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BEHAVIOR OF A HIGH-VACUUM LAMBERTSON MAGNET UNDER EXPOSURE TO H_2 GAS

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ABSTRACT

The feasibility of operating a gas jet target in the Tevatron depends on the vacuum characteristics of the Tevatron element closest to the gas jet; the Lambertson magnet. A model Tevatron Lambertson was baked and pumped to 10^{-9} Torr. By injecting hydrogen gas the pressure was cycled between 10^{-2} Torr and 10^{-8} Torr. It was found that even after days of exposure to 10^{-2} Torr, the vacuum inside the Lambertson could be brought down to 10^{-8} Torr without difficulty. The total amount of gas injected directly into the Lambertson was one thousand times that which has been proposed in P-681

INTRODUCTION

An experiment has been proposed[1] by the Purdue University-Fermilab collaboration to study p-p and p-d scattering at the Tevatron. The proposed experiment is to be performed at the CØ Internal Target area using a hydrogen gas jet as the target. During operation of the Tevatron in the colliding beams mode, the average vacuum in the CØ straight section must be $\leq 10^{-8}$ Torr. Operation of the gas jet will temporarily expose the nearby Tevatron vacuum components to pressures $\sim 10^{-6}$ Torr; of particular concern is a Lambertson magnet located 150 in. upstream of CØ. The Lambertson has steel laminations inside the vacuum, resulting in a large surface area and occluded spaces. The basic question is "will the Tevatron vacuum recover to 10^{-8} Torr after the gas jet has been used and how long will it take?" The existence of a model Lambertson magnet, similar in construction and vacuum treatment to the magnets being built for the Tevatron, suggested that this question could be answered experimentally.

EXPERIMENTAL SETUP

The experimental setup used to carry out our measurement is shown in Fig. 1. An ion pump of speed S = 30 liter/sec (ℓ/s) was connected to each end of the Lambertson magnet. The pressure in the Lambertson was read with two ion gauges connected next to the ion pumps. Heating elements were attached to the magnet and the ion pumps for the purpose of bakeout. A variable leak (V_2) into the magnet was connected through a metal valve (V_1). This variable leak was connected to the hydrogen bottle through two valves (V_3) and (V_4). A "Convectron"* pressure gauge was connected in between V_3 and V_4. To regulate the quantity of gas

*Granville-Phillips Co. Trademark

injected in the magnet, the pressure between V_3 and V_4 was brought to a fixed value with the help of the H_2 regulator, with V_4 open and V_3 closed. The volume between V_3 and V_4 was measured. By closing V_4 we isolated the V_3 - V_4 volume from the H_2 bottle. Upon closing V_2 and opening V_3, the pressure dropped and thus the total V_2 - V_4 volume was derived. Then by opening V_1 and V_2 one could slowly inject the desired amount of gas just by reading the pressure in the Convectron gauge. Since the Convectron gauges do not give an absolute value of pressure for hydrogen gas, they were calibrated with a mechanical gauge. This calibration is shown in Fig. 2. It is evident from this figure that this correlation is linear only up to a pressure of 3 Torr. Beyond that, the measured value of hydrogen gas pressure with a Convectron gauge has to be corrected.

The magnet was also connected to a turbomolecular pump and a mechancial forepump through a liquid nitrogen trap to prevent the back flow of oil. The free volume of the vacuum system on the magnet side of valve V_1 is 17ℓ.

Several thermocouples were connected at different points to the magnet in order to control the temperature during the bakeout. Thermostats were used to keep the magnet at a fixed temperature.

THE BAKEOUT PROCEDURE

The 40 in. long model Lambertson magnet used here is the one described in Ref. 2; it is actually only that part of the magnet which involves the vacuum. It consists of 1600 magnet steel laminations (14.5 in. × 4.5 in. × .0225 in.) enclosed in a tight-fitting stainless steel vacuum skin. Before assembly the laminations were vacuum baked at 800°C. The vacuum history of the model is given in Ref. 2. The total surface area of the laminations is 1.09×10^6 cm^2; the total "edge on" surface area is 1.28×10^4 cm^2.

