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Virtual instrument for controlling and monitoring digitalized power supply in SSRF

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Abstract The Shanghai Synchrotron Radiation Facility (SSRF) needs extremely precise power supplies for their various magnets. A digital controller is being developed for the power converters of the SSRF power supply (PS). In the digital controller, a fully digital pulse-width modulator (PWM) directly controls the power unit insulated gate bipolar transistor (IGBT) of the PS. A program in LabVIEW language has been developed to control and monitor the digital PS via serial communication (RS232) from a PC and to modify its parameters as well. In this article, the software design of the virtual instrument for controlling and monitoring digitalized PS and its associated functions are described, and the essential elements of the program graphical main-VI and sub-VI source code are presented and explained. The communication protocol and the structure of the developed system are also included in this article.

Key words LabVIEW, Digital power supply, Virtual instrument, SSRF, PWM

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1 Introduction

The SSRF accelerates electrons to 3.5 GeV to produce synchrotron radiations from infrared to hard X-rays. To ensure the reliability and stability of the light source, considerable effort should be made to design the magnet power supplies of the storage ring and injector, which will result in better control of the electron beams. The technical requirements for controlling the beam current are extremely high, for example a short-term stability of 1×10^{-5} and a long-term stability of 2×10^{-5}[1]. The SSRF power supplies (PS) from a single power quadrant to four quadrants use insulated semiconductor gate bipolar transistors (IGBT), with switching-frequencies ranging from 20 to 60 kHz. The digital PS uses direct digital control of the power circuit IGBT, because digital PS is not only precise, but is also independent of thermal drift, aging, and component tolerance limitation associated with the analog PS. A full digital regulator for power converter was first adopted by the synchrotron light source (SLS) power supply [2, 3]. The achieved current stability and reproducibility are excellent, and thus the extreme requirements on precision and dynamic performance are satisfied [3].

Besides the R&D of the digital controller for the SSRF power supplies, a computer program based on a personal computer is needed to control and monitor the digital PS. It communicates with the serial port and the digital I/O-card, etc, while a user interface enables the user to input the control parameters and to monitor the operation status. In this article, we report the progress in developing the computer-controlled and monitored digital PS based on LabVIEW[4,5].

2 Digital power supply structure

The basic structure of a digital PS, which is

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composed of a digital control unit, an interface, and a computer, is shown in Fig. 1. The controller is of high flexibility in structures. Adaptations to different types of power supplies can be achieved by simply adjusting the software parameters (e.g. PWM mode). The digital PWM controls the power device IGBT directly. The local service interface (e.g. RS232 port) controls and monitors the computer that runs under LabVIEW, which is discussed in Section 3. When compared with the SLS digital controller, the developed digital controller has its own advantages. In structure, it adopts advanced control elements and data acquiring chips, being integrated into a single board. Since it is a monopole control card, it is considerably simple and is also productive. Also, new functions, such as the phase shifting mode and the convenient PWM control changing mode, are added to the other functions of the developed controller. Also, the developed digital controller is easy to operate and upgrade and also has a higher ratio of performance to price. In particular, it adapts well to mid- and small-static PS of the SSRF.

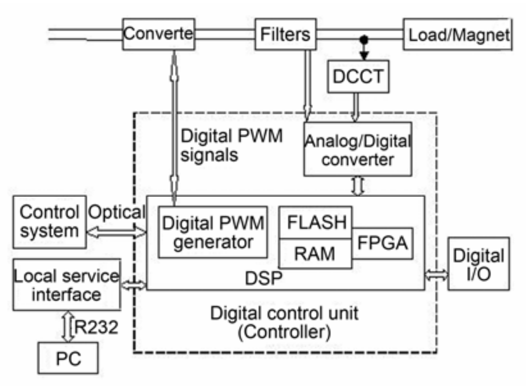

Fig. 1 Basic structure of the digital power supply.

