Modified read-out system of the beam phase measurement system for CSNS *

BAI Jiao-Ni(白娇妮)[1,2;1)] ZENG Lei(曾磊)[1] WANG Biao(王标)[1] LI Peng(李鹏)[1]
LI Fang(李芳)[1] XU Tao-Guang(徐韬光)[1] LI Zi-Gao(李子高)[1,3]

[1] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
[2] University of Chinese Academy of Sciences, Beijing 100049, China
[3] Institute of Acoustics, Chinese Academy of Sciences, Beijing 100190, China

Abstract: The customized beam phase measurement system can meet the requirement of beam loss control of the radio-frequency quadrupole (RFQ). However, its read-out part cannot satisfy the requirement of China Spallation Neutron Source (CSNS). CSNS uses the Experimental Physics and Industrial Control System (EPICS) as its control system. So it is necessary to develop the EPICS read-out system consisting of EPICS IOC databases, driver support and OPIs. The new system has been successfully tested in the RFQ. In the future, it will be applied to the beam diagnostics of CSNS.

Key words: phase, EPICS, MEDM

PACS: 07.05.Dz, 07.05.Hd, 29.27.Fh **DOI:** 10.1088/1674-1137/37/10/107004

1 Background

Based on the first high intensity proton radio-frequency quadrupole (RFQ) accelerator with four-vane structure which accelerates 44 mA proton beam to 3.5 MeV at more than 7% duty factor [1], a test beam line has been built to perform many experiments on beam loss control. Thus a number of devices for beam diagnostics have been developed. The beam phase measurement hardware is one of these crucial facilities. It measures the beam energy of the RFQ by the TOF (Time of Flight) method [2]. Schematic plot of TOF scheme is in Fig. 1. Using two beam phase detectors, beam phase difference $\Delta\theta$ is measured. Then the flight time that a proton travels between two detectors is obtained according to the distance L between these two detectors, and the velocity of the beam can be calculated. (see Eq. (1)).

$$v=\frac{L}{nT+\dfrac{\Delta\theta}{2\pi}T}, \tag{1}$$

where $L(6\times160\ \text{mm})$ is the distance between two BPMs, T the period of the RF system, n the number of the RF signal period and $\Delta\theta$ the phase difference between two detectors.

Then calculate the beam energy by Eqs. (2) and (3).

$$\gamma=\frac{1}{\sqrt{1-(v/c)^2}}, \tag{2}$$

$$E=\gamma m_0c^2. \tag{3}$$

What's more important, the beam phase measurement system is essential for China Spallation Neutron Source (CSNS) beam diagnostics system which precisely tunes the amplitude and phase of RF cavities, because

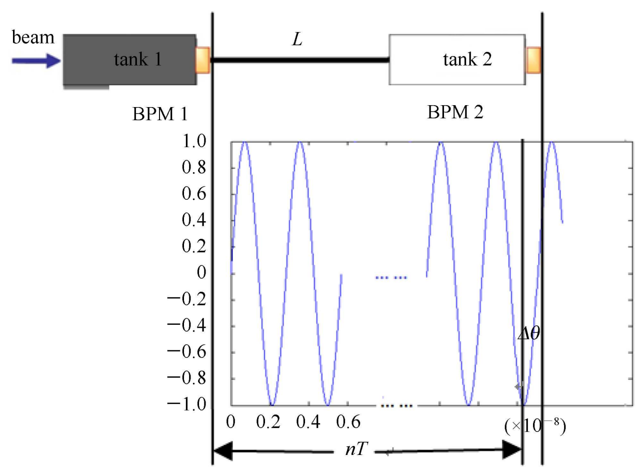

Fig. 1. The TOF scheme.

Received 7 December 2012, Revised 7 May 2013
∗ Supported by 973 Project (2007CB209904)
1) E-mail: baijn@ihep.ac.cn

requirement for the momentum spread is critical to realize effective injection to the succeeding Rapid Cycling Synchrotron (RCS). The amplitude and phase are tuned based on the phase-scan method, which determines amplitude and phase setting values of high power cavities.

