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THE FERMILAB TEVATRON I PROJECT TARGET STATION FOR ANTIPROTON PRODUCTION

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Summary

Production of 8 GeV antiprotons in the Fermilab Tevatron I project will utilize 120 GeV protons from the Main Ring. The Target Station consists of an entrance collimator, the target itself, a pulsed lithium lens for $\bar{p}$ collection, a pulsed magnet for the separation of the 8 GeV secondaries, and a beam dump. These components are mounted on vertical modules within the Target Service Building. Allowance has been made for future improvements to increase the collected $\bar{p}$ flux. The design of the Target Station and its components is discussed.

Introduction

The Tevatron I Project has the purpose of allowing operation of the Fermilab Tevatron accelerator as a proton-antiproton ($\bar{p}$) collider.[1] Antiprotons will be produced at the target station by 120 GeV protons from the Main Ring accelerator. Once every two seconds, a pulse of 2×10^{12} protons, filling 1/13 the circumference of the main ring (one booster circumference), will be accelerated and extracted towards the Target Station through a collimated shielding wall and onto a target. A fraction of the flux of secondary particles emerging from the target is "collected" by a pulsed lithium lens and rendered essentially parallel. Downstream of the lens, a pulsed dipole magnet provides selection of negative particles of energies around 8 GeV. Particles not selected by this magnet are contained within a beam dump. Negative 8 GeV particles, selected by the bending magnet, exit through a channel within the beam dump and into the transport line to the Debuncher Ring. The relatively low energy of the particles collected, plus the use of the lithium lens and pulse magnets results in a small volume for radioactive components.

The 120 GeV proton transport line fulfills a double role. It is used for the transport and focusing of protons into the target as well as transporting back $\bar{p}$ for reverse injection into the Main Ring accelerator.[2] The reverse beam bypasses the target station (3 m to the side) avoiding removal of the station components.

Access to the proton beam tunnel (upstream of the target station) and the $\bar{p}$ beam tunnel (downstream of the target station) is provided by hatches serviced by the Target Service Building crane.

D.C. power supplies for some of the beam transport elements, as well as the pulsed power supplies for the lithium lens and the pulsed dipole are contained within the building. Allowance has been made for possible future power supplies for current carrying targets and for the use of an additional lithium lens together with sweeping of the proton beam. These are promising future developments to increase the $\bar{p}$ collection rate.

A plan view, side view and section of the proposed Target Station are shown in Figure 1.

