Control And Data Acquisition System Of Tokamak KTM

K. I. Baystrukov, V. M. Pavlov, A. V. Sharnin, A. V. Obhodskij, S. V. Merkulov, Y. N. Golobokov, A. A. Mezentsev, A. V. Ovchinnikov, and I. L. Tazhibaeva

Citation: AIP Conference Proceedings **996**, 297 (2008); doi: 10.1063/1.2917027
View online: http://dx.doi.org/10.1063/1.2917027
View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/996?ver=pdfcov
Published by the AIP Publishing

Control And Data Acquisition System Of Tokamak KTM

Baystrukov K.I.[a], Pavlov V.M.[a], Sharnin A.V.[a], Obhodskij A.V.[a], Merkulov S.V.[a], Golobokov Y.N.[a], Mezentsev A.A.[a], Ovchinnikov A.V[a]., Tazhibaeva I.L.[b]

[a]-*Tomsk Polytechnic University, Russia, 634050, Lenin ave. 30, san@phtd.tpu.edu.ru*
[b]-*National Nuclear Center, Kazakhstan Republic*

Abstract. The preliminary results of control and data acquisition system (CODAS) development for Kazakhstan tokamak for material testing (KTM) [1] are presented. The KTM CODAS is completely new system optimized for KTM facility and its regimes of operation. Its development is carrying out in Tomsk Polytechnic University by Russian specialists. The first KTM launching under the control of CODAS is planed on 2008 year. The base functionality of CODAS is presented, including short description of its subsystems, such as control system of conditioning process, plasma control system, digital control system of power supplies, protection and timing system, data acquisition system.

Keywords: Tokamak KTM, data acquisition, plasma control, power plant control, synchronization, protection, control room.
PACS: 52.55.Fa, 07.05.Dz, 07.05.Hd, 07.05.Kf, 07.05.Rm

INTRODUCTION

The KTM control and data acquisition system is completely new system optimized for KTM facility and its regimes of operation. As an object of automation, the tokamak KTM and its technological systems complex have several peculiarities that put on some additional requirements to the automation system. KTM [1] is small aspect ratio device a=2, the major radius R=0.86m, minor radius r=0.43, elongation k_{95}=1.7, triangularity Δ=0.3, plasma current I_p=750kA, Bt=1T, auxiliary RF-heating power 5-7MW, thermal load on the divertor tiles 2-20MW/m^2. The duration of plasma current plateau is about 5 seconds.

KTM operation divides mainly onto conditioning and discharge regimes. KTM conditioning regime includes vessel heating, pump down, vessel clearing and boronization, water cooling, putting material samples on the moving divertor through the vacuum sluice. KTM conditioning take place mainly before or between discharges, but some operations, such as vacuum pump down, water-cooling and vessel heating, have to be done continuously. Conditioning system operation will be controlled by the conditioning control system (see Figure 1).

KTM discharge regime includes continuous lasting cycles “discharge – pause”, with duration about 5 seconds and 10 minutes respectively. The first KTM launching will be performed with ohmic heating only. It requires using KTM control coils, namely - central solenoid coil (CS), toroidal field coil (TF), poloidal field coils (PF1-

CP996, *Plasma and Fusion Science*, edited by C. Varandas and C. Silva

PF6) and two HFC coils, connected in series. The coils power supplies (PWS) and their digital control systems are placed in power supply room. Plasma modeling has shown, that plasma equilibrium requires to use MIMO control of plasma shape with control cycle about 1ms and plasma vertical position control with short control cycle about 100μs. It requires to design both modern power supplies digital control system and plasma control system.

