The Implementation of KTX Central Control System

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***Abstract*–KTX is a new reversed field pinch (RFP) device, and the Central Control System (CCS) for KTX is developed to integrate, harmonize and supervise all of the control subsystems. The new control system includes graphical user interface (GUI), discharge process control module, timing system, safety & interlock system, gas injection module and shot information server. The details about the central control system architecture and components will be described in this article.**

I. Introduction

THE Keda Torus eXperiment (KTX) is a medium-sized reversed field pinch (RFP) device, designed and implemented jointly by the University of Science and Technology of China (USTC) and the Institute of Plasma Physics at the Chinese Academy of Science (IPPCAS). It consists of the following major parts: vacuum vessel, conducting shell, Ohmic field (OH) coils, toroidal field (TF) coils, equilibrium field (EQ) coils, active feedback control coils and the supporting structures [1]. All the components fabrication and assembly completed in August 2015, and the new machine get the first plasma at 15th August with 108KA plasma current.

The Central Control System (CCS) for KTX is developed to integrate, harmonize and supervise all of the plant systems, almost all the systems are implemented by using PXI devices, and the software environment is LabVIEW Real-Time. This paper will present the description of the system design, and the details of the implementation of the CCS components.

II. Architecture of Central Control System

The CCS is the core of KTX experiment's management system to coordinate all of subsystems according to pre-set value and logic. The new control system which is based on PXI (PCI extensions for instrumentation) bus devices and virtual instrument technology provides setting parameter and control to subsystems. The main functions of the CCS are as follows:

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1.Kindly GUI for operators;
2.Process control and operation supervision;
3.Synchronization and timing service;
4.Interlock and safety protection;
5.Vacuum valves control;
6.Provide shot information;
7.Network maintenance.

The new control system is composed of central console, discharge control module, central safety & interlock, timing system, gas injection module and shot information server. It's connected with the KTX machine and other subsystems by a set of networks. The structure of central control system is illustrated in Fig. 1.

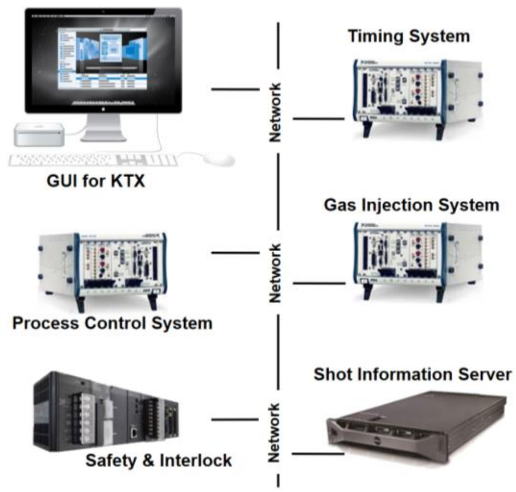

Fig. 1. Structure of KTX central control system

III. Central Control System Components

A. Central Console

The central console in KTX control room offers operators kindly interface to control the remote subsystem during the whole discharge season. The shot information, including current shot number and countdown, is shown in main interface. With the central console, control orders and values can be preset in the fold menu, such as discharge system configuration, subsystem parameter setting, timing and synchronization setting, and so forth. Parameter archiving and history recall functions are also integrated.

B. Discharge Process Control Module

The discharge control module which is used to control the logic of the discharge. The system hardware is implemented in PXI standard. The PXI platform is composed by: (i) a 8-slot chassis features a high-bandwidth backplane with PXI capability in every slot; (ii) a Commercial Off-The-Shelf (COTS) controller equipped with an Intel Core 2 Quad Q9100 CPU and 4G 800 MHz DDR2 RAM; (iii) a high-speed multifunction data acquisition (DAQ) device with 16 bits analog-to-digital converter (ADC) resolution [2]. Discharge process control module is the hinge of the whole control system, controlling, monitoring, and harmonizing the system responsibility. The discharge operation flow in KTX is illustrated in Fig.2.