To get a clean system, the magnet and the ion pumps were baked at various temperatures. At first the temperature was raised up to 100°C while pumping with the turbo pumps. Then the temperature was raised up to 300°C in three steps (200°C, 250°C, and 300°C). The system was pumped out for at least 24 hours at each step. After the final baking, the ion pumps were turned on to reach to the best possible vacuum. During this time the metal valve (V_1) was closed and the pressure was recorded periodically. The variation of pressure as a function of time is shown in Fig. 3. The vacuum reached 8×10^{-10} Torr after 24 hours of pumping with the ion pumps.

MEASUREMENT OF THE H_2 ADSORPTION RATE AT ROOM TEMPERATURE

In the first test the hydrogen pressure in the Lambertson magnet was brought to 10^{-3} Torr with ion pumps off. The system was closed off to see how much of that gas would be absorbed by the metal surfaces of the magnet. After a period of 72 hours, it was found that most of the injected gas had been absorbed and the ion gauge reading was 10^{-7} Torr. To check if the absorbed gas could be removed easily the ion pumps were turned on. It was found that the vacuum improved to 4×10^{-9} Torr within an hour.

DETERMINATION OF H_2 ADSORPTION-EMISSION EQUILIBRIUM PRESSURE AT ROOM TEMPERATURE

In the second test an amount of gas was injected at a certain pressure. The system was then closed. Periodically the quantity of gas adsorbed by the system was noted and the pressure was increased to the initial value by injecting more gas. This procedure was continued until equilibrium was reached. It was noted that after the system had adsorbed about 1.5 Torr-ℓ of gas an equilibrium was reached at the pressure 3×10^{-4} Torr; i.e., only 0.3% of the injected H_2 gas stayed in free gas form.

At this point the pumping was started first with the turbomolecular pump then with the ion pumps. The decrease of pressure is shown in Fig. 3. It may be noted that it took about seven hours to reach the vacuum of 2.10^{-8} Torr. However, it is clear that at this point even after injecting such a large quantity of hydrogen gas the system was easily pumped to the 10^{-8} Torr region.

MEASUREMENT OF THE PUMP DOWN SPEED FROM 10^{-2} TORR AT ROOM TEMPERATURE

To study an extreme situation, we brought the pressure to 10^{-2} Torr by injecting hydrogen gas into the magnet and left it there for 72 hours. After that time no appreciable change of the pressure was noticed, indicating that the inner walls of the magnet were saturated with hydrogen. Even after such a severe test, no appreciable worsening was observed. The vacuum could be brought back to 2×10^{-8} Torr after 12 hours of pumping with the ion pumps. It could even be brought down to 5×10^{-9} Torr after 175 hours of pumping.

MEASUREMENT OF THE OUTGASSING RATE AT ROOM TEMPERATURE

There are two ways to measure the outgassing rate, Q; one is to measure the pressure at a point of known pumping speed and then use $Q = S.P$. The other is to turn off the pumping and measure dP/dt, for a known volume one has $Q = V\,dP/dt$. Ususally Δp does not go linearly with t (dP/dt decreases with t); one would like to measure dP/dt at $t = 0$, but with turning off an ion pump, S does not become zero immediately. The second method generally gives a lower limit. During the last week of the test the ion pumps were turned off and the ion gauge pressures recorded for the next five minute period, pumping was then resumed; this was done once per day. P vs t is shown in Fig. 3, and on an expanded time scale in Fig. 4. On the final cycle we observed

$$P(t = 0) = 13 \times 10^{-9} \text{ Torr}, \left.\frac{dP}{dt}\right)_0 = 0.5 \times 10^{-8} \text{ Torr/s}.$$

