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Development of a VME Multi-processor System for Plasma Control at the JT-60 Upgrade

M. Takahashi, K. Kurihara, Y. Kawamata, H. Akasaka and T. Kimura
Naka Fusion Research Establishment
Japan Atomic Energy Research Institute
801-1 Mukohyama, Naka-machi, Naka-gun, Ibaraki-ken 311-01 Japan

Abstract

Design and initial operation results are reported of a VME multi-processor system [1] for plasma control at a large fusion device named "the JT-60 Upgrade" utilizing three 32-bit MC88100 based RISC computers and VME components. Development of the system was stimulated by faster and more accurate computation requirements for the plasma position and current control. The RISC computers operate at 25 MHz along with two cashe memories named MC88200. We newly developed VME bus modules of up/down counter, analog-to-digital converter and clock pulse generator for measuring magnetic field and coil current and for synchronizing the processing in the three RISCs and direct digital controllers (DDCs) of magnet power supplies. We also evaluated that the speed of the data transfer between the VME bus system and the DDCs through CAMAC highways satisfies the above requirements. In the initial operation of the JT-60 upgrade, it has been proved that the VME multi-processor system well controls the plasma position and current with a sampling period of 250 μsec and a delay of 500 μsec.

1. Introduction

In the JT-60 Upgrade (JT-60U) [2] where is performed the study of magnetically confined plasma near the thermal break-even condition, the plasma current is increased up to 6 MA in the lower X-point divertor configuration. The vacuum vessel and the poloidal field coils, then, have been replaced for these improvements.

From the viewpoint of plasma equilibrium control, the vertical positional stability is one of the most important issues for the tokamak with elongated plasma. The stabilizing index n_s due to the horizontal magnetic field coil is designed to be 1.6 for the plasma with the poloidal beta β_p=0.6. The vacuum vessel, however, dose not have much effect on the stabilization, because the vessel is made of corrugated thin walls whose time constant of the field penetration is very short (τ=8 msec). Hence, it is necessary to raise the response of the feedback control system. The control cycle of the system must be less than 0.5 msec and the delay of the system must be less than about 1 msec except for the conversion time in the magnet power supplies.

Moreover, since the stored energy of plasma and electromagnetic energy of coils will increase, undesirable events such as plasma disruption may do fatal damage to the components of the vacuum vessel and the coils. More calculations, hence, are necessary to obtain the plasma parameters of positions and clearances more precisely, to produce stable plasmas and to protect the tokamak components. As shown in Table 1, the control system must, then, have such a fast data input/output capacity that it can utilize several tens of status data and several control commands. The control system must also possess such large amount of data transfer capability that it can ship up result data of a few megabytes to its supervisory computer named "discharge control computer" within a limited short time for data analysis at a shot-interval of 10 to 15 minutes.

This paper reports how we designed the control system utilizing VME components in order to satisfy the above requirements for the JT-60U plasma control. Section 2 of this paper describes the configuration of the VME plasma control system. The characteristics of the VME system including its plasma control performance are described in section 3. The final section is a summary.

Table 1 JT-60U Plasma Control Data

Item	No. of Data Channels	Data Amount (kByte)
Input Data		
Magnetic Sensor Signals	70	2,000
Coil Voltages and Currents	11	330
Control References	5	150
Calculation Data		
State Parameters of Position	5	300
Output Data		
Control Commands	5	300
Total	96	2,280

2. Configuration of the VME Multi-Processor System

As shown in Fig. 1, the JT-60 plasma control system contains two feedback loops. The major loop is for plasma heating and gas fueling control and the minor loop is for plasma position and current control which is done by using five sets of poloidal field coils. Control cycle of each loop was decided corresponding to time scale of change in its control objectives.

