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Conceptual Design of Centralized Control System for LHD

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Abstract

A centralized control system for a fusion experimental machine is discussed. A configuration whereby a number of complete and uniform local systems are controlled by a central computer, a timer and an interlock system is appropriate for the control system of the Large Helical Device(LHD). A connection among local systems can be made by Ethernet, because a faster transmission of control data is processed by a specific system.

I. INTRODUCTION

The National Institute for Fusion Science(NIFS) was established by The Ministry of Education, Science and Culture in 1989 to integrate all of the inter-university collaboration in Japan for nuclear fusion research. The new and main project of Large Helical Device(LHD)[1] at NIFS was approved during the 1990 Japanese-fiscal-year(JFY). The LHD system presently under construction at the new site of NIFS in Toki-city, Gifu-prefecture, will be completed in the 1996JFY[2].

The LHD system, with superconducting coils, will be the first machine which can sustain the stationary magnetic field composing nested magnetic surfaces. A magnetic surface is generated from a combination of the toroidal magnetic field and the helical magnetic field. It is the outermost magnetic surface, which determines the confinement area. A ring plasma with a major radius 3.75m and an averaged radius of cross-section 0.65m is confined. A schematic view of LHD is given in Fig.1. The magnetic field is generated by a pair of superconducting helical coils and three pairs of superconducting poloidal coils. The stored magnetic energy in a typical 4T operation (the strength of the average toroidal magnetic field at the plasma center) is 1.63GJ. The initial plasma is usually produced by radio-frequency(RF) power at the electron-cyclotron-resonance(ECR). The plasma is subsequently heated by arbitrary use of 20MW neutral beam injection(NBI), 10MW ECR heating and 9MW ion-cyclotron-range-of-frequency(ICRF) heating.

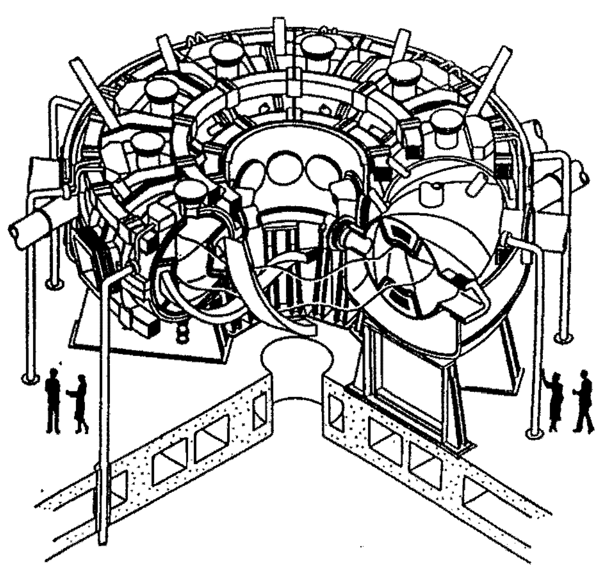

Fig.1 Schematic view of The Large Helical Device

The control system for LHD operation must be designed to ensure the safety of the whole LHD system which contains sensitive electronics as well as rough facilities handling large stored energy, high power, high voltage and high current within the same environment. It also has to manage an efficient performance of the plasma experiment. There are some distinctive characteristics in the control of such a large fusion machine still in an experimental phase.

The reliability is the most important factor in the present system. Since the power used is sufficient to cause fatal damage, the safety must be garenteed, including the case of an accident. A choice of reliable materials and an additional backup can ensure this reliability, but finally it is related to the available cost. Here, we consider only the logical reliability of the control system.

The flexibility of a configurational setup is very important for a machine in an experimental phase. Besides replacement, new types of facilities should be easily added to the system. Thus, the control system should be flexible.

There are various time scales to be controlled within. The real-time control in a pulsed plasma experiment is usually too fast to be treated by an operator's manipulation. Hence, the control of the plasma by an operator is made through pre-programming. Thus, the function of fast control necessary for plasma operation should be excluded from the role of a global controller. If necessary, such a function must be treated in a specific controller.