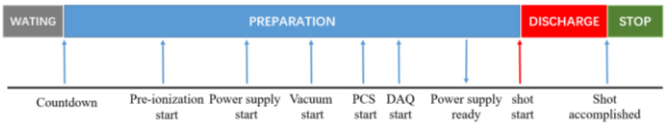

Fig.2. Discharge operation flow in KTX

The control module is based on the process control logic in pulse operation mode. Four operation states were defined, that are waiting, preparation, discharge and stop. During the preparation period, all the subsystems receive the pre-parameters and start to work [3], the power supply system (PSS) begin to charge the capacitor. Only receives ready signal from PSS, the discharge process operates normally. When any error happens during a shot, the control module switches to a preprogrammed discharge shutdown trajectory.

C. *Central Safety & Interlock*

The role of KTX safety and interlock system (SIS) is focus on protecting the machine from accidents and preventing the propagating of the risk from an accident during the operating campaign. The architecture of SIS is similar to that of I&C (instrumentation and control) system in ITER [4], two horizontal layers are known as central SIS and several local subsystem SIS. All signals between central SIS and all local SIS are transmitted through the dedicated optical SIS network.

The central SIS is implemented by a SIEMENS SIMATIC S7-300 PLC equipped with the following components:

- CPU 315-2PN/DP with 256KB Memory
- PS307 DC 24V/10A power supply
- Two SM 321 digital inputs DI 16 channels DC 24V
- One SM 322 digital outputs DO 16 channels DC 24V

To prevent false alarm, specific error detection algorithms are designed, such as filter, 3-cycle detection. A pulse with the width less than 1ms will be filtered, and will not cause response delay. If the PLC detects the status signal remains at high level after 3 cycles, the central SIS will give the off-normal signal (positive delay signal) to discharge control system to stop the discharge schedule. At the same time, protection signals to local layer will be sent out to remove or to reduce the hazardous conditions [5]. The response delay of the KTX central SIS is tested during the experiment. Fig. 3 is snapped by oscilloscope, and the results meet the design requirement.

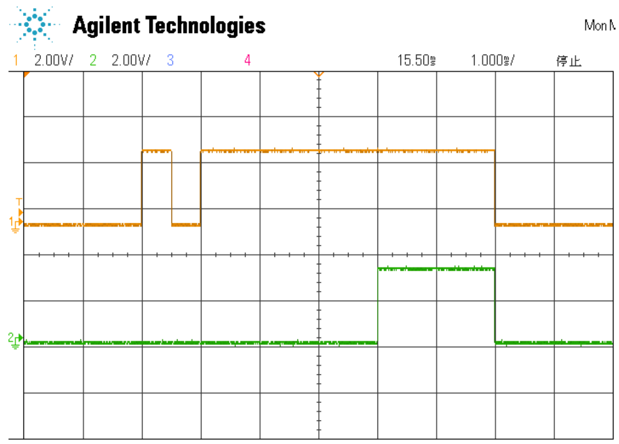

Fig.3. Test result of the new SIS response delay

D. *Timing System*

The timing system designed for KTX has three functions: (i)to provide the timing signals, ensure each subsystem working in the same reference clock (ii)to provide the trigger signals, control the participation in the experiment of subsystems in time series (iii) to acquire the outputs of itself, inspect the operation state of system automatically [5]. All the functions are implemented in the PXI and FPGA industry devices, since they are located in harsh electromagnetic environment and more signal channels are required.

The specification of KTX timing system list below.

- 8 reference clock signals, frequency rang 1Hz ~20MHz;
- 64 channels trigger, delay width from 10us ~ 6872s;
- 2 acquisition channels, sampling rate at 10 K Sample/s.

Reference clock is an important signal among of subsystem acquisition. A 10 MHz clock after custom isolation device is sampled at the rate of 12 GS/s by using NI digitizer module, 16000 periods are analyzed, and statistics histogram on the clock period jitter is achieved.