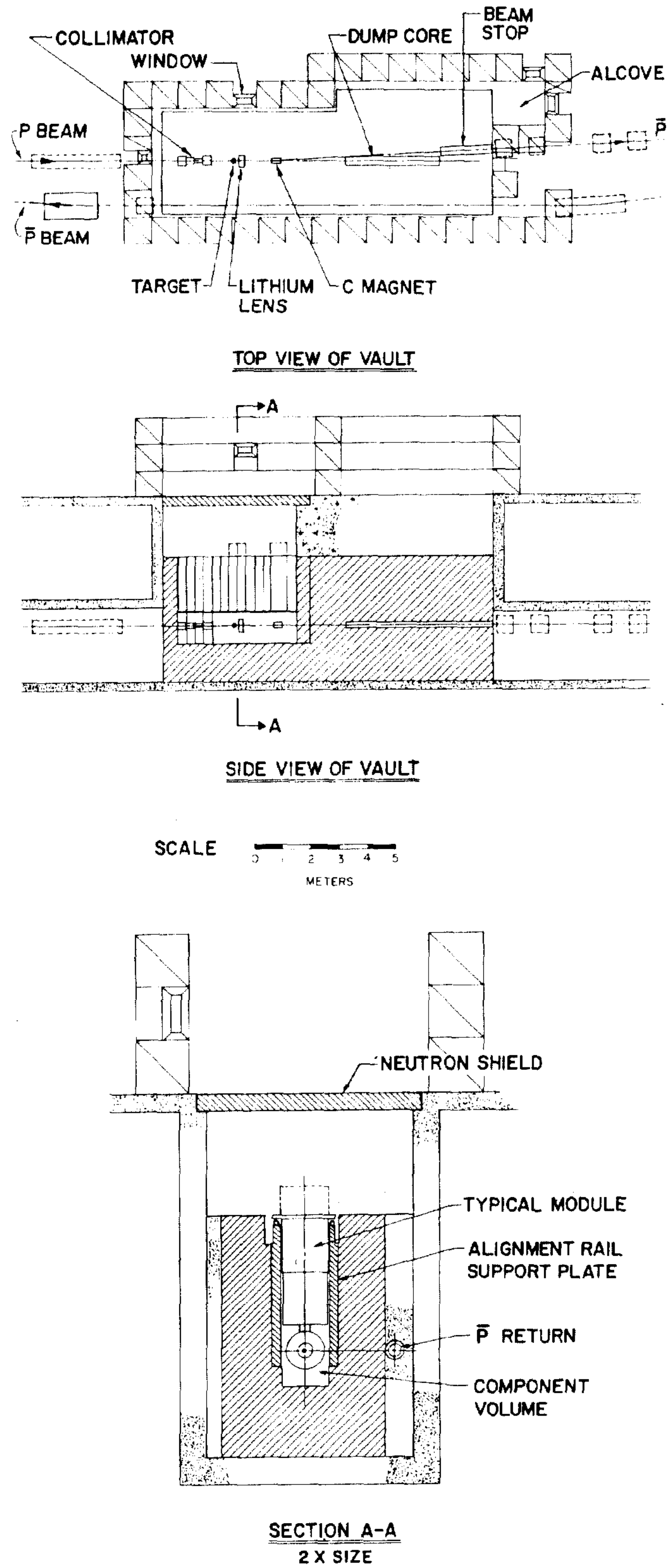

FIGURE 1.

*Operated by the Universities Research Association, Inc., under contract with the U.S. Department of Energy.

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Target Station Components

1. Targets. Smaller proton beam size at the target results in higher transverse density of produced $\bar{p}$'s. However, such high energy density impingement in the target material by the proton beam could destroy it within a beam pulse (1.6μs). We plan to operate with beam sizes so not to exceed 200 J/gm, per beam pulse, of peak energy density deposited. A heavy metal target is indicated by the depth of focus effect due to the short focal length of the lithium lens ($f^* = 14.5$cm).[3] For Tungsten, peak temperature changes of the order of 1500°C within the proton beam size (~0.4 mm rms) are expected. These temperature gradients result in large stresses in the beam region.

The choice of tungsten-rhenium is indicated by comparing materials on the basis of their yield stress times their heat conductivity, divided by the product of the coefficient of thermal expansion and the modulus of elasticity.[4] Tungsten-rhenium alloys exhibit higher yield stress than tungsten at high temperatures.

The target assembly is a series of horizontal tungsten-10% rhenium rings produced by powder technology. The targets are separated by copper discs with channels for air heat transfer. The transverse position in the horizontal plane of the alternating disk assembly is adjustable, such that the proton beam subtends a cord of the desired length through the tungsten-rhenium. By moving the target vertically and rotating it between beam pulses, every 2 seconds, a large number of beam trajectories can be achieved through one target disc. This minimizes the potential damage in any one spot, exposing the entire target ring to the beam. Larger vertical movements can either change the target ring in use, or remove the target assembly completely from the beam. Pressurized air, fed through the mounting shaft to the channels is used to remove the heat deposited by the beam (≈200 watts) and to maintain the target assembly temperature below 100°C.

2. Lithium Lens. The lithium lens[5] is contained within its associated toroidal transformer. The lens operates with a peak current of 0.67 MA for a gradient of 1000 T/m and half a sine wave pulse of length 0.33 ms. The energy deposited in the lens plus transformer by the current pulse is of the order of 11.8 kJ per pulse, at a rate of 0.5 Hz. The lens assembly itself, where 88% of the energy is deposited, is water cooled.

The lens must be positioned in line with the proton beam direction and with the $\bar{p}$ transport line. Although trim magnets on both lines help to obtain colinearity between the two beams, the lens location is adjustable to allow proper remote positioning (position and angle). The sensitivity of the positioning is calculated by considering $\bar{p}$ beam deviations in position and angle of the order of 1/10 of its transverse dimension ($X = Y = \pm 0.01$ m; $X' = Y' = \pm 2 \times 10^{-3}$rad) at the lens downstream focal plane. The result is permissable deviations of the lens with respect to the proton and $\bar{p}$ beams of $\Delta x = \Delta y = 4.5 \times 10^{-5}$m (0.0018") and $\Delta x' = \Delta y' = 4.4 \times 10^{-3}$rad (or $\pm 3.3 \times 10^{-4}$m over the length of the lens). In practice, only a small decrease in the total number of $\bar{p}$ collected is expected for these deviations. The accuracy for positioning the lens has been specified as $\Delta x = \Delta y = \pm 1.3 \times 10^{-4}$m (± 0.005").

3. Pulsed Magnet. The 3° pulsed bending magnet, presently in the design stage, selects 8 GeV negatives into the $\bar{p}$ transport line. The magnet will operate at 5.18 T and have a magnetic length of 30cm. A single turn magnet with a coupling transformer, similar in design to the lithium lens transformer, is planned.

4. Dump. The beam dump consists of a water cooled core surrounded by shielding steel. A channel through the steel allows the 8 GeV secondaries, selected by the pulsed magnet, to exit the downstream wall of the dump. This channel contains a remotely operable beam stop to block it when required for radiation safety.

The dump core is similar in design to the Tevatron dump[6]. A graphite core, 16 cm in diameter and 2m in length is enclosed in an aluminum container. The graphite is followed downstream by 0.5 m of aluminum. Cooling, by water circulation within the aluminum enclosure, has been designed for 80 kW capacity.

Both dump core and beam stop are removable from above for remote servicing.

