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A 650 mm LONG LIQUID HYDROGEN TARGET FOR USE IN A HIGH INTENSITY ELECTRON BEAM*

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INTRODUCTION

This paper describes a 650 mm long liquid hydrogen target constructed for use in the high intensity electron beam at the Stanford Linear Accelerator Center, (SLAC). The main design problem was to construct a target that would permit the heat deposited by the electron beam to be removed rapidly without boiling the hydrogen so as to maintain constant target density for optimum data taking. Design requirements, construction details and operating experience are discussed.

DESIGN REQUIREMENTS

SLAC Experiment E136 is an experiment for the measurement of the elastic electron-proton cross section at large momentum transfer. Since the cross section is quite small, it is necessary to have a liquid hydrogen target as long as practical and to operate with the highest available incident beam intensity to achieve appreciable event rates. Based on experience with previous generations of similar targets used at SLAC[1-3] the basic configuration chosen for this target was a cylinder with the axis parallel to the beam. As with previous targets, the liquid hydrogen must be circulated through the target cells to a heat exchanger submerged in a liquid hydrogen reservoir to remove the heat deposited by the beam. The length of the primary target was set at 650 mm, determined by the target length acceptance of the 8 GeV/c spectrometer for the particular scattering angles required.

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In addition, it was necessary to have a shorter liquid target for calibration, as well as two empty target cells for measurement of background electrons scattered from the target end caps, and a number of solid aluminum targets for various tests.

The experiment also requires that:

1. The LH_2 containers be constructed from a minimum of low Z material between the hydrogen and the detectors to minimize the amount of radiation length.
2. The targets be remotely positioned into the electron beam.
3. Sufficient mixing and cooling of the liquid hydrogen take place to control boiling well enough to permit productive data taking at maximum beam intensity and pulse repetition rate.
4. Average temperature of the LH_2 be measured so the hydrogen density can be determined during operation.

DISCUSSION OF DESIGN REQUIREMENTS

The SLAC electron beam consists of 1.6 microsecond long pulses of up to 5×10^{11} electrons per pulse and is presently operated with up to 180 pulses per second (pps). The beam can be focused to a 2 mm $\times$ 2 mm spot size at the target. Heat deposited from 4×10^{11} electrons (a more common rate than 5×10^{11}) passing through 650 mm of liquid hydrogen is 1.25 joules. There are two consequences of the injection of heat by the beam. First, there is a local heating instantaneously along the beam path during each beam pulse. A main purpose of the target design is to prevent this local heating from causing local boiling of the liquid along the beam path which would produce an unpredictable change in the target density. The second consequence is a general heating of the target liquid, resulting from the dispersion of the heat from many beam pulses, until an equilibrium is established between pulsed heating and cooling by circulation. When the repetition rate is 180 pps, the result is 225 watts deposited into the liquid hydrogen. Within the beam cross section, the temperature will rise 0.66 K per pulse, or at a rate of 118 K/s. Boiling of the liquid hydrogen can be prevented by rapidly circulating it through a heat exchanger and by keeping the pressure high enough. When the initial state of the liquid hydrogen is 21.0 K and 200 kPa absolute pressure, boiling temperature will be reached after 3 pulses of 4×10^{11} electrons (0.017 seconds). When initial conditions are 21.0 K and 300 kPa absolute pressure, it will take 6 pulses (0.033 seconds) to reach the boiling temperature if there is no turbulence or conduction between pulses. If the flow is parallel to the beam direction, a velocity of 19.7 meters per second is required to move the heated liquid 650 mm in 0.033 seconds. Since the maximum flow velocity to be expected with available fans is 2.0 meters per second, the target will boil unless there is turbulence or swirl. Boiling can also be reduced by starting with cooler hydrogen, operating at higher pressures, focusing the beam to a larger spot, or a combination of all of these. Higher pressures require stronger (heavier) tubes and heads which cause unwanted background. Lower temperatures can be obtained by using a refrigerator of sufficient capacity or by operating the reservoir at subatmospheric pressures. It is possible to cool the hydrogen reservoir to 16 K by reducing its absolute pressure to 20 kPa.

DESIGN DETAILS

A heat exchanger with 6400 cm^2 area with a flow cross section of 34 cm^2 was used. The heat exchanger is made of three parallel lengths of corrugated metal hose with a nominal inside diameter of 38 mm. Data from a previous target run with this heat exchanger projected that the average temperature increase of the target liquid would be 1 K from a 250 watt heat input. Experience with a 300 mm long target in the electron beam indicated that there had to be considerable mixing because boiling was much less than predicted by the axial flow model. The 650 mm long target was designed with much larger flow passages than the 300 mm target, with the expectation that the average liquid velocity through the cell would be high enough that mixing would be better than experienced in the shorter target.

