

CEBAF BEAM LOSS ACCOUNTING

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Abstract

This paper describes the design and implementation of a beam loss accounting system for the CEBAF electron accelerator. This system samples the beam current throughout the beam path and measures the beam current accurately. Personnel Safety and Machine Protection systems use this system to turn off the beam when hazardous beam losses occur.

INTRODUCTION

In the CEBAF accelerator, superconducting cavities operating at 1497 MHz accelerate electrons to 4 GeV energy in five passes. The nominal beam current is 200 μA in Continuous Wave (CW) mode, with an approximate beam size of 100 μm . An errant beam can produce hazardous amount of radiation in areas where personnel may be present. This is the domain of the Personnel Safety System (PSS). An errant beam with such high power density can also damage the machine components considerably. This is the domain of the Machine Protection System (MPS). In the past, Beam Loss Monitors (BLMs) based on photo-multipliers detected radiation due to beam loss. However, the calibration and auditing of these detectors were prohibitively time consuming. This, along with the need to accurately measure the beam current, necessitated the development of the Beam Loss Accounting (BLA) system. The BLA system measures the beam current using low Q, TM_{010} stainless steel cavities. Two major advantages of the system are the ease of auditability by means of a calibration signal and the need for only a small amount of valuable beam time for verification. Though the PSS and MPS contain systems in addition to the BLA system, this paper concentrates on the BLA aspects only.

PSS AND MPS FUNCTIONS

Personnel Safety System

The PSS protects people from exposure to prompt beam-induced radiation [1]. During normal operations, the PSS issues an active permission signal, which is a 625 kHz square wave. When a fault occurs, the PSS withdraws the permission, causing the removal of the beam at the electron gun. Figure 1 shows the location of the Beam Current Monitors (BCMs) assigned to the PSS. These BCMs serve the following functions:

1. Beam stoppers near the entrance to the experimental halls protect personnel from the beam during access to the experimental areas. When the stoppers are in place, de-energized magnets prevent the beam from going in their direction. Should this safety feature fail, it is conceivable that a beam of high power density may tunnel through the stoppers. The BCMs (EA, A1 and C1) protect the stoppers by causing the termination of the beam when they detect a beam current greater than 1 μA .

2. CEBAF's contractual requirement imposes an operational limit on the beam current. The BCM (I2) ensures that the beam current in the injector does not exceed 190 μA . In addition, the beam dumps in the experimental halls have their own limits on beam current. For halls A and C, these limits are the same as for the injector. For hall B, this limit is 1 μA . BCM (B1) provides this protection.

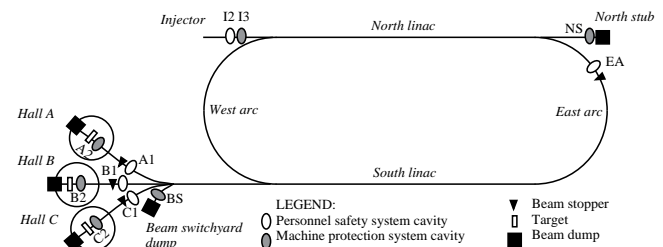


Figure 1: BCM cavities location along the CEBAF beamline.

Machine Protection System

The MPS protects the accelerator and end station equipment from beam related damage. During normal operations, the MPS issues an active permission signal, which is a 5 MHz square wave. When a fault occurs, the MPS withdraws the permission, causing the removal of the beam. Figure 1 shows the locations of the BCMs for machine protection. The BLA system performs the following functions.

1. The BLA system limits the beam current in the injector to 180 μA . This ensures that the MPS will trip before the PSS in all cases.

2. If $i(I3)$, $i(NS)$,..., represent the beam current values in BCMs at I3, NS,..., the BLA system calculates the beam loss by computing $i(I3)-i(NS)-i(BS)-i(A2)-i(B2)-i(C2)$. If this value exceeds 2.5 μA , the system will terminate the beam.

3. In case of an instantaneous beam loss, the BLA system will terminate the beam such that the integrated beam loss does not exceed 25000 $\mu\text{A}\cdot\mu\text{s}$. [2,3].

BEAM LOSS ACCOUNTING

Design Criteria

The PSS and the MPS functions described above, though different in some details, have many common features. It is economical both in time and money, to extract and modularize the common functions of the two systems. Thus, the two systems will primarily consist of the same types of devices, with obvious advantages regarding maintainability and testability. A trade off is a small increase in system fragmentation, resulting in increased interconnections.