2 Introduction to the beam phase measurement hardware and the characteristics of the original read-out system

2.1 Introduction to the beam phase measurement hardware

The beam phase measurement system consists of the sensor (FCT1)), optional BPM2)), the electronics processing board and the read-out system. The electronics hardware, a standard 6U VME3) card, is made with the cooperation of the University of Science and Technology of China. Its working principle is as follows: Firstly, the radio-frequency (RF) signal from a phase detector is conditioned and then down converted to an intermediate-frequency (IF) signal. Secondly, the electronics sample at four times the IF signal and adopt the IQ demodulation4) to deal with these data. Finally, it calculates and stores the phase and amplitude information of the signal [3]. In order to meet the dynamic range of the attenuator gain (−39–55db), the electronics are equipped with the amplification and attenuation function for each channel.

2.2 The original read-out system

The original read-out system allows operators to configure the slot of the VME crate, the calibration, the sample, the clock, the attenuator gain and the modulation signal threshold and perform the real time data acquisition and online data analysis. It can be divided into two parts: the server part running on MVME5100 which runs VxWorks5) 5.4 real time operating system; and the client part created with Microsoft Visual Studio on PC6) embedding the third-party software for the data display and processing. Its design is shown in Fig. 2.

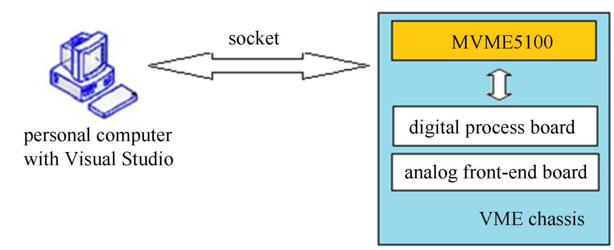

Fig. 2. The prototype of the read-out system.

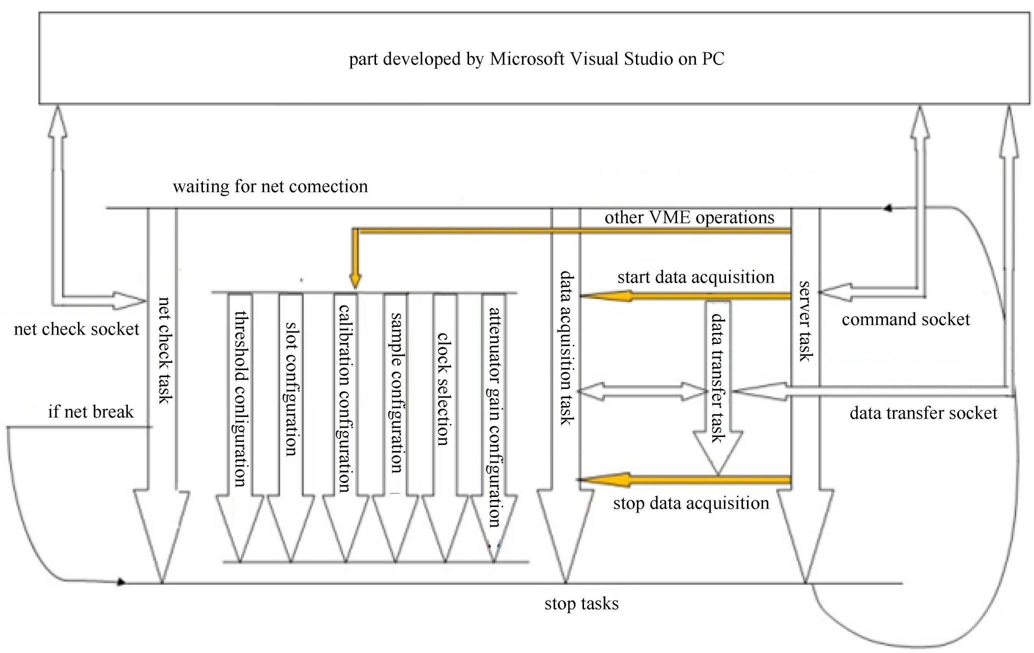

Fig. 3. The outline of four server tasks.

1) FCT: fast current transformer
2) BPM: beam-position monitor
3) VME: vERSA-module eurocard. VMEbus international trade association (VITA)
4) IQ demodulation: in-phase and quadrature-phase demodulation
5) VxWorks: real-time operation system by wind river systems
6) PC: personal computer

The client part allows users to send commands to the server part to control hardware configurations, the data acquisition and the network transmission via a socket. The server part executes these commands which are submitted by the client. It recognizes these commands according to specific command keywords, i.e., 'CMD_SLOTCONF' in the case of the slot configuration subroutine. The server part includes three main tasks and an auxiliary task as shown in Fig. 3.

1) The server task: It is mainly responsible for decoding commands and calling corresponding subroutines.

