Data monitoring system of technical diagnosis system for EAST

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Abstract Technical diagnosis system (TDS) is an important subsystem to monitor status parameters of EAST (experimental advanced superconducting tokamak). The upgraded TDS data monitoring system is comprised of management floor, monitoring floor and field floor. Security protection, malfunction record and analysis are designed to make the system stable, robust and friendly. During the past EAST campaigns, the data monitoring system has been operated reliably and stably. The signal conditioning system and software architecture are described.

Key words EAST, TDS, data monitoring

1 Introduction

EAST (Experimental Advanced Superconducting Tokamak), a fully superconducting tokamak, aims at studying the physical and technical issues involved in steady-state tokamak nuclear fusion devices at Institute of Plasma Physics, Chinese Academy of Sciences [1]. It is a cylinder of a five-layer complex structure, which consists of an inner vacuum chamber, an inner thermal shield, a magnet system, an outer thermal shield and an outer vacuum chamber. Each of the main parts works at different temperatures ranging from high temperature plasma zone to liquid helium temperature [2]. The magnet system has two subsystems: 16 toroidal field (TF) coils, and 14 poloidal field (PF) coils including 6 central solenoid (CS) coils, 4 big poloidal field coils, and 4 divertor coils[3]. Each coil is of the NbTi-based cable-in-conduit conductor type[4]. The EAST is shown schematically in Fig.1.

As an important EAST subsystem, the technical diagnosis system (TDS) serves the device safety and normal operation as follows: (1) real-time monitoring of the EAST operation status by collecting field signals accurately and timely and real-time data and signal transfer to other subsystems; (2) real time recording of all experimental data and information for off-line diagnosis; and (3) warning, once an online data analysis result is not in accordance with plasma discharging requirements or the TDS malfunctions.

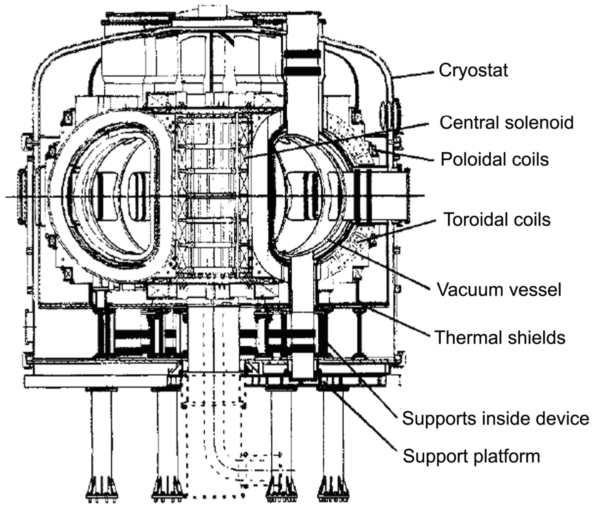

Fig.1 A schematic view of the experimental advanced superconducting tokamak (EAST).

In campaigns of EAST operations since 2006, the TDS data monitoring system has been in stable and reliable performance for real-time monitoring and fault diagnosis[5]. However, it had problems. For example,

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the run log was not complete enough for offline check, and the signal conditioning system for temperature sensors was inconvenient to maintain. Therefore, it is necessary to upgrade the TDS to improve the standardization and operation convenience. In this paper, we report our progresses in upgrading the TDS data monitoring system.

2 The TDS data monitoring system

2.1 System features and requirements

In comparison to the original design, the EAST TDS data monitoring system has the following features.

(1) A larger number of analog input signal types and quantities, as shown in Table 1.

Table 1 Profile of signals in TDS data monitoring system.

Physical Parameters	Sensor	Range	DAQ Freq. /Hz	Pieces.
LHe cooling pipe temperature	Cernox, carbon resistance	0.5–50 mV	1	190
LN cooling pipe temperature	PT100, PT1K	20–100 mV	1	200
TF coil excitation current	Current transformer	0–10 V	1	1
TF coil case displacement	Special design	0–10 V	1	8
Strain stress of tokamak support	Special design	0–10 V	5	8
SC coil resistance	—	0–10 V	1	32
SC joint resistance	—	0–10 V	1	64
Quench detection voltage	Co-wound coil	0–10 mV	100	32

(2) More types of signal sensor. Four kinds of temperature sensors, i.e. Cernox-1050, Pt100, Pt1000 and Russian carbon resistance sensors, are used for different working temperature zones. While some signals can be measured directly in voltage, specially designed sensors are needed to measure the displacement and strain stress.

