TN-63-47
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June, 1963

CONSIDERATIONS CONCERNING BEAM SWITCHYARD INSTRUMENTATION AND CONTROL SYSTEM

I. INTRODUCTION

The two-mile accelerator is expected to produce, in Stage I, 20 Bev beam pulses at a rate of 360 pps. The pulses are 0.1 to 2.1 μsec long, and the peak current is 50 ma. The 360 pulses will be divided in the beam switchyard among the three beams (see Fig. 1), so as to be able to use the accelerator for three simultaneous experiments. The three beams may have the same or different energies.

The beam switchyard contains all instrumentation and equipment required to establish the beams, to analyze their energy, to focus them, and to deliver them with sufficient shielding and separation into the experimental end stations.

Figure 1 shows the equipment planned at this time, and indicates schematically how we plan to locate auxiliary equipment in the switchyard building on top of the earth shielding in order to get away from the high radiation levels in the beam switchyard tunnel. The auxiliary equipment includes the power supplies for magnets, vacuum equipment, amplifiers and other electronic circuits, etc.

The purpose of this note is to review briefly all equipment involved in the beam switchyard and to give an outline of how we propose to build a suitable instrumentation and control center for this complicated area.

II. SCOPE OF THE INSTRUMENTATION AND CONTROL SYSTEM

A. Summary

The instrumentation and control system for the beam switchyard area is concerned with the vacuum system; the distribution of beam pulses; the setting of magnet power supplies and measurement of magnetic fields;the beam steering and monitoring; the positioning devices for slits, collimators, etc.; a great number of equipment protection devices; and the interlock systems.

The great number of instruments and the apparatus involved for three beams (about 120 pieces in the beam switchyard and about 50 in the switchyard building) and the high power of the beams allow very little room for operation on a trial and error basis. A simple and well thought out control system must be devised for the beam switchyard.

In this Section we will review the beam switchyard equipment. No reference will be made in this note to instrumentation involved with the mechanical alignment of the equipment.

B. Vacuum System

It has been decided to continue the accelerator vacuum system through the beam switchyard. The vacuum pipes will be closed in the end stations by thin vacuum windows.

Electrical breakdown requires a vacuum of 10^{-6} torr in the accelerator proper, while scattering in the beam switchyard requires only 10^{-4} torr. A differential pumping system at the beginning of the switchyard will match both areas. The ten vacuum pumps are located in the switchyard building.

A number of vacuum gauges and vacuum valves for servicing and replacing internal targets are placed along the pipes in the beam switchyard. Fast acting vacuum valves are provided in each pipe (see Fig. 1) to close off this section quickly in case of rupture of the thin window at the end of the pipe.

The vacuum pipe diameter through most of the beam switchyard is 6 inches; before the collimator it is 2 inches; and near the center quadrupole lenses (Q_{12}) and (Q_{32}), 12 inches (see Fig. 1).

The vacuum pumps will be started up locally. Vacuum gauge readings and the position of the valves need to be easily accessible to the operator. A number of vacuum interlocks are required, including one that prevents the beam from burning holes in closed valves.

C. The Undeflected Beam up to the Pulsed Magnet

The main element in this area is the collimator (C_1). It will be built with an adjustable opening. This collimator is a very complicated device and probably will require much instrumentation associated with the adjustable opening and with cooling and radiation interlocks.

Beam position monitors (P_1, P_2) and intensity monitors (I_1, I_2) are placed on both sides of the collimator. The intensity difference $(I_2 - I_1)$ shows the beam percentage scraped off by the collimator. The beam position indicators are used to adjust the beam steering. Since the steering is energy dependent, a set of pulsed steering coils (one horizontal and one vertical) is provided, so that each of the three beams of different energy can be adjusted independently. A set of dc steering coils, covering one energy only, is provided as spare.

Since both the position and the angle of the beam through the collimator have to be corrected, there are in fact two sets of steering coils. The second set is located in the last free space along the accelerator.

The current supplies for pulsed steering are fairly complex since they have to provide current pulses of adjustable magnitude covering both polarities for each of the three beams.

The signals from the beam intensity and beam position monitors in this area have to be gated in order to display separately the readings for the three interlaced beams.

A beam shape indicator may have to be put in front of the collimator to study beam symmetry when required.