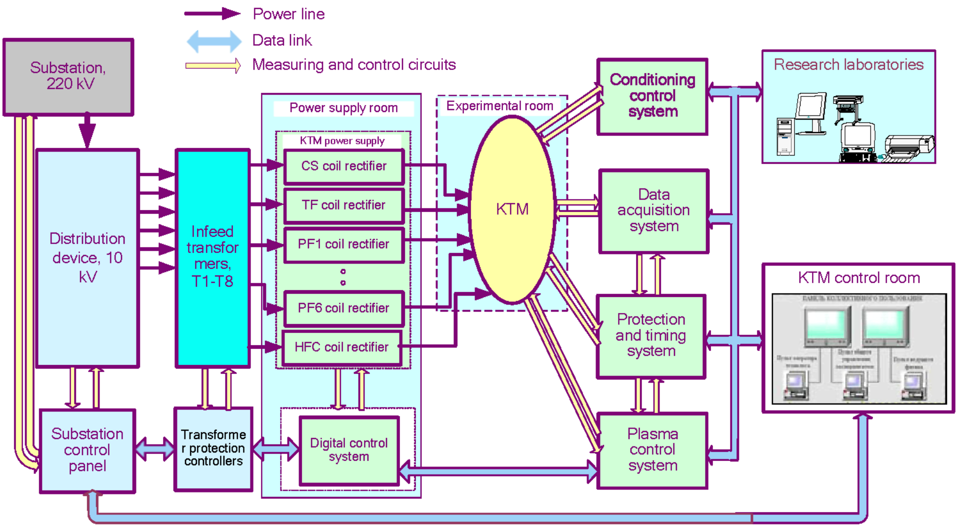

FIGURE 1. Structure of Control and Data Acquisition System of Tokamak KTM

Protection and timing system is used for providing simultaneous operation of distributed control and data acquisition equipment and protecting KTM facility during plasma disruptions and other abnormal operating conditions.

KTM data acquisition system have to perform high-speed data measurements from diagnostic equipment, transmit experimental data information to database server and, if required, directly to the plasma control system in real time. Data acquisition system also use application server for data processing algorithms realization. Advanced data visualization and KTM handling fulfilled in KTM control room both automatically and by operators from computerized consoles using human machine interfaces. Data visualization and processing is possible from KTM research libraries in off-line mode, and will be possible for remote participants through Internet.

In accordance with it the KTM CODAS system should be a high performance distributed system, in which the following basic systems are functionally separated (see Figure 1):

- Control system of conditioning process;
- Plasma control system;
- Digital control system of power supplies;
- Protection and timing system;
- Data acquisition system.

CONTROL SYSTEM OF CONDITIONING PROCESS

Control system of conditioning process (TPCS) serves to control continuous lasting or a continuous-cyclical process, the speeds of which are relatively low and has time scale 0.1-10 seconds. Such operations include vessel heating, pump down, vessel clearing and boronization, water-cooling. The system provides data acquisition from object and processes distributed in experimental room. The amount of analog and digital data acquisition channels comes to 1400; the amount of control channels comes to 256. The system brings out standard control and logical control algorithms. The low level of the system based on the industrial PC and PLC hardware (see Figure 2). Human machine interfaces are implemented on the basis of PC computers installed in TPCS switching room and KTM control room, and on the basis of Tablet PC type clipboard computers for mobile off-line parameters tuning.