(3) Higher precision demand on measurement. Measurement accuracy is 10 mK (mili-Kelvin) and 100 mK for temperature sensors installed in liquid helium cooling pipes and in liquid nitrogen cooling pipes, respectively. These mean that a voltage variation of 50 μV must be detected so as to measure relevant temperature variation. Signal conditioning is adopted to increase measurement accuracy.

(4) Longer operation time. The TDS should keep steady operation from cool-down to warm-up in every EAST campaign, so its operation time is no less than 75 days.

Besides, EAST is in. pulsed operations lasting less than 1 s or a few thousand of seconds. The former operation mode does request very high time resolution of the control systems (such as the poloidal field coils power supply and gas injection), and so does the latter mode[6], as all the TDS data monitoring signals are coming from online analysis of temperature variation for each plasma discharge and telling whether a temperature variation is out of limits or a serious breakdown occurs. On the other hand, continuous (as long as 100 days) and “slower” monitoring and control are needed for subsystems of e.g. pumping, temperature monitoring and superconducting (SC) coil resistance[7].

2.2 The data monitoring system

According to the requirements of physics design, the EAST operation parameters are as follows: toroidal field, 3.5 T at R=1.7 m; plasma current, 1 MA; and plasma discharge duration, 1000 s. There are strong neutron radiations in the later phase of EAST operation[8]. Consequently, the basis of TDS data monitoring system is of remote monitoring capacity.

As shown in the Fig. 2, the system is in hierarchy. Level I, which is on the field floor, consists of many sensors, signal conditioning system, several industrial personal computers (IPC) and an industrial Ethernet switch. The computes are connected to the Ethernet switch, which is linked via two pairs of optical fiber to other floors and a private LAN. The signal conditioning system will be described in Section 2.3. There are two operation modes for Level I: (1) local operations when supervisor computers cannot control IPCs on the field floor due to an accident; and (2) remote operations by supervisor computers at Level II.

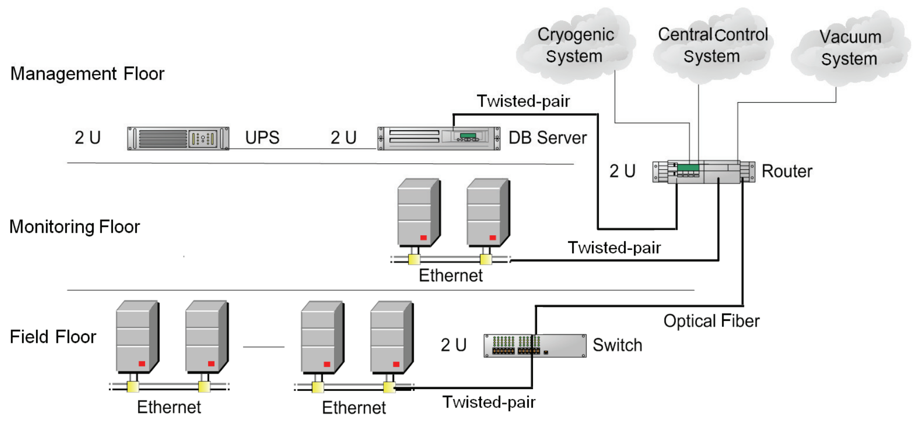

Fig.2 Block diagram of the data monitoring system for EAST TDS.

Level II, on the monitoring floor, comprises of three supervisor computers.They are responsible for: (1) control operations of IPCs at Level I including signal parameter setting and monitor their operation state via the LAN; (2) real-time display of data from Level I and data communication with other subsystems of EAST tokamak; and (3) real-time data processing for a decision of whether to send a warning signal for local safety check and for safety and interlock system of EAST tokamak [9].