A triaxial type of construction was chosen because it permits all of the heavy parts of the target to be up-stream of the interaction area, out of the region visible to the detectors, and away from the spray of secondary radiation. Figure 1 shows a cross section of the target array. This array is adjusted up and down with a screw jack. Position is monitored with a 5 digit encoder on the jack and a switch for each target location. The beam passes in vacuum through the reentrant 240 mm diameter inner tube, which is surrounded by the heavy parts of the target, and up to the beam inlet window. A 49.5 mm diameter $\times$ 0.05 mm thick Mylar inner tube directs flow to the end of the target. The hydrogen returns in the annulus between this inner tube and the 66.8 mm diameter outer tube. The hydrogen flows in series in a closed loop through the 650 mm cell, the 250 mm cell, the fan, and the heat exchanger, returning to the 650 mm cell. A typical operating pressure was 200 to 250 kPa absolute. The reservoir pressure was maintained at 106 kPa absolute with a check valve in the vent line.

The triaxial design was first used with a target in the SLAC Streamer Chamber[4] and later for a target for the LASS experiment.[5] Both those targets were for low power beams, but the principle of placing a long cylinder up to 2 meters inside experimental equipment was established.

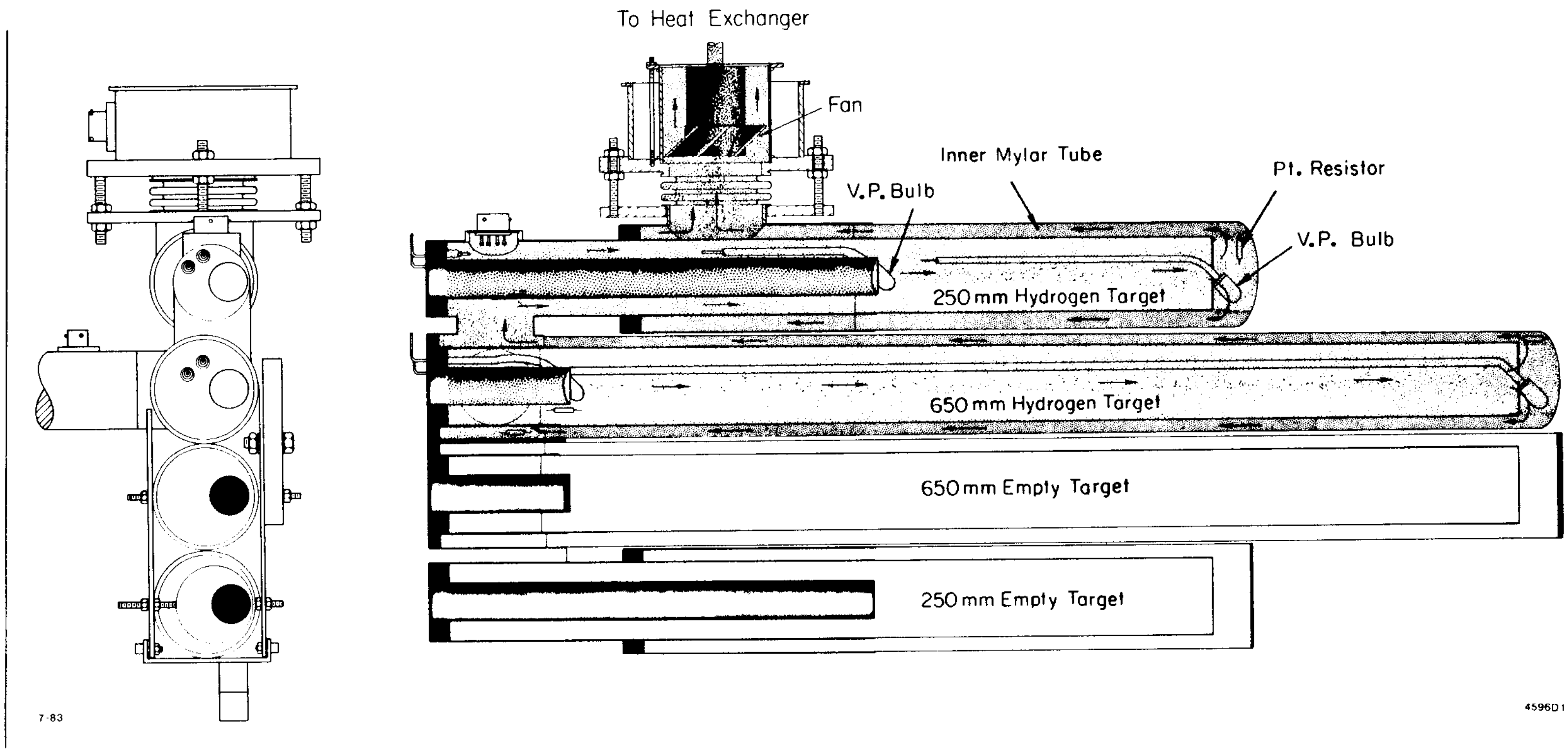

Fig. 1. E136 Liquid Hydrogen Targets

TARGET MATERIALS

The requirement for low Z material is satisfied by using Mylar for the walls and 5052-0 aluminum for the heads. The upstream heads are 0.064 mm thick, and the downstream heads are 0.127 mm. The outside walls are tubes of 0.254 mm thick Mylar sheet using epoxy adhesive on the lap joint. The tubes are joined to the stainless steel body and the heads are attached to the tubes with the same epoxy. A prototype target made of these materials ruptured at an internal pressure of 758 kPa when tested at 77 K.