3 Computer control and monitor software

3.1 Virtual instrument

LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a development environment based on the graphical programming language G. It uses terminologies, icons, and ideas familiar to scientists and engineers, and relies on graphical symbols rather than textual language to describe the programming actions. It is integrated entirely for communication with hardware such as GPIB (IEEE), PXI, RS-232, and plug-in data acquisition boards, and contains comprehensive libraries for data collection, analysis, presentation, and storage. LabVIEV programs are called ‘‘Virtual Instruments’’ or VI. The VIs are linked to each other in a certain hierarchy. One VI can serve as a Sub-VI of another VI. A VI instrument is composed of a front panel and a block diagram. The front panel is the graphical user interface of the VI. It is composed of buttons, graphs and other controls and indicators. The block diagram is the graphical source code of the VI. The controls and indicators of the front panel are associated with the terminals in the block diagram. In the block diagram, the VI is programmed to control and perform functions on the inputs and outputs created on the front panel. It can also include functions and structures from the built-in VI libraries and other Sub-VIs. The data flow between the nodes (terminals, functions, structures, Sub-VIs) is programmed by graphical ‘‘wiring’’ in the block diagram. Thus, the block diagram is also a flow chart of the program represented by the VI. One can set breakpoints, and animate program execution to see how the program executes, and single step through the program to make debugging and program development easier. The acquired data can be exported in different formats, in a text file or directly in common software files, such as, MS Excel, this being also a reason for choosing LabVIEV as the program development tool.

3.2 Communication protocol

The RS232 service link for local operation (PC control) is implemented on the digital power supply controller. The communication protocol for the link is organized in binary system format. The following are the two formats of the communication protocol: the writing format and the reading format. The writing format is used to send a command from the PC to the digital power supply controller, whereas the reading format is specified for the data that is sent back from the digital controller. Figs.2 and 3 show the writing format and the reading format, respectively. Each format starts with a ‘preamble’, followed by a control command byte or a status byte and a data length byte. The following are the data in one, two, or four bytes and the block check character (BCC) in a sum check byte, e.g. AA860479E642B6, which is used to set magnet current 123.456A to the controller, and

55010479E9E64231, which indicates reading of the magnet current 123.456 A and the current status from the controller. The preamble 'AA' or '55' is a hex digit. The hex AA is equivalent to the binary 10101010. In sum checking, the BCC is computed by adding each byte of block that is transmitted to determine whether the transmission is error free.

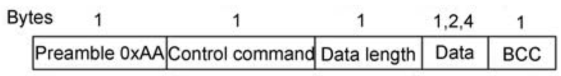

Fig.2 Writing format of the communication protocol.

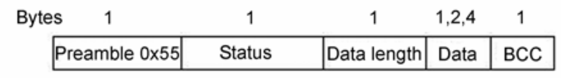

Fig.3 Reading format of the communication protocol.

3.3 Program flow

As mentioned above, the LabVIEW program is executed on a PC or on an industrial computer for controlling and monitoring the digital power supply. The flow of the computer control for the SSRF digital power supply is shown in Fig.4. Once the control program is run, all control parameters including the parameters of the RS232 port are set and are initialized. The program continually sends a query connection status command at constant intervals until the physical connection is normal. Only when the program receives status signs from the digital power supply controller, the communication between them is established. If no interlock malfunction events occur, the program is ready to be operated using the menu bars and the control command buttons, otherwise the interlock malfunction will be handled first. When the computer control and monitor for the SSRF digital power supply is complete, the program stops and exits.

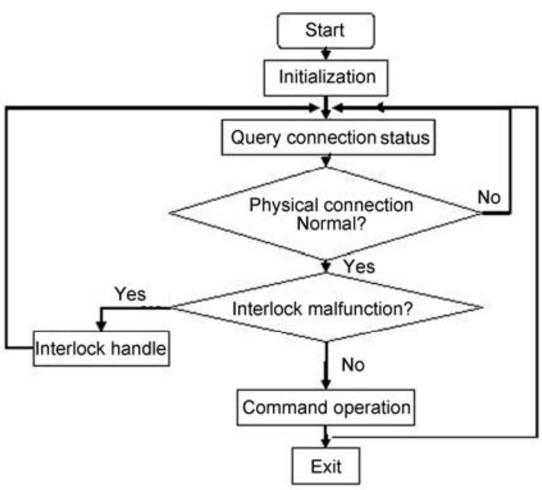

Fig.4 Flow chart of the control program.

