FERMILAB-UPC-144

Fermilab

COLD BORE VACUUM MEASUREMENTS THROUGH THE ENERGY DOUBLER SNIFFER TUBES

H. Mizuno

March 1981

1. Pressure Measurement With an Ion Gauge:

Figure 1 shows a sniffer and the temperature distribution along the sniffer tube. This temperature distribution is hoped to be a good approximation for present discussions. Furthermore, we assume that the outgassing takes place only from the surface of tube I at room temperature, shown in Fig. 1, tubes II and III have no outgassing.

The conductances of tubes II and III are calculated as follows: The temperature distribution along the tube is shown in Fig. 2.

$$T(x) = \frac{T_E - T_0}{\ell} \cdot x + T_0 = ax + b \tag{1}$$

The conductance of a long circular tube of unit length is

$$C = \frac{1}{6}\sqrt{\frac{2\pi RT}{M}} \cdot D^3 \qquad (D\text{: diameter of the tube in cm}) \tag{2}$$

$$= E\sqrt{ax+b} \qquad \left(E = \frac{1}{6}\sqrt{\frac{2\pi R}{M}} D^3 \right)$$

Therefore, the conductance, C_e, of the tube which has the temperature distribution in Fig. 2 is

$$C_e = \left[\int_0^\ell \frac{dx}{C(x)} \right]^{-1} = E\left[\int_0^\ell \frac{dx}{\sqrt{ax+b}} \right]^{-1} \tag{3}$$

$$= 1.905 \times \frac{1}{\sqrt{M}} D^3 \frac{T_E - T_0}{\ell} \frac{1}{(\sqrt{T_E} - \sqrt{T_0})} \qquad (\ell/\text{sec})$$

The conductances of tubes II and III, for M = 28, are

$$C_{II} = 54.5 \quad \ell/\text{sec}$$
$$C_{III} = 26.0 \quad \ell/\text{sec} \tag{4}$$

and a total conductance of tubes II and III in series is

$$C_t = \left(\frac{1}{C_{II}} + \frac{1}{C_{III}}\right)^{-1} = 17.6 \ \ell/\text{sec} \tag{5}$$

Therefore, the pressure distribution along tube I is represented by the differential equation

$$\frac{d^2P}{dx^2} = -\frac{qA}{C} \tag{6}$$

q: outgassing rate per unit area 1×10^{-12} Torr ℓ/sec cm^2

A: surface area of the tube per unit length 11.3 cm^2/cm

C: conductance of the tube of unit length 5.8×10^1 ℓ·cm/sec

with the following boundary conditions

$$\frac{dP}{dx} = 0, \quad (x=0)$$
$$P_{(x=\ell)} = \frac{qA\ell}{C_t}, \quad (x=\ell) \tag{7}$$

Equations (6) and (7) lead the pressure distribution in tube I

$$P_{(x)} = -\frac{qA}{2C}x^2 + \frac{qA\ell}{C_t} + \frac{qA\ell^2}{2C} \tag{8}$$

From Eq.(9) the pressure reading, $P_{(0)}$, at the end of sniffer is

$$P_{(0)} = qA\ell\left(\frac{1}{C_t} + \frac{\ell}{2C}\right) = 4.8\times10^{-12} \ \text{Torr} \tag{9}$$

with

$$C = 5.81\times10^{2}\ \ell\cdot\text{cm/sec} \qquad (9^1)$$

$$q = 1\times10^{-12}\ \text{Torr}\ \ell/\text{sec cm}^2$$

$$A = 11.3\ \text{cm}^2/\text{cm}$$

$$\ell = 6.83\ \text{cm}$$

$$C_t = 17.6\ \ell/\text{sec}$$

This figure represents a lower limit of the sniffer pressure measurement system.

2. Pressure Measurement with an Ion Pump:

2-a. Base pressure caused by outgassing in tube I -

An ion pump of speed S (30 ℓ/sec) is set at the end of the sniffer. The pressure distribution in tube I can be obtained by solving the differential equation

$$\frac{d^2P}{dx^2} = -\frac{qA}{C} \qquad (10)$$

with boundary conditions

$$\frac{dP}{dx} = \frac{PS}{C} \quad (x=0) \qquad (11)$$

$$\frac{dP}{dx} = -\frac{PC_t}{C} \quad (x=\ell)$$

Equations (10) and (11) lead to pressure distribution in tube I

$$P(x) = -\frac{qA}{2C}x^2 + \frac{qAS(\ell+\frac{C_t}{2C}\ell^2)}{CS+C_tS\ell+CC_t}\cdot x + \frac{qAC(\ell+\frac{C_t}{2C}\ell^2)}{CS+C_tS\ell+C_tC} \qquad (12)$$

The pressure at the end of the sniffer is

$$P_{(0)} = \frac{qAC(\ell + \frac{C_t}{2C}\ell^2)}{CS + C_t S\ell + C_t C} = 1.58 \times 10^{-12} \text{ Torr} \tag{13}$$

with the parameters shown in (9^1). This base pressure is quite low and can be neglected for further discussion below.

