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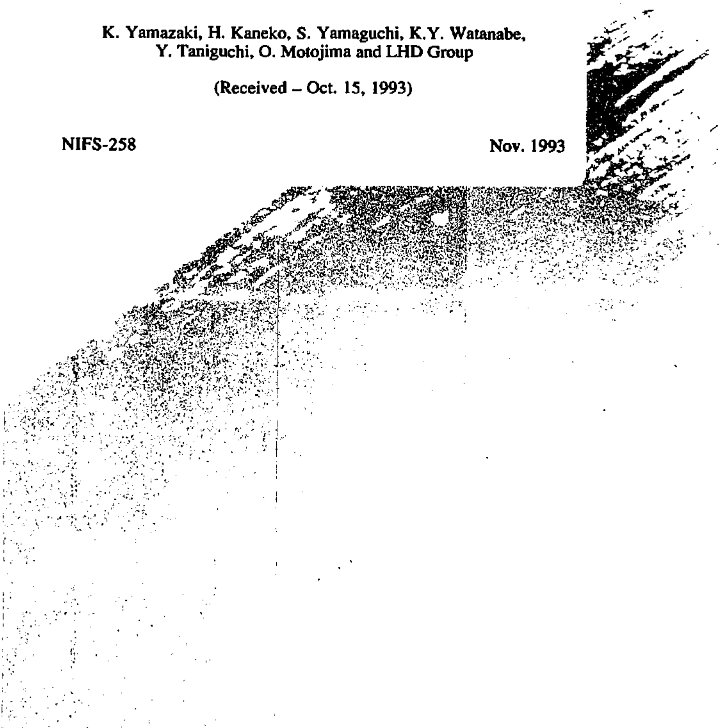

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DESIGN OF CENTRAL CONTROL SYSTEM FOR LARGE HELICAL DEVICE (LHD)

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Abstract

The world largest superconducting fusion machine LHD (Large Helical Device) is under construction in Japan, aiming at steady state operations. Its basic control system consists of UNIX computers, FDDI/Ethernet LANs, VME multiprocessors and VxWorks real-time OS. For flexible and reliable operations of the LHD machine a cooperative distributed system with more than 30 experimental equipments is controlled by the central computer and the main timing system, and is supervised by the main protective interlock system. Intelligent control systems, such as applications of fuzzy logic and neural networks, are planed to be adopted for flexible feedback controls of plasma configurations besides the classical PID control scheme. Design studies of its control system and related R&D programs with coil-plasma simulation systems are now being performed. The construction of the LHD Control Building in a new site will begin in 1995 after finishing the construction of the LHD Experimental Building, and the hardware construction of the LHD central control equipments will be started in 1996. A first plasma production by means of this control system is expected in 1997.

Keywords: LHD, design study, central control system,
system achitecture, intelliget control, feedback control

1. Introduction

The fusion energy is an ultimate and infinite energy resource for human beings and will be created in the controlled manner during next century. Among several classes of fusion concepts the tokamak is a world leader of the present fusion research, however, it requires the current of the plasma itself, which is not adequate for steady state operations. On the other hand, the helical magnetic system is created by the external helical coil only, in place of toroidal field coils and the plasma current of tokamak systems. The helical system can produce steady state and currentless plasmas, whose merits will be demonstrated in our new machine LHD.

The Large Helical Device (LHD) [1-2] is a world largest superconducting fusion machine that is now under construction in Japan. The major diameter of the LHD plasma is 7.8 meters and the central magnetic field is 4.0 Tesla. The magnetic field energy stored in the coil is around 1.6 G Joule. Different from the presently operating conventional fusion machines, all coils of the LHD are superconductive to demonstrate the steady state operation.

The design studies of the control system [3-4] for this LHD machine are carried out, emphasizing on the mode definition of the machine/plasma operations, the architecture of the LHD control system, the real-time intelligent control system of the plasma control and the R&D programs for the LHD central control system.

2. LHD system overview

2.1 Control design philosophy

Fusion experimental systems are not so large in spatial scale as accelerator systems, however, fusion machines are characterized by the complicated and intensive energy density system. Therefore the requirement of safety is important. Moreover, the present fusion machine requires flexible operations as a physics research machine to optimize the magnetic configuration itself.