2) The net check task: It examines the connectivity of the network by whether it is receiving the handshake signal from the client.

3) The data acquisition task: It transfers data from the electronics hardware to MVME5100 memory by DMA using 32-bit BLT[1)]. When this DMA transfer is finished, it continues a new DMA transfer by Ping-Pang mode [4].

4) The data transfer task: It is responsible for the data packing and its delivery to the client via the socket.

The system uses semaphore to realize the communication and synchronization between different tasks.

2.3 Limitations of the original read-out system

Unfortunately, there are several limitations when the original system is used in CSNS. Limitations are as follows:

1) We cannot control the hardware with the unified control system which is EPICS in CSNS case.

2) The original read-out system does not support multi-user interfaces.

3) The original read-out system uses the continuous mode to acquire data, which is over-designed for accelerator application.

4) The attenuator gain mapping from physical requirements of signal conditioning to practical controls is on the client part, which will be an obstacle to a new application developer.

5) The client part is not the release version and needs to comply with the executable file every time the operator uses it.

3 Introduction to the modified read-out system

3.1 Advantages of the EPICS control system

Application developers use EPICS (EPICS 3.13.8 is used in the experiment) to create a control system. EPICS contains a series of software tools and components. The basic components are [5]:

1) OPI (Operator Interface): This is a workstation running a series of EPICS extensions and tools. For example, MEDM[2)], as a real time Channel Access tool, can control and monitor IOCs.

2) IOC (Input/output controller): This is a VME based chassis which usually contains a Power PC and some hardware.

3) LAN (Local Area Network): This is the communication network allowing OPIs to communicate with IOCs.

Compared to the original read-out system, the EPICS system not only circumvents limitations mentioned above, but also offers some significant advantages [5]:

1) EPICS provides many tools to create a control system, which minimizes the need for custom coding and ensures uniform operator interfaces.

2) Distributed system scales provided by EPICS support an arbitrary number of OPIs and IOCs as shown in Fig. 4.

3) Record is a net-checking protocol itself, which enables network transparent access to IOCs by channel access.

4) EPICS has a high performance which satisfies CSNS requirement.

3.2 The new read-out system

We use the ao record to control the hardware and together with the waveform record to read out phase and amplitude data.

The EPICS driver connecting EPICS records with the hardware is usually divided into two parts [6]: the driver support and the device support.

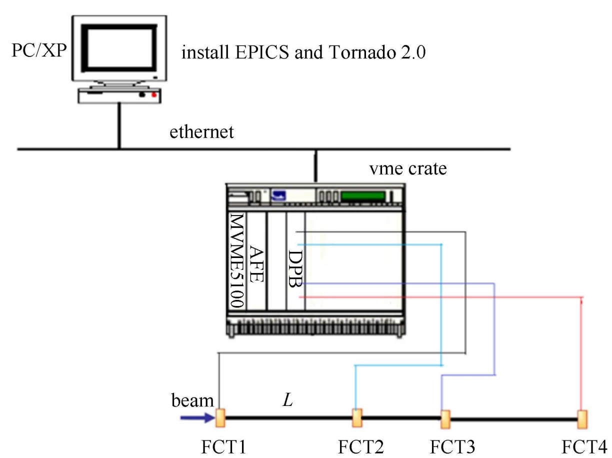

Fig. 4. The distributed EPICS read-out system design.

The driver support communicates directly with hardware as shown in the dashed box of Fig. 5. It includes only a modified data acquisition task. This task achieves

