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DESIGN AND INITIAL TESTS OF BEAM CURRENT MONITORING SYSTEMS FOR THE APS TRANSPORT LINES *

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ABSTRACT

The non-intercepting beam current monitoring systems suitable for a wide range of beam parameters have been developed for the Advanced Photon Source (APS) low energy transport lines and high energy transport line. The positron or electron beam pulse in the transport lines will have peak beam currents ranging from 8 mA to 29 A with pulse widths varying from 120 ps to 30 ns and pulse repetition rates from 2 Hz to 60 Hz. The peak beam current or total beam charge is measured with the fast or integrating current transformer, respectively, manufactured by Bergoz. In-house high speed beam signal processing electronics provide a DC level output proportional to the peak current or total charge for the digitizer input. The prototype systems were tested on the linacs which have beam pulse structures similar to that of the APS transport lines. This paper describes the design of beam signal processing electronics and grounding and shielding methods for current transformers. The results of the initial operations are presented. A short introduction on the preliminary design of current monitoring systems for the APS rings is also included.

1. INTRODUCTION

The Advanced Photon Source (APS) will be a 7-GeV synchrotron radiation facility. Non-intercepting high accuracy beam current monitoring systems suitable for a wide range of beam parameters are required for the measurement of peak current, total charge, and absolute beam loss. Fig. 1 shows the proposed layout of beam current monitors in the APS. This paper documents the developments of beam current monitoring systems for the APS low energy transport lines (LET1 and LET2) and high energy transport line (HET). The beam parameters in the transport lines are summarized in the table on the next page. The peak beam current or total charge measurements for pulsed beams of charged particals are performed by beam current transformers with the subsequent high speed beam signal processing electronics. The prototype systems were tested on the linacs which have beam pulse structures similar to that of the APS transport lines. The results of the initial operations are presented.

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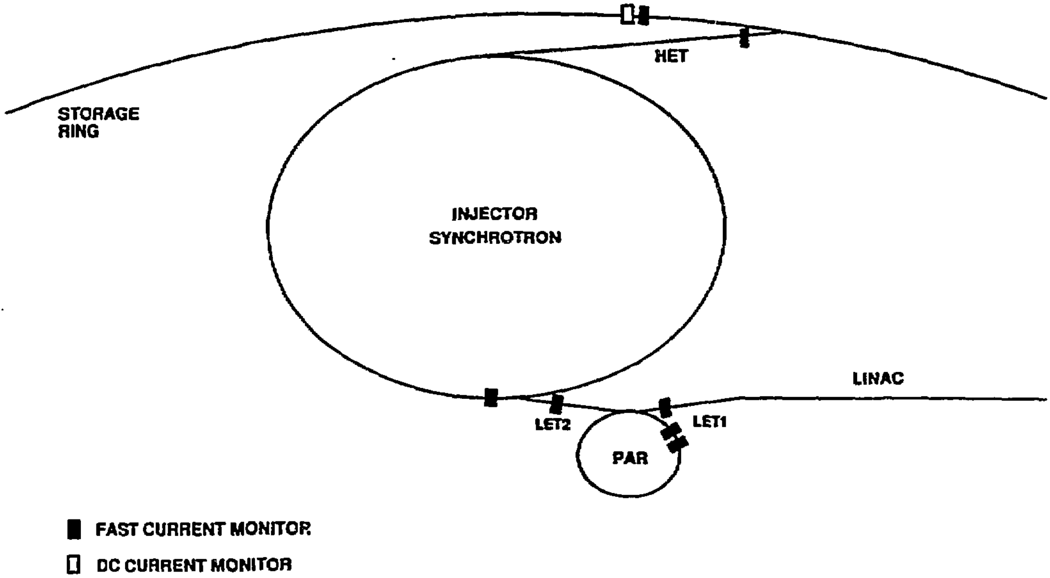

