

Digital Signal Processing for Plasma Control at KT-1

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Abstract

We report on the status of a feedback control system based on VME DSP, MIX DSP and ADC modules and a real-time operating system. A feedback control system is added to an existing analog-based control system installed at KT-1, a small size Tokamak at the Korea Atomic Energy Research Institute (KAERI). The feedback control system controls the position and current of the plasma column for optimum plasma operation at KT-1.

1 Introduction

A Digital Signal Processor (DSP) has various applications, such as image and voice processing and automatic feedback control. Recently, DSP has been applied to plasma position control and vertical stability[1,2]. In this paper, we present the status of a feedback control system based on DSP to control the position and current of the plasma column at KT-1. Section 2 briefly describes a relevant part of KT-1 to this work. The existing analog-based feedback control system is presented in Section 3. The DSP-based control system is under way and described in Section 4. Finally, conclusion and future plan are given in Section 5.

2 KT-1 Tokamak

KT-1 is a small size Tokamak with a major radius of 0.27 m and minor radius of 0.05 m. It was completed in 1987. It produces circular plasma with 5 kA for 20 msec under a toroidal magnetic field of 1 T. Fig. 1 shows the magnet system of KT-1. The vertical and horizontal field magnets, providing equilibrium fields (EF), are used in the feedback control of plasma position.

3 Analog-based feedback control system

The plasma position of KT-1 is controlled in such a way that the last closed magnetic flux surface (LCFS) is coincided with the first wall of a torus using two orthogonal saddle loops, covering a poloidal angle of 180 degrees, and equilibrium field coils. The control scheme is as follows: whenever the plasma column departs outward (or upward) from its equilibrium position, the perturbed poloidal field is immediately picked up at the saddle loop, S₀₋₁₈₀ (or S₉₀₋₂₇₀). The pick-up signal is integrated and compared to a preset value (usually zero) and then the comparator output drives the vertical field power supply

(or the horizontal field power supply) to turn back the plasma column to the equilibrium position.

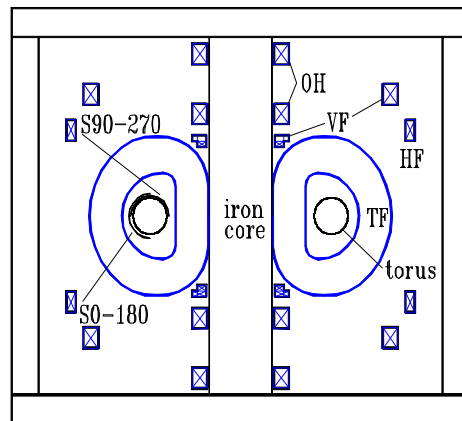


Fig. 1 The Magnet system and saddle loops of KT-1.

The plasma current (I_p) control is carried out by controlling the ohmic coil current (I_{OH}). The I_p controller compares the integrated Rogowski signal with the preset value and turns on or off the I_{OH} .

Fig. 2 shows a schematic diagram of the plasma position and the current feedback control system of KT-1. As shown in Fig. 2, the pick-up signals on all poloidal magnetic probes due to the toroidal field are subtracted using an Adder and Analog Calculator before the signals enter the I_p or EF controller.

The response time of the feedback control system is determined by several factors such as the integration constant of the integrator, TR switching time, photo TR on/off delay time and magnetic field delay time. The response time of the KT-1 feedback control system is about 50 μ sec. Considering the plasma rising time of KT-1, which is about 2 msec, the response time is sufficient.

A set of KT-1 operation data is presented in Fig. 3. It shows that the plasma position and current are well controlled.

4 DSP based feedback control system

The DSP based feedback control system consists of :

- Host computer : HP 745i
- Operating system for host computer : HP-UX 8.07

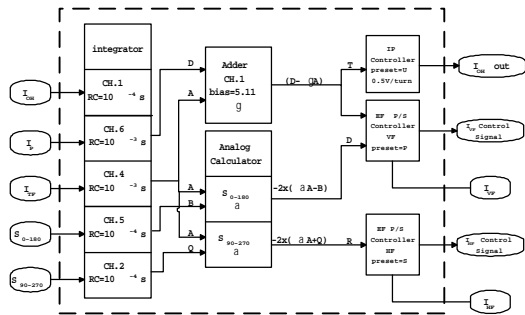


Fig. 2 The schematic diagram of plasma feedback control system of KT-1.

