MAGNET POWER SUPPLY CONTROL SYSTEM IN KEKB ACCELERATORS

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Abstract

There are more than 2500 magnet power supplies for KEKB storage rings and injection beam transport lines. To construct a control system for such a large number of power supplies, one of the important things is to reduce the cost of the interface between the power supplies and the control computers. For this purpose we developed the Power Supply Interface Controller Module (PSICM) of 3U Euro-Card mounted in each power supply. PSICMs and a local control computer are connected by ARCNET STP cables in a daisy-chain manner. A PSICM has a microprocessor which communicates with the local control computer. Magnet power supply control system is carefully designed to satisfy conditions for efficient beam handling. A PSICM can change the power supply current with an arbitrary tracking curve which is sent from the control computer. An arbitrary number of PSICMs can start tracking synchronously with each other by using an external trigger signal. The KEKB magnet power supply control system has been operated since Dec. 1998. Its software design and functions are discussed.

1 INTRODUCTION

KEKB is an asymmetric electron-positron collider at 8 $\times$ 3.5 GeV/c, which is dedicated to B-meson physics. Its operation was started in December 1998. The KEKB accelerator control system[1] has been constructed based on EPICS toolkit[2]. EPICS provides core mechanism for the distributed control system. EPICS runtime database is running on a VME based local control computer called an IOC (Input/Output Controller). There are about 100 IOCs in the KEKB accelerator control system. We use a UNIX server as the host computer.

The number of magnets (including auxiliary coils) used in the two storage rings is 4607, and the number of power supplies for them is 2245. 1711 of them are the power supplies for steering magnets. To connect such a large number of power supplies to the IOCs, we adopted ARCNET as a field bus and developed the Power Supply Interface Controller Module (PSICM) [3], which is an ARCNET interface board for the power supply. A PSICM has the shape of 3U Euro-card format (100mm $\times$ 160mm) with a DIN 64-pin connector and can be plugged into the power supply. The ARCNET allows to use several kinds of media. We adopted shielded twisted-pair (STP) cable as the media and HYC2485 as the media driver. This configuration allows up to 20 ARCNET nodes to be connected on single segment in the daisy-chain manner. The STP cable includes an auxiliary twisted-pair for the external trigger signal other than the ARCNET use.

While ARCNET and PSICM reduced a great deal of wiring cost, there are other control paths between IOCs and subsystems of the magnet power supply system[4]. The power supply output current is monitored by a digital voltmeter with scanner. They are connected to the IOC using GPIB. The PLC based interlock system of the power supplies has a connection with an IOC through Modbus Plus[5]. These subsystems are not discussed in this paper.

There are 274 magnet power supplies for the KEKB injection beam transport lines. They are also controlled in the similar manner.

2 FUNCTIONAL REQUIREMENTS AND DESIGN

Although KEKB storage rings do not need synchronous ramping of magnetic fields for the acceleration, synchronous operation of magnet power supplies is still important. For efficient beam handling, beam optics should be changed without loosing stored beam. To achieve this, the magnet power supply control system has two features. One is the synchronous operation of PSICMs. A PSICM can receive an external trigger signal to start current tracking. The external trigger signal generated by the IOC in the central control room is distributed to the IOCs in the local control rooms through the software trigger system[6]. From an IOC to PSICMs, the trigger signal is sent through the auxiliary twisted-pair in STP cables for the ARCNET. Using the external trigger signal, PSICMs can start tracking synchronously within 0.1ms or less.

The other feature is a flexible tracking curve. The PSICM is designed to receive arbitrary tracking data. This feature is useful for fine synchronous operation. Using a proper tracking curve, it is possible to compensate for the delay of magnetic field against the current setting, which is caused by the delay of the power supply and the delay of the vacuum chamber. This feature gives us another benefit even for the asynchronous operation. For the power supplies with slow response, a proper tracking curve makes current setting faster without overshoot than linear tracking.

To make application programming simple, the magnet power supply control system requires that a control parameter can be given not only by current in apms, but also by some abstracted parameter of beam optics such as K_1 for a quadrupole magnet, K_0 for a steering magnet etc. We generically call such parameters "K-values" for simplicity.

3 FUNCTIONS OF PSICM

Since the PSICM has a microprocessor, it is not only an ARCNET interface board but also an intelligent controller. The control program is stored in EPROMs on the PSICM. It provides advanced functions of the power supply. The PSICM provides the following 3 functions; (1) generating control signals to the power supply for the single actions such as power on/off, interlock reset, polarity change etc., (2) setting output current, (3) sending the status of the power supply and the PSICM itself. The status can be sent periodically, on demand or when specific status is changed.

The PSICM communicates with an IOC through the ARCNET. The elemental unit of the communication is a "message". The message from an IOC to a PSICM is called a "command". More than one commands can be packed in single ARCNET packet. The message from a PSICM to an IOC is only the status with fixed format.

To set the output current, the PSICM writes a digital value to the DAC (Digital to Analog Converter) in the power supply. There are 3 tracking modes and 2 trigger sources. The tracking modes are as followings. (1) The direct output mode: the output current is set directly to the DAC without tracking. This mode is only for diagnostics of the DAC and PSICM itself. (2) The constant slewing rate mode: the output current is changed with a linear tracking. The PSICM receives the target current and the time of the tracking duration from the IOC and writes the linearly interpolated value to the DAC every 1ms. This mode is mainly used for stand alone test of the power supply. (3) The wave-generator mode: the output current is changed with an arbitrary tracking curve. The PSICM receives tracking data as an array of currents from the IOC, then sequentially writes them to the DAC every internal clock interval which can be a multiple of 1ms. This mode is used for usual operation.