D. The Pulsed Magnet (Ref. 1)

The pulsed magnet deflects x beam pulses over 0.5° into beam channel A and z pulses into beam channel B. The y pulses for the neutrino area pass undisturbed through the gap of this magnet. The pulsed magnet will be constructed in five one-meter long sections. An adjustable supply (capacitor resonant discharge type) for each section provides x positive and z negative current pulses for the magnet. A degaussing system ensures that the y undeflected pulses are not affected by remanent magnetism.

The use of five sections has advantages from an operational point of view. When one section fails, it will be possible within energy limits to continue with four sections.

For low energies it will be advantageous to use fewer than five sections in order to maintain sufficient voltage across the ignitrons for reliable firing. When both low and high energies are used, the number of active sections has to be changed on a pulse-to-pulse basis.

The control and interlock circuits for this magnet will be fairly complicated.

E. Pulse Pattern Selection

It is desirable to have great flexibility in the selection of the pulse pattern for x, y and z for the three beams. The z-rate in beam channel B for secondary particle production may be, for example, as low as 1 pulse in 2 seconds if a big bubble chamber is used. In that case it may also be desirable to suppress the beam pulses in the other beams during the sensitive time of the chamber (10 msec before and 10 msec after the trigger pulse) so as to reduce background tracks.

The pulse patterns have to be applied to all pulsed equipment in the beam switchyard and to the trigger system for the klystrons and the injector, etc. (For a description of the proposed system, see Ref. 2.)

F. Deflected Beams

The two deflected beams are in principle the same. Beam A (24°) is designed for 2% energy spread and 0.1% resolution; beam B (12°), for 6% energy spread and 0.3% resolution.

For beam A the pulsed magnet deflects the x beam pulses into the dc zero-dispersion magnet deflection system.[3] The system consists of a quadrupole pair Q_{10-11}, a 12° bending magnet B_{10-13} (four three-meter-long sections), a horizontally focusing center quadrupole Q_{12} (field lens), a second 12° bending magnet B_{14-17} and the second quadrupole pair Q_{12-13}. The eight bending magnet sections are all in series on separate supplies with a common reference source. The required precision is 0.01%. We are considering the placing of a ninth magnet section close to the supplies in the switchyard building in series with the other eight sections in order to measure the magnetic field in the center of the gap and to provide a signal for the regulator feedback loop. This solution eliminates the need for probes able to stand high radiation fields.

The purpose of this magnet system is to bend the beam enough to allow space for experimentation and shielding and to define the energy and energy spread of the beam. The beam energy may be defined accurately by measurement of the magnetic field B with an NMR gaussmeter (the deflection angle α and the effective length of the magnet being known precisely).

The energy spread of the beam is defined by the position and the adjustable opening of the energy defining slit (SL_{10}). With respect to instrumentation, the same considerations as mentioned for the collimator C_1 apply for the slit. Extra instrumentation will be needed if the slit is to be a combination of a mechanical and a magnetic slit.[4]

A beam energy spectrum analyzer (S_{11}) (see Ref. 5) in front of the slit shows the beam intensity distribution across the horizontally analyzed beam on a CRT. This spectrum is the primary reference for the adjustment of the accelerator controls (see also Sect. III.C). This analyzer covers only ±1.8% $\Delta E/E$. For that reason we plan a very simple spectrum analyzer (S_{10}) in the 0.5° beam to be used especially during set-up or when studying excessive beam instabilities. This monitor will work mainly as a rough but sensitive energy deviation indicator and may cover ± 8% $\Delta E/E$.

In order to get the beam properly through the magnet deflection system,* we need sufficient beam monitors for the current (I_{10-13}), the position (P_{10-12}) and the beam shape (PR_{10-13}). The position and intensity monitors

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*A delicate procedure in view of the high beam power (which will be dealt with in a later note).

should provide continuous readings and should be nonintercepting. The shape indicator may be intercepting and moved into the beam only during set-up.

Small collimators (C_{10-15}) are planned at this time to protect the coil insulation of the magnets and quadrupoles against radiation produced earlier in the beam and, particularly, against malfunctioning of beam deflecting elements that would deliver a full beam pulse into the insulation. In the latter case an equipment radiation protection system (see II.L) will stop the succeeding beam pulse and give an alarm. Collimator C_{11} serves also as a protective beam stopper in case beam A is not used.

A target T_{10}, which is to follow magnet B_{11}, is planned to provide a 6° γ beam.

A set of steering coils (A_{10-11}) at the end of the magnet deflection system is provided to correct the angle of the parallel beam.