On the sixth cycle we found

$$P(t = 0) = 6 \times 10^{-9} \text{ Torr}, \left.\frac{dP}{dt}\right)_0 = 0.17 \times 10^{-8} \text{ Torr/s}.$$

Using S = 60 ℓ/s and V = 16ℓ we obtain

$$Q_I(1) = 78 \times 10^{-8} \frac{\text{Torr-}\ell}{\text{s}};\ Q_{II}(1) = 8 \times 10^{-8} \frac{\text{Torr-}\ell}{\text{s}}$$

$$Q_I(6) = 36 \times 10^{-8} \frac{\text{Torr-}\ell}{\text{s}};\ Q_{II}(6) = 2.7 \times 10^{-8} \frac{\text{Torr-}\ell}{\text{s}} .$$

Method II gives a result ~10 times smaller than method I (if the gas is mostly H_2, one should multiply both by a factor 2.5 to give the true rates, since the "air" calibration was used for the ion gauge). To obtain outgassing per cm² of surface, one has to decide what is the relevant surface area. Using the full lamination surface area of 1.09×10^6 cm² yields $Q_I(6)/A = 8 \times 10^{-13}$ Torr-ℓ/s·cm².

CONCLUSIONS

1. Our results show (Fig. 3) that after baking for about 80 hours at up to 300°C the system has been made quite clean and 8×10^{-10} Torr could be attained. However, even at that point we have noticed that if the ion pumps were turned off momentarily, the pressure would rise to 10^{-7} Torr within a minute (not shown in Fig. 3). We concluded that the outgassing was persistent.

2. During the experiment at CØ the Lambertson magnets will be under hydrogen pressure of 10^{-6} Torr during 2000 hours. That is to say

that they will be exposed to 2×10^{-3} Torr hours of hydrogen. This unit of Torr hours is very convenient for comparing with our proposed experiment because it is proportional to the number of hydrogen molecules hitting the inner wall of the container. If we look at the tests with the Lambertson, we find that even after an exposure of 2 Torr hours, the magnet was capable of maintaining a clean vacuum of 10^{-8} without any difficulty. This is 1000 times more exposure than was proposed in P-681.

3. Repeated injection and pumping out of hydrogen gas does not seem to have affected the vacuum properties of the magnet. As we have seen, after having left the system at 3×10^{-4} Torr for 24 hours we were able to pump down the system to 2×10^{-8} Torr within eight hours. his test was repeated at 10^{-2} Torr for 72 hours and we again were able to achieve 1×10^{-8} Torr with 30 hours.

4. The magnet could adsorb up to 1.6 Torr-ℓ of hydrogen gas in 18 hours.

5. It is seen in the last set of tests that the rate of outgassing decreases slowly with time, as it is expected. We observe that the gross outgassing rate after a severe exposure to H_2 (and one week of pumping) is about nine times larger than the rate obtained following a 300°C bakeout.

REFERENCES

1. Proposal to measure p-p and p-d elastic and inelastic cross sections in .4 TeV/c → 1 TeV/c beam momentum range. Purdue University and Fermilab (P-681).
2. H.Jöstlein, G.Lawrence, M.May, and M.Raphael, "Vacuum Test on a Sample Lambertson Magnet," Fermilab Report UPC No. 122 (1980).

FIGURE CAPTIONS

1. Experimental setup to carry out the vacuum tests with the model Lambertson magnet.
2. Calibration of the Convectron gauge readings for hydrogen gas.
3. Variation of pressure as a function of time for the total duration of the tests.
4. Rise of pressure due to outgassing as noticed in six different tests lasting for 4-5 minutes each.