The constant slewing rate mode and the wave-generator mode require a trigger to start tracking. The trigger source is either a "start" command sent from the IOC through ARCNET or an external trigger signal sent through the auxiliary twisted-pair.

4 DRIVER LEVEL SOFTWARE

Low level software is EPICS Driver support and EPICS Device support in the IOCs. The driver support is designed to perform communication through the ARCNET. The elemental services of the driver support are transmitting and receiving single packet. Inside the driver support, packets are queued. There are a transmission queue and a receiving queue for each power supply independently.

The device support is designed to provide two kinds of services. One category includes the services dedicated to the PSICM. Each service corresponds to the single command of the PSICM such as power on/off, interlock reset etc. Using these services EPICS records which perform the single action can be easily created. Other category includes general purpose services which perform single packet I/O. They are nearly same as ones in the driver support. Using these services, although EPICS record support should directly encode or decode messages on the ARCNET packet, it is rather convenient when a record issues various commands sequentially.

5 MIDDLE LEVEL SOFTWARE

Middle level software provides various logic to the power supply system. Most of them are resident in IOCs using EPICS runtime database which is the collection of the EPICS records. Each power supply has a large special record called the PS-record, which has been developed only for magnet power supply in KEKB. Most of the control logic is concentrated in the PS-record and programmed in C.

5.1 Parameter Conversion

The most complicated logic is current setting. Since an application program may request current setting in term of a K-value, middle level software must have parameter conversion logic using some information such as magnetic field excitation curve. The parameter conversion is carried out typically in the following manner. (1) A K-value is multiplied by the beam line momentum to yield an integrated magnetic field strength. The momentum is kept in an EPICS software record. Each storage ring or injection beam transport line has such a momentum record. (2) The integrated magnetic field strength may be modified by a "fudge" factor and a fudge offset. They are introduced to correct the magnetic field excitation curve in an empirical manner. (3) The integrated magnetic field strength is converted to current using the magnetic field excitation curve. Each PS-record has the characteristic parameters of the excitation curve of its own magnet.

5.2 Asynchronous Operation

Asynchronous operation of current setting is the operation on a single power supply independently of other power supplies. For this operation, the external trigger is not used. PS-record provides 4 methods of current setting. One is called "Direct Setting", in which current setting is carried out regardless of magnetic hysteresis.

The other 3 methods are "Standardize Setting", "Simple Standardize Setting" and "Sequence Setting". In these methods, the regular hysteresis loop is more or less considered. To set lower current by Sequence setting for example, the current goes up to the maximum current first, then it keeps the maximum current for a moment. Next, it goes down to zero current, then it keeps zero current for a moment. Finally it goes up to the target current. Thus, unless Direct Setting is used, magnetic fields is kept on the regular hysteresis loop. These methods are particularly useful for magnets in the injection beam transport lines.

5.3 Synchronous Operation

Synchronous operation of current setting is the operation on more than two power supplies simultaneously without loosing beam in the storage ring. In this operation, only Direct Setting is possible.

To perform the synchronous operation, frequent negotiations among power supplies are necessary. As an arbiter of them, we introduced a server process for each storage ring. It manages the sequence of the synchronous operation. The server process runs in the host computer and is programmed in Python. The synchronous operation is carried out in the following steps. (1) The server receives a request with parameters from an application program. The parameters are a set of power supply ID numbers, a set of K-values to be set and a time of the tracking duration. These parameters are passed through EPICS software records. (2) The server sends the K-values to the PS-records. (3) Each PS-record converts the given K-value to current, then it estimates minimum time of the tracking duration and sends it back to the server. (4) The server checks the estimated minimum times. If the application program does not specify a time, the maximum of the estimated times is adopted. (5) The server sends the adopted time to the PS-records. (6) Each PS-record calculates tracking data and sends them to the PSICM. (7) Each PS-record checks status of the PSICM. If the PSICM is ready to start tracking, the PS-record sends "ready" to the server. (8) The server waits until all PSICMs become ready, then the server generates an external trigger signal. (9) The server checks whether all power supplies have started tracking.

6 APPLICATION LEVEL SOFTWARE

Application programs are developed by many users. They use not only EPICS standard tools such as MEDM, but also write programs in some programming languages[7]. The application program which requires knowledge of beam optics are written by accelerator physicists. In this case, the program is usually written in SAD[8]. SAD is a computer program complex for accelerator design developed at KEK. It has script language called SADScript in Mathematica style. Using SAD, optics calculation and operation of power supplies are easily combined.

Another popular language in KEKB accelerator control system is Python. Python is a portable, interpretive, object-oriented programming language. The operator consoles for magnet power supplies are mainly written in Python. Python is easier to learn than C/C++ and more productive for beginners.

7 CONCLUSION

Introducing PSICM and ARCNET, wiring between the IOCs and the power supplies became simpler. The PSICM also provides rich functions to the power supplies, such as the wave-generator mode and the external trigger to start tracking. As the middle level software, the complicated logic is implemented in IOCs and in the synchronous operation servers. The middle level software systematically provides simple but powerful functions to the application programmers. Using these functions in scripting languages, SAD and Python, it became much easier to develop high level application programs.

8 REFERENCES

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