3.4 Program user interface

A view of the main front panel in the user window that appears when the program is started is shown in Fig.5. This user interface allows the user to interactively adjust all the control parameters and view the curves of the magnet current and to check the operating status of the digital PS. It can be divided into four areas, which are discussed successively: 1) parameters setting; 2) parameters debugging; 3) control buttons; 4) chart and status displaying. Fig.6 shows another front panel, the user's sub-window that appears as the user presses the run button in the user's window. The parameters setting for the RS232 serial link are selected in the user's sub-window. It consists of the serial resource name, the baud rate, the data bits, parity, and the stop bits. The highest baud rate is 115.2 k. The sub-window is closed once the parameters setting operation is complete.

3.4.1 Parameters setting

In the user interface, the user can set the parameters. Before the parameters are set, the user has to press the PWMO button to turn off the PWM output to protect the digital power supply. The parameters are listed below:

- The PWM mode, i.e. normal H-bridge, half bridge, full bridge, and single quadrant chopper
- The digital input and output signal mask
- The PWM dead time
- The PWM frequency (kHz), typical values including 10, 20, 50, 33 and 100 kHz, and
- The reference current slope maximum and minimum values.

3.4.2 Parameters debugging

During the PWM signal output, the user is allowed to debug and adjust the parameters of the digital power supply using the user interface to view its performance and behavior. These are the following parameters:

- The PID (proportion-integral-derivative) parameters, which include the proportional coefficient, the integral coefficient, the derivative coefficient and the PID sample rate

- The low pass filter frequency
- The reference current maximum and minimum values, and
- The setting magnet current value.

3.4.3 Control buttons and the chart and status displaying

The main buttons include PWMO/PWMD, Run/Stop, Read, Download and Save in the user interface. The PWMO/PWMD button controls the PWM output, which turns on or turns off the digital power supply. The Run/Stop button is used for starting or stopping the program. The function of the “Save” button is to save all the names of the current parameters and their values on the user interface into a plain-text file, whose name and path can be defined in the dialog box “File Path” in the program interface by the user before the program exits. The function of the “Read” button is to read all the values of the parameters that are displayed on the user interface from the plain-text file. By pressing the “Download” button, all the desired parameters in the user interface are sent to the digital power supply controller to control the digital power supply.

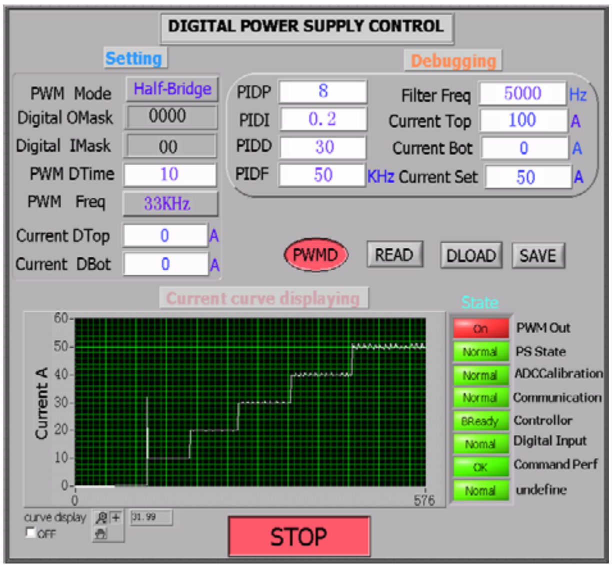

Fig.5 Main front panel of the computer control and the monitor software.