Each module in the system has a supervisory circuit to ensure safe operation. Upon detecting an error in its operation, a module will generate a fault signal. This fault signal prevents beam from leaving the injector. The system as a whole will have self-test capability and in case of failure, the ability to identify failed modules.

The Cavity

The BCM is a simple pill box cavity, exciting the TM_{010} mode at 1497 MHz. Constructed of stainless steel in order to minimize drifts due to temperature, its Q_0 is approximately 3000 and the geometric shunt impedance is 180Ω . A stub tuner, mounted on a micrometer, facilitates the frequency adjustment of the cavity. The cavity is available with two or three couplers, depending on the application (figure 2a). The tuning of the cavity is such that its loaded Q is the same in the two coupler configurations. The two coupler cavities are used for the MPS, the three coupler cavities are used in the PSS to provide redundancy.

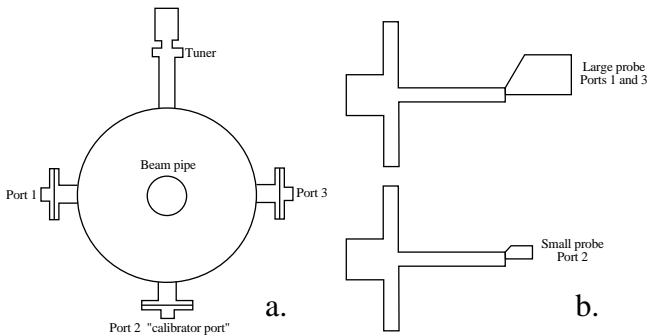


Figure 2: a. The CEBAF beam current monitor pill box cavity, three port configuration. b. Two styles of couplers.

Magnetic field loops situated around the cavity (where magnetic field is the largest), accomplish the coupling in and out of the cavity. The loops, (couplers), mount on 2.75" rotatable conflat flanges and proper coupling is achieved by adjusting the flanges. The couplers are of two styles: a large area loop and a small area loop (figure 2b). The large area loop couples the outgoing beam signal and the small area loop couples the incoming test signal. A cavity with two

couplers has one large area loop and one small area loop. A cavity with three couplers has two large area loops and one small area loop. For a cavity with two couplers, the large area loop couples critically to the cavity. For a cavity with three couplers, each large area loop slightly undercouples to the cavity, in order that their sum couples critically. For all cavities, the small area coupler undercouples to the cavity by 14 dB. As a result, the test source has sufficient isolation and does not disturb the resonance frequency.

Standard Electronic Modules

The 'standard' electronic modules are the down converter, a test source, RMS to DC converter, an equalizer and an integrator. Figure 3 shows the 'standard' configuration.

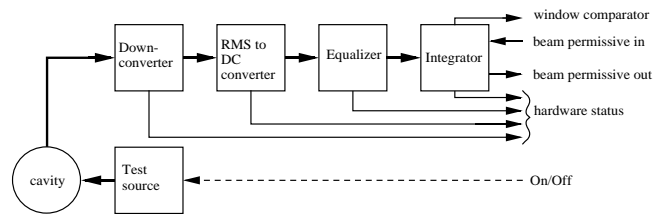


Figure 3: Standard modules and their configuration.

The Down converter shifts the 1497 MHz spectral component of the cavities to 1 MHz. There is a separate down converter for each dynamic range in current: one for 0-10 μA (for use by BCMs of the PSS at the beam stoppers) and one for 0-200 μA . The down converters and the 1497 MHz test source reside close to the cavity in the accelerator tunnel. Such proximity minimizes cable attenuation drifts due to temperature variation. Low loss 10m long 0.5" Heliax cables connect the cavity to the down converter and the test source. The same type of cable connects the down converter to the electronics in the service buildings.

An RMS to DC converter converts the bandpass filtered 1 MHz signal to a baseband signal. This module uses the AD637 RMS to DC converter IC [4], which has excellent linearity and temperature stability.

An equalizer module compensates differences in cable losses. The output of the equalizer scales with the beam current.

All the above modules, except the equalizer, are calibratable in the laboratory and interchangeable with the same type in the field. The equalizer is specific to each BCM and its calibration is *in situ*. However, two identically calibrated equalizers exist for each BCM; the second one acting as a quickly available spare should the first one fail.

The integrator monitors the average beam current or beam loss. When the beam current or beam loss exceeds a preset threshold, the integrator withdraws the permissions.

