Sixth IAEA Technical Meeting on
Control, Data Acquisition, and Remote Participation for Fusion Research
4 ~8 June 2007, Inuyama, Japan

Software Development of the KSTAR Tokamak Monitoring System

K. H. Kim, T. G. Lee, S. Baek, S. I. Lee, Y. Chu, Y. O. Kim, J. S. Kim, M. K. Park, and Y. K. Oh

National Fusion Research Center, 52 Eoeun-dong, Yuseong-gu, Daejeon 305-333, Republic of Korea

Abstract

The Korea Superconducting Tokamak Advanced Research (KSTAR) project, which is constructing a superconducting tokamak, was launched in 1996. Much progress in instrumentation and control has been made since then and the construction phase will be finished in August 2007. The Tokamak Monitoring System (TMS) measures the temperatures of the superconducting magnets and structures and hence monitors the superconducting conditions during the operation of the KSTAR tokamak. The TMS also measures the strains and displacements on the structures in order to monitor the mechanical safety. There are around 500 temperature sensors, more than 360 strain gauges, and 20 displacement gauges.

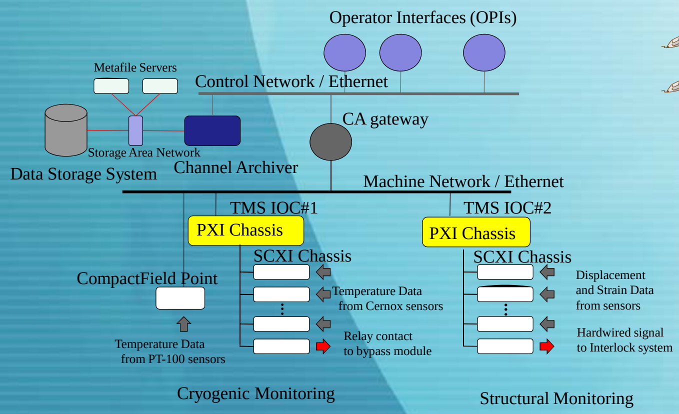
The TMS utilizes Cernox sensors for low temperature measurement and each sensor has its own characteristic curve. In addition, the TMS needs to perform complex arithmetic operations to convert the measurements into temperatures for each Cernox sensor for this large number of monitoring channels. A special software development effort was required to reduce the temperature conversion time and multi-threading to achieve the higher performance needed to handle the large number of channels. We have developed the TMS with PXI hardware and with EPICS software. We will describe the details of the implementations in this paper.

Functions of KSTAR Tokamak Monitoring System (TMS)

- Cryogenic Monitoring
  - Monitoring superconductive characteristics
  - Temperature monitoring
    - Cernox/PT-100 sensors
  - Calculate Helium properties (super-critical He)
    - Input: pressure, temperature
    - Output: density, entropy, internal energy and etc.
- Structural Monitoring
  - Monitoring mechanical safety
  - Displacement
  - Strain-Stress
  - Magnetic filed: Hall sensors

Structure and functions of TMS

- TMS IOC#1: Cryogenic monitoring
  - SCXI modules: cernox sensors & Hall sensors
  - CompactFieldPoint: PT-100 sensors
- TMS IOC#2: Structural monitoring
  - SCXI modules: Displacement, Strain-Stress
- Channel Archiver
  - Continuous data archiving
  - SAN Storage
- Operator Interface
  - User Interface, Alarm, Stripchart
- CA gateway
  - Communication relay between the machine network and control network
  - Reduce communication overhead on IOCs