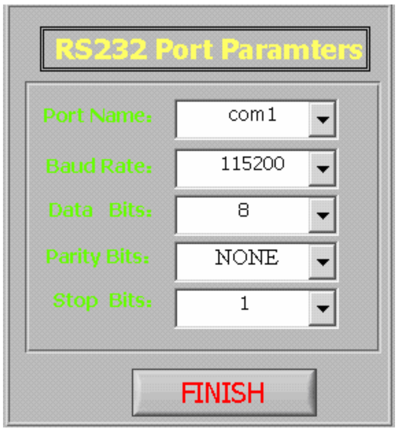

Fig.6 Font panel of the RS232 serial communication parameters setting.

The program also monitors the magnet current data and status of the digital power supply. A chart with eight indicator lights is available in the user interface. The real-time magnet current value is displayed in the moving curve chart to monitor the output performance of the digital power supply. The eight indicator lights with red and green indicate the current status of the digital power supply. For example, when the PWM output indicator light is red, it indicates PWM signals output from the controller. In the absence of PWM signals output, the PWM output indicator light is green. It is thus convenient for the user to instantly detect malfunction of the digital power supply using the chart and indicator lights.

3.5 Program block diagram

The program code of the computer control and the monitor program in LabVIEW is given in Fig.7. As shown in the block diagram, a major part of the code is integrated into sub-VIs, which are just icons with terminals instead of codes. Double-clicking on the icons can open the sub-VIs and their codes can be edited. The use of sub-VIs masks the structured programming details of the task, which makes it easier to read the code in the program, and thereby shortens the development time for programming. The block diagram uses the structure types in LabVIEW, e.g. for-loop, while-loop, sequence structure, case structure, and event structure. In the block diagram, the data flow is from left to right. The left is a sequence structure that defines the order of execution of the program. The initialization program code is contained within it. The right is a while-loop. The event-driven program code built within it is the core of the program. An event structure is placed inside the while-loop to handle a series of events that are caused by the actions of the user in the user interface until a terminating condition occurs. In the event-driven program, the program first waits for events to occur, responds to these events, and then returns to wait for the next event. The timeout terminal at the top left of the event structure specifies 10 milliseconds, the time for which the event structure waits until an event occurs. The timeout event is the first event case that is not observed in the block diagram. The query magnet current and the status events codes are built within the first event case. When the timeout expires before an event occurs, the program generates the timeout event. The second event case is the PIDI event seen in the block diagram. A case structure is contained within it. The event data field on the event data node that is attached to the left side of the event structure is used. The scan code element data output in the node controls the case structure. In case 28 of the case structure, there is a block diagram including two sub-VIs to perform the desired controlling and monitoring tasks. Other event cases of the event structure that are not shown in the program are very similar to the above detailed PIDI event case.

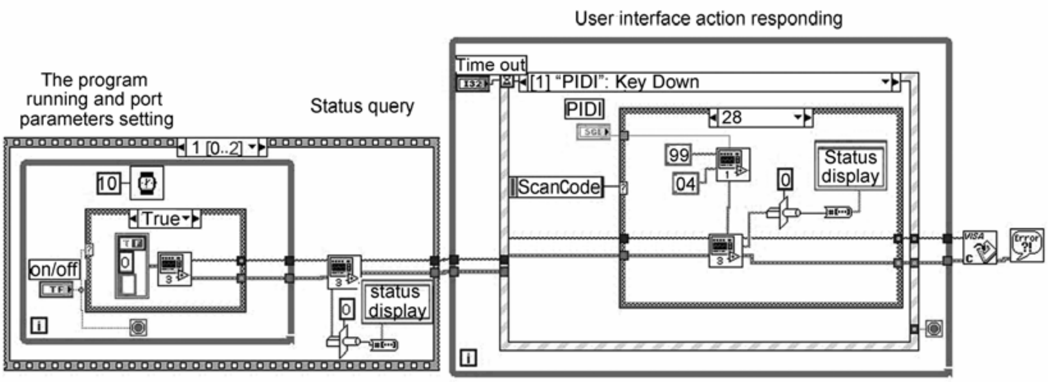

Fig.7 Program code of the computer control and monitor program.