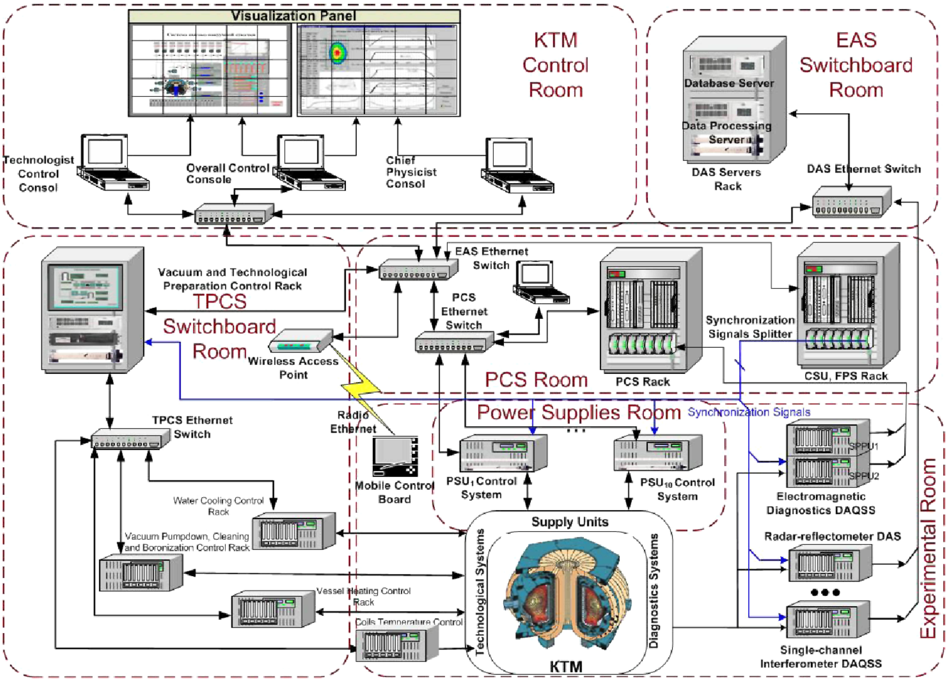

FIGURE 2. KTM data acquisition and control system hardware

PLASMA CONTROL SYSTEM

Plasma control system (PCS) serves to control technological and plasma-physical processes in discharge regime of tokamak KTM operation in order to get plasma equilibrium and reach required parameters of high temperature plasma. The system implements plasma current control (central solenoid (CS) control), plasma position control (HFC coils control), shape control (PF1-PF6 coils control), density (gas puffing) and power content control (ICR and ECE auxiliary heating control). KTM launching will be realized without auxiliary heating. Design values of control loop control cycles are in the range of 0.1-1 ms. Constructively, plasma control system represents multiprocessor VME crate with auxiliary high speed serial interconnects, which brings out parallel solution of tasks on calculation of plasma parameters and values of control actions in real time. The system is strictly synchronized with above-mentioned subsystems.

The PCS integration with data acquisition subsystem of electromagnetic sensors and digital power supply control system is presented on the Figure 2.

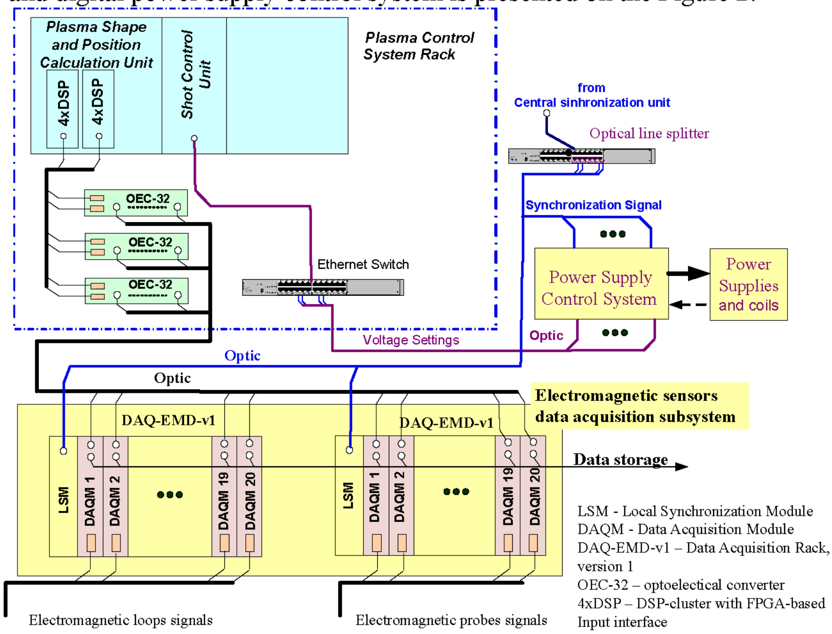

FIGURE 3. PCS integration with electromagnetic sensors data acquisition subsystem and power supply control system

Electromagnetic sensors data acquisition subsystem is designed and fabricated in Tomsk Polytechnic University. It provides individual galvanic isolation for each input cannel up to 2,5kV, simultaneous data sampling up to 1MSPS for 160 ADC channels, dynamic range 12bit, anti aliasing and digital filtering and fast data preprocessing. The synchronization of all operations provides configurable local synchronization module (LSM), connected directly to each of DAQM module and central synchronization block.