The database server at Level III works both as a database and as a clock server to synchronize system clock of every computer in the system, while it is also a clock client of the clock server of central control system of EAST tokamak [10].

Computers at Levels I, II and III form a private LAN, which is physically separated from the internet by a router with software firewall. Computers at Levels II and III are installed in the TDS control room and central control room far from the experimental site. Data communication between supervisor computers at Level II, database server at Level III and real-time computers at Level I are via the private LAN through optical fibers. Besides, TDS data are transmitted through the router and a hardware firewall to cryogenic system, vacuum system and central control system.

2.3 The signal conditioning system

The signal conditioning system improves overall data acquisition system performance and accuracy by up to a factor of 10 and even 100. As shown in Fig.3, it consists of analog signal conditioning system and digital signal conditioning system. Key signal conditioning technologies, such as amplification, are applied to meet the requirements of the data monitoring system. The function boxes in Fig. 3 are explained as follows.

2.3.1 Excitation

Excitation is required for many sensors and transducers in TDS as shown in Table 2. For example, strain gages require external voltage excitation signals while Cernox-1050 resistance temperature sensors require external current excitation signals.

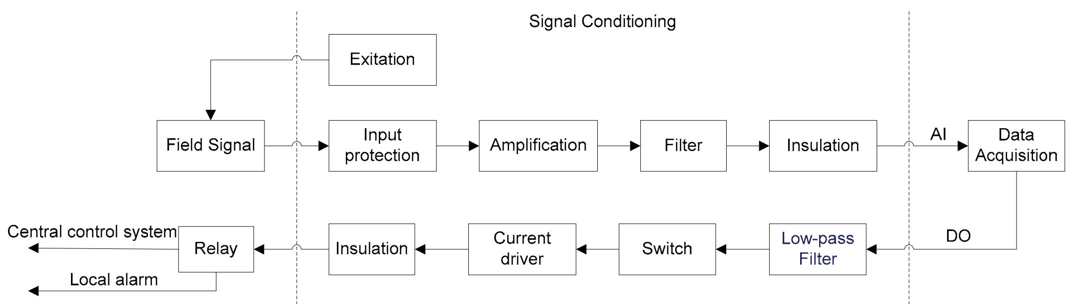

Fig. 3 Signal conditioning flow in EAST TDS data monitoring system.

Table 2 Excitation required in TDS

Signal	Excitation
Temperature in LN pipe	1 mA
Temperature in LHe pipe	10 μA
Displace-ment	5 V
Stress-strain	2 V
Current transducer	±48 V
SC Coil Resistance	0.5 A

2.3.2 Isolation

According to different levels of withstanding voltage, transformer, optical fiber and linear optical coupling techniques are used to pass signals from their sources to data acquisition system without a physical connection. In addition to breaking ground loops, isolation blocks high-voltage surges and rejects high common-mode voltage and thus protects both the operators and equipments.

2.3.3 Filtering

Nearly all data acquisition applications are subject to some level of 50 or 60 Hz noise picked up from power lines or equipment. The frequency of most signals in TDS is no more than 10 Hz. Low-pass filters are specifically designed to provide maximum rejection of 50 to 60 Hz noise[11] .

Accuracy and stability of the electric instruments are required to make sure of minimum errors in TDS data monitoring system. For instance, error of the 10 μA current excitation is no more than 0.3% with negligible temperature drift or time drift. DAQ cards with 16-bit A/D resolution are adopted in the system.

2.3.4 Digital signal conditioning system

In the TDS system, digital signals are output for local safety warning and for sending warning to the safety and interlock system. Two functions should be realized. One is to enlarge capacity of the signal to drive the multi-contact relay. The other is to break ground loop between TDS data monitoring system and EAST central control system while sending the digital signal to the central control system. On occurrence of a fault defined by the central control system, the buzzer works for local warning and relevant digital signals are sent to the central control system. This isolation function is achieved by using optical coupling.

2.4 Software architecture and network communication

Program on DB server at Level III is developed with Microsoft Visual C++ under Windows 2003 server platform. Programs at other levels are programmed with Microsoft Visual C++ and run under Windows 2000 professional platform. Object orientation design, Winsock network programming, multi-threading technologies are applied in programming. The application programs are driven by message, event, scheduler, command and the error handler.

