DESIGN, CONSTRUCTION, AND EARLY OPERATING EXPERIENCE
OF THE SLAC BEAM SWITCHYARD AND EXPERIMENTAL AREAS*

H. Weidner, E. J. Seppi, J. Harris
Stanford Linear Accelerator Center. Stanford University. Stanford. California

Summary

This paper gives a description of the overall design and construction of the SLAC beam switchyard and experimental areas. The electron optics and transport components of the switchyard are described. The high intensity beams transported by this system present special problems requiring design for radiation resistance, remote-precise location, quick refocusing, and resistance to corrosive environments. These problems and their solution are discussed. The SLAC research yard and its present experimental facilities are discussed. Finally, a design evaluation and summary of early tests and operation experience in this area are presented.

Introduction

The design of the SLAC two-mile accelerator makes it possible to run several experiments simultaneously. The beam switchyard is designed to define the momentum of beams from the accelerator, to transport beams to the experimental areas, and to control high-power beams until their dissipation in targets or beam dumps. A system of pulsed and dc magnets delivers the beam from the accelerator to the various experimental setups on a pulse-to-pulse basis. Two shielded and physically separate end-station buildings are provided for experimental setups. In addition, a large area external to the buildings is available for experimental arrangements involving bubble chamber, spark chamber, and counter experiments using primary and secondary beams. Present arrangements provide for electron, photon, positron, K particle and K meson beams. Three spectrometers are available in end station A. Considerable flexibility has been provided by allowing space for future beams and experimental facilities. Figure 1 shows the arrangement of the structures and experimental setups and shows some of the provisions for future beams and additions. Figure 2 is an aerial view of this research area. The design of systems capable of handling the intense beam available from the accelerator and also using the accelerator's multiple beam flexibility presents numerous problems in optimum instrumentation, mechanical design and physical layout for high-energy systems. Experimentation. Some of these problems have been treated in other papers at this Conference.\(^1,2,3,4\)

The beam momentum resolution is achieved by the use of precisely machined magnets and accurately regulated power supplies controlled by a computer, which monitors a long scan coil in one of the magnets and precise slits. Details are given in other papers.\(^2,5\)

The positioning of magnets, slits, and other components by optical tooling and precise surveying with reference to a laser beam is also discussed.\(^4\) We shall discuss design considerations in the development of the beam switchyard and research area facilities, describe the presently existing system, and give results of the early tests and operation of the systems.

Beam Switchyard Transport System

The beam switchyard contains the beam transport system which delivers the beam from the accelerator to the experimental areas. The arrangement of the beam transport components is shown in Fig. 3, and design criteria for the systems are presented in Table 1. The A-Beam, B-Beam transport systems are nearly identical; therefore, only a description of the A-Beam transport system is given. The beam from the accelerator is directed through the collimator C-1 by the pulsed steering magnets AD 1-4. After being defined in size and position by the collimator the beam enters the pulsed magnets PM 1-5. The doublet Q-10-11 forms a horizontal image of the center of the pulsed magnet at the symmetry quadrupole Q-12 and a vertical image of the center of the pulsed magnet at the front edge of the slit SL-10. The bending magnets B-10-13 disperse the beam for momentum resolution at the slit. The symmetry quadrupole has little effect on the beam vertically because of the small vertical size of the beam resulting from the vertical focus at the symmetry quadrupole; however, in the radial plane the symmetry quadrupole recombines the different momenta, so that after passing through the second set of bending magnets, B-14-17, the beam will be achromatic. The quadrupole doublet Q-13 produces a low-divergence beam by imaging (approximately) the slit to infinity. The final beam then drifts without appreciable spreading to the end station. A small adjustment of the final location and direction of this beam can be made using the horizontal and vertical steering magnets A-10-11. Essentially, the transport system up to this point has traded beam size for divergence, the phase volume being kept constant. If necessary, a doublet can be inserted in the beam prior to the target to achieve a desired spot size or to phase-match the beam to an experiment. The drift space following the doublet must be chosen in conjunction with the gradients of the doublet to give the desired spot size or the proper phase match into the experiment or auxiliary system. In the A-Beam, a target, beam dump and the associated magnets and instruments for generating a photon beam are located in the drift space following Q-13-14. The pair of doublets, Q-13-14 and Q-20-21, can be used for phase matching the electron, and to some extent the photon-beam, to experiments. In the B-Beam, the corresponding drift space, two magnets--bending magnet B-38 and a specially designed magnet B-36, "magnetic slit"--have been placed to distribute the beam into three beam channels.