2-b. Sensitivity of ion pump pressure measurement for helium gas in the cold bore.

The helium pressure in cold bore causes gas flow through the sniffer to the ion pump. This flow rate, Q, is represented by the next relations (see Appendix).

$$Q = \sqrt{\frac{T_c}{T_w}} \cdot \frac{C_T P_c}{T_c} \tag{14}$$

T_c: temperature in cold bore 4.8K

T_W: temperature at ion pump 300K

$C_T = \frac{CS}{C+S}$: effective pumping speed of an ion pump with conductance C.

Therefore, the pressure P_i, observed by an ion pump is

$$P_i = \frac{Q}{S} T_w = \sqrt{\frac{T_w}{T_c}} \cdot \frac{C}{C+S} \cdot P_c \tag{15}$$

Putting S = 0 into Eq. (15) leads to the relation of "Thermal Transpiration Effect."

For an estimation, we assume S = 4.0 ℓ/sec for helium, C = 34.1 ℓ/sec for helium with the sniffer shown in Fig. 1 and the lowest pressure detectable by the ion pump is 1×10^{-9} Torr.

This yields the minimum detectable pressure, $P_{c\,limit}$, in the cold bore

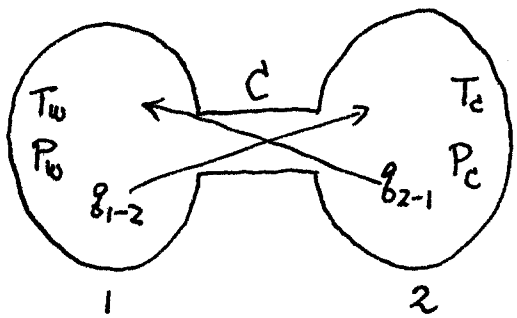
$$P_{c.limit} = \sqrt{\frac{T_c}{T_w}}\,\frac{C+S}{C}\,P_i = 1.41\times10^{-10}\ \text{Torr (at 4.8°K)}$$

For the same mass density, this value corresponds to a helium pressure P_{He} at 300°K of

$$P_{He} = \frac{T_w}{T_c}\,P_{c\,limit} = 8.83\times10^{-9}\ \text{Torr}$$

APPENDIX

GAS FLOW BETWEEN TWO CHAMBERS AT DIFFERENT TEMPERATURE



As shown above, the two chambers at different temperature, T_C and T_W respectively, are connected through a pipe. In equilibrium the pressure ratio is equal to the square root of the temperature ratio of the two chambers. (Thermal Transpiration Effect):

$$\frac{P_w}{P_c} = \sqrt{\frac{T_w}{T_c}} \tag{1}$$

The two fluxes q_{1-2} and q_{2-1} must be equal.

$$\frac{P_w C}{T_w} = \frac{P_c C'}{T_c} \tag{2}$$

From Eqs.(1) and (2) C' is represented as

$$C' = C\sqrt{\frac{T_c}{T_w}} \tag{3}$$

The coefficient, $\sqrt{\frac{T_c}{T_w}}$ in Eq.(3) is the ratio of the mean velocity of molecules in two chambers.