Expansibility must be considered for future developing of EAST. Based on demand analysis, the TDS data monitoring system is divided into different modules that can be integrated easily into a whole system. Ten main modules are designed according to different functions. Online analysis for a temperature variation exceeding the limits in plasma discharging, real-time analysis for a serious breakdown, control signal output for vacuum heating system, etc. are of independent modules. Overall software architecture in function model is shown in Fig.4.

The private LAN is based on 10 MB or 100 MB self-adaptive Ethernet. Its data transmission rate can be up to about 25 KB/s without network congestion, and with enough capacity for future incremental network traffic. Fig.5 shows a block diagram of data flow. Data types include parameter setting, experimental data, command and standard clock information. Parameter setting and command are of pulse data and are passed with UDP/IP protocol. Experimental data and standard clock information are of steady data and are dispatched with TCP/IP protocol.

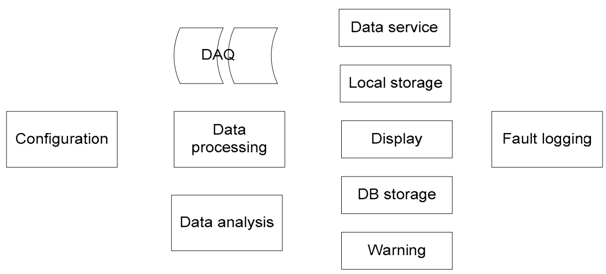

Fig. 4 Software architecture of TDS data monitoring system.

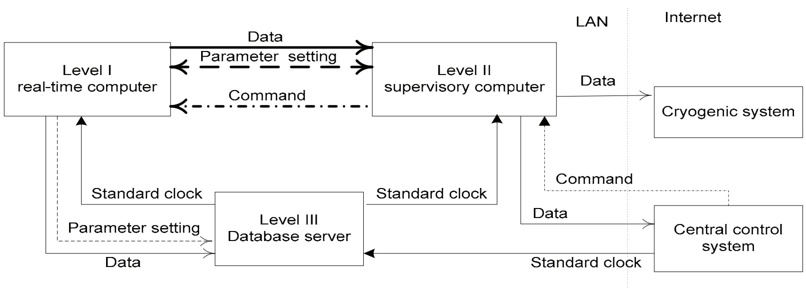

Fig. 5 Dataflow in TDS data monitoring system.

Network protocol is improved according to different data types in order to make it easy to process data in network communication. Data format of network protocol is shown as Table 3.

TDS data monitoring system has achieved remote control and integrated supervision based on TCP/IP and Ethernet technologies. Parameters of EAST device status are real-timely displayed in the TDS control room and on the website of EAST experiment.

Table 3 Data format of network protocol.

Frame	Meaning
Head	Computer ID of the two communicating sides
Type	Frame information type
Data Type	Parameter setting; Data; Command; Standard clock information
Frame ID	Frame ID
Data Size	Length of data segment
Data	Data segment

3 Analysis of experimental data

3.1 Temperatures of the cooling down inlet and outlet of outer shield

The major parts of EAST work at different temperatures. In the period of cool down and warm up, limits on temperature difference (<50 K) and temperature-changing rate (<50 K/h at different locations of some main parts) are required to prevent possible deformation damage caused by excessive thermal stress. Fig.6 shows temperature changes and temperature difference of the outer shield inlet and outlet during EAST's cool down in 2008. The outer shield cooled down from room temperature to about 90 K in about 15 days, with the temperature difference of <50 K in most time of the period and the temperature-changing rate of <40 K/h.

