LABVIEW AND MATLAB-BASED VIRTUAL CONTROL SYSTEM FOR VIRTUAL PROTOTYPING OF CYCLOTRON*

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Abstract

A virtual control system designed to control and monitor the process of a cyclotron virtual prototyping is presented in this paper. Based on the feature of cyclotron, a distributed control structure is proposed according to the knowledge of software engineering. LabVIEW is employed to develop human machine interface(HMI), sequential control, safety interlock, and MATLAB is used to implement analysis and simulation. Dynamic data exchange (DDE) supported by Win32 Platform SDK is adopted to process data exchanging by a Server/Client mode. Any additional functions can be extended easily in this system in future.

INTRODUCTION

Based on the cyclotron theory and virtual prototyping (VP), a compact cyclotron virtual prototyping system (CCVPS) is being developed, which implements the innovative design of the cyclotron and avoids risks mostly [1]. The framework of CCVPS takes into account the needs of manufacture, assembly/disassembly, operation, and maintenance in a virtual environment during the design phase. In order to guarantee the reliability of CCVPS, Augmented Reality (AR) technique is used to integrate the virtual environment and experimental subsystem. The over all lifecycle models of the compact cyclotron via CAD system includes cyclotron virtual design, modelling, virtual assemble/disassemble, virtual manufacture, virtual commissioning, virtual operation, virtual maintenance, and other relevant domains. It can be used to reduce the physical experimental prototype.

As a sort of super accurate and sophisticated equipment, cyclotrons require highly automated control system [2] in order to make the total system work reliably, steadily and safely, so virtual control system is a vital section in virtual cyclotron. As well known, cyclotron control system is responsible for the supervision of system parameters and the control of logic interlocks. This paper discusses to apply virtual instrument, MATLAB and Visual C++ to build a cyclotron virtual control system, which can simulate the real control system to operate virtual cyclotron. It provides a friendly interactive interface allowing designers to track and control the design process. Using the virtual control system, Engineers can test their ideals, find defects and then make modifications in earlier time that far reduces design works. Also the virtual control system can be used as a simulator for the purpose of training operators off-line.

THE VIRTUAL CONTROL SYSTEM ARCHITECTURE

A cyclotron virtual control system can be divided into three parts in the framework: Subsystems and Controllable Components, Control Logic and Interlocks, control algorithm. Subsystems and Controllable Components mainly includes cyclotron control subsystems like vacuum, magnet, RF etc. and all controllable components such as gas valves, electro motors and stripper. These models have information on objects, control methods, I/O, geometrical and physical characters. Control Logic and Interlocks is a regulation library including interlocks that promise correct and safe system running and sequential logic for cyclotron routine operation such as system start-up and shutdown in automatic/manual modes. Control Algorithm is a software library covers control-system algorithms most widely used in engineering, which can be embed into particular component model.

When designing the virtual control system, some requirement must be considered:

- Control subsystems should be integrated into the virtual control system easily.
- The programming system for application programs should be programmer-friendly.
- Incremental amendment and extension should be possible.
- To minimize man-power and efforts, the international collaboration or commercially available products should be applied.

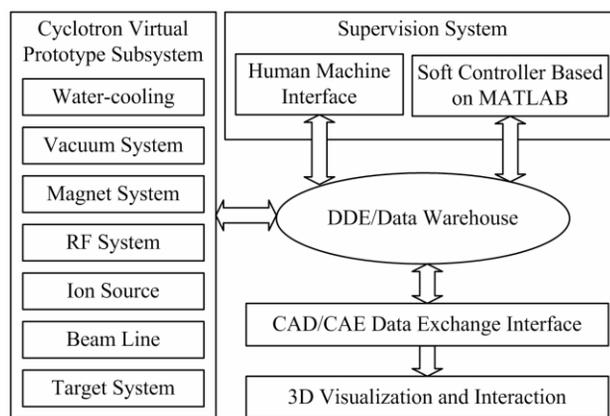The system is developed on Windows 2000 operating system. Figure 1 shows the virtual control system architecture.

Figure 1: Virtual control system architecture.