The pulsed characteristics of the plasma experiment, on the other hand, make the target very clear and simple. All facilities are operated in order to produce a high-temperature, high-density and well-confined plasma.

The last requirement is a possible local operation of some part of the facilities. When such an operation is demanded, global safety must be assured by the central controller.

Considering the characteristics of the LHD operation, we have discussed the conceptual design of the centralized control, which can more easily establish a logical relation between various manipulations. By the way, the data acquisition is closely related to the machine operation. However, the transfer of the vast plasma data from the data acquisition system to the control system is not necessary. Instead, a small amount of diagnostics signal will be directly provided to the local controller which needs the signal for the control. The diagnostics are loosely coupled to the central control system.

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II. SUBSYSTEM

A. Functional Decentralization

All facilities contained in the LHD system have a local controller. The local controller is assumed to (1)fully control all of the devices under its control, (2)monitor the devices and the peripheral conditions, and (3)communicate with the central controller (also with the other local system in a restricted case) in order to establish mutual cooperation, as displayed in Fig.2. This unit is called a subsystem(SS). To simplify the whole control system the division into SSs must be optimized as to the quantity and quality of the communication, because the number of items to be communicated with others will be greatly different according to the division. An individual SS may have many sensors to assure the safety of itself. If a particular operation is not dangerous and has no necessity to cooperate with others, the operation can be managed locally. Such a inner-interlock, solved within the SS, gives the reliability and simple configuration. This decentralization, however, is designed to draw out more centralized control for the whole system.

B. Operation of Utilities

There are several SSs which are continuously operated to supply necessary utilities, such as, water, electricity, liquid helium and liquid nitrogen. Since the interaction of the facilities with the plasma experiment is infrequent, they could be operated independently. However, it also means that the load to the data transmission is small. The utilities can be operated within the same frame with the plasma experiment. This makes the whole control system uniform, and the system becomes transparent to the operator.

C. Plasma Production

There are two distinctive modes for plasma production. One is a pulse operation. The necessary electricity is stored in a fly-wheel generator and used in 10 seconds. The pulse can be repeated every 5 minutes. Although the amount of the control data is considerably large, they are managed before the start of the pulse by pre-programming. In designing the control system of the pulsed plasma machine, it is important to classify much of the control data to the pre-programming level, because they eventually determine the range of parameters adjustable by the operator. The real-time control of the plasma by the operator is thus excluded from the present design. When real-time control is truly necessary for some device, the function must be supported by a specific local machine.

III. CENTRALIZED CONTROLLER

A. Control Computer

When every SS is designed to be a complete local system, the role of a central controller is; (1)to establish the total safety, cooperation, collaboration and total efficiency of experiments and (2)to help an operator, who is usually monitoring some number of SSs at a time, by providing proper data, warning, guidance, and various routines useful in the operation. The centralized control of the whole system is mainly attained by a control computer(CC). Fast control for generating a proper time sequence for different SSs or an emergency stop due to an accident is one of the basic functions of the centralized system. This function should not be supported by CC but by an additional specific controller. When we use a timer system and an interlock system for this purpose, the configuration of the control system is displayed as in Fig.3, where the time scale of the action is distinguished as labeled on the right.

