TUNING AND OPERATION OF THE EXTERNAL PROTON BEAM LINES OF THE ZERO GRADIENT SYNCHROTRON (ZGS)*

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Introduction

The ZGS extracted proton beam (EPB) lines transport beam to as many as ten simultaneous experiments. Two main proton beams are extracted from the ZGS: EPB-I and EPB-II. Both EPB lines have consecutive targeting stations. EPB-II is also magnetically switched, creating two separate EPB-II lines during the same ZGS pulse.

Diagnostics in the lines indicate the beam intensity, position, and profiles at various stations. A beam profile and an intensity monitor are stationed immediately before each target.

The EPB lines are tuned and operated through one central control console in the ZGS Main Control Room (MCR). This centralized location of all controls and readouts of magnets, diagnostics, radiation safeguards, etc., is a savings in time and cost for the tuning and operation of the lines and greatly improves their radiation safety aspects.

All new line tunes are computed on a CDC-924A computer with available tune programs. Emittance measurements can be made while the beam line is in operation without affecting the beam transported to the various experiments.

The radiation safety aspects of the proton lines are an integral part of beam tuning and operation.

Present Configuration of the EPB Lines

The extraction of the two EPB lines from within the ZGS on the same machine pulse is either by resonant means or energy loss targeting. The resulting beams emerge through a series of Piccioni septum bending magnets to each beam line.

The EPB-I beam from the ZGS passes through a thin septum beam-splitting magnet station, then to a target station within a beam bending magnet (a momentum selector for the secondary beam), then to another septum beam-splitting magnet station, and then to a last target station used by three experiments. Finally, the beam goes on to its beam stop. The septum beams are for low intensity proton beam experiments.

The EPB-II line from the ZGS passes through a fast beam switching magnet.[1] One switched beam is usually a slow spill which proceeds to three consecutive target stations. The other switched beam is usually a fast spill, either to a target to produce a neutrino beam for the 12 ft bubble chamber (12 BC), or to a target producing particles through an RF separated line to the 12 BC, or to a third target producing other particles into the 12 BC at 90° from the original neutrino line.

EPB Diagnostics

Diagnostics are important aspects of the proton lines. These tools allow the operator to quantitatively know the condition of the beam from the start of the extraction process down to the final beam stop in each line.

The segmented wire ion chambers (SWIC) are beam profile monitors. Although described before,[2] a short description follows because of their importance to the lines. The proton beam passes through the chambers, ionizing the air atoms inside. Under the influence of an electrical field, the ions drift toward the nearest wire of a 48-wire, 1-mm spaced plane electrode. This wire collects a charge proportional to the original beam intensity that had existed within the region of the wire and transfers it to an integrating capacitor. Electronically scanning these separate 48 charged capacitors results in a gaussian oscilloscope profile that is a representation of the intensity distribution and location of the original proton beam. The vertical and horizontal wire planes in each chamber render horizontal and vertical beam profiles, respectively. The information from each wire is also processed by a computer controlled multiplexer and analog-to-digital converter to be stored on disk for later processing. The beam size indicated by the SWIC may be 10-15% larger than the actual beam size depending on the operating voltage level of the SWIC high voltage electrode. As an illustration of the response of the SWIC when the proton beam to the 12 BC target is fast double-pulsed during a single ZGS pulse, each of the two SWIC beam profiles is shown on a separate display.

The beam ion position system (BIPS) shows the beam location and its movements differentially in one plane.[3] The proton beam forms charged ions which then drift perpendicularly to the beam direction to a diagonally split electrode. Offcenter beam motion then results in one side of the split electrode collecting more charge than the other. The resulting differential voltage level indicates beam position with respect to the center of the BIPS electrode vs. time. A BIPS can measure either vertical or horizontal beam position, depending on the orientation of the electrode. Relative beam intensity information is also available from the BIPS.

Beam intensity is monitored by a simple ion chamber (IC) made of foil electrodes. The device integrates the ion current created by the proton beam passing through helium gas in the chamber and gives an output voltage proportional to beam intensity.

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Secondary emission monitors (SEM) are also used to measure beam intensities.[4] The SEM integrates the secondary electrons created by the proton beam when it strikes a metal surface and gives a proportional output voltage. Their accuracy and stability are considered slightly higher than the IC, and they are usually used to measure the intensity of the proton beam as it is extracted from the ZGS.

Scintillators with TV viewing are also used. However, their effects on the proton beams are beam destructive. Therefore, they are rotated out of the beam after use. Though their quantitative properties are questionable, they do give a good overall display of beam shapes and positions. They prove especially useful for viewing the resulting two beams split by a septum magnet.

EPB Control Console

The control console for the EPB lines is divided into two main sections. Each section is for controlling each of the two main proton lines, EPB-I and EPB-II. This permits simultaneous tuning and operation of each line. In the center of the console between these sections is a pair of TV monitors. They are for viewing the scintillators temporarily rotated into the beam lines at various beam stations. The TV monitors are also used to remotely check and log persons entering or leaving the proton tunnel access doors. Special counters, extraction targets, and ZGS circulating beam detectors are also viewed on these same monitors.