All modules conform to 3U eurocard standard. The interconnection among modules is through the back plane. Blindmate snap on RF connectors carry the 1497 MHz

signals, while 96-pin DIN connectors carry the baseband and digital signals. Keyed connectors on the modules and the backplane prevent insertion of the modules in the wrong place.

Implementation of the BLA system in PSS

The BLA system for the PSS consists of 4 cavities at the beam stoppers and 1 cavity in the injector. Each cavity has three couplers. The small area coupler connects to the test source. Each large area coupler connects to a downconverter. The reason for two large area couplers is that the PSS requires redundant logic paths and thus two identical electronic systems. Figure 4 shows the PSS logic. The PSS permission from the electronics associated with the BCMs at EA, A1, B1 and C1 go to the injector. At the injector, these permission pass through logic associated with the BCM I2. The latter limit the beam current to 190 μA . For the stopper BCMs two modes of operation exist; one with beam stopper in place and the other without the stopper. For a given mode, faults occur if the beam current in any stopper BCM exceeds 1 μA when the beam stopper is in place. Occurrence of a fault results in the PSS permission going inactive and consequently in the removal of the beam.

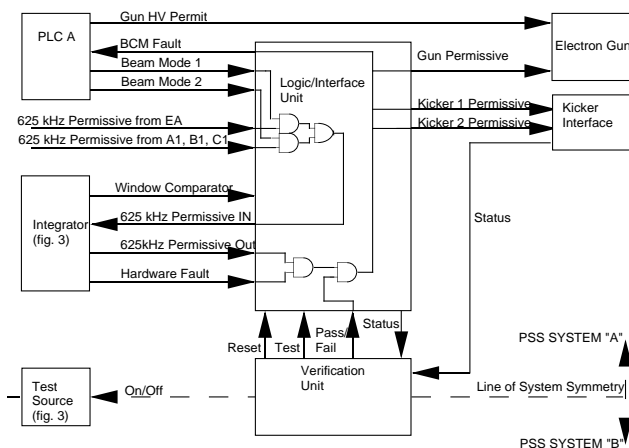


Figure 4: PSS BCM implementation block diagram.

The BLA system for the PSS also contains a verification unit, which is a time sequencing state machine. Through the control system interface to the verification unit, the operators can test the BLA system and remotely reset any BCM.

Implementation of the BLA system in MPS

The BLA system for MPS consists of 6 cavities. Each cavity has two couplers. The small area coupler connects to the test source and the large area coupler connects to a down converter. Cables carry the signals from the down converters to the beam switch yard service building (figure 5). RMS to DC converters process the signals. The MPS implementation requires a slight modification to the standard configuration of figure 3. This modification results in a comparator board that consists of 6 equalizers and a

circuit that calculates the difference between the injector signal and the sum of the other 5 BCM signals. The comparator board has two outputs, each of which goes to an integrator. One output is for the case that the beam current in the injector exceeds 180 μA . The other is for the case that the average beam loss exceeds 2.5 μA or the instantaneous beam loss (above 2.5 μA) exceeds 5000 $\mu\text{A}\cdot\mu\text{s}$. Both outputs force the integrators to withdraw MPS permissions.

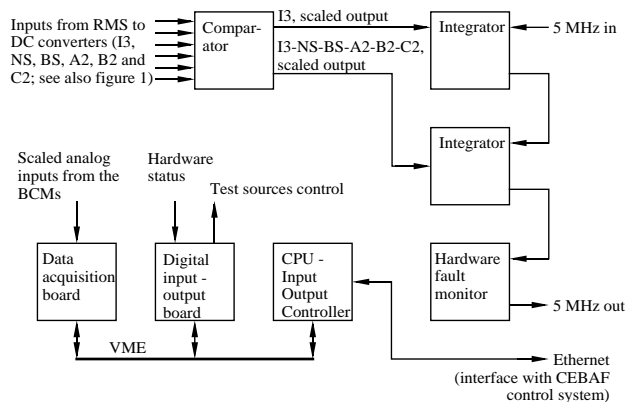


Figure 5: MPS BCM implementation block diagram.

The control system interface to the BLA system of the MPS, permits the operators to initiate and control the self-test sequence, monitor the beam current and hardware status.

CONCLUSION

The BLA system fully conforms to the requirements of both the PSS and the MPS, providing personnel safety and machine protection. Additionally, it will provide an accurate measurement of beam current. A prototype MPS system will be in place during May '95 and the final system will be in place during September '95.

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