Predictable real time data transition to plasma control system is realized through multiple plastic optical fibers, custom 32 channels optical-electric converters OEP-32, and FPGA-based custom deserializers, integrated in DSP-clusters. DSP clusters realize plasma shape and position calculation. Shot control unit realize control algorithms and output new digital voltage settings for power supply control system through fiber optics Ethernet network.

DIGITAL CONTROL SYSTEM OF POWER SUPPLIES

It serves for automatic implementation of acquisition functions, as well as for registration and control of electrical current and voltage parameters from power supplies of KTM electromagnetic coils. The system also serves for software implementation of pulse-phase control scheme and for signal conditioning and delivery of protection signals. Digital control system includes 6 specialized controllers. Total amount of measuring signals and power sources parameters amounts to 260 and 1150 correspondingly. Galvanic isolation level of control and measuring circuits comes to 3 kV. The environment of control signals transmission to force schemes is made on the basis of plastic fiber-optic lines. Coils PF1-PF6, CS and TF have just the same controllers. HFC power supply is based on the IGBT, and HFC controller has another design and is under development now.

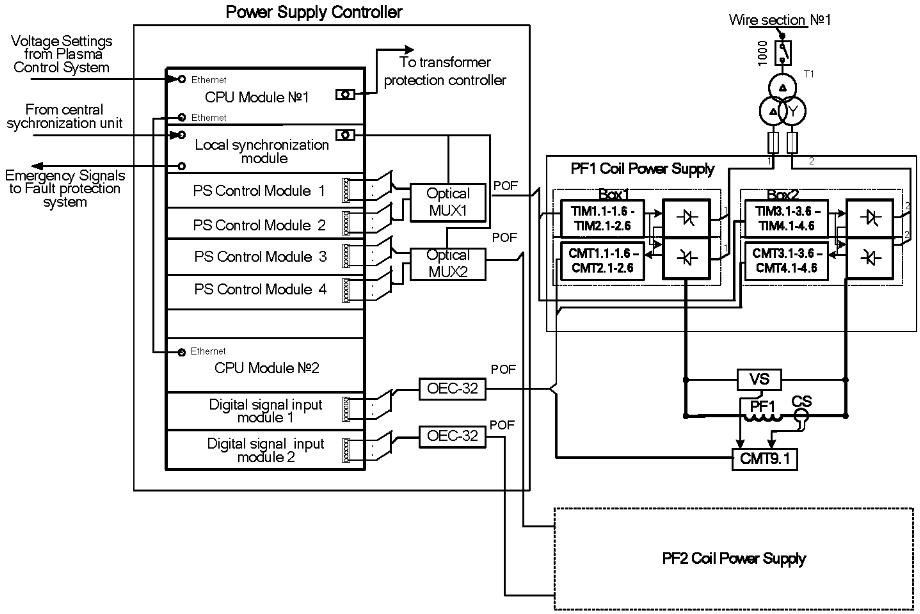

FIGURE 4. PF1-PF2 coils power supplies controller

PF coils power supplies specialized controllers (Figure 4), integrated into power supplies transistor ignition modules (TIM) and current measurements transducers (CMT) are designed and fabricated in Tomsk polytechnic university.

In the normal mode of operation controller receives voltage settings for PF1 and PF2 power supplies from plasma control system each 3.3ms. Power source (PS) control modules calculate the angle of opening for power supply thyristors and forms opening pulses for transistor ignition modules. Specialized multi channel optical multiplexers (Optical MUX) distribute those signals to the proper TIMs. Power source output voltage and current in the coil are measured by voltage and current sensors (VS, CS) and acquires by current measurement transducer CMT module. CMT modules also measures current in each branch of thyristor inverter. It's used in plasma control system and for fault protection. If there are no voltage settings from plasma control system, power source controller automatically turn on stabilization mode and maintains power source output voltage according to the last valid voltage setting.