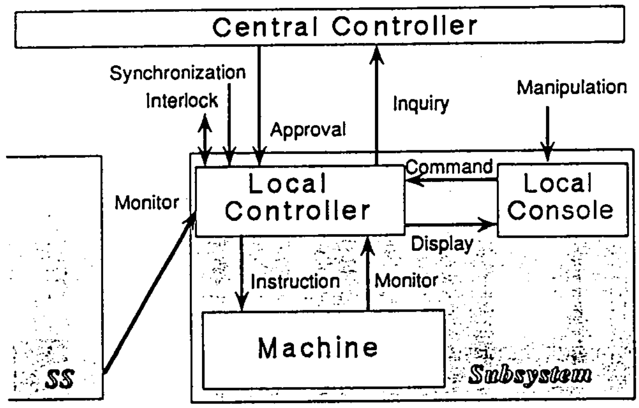

Fig.2 Flow of control data at a subsystem

B. Man-Machine Interface

As shown in Fig.2, every manipulation of a device by an operator is evaluated by the local controller, and then by CC when it is necessary, and the actual instruction is issued to the device from the local controller. In a centralized system it is not necessary for a SS to have its own console, because the command can be transmitted from CC. Since the information describing a manipulation is of the order of the manual input, the amount of transmission is never critical. Although a classical form of a direct input at SS is not excluded, control

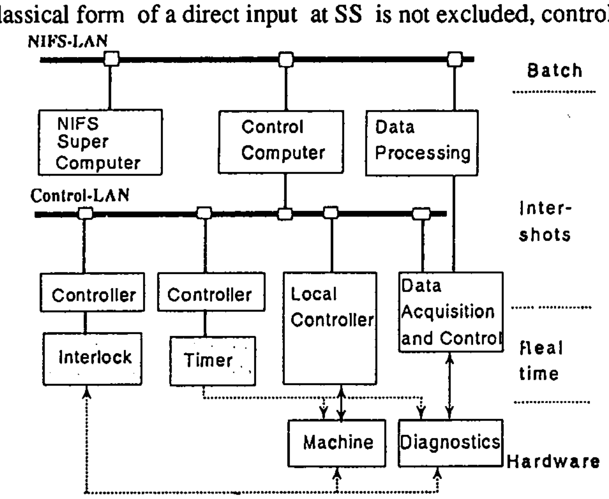

Fig.3 Structure of the control system

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through the commonly-available general terminal of CC is considered to be the standard in the present system. Since a terminal can be used as a console for a number of SSs simultaneously, it is preferable for an efficient operation of the whole system by only a few operators. A number of workstations are used as a terminal of CC to provide a high-quality services as stated in (2) above.

C. Synchronization and Interlock

It is a basic function in a plasma machine to assure any SS to synchronize with the plasma production. This function is served by a specific timer. As already discussed, the control of the synchronization is completely pre-programmed. So the timer can be controlled by CC in the same way as a SS which is pre-programmable.

The other type of fast control is a safety interlock. In cases of emergency, the signal of the event must be transmitted much faster than the normal control data. The function must be also excluded from a design of CC. The signal is transmitted through a specific line to the device which needs a quick response. The use of this specific line must be restricted to the case where it is truly necessary. Since the action interrupt the uniform control of the whole system, it causes some vacancy of the control. A particular case will be studied later.

The reliability is sometimes insufficient in the circumstances with high power and high voltage. Then, a hardwired interlock is demanded for safety. The action is basically the same as the electronics. The action of the interlock system of both levels is monitored and recorded by a specific controller. The interlock system acts like one specific SS.

D. Network in Control System

A local area network(LAN) is used to connect the SSs and CC as schematically drawn in Fig.4(control-LAN), because an established standard of LAN is extremely useful to connect between different local controllers, each of which is differently designed from SS to SS by the person in charge. (It is not considered here to specify the local controlling computers in advance.) Also, it is inexpensive and flexible in the system configuration, and gives an easy method for electrical isolation, when an optical bus is used. To find a required network to LHD, the data transferred through the network is examined. There will be about 30 SSs. Although the amount of manipulation data is not so large, the amount of status data is considerably large in some of SSs, say 20kB. Considering the effective throughput, the rate of about 10Mbps is necessary. Then, the status data of 20kB correspond to 16ms for transmission. The operation of several such SSs at a time will be supported. Two possible standard of LAN are investigated: Ethernet and mini-MAP.