Fig. 1. Proposed layout of beam current monitors in the APS

Table Beam parameters for the APS transport lines

	LET 1	LET 2	HET
PEAK CURRENT	8 mA	11.9 A	28.9 A
BUNCH LENGTH	30 ns	0.29 ns	122 ps
INTENSITY PER PULSE	1.5×10^9 positrons	2.2×10^{10}	2.2×10^{10}
CHARGE PER PULSE	240 pC	3.5 nC	3.5 nC
PULSE RATE	60 Hz	2 Hz	2 Hz

2. SYSTEM DESIGN

2.1. Current Transformers

A total of three current transformers are provided for the APS transport lines: one each for LET1, LET2, and HET. The peak current and total charge in LET1 are measured by the fast current transformer (FCT). Because of narrow pulse width, only total charge is measured in the LET2 and HET lines. The transformer used to measure total beam charge is the integrating current transformer (ICT) proposed by K. Unser [1]. Both FCT and ICT are based on toroids. They are available commercially from Bergoz company in Crozet, France. The current transformer is external to vacuum and encased in a copper and Mu-metal shell to provide an electromagnetic shield. In the subsequent electronics, a fast pulse signal from the FCT or ICT is processed and converted to a DC level output proportional to the beam peak current or total charge for the digitizer input.

2.2. Signal Processing and Data Acquisition

All the signal processing electronics have been designed and tested. A block diagram of the beam current monitoring system in the APS transport lines is shown in Fig. 2. Fig. 3 shows a timing diagram of the system. A beam pretrigger enters a variable delay generator which triggers a variable width generator. This produces the pulses used to control the linear gates. The current transformer output signal is first amplified by a low noise fast pulse preamplifier three feet from the transformer and then sent to the control room. Beam current signal processing electronics occupy a single slot in a VME chassis. The signal from the preamplifier enters a variable gain line receiving amplifier. When the gate is opened by the gate pulse, the signal passes to a fast integrator. The integrator output is digitized by a commercial VME format A to D converter which is linked to the control system. Associated operating programs will be developed. Data on beam current and total charge will be displayed on a workstation. The programs provide mouse-controlled operation for system setup and control.

The current monitoring system can be calibrated by sending a current pulse to the one-turn calibration winding. Calibration can be performed on line or off line.

2.3. Ultrafast Gated Integrator

An ultrafast resettable gated integrator with a gate window as narrow as 10ns and the settling time as short as 50 ns has been developed to accurately calculate the ICT output waveform area which is proportional to the total beam charge. This gated integrator provides fast reponse and short settling time by introducing new design approaches which overcome the problems associated with earlier circuits. Its output offset errors, introduced mainly by the charge injections from analog switches and opamp input bias current, are minimized. The output offset error is less than 1mV. The integrator has a totally bipolar input, a large linear dynamic range (70 dB) and a very small droop rate (0.5mV/us). A reset pulse automatically returns its output to zero after

