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DESIGN PROBLEMS IN THE BEAM SWITCHYARD OF THE STANFORD LINEAR ACCELERATOR*

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SUMMARY

A discussion is presented on design problems encountered in the Beam Switchyard area of the two-mile electron accelerator due to the requirement of a maximum average beam power of 2 megawatts. A description is given of the various aspects of beam interception.

The paper describes the general solution to these problems, particularly with respect to the construction of beam monitors and beam protection equipment.

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I. INTRODUCTION

The handling of electron beams of high average power raises serious design problems when the electrons are intercepted. Interception can happen deliberately whenever the beam properties have to be defined, or accidentally because some failure has caused the beam to be misdirected.

These problems have two distinct aspects, one involving heat transfer and thermal fatigue problems, and the other involving secondary effects such as radiation exposure, induced radioactivity, formation of corroding gases, limited access to equipment, etc. This paper deals primarily with design problems in the last group.

II. BEAM INTERCEPTION IN THE SWITCHYARD

The Switchyard[1] consists of two momentum-analyzing beam transport systems[2] serving two target areas, A and B.[3] A schematic component layout of the Switchyard is shown in Fig. 1 and we will give first a brief description of the areas in which interception is most likely to occur in the Switchyard.

Beam interception by the collimator C-0 and the slits SL-10, SL-30 will be high because of the precision required in position and momentum, respectively. The actual absorption will depend largely on the shape, the stability, and the spectrum of the beam from the accelerator. The slits and collimators[4] must be able to absorb the full 2-MW beam power for long periods of time.

The beam-absorbing devices in the Switchyard have been made 25 to 30 radiation lengths thick in the beam direction. More than 99.95% of the shower should be absorbed in this thickness of material. The actual absorption will be much lower as a result of the leakage through the gaps. The induced radioactivity and radiation exposure in these areas will, therefore, be very high.

Figure 1 shows two 60-kW beam dumps. A temporary dump, D-2, is placed in the straight-ahead beam for initial accelerator startup and for beam steering adjustments through the collimator. A permanent accelerator tune-up dump, D-10, is located between the straight-ahead beam and Beam A. The radiation from these dumps should be relatively low.

A photon beam is built inside the switchyard housing at the end of channel A (radiator TC-20, dump magnets B-23 to 26, and a 2-MW underground dump[4].) Several kilowatts of low-energy particles can be absorbed by the water-cooled vacuum system before the dump, and will be the cause of high radiation in this area. The 20 protection collimators (20-kW) shown in Fig. 1 serve to protect equipment and to localize beam interception in case of beam steering errors. Some of the protection collimators (PC-10, -18, -11, -30, -31) also absorb the low-energy spectrum tail of the beam, while others (PC-1, -2, -9, -8, -7, -3, -4) also absorb the low-energy particles leaking through the main collimator. The radiation around several of these protection collimators will be high.

III. DESIGN LIMITATIONS

An excellent discussion on this subject has been given by R. E. Taylor.[5] We would like to make some additional observations.

A. Radiation Exposure

The beam-absorbing devices described in Section II produce high radiation areas at many locations in the Switchyard as a result of the fast neutrons which are produced and because of the tail of the electromagnetic shower. Measurements were made of the radiation exposure around a protection collimator with the low-power 1-BeV beam of Stanford University's Mark III accelerator. By extrapolation, it was found that the angular distribution of a 10-year radiation exposure calculated at a distance of 1 meter from a protection collimator absorbing 20 kW is:

Forward direction	6×10^{11} ergs/gram
Sideways	1×10^{11} ergs/gram
Backward direction	6×10^{10} ergs/gram

The contribution in these figures due to isotropic fast neutrons = 4×10^{10} ergs/gram

These results were used to estimate the radiation exposure integrated over a ten-year operation period around the various beam absorbers in the Switchyard.[6]

Typical figures for the Switchyard housing are 10^{9} ergs/gram in the upper tunnel (see Fig. 2), 10^{11}-10^{12} ergs/gram around instruments and magnets, and 10^{13}-10^{14} ergs/gram around some of the most critical locations. The exposure is so high that a careful selection of construction materials and design techniques is necessary.