1) BLT: block transfer

2) MEDM: motif version of combined display manager and display editor

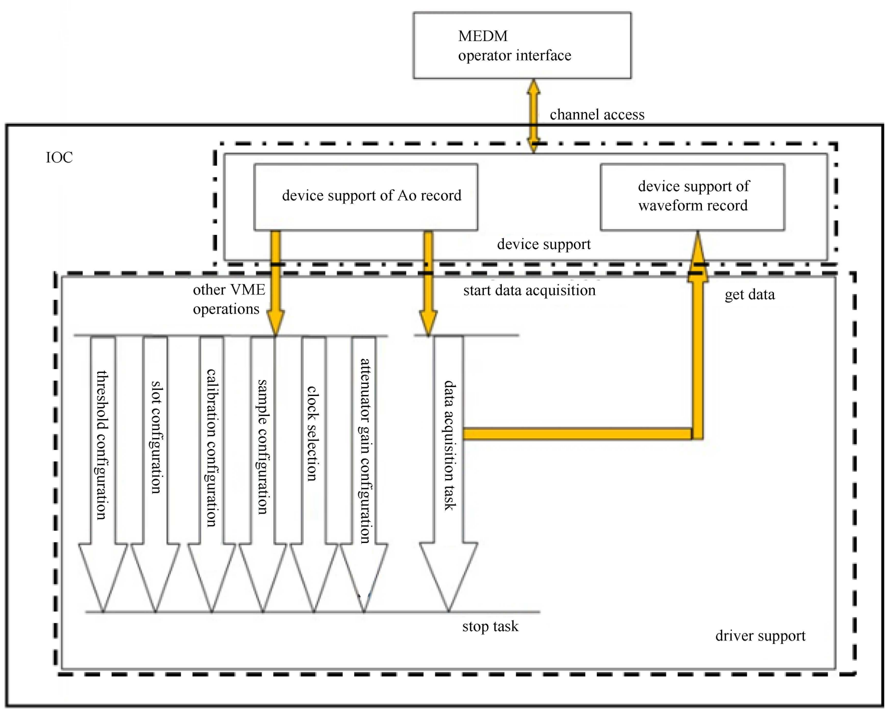

Fig. 5. The design of the new read-out system.

one DMA transfer from the electronics hardware to MVME5100 memory. Besides, the driver support is responsible for configurations by the VME single read/write.

The device support provides the interface between records and the driver as shown in the dash-dotted box of Fig. 5, the purpose of which is to hide the hardware specific details from record processing routines [6]. In the new read-out system, all the ao records have one device support module and so do waveform records. The device support routine of record has knowledge of the record definition and also knows how to call API[1)] functions of the driver. The record, device support and driver are connected by the database definition (dbd) file as in Fig. 6.

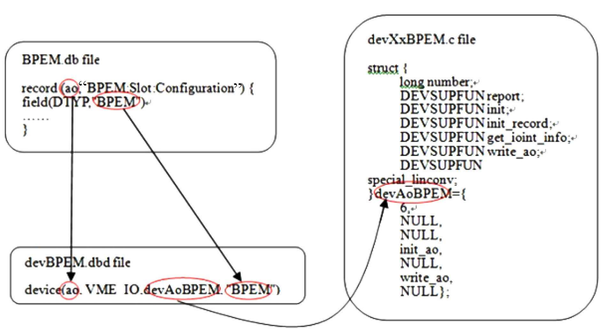

Fig. 6. The relation of records, device support and driver.

1) API: application programming interface

4 Operator interfaces and results

OPIs of the new read-out system are developed by MEDM [7]. There are three kinds of operator interfaces: the configuration interface, the phase and amplitude displaying interface and the data analysis interface.

The configuration interface as shown in Fig. 7 includes the slot of the VME crate configure module, the calibration selection module, the sample module, the clock selection module, the attenuator gain module and the threshold module.

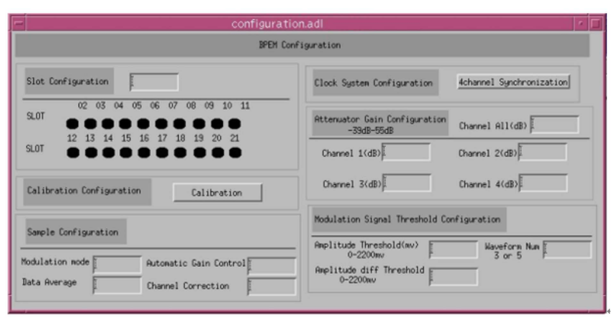

Fig. 7. The configuration interface of the new system.

With the phase and amplitude display interface, the operator can observe the actual phase and amplitude of the beam as shown in Fig. 8. Each segment represents a macro pulse and there exist interference signals caused by the electromagnetic noise of the chopper at the end

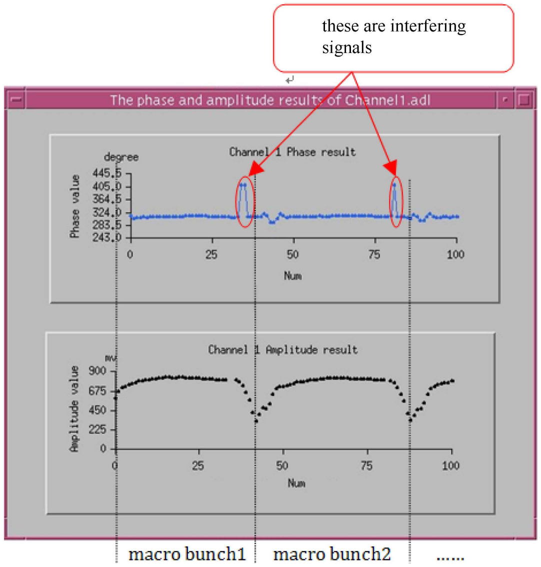

Fig. 8. The phase and amplitude information of the beam with manual gain 8db, the amplitude threshold 300mV and the amplitude difference threshold 500 mV.

