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UCRL-8857
Instrumentation
TID-4500 (15th ed.)

MASTER

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

LIQUID-HYDROGEN TARGET

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ABSTRACT

A 48-in. -long liquid-hydrogen target is described. This report stresses the operating characteristics of the target and its safety features which follow the regulations laid down by the Hydrogen Safety Committee of the Lawrence Radiation Laboratory.

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INTRODUCTION

The liquid-hydrogen target described here has been designed for transmission experiments using high-energy particles. Since the density of liquid-hydrogen is only 0.07 gm/cc, the target must be quite long in the direction of the beam in order to obtain a reasonable attenuation of the beam.

This report stresses the over-all characteristics of this target with special emphasis on the safety features that are required for operation in the vicinity of a high-energy particle accelerator. In some experiments, it may be necessary to place the target in a relatively inaccessible position. The electric circuitry and remote-indicating features of the target are described.

DESCRIPTION OF TARGET

The target, shown in Fig. 1 consists of a hydrogen reservoir surrounded by a liquid-nitrogen jacket, which in turn is surrounded by the outside steel jacket of the vacuum container. Below the hydrogen reservoir and connected to it is a 4-ft-long hydrogen flask surrounded by a concentric copper tube maintained at liquid-nitrogen temperature by thermal contact with the liquid-nitrogen reservoir. Figure 2 shows in detail the upper part of the target. Liquid hydrogen is introduced into the hydrogen reservoir by a double-walled flexible transfer tube which is inserted into the inlet fitting. The hydrogen reservoir is made of stainless steel tube 6 in. in diam. by 36 in. long with 1/32-in. walls; its total capacity is 30 l.

The liquid-nitrogen jacket is made of rolled copper 1/16 in. thick welded into a cylindrical form. It is rigidly suspended from the top of the steel envelope by 4 thin-walled stainless steel tubes which serve as inlets and exhausts for the liquid nitrogen.

Figure 3 shows in detail the bottom part of the target. The cylindrical copper tube which serves as a radiation heat shield for the hydrogen flask is rigidly clamped to and in good thermal contact with the bottom of the liquid-nitrogen reservoir.

The hydrogen flask is made of 4-in. -o.d. stainless steel tubing with 1/32-in. walls; it is suspended from the reservoir by the inlet and outlet stainless steel tubes that connect it to the reservoir. The concentric positioning of the cylindrical flask relative to the copper heat shield is maintained by three positioning pins at each end. The circular heat shield is only approximately concentric relative to the outside walls of the vacuum

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Fig. 1. Target assembly showing reservoirs and target volume.

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Fig. 2. Upper jacket detail.

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Fig. 3. Lower jacket detail.

container, since it is free to move up and down relative to it because of the thermal contraction of the metal jacket of the nitrogen reservoir.

The end windows of the flask are made of two sheets of 0.010-in. -thick Mylar cemented together with an epoxy-resin mixture. The sandwiched window is cemented onto the brass flanges at both ends of the stainless steel tube. The details of the procedures used for making and cementing these windows are given in the Appendix. The outer windows are made of 0.030-in. -thick Mylar (three 0.010-in. -sheets cemented together) and held in place by a flange that presses them against an "O" ring, forming a vacuumtight seal. All four windows are transparent, and therefore the hydrogen level in the flask can be determined visually, if desired. The exact length of the hydrogen flask is 48-7/8 in. measured from the centers of the Mylar windows at a pressure difference of 1 atmosphere.

Figures 3 and 4 indicate three tubes tapping off from the hydrogen containers. These are thin-walled, 1/8-in. -diam., stainless steel tubes, connected respectively to the bottom of the flask volume; to the inlet pipe between the top of the flask and bottom of the reservoir, and to the top of the reservoir. These tubes are connected to two sensitive Magnehelic pressure gages** which measure the hydrostatic pressure differences between the two lower tubes and between the two upper tubes and thus give a reliable indication of the hydrogen level in the target and reservoir. The two lower tubes which are normally in contact with liquid hydrogen are brought out horizontally for a distance of about 6 in., then make thermal contact with the copper radiation shield before connecting to the outside shell. The thermal gradient along the horizontal portion of these tubes is sufficient to keep the liquid from flowing through to any appreciable distance; hence, the pressure difference measured by the gages corresponds to the difference in hydrostatic pressure between the pressure taps.

