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SLAC HIGH POWER HYDROGEN TARGET*

Robert L. Anderson

Stanford Linear Accelerator Center
Stanford University, Stanford, California

ABSTRACT

We describe a hydrogen target designed for use with the SLAC high power electron and photon beams. The target makes use of rapid convection currents caused by the heating of the hydrogen by the beam and the immediate cooling of the warmed hydrogen by a heat exchanger positioned a few centimeters above the beam. Provided that the size of the beam spot is not too small, the convection currents set up cause the hydrogen to move sufficiently rapidly to prevent the hydrogen (held several degrees below its boiling point by the heat exchanger) from boiling.

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I. INTRODUCTION

The electron beam at SLAC has at the present a maximum intensity of about 15μa. In a 12-inch long hydrogen target, which is typical of the target lengths used at SLAC, the electron beam intensity will lose 120 watts in the hydrogen. This appears to represent a formidable targeting problem. We have found a solution to the problem which has allowed us to operate at these power levels.

II. PRINCIPLE OF TARGET

The target is a convectively-cooled condensation target. The liquid in the cell is maintained at some pressure above atmospheric (say 15PSI) so that its boiling point (23°K) is above the boiling point of liquid hydrogen at STP (20.4°K). A typical target cell contains about a liter of liquid hydrogen. It is maintained at 20°K by being in contact by a means of copper interface with a reservoir of liquid hydrogen (see Fig. 1.). Heat deposited by the beam causes the warm hydrogen to rise and be cooled by the copper interface setting up convection currents as indicated in Fig. 1.

Our calculations show the temperature of the hydrogen at the beam is a rapid function of the width of the beam. For example, an increase in the width of the beam by a factor of 2.2 allows a ten times increase in the maximum beam intensity allowed.[1] We have estimated the rate of flow of the natural convection currents set up by the heat from the beam assuming 1cm for the horizontal dimension of the beam. The results indicate that the target could operate up to the maximum beam currents available at SLAC with a change of density of the order of less than one percent. The conductivity of the copper in the heat exchanger is such that it can easily transfer this amount of heat. If very small beam spot sizes are used, it is possible to cause boiling in the hydrogen. Once bubbles form we expect the target to fail so they will rise to the top causing the heat transfer between the copper and the hydrogen in the cell to decrease sharply. For no bubbling in the cell and with plausible assumptions, the "scaling law" of the target can be shown to be of the following form: if I^{P}_{max} is the beam current at which the target fails (with the cell pressurized at pressure P), the temperature of the hydrogen seen by the beam T_B lies within the limits,

$$\left[T_{RES} + \Delta T^{P}_{max} \left(\frac{I}{I^{P}_{max}}\right)^{1/2}\right] > T_B > T_{RES}$$

where T_{RES} is the temperature of the reservoir (20.4°) at Standard Pressure ΔT^{P}_{max} is the maximum temperature difference obtainable between the hydrogen in the cell and the hydrogen in the reservoir at cell pressure P (about 3°K for P = 15PSI). I^{P}_{max} must be found experimentally and is expected to be of the order of 30μa to 50μa at these operating conditions for the relative size of target cell to capacity of the heat exchanger used and for a 1cm wide beam. To increase the maximum beam current for which failure occurs requires increasing ΔT^{P}_{max}. This can be done by raising the boiling temperature in the target cell by increasing its overpressure or by lowering the boiling temperature in the reservoir by reducing its overpressure. We note that if deuterium is used in the cell, ΔT^{P}_{max} is larger because the boiling point of deuterium is 3.2°K above that of hydrogen. However, the ionization in deuterium is 20% greater than that in hydrogen, slightly decreasing this advantage.

The response of the target depends on the size and shape of the beam.