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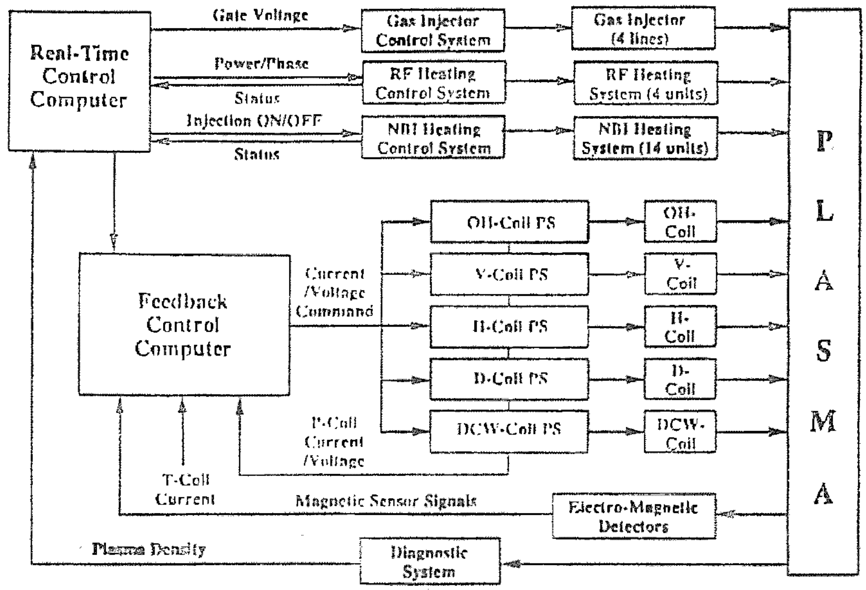

Fig. 1 Data flow in the JT-60U plasma control system

named MVME050A (Motorola, Inc., U.S.A.), which has functions of bus arbitration, system reset, system clock generation and serial clock generation. A host computer of the workstation Sun3/140M (Sun Microsystems, Inc., U.S.A.) is provided for developing the VME microcomputer programs under a Unix operating system, where C language is available.

Three MC88100 based RISCs named MVME181 (Motorola, Inc., U.S.A.) are equipped in the rack A. The 32-bit RISC computer, which supports floating arithmetic, operates at 25 MHz along with two 16-kilobyte cashe memories named MC88200. One of those (CPU#1) is dedicated for collection of the magnetic probe signals and coil currents, calculation of the state variables of plasma current and position, and the plasma vertical position control. The others (CPU#2 and CPU#3) execute the feedback control of plasma current,

The response of the plasma control system for the JT-60 Upgrade must be more than three times faster than that of the original system from the viewpoint of the vertical positional stability of the plasma. However, it is very difficult to reduce further the execution time required for the data input/output and more accurate calculation because the original JT-60 plasma control system, where the minicomputers and the microprocessor were equipped with accuracy of 16 bit and clocks of 2 to 2.5 MHz, was designed about ten years ago.

Although adoption of analog controllers may be one of the methods to satisfy the above requirements from the viewpoint of control response, it is hard work to keep the controllers be in good condition and it takes much time to develop their control algorithm for sophisticated control.

A VME bus system has the features that (1) we can utilize the fastest processor with 32-bit or more accuracy at present, (2) its system clock (16 MHz) is faster than the CAMAC system clock (5 Hz at maximum), (3) VME bus modules interfacing with CAMAC systems are on the market, etc.. Hence, we have decided to replace the 16-bit minicomputer and microprocessor based system with a VME multi-processor system where 32-bit reduced instruction set computers (RISCs) of MC88100 and 32-bit microcomputers MC68030 are adopted for the plasma feedback control and magnet coil current control respectively.

As shown in Fig. 2, the VME multi-processor system is composed of 4 VME racks, which are connected with each other through 6 bus repeater/expanders (PT-VME902A-1, Performance Technologies, Inc., U.S.A.). One of the racks is dedicated for microcomputers and the others for I/Os. The first slot in the rack A is occupied by a system controller

horizontal position and the height of X-point from the divertor plate, and the calculations for the protective interlock of the coil system.

The rack A is also equipped with a MC68030 based microcomputer named MVME147 (Motorola, Inc., U.S.A.), which communicates with the three RISCs through VME bus and with the host computer through a local area network of Ethernet. The communication programs are executed under a real-time operating system named VxWorks (Wind River System, Inc., U.S.A.).

In the racks B, C and D, analog-to-digital converters (ADCs) and up-down counters (UDCs), which have been newly developed, are provided for digitizing the coil currents and integrating the magnetic probe signals respectively. The ADC has eight input channels and its resolution and conversion time are 12 bits and 5 μsec respectively. The UDC has four 16-bit up-down counters for the input of the pulse signals with a maximum frequency of 2 MHz from voltage to frequency converters. A digital input/output board named MVME340A (Motorola, Inc., U.S.A.) is equipped in order that event signals from the plant and plasma can interrupt the computers and that the computers can put out interlock signals to the actuators. A digital-to-analog converter named DT1403-4 (Data Translation, Inc., U.S.A.) is used for feeding the plasma current to the DDC.