The standard Ethernet based on CSMA/CD seems eventually sufficient transmitting capacity for present application, if there is no problem on a use of optical fiber for the bus line. The adoption of Ethernet will contribute to the

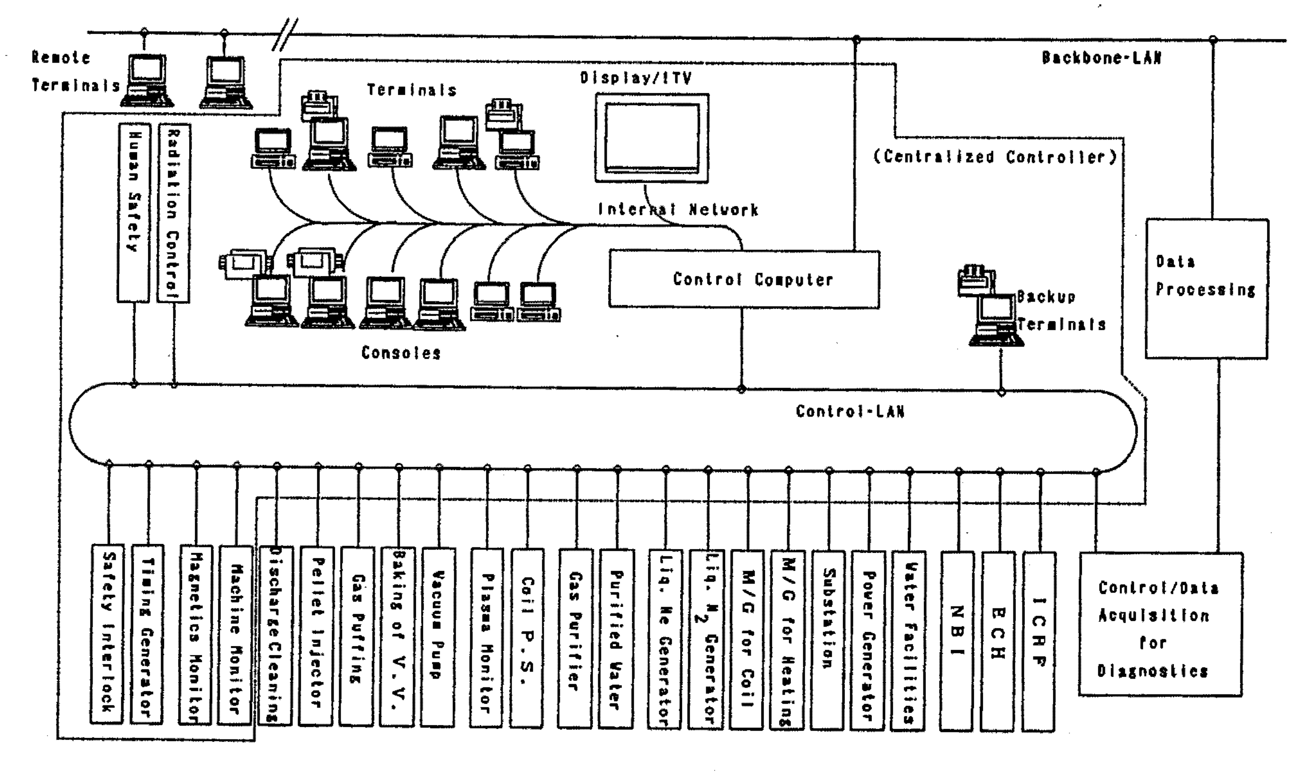

Fig.4 Global configuration of the control system for LHD

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inexpensive construction of the centralized system. The use of fiber inserted into the coaxial bus is already proved to be effective to isolate between the divided segments. However, the insertion is rather expensive compared with the usual co-axial connection, because it does not contribute to the improvement of the transmission.

The mini-MAP based on token-passing seems more appropriate for the present application. The difference of the data to be transmitted, such as between the control command and the status report, can be treated by a distinctive service class in the token controller. A bus line by fiber is becoming popular. The use of mini-MAP is attractive for the design of the control system. However, the adoption might be difficult owing to the considerably high cost and some ambiguity in the standardization.

