BEAM SWITCHYARD INSTRUMENTATION FOR THE STANFORD TWO-MILE ACCELERATOR*

D. A. G. Neet
Stanford Linear Accelerator Center
Stanford University, Stanford, California

Summary

This paper reviews some engineering aspects regarding the construction of instrumentation for the high power beam transport system in the beam switchyard of the Stanford Linear Accelerator Center. A small control computer system is described that will be used for handling of data and for setting up the magnet systems in a quick and reproducible way.

Introduction

The purpose of the switchyard is to deliver a momentum analyzed beam in each experimental area. At this time two experimental areas are being developed: End Station A for electron scattering and photon experiments, and End Station B for secondary particle experiments. Each end station is associated with a beam transport channel using dc magnets and a momentum-analyzing slit. A switching magnet located at the beginning of the switchyard can deflect beam pulses from the accelerator into either channel on a pulse-to-pulse basis.

Provisions are made in beam A to deliver photon beams in End Station A. A switching magnet at the end of beam B allows beam sharing for experiments in End Station B.

The switchyard is designed to provide simultaneously beams of different momentum, different beam intensity, and different pulse rates to the end stations. The maximum pulse rate is 360 pulses per second. Eventually the 20-BeV beam is expected to carry an average power of 2.2 megawatts. This powerful beam will cause thermal destruction when intercepted by instruments or by the vacuum chamber. Such destruction will be prevented by placing protection collimators at well chosen locations along the beams.

These and other absorbing devices will cause a high level of radiation exposure to all the components in the switchyard and a high level of residual radioactivity which will limit access of personnel. In this paper we will discuss some of the construction aspects as they are influenced by the radiation environment.

The switchyard is a complex area with a large number of components and auxiliary equipment. A small computer system is described that will perform bookkeeping functions on all the data involved with this equipment. It will also provide for digital adjustments of the magnet currents and other parameters.

Instrumentation for Analyzing Channel A

Figure 1 is a simplified diagram of the basic magnet deflection system, the slit, the beam monitors, and protection collimators for beam-analyzing channel A. The optics of the magnet deflection system are discussed in Papers I-1 and II-25 of this conference.

Electron pulses from the accelerator will enter channel A after deflection by the switching magnet. The adjustable slit opening can accept a beam with a momentum spread between zero and 1.8% $\Delta p/p$. A beam spectrum analyzer (S_2) in front of the slit measures the current distribution as a function of the momentum with a momentum resolution of 0.1%. A beam current intensity monitor is placed before and at the end of the channel; and beam position and beam profile monitors are placed at the locations shown in Fig. 1.

The four protection collimators shown in Fig. 1 will prevent an incorrectly steered beam from being intercepted directly by an instrument, a magnet, or a vacuum chamber. Protection collimators 1 and 2 will in addition absorb the low energy tail of the electron beam. Ionization chambers located close to the protection collimators provide for a beam interlock signal if an intolerable part of the beam is absorbed. Additional instrument protection is obtained by surface thermometers at critical vacuum chamber locations.

There will be occasions, particularly when starting up the accelerator, when the beam energy is very unstable or the beam spectrum very wide. In such cases the beam will first be deflected into a 50 kilowatt tune-up dump for rough accelerator adjustments. A rough spectrum monitor (S_1) for this purpose is located in front of the tune-up dump. This tune-up facility will accept beams with spectrum variations of $\pm$ 20% and the resolution of the monitor is 1.2% $\Delta p/p$.

Radiation Exposure

The radiation exposure over a ten-year operation period for components close to the high power slits is estimated at 10^{13} - 10^{14} ergs/gram. Local shielding will be provided around these absorbers to bring the radiation levels in the vicinity down to tolerable values.

As seen from Fig. 1, the beam monitors are exposed particularly to radiation from the protection collimators. The protection collimators are designed for 20 kilowatt absorption. The shower developed in the protection collimator is absorbed only to a limited extent, and forms with the fast neutrons a strong source of radiation.

*Work supported by U.S. Atomic Energy Commission.

The angular distribution of the radiation exposure at a distance of one meter from a 20 kilowatt protection collimator over a ten-year operation period is estimated to be:

Forward direction:	$6\text{x}10^{11}$ ergs/gram
Sideways:	$1\text{x}10^{11}$ ergs/gram
Backward direction:	$6\text{x}10^{10}$ ergs/gram

The contribution in the figures due to the isotropic fast neutrons is $4\text{x}10^{10}$ ergs/gram. Radiation levels in the forward direction close to the beam may be a factor of ten higher. A safety factor will be observed in engineering applications.

The residual radioactivity in these areas will build up quickly to such levels that access to the beam switchyard becomes very restricted.

General Engineering Aspects

The switchyard equipment is located in the lower part of an earth covered double tunnel. Access is provided through the upper part. Removable shielding blocks can be installed between the levels (see Fig. 1a).