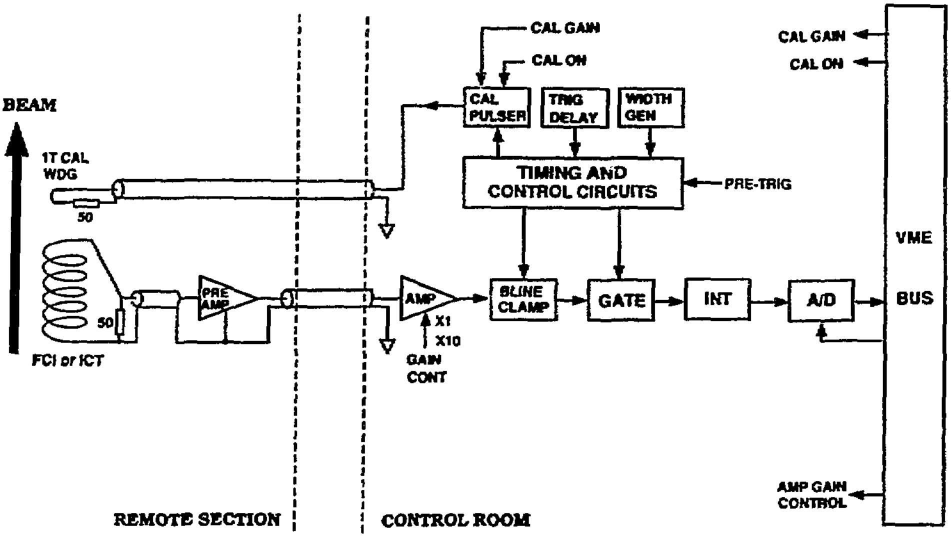

Fig. 2 Block diagram of current monitoring system in the APS transport lines

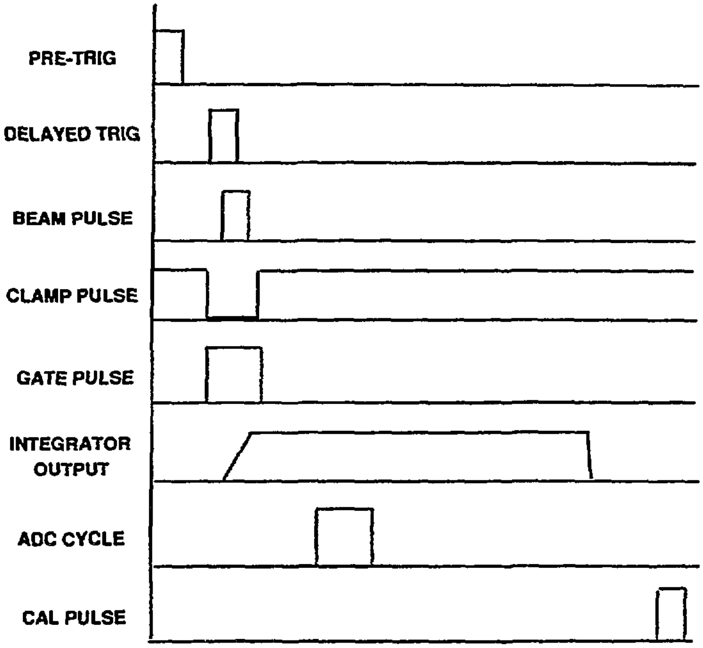

Fig. 3 Timing diagram

the A/D conversion is completed. The integrator output is independent of input pulse rate and the on-resistance of the analog gate switch. The relationship between the input and output of the gated integrator is clearly defined. The fast response and settling time are demonstrated in Fig. 4. The integrator gives the same output DC level for several input signals with different pulse shape but the same area. Fig. 5 shows that the integrator has a totally bipolar input and automatic reset capability.

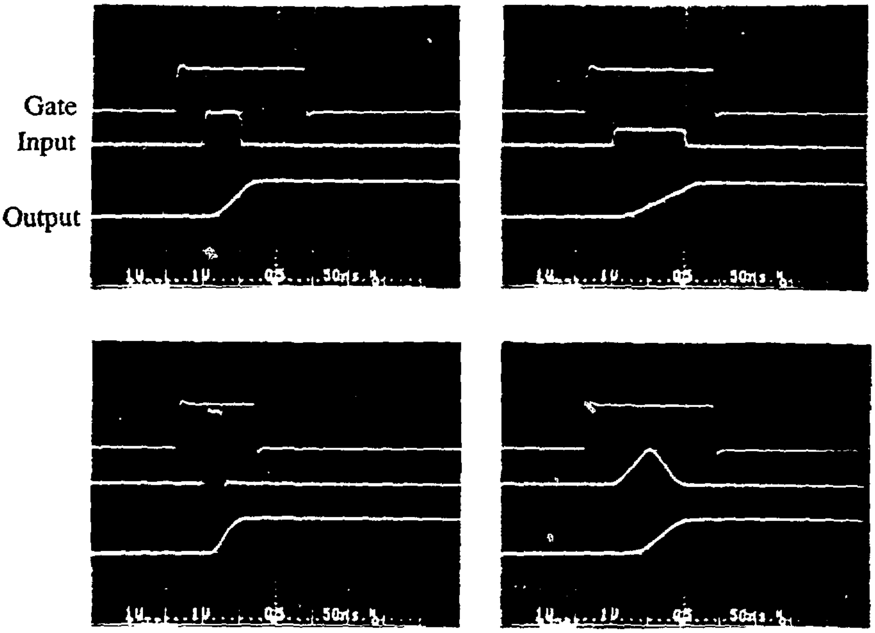

Fig. 4 High speed waveform area caluculation .
1 V/div, 50 ns/div for all middle and bottom traces