As for the LHD machine, it is a large intensive plant requiring reliable and safe operations, and a physics machine requiring flexible operations. Moreover, the control system itself should be extensible to the future modifications. Therefore, the following characteristics are required:

(1) Safe and reliable distributed processing for machine operations,
(2) Flexible and centralized operation for experiments, and
(3) Standardization and flexible design using open system.

The conceptual and detailed designs of control, protective interlock and timing systems are under way by taking these characteristics into account.

2.2 Operation scenarios

The LHD machine operation is divided into three modes; shut-down mode, facility operation mode and experiment mode (Fig.1). The experiment mode consists of the SC(superconducting) magnet operation mode and the plasma experiment mode. These modes are defined for clarifying the personnel entrance permission, magnetic field hazard and possible radiation exposure. Besides the slow software interlock, the hardwired interlock logic should be determined independent of these modes. The SC magnet will be operated for about 10 hours per day, and the number of short-pulsed plasma operations with 10 second duration will be typically 50 - 100 shots per day. Different from the present conventional pulsed fusion machines, the LHD is going to be operated in steady state (more than 1 hour pulse length) and requires interactive control of the machine and the plasma. The electromagnetic sensors for the long-pulsed control are required, which is different from the control concept of present conventional fusion devices.

3. LHD control system and its standardization

3.1 Global control architecture

On the basis of the above-stated operation scenarios, the designed control system is composed of the central experimental control system to arrange plasma experiment mode, and several sub-supervisory control systems to arrange operation modes of facilities such as torus machine control, heating machine control, diagnostic control and electric / cooling utility control systems, as shown in Fig.2. All sub-supervisory systems are connected by the Ethernet-LAN(local area network). The data acquisition system with conventional CAMAC modules with our specially developed softwares and the large super-computer system for theoretical analyses using experimental data are connected to the experimental control computer by the inter-laboratory backbone FDDI-LAN.

3.2 Design of central system and sub-systems

The detailed diagram of the LHD control system is shown in Fig.3. Within the facility operation mode, basically almost all equipments are operated by each subsystem controller. The liquid helium refrigerator, the coil current power supply, the vacuum pumping, and the wall conditioning systems are controlled by the main torus control system. Each plasma heating system such as NBI, ECH and ICRF is operated by each control computer. On the other hand, main parameters in the experiment mode are controlled by the engineering workstation (EWS) of the central experimental control system.

The timing system is important to create flexible and reproducible plasma, and its functions are reasonably distributed to the main timing system and the torus timing system.

The each equipment has own simple and reliable interlock system and the cooperative protection is performed by the common quick interlock system with multiple hard-wired lines, besides the slow software computer control system. Especially, it is important to arrange a complicated emergency quick stop during the plasma operation. For example, when the SC coil is quenched, it is necessary to wait for one second before making an emergency stop of the coil current, to avoid the plasma current induction and the hard X-ray production by means of the protective gas puffing or the protective rod insertion. The informations on these protective actions are transferred to the experimental control computer via LHD control Ethernet-LAN.

4. Intelligent feedback control scheme

The feedback control for plasma current, position and cross-sectional shape will be carried out using intelligent control systems, such as applications of fuzzy logic and neural networks in addition to standard PID algorithm. For example, the fuzzy logic will be applied to the change in the control algorithm or to the fuzzification of input parameters for the control of the plasma current and position. The former application has been checked with the simulation model of the plasma current control and it was found that the fuzzy control is better for the non-linear control response than the classical PID controller [3]. The neural network will be applied to the fine-tuning control of the plasma cross-sectional shape and is now under investigation.

5. R&D program for control system

As a R&D program for this LHD control system, a new simulation system is made consisting of UNIX-EWS (Sun Sparc Station), Ethernet-LAN, VME multiprocessors (CPU 68030) with VxWorks real-time OS, simulation power supplies and plasma-coil system (Fig.4). For quick and accurate control response, a DSP(digital signal processor) board will be installed and the fuzzy logic plasma control algorithm [3] in addition to a PID controller will be tried for the demonstration of the plasma control and display. This R&D program will help the design and construction of LHD central control facilities.

