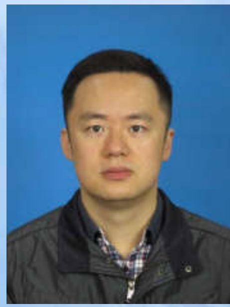
An FPGA-Based Implementation of Real-Time Feedback Control System in Keda Torus eXperiment

Shuchen. Song[1,2], Kezhu. Song [1,2], Tianbo. Xu[1,2], Jiahong. Jiang[1,2]

1. State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei,China

2. Department of Modern Physics, University of Science and Technology of China,Hefei,230026,China

E-mail: ssc1227@mail.ustc.edu.cn, skz@ustc.edu.cn



Research Background

Keda Torus eXperiment (KTX) is a reversed field pinch(RFP) device at the University of Science and Technology of China(USTC). Error field and magnetohydrodynamics(MHD) instabilities limit the increase of discharge duration and plasma current. A feedback control system has been implemented for KTX to achieve the following goals:

1) 3-D plasma stability control,

2) improvement of plasma discharge quality.

The real-time electronics system which is the key unit of this feedback control system helps to resolve the lack of high-speed transmission and real-time processing capability of the previous data acquisition (DAQ) system. FPGA is the core component of the electronics system. Some tests indicate that the system can control the whole process and calculation in a low latency.

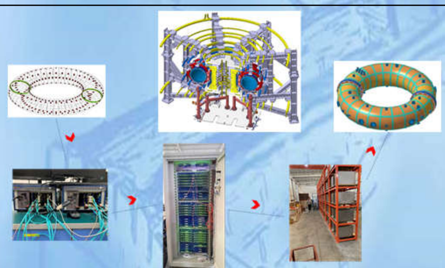


Fig.1 Feedback Control System

Contribution

- **The system prolongs the discharge time and improves the plasma current through active feedback control on MHD and error field in KTX.**
- **The latency from sampling to feedback is within tenths microseconds.**
- **In addition, the system is scalable from tenths to thousands channels, applicable to a broad class of pulsed plasma experimental devices.**

Control Method

As Fig. 2 illustrates, two control strategies are distinguished here. On the right is the feedback strategy for error field in real domain. On the left is the strategy for MHD instabilities in imaginary domain. Functions, such as data acquisition, data transmission, mode analysis, PID control are included here.

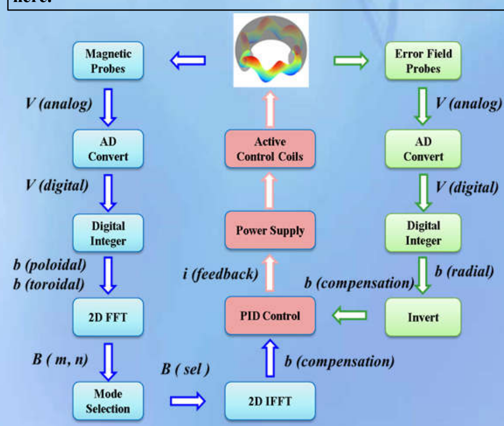


Fig. 2 Control Method

System Architecture

As Fig. 3 illustrates, the electronics system is based on PXIe platform and consists of four PXIe chassis. 516 channels probes belonging to 6 classes are sampled. Each chassis has several magnetic signal acquisition cards (MSAC), a transfer synchronize card (TSC). A data summary processing card (DSPC) is used to send feedback control signals to the power supply. The work station running as a host machine can get data and send instructions to each chassis via local area network (LAN).

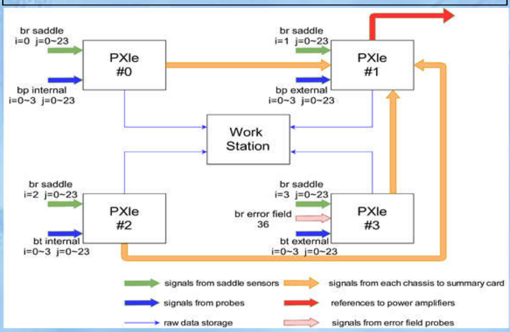


Fig.3 System Architecture

Xilinx Kintex-7 FPGA is the core component of the system. FPGA mezzanine card (FMC) structure is used for expansibility of the design, as Fig. 4 shows. The feature is useful for update and mainten-ance of whole system.