We mentioned previously the dependence of the calculated temperature rise on the width of the beam. For a beam of very small cross-section the instantaneous heating during a beam pulse becomes a consideration. For example, the temperature rise in one beam pulse for a 10μa beam of 0.1cm^2 cross-section is 0.1°K. Since the cross-section of the SLAC electron beam can be made very small, it is important to keep this consideration in mind. Since the convection currents are vertical, it is better to fan the beam out horizontally than vertically in attempting to increase the area.

With the high velocities (of the order of 10 to 20cm/sec) set up by the convection currents, the relaxation time of the target is a fraction of a second. The maximum repetition rate of the SLAC beam is 360pps. Heating effects in the target can be reduced by lowering the repetition rate. However, the response of the target will depend on the pattern of the pulses with a uniformly distributed pattern expected to be the best.

III. DESCRIPTION

Fig. 2 gives a simplified description of the target which is constructed in three main parts to the target: 1) target cell assembly; 2) reservoir assembly; and 3) scattering chamber. These sections are interchangeable and several variations of each have been constructed.

The reservoir assembly is composed of the reservoir, the fill lines and the mechanism for raising and lowering the position of the reservoir and target cells. The reservoir holds approximately 50 liters. The hydrogen in the reservoir is used as a coolant to keep the hydrogen in the cell at 20.4°K. The reservoir assembly can be raised by means of an air piston to allow the full or dummy target to be brought into the path of the incident beam.

The target cell assembly is composed of a heat exchanger, a hydrogen cell and a dummy cell. In some of the later versions the heat exchanger has been made part of the reservoir. The copper and stainless steel parts are joined together with standard brazing techniques. To date a variety of cells has been constructed. There have been two main classes of cells, horizontal and vertical cylinders. The larges horizontal cell constructed to date is 40-inches long while the largest vertical cell is a cylinder 12-inches in diameter. The cells for use with the electron beam have been made of aluminum or of nickel plated stainless steel usually 2-mil thick with minimal support structure. No failures have occurred to the foils due to the intense electron beam passing through them. It is possible to use the dummy cell as a second cell filled with hydrogen or deuterium using the hydrogen in the cell above as a coolant to condense the liquid in the cell below. This can be useful if an experiment requires two different shaped target cells or if a comparison between hydrogen and deuterium is required. The cell assemblies bolt on the bottom of the reservoir and are all interchangeable. Temperature measuring devices have been installed in some of the cells.

The scattering chamber gives vacuum insulation for the target cell and allows scattered particles to be observed by the experimental apparatus. Several chambers have been built, one of which is shown in Fig. 2. Thin aluminum foils of 4 to 10-mil thickness have been used for the thin windows of the chamber.

IV. CONCLUSION

We have described a hydrogen target capable of operating at the present SLAC electron beam intensities. The target is simple in principle and construction. It is, however, constantly undergoing refinements and changes.

Some changes are for improvement of operation and some to meet experimental demands. Even when used with beams not as intense as the maximum possible at SLAC, this target has the advantage that there is no bubbling and therefore the density of the hydrogen is better determined.

V. ACKNOWLEDGEMENTS

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REFERENCES

1. John Litt, private communication. These estimates are consistent with experimental measurements.

FIGURE CAPTIONS

Figure 1 End-View of target cell. Beam is perpendicular to the paper. Shown are the convection currents set up by the warm hydrogen heated by the beam.

Figure 2 Simplified drawing of the hydrogen target.