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The beam switchyard transport system is a permanent part of the accelerator; a serious attempt was made to solve the problems associated with the transport of intense beams discussed above. We will briefly describe the physical layout and some of its components and subsystems design features unique to the beam switchyard. The beam switchyard equipment is located in a 1000-foot-long concrete housing buried under 30 feet of earth. A typical housing cross section is shown in Fig. 4. An underhanging crane riding on rails suspended from the ceiling has access to all equipment. Steel rails for a future shielded car are laid above the shielding ledge. All beam transport equipment is in the lower part of the housing. Shielding may be placed between the two levels to protect cable and electronics in the upper part from radiation during operation and to protect personnel from radioactivity during shutdowns. All equipment can be disconnected and removed from the upper level; all position measurements and adjustments can be made from above, through holes in the shielding.

The primary subsystems and components of the beam switchyard include: the vacuum system, water systems, power distribution system, magnets of various types, instrumentation and control, beam absorbers and targets, and stands of various types. The design of each of these is affected by the considerations discussed above. We will here mention some of the salient features which are not described elsewhere. The vacuum chamber system for the transport system is entirely inorganic; all chambers are aluminum or stainless steel. Weldments with the exception of the vacuum chambers for the pulsed magnet chambers which are discussed below. The remotely replaceable vacuum joints use indium gaskets in a SLAC-designed coupling. Water cooling of the vacuum chamber is provided where beam heating is expected. The vacuum pump system consists of conventional oil diffusion pumps with refrigerated baffles and mechanical backing pumps. The

### Table 1: Parameters For The Transport System Of The SLAC Switchyard

<table>
<thead>
<tr>
<th></th>
<th>System A</th>
<th>System B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>2.5 to 25 GeV</td>
<td>2.5 to 25 GeV</td>
</tr>
<tr>
<td>Acceptance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam Power</td>
<td>0.6 MW max</td>
<td>0.1 MW max</td>
</tr>
<tr>
<td>Rep rate</td>
<td>10 - 360 PPS</td>
<td>10 - 360 PPS</td>
</tr>
<tr>
<td>Pulse Width</td>
<td>0.020-1.7 µsec</td>
<td>0.020-1.7 µsec</td>
</tr>
<tr>
<td>Achromatic</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Problems Associated With Transport Of High-Intensity Beams

Equipment must be protected from direct impingement by the electron beam due to missteering and from lower-energy electrons in the spectrum from the accelerator which will be detected into vacuum chambers walls by the transport systems magnets. For reasonable temperatures, the full beam power will heat most materials faster than they can reject heat. For example, a 600-kW, 20 GeV, 0.6-cm diameter beam resulting from 1.7 µsec long, 50-mA peak current, electron pulses at 360 pulses/sec, will cause a rise of 50°C per pulse at the shower maximum in copper. Materials having low thermal conductivity or high atomic numbers will sustain severe damage after only a few pulses from the accelerator operating at high power. By proper design and water cooling, beam absorbers can be made for these power levels. The shower maximum at 15-20 GeV occurs at 5 to 7 radiation lengths and power absorption near the entrance is comparatively low; hence, windows of reasonable thickness - e.g., 0.060" stainless steel - can be used with water cooling. Also, if the beam strikes a chamber at sufficiently small angle the power deposition density is at reasonable levels.

