Real-time resonant magnetic perturbations feedback control system for tearing mode suppression on J-TEXT

Wei Zheng, Feiran Hu, Ming Zhang, Da Li, Qiming Hu, Hai Jin, Yuan Pan

***Abstract*–Tearing Modes (TMs) degrade the performance of tokamak plasma, and can even lead to disruption. Using externally exerted resonant magnetic perturbations (RMP) to suppress tearing mode is a promising and effective way. In order to suppress 2/1 tearing mode, 2/1 RMP applied in given phase region to stabilize magnetic island and accelerate island rotation. The RMP feedback control system acquires 15-channels Mirnov poloidal signals, processes the acquired data and calculates the phase in real-time; outputs RMP power supply control signal by comparing with the given phase to drive RMP coil. The feedback control system is based on NI C-RIO and mainly using LabVIEW to develop. The typical 2/1 mode magnetic island on J-TEXT rotates at a frequency from 2 KHz to 10 KHz. To ensure the control precision within 2 degrees, the control period must be within 500 ns. Due to acquired signals are noisy, the feedback control system uses a series of error correction methods in real-time to obtain accurate phase.**

***Index Terms*—Tearing mode suppression, RMP, feedback control, C-RIO, LabVIEW FPGA, fusion, J-TEXT tokamak**

I. INTRODUCTION

The tearing mode (TM) is an important unstable mode in tokamak plasmas, which degrades the performance of tokamak plasma, and can even lead to disruption. Real-time control of TMs plays a key role for increasing the performance of tokamak.

The use of the electron cyclotron current drive (ECCD) for TM control has been studied in various tokamaks including ASDEX-U [2], DIII-D [3], FTU [4]. Using ECE and Mirnov signals to detect and spatially localize the islands, and control the movable mirror in the ECCD launcher to deposit ECCD precisely at the island O-point.

The resonant magnetic perturbation (RMP) is a type of perturbation that directly interacts with the tearing mode [1]. Apply RMP in the island particular phase can stabilize the TMs. In the current RMP feedback control system, it is not necessary to know the island location, amplitude or other information, only need to calculate the magnetic island phase, with the same computing resources, less signal detection and computation is able to obtain faster response.

Manuscript received May 30, 2016.

This work was supported by National ITER Project of China (No. 2013GB113003).

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II. REAL-TIME FEEDBACK CONTROL

A. *The principle of TM suppression by RMP*

Static RMP can contribute stabilizing, destabilizing, accelerating, or decelerating effect on the 2/1 island when RMP applied in different phases. Apply RMP only in the particular phase can speed up the island rotation in addition to suppress the island for avoiding mode locking of a large m/n = 2/1 island [5]. In this way, it can effectively stabilize tearing mode. The diagram of the effects of RMP on TM is shown in Fig. 1. The stabilizing region is from 0.5π to 1.5π while the accelerating region is from π to 2π. Ideally, apply RMP in this rage can produce good results.

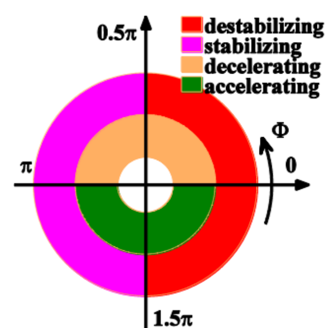

Fig. 1. Diagram of the effects of RMP on TM

In order to use this method to suppress TM, first of all, we should obtain the magnetic island phase. We can get the island phase by acquisition of Mirnov poloidal signals.

B. *Real-time phase compare algorithm*

We define the island rotation cycle as α-cycle, the time difference of zero-crossing of each adjacent channel determines a β-period. The 12-channels Mirnov probes spatial evenly distributed around the vacuum vessel. Each time the first channel zero-crossing marks a new α-cycle begins and the end of the previous α-cycle. In each α-cycle, the 1st to 12th channels are zero-crossing sequentially. Thus the real-time algorithm can use the data of the last α-cycle to estimate the upcoming phase, using the time of last β-period to calculate the current precise phase. Then it is compared with the given phase and outputs the power control signal.

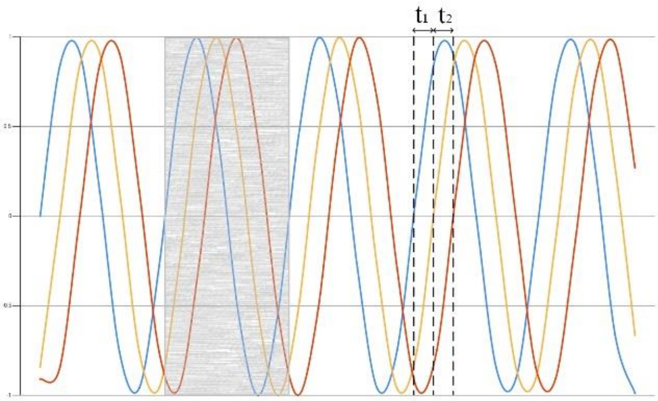

Fig. 2. Diagram of phase calculation. The blue line represents the 1st channel signal, all the three lines represent three adjacent channels. The gray box indicates a complete α-cycle, t_1 and t_2 are the adjacent β-periods.

