STUDY ON PXI AND PAC-BASED HIL SIMULATION CONTROL SYSTEM OF CYCHU-10 CYCLOTRON

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Abstract

Using the technology of hardware in loop (HIL), control system simulation model of the CYCHU-10 cyclotron is developed with real-time, simulation and statechart module under the LabVIEW environment. A prototyping design method based on NI PXI operation condition virtual platform and PAC controller is presented. The result indicates that the platform is feasible and effective in completing control system test under hardware virtual environment and shortening development time.

INTRODUCTION

The core problem of cyclotron control system design is how to ensure the high availability (HA) of the control system which involves the reliable operation study, failure mode and detection algorithm analysis, and avoidance of conflict strategy research. Hardware-in-the-loop (HIL) simulation is becoming a significant tool in prototyping complex, highly available system, especially when a portion of the given system is a simulation algorithm and a portion of the same system is a hardware implement. HIL technology is introduced into CYCHU-10 control system design, prototyping and testing because of the complex internal algorithms, possible catastrophe if failed in the testing, and difficulty in building a laboratory test environment with fully real system [1].

In order to improve efficiency and reduce risk, our team has accomplished the whole machine running simulation by use of virtual prototyping (VP) technology relied on the existing control design tool, experimental data and operating experience. But from off-line simulation to prototype test, it is impractical to proceed under fully real facility environment in consideration of safety, feasibility and cost. This paper describes a HIL simulation platform based on NI PXI, PAC and LabVIEW, which accelerating the controller validation test under hardware virtual environment, and shortening the design cycle.

THE HIL SIMULATION SYSTEM

The purpose of the HIL simulator is to achieve an interaction between a real implement of a closed-loop control system and a simulated plant. There are many commercial off-the-shelf (COTS) tools for HIL, such as dSPACE, xPC target, RT-lab [2], etc, which are widely used in the fields of auto industry, aerospace and weapon manufacturing. But dSPACE development tools are expensive while the data acquisition board of xPC Target may bring some inconvenience to user. With the evaluation of performance, learning time, acquisition cost and required coding, we choose NI LabVIEW to simulate a plant model with real-time hardware and add real-world I/O to the model created in Simulink software environment.

Hardware Structure

The HIL simulation platform consists of host station, PAC controller, PXI simulator, and external actual auxiliary system (see Fig. 1).

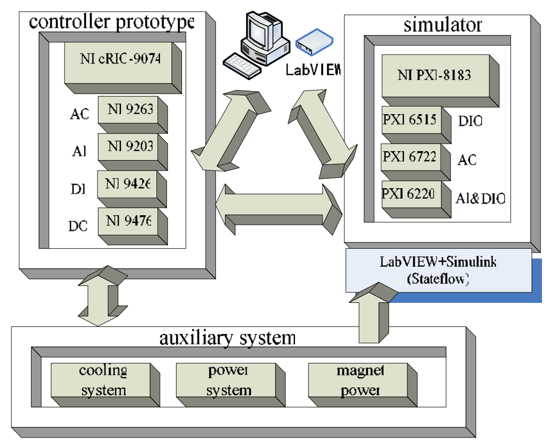

Figure 1: Hardware structure of HIL platform.

- The host station is an industrial PC with a Windows operation system, which serves as the user interface (see Fig. 2) adopting network sharing variable technique and allows user to edit and modify models with any popular model builder software such as LabVIEW. In addition, it also used in fault inserting, parameter configuring, and data recording.

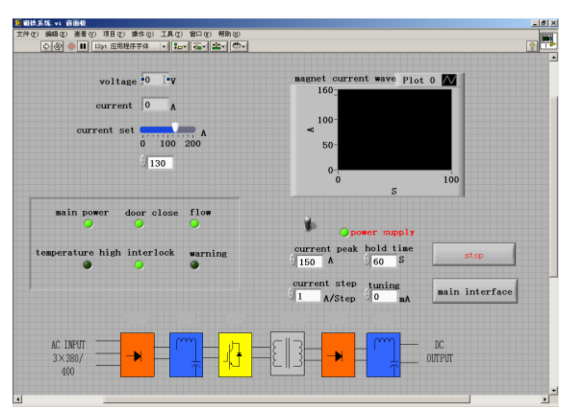

Figure 2: GUI of magnet power supply.

