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Control System of Neutral Beam Injection on HT-7*

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Abstract Neutral Beam Injection control system (NBICS) is constructed to measure the plasma current, Magnet current, vacuum pressure, cryopump temperature, control water cooling, filament voltage, and power supply, etc. The NBICS, consisting mainly of a Programmable Logic Controller (PLC) subsystem, data acquisition and processing subsystem and cryopump and vacuum pressure monitoring subsystem, has successfully been used on a NBI device. In this article, the design of NBICS on HT-7 is discussed and each subsystem is described in particular. In addition, some experimental results are reported which are very important data for further research related to the HT-7 tokamak.

Keywords: neutral beam injection, data acquisition, monitoring, PLC control, network

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1 Introduction

The system of Neutral Beam Injection (NBI) for HT-7 tokamak had been developed and was commissioned in 2002 at the Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP). The device of NBI comprises an ion source, neutralizer cell, ion bending magnet, residual ion dump and two cryopumps. As one of the most important auxiliary plasma heating methods, the pulse power and pulse width of neutral beams directly affect the HT-7's experimental results. Therefore, NBI is also largely relied on for HT-7 to achieve a high-performance plasma with higher temperature and favorable plasma profiles. As many subsystems with different functions are involved such as electrical power systems, vacuum system and cryopumps, a powerful control system is needed to carry out the tasks for communication, data acquisition, monitoring and control. This injector is capable of injecting a hydrogen beam with 700 kW power into plasma at radial direction with all the power supply (PS) and measuring units needed for operation and control.

To achieve high performance neutral beams, the plasma current and its existing environment (e.g. vacuum pressure, power supply and water cooling) has to be controlled in Real Time. So, the construction of a reliable, flexible control system is necessary. A carefully designed NBICS on HT-7 will meet the experimental requirements and provide the physicist/operator with a friendly graphical-user interface.

2 Requirements for NBICS

Since NBI is the auxiliary heating system for the HT-7 tokamak and its control system serves as a part of the HT-7 central control system, the NBICS on HT-7 should be operated synchronously with HT-7 for experiments and asynchronously for testing and conditioning. In order to meet the requirements of plasma discharge and obtain a good experimental result, the following considerations should be taken into account while designing the NBICS on HT-7[1].

a. High precision and short time-delay.

b. With thirty plus analog inputs, over twenty digital outputs and about sixty controlled switches.

c. High speed data acquisition, saving and transfer.

d. Good reliability and safety, good flexibility with extension.

e. Network communication conforming to industrial standard.

Due to these characteristics, building an open distributed system for NBICS on HT-7 is the best choice. Thus, every part of the control system located in different fields can be connected and communicate with each other via a network. The NBICS on HT-7 can be categorized into a high voltage part and a low voltage part. The high voltage part contains the diagnostic instruments and industrial computers placed within the experimental field. This part performs data acquisition and command executions. The low voltage part is the main control computer placed in the control room 50 meters away from the high voltage area. It displays experimental results and receives commands from the operator. It is accepted that the hydrogen density in the tank is a crucial factor for plasma current stability and the filament's life is relevant to the added voltage. As a result, the control of the hydrogen density and filament voltage is also considered in designing NBICS on HT-7.

3 Control system

Considering the control requirements listed above, the distributed control fields, and necessary safety measures for the signals and subsystems, we constructed the NBICS on HT-7 as a distributed control system with powerful communication ability among the fields and

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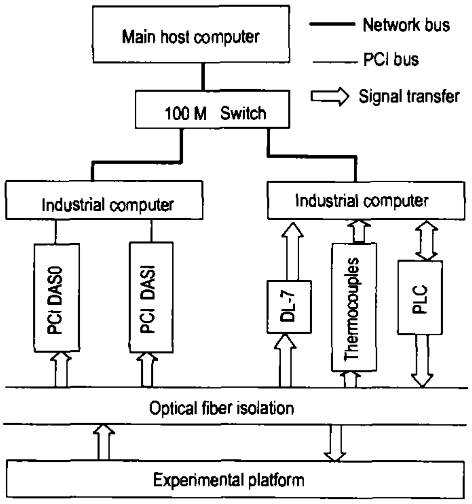

Fig.1 Structure of NBICS on HT-7

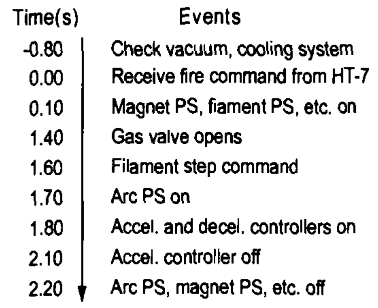

Fig.2 The PLC operating sequence

subsystems based on Ethernet communication technologies. With communications, the control unit and the field are connected with each other, too.