Sampling data rate of ADC is 250 kSamples/s, the resolution is 16 bit. Data rate between each card is 2 Gbps.

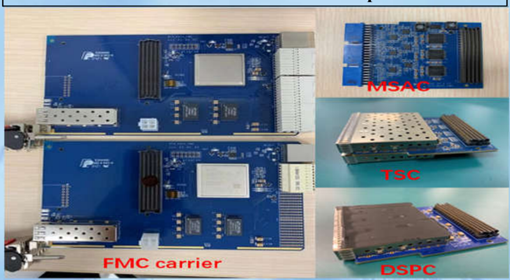


Fig. 4 PCB Developed

Tee Connector

A kind of tee connector has been designed by us and LEMO, as fig. 5 shows. The signal from the magnetic probe is divided into two channels, one is still connected to the previous DAQ, the other is used in our real-time system.

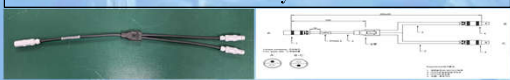


Fig.5 Tee Connector

Experiments indicate that the tee connector has little effect on the magnetic signal. The blue and red curves represent the magnetic field data of different three shots sampled by the same probe of the previous DAQ system when the tee is connected/unconnected, respectively.

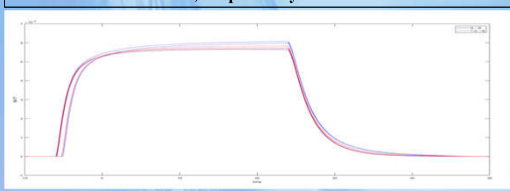


Fig. 6 Magnetic Data with/without Tee Connector

Software Architecture

The software is designed based on Labview, including the driver of DAQ system and the summary and storage of raw data.

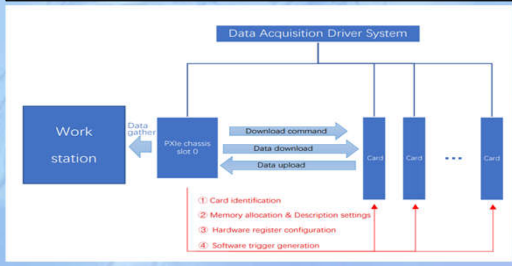


Fig.7 Software Architecture

As Fig.8 shows, the setting of the shot number, the selection of the shot number and length of the download data, the completion mark of download and upload, are included on the interface of the host computer.

The download channel is established in order to use the data of reference shot to eliminate cross disturbance from the vertical field.

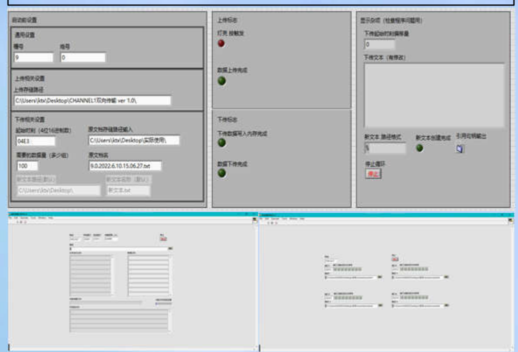


Fig.8 Host Computer Interface

Performance and Discussion

The test of adding active control to the error field is performed first. As Fig. 9 illustrates, the peak of plasma current is increased by 70%, and the discharge time is prolonged by 3ms compared with no active control.

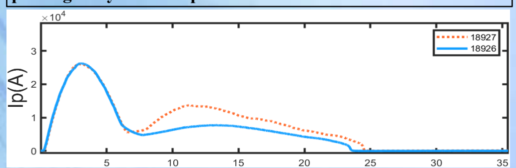


Fig.9 Comparation of Ip with/without Active Control

As Fig.10 shows, on the surface of the small torus away from the gap, the iso-flux and iso-current lines are both closer to the center via active control.

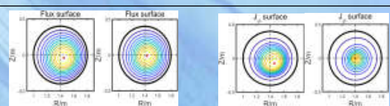


Fig.10 Isomagnetic Flux & Isocurrent Surface away from the gap at 10ms

Status and Future Work

The feedback control system has been basically deployed. All 80 active control power supplies are tested. Active control experiments with plasma for more modes will be fully carried out.

University of Science and Technology of China

23rd Virtual IEEE Real Time Conference 1-5 Aug. 2022