A CAMAC crate is provided for transferring data between the RISCs in the VME system and its supervisory control computers and between the RISCs and the DDCs. The VME system is connected through a CAMAC branch driver named CBD8210 (Creative Electronic Systems, Switzerland), a branch highway and a type A2 crate controller (CCA2,

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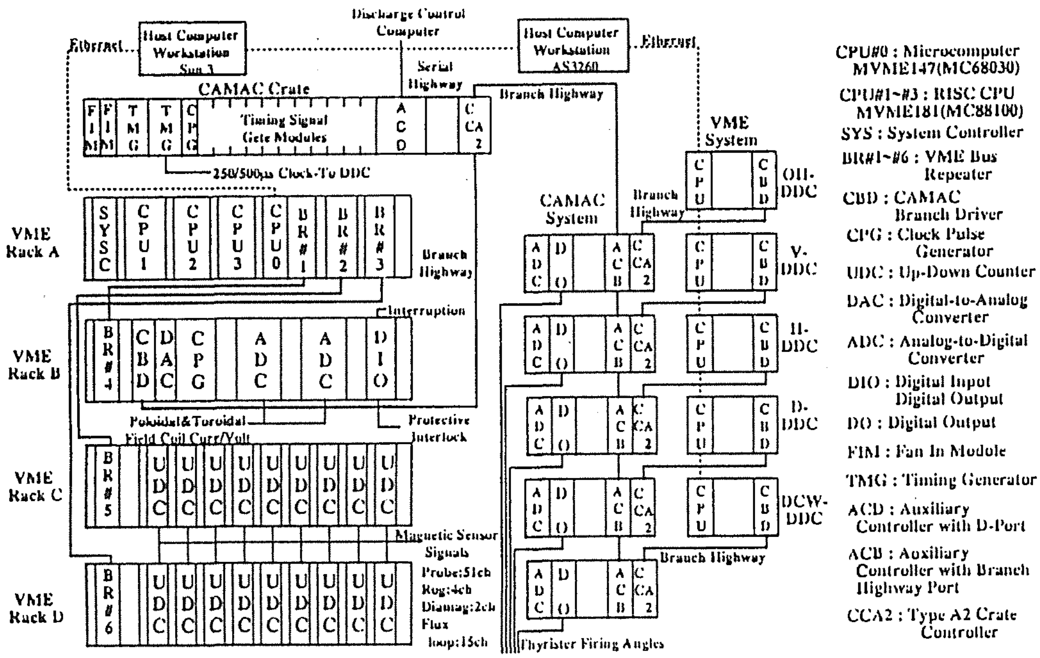

Fig. 2 VME multi-processor system for the JT-60U plasma control system

Standard Engineering Corp., U.S.A.). All the CAMAC system parameters such as addresses, functions and data word length are mapped on the VME address field in the branch driver, which also has a multi crate addressing capability. The branch driver is, hence, suitable for fast and large amount of data transfer in the plasma control.

The CAMAC crate is equipped with an auxiliary controller with D-port (ACD, Kokusai Electric Co., Ltd., Japan), which is provided for transferring the discharge result data from the VME system to the discharge control computer. The control commands are directly transferred to the DDCs through auxiliary controllers with branch highway port (ACB, Kokusai Electric Co., Ltd., Japan). Many timing modules are also installed in the CAMAC crate for generating, receiving, transmitting and masking clock pulses and trigger signals.

3. SYSTEM CHARACTERISTICS

3. 1 Pipeline processing

Figure 3 shows the plasma control time chart of the VME system including the DDC control system. The VME multi-processor system for the JT-60U control is a pipe-lined system with two kinds of sampling clock of 250 μsec and 500 μsec. The former is for the control of the plasma vertical position and the latter for the control of the other parameters.

The CPU#1 first collects the data from the magnetic sensors and the magnet coil power supply shown in Table 1 with a sampling period of 250 μsec. The time required for the data collection is less than 50 μsec. The CPU#1, then, calculates the plasma state variables with the signals from magnetic probes and flux loops. The CPU#1 also executes the calculation for the plasma vertical control and transfers the calculated command of the current or voltage to the DDC in the horizontal field coil power supply (H-DDC) with a cycle of 250 μsec. The time required for the above execution is less than 250 μsec.

The CPU#2 and the CPU#3 execute the calculation for the control of the other parameters such as the plasma current, the horizontal position and the X-point position and the interlock calculation for protecting the magnet coils and the first wall components, following which they transfer their control commands to the DDCs except the H-DDC every 500 μsec. The time required for the execution in these CPUs is less than about 300 μsec. Since the DDCs execute their control calculations in 250-500 μsec, the delay in the plasma control system for the vertical position control is less than 500 μsec and the delay for the other parameter control is less than 800 μsec. The plasma vertical position control loop including the magnet power supply and the magnetic measurement system, hence, has a sampling period of 250 μsec and a delay of about 2 msec in total.