PROTECTION AND TIMING SYSTEM

It serves both for producing and distributing of common experimental time marks and individual events to subsystems, and subsystems fault signals input and processing (Figure 5).

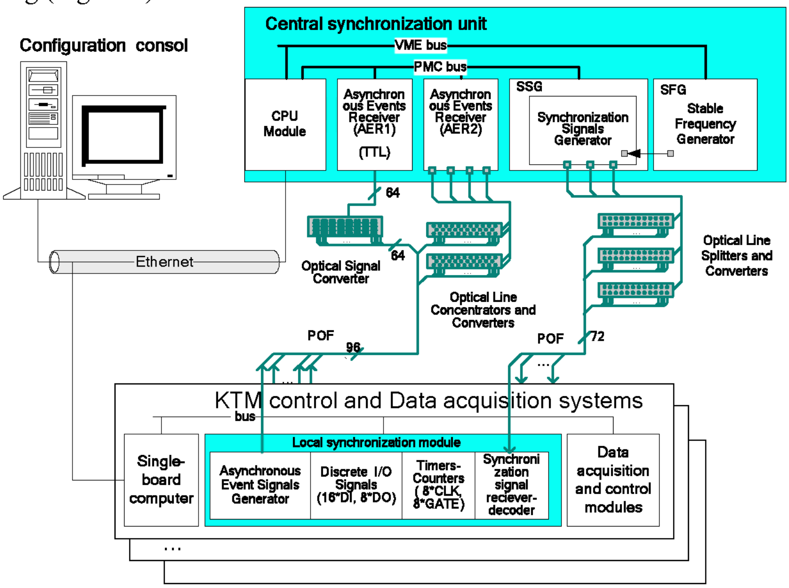

FIGURE 5. KTM Protection and timing system

Synchronization signals are transmitted through high-speed radial optic lines to all control and measuring units. The system also serves to receive asynchronous events including emergency, as well as to carry out algorithms of equipment protection from outage in worst-case situations. Complex timing system provides clock-timing error < 100 nanoseconds and accuracy of binding of trigger signals no worse than 10 microseconds. The amount of timing channels for central synchronization block comes to 72. The use of phase encoding methods allows combining transmission of clock rate and commands. Speed of trigger signals transfer comes to 80Mbit/sec. Each synchronized subsystem has local synchronization module (LSM). It can generate and distribute inside the subsystem up to 8 clock signals (CLK), 8 timing signals (GATE), and 8 digital output (DO) signals and check 16 digital input (DI) signals. All LSM operations are synchronized with central synchronization unit through synchronization signal receiver/decoder. Fault protection can be produced locally in subsystem or controlled by central synchronization unit. In any case alarm events must to be submitted to asynchronous events receivers AER1, AER2 of central synchronization unit.

DATA ACQUISITION SYSTEM

KTM tokamak data acquisition system (DAS) (see FIGURE 6) has to provide most important for fusion researchers functions on acquisition, storage, analysis and visualization of large amount of fusion data during fusion experiments, and in the post experimental regimes of its operation.