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As a support module, cyclotron virtual prototyping subsystems, such as water-cooling, vacuum, magnet, RF, ion source, beam line, target, which simulate the physical prototype, provide real-time parameters for supervision system through D/A. Accordingly supervision system receives data through DAQ (Data Acquisition) card, and processes integrated data handing subsequently. After the control algorithms are designed, analyzed, checked and optimized, supervision system transfers the control signals back to the subsystems; therefore establishes a close control loop. At the same time, supervision system takes charge of the running status and accomplishes logic and interlocks control. In this complete system, CAD/CAE data exchange interface is a bridge of control system and 3-D graphic library.

SYSTEM ANALYSIS

Human machine interface

LabVIEW is a sort of graphical programming software which provides a friendly human machine interface. Because it is very easy to learn and has high stability as well as powerful technical support, it is the most universal software in the visual simulation field. Considering the predominance of LabVIEW, we build this human machine interface (HMI) with LabVIEW. Figure 2 shows the main interface of this system.
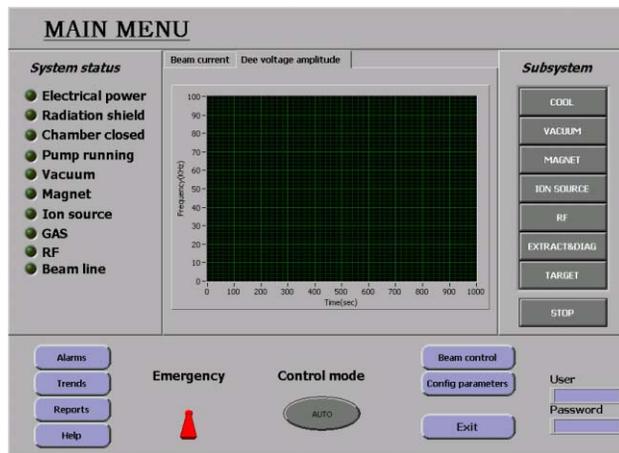

Figure 2: The main interface of cyclotron.

State machines have been adopted in the framework of the HMI program. State machines revolve around three concepts: the state, the event, and the action. No state machine operates effectively without all three components. The only information external code should give to the state machine is an event that has occurred. Under no circumstance should external code be allowed to change the current state, moreover, the current state is not normally given to code external to the state machine. Changing state and dictating actions to perform is the responsibility of the state machine. We define the essential virtual prototype subsystems: water-cooling, vacuum, magnet, RF, ion source, beam line, target as states of a state machine which transfer from states when an event is occurred. Events are the external operation,

such as, start-up, turn on water-cooling system, and start vacuum system. The action decided by the current state and the occurred event execute internal operations of each subsystem. This structure makes the codes easier to maintain, easier to document, and easier to reuse.

The principal functions fulfilled of the HMI are as follows:

First, it is the basic task of HMI to monitor the inputs and outputs, so runtime parameters are obtained by DAQ and displayed synchronously. Especially some important parameters are displayed in graphs in order to make observe more directly. At the same time, system running status and interlock state are also showed by indicators.

Second, it provides virtual cyclotron with mature sequential control logic which ensure cyclotron run steadily. There are two operation modes: manual mode and automatic mode and each mode include normal working and debugging situation. The debugging situation is to meet the need of assembly and debugging of subsystems.

Third, when cyclotron is running, its components have high voltage and it shall deliver some harmful radiation, such as, γ-ray. Considering personal safety and equipment safety, security interlock control logic must be thoughtful. In all operation open water-cooling system is the precondition. Only when chambers are closed and vacuum is ok, cyclotron can be started. Only when there are definite flow of cooled water flowed through target, ion source and magnet coils, etc, beam can be shoot to the target. Only when radiation shields and radio frequency shields of ion source are closed, beam can be extracted. Only when the dose in the cyclotron chamber is lower than limited value, the defend door can be opened.

Fourth, much useful information is stored in database so that other sections can call real time data needful from it. On the other hand, historical data in the database also can be invoked for survey past running states. This function is of benefit to maintenance and overhaul.

Fifth, as guidance, logging, trend and report with friendly dynamic graphic indicators are important assistant tools. Malfunction alarm is also necessary. We have defined the value range to parameters, and then it will alarm if the actual value are out of the limitation. Besides control buttons can be shown or hided by control logic to avoid operation mistake.