Beam loss in the transport system causes intense radiation. Continuous beam losses near the slits, collimators, protection collimators located after magnets, and, of course, in the dumps. DeStaebler(11) has estimated the integrated radiation exposure 10 feet from a shielded slit to be about 10^{10} ergs/gm in ten years. This figure was confirmed by Nee(8) whose tests also showed that radiation inside the shielding would be as high as 10^{13} ergs/gm in ten years. Preliminary measurements of radiation in the beam switchyard confirm these results. These intense radiation fields require a careful selection of radiation-resistant materials to avoid early failure of equipment due to radiation damage. In most cases the use of local electronics is prohibited.

Further complication in material selection results from nitric acid formed in the air of the switchyard as a result of the radiation. Calculations and measurements indicate that possibly 50 watts of ionizing power will be absorbed in the air of the beam switchyard when handling a 600 kV beam. This will result in the production of 80 grams of nitric acid per day and can cause serious corrosion problems in critical components.

Equipment which absorbs beam will become radioactive. DeStaebler(11) has estimated that saturation levels would be 10^5 to 10^6 mrem/hr at 5 feet from a material that has absorbed 1 MW of electron beam power over a long period. Repair and maintenance will become difficult at materials which have low thermal conductivity or high atomic numbers. For example, a 600-kW, 20 GeV, 0.6-cm diameter beam resulting from 1.7 µsec long, 50-mA peak current, electron pulses at 360 pulses/sec, will cause a rise of 50°C per pulse at the shower maximum in copper. Materials having low thermal conductivity or high atomic numbers will sustain severe damage after only a few pulses from the accelerator operating at high power. By proper design and water cooling, beam absorbers can be made for these power levels. The shower maximum at 15-20 GeV occurs at 5 to 7 radiation lengths and power absorption near the entrance is comparatively low; hence, windows of reasonable thickness - e.g., 0.060" stainless steel - can be used with water cooling. Also, if the beam strikes a chamber at sufficiently small angle the power deposition density is at reasonable levels.

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accelerator vacuum system operating at \(10^{-7}\) torr is
separated from the switchyard vacuum of \(10^{-4}\) torr by a
differential pumping system including ion pumps, a re-
frigerated baffle and fast-vacuum valves.

Two types of water systems are required, magnet
water, and radioactive water for beam energy absorbers.
The magnet water system is all-copper and stainless
steel. The radioactive water systems are all-stainless
steel and aluminum or copper. The magnet water sys-
tems are so arranged that the piping runs inside the
housing are minimized. Headers in the housing run in
the upper level where they are accessible during shut-
downs and shielded from excessive radiation during op-
eration. All heat exchangers, pumps, surge tanks and
instruments are outside the switchyard. The radioac-
tive water system equipment is shielded. It is so ar-
ranged that leakage of radioactive water will drain into
the switchyard housing where it can be stored until it
has "cooled" and can be disposed of. No provision was
made initially to handle evolved gases.\(^1\) Magnet coils
are potted in radiation-resistant alumina-loaded epoxy,
insulators in the magnet water circuits are alumina.
Pulse-to-pulse switching is done by laminated-core
pulsed magnets. Figure 5 shows a 0.1 pulsed magnet
ready for installation. A ceramic vacuum chamber is
used because eddy current heating makes conducting
materials unsuitable. Some apprehension was felt about
internal charge buildup in ceramics, due to radiation,
so attempts were made to improve the internal and sur-
face conductivity of ceramics. Water-cooled water-cool-
tection-collimators are located throughout the trans-
port system to protect equipment from missteered beams
interlock chain to shut off the accelerator when a pro-
tection-collimator is hit by the beam. Beam instrumenta-
tion is provided to keep track of the beam position,
using room angles of up to 15°, 90° and 180°, respec-
tively. The first positron beam was delivered to End Station B on
September 21, 1966. Since that date, numerous tests and experiments have been per-
formed on the beam switchyard transport system. In addition, several preliminary experiments\(^9,10,11\) of a survey nature have been completed and others are
in progress. In general the operation of the system has
been exceedingly satisfactory. The maximum beam power which
has been transported through the system is 170 kW. It
is anticipated that the power level will soon be more
than doubled. Multiple beams of various energies, cur-
rents, pulse lengths, and repetition rates are now rou-
tinely delivered to experimenters in the end stations.

