Hydrogen Coverage in the Capture Cavity

Dieter Trines
DESY
April 22, 1993

INTRODUCTION

As we learnt for example from the operation of the superconducting cavities in the Electron ring of HERA, the outgassing rate of neighbouring vacuum chambers at room temperature leads to a substantial accumulation of Hydrogen on the surfaces of the cold cavities. At 4.2 K the growing surface coverage gives rise to a pressure increase in the cavities, which is strongly dependent on the wall coverage and the temperature (see fig. 1). The adsorbed gas can lead to a reduction of the cavity quality Q_0; give rise to field emission and thus reduce the maximum obtainable field strength [Ref. 2,3,4].

At 4.2 K without external pumps the pressure would rise up to order 10^{-6} mbar (see fig. 1).
With an external pump there can be an equilibrium state where the number of molecules adsorbed on the cold walls equals the number of released molecules. This can occur if the hydrogen vapor pressure is larger than the pressure at the external pump taking the complete outgassing rate. In other words in this case the pumping speed of the Cryo pump which the cavity constitutes goes to zero and the external pump takes the complete gas flow from the outgassing rate. In this regime the equilibrium pressure thus depends only on the outgassing rate and the pumping speed of the external pump .

If however the vapour pressure of hydrogen is lower than the pressure at the external pump the cavity will continue to pump with increasing wall coverage. This can be the case for the TESLA cavities operated at 2 K or below. But although the pressure will be small the molecular coverage can be substantial. When RF power is fed into the cavity, part of the wall coverage will be desorbed off the wall, leading to a steep increase in pressure.
This effect, well known at all temperatures, could be very large in our case (especially for the capture cavity) due to large coverages after a longer period without RF operation.

EXPECTATION FOR UNTREATED VACUUM CHAMBERS AT ROOM TEMPERATURE

If we use stainless steel vacuum chambers in the neighbourhood of the capture cavity, the outgassing rate for hydrogen from the steel will be of order

10^{-10} mbar l/sec cm² .

This number is valid for chambers which have not been vacuum fired.
The hydrogen being pumped by the cold cavity will be originating from about 1 m chamber length on either side. The outgassing of the chambers further away will be blocked by external pumps.

Now I make the following assumptions:

* The diameter of the "warm" beamtube is 70 mm (as the neck of the cavity)

* The pumping speed S_{eff} of the "Cavity-Cryo-Pump" is given by the conduction L of the beamtube between 2 K and 300K with a length of about 0.5 m and a diameter of 70 mm.

* The cold pumping surface of the cavity amounts to about 10^4 cm²

The first assumption results in a total hydrogen gas flow of:

$$\dot{Q} = \frac{d\dot{Q}}{dF} \cdot F = 10^{-10} \frac{\text{mbar l}}{\text{sec cm}^2} \cdot 7 \cdot \pi \cdot 200 \text{ cm}^2 =$$

$$= 10^{-10} \times 4400 \frac{\text{mbarl}}{\text{sec}}$$

$$= 4.4 \cdot 10^{-7} \text{ mbarl/sec}$$

The pumping speed S_{eff} given by =

d = tube diameter l = tube length

$$S_{eff} \approx L = 12.1 \frac{d^3}{l} \sqrt{\frac{M_{N2}}{M_{H2}}}$$

$$= 12.1 \cdot \frac{7^3}{50} \sqrt{\frac{28}{2}} \approx 300 \text{ l/sec}$$

or for both ends : ~ 600 l/sec.

From those two numbers we get the pressure at the entrance to the cavity:

$P_{ext} = 4.4 \cdot 10^{-7} / 600 = 7 \cdot 10^{-10}$ mbar

without any additional pumps.

This corresponds to a pressure at 1.8 K

$$7.7 \cdot 10^{-10} \text{ mbar} * \sqrt{\frac{T_{cold}}{T_{warm}}} = 7.7 \cdot 10^{-10} * \sqrt{\frac{1.8}{300}}$$

$= 5.5 \cdot 10^{-11}$ mbar.

At this pressure the cold surface can pump forever (see fig. 1).

The number of molecules per sec ending in the cavity is given by

$$\dot{n} = \frac{\dot{Q}}{kT} = \frac{4.4 \cdot 10^{-7} \text{ mbarl/sec}}{1.4 \cdot 10^{-22} \cdot 300 \text{ mbarl}}$$

$$\approx 10^{13}/\text{sec}$$

Thus with the surface of 10^4 cm² we get a coverage per sec:

10^{13}/sec/10^4 cm² = 10^9/sec cm²

As a monolayer is about ~ 10^{15} /cm² this will be obtained after 10^6 sec., which is 260 h. *
Or as rule of thumb

0.1 Monolayer / Day	Capture Cavity

For the test LINAC due the larger surface this would take ~ 32 times longer or again rule of thumb

1 Monolayer / Year	Test LINAC

From reference [4]** it seems that a coverage of more than a monolayer leads to increased field emission. This would be reached on the capture cavity after 10 days.

PROPOSAL

1) Use only stainless steel vacuum chambers which are vacuum fired.
This will reduce the hydrogen outgassing between a factor of 10 and 100.