The humidity of the air in the enclosed atmosphere of the switchyard may be high and will contain highly corrosive nitric acid. Radiation in the upper tunnel is low enough that standard polyethylene cable insulation can be used. Connections to the instruments and equipment in the lower tunnel will be made with radiation resistant cable, with connectors that can be operated from the upper tunnel by remote manipulators.

Commercially available radiation resistant cables use magnesium oxide (RG 81-U), mica or quartz fibers as insulation material. The RG 81-U can be exposed to 10^{14} ergs/gram, but is not flexible and is very hydroscopic. A seal that will stand this exposure is difficult to make. Quartz fiber cable can be exposed to 10^{12} ergs/gram, and it is flexible and fairly homogeneous. The leakage resistance may become 10 kilo-ohms in a humid atmosphere. Radiation resistant seals have been made using a gas filled, flexible metal tube.

The electronic circuits associated with instrumentation and equipment in the switchyard will be located outside the radiation environment in a building on the slopes of the earth covered tunnels. Some exceptions have been made for low level preamplifiers and the vidicon **cameras** used for visual beam observation (see next section). These electronic circuits are specially selected and will be located in alcoves as shown in Fig. 1a.

The mechanical design of monitors and instruments is influenced by the limited access to the tunnel. The replacement of instruments should be possible with simple operations using remote manipulators in the upper tunnel. The monitors in the vacuum system are therefore designed with bellows and fast-disconnect vacuum flanges on both sides of the instrument. Each instrument can be disconnected from the common instrument support structure by one simple manipulation.

Instrument Design

Construction techniques and design considerations for some of the instruments will be discussed below. The characteristics are shown in Table I.

The Spectrum Analyzer

Figure 2 shows the general appearance of the instrument looking in the direction of the beam. The spectrum of the electron beam is measured by a row of insulated secondary emission foils. The width of the narrowest foil in the center of the beam is 6 mm, corresponding to 0.1% $\Delta p/p$. The secondary electrons are collected by electrodes located above and below the beam plane. Both the secondary emission foils and the collector electrodes are supported by one ceramic rod. The foils are connected to the vacuum feedthroughs in the top of the instruments by ceramic-insulated wires. The foil assembly of the spectrum analyzer consists of two halves which may be retracted sideways if beam scattering by the 1-mil-thick aluminum foils is unacceptable.

Radiation exposure in the horizontal plane near the foils is very high. The drive mechanism for moving the foils into and out from the beam has therefore been located well above this beam plane (see Fig. 2).

Dicronite dry lubrication, which consists of a very thin layer of tungsten applied to the metal surface by high velocity spraying will be applied to all moving parts. Dicronite is a promising dry lubricant for use in high radiation areas. The friction coefficient is two times lower than for graphite.

The position of the foil assemblies will be measured with commercially available linear variable differential transformers using ceramic insulation. The drive mechanism is activated with a standard drive motor located in a shielded area in the upper tunnel; the motor can be replaced easily. Air motors with dicronite lubrication are being considered as an alternative.

The spectrum analyzer is constructed in such a way that the entire assembly can be lifted out of the vacuum housing in a vertical direction by opening one 12-inch fast-disconnect flange.

This instrument is expected to function properly after exposure to a radiation of 10^{12} ergs/gram.

Beam Profile Monitors

The beam profile can be observed satisfactorily with conventional zinc sulfide screens placed in the beam at an angle of 45 degrees. A screen is made by spraying zinc sulfide on a one mil-thick aluminum foil. The major drawback of the screen is the limited life when used in a beam of high current density.

Replacement of screens is difficult in the radiation environment in the switchyard. One approach to this problem was the construction of a carrousel with 48 zinc sulfide screens that may be used in the beam one after another (see Fig. 3). The carrousel may be replaced after all the 48 screens have been used by opening one 12-inch fast-disconnect flange. One carrousel is expected to provide adequate screens for several months of operation.

A different approach for the construction of a profile monitor uses the Cerenkov light from a cell filled with argon at atmospheric pressure. The Cerenkov light is emitted in a cone of 48 milliradians and is observed from above by reflection from a 2-mil-thick polished aluminum mirror in the beam. The optical system is set up to observe one part of the light cone. A reference mark will be provided by four glowing filaments built into the cell. The retractable cell causes considerable multiple scattering as a result of the 5×10^{-3} radiation lengths of material which it presents to the beam.

The light from both monitors will be observed by a vidicon tube with a face plate of non-browning glass placed in an alcove in the upper tunnel (see Fig. 1a). The light is observed in the vertical direction, through a non-browning vacuum window. The window is located at the end of a vertical extension to the vacuum chamber in between 2 removable shielding blocks.