B. Corrosive Gases

Oxides of nitrogen are formed in air if subjected to radiation.[7] The nitrous oxide combines with moisture in the air to form the highly corrosive nitric acid (HNO_3), which will deposit on metal surfaces, electrical contacts, etc. Calculations by G. Rogers[8] indicate that the concentration of nitric acid may give difficulty. The most straightforward solution seems to be a good ventilation system. However, because of induced radioactivity of dust in the air, it is intended to seal off the Switchyard housing during operation at high beam intensity. We hope that the nitric acid production will be localized to the high-power devices. The extent of the corrosion is not easy to calculate.

C. Induced Radioactivity and Limited Access

The induced radioactivity may build up to saturation levels of 10 rad/hr or more at some locations. Personnel access to the housing will be extremely limited. Much extra expenditure was incurred in keeping auxiliary equipment such as power supplies, vacuum pumps, and electronics outside the housing to permit servicing.

IV. SOLUTIONS PLANNED IN THE SWITCHYARD

A. General Aspects

Figure 2 is a typical example of an instrumentation area in the Switchyard housing. An important solution to the problems mentioned in the previous section is the double tunnel structure with a removable shielding floor between the lower and the upper sections. Equipment can be brought in and out through the upper tunnel while keeping personnel relatively well shielded from induced radioactivity from the many hot spots.

The construction materials and components have been carefully selected in view of the radiation exposure and the possible corrosion by nitric acid. The components most affected by these limitations are optical parts, gauges, cables, plugs, switches, small motors, and lubricants. The proper choice of these components is not inconsequential, because the costs increase considerably with the required degree of radiation resistance. Very often it is difficult to find suitable solutions at all, and compromises must be made. Table I lists some of the radiation-resistant components selected for the Switchyard.

The radiation-resistant cable will be used in the lower tunnel only. Such cables present problems of leakage resistance, inhomogeneity, stiffness, suitable terminations, etc.

In order to avoid corrosion by nitric acid, we will use gold-plated electrical contacts. A study is being made of radiation- and NHO_3-resistant coatings for support structures, cable trays, etc. The high temperature paint listed in Table I seems good but needs baking.

We plan to make it possible for a person in the upper tunnel to replace instruments in the lower tunnel (see Fig. 2). For this purpose, special connectors have been developed for cables (see Fig. 4), for cooling water lines, and for the vacuum system[9] (see Figs. 4 and 5). We tried to reduce the time required for connection and disconnection by making a simple design and a good guiding system. The 12-pin plug in Fig. 4 was purposely made big and rigid for easy remote handling.

Simplified special tools are being designed to operate these connectors from the upper tunnel. It is believed that such special tools are more useful than the robots discussed in other papers.[10]

In the future, the induced radioactivity may become excessive for personnel in the upper tunnel. At that time, the special tools may have to be operated from a shielded tool car. This car will probably have a thick viewing window in the bottom and use in addition a TV camera. The car will be movable on rails which are already installed.

It is important to include the criteria for remote operations early in the design plans. In a few cases (ionization chambers, thermometers) we used normal connectors with enough play in the cables and the gas line to allow the instrument to be lifted into the upper tunnel and disconnected there. The ionization chambers (Section V) are fixed to a special frame which is normally hooked on to the protection collimator (Fig. 2), and which can be lifted easily.

B. Instrument Design Aspects

For some of the instruments it was necessary to place the electronics close to the beam monitor. For this purpose we have provided alcoves in the wall at several locations in the Switchyard.

The alcove in Fig. 2 houses microwave electronics associated with the beam position monitor and the Vidicon TV camera, which uses mirror optics for observing the Cerenkov light from the profile monitor.[11] (Mirror optics is used to avoid the need for non-browning lenses.)

The equipment is well shielded in the alcove from radiation and mechanical damage. Nitric acid can be kept out of the alcove, if necessary, by closing it off and releasing air inside.

The mirror box in Fig. 2 uses non-radiation-resistant motors for remote adjustment of the mirror. The box is placed between two shielding blocks in order to shield it from direct radiation by the protection collimator. It is supported from the monitor and can be lifted out easily. In other locations we have taken advantage of the shielding floor in a similar way to protect viewing ports, etc.

The instruments are placed on a common support that can be adjusted for alignment from the upper tunnel. Alignment targets are placed on the support and on some individual instruments that need critical adjustment. Conventional alignment techniques are used from the upper tunnel.

The design of instruments for the Switchyard has been discussed in Ref. 12. Figures 3,4, and 5 give illustrations of some still incomplete instruments. These instruments are constructed with all essential parts mounted on a 12-inch, fast-disconnect vacuum flange and can be lifted vertically with relative ease out of the housing for servicing or replacement. The two clamps of a 12-inch flange must be rotated 120° to disconnect the instrument. Guiding pins for this lifting operation are visible in Fig. 5, showing the spectrum analyser (S-11, S-3, in Fig. 1).