Structure of the TMS

System requirements of the TMS

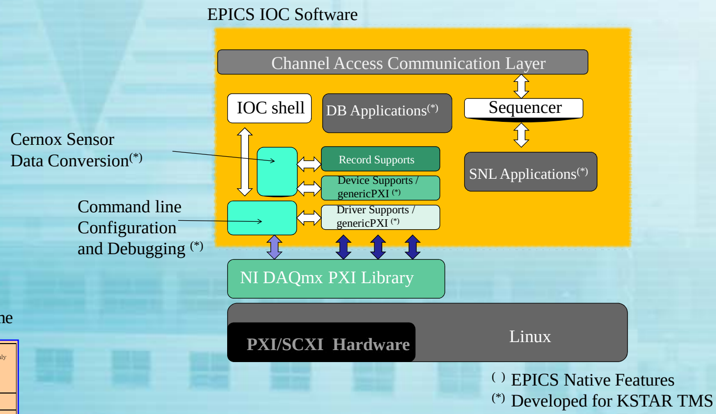
- Measure large number of channels (~ 700 channels)
  - Temperature: 500 channels
    - Cenorx Sensor: ~400
    - PT-100 Sensors: ~100
  - Displacement: ~20
  - Strain-Stress: ~ 250
  - Hall sensor: ~ 10
- High voltage isolation and Noise filtering
- Fast monitoring : 10~50Hz sampling
- Continuous operation: 24 hours in a day
  - Continuous monitoring
  - Continuous archiving

Choice of Hard ware and Software

- Hardware
  - National Instruments: PXI / SCXI
    - Cheap & Powerful CPU board
    - Multi channel I/O : >100ch/module
    - Signal Conditioner: 15kV isolation, Low-pass filter, adjustable gain control, and etc
  - A/D converter (digitizer): PXI-6280
  - Signal Conditioner:
    - Cernox/Hall sensor: SCXI-1125
    - Displacement/Strain-Stress: SCXI-1520 and etc.
- Software
  - OS: Linux (kernel-2.6)
  - Middleware: EPICS (R3.14.8.2) - control software standard in KSTAR
    - Measurements & I/O control: EPICS IOC software
    - Data conversion & network transmit: IOC software
    - Data Archiving: EPICS channel archiver
    - Monitoring & User Interface: EPICS channel access library, Qt Applications

Implementation of TMS IOC software

- EPICS IOC core software
  - Communication: Channel Access Server/Client
  - Bundled device/record supports
  - User programming environment
    - DB Application: Graphical/Visual programming
    - State Notation Language (SNL): C like syntax / finite state machine
- Development of Software
  - PXI hardware driver & device
    - drvPXISCXI: interface layer between NI DAQmx and EPICS device support layer
    - devPXISCXI: data transmit between hardware to EPICS record, data conversion, and etc
  - DB Application
    - Data conversion: Raw data to Physical data (for displacement, strain-stress , Hall sensors and PT-100)
    - Hardware control: sampling rate, gain, filter option and etc. (by operator or by control logic)
  - SNL program
    - Cooling status, Detection of abnormal status
  - Cernox Data Conversion (Special requirement)
    - each Cernox sensor has its own characteristic curve (fit the curve by Chebyshev polinomials)
      - require a database for fitting coefficients each sensor
      - fast conversion time
    - Implement a function block in device supports with C language
      - an IOC thread
      - executed by a request from record support
      - asynchronous processing to avoid blocking of the record processing



Function block in EPICS IOC

Reducing the calculation time : example of the Cernox Data Conversion

- Implemented with C and embeded into the device supports
- Choose more faster algorithm

