BEAM POSITION MONITORING SYSTEM FOR THE BEPC STORAGE RING

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ABSTRACT

BEPC is a 2.2 GeV electron-positron collider. Thirty-two button-type beam position monitors (BPMs) are used for the position measurements of the colliding $e^+ e^-$ beams in the storage ring. The beam positions can be measured separately and simultaneously for e^+ and e^- beams due to the wide-band processing electronics. The reliability of measurements is assured by the self-consistency check. The C program “WINBPM” running on a personal computer (PC) in the local station, controls the BPM processing electronics. The function, “BPMSCAN” of “WINBPM” loops forever, scanning each button of all BPMs, reading button voltage values, converting these values to x and y positions, and storing button voltage and orbit position values in memories on another PC, which serves as a communication server. These data can be accessed by the main computer in the BEPC central control room through network. The communication software relies on the TCP/IP socket library.

1 INTRODUCTION

The Beijing Electron Positron Collider (BEPC)[1] is a machine with a designing energy up to 2.8 GeV, but it has routinely operated at the energy below 2.2 GeV since it was first put into operation at the beginning of 1989. The collider can provide beams over 5000 hours each year for high energy physics experiments as well as the synchrotron radiation research in parasitic and dedicated modes. Beam diagnostics were very important and have been highly beneficial to the success of the BEPC operation.

Beam position monitor is one of the most important beam diagnostic tools and the orbit control is one of most crucial beam quality assurances to every accelerator. The beam position measurements are used to correct the closed orbit distortion (COD) and to perform local beam steering for the synchrotron radiation beam lines. The measurements of dispersion functions and the residual orbit due to electrostatic separators are also implemented by the reliable beam position mea surements.

BPM pickups are installed in 32 locations next to defocusing quadrupole magnets along the 240.4 meters long circumference of the BEPC storage ring. Each BPM consists of four button-type electrodes, labeled A, B, C and D. The button with a 20 mm in diameter is mounted on a BNC-type feedthrough. The structures of all BPMs can be divided into two types. The one with a race track cross-section (120 mm in width and 58 mm in height) is used in the bending sections of the storage ring and their pick-up connectors are directly welded on to the aluminum beam duck. The number of BPMs of this type is 24. The another type with a circular cross-section (153 mm or 103 mm in diameter) is used close to the two IPs of the ring. The four buttons with their feedthough connectors are mounted on a section of the circular stainless steel beam pipe with flanges for button or feedthough exchange. The number of this type BPMs is 8. The sensitivity of the latter type is less than the former one due to the larger distance from the button to the axis of the BPM. A set of four RG223/U coaxial cables bring up pick-up signals of each monitor to the local control room where the signal processing electronics is located. The lengths of cables vary from 60 to 90 meters depending on locations of the monitors in the ring. The relative attenuations of four cables for each monitor have been carefully measured and saved into computer.

2 ELECTRONICS HARDWARE

2.1 *Processing Electronics*

Figure 1 shows a schematic block diagram of the signal processing electronics for beam position monitors.

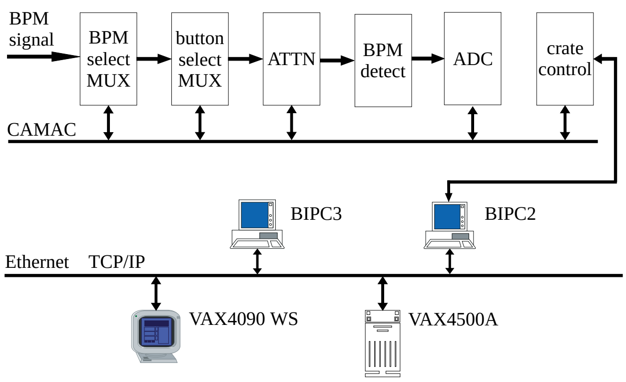

Figure 1: Schematic block diagram of the BPM signal processing electronics

For 32 BPMs with 4 buttons each we have 128 cables from tunnel to the local control room. A set of 16 ten-to-one PIN diode multiplexer modules is used for the