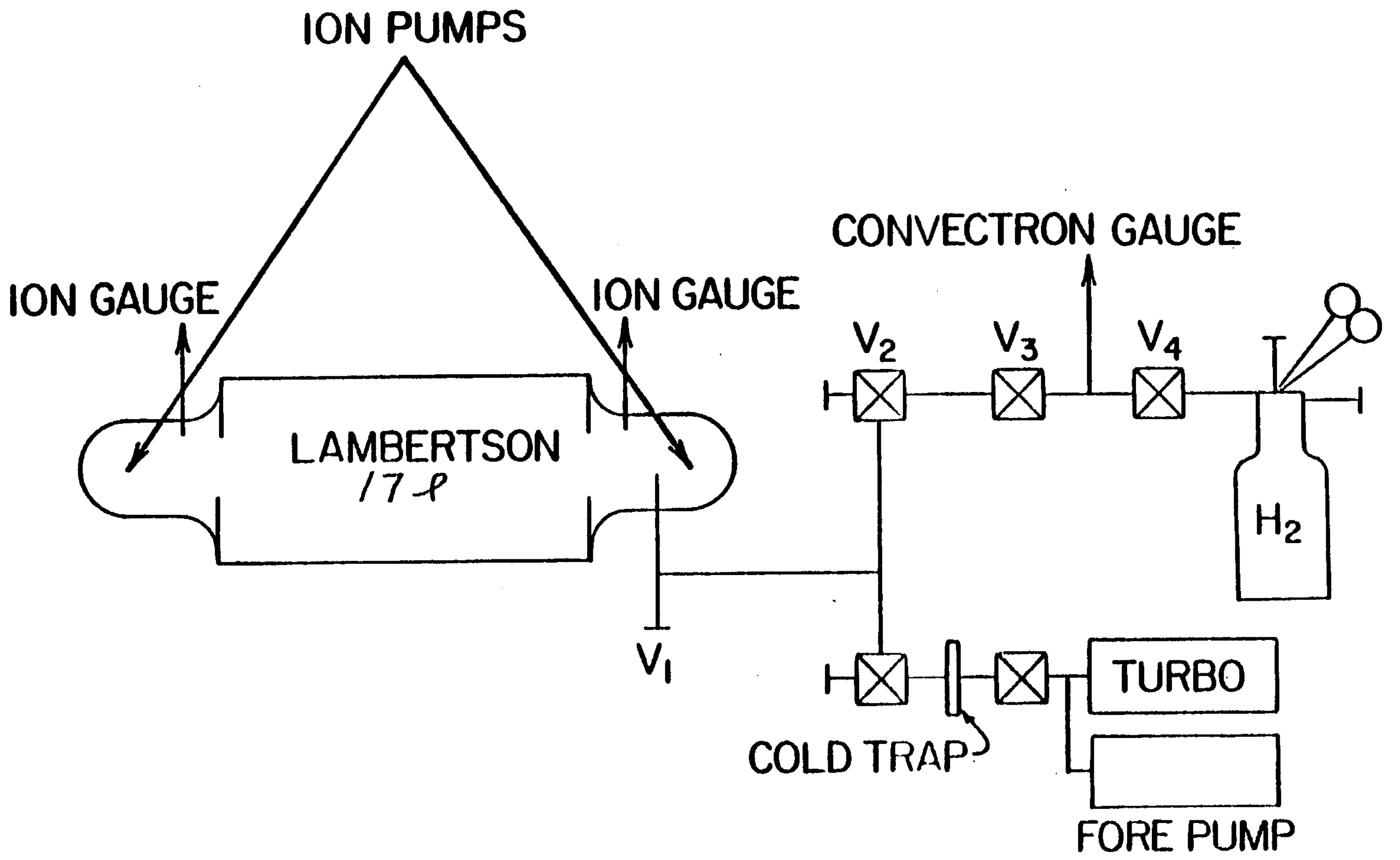
ION PUMPS
ION GAUGE
ION GAUGE
LAMBERTSON
17-ℓ
CONVECTRON GAUGE
V2
V3
V4
H2
V1
COLD TRAP
TURBO
FORE PUMP