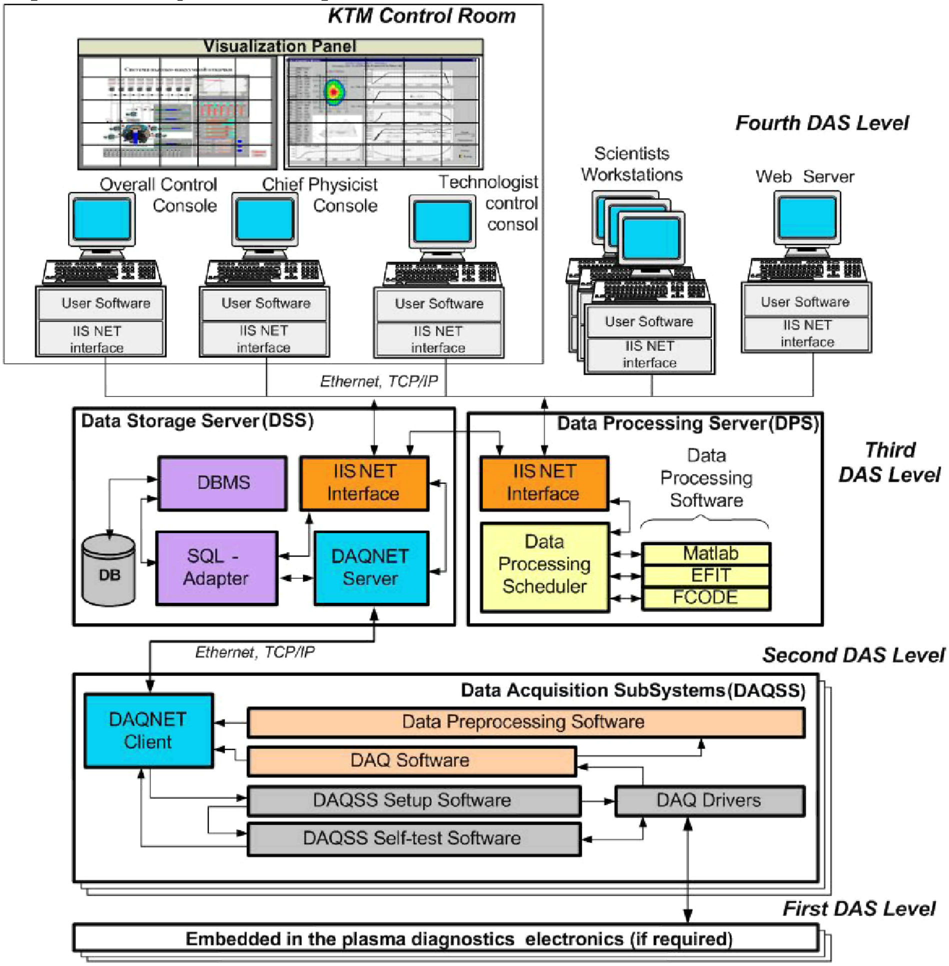

FIGURE 6. DAS KTM software structure

DAS KTM has a 4-level hierarchical structure (Figure 6). The lower two levels are mostly dedicated to data acquisition from diagnostics. In the TABLE 1 information flows from KTM diagnostics are shown. On the low levels DAS KTM includes 19 data acquisition subsystems (DAQSS): radar-reflectometer DAQSS [2], single channel interferometer DAQSS, electromagnetic diagnostic DAQSS and others. DAS KTM has more than 400 data acquisition channels for physical diagnostics with summary raw data quantity about 1GB per shot.

TABLE 1. KTM diagnostics data flows

№	Diagnostic	Number of channels	Sampling rate, ksps	Bytes per sample	Data flow, MB/s	Data per shot, MB
1	Electromagnetic diagnostic:					
	Two-component magnetic probes	72	100	2	14,063	70,313
	Two-component divertor magnetic probes	20	100	2	3,906	19,531
	Diamagnetic coils	4	10	2	0,078	0,391
	Rogovski coils	10	10	2	0,195	0,977
	Gradient flux loops	16	100	2	3,125	15,625
	Flux loops	20	100	2	3,906	19,531
	Sector loops	36	100	2	7,031	35,156
2	Survey bolometer	1	0,1	2	0,000	0,001
3	AXUV bolometric measurement system	32	100	2	6,250	31,250
4	Hα-Dα	8	10	2	0,156	0,781
		2	1000	2	3,906	19,531
5	Survey VUV-spectrometer	10	1	2	0,020	0,098
6	High resolution VUV-spectrometer	10	1	2	0,020	0,098
7	SXR	32	50	2	3,125	15,625
8	Pulsed time-of-flight refractometer	2	100	2	0,391	1,953
9	Two channel pulsed radar reflectometer	2	100	2	0,391	1,953
10	Multichannel interferometer	10	100	2	1,953	9,766
11	Sweeping pulsed radar reflectometer	10	10	2	0,195	0,977
12	X-point interferometer	10	100	2	1,953	9,766
13	Divertor thermal imaging system	5	10	2	0,098	0,488
		1	0,1	81920	8,000	40,000
14	SXR spectrometer	10	1	2	0,020	0,098
15	HXR	3	100	2	0,586	2,930
16	Langmuir probes	3	100	2	0,586	2,930
17	Corpuscular diagnostic	12	10	2	0,234	1,172
18	MHD	72	500	2	70,313	351,563
19	Visible light plasma imaging system	4	0,05	81920	16,000	80,000
		1	0,5	153600	75,000	375,000
				Total:	221,5	1107,5