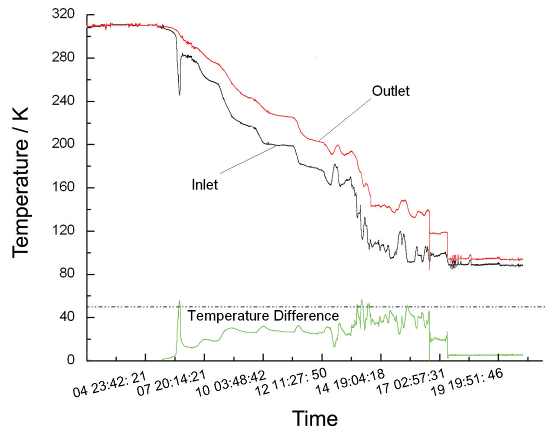

Fig. 6 Temperatures of inlet and outlet of the EAST outer shield during its cool down in June 2008.

3.2 Displacement of TF coil during cool down

In the EAST cool down, temperatures of the inner shield and outer shield drop to about 80 K, and temperatures of the SC coils drop to 4.5 K. In such a sealed vacuum system like EAST, deformation and displacement are inevitable when SC coil temperatures drop to 4.5 K from room temperature [12]. It is necessary to measure SC coils position after cool down in order to avoid possible operation risks when plasma discharging.

During cool down of EAST in 2009, displacements were measured in both *R*- and *Z*-direction of the TF coil from three positions (Fig.7). Contract speed of TF coil was not too fast. Displacements in *R*-direction were no more than 9 mm, while those in *Z*-direction were near 15 mm. Space between the TF coil and inner shield was 15mm when EAST was set up and displacement of <10 mm is allowed [13]. So the close attention should be paid to displacement in *Z*-direction. There are three displacement benchmarks on the outer shield, where displacement occurs, too, during the EAST evacuation. The experimental data was used as a reference. In the

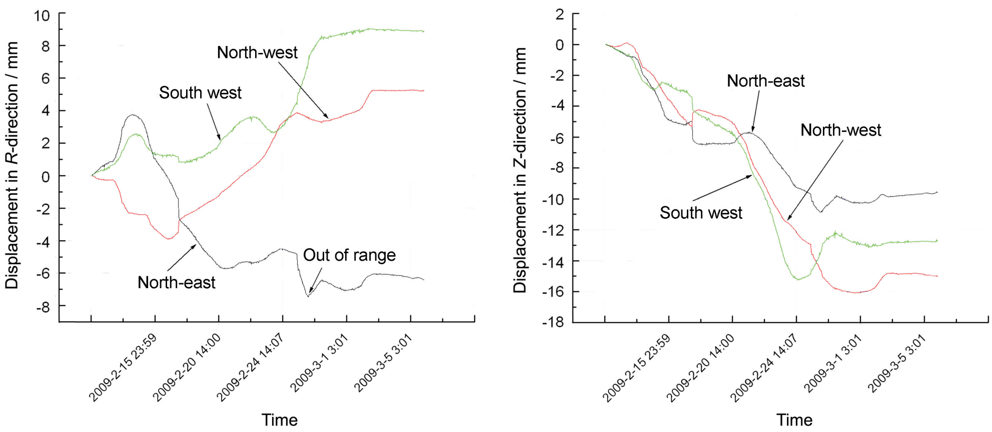

Fig.7 Displacement of the TF coil in *R*- and *Z*-direction during EAST's cool down in 2009.

coming EAST campaign, displacement benchmark will be selected in some unchangeable positions outside EAST and a fourth position will be measured to improve the TF coil displacement measurement.

4 Conclusion

EAST technical diagnosis system (TDS) has been commissioned since February 2006. During the past EAST campaigns TDS data monitoring system has been operated reliably and steadily. The requirements on the EAST TDS data monitoring system have been met basically. And in accordance with problems occurred design update of the TDS data monitoring system has been presented and is in progress. The improvements in TDS data monitoring system include:

(1) Easy to maintain. New types of signal terminals are selected to make contact firmer and more convenient to measure with the aid of blades. Main modification on signal conditioning system is to integrate excitation current with other functional circuits;

(2) Centralized management of the TDS power supply. An electric power distribution cabinet is designed to monitor the status of power usage of each part in TDS data monitoring system;

(3) Complete run log and make automatic printing of defined experimental data at fixed time intervals;

(4) Separate signals with possible high voltage from weak signals; and

(5) Develop application programs with LabVIEW software package under Linux platform.

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