- NI compact RIO platform (Programmable Automation Controller) is used as rapid controller prototype running feedback control algorithm. NI 9203 module (AI board) reads not only the pressure,

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vacuum degree, ion source voltage and current, motor position, beam amplified current, and phase load from cyclotron simulation model, but also the real temperature and conductivity signal from the existing cooling system. NI 9263 module (AO board) sets the parameter of Dee voltage, motor speed, flow of hydrogen and current in ion source. NI 9426 and 9476 (DIO board) mainly treat with the interlock signals, valve on/off, water flow switch and contactor in the power distribution system.

- PXI simulator builds up a whole model of CYCHU-10 cyclotron based on graphical programming language, which can reflect the system response under various conditions in the real time. In order to guarantee the fidelity of a real running cyclotron, PXI system needs to embody all kinds of working conditions such as automatic operation, manual operation and faults maintenance. Configurable parameters supplied by the simulator allow the user to rapidly investigate interactions between components or to explore the influence of design parameters on system performance.
- Auxiliary system includes power distribution system, high precision magnet power supply and water cooling system. In the HIL simulation, these equipments are connected to each load in close loops for the purpose of acquiring real time test data.

The host PC, controller and simulator exchanges data through the field bus and the auxiliary system transfers the real time signals to the PXI and PAC by means of sensors, actuators or serial communication module of its own. In addition, the PXI simulator also modifies the cyclotron model dynamically by inverse operation of the acquisition signals such as temperature, water level, conductivity, *etc*. One of the most important characters of the PXI simulator is the ability to change among different working conditions, even the extremely error pattern. For example, it can simulate the system response when Dee sparks, flow deficiency in RF subsystem, grid power supply error or diffusion pump temperature switch operation, *etc*. These test items are significant to improve the reliability of control system, and HIL simulation is beneficial in both cost reduction and risk control.

Software Design

As an effective and extensive use tool, Simulink is suitable for modelling, simulating, and analyzing complex dynamic system like cyclotron. Beside, its statechart module which complements Simulink with its handling of event-based system can describe the sequential control process of CYCHU-10 graphically. So we firstly create the finite state machine (FSM) off-line model of the subsystem of vacuum, RF, ion source and so on. Then separating the model into target part and main control logic part, and introducing respectively to the PXI and PAC real time HIL simulator via interactive environment between LabVIEW and Simulink. This hybrid programming method based on the comparative advantages of different development packages increases the efficiency and reduces the repeated work. The Simulation Interface Toolkit (SIT) Connection Manager in LabVIEW can connect real time signal to the input node of the Simulink model to ensure determinism and change the parameters or introduce parameters on text in the process of simulation, contributing to the regulation of multi-parameter complex system like cyclotron. Moreover, the use of statechart module is helpful to the control system modelling based on state transition and event driven.

HIGH AVAILABILITY OF HIL

The definition (see Eq. 1) shows that availability is proportional to the Mean Time Between Failures (MTBF). A failure has some Mean Time To Repair (MTTR). The key techniques used to build a high availability system are 1 modularity, 2 fail-fast (means either operate correctly or stop immediately), 3 independent failure mode, 4 redundancy [3] .These concepts embody both in the software design and the hardware construction. NI hardware itself has the outstanding performance of availability and the characteristic of modularity. So we put more emphasis on the part of software. The software structure in Figure 3 is modularized and the reboot files are a valuable tool for running infrastructures that provide services with high availability requirements. The Simulink (stateflow) model in Figure 4 indicates that special fault handling modes are designed to tolerate fault (means to detect the fault, report it, mask it, and then continue service while the faulty component is repaired offline).