Soft controller based on MATLAB

As have mentioned above, LabVIEW has a friendly graphical interface, but it is difficult to implement complicated control algorithm. MATLAB makes up the shortage of LabVIEW. The SIMULINK toolbox in MATLAB package provides interactive model input and simulation environment for dynamic system simulation. Most kinds of running state and failure state can be denoted by changing model variables so it is convenient to study intricate control algorithm and optimize control parameters.

Whether the holistic performance of cyclotron reaches optimum condition depends on the working status of

subsystems. Normally subsystems must be tuned time and again. It is realized more easily in software environment. Soft controller based on MATLAB is such a platform which can be expanded for further algorithms. It is helpful in understanding the principle, studies and optimal design of cyclotron. The choice of parameters can also be tested by this system. Figure 3 shows its simulation flow chart.
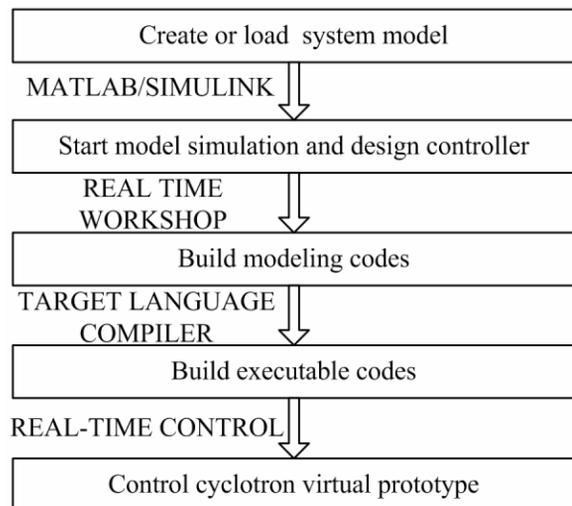

Figure 3: Simulation Flow.

For example, the RF system has two main functions in the cyclotron: pulling the ions out of the ion source; accelerating the beam by giving the ions four energy kicks per orbit revolution in the cyclotron. The Dee voltage of the RF system is a pacing factor which affects ion quality and beam current. However, it is not stable because there are temperature distortions of RF cavity that results in detuned Dee circuit and changes of ion source's work condition. The fluctuation of RF oscillator/ modulator can also impact Dee voltage. To improve the stability of Dee voltage we can a add negative feedback loop into RF system circuit. That can be completed better in MATLAB. First it is to create system model and design controller according to characters of model. Then in SIMULINK circumstance, modify simulation parameters to reach the system requirement. By real time workshop (RTW) control algorithm is converted to executable codes that are used to process real-time control study. In the process of real-time control parameters can be modified on-line to implement optimization.

Dynamic data exchange/database

The essential of virtual cyclotron is to use an exact digital model to simulate all activities of accelerator during its lifecycle. Huge data will exchange among subsystems, HMI, controller, etc. Therefore, an efficacious database is very important.

Dynamic Data Exchange (DDE) is adopted to communicate with database. DDE implement data exchanging by a Server/Client mode. We use Visual C++ as master control program which working in the background. The real time data obtained from DAQ are

stored in some location of database. LabVIEW and MATLAB can access database as clients. DDE ensures information is available for immediate querying and analysis by clients.

CAD/CAE data exchange interface

The model library created by CAD/CAE includes at least the following information: geometry structure of the cyclotron and its parts, the position and link relation of the parts, physical properties and its main parts, particle beam information, and so on. The cyclotron virtual prototype can simulate its physical process realistically under the virtual control operation and show directly on the model. CAD/CAE data exchange interface provides a dynamic channel to exchange information between control system and 3-D graphic library.

CONCLUSION

This paper introduces the framework design for the virtual control system of the cyclotron virtual prototyping. It can simulate processes during cyclotron running with well-designed HMI. The system is of flexibility and extensibility due to the easy program language. So it is really useful before lab experiment and hardware design for cyclotron. It gives a clear direction to the design of cyclotron control system and the entire optimum design of cyclotron system.

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