*, www.realtime-info.be, (1997).

[6] *LabWindows CVI Reference Manual*, National Instruments Co., Austin, Texas, USA, (1995).