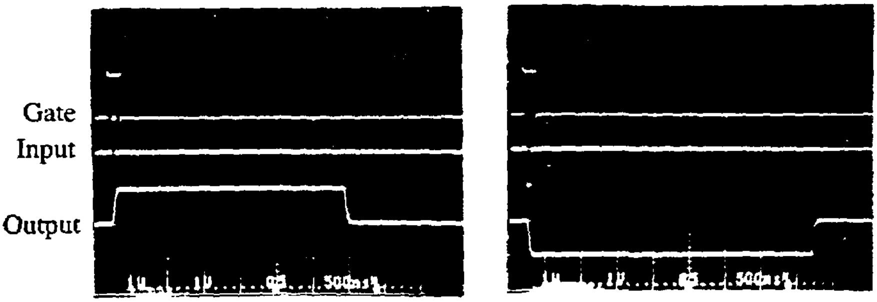

Fig. 5 The integrator is ressettable and has a totally bipolar input
1 V/div, 500 ns/div for all middle and bottom traces

2.4. Grounding and Shielding

The quality of the signals from the FCT or the ICT can be improved by careful noise shielding and system grounding. Fig. 6 illustrates a proposed grounding and shielding method for the current monitor which has been proven effective in the prototype tests. Notice that the current transformer is floated inside the shielding house. The cable is grounded only at the one end. The ground loop is therefore eliminated.

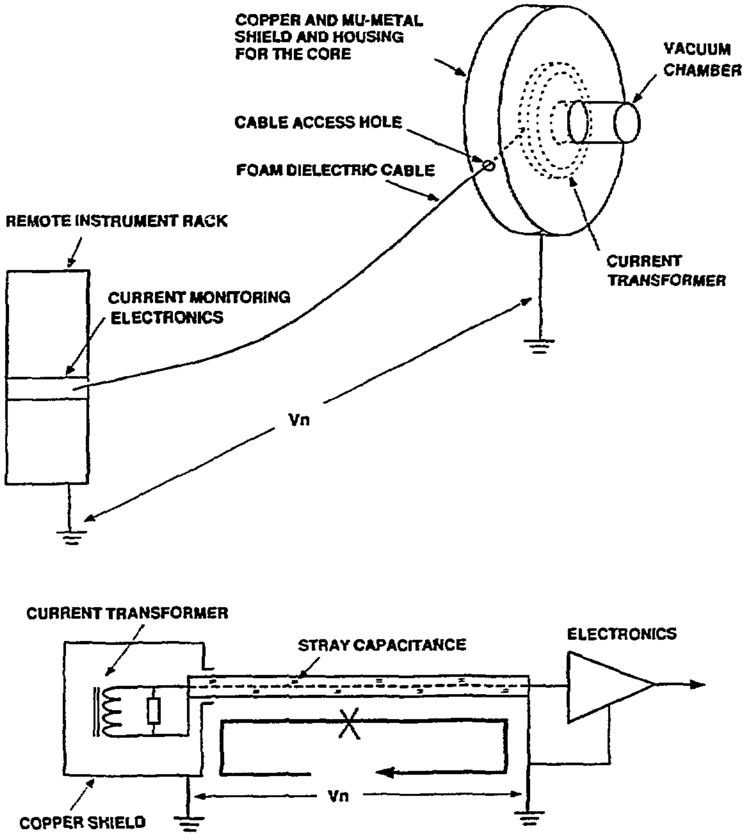

Fig. 6 Grounding and shielding for beam current monitor

2.5. Current Monitors for the APS Rings

The APS will have three rings: the positron accumulator ring (PAR), 7-GeV injector synchrotron, and 7-GeV storage ring. The number and location of the rings' current monitors are shown in Fig. 1.