So, the NBICS on HT-7 consists of industrial computers, a data server, operating stations, LAN and interfaces to hardware. Its purpose is to provide an integrated control of each subsystem which performs different functions respectively. These functions involve waiting for the trigger signal from HT-7 to begin the work of NBICS, inspecting the switches' state and controlling the power supply, providing safety protection for devices such as the ion source, cryopumps and water cooler; data acquisition, saving, transfer and analysis; monitoring the cryopump temperature and vacuum pressure; providing a communication interface to each subsystem.

The structure of the NBICS on HT-7 is shown in Fig. 1. This complicated system can be divided into several subsystems, with each subsystem performing the process with its own control tasks. At the top layer of the structure of NBICS on HT-7 is the main host computer, which is a key component of the NBICS on HT-7. It plays the most important role in controlling and monitoring functions of the whole system, such as presetting experimental parameters, control commands, data reception and display, communication between the host computer and industrial computers and use of the discharge database for the experiment [2].

3.1 PLC control subsystem

In the NBICS on HT-7, a PLC of type OMRON CPM2A is employed to control the on/off state and time sequence of the magnet PS, gas valve, arc PS, etc. (The time sequence for a discharge is issued by the discharge control system of HT-7. According to the overall time sequence, the local sequence for NBI is then calculated and determined by the PLC system, e.g., magnet PS opens at 0.1 s, gas valve opens at 1.4 s, arc PS opens at 1.7 s.). The whole operating sequence is shown in Fig. 2. A safety interlock protection method is used in the PLC. When an exceptional condition occurs within the controlled time sequence or an interrupted input during the course of plasma discharge, the PLC can stop the operating flow immediately, switch off all the PS, and finally reset the system. These protection functions can easily be realized by software programme. Ladder logic programming is used in the PLC, which brings the programmer facility, improves running efficiency and reduces malfunctions. As far as NBICS on HT-7 is concerned, the PLC plays a master and coordinator role, which ensures that the NBICS system will work synchronously with the HT-7 central control system and triggers the DAS card to start data acquisition. With its extendable assembly, the PLC system can manage over 120 digital inputs/outputs and control them more accurately than would relays.

3.2 Data acquisition subsystem

This subsystem consists of the following components: an industrial computer, two PCI 9112 DAQ cards, diagnostic instruments and Voltage-Frequency (VF) converters. The PCI-9112 card is a multi-function card with 16 analog input channels with a maximum sampling rate up to 110 kHz for each channel. Two operating modes, single-buffered data transfer and double-buffered data transfer are used in the card. In single-buffered input operation, a fixed number of samples are acquired at a specified rate and transferred into the user's buffer. In double-buffered input operation, a large amount of data can be acquired continuously by using the two buffers alternately [3].

Double-buffered operation of PCI-9112 DAQ cards is adopted in the data acquisition subsystem. Theoretically, data can be acquired for an infinite time. In order to make the two PCI-9112 DAQ cards work simultaneously, multi-thread programming is used in this subsystem and each card occupies one thread for data acquisition. When more analog inputs are needed, the only thing needed is to plug one PCI-9112 card into the PCI slot of the industrial computer and add one thread into the program for the data acquisition of the new card. This function offers programmer convenience when the system is extended or maintained. A simplified block diagram of the data acquisition system is shown in Fig. 3. The diagnostic instruments are connected to the two PCI-9112 cards via VF converters and optical fibers which act as an isolator between the High Voltage platform and industrial computer. The analog input range is set from -10 V to 10 V to improve the

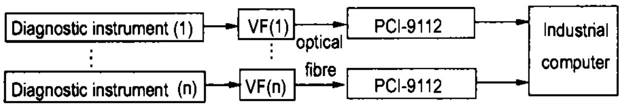

Fig.3 Block diagram of acquisition system

Signal-to-Noise ratio and the coaxial-cable is also used to avoid the influence of electromagnetism. The acquired data are directly transferred from the DAS card into the memory of the industrial computer in DMA mode, then stored in the local hard disk in the text format and compressed by using the LZO file format. The volume of the compressed data is only one tenth of that of the original data. It greatly relieves the burden of Ethernet communication. Finally, the compressed data are transferred to the main control computer through the Ethernet.