Position Monitors

The primary position monitor is a microwave cavity in which the beam excites a TE_{012} mode. This non-intercepting monitor is very suitable for use at a high level of radiation exposure. The maximum aperture that could be obtained with this cavity is 2 inches in diameter. A part of the electronics associated with the cavity is located in the alcove.

An additional position monitor uses synchrotron light. Synchrotron light is emitted in the forward direction by the electrons when deflected in the quadrupoles and in the bending magnets. The location of the beam in these magnets will be detected by observing the light after bending magnet B_1 in Fig. 1. The beam position will be referenced with respect to a retractable reference mark in front of B_1. The light can be observed permanently via a metal mirror placed 2 inches away from the beam and a non-browning window.

The synchrotron light intensity is too low to be observed effectively by a vidicon camera. Therefore, provisions are made to install an image orthocon camera located on top of the earth shielding.

Beam Current Monitors

Ferrite transformers are used inside the vacuum. The wires are isolated with fiberglass insulation. The ferrite is expected to work properly in an exposure of 5×10^{11} ergs/gram. A large (3.5-inch) aperture was chosen in order to minimize the interception by the ferrite of the halo around the beam.

Control Computer System

It is important to have a control system in the switchyard that provides flexibility and reproducibility in beam conditions. Beam shutdown periods should be kept to a minimum. The computer system shown schematically in Fig. 4 is being designed with these objectives. Initially it will perform three functions:

Analog Adjustments

The proper current in all magnets and quadrupoles for a beam with a particular momentum will be computed and punched out on cards or tape. The information from the cards will be read into the control computer. The computer, under program control, will send digital information to the regulators in the magnet power supplies where a digital-to-analog converter will transform the digital information to an analog reference voltage. Manual entries into the computer system will allow fine adjustments on each magnet current and will also allow bypassing the computer if it is not working properly. Similar techniques will be used to adjust slit openings, etc.

Scanning of Interlock and Status Signals

About 120 signals from various sources will be scanned every accelerator pulse (1/360 sec) and about 600 signals will be scanned at a slower rate. Any change in the signals being scanned will interrupt the computer and the change will be stored in its memory. The changes will be printed out in proper sequence with additional information such as time, date, etc. The action of the interlock signals does not rely on proper functioning of the computer.

Data Acquisition

All data that determine the conditions of a particular beam can be printed out for record together with auxiliary information.

The 18 bid word computer has adequate capacity to perform at a later date additional functions such as the optimization of beam steering, etc.

Acknowledgement

The work reviewed in this paper contains contributions of several members of the SLAC staff.

Table I

Instrument	Characteristics
Beam Spectrum Analyzer:	Covers a spectrum width of 3.6%. Spectrum resolution = 0.1%. Lowest usable beam pulse current approximately 1 milliamp. Display modes on CRT: a. Average beam spectrum. b. Spectrum of one beam pulse. c. Spectrum behavior over the 2μs beam pulse duration.
Beam Profile Monitors: Zinc sulfide screen changer	48 retractable screens, 5x10 cm or 5x25 cm. Material in beam: 10^{-3} radiation lengths. Observation: Vidicon TV camera. Lowest observable average beam current: 0.02 $\mu A/cm^2$. Spacial resolution: about 0.5 mm
Argon Cerenkov Cell:	15 cm long retractable gas cell. Material in beam: 5.10^{-3} radiation lengths. Observation: Vidicon TV camera. Lowest observable average beam current: 0.01 $\mu A/cm^2$. Spacial resolution: about 1 mm. Maximum allowable beam dimension: 50 mm.
Beam Position Monitors: Microwave Cavity	Horizontal and vertical position. Sensitivity: 10 mv/mm.mA. Resolution in center: 1 mm. Lowest usable beam pulse current: 0.1 milliamp.
Synchrotron Light:	Expected resolution: 1 mm. Lowest observable average beam current: a. With vidicon TV camera: 2 $\mu A/cm^2$. b. With orthocon TV camera: 0.02 $\mu A/cm^2$.
Beam Current Monitor:	Sensitivity: 2 mv/mA. Display: Dynamic pulses on CRT, rise-time 35 n secs Average current: 0.3% accuracy.

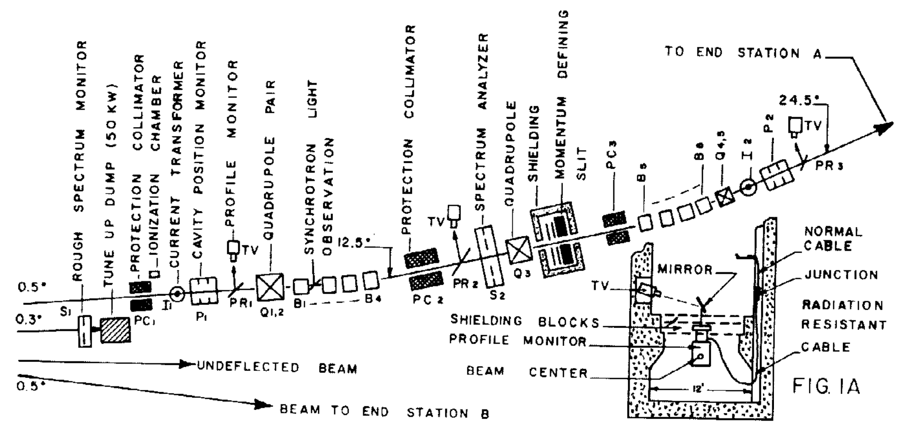

Fig. 1. Instrumentation in beam analyzing channel A.