EMERGENCY AND SAFETY FEATURES

The safety features of this flask follow the regulations prescribed by the Hydrogen Safety Committee of the Lawrence Radiation Laboratory. The weakest parts of the hydrogen containers are the Mylar windows. These have been tested at up to 90-lb internal pressure at liquid-nitrogen temperature. The outer casing and its Mylar windows have been tested to an internal pressure of 150 lb. If for any reason a leak should develop in the window or elsewhere, and the hydrogen should escape into the vacuum tank, high gas pressures can develop very rapidly. In order to provide for safe disposal of the hydrogen gas, a blowout patch is connected to the side of the vacuum casing. This patch ruptures at an overpressure of 15 lb, and exhausts the hydrogen through a 4-in. flexible metal hose to a vent pipe connected to the exterior of the building.

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*Manufactured by E. L. DuPont de Nemours and Co., Wilmington, Delaware.
**Made by the F. Dwyer Manufacturing Co., Michigan City, Indiana.

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Fig. 4. Schematic flow diagram.

As shown below in the schematic of the interlock system, an excess pressure of 1 lb above atmospheric will trip a solenoid valve which turns off all electric power to the target. All electrically operated auxiliary equipment attached to the target is enclosed in metal explosion-proof containers strong enough to withstand the effect of a hydrogen explosion and gastight to prevent hydrogen diffusion into the case. In this manner protection is afforded to the diffusion-pump heater, the two thermocouple gages (Hastings gages), the ionization gage, and the target-empty solenoid valve in the flask exhaust line.

TARGET CONTROLS

The target and auxiliary pumps can be operated by remote control from a relay rack which also contains the Magnehelic pressure gages. The circuit diagram of the electrical system and interlock connections is shown in Fig. 5. The following interlocks are provided:

1. Solenoid valve between forepump and diffusion pump. This is connected to the forepump ac input and closes off the vacuum manifold if ac power is lost.
2. Excess-pressure switch. Turns off all power if pressure in vacuum tank exceeds 1 psig.
3. Diffusion-pump interlocks.
  - (a) The Hastings gage on the high-vacuum side of the diffusion pump will trip off the diffusion pump power at any predetermined setting between 100 and 500 microns.
  - (b) Thermal interlock. Will turn off diffusion pump if the diffusion-pump-barrel water temperature rises above a predetermined value ($\sim 180^{\circ}\text{F}$).

Hydrogen Fill-Empty Controls

As long as the reservoir has liquid H_2 in it, the liquid will flow by gravity into the hydrogen flask, provided that the target-empty solenoid valve in the flask exhaust is open. To empty the flask, this solenoid valve is closed by the switch on the relay rack. The pressure of the hydrogen boil-off will force the liquid back into the reservoir. In order to expedite this, helium gas at less than 2 psig is let into the exhaust line (with the solenoid valve closed) for about 2 min, which is sufficient to empty the flask. The helium gas pressure can then be turned off and the flask will remain empty until the solenoid valve is reopened. When the flask is empty, the bottom Magnehelic pressure gage will read less than 0.05 in. (water) pressure. The upper gage will read the level of the hydrogen in the reservoir. With the flask full, the bottom gage will read approximately 0.60 in. (water). When the flask is full, the hydrogen reservoir should not be filled to more than 1-in. gage pressure in order to leave space for the liquid hydrogen when the flask is emptied again. Excess filling of the reservoir under these conditions will merely cause a more rapid consumption of hydrogen in the target, since the liquid level will be forced to the very top of the reservoir into the warm section above the liquid-nitrogen shield and will then evaporate and exhaust from the top of the target.