FIGURE 1

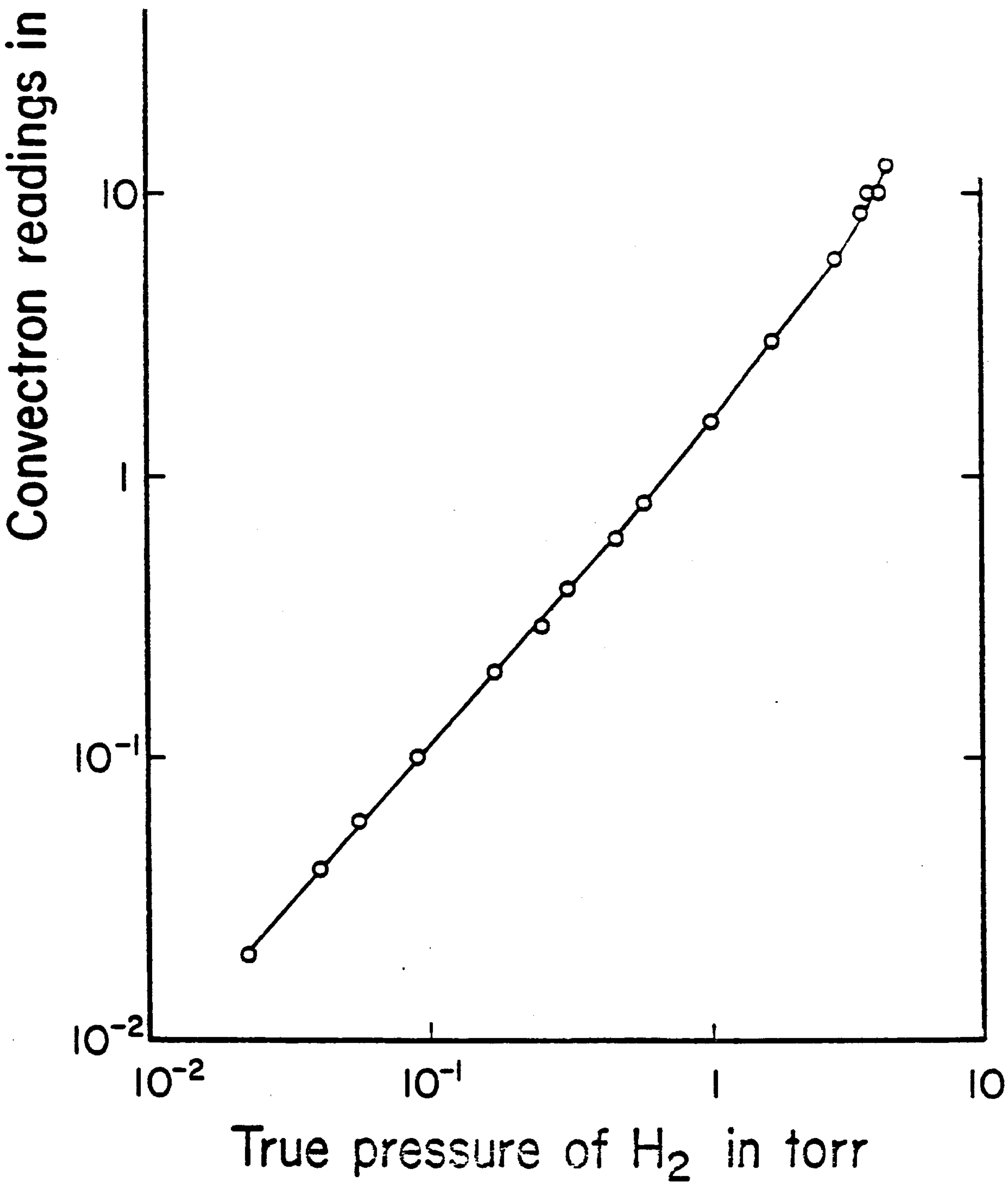
Convectron readings in
10
1
10^{-1}
10^{-2}
10^{-2}
10^{-1}
1
10
True pressure of H_2 in torr

FIGURE 2