3.3 Monitoring subsystem

Plasma current is achieved only when the cryopumps work well and the vacuum pressure is below 10^{-3} Pa. For this reason, the vacuum pressure is monitored by a DL-7 vacuometer 24 hours a day and the temperatures of the two cryopumps are measured by sixteen thermocouples placed at different locations of the cryopumps. The state of the cryopumps can be found out at any moment via the signals from the thermocouples. Furthermore, the rules of vacuum and temperature variation can be mastered through data analysis.

3.4 Network communication

Network performance is a critical factor in the system performance of NBICS on HT-7. Remote measurement and control are necessary for avoiding the damage of magnetic field and electric field. It is well known that there are many methods of communication, such as file sharing, the Winsock programme and the Component Object Model (COM) programme.

In NBICS on HT-7, COM programme is used in the monitoring subsystem. The data and signals acquired from the diagnostic instruments are sent to the industrial computer through the COM port. This method is relatively simple compared to the Winsock programme. An Ethernet with a 100 Mbps rate is also used for communicating within the subsystem control. The model of client/server structure is adopted in NBICS on HT-7. The main host computer serves as the server and other subsystems serve as clients. The standard Sockets and Winsock based on TCP/IP protocol are used in these situations, such as presetting the values of power supply, data transfer and command exchange between the main control computer and a subsystem system [4].

4 Results for data analysis

With the progress of the whole NBI system, the NBICS on HT-7 has been utilized in experiments and large amounts of valuable data have been obtained from the experiments. The data may be displayed in graph form after each shot by graphical tools such as Origin,

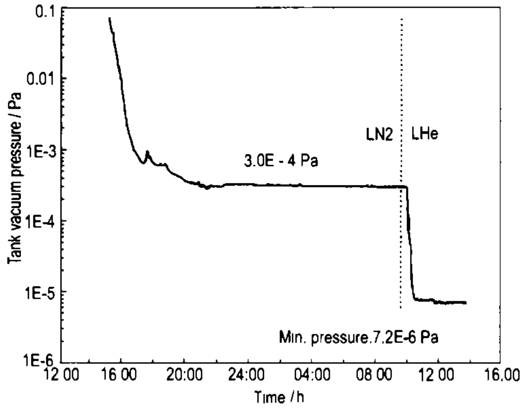

Fig.4 Graphical display of vacuum pressure

GT-7 (A graphical software used in plasma experiments on HT-7, and designed by ASIPP using VC++). Everyone with permission may obtain the waveforms from a workstation or retrieve the data from the data server.

When the desired waveforms have been displayed, physicist/operator can manipulate the curve directly by using the mouse to get interesting information, and then modify some parameters to get a better result for the next shot. The curve of the tank vacuum pressure is shown in Fig. 4, which is one of the most successful results we have achieved. It is clearly evident that the vacuum pressure changes from 3.0E-4 Pa to 7.2E-6 Pa when the cryopumps have gone into operation.

5 Summary

The NBICS on HT-7 has proved to be successful in the experiment. Hardware and software function perfectly in the beginning of its operation. The NBICS enables the experiment to run in a stable state and relieves the labor intensity of the experimenters. Moreover, new improvements may be added into the NBICS on HT-7 in near future, strengthening the feedback control subsystem for the hydrogen density to improve the stability of plasma current, and the function of filament voltage presetting to enhance the robustness of the filament. More attention will be paid to the improvement of reliability and maintainability of the NBICS. The harmonization between the NBICS and the HT-7 central control system will also be carefully ensured.

References

1 Martimez Laso L, Liniers M, Alonso J, et al. Fusion Engineering and Design, 2001, 56 ~ 57: 477 ~ 480

2 Wang L, Luo J R, Yin F X, et al. Fusion Engineering and Design, 2002, 60: 421 ~ 426

3 McHarg B B, et al. DIII-D data management, Fusion Engineering and Design, 2002, 60: 305 ~ 309

4 Luo J R, Shu Yantai, Wang H Z, et al. The Distributing Control and Data System in HT-7 Tokamak. Proceedings of the IEEE Conference on Real-Time Applications of Computers in Nuclear, Particle and Plasma Science. June, 2001

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