Above the console is a lighted panel with a plan drawing of both EPB lines. All diagnostics and radiation monitors are clearly identified with colored, numbered markers on the panel.

Both beam control sections are similar, and each contains the following equipment: A digital voltmeter readout displays the values analogous to the line bending and quadrupole magnet currents. It also displays the values pertaining to the currents for the dipole and sextupole resonant extraction magnets, the Piccioni septum extraction magnets, their correction coils, and the thin septum extraction magnets. Two compact multisweep oscilloscopes are utilized to simultaneously view the various diagnostic SWIC and BIPS displays. They also facilitate timing of the resonant extraction sequences by displaying various combinations of extraction magnet current pulses and other information such as ZGS circulating beam position and beam loss monitors.

Multicounters on the console display the beam intensity of each line IC and SEM station. Also, the beam line extraction and transmission efficiencies are so displayed. Beam positions and sizes are shown in digital form as computed from the analog SWIC profiles.[5] Since a SWIC and IC precede each target station, this information is also sent to each experimenter so that he is reassured that the beam on his target is centered and of the required size.

Each section of the console also contains the radiation safety system for each EPB line. The system provides interlocking visual indication of status and control of personnel access and beam handling so that safe operations will result.

Computed Tunes

The CDC-924A computer programs used in the determination of external proton line emittances and tunes are SWEM, PROFIL, NUWIE,[6] and MAYPO.[7] The SWEM program is used to create a data base via a foreground environment by monitoring on-line four SWIC's simultaneously and storing the data on a disk. Then the PROFIL program is invoked in a background environment, and the sizes of the beam profiles stored on the disk are determined. The next step is to put the evaluated sizes and corresponding quadrupole settings into a data set describing the beam line that was measured. Program NUWIE then varies the input emittance until all size conditions are met. From this point, proton line tunes are made theoretically by using program MAYPO and the calculated emittances. Programs NUWIE and MAYPO are also run in a background environment. As many as 300 proton line tunes can be stored on disk for future reference. Calculated beam tunes currently are within 15% accuracy of resulting beam sizes.

Some Features of EPB Tuning and Operation

The simultaneous multiple targeting techniques previously described,[8] producing four different beam lines on each ZGS pulse, now also include the fast spills to the 12 BC line as a fifth line. There is a different emittance and extraction path when fast resonant extraction is used to this last line. Therefore, the thin septum magnet within the main ZGS ring and the last Piccioni extraction magnet are both pulsed in synchronism with the fast switching magnet.

The beam intensity of the 12 BC beam is controlled for desired ranges of from 5 protons/pulse to 2×10^{12} protons/pulse. Long spills are of 750-ms duration while short spills are as small as 15 μs.

The proton beam path is distorted after passing through a target stationed within a beam bending magnet. To restore this beam, a second bending magnet is remotely moved out and adjusted magnetically to return the beam back into a third on-line bending magnet. The third magnet is adjusted to redirect the proton beam back on line. A pair of movable quadrupoles precedes and another pair follows the second bending magnet in this restoring chain of magnets to enable better capturing of the beam after the target. All these magnet movements and adjustments are directed remotely via the control console to better restore the beam and improve its transmission efficiency.

Radiation Safety System for EPB-I and EPB-II

The extracted proton beam lines are contained within shielded enclosures or tunnels. Outside the enclosures are radiation monitors which display radiation backgrounds pulse by pulse on various TV viewers about the ZGS. One such viewer is on the EPB central control console. These viewers can also alarm if any radiation monitor exceeds a preset value.

Some radiation monitors are also interlocked to turn off a proton line if preset levels outside the enclosure should be exceeded.

Each of the EPB's is divided into three separate enclosures. Access to within an EPB enclosure is permitted when the beam line is turned off and only when the person is identified by phone, viewed by TV, and his name is recorded. After entering the tunnel, personnel must lock down a pull bar, thereby prohibiting an introduction of beam into the enclosure. Before beam is reintroduced into the enclosure, the lock must be removed and audible and visual warnings are operated.

Beam exclusion from an area is provided by three failsafe redundant facilities, each of which would stop the beam. In some cases there are three independently operated beam stop plugs, or in place of plugs there are normally-on bending magnets that are independently operated to a low value, allowing the beam to dissipate on stationary shielding stops.

In all cases of doors, plugs, and magnets, extra sensors are used to automatically verify that the operation has been satisfactorily carried out before beam can be reintroduced into the lines or personnel access is allowed.

Conclusion

The SWIC is a most important diagnostic device and, as such, is an integral part of the proton lines. It is accepted by all as a verification of proper beam delivered to target. This is a radiation asset, as well as an operational one.

The single control console is a necessity for the operation of the proton lines. Its all-inclusive, centralized features maintain better operation and safety because it is possible for the operator to know what is taking place at all locations at any time.

The modes of extraction and their combinations, consecutive target stations, septum magnet beam splitters, line-switching magnets, and standby alternate lines, enhance the versatility of operation of the proton lines. As an example of the general concern for safety commensurate with this versatility, the needed radiation system interlocks are all hard-wired to accommodate all of these various modes and maintain their radiation safety integrity.

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