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ULTRA-SENSITIVE LEAK DETECTION OF LARGE VOLUMES

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INTRODUCTION

The construction of superconducting magnets requires the fabrication of shells or vessels that must have extremely low leak rates. In particular, the helium vessel has stringent requirements because any leakage of helium into the surrounding vacuum insulating space will eventually lead to vacuum degradation and hence insulation degradation. Leak tightness requirements on the vacuum vessel are not as stringent because the surface of the helium vessel will serve as a cryo-pumping surface. In addition, the helium surface is usually equipped with charcoal adsorbers. This paper will describe leak check methods and techniques which are sufficiently sensitive to detect leak rates which would degrade the insulating vacuum.

Barron[1] shows that a multilayer insulating system requires an insulating vacuum of 10^{-3} Torr or better for best results. A typical superconducting magnet (DELTA) has a vacuum space volume of 1575 ℓ. Simple gas law calculations indicate that leak rates must be 1.5×10^{-9} scc/sec or less if it is desired to hold 10^{-3} Torr vacuum for a period of 5 years with no pumping.

Such rates are at the limits of accuracy of conventional helium mass spectrometer-type leak detectors (MSLD). Hence one is forced to use accumulation techniques. However, since the coil materials inside the helium vessel outgas, the vessel pressure changes and affects the accuracy of the leak detector and may damage the spectrometer tube. The use of pumps to maintain vessel vacuum limits the sensitivity of the leak detector. Thus one must analyze the trade offs associated with accumulation and pumping techniques and choose the one which is applicable and gives sufficient sensitivity for one's specific application.

APPARATUS

The system shown in Fig. 1 was used for all tests. Initially

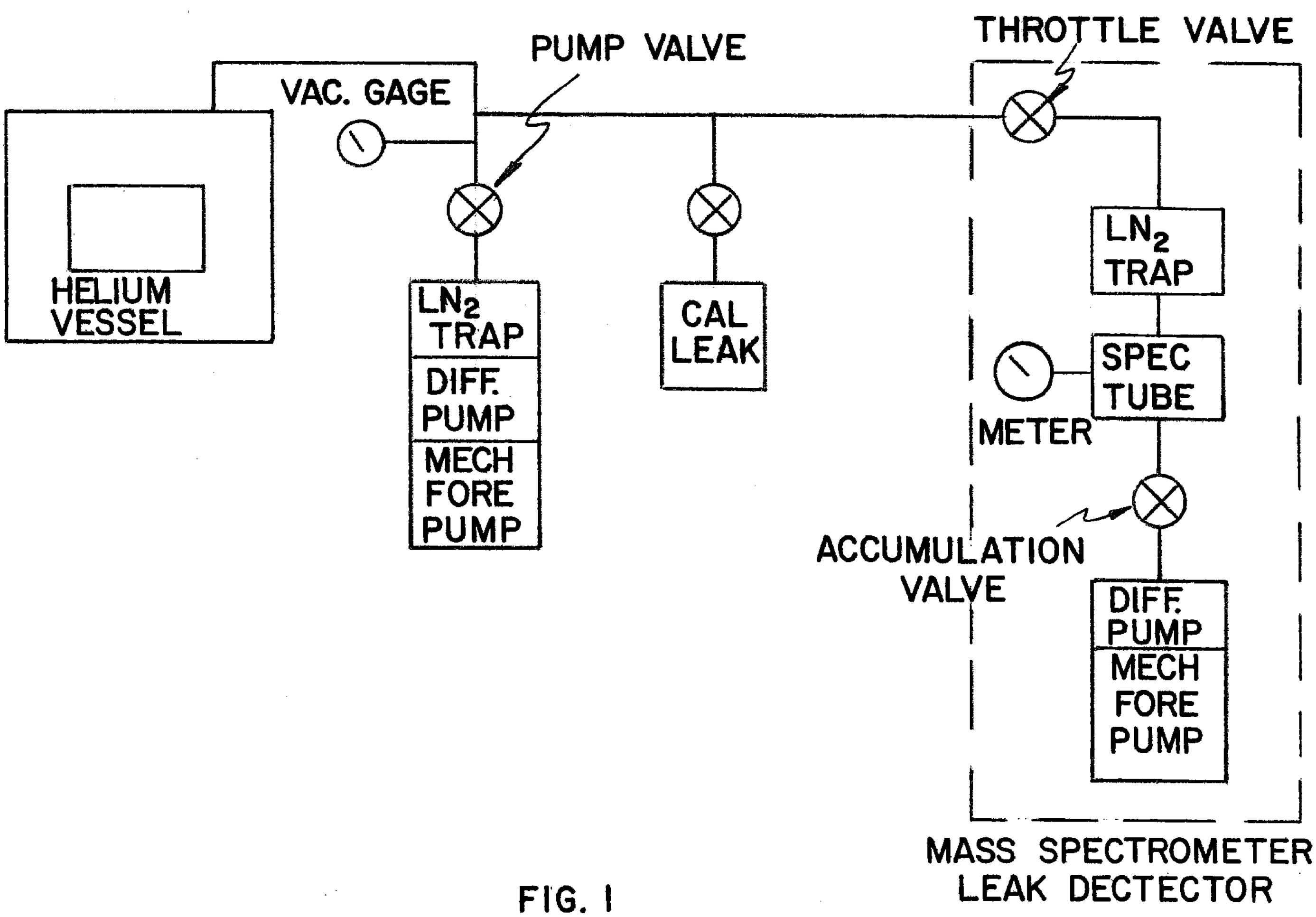

FIG. 1

the helium vessel was pumped on for a period of 15 days to outgas the internal components. At this point the ultimate vacuum was 10^{-5} Torr and the outgassing rate was such that when the pump valve was closed, 2 to 3 hours were required for the presure to rise to 5×10^{-3} Torr.