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Fig. 5. Simplified electrical schematic diagram.

INSTALLATION OF TARGET

The Lawrence Radiation Laboratory hydrogen safety regulations require that all boil-off or purge hydrogen gas from the target be evacuated from the building through appropriate vent lines. For this target, 2 vent lines are required--a 4-in. vent line and a smaller line approximately 1 in. in diameter. The reservoir exhaust at the top of the target, the blow-out patch line, and the exhaust from the hydrogen dewar are normally connected to the 4-in. vent. The 1-in. vent is connected to the exhaust from the mechanical pumps.

Before filling the liquid-nitrogen reservoir, the flask and hydrogen reservoir and the tubes that lead to the Magnehelic gages should be pumped out thoroughly and flushed with helium in order to prevent any moisture or air from condensing in the pressure-gage lines and clogging them. During these operations, the bypass valves shown in Fig. 4 should be opened to prevent changes of pressure from damaging the diaphragms of the Magnehelic gages. All vents should be purged with dry nitrogen or helium.

Liquid nitrogen should not be poured into the reservoir until the tank pressure is less than 10^{-4} mm. Approximately 3 hr is sufficient for the liquid nitrogen to cool the stainless steel hydrogen reservoir and flask, volume. The liquid hydrogen can then be introduced into the reservoir, and the target is then ready for use.

If the hydrogen is to be removed rapidly, the simplest procedure is to turn off the diffusion pump, allow time for it to cool, if possible, and then close the valve connecting it to the forepump. A small amount of helium let in through a metering valve--enough to raise the tank pressure to 50 to 200 microns--will cause rapid boiloff of the hydrogen by heat conduction without incurring any damage to the target.

Approximately 30 l of liquid hydrogen are required to cool down the flask and reservoir for the initial filling. Normal daily consumption of the target is 20 to 50 l per 24-hr day; the exact amount depends on the number of filling and emptying operations during that period.

ACKNOWLEDGMENTS

The target design described here has evolved gradually from many previous targets. The basic arrangement of the reservoirs and steel containers is taken from a target designed by R. A. Byrns for the Physics Research group under Dr. Burton J. Moyer. Drs. Robert W. Kenney and Edward A. Knapp made various modifications to this target before it achieved its present structure. The late Robert Mathewson offered many valuable suggestions which have been incorporated into this design. Marion Jones and Chester Pike were responsible for the design and construction of the control rack and interlock system.

This work was done under the auspices of the U.S. Atomic Energy Commission.

APPENDIX: MYLAR WINDOWS

Pressure requirements on the flask necessitated the use of end windows made of two layers of Mylar sheet cemented together and preformed to a convex shape for extra strength. In order to produce these windows, two circular sheets of 0.01-in. -thick Mylar are first sandblasted with No. 600 grit over their entire surface. An adhesive consisting of a mixture of 50% Epon 820* and 50% Versamid 125† is then applied to both sandblasted surfaces. Excess adhesive is rolled out, with special attention given to the removal of air bubbles. The "sandwich" is then placed between flats and partially cured at room temperature for 2 to 3 hr. The final curing and forming is done in the mold shown in Fig. 6a. The Mylar sandwich is placed in the mold and heated to 150°C for 30 min. Air at ≈ 100 psi is then introduced into the die and this pressure is maintained until the die has cooled.

The formed window is then removed from the die and sandblasted over the area that will be in contact with the brass flanges shown in Fig. 6b. It is cemented between these flanges with the same adhesive mixture as above. The joint is then cured at $\approx 70^\circ\text{C}$ for a period of 3 hr.

The outer target windows are made of three 0.01-in. -thick Mylar sheets cemented together. The windows are cemented flat and held in the target assembly by O-ring gaskets as shown in Fig. 6c.

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*Shell Oil Co., Emeryville, California.

†General Mills, Chemical Division, Kankakee, Illinois.

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Fig. 6. Mylar window assemblies.

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