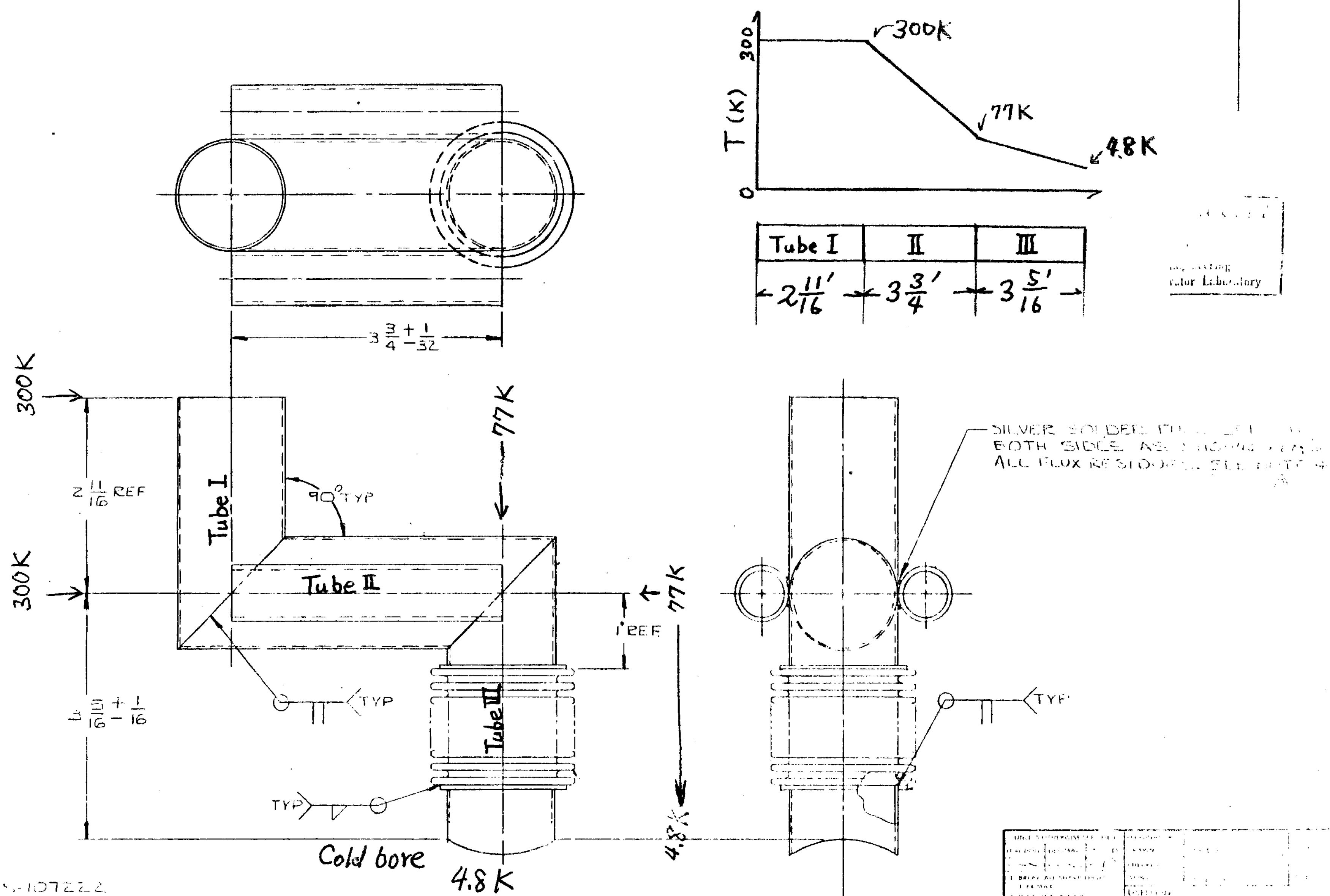
If the pressure in chamber 1 is zero, the gas flow, q_{2-1} from chamber 2 to 1 is

$$q_{2-1} = \frac{P_c C'}{T_c} = C\sqrt{\frac{T_c}{T_w}} \cdot \frac{P_c}{T_c} \tag{4}$$

this leads to Eq.(14) in Section 2-b.

Fig 1

REV	DESCRIPTION
A	ADDED MA-124518 TO TOP VIEW & ADDED NOTE 4



NOTES:
1) FAB PER ES-107222
2) WELD PER ES-107780
3.) LEAK TEST PER ES-107240
△4.) PRIOR TO SILVER SOLDERING MA-124518 (2 PLC'S) VACUUM BAKE ASSEMBLY FOR 1 HOUR @ 900°C AND 10^{-5} TORR. COOL TO ROOM TEMPERATURE IN ARGON GAS BEFORE EXPOSING TO AIR.

1620-ME-124400

FERMI NATIONAL ACCELERATOR LABORATORY

ENERGY DOUBLER
TYPE TQ QUADRUPOLE SPOOL (72)
BEAM TUBE SNIFFER SUB-ASSY

1620-MC-124511 A

Fig-2