Recursion with Trigonometric function

$$r = \log_{10}(R)$$

$$r_{norm} = \frac{2r - a - b}{b - a}$$

$$T = \sum_n C_n \cos\left(n \cos^{-1} r_{norm}\right)$$

Recursion with arithmetic only

$$T_{n+1} = 2xT_n - T_{n-1}$$

$$\begin{cases} T_0 = 1, \\ T_1 = x \end{cases}$$

$$T(r_{norm}) = \sum_n C_n T_n(r_{norm})$$

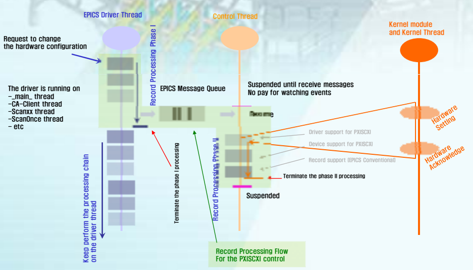
Measurements of computation time

	Iteration with Trigonometric Function $T(x)=\sum_{n=0}^{9} C_n \cos\left(n\cos^{-1}x\right)$		Iteration with arithmetic only $T(x)=\sum_{n=0}^{9} C_n T_n(x)$, $T_{n+1}=2xT_n-T_{n-1}$	
	Calculation Time	Fail	Calculation Time	Fail
Cache Fail	25.677 μsec	L1 Cache	1.684 μsec	L1 Cache
Cache Hit	2.113 μsec		0.106 μsec	

Sixth IAEA Technical Meeting on
Control, Data Acquisition, and Remote Participation for Fusion Research
4 ~8 June 2007, Inuyama, Japan

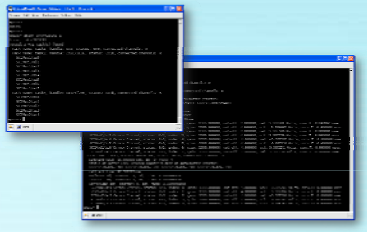
How to avoid blocking of the Record processing during hardware configuration

- Sampling Rate, Gain, Low-pass filter control
  hardware setup delay > 100 ms for PXI/SCXI modules
- To avoid blocking of record processing: multi-threading
  - control thread
  - message queue
  - resume and suspend



Command line interface (CLI) on IOC shell

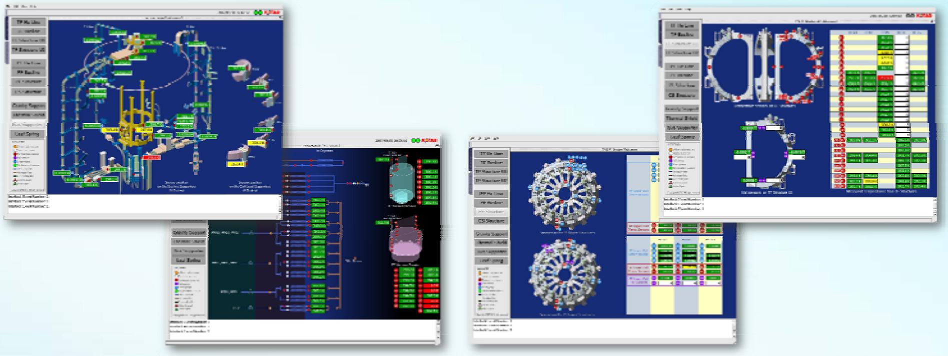
- Extensions for IOC shell command
- Debugging Features
  - Report information of hardware configuration, task status, channel configuration
  - List up information of sensors, counters, parameters for software internal
  - Turn on and turn off the debugging messages
- Configuration Features
  - Create task to handle PXI hardware
  - Create channel and configure properties of channel
  - Destroy the channel
  - Destroy the task



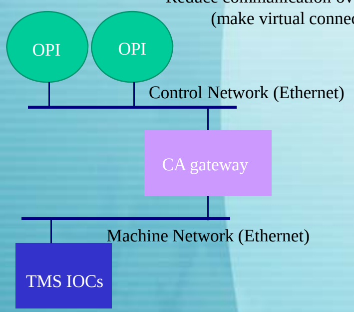
Example of IOC shell command

Operator Interface (OPI)

- Developments
  - Graphic library: Qt/Qt Designer
  - Communication: EPICS Channel Access library
- Operation evironment
  - Redhat Enterprise Linux WS4
- Network Connection
  - TMS OPIs: control network (Ethernet)
  - TMS IOCs: machine network (Ethernet)
  - CA gateway
    relay station of Channel Access communication
    Reduce communication overhead on IOCs
    (make virtual connection with OPIs)



