DSP Application to Parallel Processing in JT-60 Plasma Control

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Abstract

A real-time plasma shape visualization system has been developed for plasma control in the JT-60 tokamak. Fast digital signal processors (DSPs) having inter-processor communication ports are applied to parallel processing in this system. The optimum number of the DSPs was estimated according to the degree of the parallelism and allowable delay in the process of the plasma control. This system can visualize time evolution of the plasma shape clearly every 60 ms in real time. It has been fully used for monitoring the plasma behavior in the tokamak experiments.

1 Introduction

Plasma shape control in tokamak-type fusion devices like JT-60[1] and ITER[2] is one of the important issues for improving plasma performance. For example, plasma confinement performance depends on the shape of the plasma column cross section like ellipticity and triangularity[3]. A gap between plasma surface and an antenna of a radio-frequency (RF) wave heating system is more essential factor for increasing its plasma heating efficiency than the plasma column center position. It is very important for protecting in-vessel components like divertor tiles and for producing desirable plasmas to control strike points of separatrix lines on divertor tiles.

From the above points of view, we have developed a real-time plasma shape visualization system for plasma control in the JT-60 tokamak. Fast digital signal processors (DSPs) having inter-processor communication ports are applied to parallel processing in this system.

Section 2 of this paper describes an overview of computational procedure in the plasma shape identification. The structure of the parallel processing for identification is shown in section 3. The configuration of the real-time plasma shape visualization system and its performance are described in section 4. Final section has concluding remarks including the prospects of the system in application to real-time plasma control.

2 Computational procedure of the plasma shape identification

So far various methods like the filament-current-plasma (FCP) approximation, Legendre-Fourier expansion and boundary integral equation-based methods have been proposed for the plasma shape identification [4], where magnetic sensors such as flux loops, magnetic probes and Rogowski coils are used. We can obtain the shape as the outermost magnetic surface of the plasma using the flux function, which is expressed by

$$f\,(r, z) = \sum a_i(r, z, \mathbf{h})\cdot\phi_i + \sum b_j(r, z, \mathbf{h})\cdot B_j + \sum c_k(r, z, \mathbf{h})\cdot I_{ck} + d(r, z, \mathbf{h})\cdot I_p\,, \qquad (1)$$

where ϕ_i, B_j, I_{ck} and I_p are the measured values of magnetic flux, magnetic flux density, poloidal field coil current and plasma current respectively, and a_i, b_j, c_k and d are the coefficients given by both the observation point in cylindrical coordinates (r, z) and the parameter vector **h**. In the FCP approximation method, for example, this vector is defined as the locations of all the filament currents. We can calculate the coefficients in Eq.(1) for all possibly utilized positions (r, z) in the 2-dimentional space of the vacuum vessel cross section and the parameter vector **h** in advance of obtaining the flux function values. We can store these coefficients on a large-capacity memory as a tabular form corresponding to the positions. Hence, we can execute fast calculation of the flux function values by the table look-up method.

The algorithm to obtain the outermost magnetic surface of divertor plasma is expressed as follows [5]:

- Step 1: The position of the divertor X-point is searched as a saddle point on the three-dimensional curved surface (r, z, f (r, z)).
- Step 2: The flux values at the fixed limiters on the first wall are calculated for investigating whether the plasma configuration is limiter one or divertor. The smallest flux value f_{min} among those at the limiters and the

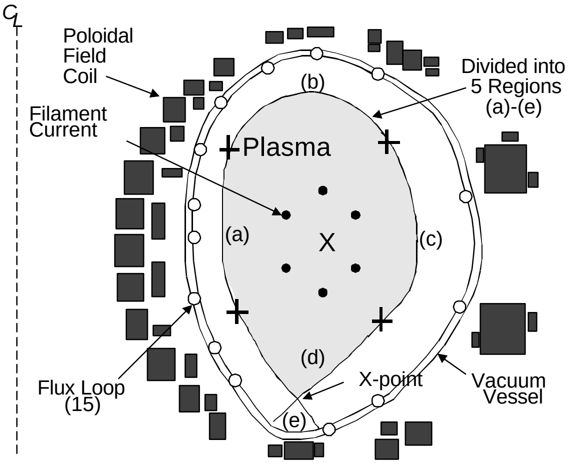


Fig. 1 Search for the plasma boundary.

X-point indicates the flux value of the plasma boundary.

