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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. 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 elastic cross section at large momentum transfer 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[1,2,3] the basic configuration chosen for this target was cylindrical geometry with the cylinder axis parallel to the beam. As with previous targets, the target hydrogen must be circulated through the target cells to a heat exchanger submerged in a liquid hydrogen reservoir to remove the heat

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deposited by the beam. The length of the primary target was [illegible] 650 [illegible] determined by the target length acceptance of the SLAC 8 GeV/c spectrometer for the particular scattering angles required. 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:

1. Target containers constructed from low Z material to minimize the amount of radiation length between the hydrogen and the detectors.
2. All targets built with an absolute minimum of material between the interaction region and the detectors.
3. The assembly of targets that can be remotely positioned into the electron beam.
4. The target assembly to be enclosed in a vacuum tank built with thin aluminum "windows" at the electron beam elevation.
5. Sufficient mixing and cooling of the liquid hydrogen to control boiling well enough to permit productive data taking at maximum beam intensity and pulse repetition rate.

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 progressing to the point where there is local boiling of the liquid along the beam path which produces 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. Another requirement of the target design is that the average temperature of the liquid be measured under all operating conditions so the actual target density can be obtained. When the repetition rate is 180 pps, the result is

225 watts deposited into the liquid hydrogen. Within the 2 mm × 2 mm beam cross section, the temperature will rise 0.66 K per pulse, or at a rate of 118 K per second. Boiling of the liquid hydrogen can be prevented by rapidly circulating it through a cooled 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 the above. Higher pressures require stronger (heavier) tubes and heads which cause unwanted background. Lower temperatures can be obtained by using a helium 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 300 mm target.

A triaxial type of construction was chosen because it permits all of the heavy parts of the target to be up-beam 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

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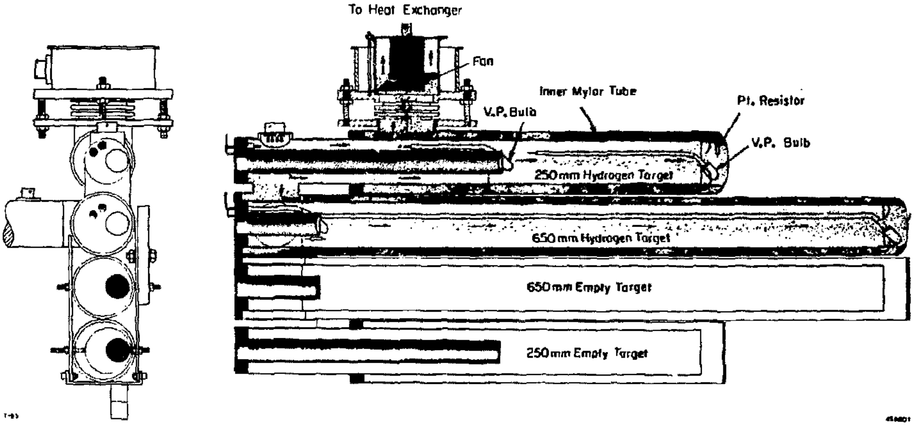

Fig. 1. E136 Liquid Hydrogen Targets

digit encoder on the jack and a switch for each target location. The beam passes through vacuum through the reentrant 240 mm diameter inner tube surrounded by the heavy parts of the target up to the beam inlet window. A 49.5 mm diameter × 0.05 mm thick mylar tube directs flow to the end of the target down its center. The hydrogen returns in the annulus between the 49.5 mm diameter 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. Typical operating pressure was 200 to 250 kPa absolute. 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.

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 66.8 mm diameter 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 mixture. A prototype target made of these materials ruptured at a 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 roughly 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 both the vapor pressure bulbs of the 650 mm target for additional temperature checks. 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 3 inch 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, theoretical flow is 3900 cm^3 per second which would result in a velocity of 2.0 meters per second in a 49 mm diameter tube. Experimenters at other laboratories have also used Globe vaneaxial fans.[6]

OPERATING EXPERIENCE

The target 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 repetition rate increased from 30 pps to 170 pps. With 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. That implies a flow rate of 180 to 200 mm per second in the cell. Since the temperature of the hydrogen 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 lack of 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 operation at various rates. This amount of radiation reduces 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.

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. 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, that 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.

Since substantial gains can be made by operating the reservoir at lower temperatures, plans are being made for making it possible to reduce the reservoir pressure by connecting the vent line to a vacuum pump through suitable heat exchangers and pressure controllers. Means of increasing the effectiveness of the vaneaxial fan are also being pursued.

CONCLUSIONS

A hydrogen target system was built that could handle beam power up to 250 watts with flow parallel to the beam direction. Mixing transverse to the beam direction was insufficient to prevent local boiling in the beam spot 2 mm $\times$ 2 mm square.

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

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