Two current transformers are provided for the PAR. A FCT is used to determine the bunch length and to observe bunch shape in the PAR down to several nanoseconds. An ICT is used to measure bunch charge which can be converted to average current for beam lifetime measurement. Two transformers in the PAR will share the same housing. The FCT output is directly connected to a digital scope for the bunch length readout. The ICT output signal is processed by in-house high-speed signal processing electronics with higher accuracy requirements than are needed for the current monitors in the transport lines.

A single ICT is provided for the injector synchrotron to measure bunch charge. This system will be similar to that used in the PAR.

A total of two current monitors are provided for the storage ring. One is designed for high accuracy DC current measurement, the other for high speed bunch charge measurement. DC current is measured by a parametric current transformer (PCT), originally proposed by K. Unser [2]. The PCT and its associated electronics are available commercially from the Bergoz company. The output of PCT front end electronics will be digitized by a 16-bit A to D converter. The total charge of a selected bunch in the storage ring is measured by an ICT. The system is similar to that used in the injector synchrotron, except for the higher accuracy requirements for signal processing electronics and a different data acquisition system layout.

3. INITIAL TESTS

In order to evaluate the designs, the prototype current monitoring system was implemented and successfully tested on linacs which have beam pulse structures similar to that of the APS transport lines. The current monitor prototype for LET1 based on the FCT was tested on the APS 45 MeV linac test stand (30 ns macropulse width). Test results are shown in Fig.7 and Fig. 8. The current monitor prototype for LET2 and HET was tested on the Argonne Chemistry linac (25-40 ps pulse width). Test data are shown in Fig. 9 and Fig. 10. Since the ground loop was eliminated in the design, noise present in the beam signal is minimized. The signal baseline is stable. Modulation noise equivalent to ±60 mV in the signal baseline (with Ib = 1.6 A) is observed. This is because the shielding material used in the prototype is copper which is not good for shielding intermediate frequency noise from the nearby modulator. In the final construction unit, the high permeability Mu-metal will be added to make multi-layer shields.

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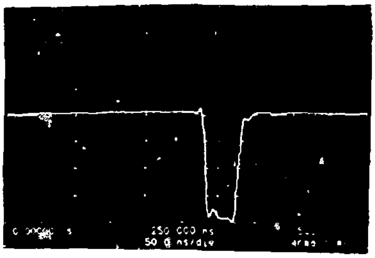

Fig. 7 FCT output signal.
30 mV/div, 50 ns/div
Ib = 100 mA

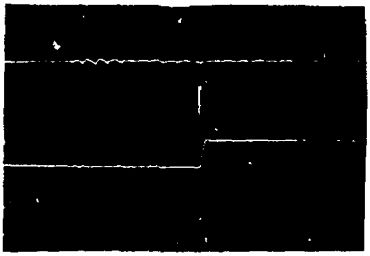

Fig. 8 Test of FCT with processing electronics. Top: FCT output (1V/div), Bottom: Gated integrator output (2V/div). 1 us/div. Ib = 1.6 A

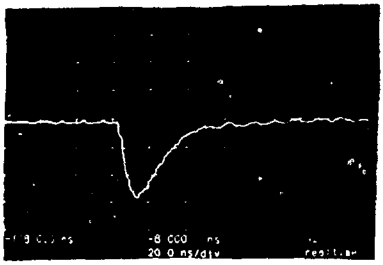

Fig. 9 ICT output signal.
100 mV/div, 20 ns/div
Beam pulse width: 25 ps (rms)
Total charge: 5 nC

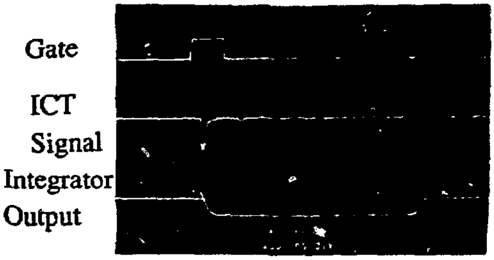

Fig. 10 Test of ICT with processing electronics. 200 ns/div, 200 mV/div for middle and bottom traces.

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[2] K. Unser, " A toroidal DC beam current transformer with high resolution, " IEEE Trans. Nuclear Science, Vol. NS-28, No. 3, pp 2344-2346, June 1981.