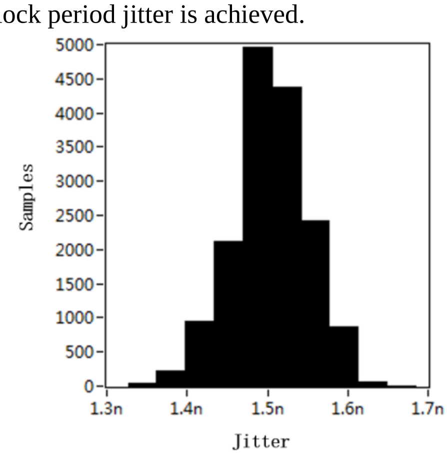

Fig. 4. Histogram of clock output jitter test result

E. *Gas Injection Control*

Similar to the discharge of a tokamak device, working gas which is injected into the device, is ionized by the loop voltage, and the collision between free electrons and neutral atoms generates plasma current [3]. In order to control the different position values with an open-loop control mode, gas injection module is developed to send commands waves to vacuum valves [6]. Custom multichannel VF/FV devices are designed to transfer the analog signal to vacuum system. The principle of the VF/FV devices is shown below.

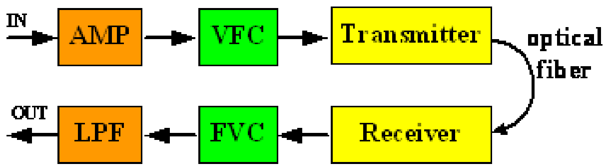

Fig. 5. Principle of custom VF/FV devices

After signal conditioning circuit (AMP), the VFC (Voltage Frequency Converter) ship changes the analog control signal to digital, then the transmitter sends the processed signal to subsystem through optical fiber; On receiving the optical signal, the receiver transmits the electrical signal to FVC (Frequency Voltage Converter) module, the digital information is converted to analog signal, after LPF (Low Pass Filter) , the vacuum system gets the valve command.

In order to inspect the correctness of control function, the preset control wave and FV device output are acquired by DAQ system.

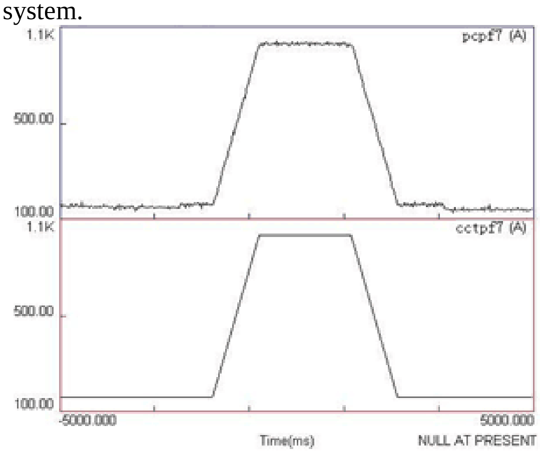

Fig. 6. Test results of VF/FV devices

Fig. 6 shows the test results of VF/FV devices, cctpf7 is preset wave, pcpf7 is physical signal after FV device. The two signals have similar wave and value.

F. Shot Information Server

All the KTX diagnostic systems and subsystems acquire experiment data through KTX DAQ (Data Acquisition) system coherently and consistently. Many Physicists and engineers from other research institutions need shot number to trigger their own systems and catalog the acquired data. The shot information server provides the current shot number and discharge length to various devices through two ways: positive mode and passive mode. The positive mode is that sends the shot information to the equipment IP addresses via UDP when start a new shot. On receiving shot-information request, the passive mode server give an immediate reply through TCP.

IV. NETWORKS

Network performance is a critical factor for a distributed system since all subsystems are distributed in different places [7]. All the operation command, preset parameters and acquired data are exchanged by a set of networks, viz. an optical safety & interlock network, a timing network, a RFM real-time network, a gigabit Ethernet network for machine control and data transmission.

The safety & interlock network is composed of multi-model fibers in order to remove ground loops among different subsystems; The optical timing network offers accurate triggers, so all fiber lengths are the same to guarantee that all signals arrive at different nodes within the same delay; RFM network allows distributed systems to share real-time data regardless of bus structure and operating system[8]; The stand-alone Ethernet network is isolated from the Internet to protect equipment from inadvertent or malicious incidents[7].

V. SUMMARY

The new central control system has already been applied to KTX experiment since August,2015. The whole system has correct control schedule during the discharge process, provides accurate operation sequence to plant systems, and monitored the status of subsystems without interruptions. The application shows that the new system runs stably and accurately, fulfills the design requirements of KTX central control system.

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