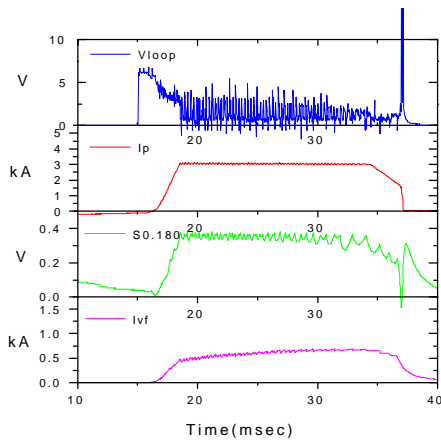


Fig. 3 A set of data of KT-1. V_{loop} : loop voltage, I_p : plasma current, S_{0-180} : saddle loop signal, I_{vf} : vertical field coil current.

- Target : MVME 167 (Motorola MC 68040)
- Target operating system : Tornado 1.01
- VME DSP module : Pentek 4284
- MIX DSP module : Pentek 4254
- MIX ADC module : Pentek 4248
- DSP related software : Texas Instrument software and Pentek SwiftTools and SwiftNet

The VME DSP module is based on the Texas Instruments TMS320C40 Floating Point Digital Signal Processor with 4 MB DRAM. The VME DSP acts as a MIX bus master. It serves as a 40 Mflop DSP, as well as a complete DMA controller. The MIX DSP is also based on the Texas Instruments TMS320C40 processor. The MIX ADC module is a data acquisition expansion module for the Pentek series of VME/MIX Baseboards. It provides up to 32 input channels of A/D conversion to a 12-bit accuracy. The inputs are connected to 32 sample-and-hold amplifiers for simultaneous sampling. The sampling rate is software programmable to 124 kHz with 32 channels and to 588 kHz with 1 channel. The Texas Instruments DSP software includes a C-compiler, assembler, archiver, linker and hex conversion utility. SwiftTools is an integrated

software development environment for Pentek's MIX family of digital signal processing and data acquisition products. SwiftTools provides a) Source code creation and editing b) C/C++ compiling/assembling/linking c) Object code downloading and d) Program debugging

Swiftnet provides an interrupt driven, inter-device communication protocol for distributed digital signal processing applications. An Ethernet link is used for host-node controller communications.

4.1 System requirements

As described in Section 3, the plasma control system uses a Rogowski, a toroidal and two saddle loop signals with a feedback loop time requirement of about 50 μ sec. We expect a conversion time of 4 channels to be less than 5 μ sec, since the total maximum conversion time of 32 ADC channels is less than 10 μ sec. Mathematical operations to be done with TMS320C40 are simple multiplication, addition and comparison, each of which takes less than 1 μ sec. The TTL pulse outputs to control the power supplies are provided by Pentek 4284 DSP modules with negligible time delay.

The toroidal, poloidal filed and saddle loop coils pick the signals only if the plasma condition in Tokamak changes (i.e., differentiated signals). Four signals to be used for the feedback control are differentiated signals or integrated signals. The integrated signals are obtained by analog integration circuits which integrates the four differentiated signals. If the integrated signals sampled with 20 kHz are to be used for the feedback control, the MIX DSP is not needed. If we start with the differentiated signals which have to be sampled about 200 kHz, VME and MIX DSPs are needed for parallel processing described more in Section 4.3. In any case, the plasma feedback control system is expected to be adequate for our purpose.

4.2 System configuration

Fig. 4 shows the hardware configuration of the VME data acquisition system at KT-1. The entire data acquisition system consists of VME, VXI and CAMAC modules. The MIX ADC in the top VME crate digitizes the plasma current (I_p), the toroidal coil current (I_{TF}) and two saddle loop signals (S_{0-180} , S_{90-270}) used for feedback control, with sampling rates of 20 kHz for integrated signals or of 200 kHz for differentiated signals. The ADC modules in the bottom VME crate digitize other signals such as the vertical and horizontal coil current (I_{vf} , I_{HF}), ohmic heating coil current (I_{OH}) and loop voltage (V_p).