G. Beam A Before Entering End Station A (area after a-a' in Fig. 1)

The purpose of end station A is to do electron, positron* and γ-ray** experiments. **Several solutions to the problem of providing versatile beam layout for this area are presently under study.**

One of the problems is the dumping of the high-power electron beam after using a γ target. The original idea was to deflect this beam by a simple dumping magnet into a beam dump (shown in the upper part of Fig.1). The current thought is to make use of this beam instead of dumping it. One of these schemes is included in Fig. 1. We will not discuss the alternative schemes here, but will mention that much instrumentation will be required in this area.

H. Beam B Before Entering End Station B (area after b-b' in Fig. 1)

This end station is planned for secondary particle production. A second pulsed magnet is being considered to serve three rotating targets.

I. Straight-On Neutrino Beam

Very little work has been done so far on this beam.

A $1/3^{\circ}$ vertical bending magnet (B_{3-4}) corrects for the $1/3^{\circ}$ downward slope of the accelerator. It is hoped that by making a special but simple spectrum monitor, this bending magnet can be used to measure the energy of the beam. If this is not possible, the energy of this beam must be measured in one of the deflected beams, which will entail complicated calibration procedures.

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*By putting a radiator somewhere along the accelerator, changing the accelerator phase after this point by 180° and reversing the polarity of all magnets. [See Nuclear Instr. 15, 45-50 (1962).]

**Using a thin target.

J. Power Supplies for Magnets

The power supplies and detailed status monitoring for all magnets will be located in the switchyard building. All power supplies are adjustable over a wide range and have electronic regulators, some of them with a precision as high as 0.01%.

K. Cooling Systems

Magnets, collimators and slits require cooling water. Some of this cooling water will be radioactive. Instrumentation such as flow meters, thermostats and radiation monitors are needed, as well as controls for the pumps and the heat exchangers. Most of this equipment will be located in the switchyard building.

L. Equipment Radiation Protection

The high power electron beam is very destructive in nature and creates high radiation levels in the beam switchyard, particularly around the collimators and slits. For this reason, and also since access to the beam switchyard is excluded during operation and limited after shutdown, it is planned to locate all auxiliary equipment in the switchyard building. In the beam switchyard a reliable interlock system is needed to protect equipment from being melted or otherwise damaged by radiation. The use of signals from surface radiation monitors and differential signals from either beam intensity or beam position monitors on both sides of the bending magnets are under consideration for the radiation interlocks.

A compromise must be found between the number of interlocks and their actuation levels, or it will be almost impossible to get the beams through to the end stations. Particular difficulties would be encountered during setting-up periods. The equipment protection system is an extensive subject, which will be considered in a later note.

M. Personnel Protection*

Sufficient instrumentation will be provided to protect people from radiation exposure, high voltage, etc.

N. Cranes and TV Sets

Cranes will be available in the yard for installing equipment. The equipping of the cranes with remote handling (hot cell) tools and the use of closed circuit TV sets for work at hot spots after shutdown are under consideration.

O. Communications

Personnel communication facilities will be provided between the beam switchyard

*This topic is mentioned in this note for completeness only. Radiation survey and personnel protection are under study by M. Whitehead.

building, the beam switchyard tunnel, the central control room, the accelerator and the end stations.

We plan to use the following systems.

a. Telephones

b. Public address system, operated from the central control room

c. Intercommunication system

d. Service communication channels using headsets

During the initial start-up period of the accelerator (see Section IV.B) it may be desirable to provide visual communication between the central control room and the beam switchyard building using two wide-angle closed circuit TV sets. In this way the main operator will be able to follow visually, to a certain extent, the activities in the switchyard building and vice versa.

III. SOME REMARKS ON BEAM MONITORING INSTRUMENTATION

A. Intensity and Position

The beam intensity and position monitors[6] before the collimator can be of the same type (1-inch aperture, magnetic induction) as those developed for the accelerator. The precision, however, should be about five times better for the intensity monitor (1% instead of 5%).

The monitors should work for peak currents of 1 ma. or lower. The beam monitors after the collimator will need larger apertures (at least 2 inch), and will require extra attention since the radiation levels in the beam switchyard are considerably higher.

For the beam intensity in this area we may use a monitor similar to the Ferrite induction transformers developed by T. de Parry for the Z.G.S.* This transformer has a four-in. aperture, the sensitivity is 7 volts/amp, the frequency response 40 mc.

The construction of nonintercepting beam position monitors with a large aperture is a more difficult problem. Magnetic induction coils are not sensitive enough for apertures larger than 2 inches, and sensitive electrostatic electrodes have limitations because of charge pick-up by scattered electrons.