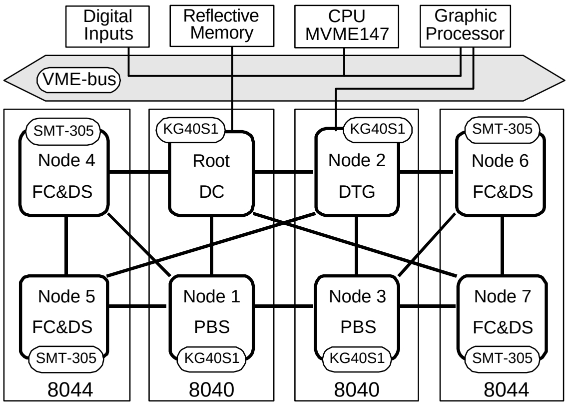
- Step 3: The contour of the curved surface having f_{min} is searched. This contour corresponds to the outermost magnetic surface of the plasma, i.e. the plasma boundary.

3 Structure of the parallel processing

It is possible to divide each of the computational steps for the plasma shape identification into plural and parallel processes. For example, the computational step for the boundary search (step 3) is divided into five parallel processes corresponding to four regions of the main plasma boundary (a)-(d) and a region of the divertor separatrix lines (e) as shown in Fig.1. Hence, we applied parallel processing to the real-time plasma shape visualization system so as to realize fast computations. We adopted the TMS320C40 DSP (Texas Instruments Co., U.S.A.) as processors in this parallel processing [6], because this DSP has six communication ports available for fast inter-processor data transfer. Another reason why we selected this DSP is that we can use a compiler named "Parallel C" (3L Ltd., UK) on this DSP-based platform. We can easily define the configuration of this parallel processing system and assign the computational processes to each DSP using this compiler.

Two kinds of VME bus-based DSP boards named DSP8040 and DSP8044 (MTT Corp., Japan) are applied to this system. The DSP8040 board has two KG40S1 modules (MTT Corp., Japan) with VME bus interface. Each module is equipped with one TMS320C40 DSP running at 40 MHz and three 256 kB SRAMs. On the other hand, the DSP8044 board has two SMT305 modules (Sundance Multiprocessor Technology Ltd., UK) without VME bus interface. Each of these modules, however, provides two 16-MB DRAMs and two 1-MB SRAMs in addition to one TMS320C40 DSP. These DRAMs are used for installing the look-up table described in section 2.

The performance of the TMS320C40 DSP is summarized in Table 1. Data of fifteen flux loops, four poloidal field coil currents and a Rogowski coil are used for calculating the flux function values by Eq.(1). 6.5 megabytes of memory are allocated for a set of the coefficient table corresponding to one pattern of **h** in application of the FCP approximation method to JT-60. The number of flux computations required for the plasma boundary search amounts to about 1500.



DC:Data Communication, DTG:Data Transfer to the Graphic Processor
FC&DS:Flux Calculation & Data Storage,PBS:Plasma Boundary Search

Fig. 2 Topological structure of the parallel processing system.

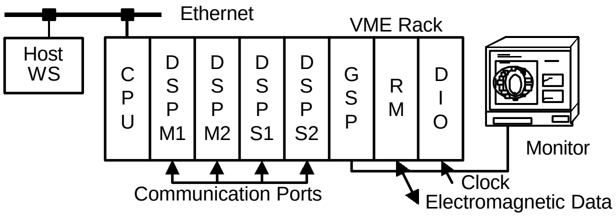
Taking the degree of parallelism in the identification processes into consideration in addition to the above data, we estimated the optimum number of the DSPs for this system [7]. Fig. 2 shows the topological structure of the system, where eight DSPs are connected with each other through the communication ports. Four SMT305 modules having two 16-MB DRAMs (nodes 4-7) are dedicated for the parallel processing of the flux function value computations. One KG40S1 is assigned as the root processor for data I/O. Another one (node 1) is used for sending the plasma boundary data to a graphics processor. The other two KG40S1 modules (nodes 2 and 3) are used for deciding the plasma boundary positions from the results calculated by the SMT305 modules.

4 Configuration and performance of the real-time plasma shape visualization system

The real-time plasma shape visualization system for the JT-60 operation is a VME bus-based multiprocessor system. As shown in Fig. 3, two DSP8040 boards and two DSP8044 ones are installed in a VME rack. A reflective memory (RM) board named VMIVME-5576 (VMIC Co., U.S.A.) is also installed for fast communication of input signals of the magnetic sensors and the coil current data. For drawing the plasma shape on a monitor, we adopted a TMS34020-based

Table 1 Performance of the TMS320C40 DSP

Item	Time (µs)
Multiply and add	0.05
Scalar product of vectors with 20 components	1.60
Interpolation between two positions	1.50
Comparison of two values	0.35
Data transfer (4 Bytes)	0.85