BPM selection, and one same module for the button selection. The PIN diodes can switch short bipolar impulses. These multiplexer modules have a 1 dB insertion loss and a −50 dB cross channel coupling. Switching time from one input to another takes the order of a few microseconds. Two attenuation modules provide an 81 dB maximum signal attenuation in steps of 1 dB. The programmable attenuators Model HP33320G (11 dB) and HP33321G (70 dB) are used in the two modules respectively. A wide-band BPM detector with one input and two outputs can measure positions for e^+ and e^- beams simultaneously. The beam induced bipolar pulses are filtered by the RG223/U cables due to the dispersion and the attenuation of the cable. The signal is further filtered by a lowpass filter in the detector leaving asymmetric pulses. Then the pulses are amplified and are rectified, finally the surfaces of the first part of e^+ and e^- pulses are integrated respectively at the same time. The setting time of the detector is less than 10 ms. The DC output signals from the detector are digitized by two 12-bit fast ADC modules, Model 3553Z1B of Kinetic System Corporation, with 25 μs analog-to-digital conversion time. All of these modules, except the BPM detector, are installed in two CAMAC crates which are controlled via a CAMAC crate controller Model CCU-2-80B.

2.2 Crate Controller

The Model CCU-2-80B double-width CAMAC crate controller with a PC interface card was developed by the Electronics Division of IHEP. The CCU-2-80B meets all the requirements of IEEE Standard 583 for CAMAC crate controller. When used with the interface card, the CCU-2-80B forms a computer-based CAMAC system with an IBM PC or compatible processors as the host and performs a wide variety of CAMAC commands to modules in the crate. One to eight CCU-2-80Bs can be connected to a single interface card. The crate address is selected by a front-panel switch. A 50-wire flat ribbon cable is connected to the computer interface card and looped-though the crate controllers. The last CCU-2-80B terminates the bus and can be up to 12 meters from the interface card. The interface card can be installed in any available expansion slot of the PC. Like most PC plug-in cards, the interface card is an "I/O-mapped" card, which uses the Intel processor's 16 continuos I/O address space for two 8-bit controller's control/status registers. The starting address of I/O ports is determined by the crate address setting. The CCU-2-80B/interface card system is only capable of transferring 8-bit CAMAC data word.

The high level language CAMAC library routines supplied with the crate controller can be used in conjunction with Microsoft FORTRAN, C and other high level languages.

3 SOFTWARE

The BPM processing electronics and the measurement behaviors can be fully controlled by the PC, named BIPC2, as illustrated in Figure 1. BPM application programs on this PC are developed on the platform of Microsoft Windows for Workgroup 3.11 and Microsoft Visual C/C++ 1.5.

3.1 Data Acquisition and Processing

When the BPM measurement program "WINBPM" starts, it first initializes the electronics hardware of the system. Then the C function "BPMSCAN" of "WINBPM" begin to loop forever. In each loop, the function performs the following procedure:

- Read the user specified measurement control parameters from the data buffer in the memory of another PC, BIPC3, which serves as a data communication server. These parameters include the *beam_mask* (default is for e^-), the *bpm_mask* (default is for all 32 BPMs), and the number of ADC readings per button, *N* (default value is 500).
- Adjust attenuation settings automatically according to the intensity of the e^+ or e^- beam, which is specified by the *beam_mask* parameter.
- Switch the button-selection multiplexer to the input which connects to a 50-ohm terminating resistor to obtain the background readings of the system for e^+ and e^- beams.
- Read the raw button voltage value of each button *N* times and average them for all selected BPMs specified by the *bpm_mask* parameters.
- Subtract background readings from raw button voltage values and then compute x and y positions according to each BPM's relative attenuation coefficients of 4 channels, calibration coefficients (from mapping) and alignment offset values with respect to the nearby quadrupole geodesic axis (from survey).
- Write button voltage values and orbit positions to the data buffer of BIPC3.

The refresh rate of the data buffer on BIPC3 depends on the number of BPMs to scan and the number of ADC readings per button, *N*. It takes about 11 seconds for the default selections of the *bpm_mask* and *N*. The position measurement resolution is better than 10 μm rms with the default value of 500 ADC readings per button.