Figure 3 shows a zinc sulfide screen profile monitor with 48 screens lifted out of the housing. The screens can be observed with the same TV setup as shown in Fig. 2. The Cerenkov profile monitor is shown in Fig. 4. Both types profile monitors are used in the Switchyard because of the particular advantages of each type: The Cerenkov cell is not quickly damaged when exposed to the beam, while the zinc sulfide screen is damaged after exposure to about 10 $\mu A \cdot hr/cm^2$. The Cerenkov monitor, on the other hand, places $5 \cdot 10^{-3}$ radiation length material into the beam, the screens only 1.2×10^{-3}. The screens are more useful at locations where the beam cross section is large (PR-11, -31, -34 in Fig. 1).

The Cerenkov cell visible in Fig. 4 is normally kept out of the beam path by the weight shown. This picture also shows a male part of a 6-inch, in-line fast-disconnect flange with the guiding plate.

All instruments are now under construction, and installation should be completed early in 1966.

V. POWER DEPOSITION IN BEAM ABSORTION AND EQUIPMENT PROTECTION

The beam from the accelerator may have a diameter of 3 mm or even less. The power deposit at shower maximum for a 2-MW beam with a 3-mm diameter absorbed in aluminum is 16-kW/cm^3 and 190 kW/cm^3 in copper.[13]

These high figures justify the choice of low-Z materials for the 2-MW absorbing devices described in Ref. 4. Such high values of power deposition present serious hazards to the stainless steel vacuum chambers and to instruments. For example, the local stresses in stainless steel exceed the design limits if only two or three beam pulses, as described above, pass through the chamber wall. Vacuum leaks may develop quickly in this way, particularly when the shower maximum happens to occur in one of the vacuum flanges using indium seals.

Interception of the beam may cause damage to the ferrite of the current transformer and other critical instrument parts. These hazards are prevented largely by the protection collimators, which are placed in locations where they shadow groups of instruments, magnet coils, and vacuum components as much as possible (see Figs. 1 and 2). In some locations the protection collimators will absorb low-energy tails which otherwise would gradually heat up the chamber and the instruments.

Two ionization chambers are located close to each protection collimator (see Fig. 2) and provide a "beam shut-off signal" in case of excessive power absorption. The signal from the ionization chambers will be calibrated against the beam power absorbed in each protection collimator and gives a response within a beam pulse period (2.7 milliseconds).

Additional equipment protection is provided by several thermometers at critical locations in the vacuum system and by differential current measurements.

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TABLE I

Radiation-Resistant Components for the Switchyard

Component	Description	Safe Exposure Levels (ergs/gram)
12-pin plug	SLAC design; Al_2O_3 insulation, gold-plated contacts, chrome-plated housing*	10^{14}
Type-N coaxial plug	Specially ordered with Al_2O_3 insulation, gold-plated contacts,* chrome-plated housing.*	10^{14}
Wire	Al_2O_3 coated wire (Permaluster).	10^{14}
	Ceramic beads.	10^{14}
	Mica asbestos insulation (Micatemp).	10^{13}
Coaxial cable	RG 81-u(50-ohm) magnesium oxide insulation.	10^{14}
	Specially ordered equivalents of RG 58/214/22 with S994 fiberglass insulation.	10^{12} - 10^{13}
Micro-switches	Ceramic body, sealed,* gold-plated contacts*	10^{14}
Viewing Windows	Non-browning Corning - 7940 fused silica 100% pure.	10^{12}
Plane and spherical mirrors	Chrome plated;* probably coated with titanium dioxide.	
Vacuum feedthroughs	Al_2O_3	10^{14}
Vacuum Seals	Indium or metal	10^{14}
Drive Motors	Standard type. Made by SLAC as plug-in units	10^{9}
Water Connectors	All metal, fast-disconnect	10^{13}
Position pickup	Standard encoder. (Easy replacement mounting.)	5×10^{9}
	LVDT ceramic insulation.	10^{13}
Magnet Coils	Alumina - filled epoxy - (see Ref. 14)	5×10^{12}
Lubrication	Dry film lubrication. Fusion bonded film of tungsten (Dicronite).	10^{14}
Paints	High temperature paint* (Sperex VHT)	10^{13}

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*Required because of nitric acid atmosphere.