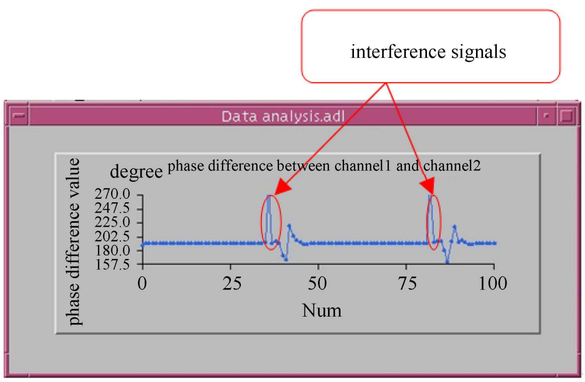

Fig. 9. The phase difference between Channel 1 and Channel 2. Channel 1 with manual gain 8 db, Channel 2 with manual gain 20 db.

of each pulse.

The data analysis display interface shows the phase difference between Channel 1 and Channel 2 as shown in Fig. 9. Because the phase difference of these two channels is stable for every macro pulse, the beam energy of the RFQ accelerator is steady.

With Matlab® software, we get the variance of the beam phase difference=1.5812 and the mean =167.2192°. Using Eq. (1), we get n=18. Further, we calculate the stability of the beam energy measurement by Eq. (4), which equals 0.075%. If the distance between two BPMs is too close, the stability will be seriously affected by $\Delta\theta$.

$$\frac{\mathrm{d}E}{\mathrm{d}\Delta\theta}=-\frac{m_0c^3L^2T}{2\pi}\left[c^2\left(nT+\frac{\Delta\theta}{2\pi}T\right)^2-L^2\right]^{-\frac{3}{2}}. \tag{4}$$

5 Further development

1) Get rid of interference signals during two bunches by the software algorithm.

2) Calculate the mean and variance of beam phase and amplitude on line. This improvement will allow operators to better analyze the beam.

3) Store beam phase and amplitude data by Channel Archiver or other EPICS tool. It will be convenient for the experimenter to analyze data at any time.

4) Upgrade the read-out system from EPCIS 3.13 to 3.14.

6 Conclusion

Based on the original system, the modified beam phase measurement read-out system for the EPICS control system has been accomplished. It has been used in the RFQ accelerator with good results achieved. In the future, it will be used in CSNS.

The authors acknowledge many useful discussions with the technical staff at the IHEP. We thank the CSNS Control Group, Accelerator Centre, IHEP for providing the EPICS platform to work on, as well as the EPICS tech-talk, Argonne National Laboratory, for providing technical support. Besides, we thank the University of Science and Technology of China.

References

1 FU Shi-Nian, GUAN Xia-Ling. Atomic Energy Science and Technology, 2009, **43**(z1): 1–6

2 Masanori Ikegami, Yasuhiro Kondo, Akira Ueno. RF Tuning Schemes for J-PARC DTL and SDTL. Proceedings of 22nd International Linear Accelerator Conference (LINAC 2004). 414–416

3 ZHAO Lei. The Design and Realization of Beam Phase and Energy Measurement Read-Out System for CSNS. Hefei: University of Science and Technology of China, 2009. 1–190

4 ZHAO Lei, LIU Shu-Bin, ZHOU Jiao-Wen, AN Qi. Nuclear Electronics & Detection Technology, 2009, **29**: 1–5

5 Argonne National Laboratory. Experimental Physics and Industrial Control System. Available: http://www.aps.anl.gov/epics/

6 Martin R. Kraimer. IOC Application Developer Guide. 1998. 1–180

7 Kenneth Evans, Jr. MEDM Reference Manual. Available: http://www.aps.anl.gov/epics/EpicsDocumentation/ ExtensionsManuals/MEDM/MEDM.html