2) Reduce the cross section between room temperature and 2 K by say two diaphragms at intermediate temperatures (having the diaphragms will reduce the thermal radiation into the cavity at the same time). By going from 70 mm diameter to 20 mm would reduce the pumping speed of the cavity by another factor of ten.
Thus by combining the two remedies we could easily gain more than a factor of 100 on the amount of adsorbed gas, per unit time.

References

[1] C. Benvenuti, R.S. Calder
Low Pressure Cryo Pumping of Hydrogen
CERN - ISR - VA 69-78

[2] R.W. Röth et. al
Universität Wuppertal
Proceedings of the 5th Workshop on RF Superconductivity
P. 559

[3] T. Tazuma et. al
KEK
IBID. P. 766

[4] H. Padamsee et. al
New results on RF and DC field emission
4th Workshop on RF Superconductivity
Tsukuba, Japan 1989

*** I am grateful to Maury Tigner for reading the draft and finding a missing factor of ten in my calculation.**

**** I want to thank Peter vom Stein who drew my attention to ref. [4].**

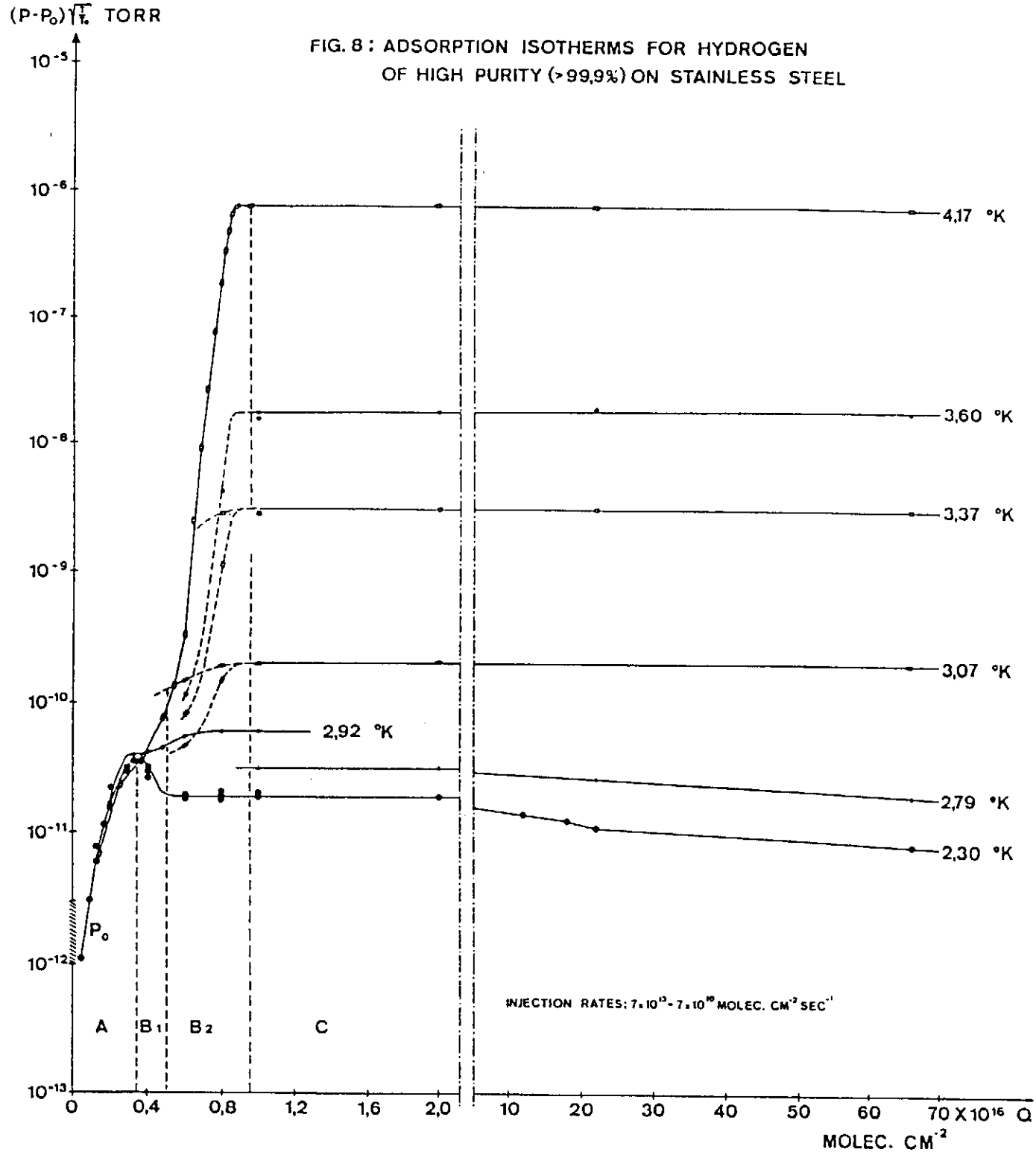

fig.1 **Hydrogen pressure as a function of wall coverage (taken from reference / 1/)**