The third level is dedicated to data storage and processing. The size of storage devices is equal to 1 Terabyte. For the first time, amount of information, which have to be processed between discharges on the data processing server, are in the range from 50 MB to 250MB per shot.

The fourth level is used for data visualization and data presentation for end users. It includes tokamak control room computers and consoles (overall control console, chief physicist console, technologist control consol, sharing visualization panel), web-server and scientists workstations.

High speed data acquisition and information transfer from some data acquisition subsystems to the plasma control system requires making universal interfaces of inter-level data transmission and communication. DAQNET and IISNET software interfaces are used to provide all connections between three upper levels of DAS. DAQNET interface interconnects second and third DAS levels and is adopted for real time data transfers to plasma control system. IISNET interface provides common approach for the third and fourth DAS levels interactions.

It's proposed to develop interfaces using some middleware e.g. ACE, Indy, Synapse, to increase software portability. DAQNET and IISNET interface connection with DSS database management system is made using SQL-adapter, a service, that converts DAQNET and IISNET requests to DBMS-requests on the fly. This software component is developed using native database interface libraries, namely, libpq_fe C/C++ pack for PostgreSQL database.

DSS have to be a specialized database for KTM tokamak. It has to use both specialized data formats and network software interfaces in order to store quickly huge experimental data flows, and provide quick information search, selection and transfer to end users, for further processing, visualization and analyze. On the other hand it's required to search and compare information from multiple fusion experiments. Data amounts are huge for each fusion device, so it's required to use both fast network connections and common data format or provide data formats compatibility. Unfortunately, there are no common data formats for international fusion community. Most of fusion devices have custom data formats and some of them provide support for other more or less widely used formats. So, it's required for KTM to develop both own data format and open services for implementation of fusion data formats converters in order to reach compatibility.

Fusion data processing is another important task to decide. It has deal with great amount of data and complex calculation algorithms, so, for the first time, high performance server and then supercomputer and grid network have to be used. KTM data processing server (DSS) must to provide predictive data processing management while huge quantities of service requests from KTM end users and Internet. Data processing services can include wild used calculation fusion codes such as EFIT/rtEFIT, and custom Matlab implemented or specialized executable codes for KTM.

KTM control room is a part of data acquisition system. It includes (Figure 6) computerized overall control consol, chief physicist consol, technologist control consol and main visualization panel. Main visualization panel dimensions are $4.4x2m^2$, resolution 1000 dpi, brightness 500 Cd/m^2, contrast 1000:1, angle of view 160^0 regeneration frequency 60Hz. It's fully programmable and used together with consoles both for most important results visualization and KTM configuration for new discharge.

REFERENCES

1. E. A. Azizov, V. N. Dokouka, N.Ya. Dvorkin, et al., Kazakhstan tokamak for material testing (KTM), Plasma Devices and Operations, 11(1), 39–55 (2003).
2. A.V. Sharnin, R.I. Baystrukov, D.V. Rogozniy. Design of data acquisition and control subsystem of the KTM tokamak multifrequency pulse radar reflectometer. - Plasma Devices and Operations. Vol. 11, No. 4, December 2003, pp. 237–241