5. Future Components. As developments in the cooling and accumulation of $\bar{p}$'s take place, we expect a demand for larger production of $\bar{p}$. Some of these requirements could be met by the evolution of target materials and geometry. Nevertheless, schemes have been tentatively proposed for future improvements to the $\bar{p}$ flux.

One such possibility is the passing of an electrical current through a cylindrical target. Focusing of the $\bar{p}$'s will take place through the target as in the Lithium Lens. Allowance has been made within the Target Station to locate a pulsed power supply and bring the necessary services to such a target.

A second proposal has been to focus the proton beam strongly onto the target by using a lithium lens with gradients of up to 4000 T/m.[7] To prevent damaging the target, the design provides for transverse scanning of the beam through the target by several beam diameters during the length of the beam pulse. At the same time the $\bar{p}$ acceptance channel is scanned to track the proton beam spot.[8] Allowance has been made for a proton lithium lens, a pair of sweeping magnets upstream of the entrance collimator and a pair of sweeping magnets between the $\bar{p}$ lithium lens and the 3° magnet and for the necessary power supplies and services.

Target Station Vault

Our target station design embodies the above elements and satisfies the following functions. Fast replacement of components at reproducible positions is required for continuous operation with minimum down time. Storage, observation and remote servicing of damaged elements is necessary. Eighteen feet of earth equivalent shielding must be interposed between the radioactive target and operating personnel while at least two, and perhaps six, pulsed power supplies must be within close proximity to their corresponding highly radioactive components.

The target station components are placed in a volume 0.8 m wide, 1.0 m high and 4.1 m long, surrounded by 1.3 m of steel to the sides and bottom and 1.8 m of steel plus 0.3 m of neutron absorbing borated wax to the top (fig. 1). The components are individually hung from blocks of steel immediately above them called "modules". Modules can be lifted out and replaced like vertical drawers with a crane. Once the module is lifted out of its slot, the crane brings it to a storage area or work station anywhere within a concrete shielding wall defined area, surrounding the target and beam dump. The concrete pit and wall comprise the target vault. Viewing through the shielding wall is provided by thick lead glass and mineral oil windows placed within the wall. The modules are guided back into their slots by tapered legs at the module corners after the crane has positioned it in its pre-determined position over the slot center. All utilities to the components can be disconnected from the top of the module. Thus, components may be deposited in radioactive storage or attached to the module bottom without radiation exposure. Module alignment surfaces are at the top for the same reason. Removal and reattachment of components is done in an alcove in the floor level, concrete shielding wall.

Alignment. The alignment system is based on two shielding plates 1.8 m deep, acting as stiff support rails, suspended from the vault walls and adjustable to within 0.1 mm of true position. The two plates have a groove on their top edge to accept hardened rounds that act as the module contact surfaces. Their inner sides are machined flat to maintain minimum clearance to the modules.

Module Details. The target vault contains thirteen modules. The first four suspend collimator blocks that fill the upstream portion of the target vault. The blocks can be remotely released from the modules. The fifth, sixth, ninth, tenth, eleventh and thirteenth modules are fillers with no present active components. These will be used for instrumentation to be developed. The seventh module suspends the target from a hollow shaft. It conveys compressed air directly to the target as well as provides the three motion modes required, rotation of the target, and transverse and vertical linear movements. The movements are produced by remotely operated D.C. electric motor driven mechanisms at the top of the module.

The eighth module is required to suspend the lithium lens within 0.1 mm of its ideal position. Movement is achieved in the horizontal plane by mounting the lens suspension rod within two module length tubes, excentric to each other by 6.35 mm and mounted in ball bearings. Individual D.C. motor drives on each tube, position the center of the lens anywhere within a 12.7 mm circle to the required tolerance. The vertical position is obtained by a similar mechanism to the target module. To sense possible vertical position changes due to thermal expansion excursions, a low expansion alloy rod through the module, touching the lens, is provided. A linear transducer coupled to the rod at the module top provides the information to maintain the lens within the required tolerance. Other utilities include a flat strip line, a water circuit and an instrument connector; all disconnectable from above.

Service Building Features. Radioactive storage facilities are provided by a module width trench built into the side of the dump shield. Components are stored at the bottom or as complete modules. This mode of storage allows personnel access to the vault area immediately after a module substitution. The storage trench is formed by leaving a space between already existing station elements, the dump shield and the concrete vault edge.

We provide two closed loop water cooling systems. The larger 80 kW system cools the dump and dump core. The smaller 10 kW system, equipped with a deionizer system, cools the lithium lens and transformer assembly and the pulsed dipole magnet.

Dehumidification and circulation of the air within the target vault and beam dump is achieved with a special handling unit. The vault is at a lower pressure than the building above to prevent escape of radioactive gases, and airborne dust. The air is swept along the upstream beam tunnel and exhausted through a filtering system after a holding time of 20 minutes. The air in the area between the neutron shield and the top of the modules is also swept by a fraction of the air flow. Air humidity is controlled to prevent condensation on the water cooled devices as well as to prevent formation of corrosive acids in the highly ionized environment during beam operation.

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