4.3 Methods

All signals used for feedback control are originally differentiated which have to be integrated by analog integration circuits (Method 1) or by DSP (Method 2). The Pentek 4248 ADC digitizes the differentiated signals with a sampling rate of 200 kHz or the integrated signals with a sampling rate of 20 kHz. Digitized data occupy a memory space at DSP and are later transferred to a hard disk for further analysis.

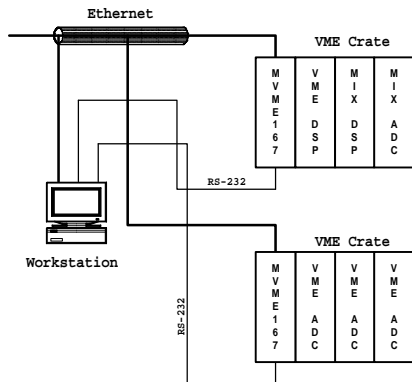


Fig.4 The hardware configuration of the VME data acquisition system at KT-1.

Fig. 5 shows the flow diagram when the Pentek 4248 ADC digitizes the differentiated signals (Method 1). In Fig. 5, paths \hat{A} and \hat{A} have to be done in parallel. We plan to use the VME DSP for the path \hat{A} and MIX DSP for the path \hat{A} .

Mathematical operations for plasma position and current control by DSP can be summarized as follows:

- Vertical field control : position control
 - Integration of the toroidal coil current I_{TF} (A)
 - Integration of the saddle loop signal S_{0-180} (B)
 - $B - \alpha A = C$
 - Comparison of C with a preset value P
- Horizontal field control : position control
 - Integration of the toroidal coil current I_{TF} (A)
 - Integration of the saddle loop signal S_{90-270} (Q)
 - $Q + \beta A = -R$
 - Comparison of R with a preset value S
- Current control
 - Integration of the toroidal coil current I_{TF} (A)
 - Integration of the plasma current I_p (D)
 - $D - \gamma A = T$
 - Comparison of T with a preset value U

Here, α , β and γ are to be experimentally determined. If C (or R, T) is bigger than P (or S, U), a TTL high pulse from Pentek 4284 is provided to power supplies. Otherwise, a TTL low is provided.

One of the reasons that we try to start with the differentiated signals is sensitive variations of analog integration circuits due to the change in temperature.

In the Method 2, the integrated signals obtained from the analog integration circuits are sampled by the Pentek 4248 ADC with 20 kHz. The Pentek 4284 DSP does the same mathematical operations as in the Method 1, except for the signal integration.

4.4 Status

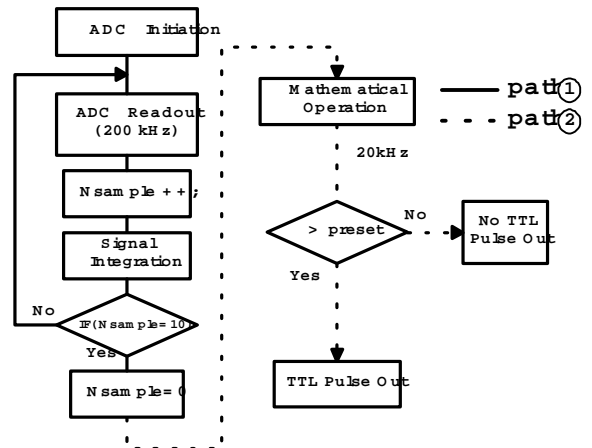


Fig. 5 Feedback flow diagram (Method 1).

The entire system except for the MIX DSP module has been installed and tested. We have simulated the Method 2 with a pulse generator. We find that the DSP based feedback control system in the Method 2 gives a feedback loop time about 30 μ sec. Considering that the analog-based feedback system results in a feedback loop time of 50 μ sec, the DSP based system is adequate for KT-1.

5 Conclusion

We have installed the DSP based feedback control system and tested all the hardware and software except for the MIX DSP board. Initial test shows the DSP based system is adequate for KT-1. We are testing the DSP based system (Methods \hat{A} and \hat{A}) in parallel with the analog-based system. We also plan to integrate the existing VME, VXI and CAMAC system for plasma heating facilities and proton accelerator projects at KAERI.

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