Early Operating Experience And Design Evaluation

The first electron beam was delivered through the
A-Beam transport system and the End Station A to
beam dump east on September 21, 1966. Since that
date, numerous tests and experiments have been per-
formed on the beam switchyard transport system. In addi-
tion, several preliminary experiments\(^9,10,11\) of a survey nature have been completed and others are
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Research Yard

A level paved area some 12 acres in area and sur-
rounded by natural and manmade dikes up to 75 feet
high forms the experimental area at the east end of the
beam switchyard. Two major permanent buildings serve
as housings for some of the major pieces of scientific
apparatus. End Station A is a 25,000-square-foot
shielding enclosure with three large spectrometers hav-
ing maximum momentum acceptances of 20 GeV/c, 8
GeV/c and 1.6 GeV/c mounted within it on a common
axis. These spectrometers and their shielding enclo-
\(9,10,11\) of a survey nature have been completed and others are
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Electron beam spot sizes of one millimeter diameter
have been achieved. Various early checks on the mo-
mentum calibration of the transport system have been
made by comparing the A and B transport systems, by
using a quartz meter and Faraday cup, by comparing
the end station spectrometer with the A transport sys-
tem, and by calorimeter measurements. Although
much more refined tests are required, the early tests indicate that the beam switchyard system satisfies the design criteria for momentum calibration and resolution given in Table 1. Early experimental studies of beam optics and beam isochronism indicate that the transport system behaves in agreement with the predictions of the SLAC TRANSPORT(12) computer program which was used to design the system. However, optics tests indicate that the transport system solid-angle acceptance is less than expected. This effect is not clearly understood, but is probably the result of misalignment of components and certain known differences in the bending magnets of the system. Since the emittance phase space of the accelerator is much smaller than the achieved acceptance of the beam switchyard transport system, there is no difficulty in delivering the beam to the experimental areas.

Operating experience to date has emphasized the need for high reliability of equipment. Problems which hamper delivery of the beam are the usual ones of getting such a system to operate—e.g., interlock faults, power supply failures, slit drive failure, burning of TV camera lenses, vacuum failure, personnel protection system failure, etc. Since the initial turn-on, equipment has been damaged by the electron beam on two occasions: (i) a spring in a vacuum quick disconnect was overheated resulting in loss of temper and a vacuum leak and (ii) a vacuum quick disconnect was overheated causing the indium seal to melt, again resulting in a vacuum leak. At the power levels run to date, usually about 1 - 10 kW, no serious radiation or radioactivity problems have been encountered. The radioactivity induced in the radioactive water systems is already sufficient to restrict system ventilation during operation. Some of the cooling water becomes intensely radioactive, but most of the activity is short-lived (O15, C11). Be7 is produced in the water and removed by the demineralizers. Demineralizers have been found to have about 100 microcuries of activity when depleted. Equipment close to the beam is becoming radioactive but remote operations have not yet been necessary. It is too early to evaluate the radiation resistance of special components.

Acknowledgments

The authors are indebted to the large numbers of people at SLAC, from other laboratories, and from commercial firms who assisted in this complex undertaking. Special recognition is due Dr. R. Taylor, who produced the switchyard criteria, and D. A. G. Neet, who was responsible for the instrumentation and control systems, but whose interests were far wider.

References

1. D. R. Walz, et al., Paper II-3 of this Conference.
5. S. K. Howry, et al., Paper I-10 of this Conference.
FIG. 3--Layout of beam switchyard components.

FIG. 4--Typical cross-section of switchyard housing.

FIG. 5--0.1° pulsed magnet.

FIG. 6--8, 20, 1.6 GeV spectrometers in EndStation

FIG. 7--Momentum spectrum of 6-GeV electron bear