We plan to consider two other techniques for beam position monitoring.

a. Microwave cavities, either a TM_{11} structure[7] or the 4 resonant cavity type.[8]

b. Residual gas detector (see beam shape)

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*Private communication.

B. Beam Shape

We have two ideas in mind to monitor the beam shape.

a. A screen made of a grid of thin impure quartz wire, looking at the fluoresence with a TV set and some highly polished 45° metal mirrors. The lenses of the TV camera should be made of the non-browning glass used in hot cells, to avoid blackening.

b. A residual gas detector. The idea is to allow locally into the vacuum chamber a gas with high ionization light efficiency at a pressure of about 10^{-3} torr. We may also use the fluorescence of a gas. A special pump will be required to control this gas pressure.

If sufficient light is produced, the beam shape and position may be observed when looking with a TV set perpendicularly from two sides. It is not known at present whether the high energy electrons will produce enough ionization. If enough light were produced, the gas pressure might be adjusted for minimization of scattering.

C. Energy Spectrum Analyzers

The analyzer described in Ref. 5 is built in two halves, which can be retracted sideways as much as the width of the slit opening so as to avoid scattering in the useful part of the beam by the foils. In this retracted position the monitor still provides information on the stability of the accelerator.

The energy range covered by this analyzer is 3.6% (resolution 0.1%) and the minimum intensity for which it is expected to work properly is a peak current of 1 ma. Since the above figures may be insufficient during beam set-up periods, we plan (as mentioned above) to develop a simple monitor covering 16% $\Delta E/E$, which will work at lower intensities. (Peak currents lower than 100 μa) The spectrum display for this monitor may be simplified to 16 lamps which show in percent how much the energy delivered by the accelerator deviates (+ or -) with respect to the desired value set by the first bending magnet. These signals might also be used to take out or add klystrons automatically so as to limit beam dumping.

D. Positron Beams

The conversion efficiency from electrons to positrons is 10^{-4} to 10^{-3}. The positron beam intensity, therefore, will be so low as to make it difficult to use nonintercepting beam monitors. Consequently, for setting up the positron beam it will probably be necessary to use intercepting beam monitors with greater sensitivity (ionization chamber or multiplate secondary emission monitor). During the experiment these monitors should be taken out, and the beam stability should be watched by special techniques.

IV. LAYOUT CONCEPT FOR CONTROL SYSTEM

A. General

The following three points play an important role in the construction and cost of a practical control system for the beam switchyard.

1. The amount of equipment and the large area over which it is spread

2. The high beam power and high radiation levels which put severe limitations on the construction materials that can be used

3. The fact that the beam switchyard control system cannot be considered independent of the accelerator and, in fact, is part of it

B. Location of the Control System

The logical and most convenient location for all controls is in the central control room of the accelerator. This control room is located about 1000 feet from the end of the accelerator (cable length, 1500 feet). Because of this distance and the amount of signals involved this solution will be expensive, even if multiplexing is used.

Our intention at present is to bring information and controls essential for the operation of the accelerator into the central control room but to leave, for the moment, the bulk of the controls located in the switchyard building. Our intention is to start up the accelerator and to gain enough operational experience before we decide how to devise a more permanent location for the switchyard control system.

C. Data Transmission Equipment

In view of the above, at this time we expect to use multiplexing or semi-multiplexing techniques only to a limited extent.

D. Control Computer

Recently we have given some thought to the use of a fast control computer. Also, Argonne plans to use a fast computer to control the Z.G.S. There are many aspects of our accelerator that make the use of such a computer very attractive. We hope to clarify a number of unanswered questions in the near future.

E. Cable System

We plan to use to a great extent magnesium oxide insulated cable in the beam switchyard tunnel. This insulation material does not change properties in high radiation fields and has a much lower radiation induced noise level than standard cables.[9]

We plan to use this MgO cable only in the beam switchyard and to change to Standard PVC cable on cable terminal racks before going up through the vertical cable penetrations to the beam switchyard building (see Fig. 1). These cable terminal racks may be placed in shielded alcoves in the yard or simply against the wall, depending on whether we are going to have a normal tunnel or a double deck tunnel for the beam switchyard structure.

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Graphic Arts 659-B-1

Fig. 1

BEAM SWITCH YARD INSTRUMENTATION AND CONTROL

SCHEMATIC LAYOUT

MAY 10, 1963.