Symbol	Type	Manufacturer (Nation)	Functions / Specifications
DSP/M1, M2	DSP8040	MTT Co. (Japan)	TMS320C40, 40 MHz (KG40S1)
DSP/S1, S2	DSP8044	MTT Co. (Japan)	TMS320C40, 40 MHz (SMT305)
GSP	UDC6000TI	Univision Tech. (U.S.A.)	TMS34020-based graphics accelerator
CPU	MVME147	Motorola Inc. (U.S.A.)	MC68030, 25 MHz, 32-MB DRAM
DIO	DSP8230	MTT Co. (Japan)	64-bit digital inputs/outputs
RM	VMIVME-5576	VMIC Co. (U.S.A.)	256-kB reflective memory, 6.2 MB/s

Fig. 3 Configuration of the real-time plasma shape visualization system.

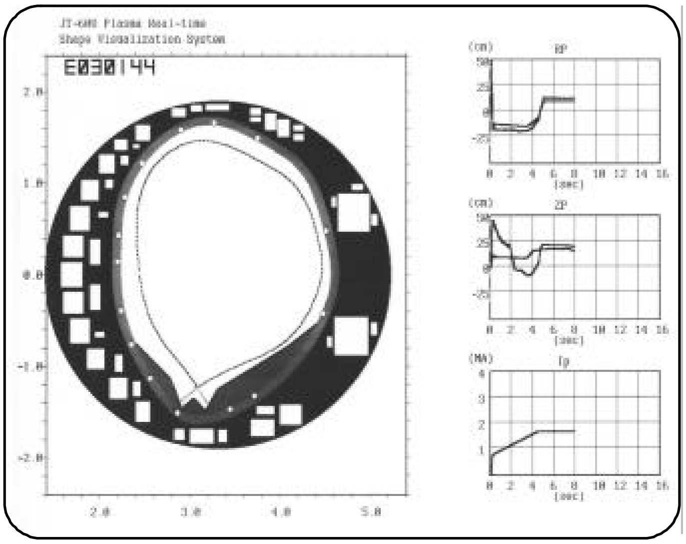


Fig. 4 Example of the reproduced plasma shape.

graphics processor named UDC6000TI (Univision Technologies Inc., U.S.A.). A 16-bit digital inputs/outputs board named DSP8230 is used for input of a clock signal. A 32-bit MC68030-based CPU board is dedicated for supervising this VME system and communicating with its host workstation via an Ethernet LAN.

The real-time plasma shape visualization system has been applied to the JT-60 divertor operation since the last June. This system can display the plasma shape on the monitor about 16 times per second. Then, we can easily observe the sequential behavior of plasmas such as formation of limiter plasma and configuration transition from limiter to divertor with the X-point in addition to the oscillation of the plasma position. An example of the reproduced plasma shape is shown in Fig. 4. Time evolution of the plasma current and the horizontal and vertical positions of plasma column center can be displayed as well as that of the plasma shape. The functions of slow playback and enlargement of the divertor region are also available for detailed observations.

It takes about 47 ms to identify the plasma shape and about 13 ms to draw it. In the design of the visualization system, however, we had estimated the time required for the identification to be 3 ms. The reasons why the actual execution time required for the identification is about 16 times longer than the estimated one are supposed to be as follows. First the program assignment to each DSP has not yet been optimized. Second, we have not yet made effective use of the function of pipeline processing which the DSP itself possesses. For example, we have not yet changed the order of decision and branch instructions in the programs so that they may not interrupt the pipeline processing. When we simply compile source programs using Parallel C, a temporary save area for the data in the middle of computation is allocated to the SRAM on the global bus. Hence, it is necessary for efficient pipeline processing to modify the compiled programs manually so as to allocate the stack area to the internal registers of the DSP. By taking these measures, we can improve the programs so that the DSP will give its full performance.

5 Concluding remarks

For the operation of the JT-60 tokamak, we developed the parallel processing system for real-time plasma shape visualization, where VME bus-based DSPs, a graphics processor and a reflective memory are applied. This system can reproduce the plasma shape about 16 times per second and it has been fully used for analyzing plasmas in the experiments since this June. The real-time visualization system can also display the time evolution of the plasma current and the plasma horizontal and vertical positions along with the time evolution of those used in the feedback control system for the plasma position and current. We can check the integrity of the magnetic sensors and their signal conditioners used in the feedback control system.

Hereafter, we are going optimize the programs of the present system in order to increase its processing speed. In addition, we are going to develop the algorithm for improving the computational stability in the identification. Our goal is to apply this system to real-time feedback control of plasma position and shape for improving the plasma performance.

Acknowledgments

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