The following block diagrams illustrate two sub-Vis, as shown in Fig.8 (writing sub-VI) and Fig.9 (reading sub-VI). The writing sub-VI is responsible for writing the binary command and sending it to the digital power supply. The function of the reading sub-VI is to read the binary data from the digital power supply and to check this data. Binary BCC is realized in both of them. Two for-loops are very similar. The former generates a binary BCC code, while the latter checks the binary BCC code.

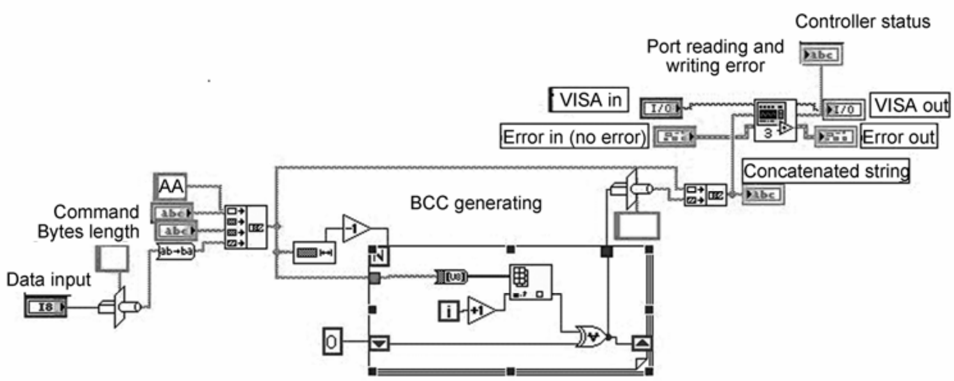

Fig.8 Writing sub-VI block diagram.

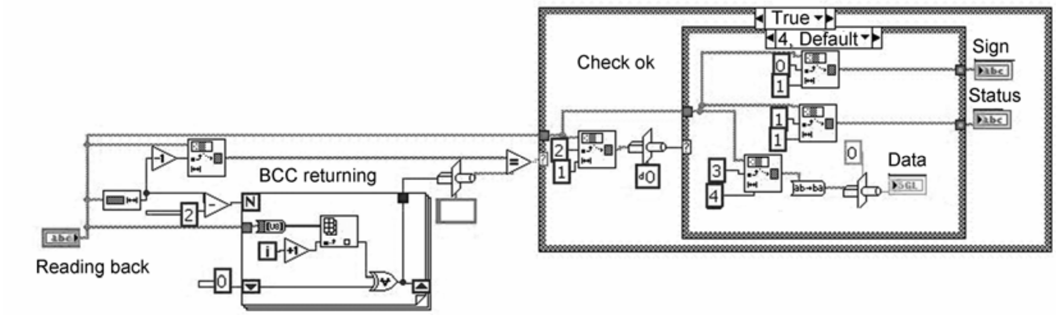

Fig.9 Reading sub-VI block diagram.

4 Summary

The LabVIEW program has been developed to control and monitor the SSRF digital power supply in minimum time, especially when compared to designing graphical interfaces in a conventional programming language such as C/C++, wherein more time is needed for the control and monitor process. The development of the digital power supply controller on a single board with an embedded processor has been completed. The software runs stably and reliably. The graphical user interface of the program is very convenient for the user to observe and gain an insight into the behavior of the developed system. As the next step, the developed system will be upgraded to double board with the embedded processor for SSRF digital PS. It is easy to expand new functions into the VI program as needed (e.g. waveform functionality and data logger function) for the SSRF digital PS. To summarize, the VI software developing environment simplifies the digital PS development process, realizes the computer control and monitor of the digital PS, and extends the functions of the digital PS.

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