6. Construction schedule of control system and control building

The LHD machine is under construction now, and the detailed design of its central control system is under investigation during JFY(Japanese Fiscal Year) 1993-1995. Its central computer system will be installed in the LHD Control Building.

The initial test operation of the LHD magnet system will induce the strong leakage magnetic field to the adjacent building and make the computer unworkable. To avoid this, the LHD Control Building is planed to be located ~100 meters far from the LHD machine. The expected magnetic field is 1 Gauss in the initial coil test phase and less than 0.1 Gauss in the normal operation phase. The construction of this control building in new site will begin in 1995 after finishing the construction of the LHD Experimental Building, and the hardware construction of the LHD central control equipments will start in 1996. The first plasma production by means of this control system is expected in 1997.

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Figure Captions

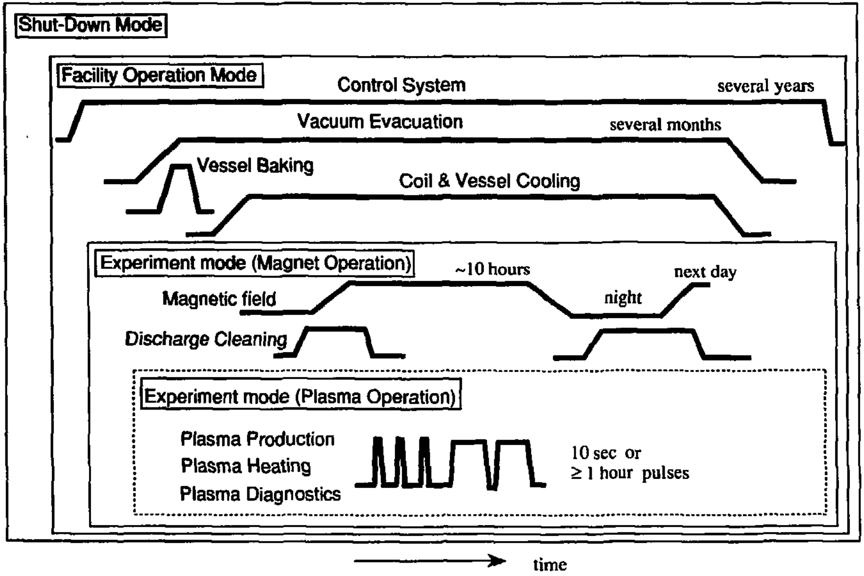

Fig.1
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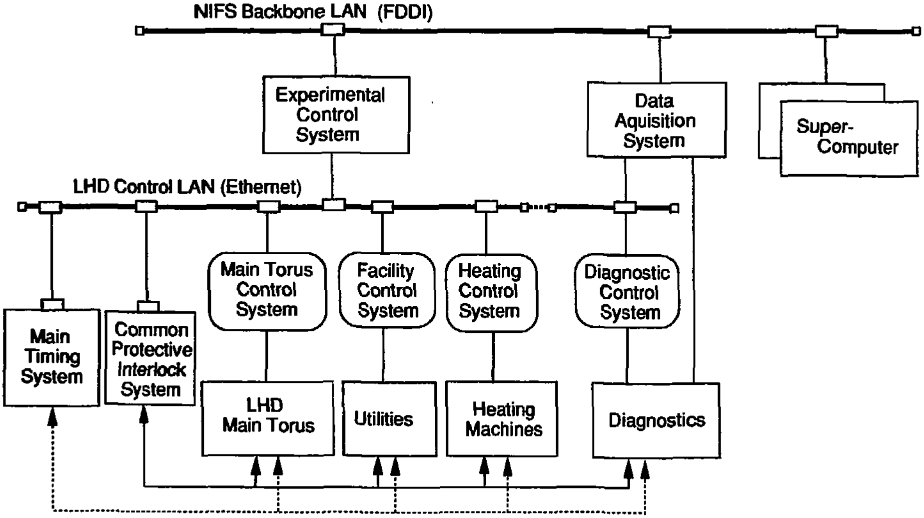