TEMPERATURE MEASUREMENT

Each liquid target has a hydrogen vapor-pressure bulb at each end of the active volume. These measure the average temperature of the liquid at the input and output of the volume heated by the beam. Platinum resistance temperature detectors are attached to the outlet vapor-pressure bulb of the 250 mm target and to both of the vapor-pressure bulbs of the 650 mm target for additional temperature information. With no power input to the long cell, the inlet temperature to the short cell will be the same as the outlet temperature of the long cell.

FAN FORCED FLOW

The liquid hydrogen is circulated through the targets and heat exchanger with the same 70 mm Globe VAX-3-FC vaneaxial fan, manufactured by Globe Industries Division of TRW in Dayton, Ohio, that we have used in previous targets. Operating at 1000 rpm, the theoretical flow is 3900 cm^3/s resulting in a velocity of 2.0 m/s in a 49 mm diameter tube. Experimenters at other laboratories have also used these vaneaxial fans.[6]

OPERATING EXPERIENCE

The target was operated in the electron beam with heat input of up to 250 watts. A series of special measurements were made to look for possible effects of target boiling. With the electron detectors set to detect scattered electrons at high counting rate, the electron counting rate was measured for various values of the beam intensity, repetition rate, and with various spot sizes. The counting rate normalized to the rate extrapolated to zero pulse rate showed a linear decrease as the accelerator repetition rate increased from 30 pps to 170 pps. With a beam intensity of 4×10^{11} e/pulse and a spot size of 2 mm $\times$ 3 mm the total decrease in target density was about 7 percent at 170 pps. When heat input was 250 watts, inlet temperature was 21.0 K and outlet temperature was 21.9 K, implying a hydrogen flow rate of 180 to 200 mm/s in the cell. Since the temperature of the liquid in the reservoir providing the refrigeration was 20.6 K, and target inlet temperature was 21.0

K, the flow rate through the target was the limiting factor rather than heat exchanger area. The approximately 1 K increase in average temperature reduces the hydrogen density about 1 percent.

A large flux of ionizing radiation from secondary particles generated by the electrons entered the target in addition to the heat. The target received a total of approximately 3×10^9 rads of radiation in the course of 2 months of operation at various rates. This amount of radiation reduced the strength of Mylar to approximately 10 percent of its normal value. The cell disintegrated, dumping the liquid into the vacuum tank. The shock wave and turbulence thoroughly shredded most of the plastic in the vacuum tank. The vacuum tank contained the burst, so there was no external damage.

CONCLUSIONS

A hydrogen target system was built that could absorb up to 250 watts of beam power with flow parallel to the beam direction. Liquid mixing transverse to the beam direction was sufficient to limit local boiling in the beam spot to a maximum of 7 percent.

Mylar in close proximity to a high power electron beam will be damaged by radiation even though the beam does not pass through it.

FUTURE WORK

This target will be rebuilt with aluminum replacing the Mylar and soft solder replacing the epoxy in places that are subjected to damaging radiation at some sacrifice in radiation lengths. A practical way of soldering aluminum has been used on a subsequent target. The technique we use is to plate the aluminum with zinc, then copper, then tin on the area to be soldered. The parts are fitted together on suitable supports. Number 62362M solder cream from G.S.P. Metals and Chemicals Corp., Los Angeles, CA 90058, which is powdered solder in a paste flux, is applied to the joints. The assembly is heated in a 205°C oven until the solder flows and the joint is shiny. Solder is substantially stronger than the epoxy adhesives that are used extensively for non-metal targets. The assemblies that we tested failed well away from the solder joint.

The circulation of the liquid hydrogen will be increased substantially with new two-stage vaneaxial fans. They will pump in series through twice as much heat exchanger as with the original arrangement.

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REFERENCES

1. R. Bell, H. Clay, J. Mark and W. Pierce, A liquid hydrogen target for SLAC's 30 Ma electron beam, IEEE Trans. On Nucl. Sci., NS-16 : 631 (1969).
2. J. W. Mark and W. B. Pierce, Hydrogen targets at SLAC, IEEE Trans. On Nucl. Sci., NS-18 : 806 (1971).
3. Bodek et al., Experimental studies of the neutron and proton electromagnetic structure functions, Phys. Rev. D, 20 : 1471 (1979).
4. C. del Papa et al., Inelastic muon-proton scattering: multiplicity distributions and prong cross sections, Phys. Rev. D, 13 : 2934 (1976).
5. Alan K. Honma, "A Study of Leading Strange Meson Resonances and Spin-Orbit Splittings in $K^-p \rightarrow K^-\pi^+n$ at 11 GeV/c," SLAC Report 235, Stanford Linear Accelerator Center, Stanford, CA (1980).
6. K. D. Williamson et al., Prototype tests on a 200-W forced convection liquid hydrogen/deuterium target, in "Advances in Cryogenic Engineering Vol. 19," Plenum Press, New York (1974), p. 241.