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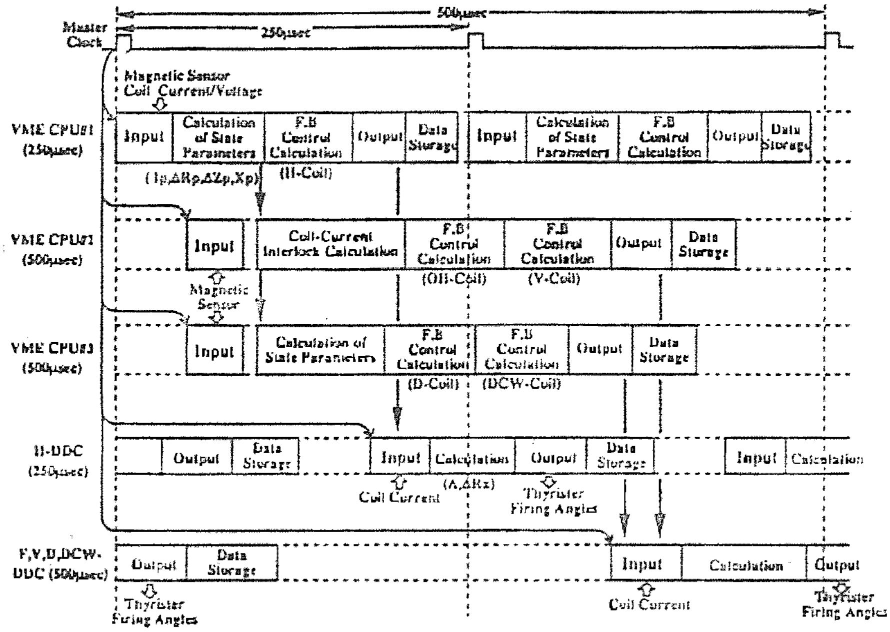

Fig. 3 Control time chart of the VME multi-processor system

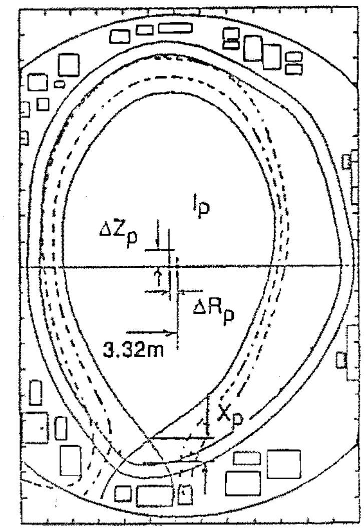

Fig. 4 JT-60U plasma shape and the controlled parameters

3.2 *Plasma Control Performance*

Figure 4 shows the shape of the JT-60U plasma along with its controlled parameters, i.e. the plasma current (Ip), the plasma horizontal position (ΔRp), the plasma vertical position (ΔZp), and the diverter X-point position (Xp). In the initial operation of the JT-60U, the feedback control system well controls these parameters by PD (proportional and differential) control with matrix gain and stable divertor plasmas with plasma current of 5MA have been obtained. As an example of the control performance, the step response of the vertical position ΔZp is shown in Figure 5. The amplitude of the fluctuation is less than 5 mm and the settling time is less than 10 msec short, though we observe the overshoot which may not give bad influence on plasmas.

4. SUMMARY

The VME multi-processor system, where three RISC computers are adopted, have been newly developed for the JT-60 plasma control. The new system makes it possible to execute more accurate and faster control of the plasma position and shape. In the initial JT-60U experiments performed from the last April through October, stable divertor plasmas with the current of 5 MA have been obtained with this control system.

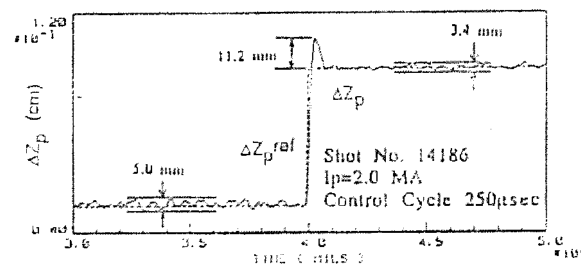

Fig. 5 Step Response of the Plasma Vertical Position in the Feedback Control

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