The design of control-LAN by Ethernet is selectively investigated.

E. Centralized System for LHD Operation

As already shown in Fig.4, the man-machine(man-controller) interface is basically connected to CC. A manipulation of SS is received by CC and then checked in reference to the current status of the whole system. An approved manipulation is analyzed into the command(s) to be transmitted to the concerning SS(s). The status report must be collected by CC in order to be served to the operator before he determines a proper manipulation at the console of CC. If once-a-second update of the status report for a few SSs is demanded for operation of each SS, the LAN might get choked. However, such a use of console is well processed, if the update is demanded only every 5 seconds, which will usually be sufficient compared with the manual response. The capacity necessary for the plasma control is not critical, because the control is pre-programmed. The sufficient capacity of CC will be utilized for allowing a flexible management of the control data for the plasma pulse. An experimental parameter, once selected and fixed for the coming shot, can be safely modified, because the centralized control can easily and quickly review the change. This function will be very helpful for a series of physical experiment.

The real-time control of stationary plasma is not taken into account in the present design. Such a control is possible only within the ability of the CC designed as above.

IV. EMERGENCY PATICULAR TO LHD

A quench of a superconducting coil is detected by many comprehensive monitors on the temperatures and voltages. The signal is transmitted to the interlock system. There are many SSs to be interrupted by the occurrence of a quench, when the quench takes place during the plasma production. However, such an emergency stop is not sufficient in the LHD system. There are many other requirements caused by a large stored energy; the current on a quenched coil must be decreased rapidly, say within 20 seconds; the induced voltage due to fast decrease of current must not exceed the insulation specification of the coil conductor; the production of runaway electron due to the induced voltage in the plasma vacuum vessel must be suppressed during the current reduction; and the transiently induced current due to mutual coupling must not yield an excess electromagnetic force. Therefore, gas puffing or some hard object insertion to the plasma vacuum vessel is applied for the induced voltage not to cause the production of runaway electron. Then, the power supply of the coils is switched to the emergency reduction mode. To avoid excess concentration of the current to a particular coil, the current on every coil including what has not quenched is reduced simultaneously. To setup a proper time sequence for those steps, the analysis of the quenching, transmission to other systems and synchronization are processed in the interlock system. After a satisfactory response to the quench there remains an emergency state in many facilities. The recovery is complicated and not predictable. However, a centralized system will be very effective to support the recovery.

A power cut is a trouble common to any control. Emergency stop of the whole sytem at the power cut is a usual action. However, there are some facilities which must not stop but rather be initiated in order to keep the whole system safe in the present case.

V. SUMMARY

A conceptual design of the control system for the LHD operation is discussed The fusion machine, with a large superconducting coil system and still in an experimental phase, requires an advanced control system for a reliable and efficient operation. To achieve a labor-saving operation and to minimized human errors there, it is concluded that the control needs a uniform structure over the entire system The CC is designed to be devoted in the logical cooperation among SSs, while every SS is designed to have a complete local controller for each. The manipulation by an operator is given preferably from a console connected to CC, because every manipulation should be checked and confirmed by CC. Then, the cooperation is managed by CC before the issue of the commands to local devices. The pre-programming for pulsed plasma control can be fully supported by the centralized CC system. However, an interlock system, which governs emergency action, is necessary to assure the safety in case that an accidental event has occurred. Thus, fast transmission of emergency data is differently processed from the normal control data. Then, the use of Ethernet for connection among CC and SSs is an inexpensive choice for the present requirement.

Since the relation between SSs must be definitely controlled for the safety of the whole system, a completely decentralized control is impossible. The SS is completely designed to allow CC more centralized. The CC can be regarded as a specific subsystem taking only the role of centralization.

VI. REFERENCES

[1] A.Iiyoshi, et al., Fusion Tech. 17(1990)169.
[2] K.Yamazaki, et al., this Conference.