ANALYSIS

If all pumping is suspended, a hole leaking at a constant rate would produce equal meter readings, I, for equal storage periods, Δt. Having determined the calibration factor, C, of the leak detector as described later, the helium partial pressure, P, accumulated may be determined by the product IC. The rate of the leak, R, may then be determined by

$$R = \frac{ICV}{\Delta t} \quad , \qquad (1)$$

where V is the total volume of the accumulation system in cc's, C is in atmos/unit meter reading, Δt is in seconds and R is in scc/sec.

However, if outgassing is a problem so that the leak detector pumps must be run, then the leak rate becomes the product of the helium partial pressure and the pumping speed and the equation becomes

$$R = ICS \quad , \qquad (2)$$

where S is the pumping speed in cc/sec. Hence one may compare these two expressions to determine what accumulation time is required to obtain an increase in sensitivity.

J.L. Lineweaver[2] analyzed extremely low leak rates and found that the leak rate through a hole is not linear from the time the hole is initially exposed to helium. This is because the hole is a finite volume and the gas that is in the hole initially must be replaced with helium. This is a classical gas mixture problem with the result that the meter reading, I, will be given by

$$I = I_\infty [1 - e^{-1/(tR/L)}]$$

where I_∞ is the final constant value,

R is the linear leak rate,

L is a constant which is a function of the individual hole.

Hence by taking readings (t_1, I_1) and (t_2, I_2) such that $t_2 = 2t_1$, I_∞ may be determined by

$$I_\infty = \frac{I_1^2}{2I_1 - I_2} \quad . \tag{3}$$

Knowing I_∞ the linear leak rate R may be determined from (1) or (2). The calibration constant C in (1) and (2) is determined by opening a calibrated leak into the system with no other helium sources present. Ideally, this leak should be as far from the leak detector as possible, to give a worst possible case. With a known leak rate the meter readings, I, should be constant and C may be determined from (1) or (2) as appropriate.

RESULTS

This scheme was used to leak check the helium vessel of the DELTA magnet. The volume of the vessel is 1050 ℓ and the pumping speed of the leak detector at the vessel inlet is 0.27 ℓ/sec. This latter figure is arrived at by considering all the conductances in the line and the leak detector manufacturers rated pumping speed of 85 ℓ/sec. Comparing (1) and (2)

$$R = ICS = \frac{ICV}{\Delta t} \quad , \qquad \text{or}$$

$$\Delta t = \frac{V}{S} = \frac{1050}{0.27} = 3930 \text{ sec} = 65 \text{ min.}$$

Hence accumulation times greater than 65 minutes would be required to get an increase in sensitivity. Due to the outgassing of coil components the system pressure would rise beyond the tolerable limits of the MSLD in this time period and we were forced to use the method associated with (2).

The calibration constant, C, obtained as described above, was $2.16 \times 10^{-12} \dfrac{\text{atmosphere}}{\text{meter reading}}$.

The entire vessel was surrounded with a plastic bag which was filled with helium. Meter readings were taken every ten minutes and the final constant meter reading, I_∞, as calculated by (3) was 0.400. Therefore, the linear leak rate was

$$R = ICS = (0.4 \text{ MR})(2.16 \times 10^{-12} \frac{\text{atm}}{\text{MR}})(0.27 \frac{\ell}{\text{sec}})$$

$$R = 2.35 \times 10^{-10} \text{ atm cc/sec.}$$

Using the gas laws, one can calculate the time period required for this leak rate to degrade the insulating vacuum. Assume the vacuum volume, V_1, is 1575 ℓ, the temperature of the vacuum volume, T_1 is 150°K, the pressure within the helium vessel, P_2, is 760 Torr, the helium vessel temperature, T_2, is 4°K and the volume of helium leaking into the vacuum volume is the product of the leak rate and time. If we require the vacuum volume to maintain a pressure, P_1, of 10^{-3} Torr, then

$$V_2 = LR \times T = \frac{P_1 V_1}{T_1} \frac{T_2}{P_2} =$$

$$= \frac{10^{-3} \text{ Torr} \times 1575\ell \times 4°K}{150°K \times 760 \text{ Torr}} = 5.52 \times 10^{-5}\ \ell\ .$$

Since our leak rate is 2.35×10^{-10} scc/sec, the time required for vacuum degradation is

$$T = \frac{V_2}{LR} = \frac{5.52 \times 10^{-5}\ \ell}{2.35 \times 10^{-10} \text{ scc/sec} \times (10^{-3}\ \ell)/\text{cc}}$$

$$= 2.36 \times 10^{-8} \text{ sec} = 7.5 \text{ yrs.}$$

LABORATORY OBSERVATIONS

It has been observed that MSLD's are often nonlinear, that is, the meter reading for a given leak rate may be a function of system pressure or time. It is therefore necessary to analyze the leak detection system and obtain the appropriate correction factors which are subsequently used in calculating I_∞.

When testing for extremely low leak rates, all extraneous helium sources must be eliminated. We found it necessary to surround all rubber hoses and hose connections with a constant nitrogen purge. We also kept a constant purge of nitrogen inside the leak detector by connecting nitrogen gas to the cooling air intake. These two measures reduced the background reading by a factor of 10.

REFERENCES

1. Barron, Randall, "Cryogenic Systems", McGraw-Hill, 1966, pp. 494.

2. Lineweaver, J.L., "Leak Detection -- Ultrasensitive Techniques Employing the Helium Leak Detector," IRE Transactions on Electron Devices, Volume ED-5, No. 1, January 1958, pp. 28-35.