Fig.2
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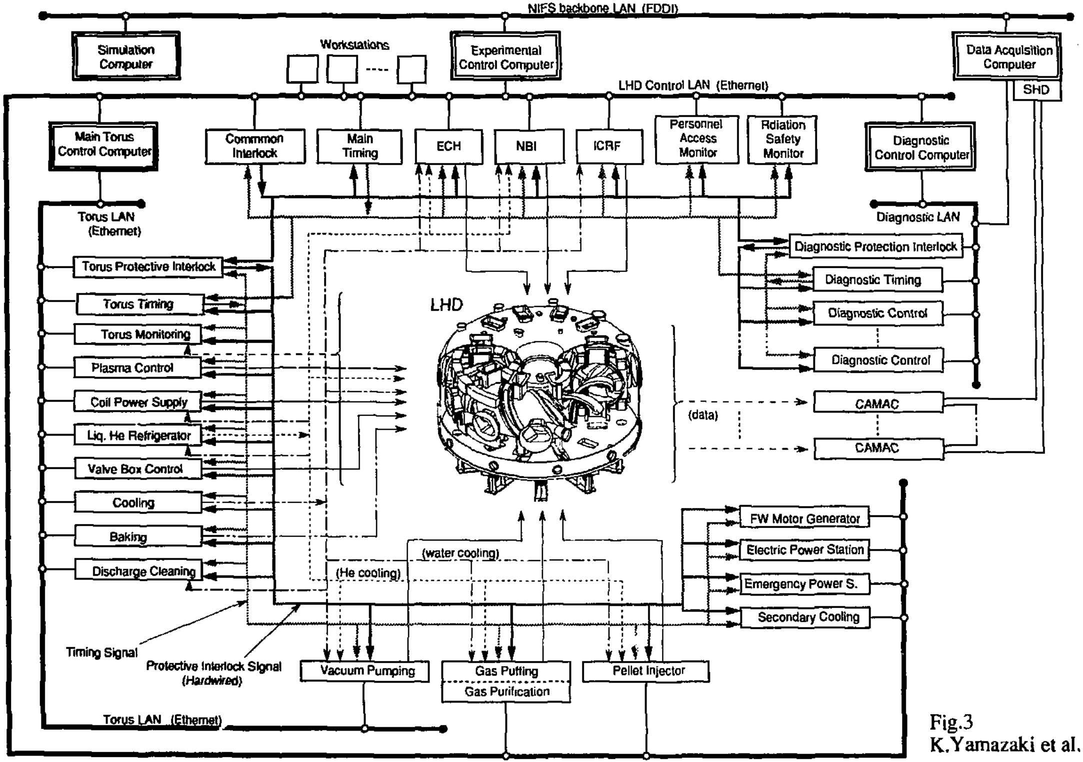

Fig.3
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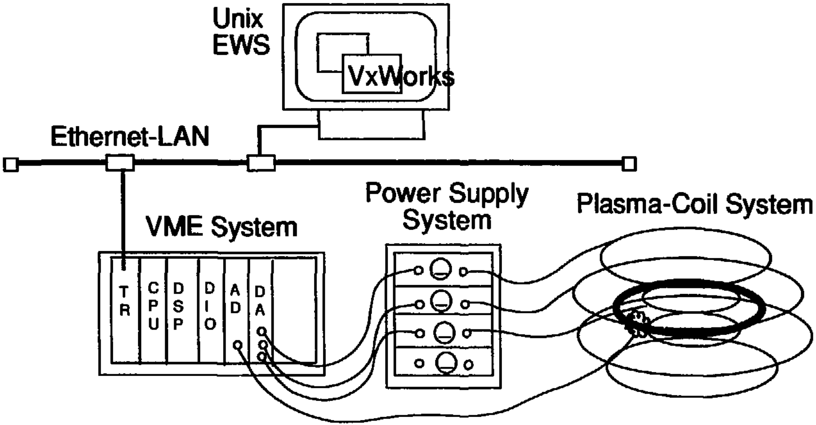

Fig.4
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