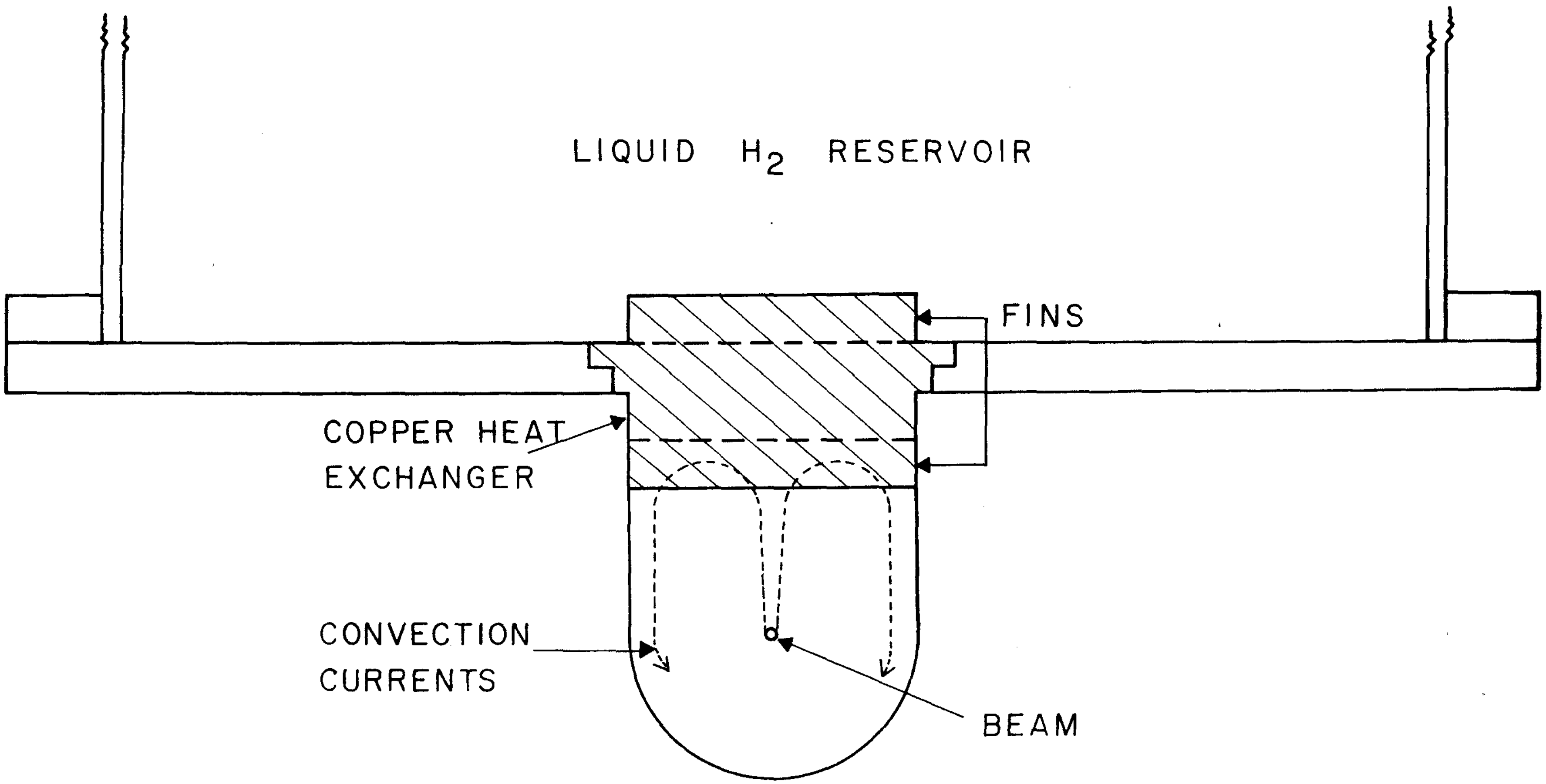
LIQUID H_2 RESERVOIR
FINS
COPPER HEAT EXCHANGER
CONVECTION CURRENTS
BEAM

Fig. 1

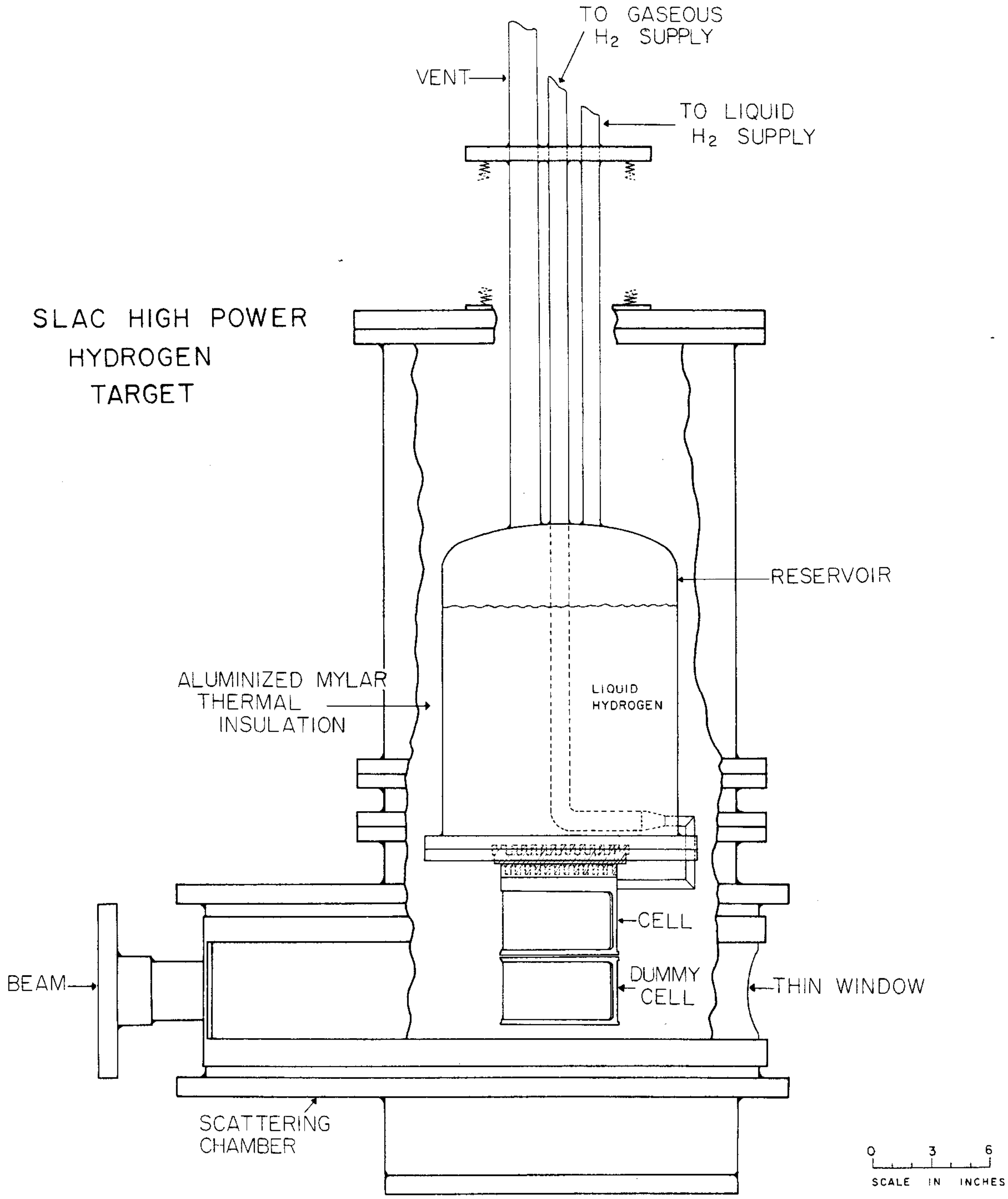
TO GASEOUS
H2 SUPPLY
VENT
TO LIQUID
H2 SUPPLY
SLAC HIGH POWER
HYDROGEN
TARGET
RESERVOIR
ALUMINIZED MYLAR
THERMAL
INSULATION
LIQUID
HYDROGEN
CELL
BEAM
DUMMY
CELL
THIN WINDOW
SCATTERING
CHAMBER
0
3
6
SCALE IN INCHES

Fig. 2