As show in Fig. 2. Assume that there are N channels zero-crossing in each α-cycle, that means there are N β-period in each α-cycle. So the island phase is $\frac{360\times(n-1)}{N}$ when the n-th channel is zero-crossing, after t time, the phase increase $\frac{t}{t_n}\times\frac{360}{N}$, t_n is the n-th β-period. Thus after the t time island phase is $\Phi_t=\frac{t}{t_n}\frac{360}{N}+\frac{360\times(n-1)}{N}$.

C. Real-time error correction algorithm

In order to implement the real-time phase compare algorithm, the most important is to eliminate the impact of wrong zero-cross and determine the accurate zero-crossing moment.

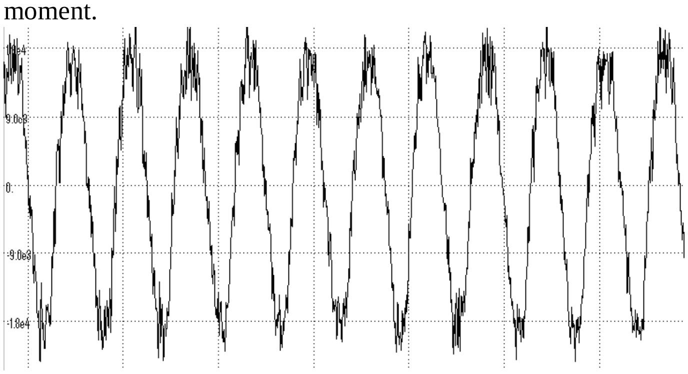

Fig. 3. One channel of the typical Mirnov signal, it is sine-link but not smooth.

Due to the Mirnov signal is not smooth, and the controller and DAQ card installed in the power supply area, the electromagnetic environment is very complex, the acquired signals may be disturbed and distorted. Fig. 3 shows one channel of typical Mirnov signal. The noise of Mirnov signals will affect the accuracy of the phase calculation. Noise causes the error of zero-crossing judgment, which leads to the error of phase calculation. Hence the feedback control system must pre-process the signal.

III. The implementation of the real-time feedback control system

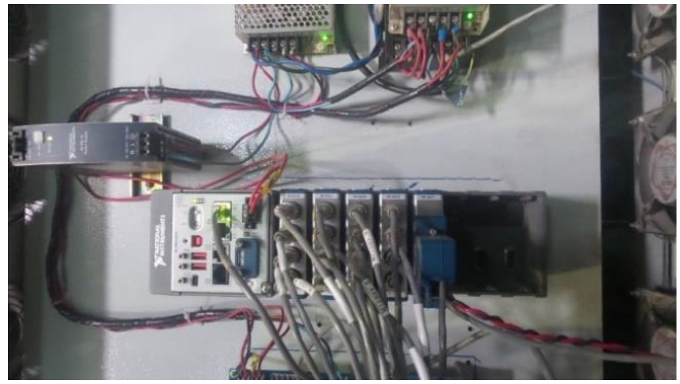

Fig. 4. Installed cRIO plantform.

The RMP feedback control system integrates data acquisition system and acquires Mirnov signals by DAQ card. The core of the system is the FPGA module which the real-time algorithm is running on. FPGA module outputs the power supply control signal and transmit all the raw data, calculated phase and control signal to host via FIFO. Host provides the user interface and saving data to the database through the Ethernet automatically.

The hardware of RMP feedback control system is based on NI cRIO. There are four analog input modules to acquire Mirnov signals at 500 kHz and one Digital I/O module to output power supply control signal, as shown in Fig. 4.

IV. Conclusions

The RMP feedback control system for tearing mode suppression has been set up on J-TEXT tokamak. Using cRIO-based FPGA to implement the real-time island phase calculation algorithm, the accuracy of phase judgement is within 2 degrees and meets the experimental requirements. In the future, after improve the output capability and the response frequency of the pulsed power supply, better result will be obtained.

Acknowledgment

The authors wish to thank the members of RMP team and computer control team in J-TEXT laboratory for designing, developing and testing work. This work is supported by National ITER Project of China (No. 2013GB113003).

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