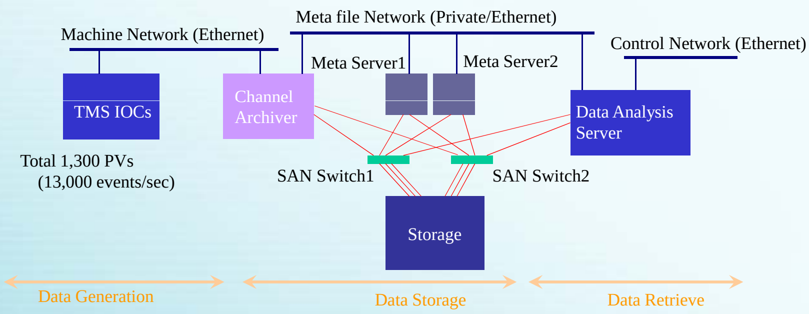
Screen Shots of the TMS OPIs



Function of CA gateway

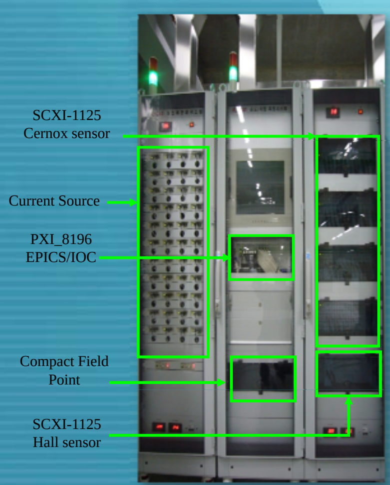
Data Archiving & Retrieve System

- Data Archiving
  - EPICS Channel Archiver
  - Continuous archiving
  - Periodic / Event driven archiving
- Data Storage
  - SAN Storage
  - IBM DS8100 Storage
  - StorNext File system (Shared file system)
- Data Retrieve
  - by Data analysis server
  - ArchiverExport (CLI tools)
  - Web based export (apache, XML rpc, cgi)
  - Java export (graphical tools)
  - GNUplot, Excel, and etc

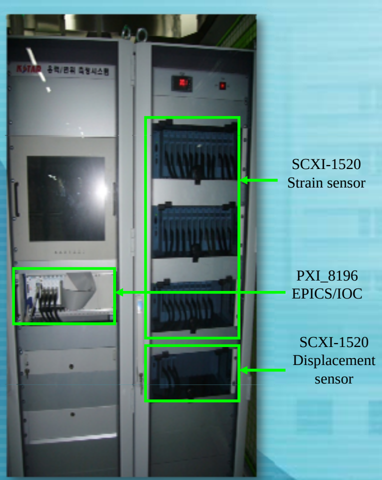


Data Archiving System

TMS Control Racks



Cryogenic Monitoring



Structural Monitoring

Pre-Commissioning

- Hardware check
  - Check for sensors, signal lines and connections
  - Calibration digitizer offset
  - Check long term drift of measurement data
- Software check
  - Check basic functions of IOCs, OPIs, and Data archiving system
  - Check software stability
- Stability check conditions
  - Total PVs: ~1,300 PVs (10Hz processing, 13,000 events/sec) in two IOCs
  - 10 OPIs connection
  - CA gateway: 1,300 PV connection, 13,000 virtual circuits, 130,000 server events/sec
  - Channel archiver: Archive whole channels, every events.
- Results of Stability Check
  - IOCs: worked well during 2 months (no memory leak, no hang-up, less than 10% CPU loads)
  - CA gateway: passed (no hang-up, less than 5% CPU load)
  - Channel Archiver: keep evaluation (less than 30% CPU load, have been crashed once)
  - OPI Application: fixing –up memory leak on graphic widget

Summary and Future Plan

- We have developed the TMS and performed pre-commissioning with room temperature conditions under which the measurements values and system performance were satisfied. The TMS also passed a 2 months aging test and was found to be very stable.

- The next step is to implement automatic gain control functions for the Cernox sensors and measurements of the helium properties to prepare for the cool down process and operation.