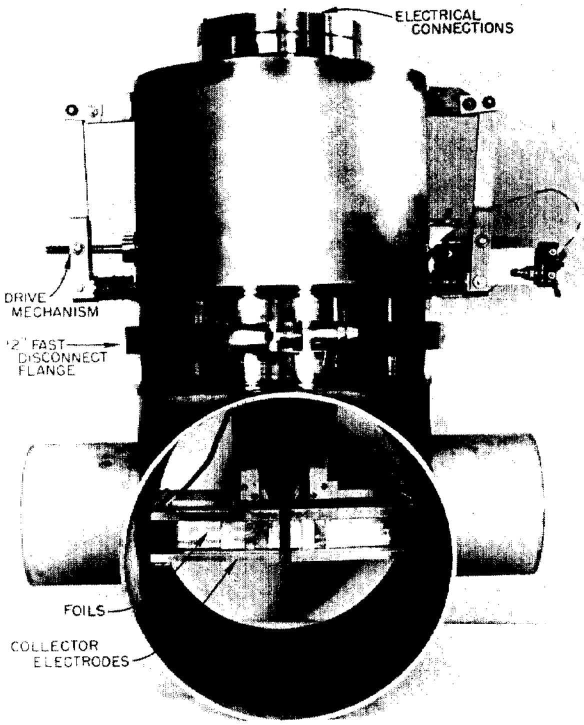

Fig. 2. Prototype spectrum analyzer.

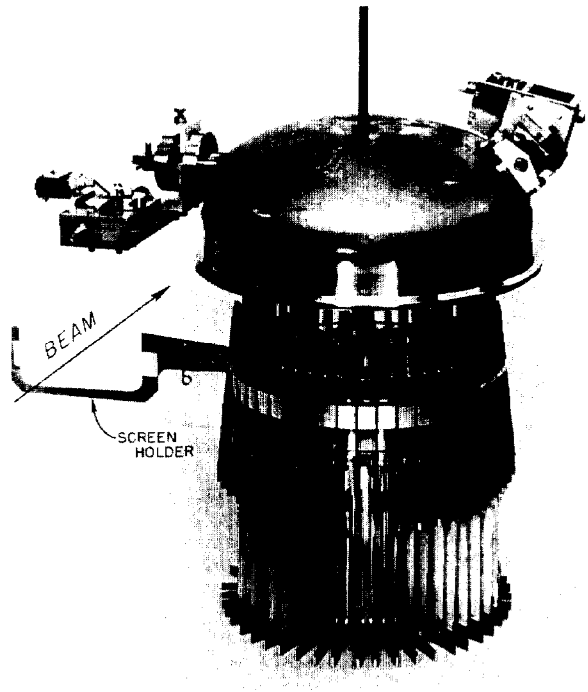

Fig. 3. Prototype screen changer.

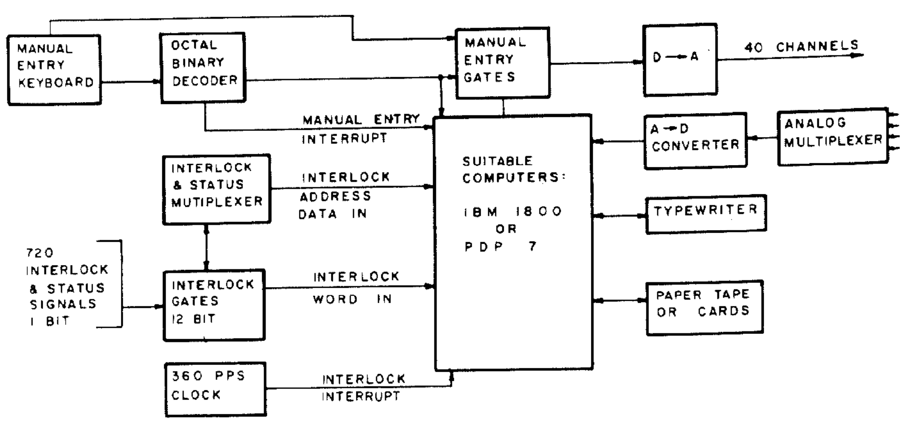

Fig. 4. Control computer system.