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \quad (1)$$

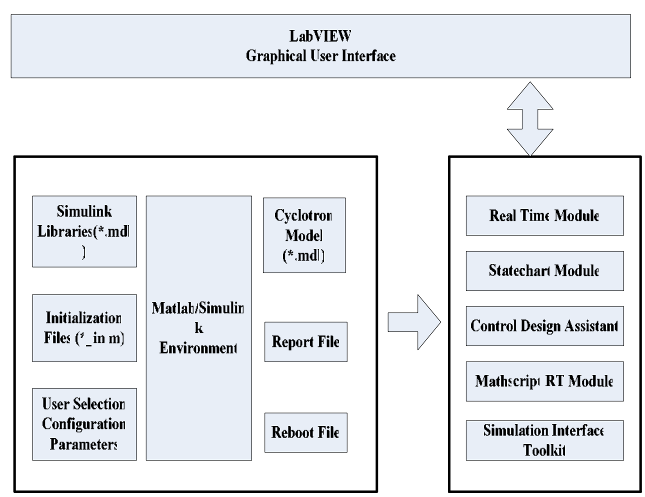

Figure 3: Software structure of HIL platform.

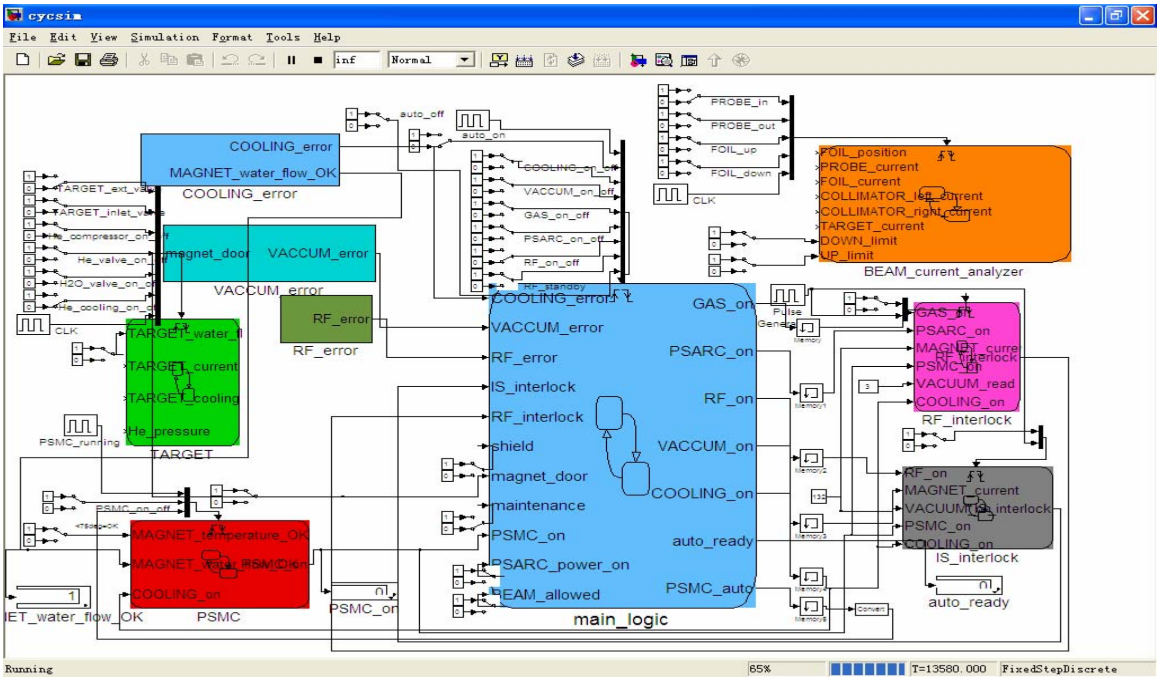

Figure 4: Simulink model of CYCHU-10 cyclotron

CONCLUSIONS

On account of the particularity of cyclotron, the reliability is the primary consideration for control system designer. NI software and hardware are widely used in accelerator measure and control field, such as LHC in CERN, KIRAMS-13 in Korea, XAFS experimental system in IHEP, etc. But we can not find many researches on cyclotron HIL simulation system. The HIL close-loop between controller rapid prototyping on the PAC platform and working condition simulation on the PXI hardware can avoid accidents within controlled extreme test environment. Furthermore, the components characteristic of high real-time property can verify the controller function precisely, correct the system design without delay and greatly reduce the development time.

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