The process "BPM", running on the BEPC storage ring main control computer VAX4500A in the central control room, lets operators use the control panels on VAX4090 Workstation to send the new specified measurement control parameters to and receive the latest measured button voltage values and x, y position data from BIPC3, and to display the orbit positions on the workstation. Actually, the system response time to operators is much less than the 11 seconds of the scan time for all 32 BPMs because the beam orbit data of the last measurement are always available in the memory of BIPC3 and can be obtained within 1 second through network.

3.2 Data Communication

The software of the BPM system is based on the client/server model which is the most commonly used paradigm in constructing distributed applications. As can be seen in Figure 2, the software is divided into three parts: the data acquisition part on BIPC2, the data management part on BIPC3 and the data display part on the VAX4500A. The first and the third parts are client application processes and the second part is the server application process. In this scheme client applications request services from the server application. The communication software relies on the TCP/IP socket library.

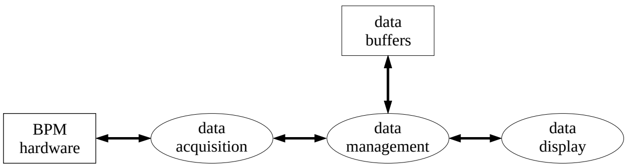

Figure 2: Software structure of the BPM system

The server application manages an one-dimension float-point array with a size of 1024. The array stores user specified BPM measurement control parameters and measured button voltage values and beam positions, as well as many other measured beam and machine parameters such as the beam intensity, the beam width and height, the tunes, the RF voltage, etc. The server process remains dormant until a connection is requested by a client process. At such a time the server process "wakes up" and services the client's requests of accessing the data array.

The data acquisition application updates corresponding elements of the data array at the end of each BPM scan, while the data display application receives and displays measured BPM data whenever operators issue a measurement command via the control panel on the workstation.

4 SELF-CONSISTENCY CHECK

Bench calibration for each monitor was carried out in the laboratory before installation. A movable rod parallel to the monitor axis was put at the position (X, Y) to simulate the beam electric field and the 4 electrode signals V_A, V_B, V_C, V_D were measured. Since the normalized difference signals $U=(V_B+V_C-V_A-V_D)/(V_A+V_B+V_C+V_D)$ and $V=(V_A+V_B-V_C-V_D)/(V_A+V_B+V_C+V_D)$ are independent of bunch shape and intensity, we used a 5 MHz continuous sinewave as the calibration signal. The calibration was made at the 25 mesh points in each monitor's center area of 20 mm x 20 mm in steps of 5 mm. To calculate a beam position (X, Y), third order polynomials of U and V were fit for these 25 mesh data. The beam position can also be calculated from any three electrode signals instead of four signals. At this time, the normalized difference signals are $U'=(V_C-V_D)/(V_C+V_D)$ and $V'=(V_B-V_C)/(V_B+V_C)$ if B, C, D electrodes are used. We fit fourth order polynomials of U' and V' for the same mesh data. The fitting errors of each monitor are less than 0.1 mm rms for both 4-electrode and 3-electrode calibrations.

Whenever we measure the COD, if the difference between the position data computed by using 4-electrode calibration and any one of four 3-electrode calibrations for a BPM is larger than a small value δ in either x or y plane, we will mark the position of that BPM as a bad reading. When we first used this self-consistency method to check the reliability of the beam position measurement, most position readings of 32 monitors were bad. We found that it is mainly caused by the relative attenuation change of coaxial cables and channel to channel offset change of PIN diode multiplexers. We remeasured these parameters carefully and replaced the old ones. At present, the differences between position data obtained from the 4-electrode calibration and other 3-electrode calibrations are less than 0.2 mm for most BPMs. The typical measured COD is X_{ms}=2 mm and Y_{rms}=1 mm after the orbit correction.

5 SUMMARY

The beam position monitoring system of the BEPC storage ring basically satisfies the requirements for the machine operation and machine studies. The short-term reproducibility of measurements is better than 10 μm. The measurement time for scanning all 32 BPMs is about 11 seconds. The dynamic rang of the system is over 81 dB and the minimum measurable beam intensity is less than 0.5 mA. The reliability of the measurement is guaranteed by the self-consistency check. Absolute beam position with respect to the magnetic center of the adjacent quadrupole magnet will be determined directly with the beam[2] in the near further.

6 ACKNOWLEDGMENTS

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