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Heat Leak Measurement of Energy Doubler Magnet Cryostats

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HEAT LEAK MEASUREMENT OF ENERGY DOUBLER MAGNET CRYOSTATS
(Ref. Drawing No. 1650-MD-107086)

Introduction

The measurement of heat leak of the energy doubler cryostats when installed in the magnet test facility has proven to be difficult. It appears that it is difficult to obtain good stability when flowing liquid through the magnet. There are some alternate methods, which could be used to measure heat leak. Both methods described in this text employ cold helium gas rather than liquid.

One of the methods requires additional equipment to be used. This method uses flowing helium gas and employs the single-phase volume of the cryostat for the evaluation of the stability and steady state condition. The other method is geared to the present test stand and probably could be useful to provide a quick comparison between magnets to determine whether the heat leak is "in the ball park." With use of the method, it may be possible to find refinements and make the second method an acceptable test for heat leak measurement.

Method I

Flow gaseous helium through the two-phase cryostat channel. Determine flow rate, temperatures in and out, and evaluate steady state by observing the pressure in the single-phase path of the cryostat in the sealed condition.

1. In principle, we can use cold helium gas and measure flow rate and temperatures in and out. (This has been done by Rode with good success.)

   For instance, an anticipated heat leak of 10 W requires the following:

   $T_{in} = 10°K$ $\qquad H_{in} = 64.25$ J/gr

   $T_{out} = 12°K$ $\qquad H_{out} = 75.14$ J/gr

   $P_{gas} = 1.4$ atm

   Flow Rate: $\dfrac{10}{75.14 - 64.25} = .918$ g/sec

To obtain .918 g/sec of helium gas at 10°K, start from liquid and add heat to reach the temperature. Amount of heat required is:

$$.918\ (64.25 - 11.91) = 48.05\ \text{W}$$

Consumption of liquid helium is at the rate of 28.4 liters/hr.

2. Cold mass of magnet is 1,100 lb of which 350 lb is copper. This material has a specific heat of .00015 J/g °K for copper and .00045 J/g °K for steel. To change all of the mass by .1°K requires an increase or decrease of (750 x x 454 x .1 x .00045 + 350 x 454 x .1 x .00015) = 17.70 joules. The gas flowing through the magnet in changing .1°K temperature will take or give up .918 x .1 x 5.51 = .51 joules/sec. A change of temperature of .1°K then moves through the magnet in approximately 1/2 min.

3. Gas flow used to measure heat leak of the magnet will flow through two-phase channel only. The single-phase channel will be filled with helium gas and sealed. By measuring its pressure, steady state can be evaluated, because pressure will change when not at steady state. The effect of temperature and pressure variation can be estimated. Assume magnet single-phase system is filled with helium gas at 2 atm and 11°K.

Volume = 20,000 cc

Mass in volume is: $\frac{20000}{107.8} = 185.53$ gr

Pressure versus temperature is then as follows:

T (°K)	P (atm)	V_s cc/gr
9.98	1.8	107.8
11.00	2.0	107.8
11.50	2.1	107.8
12.01	2.2	107.8
12.52	2.3	107.8

$$\text{Derivative } \frac{dT}{dP} = \frac{.51}{.1} = 5.1°\text{K/atm}$$

$$= .347°\text{K/psig}$$

If we can read the pressure to an accuracy of .1 psig, then temperature is read to .035°K. This provides approximately 2% accuracy relative to an increment of 2°K as measured for heat leak measurement.

4. Magnet Cooldown:

Total heat to be removed is:

$$1100 \times 454 \times 80 = 39.95 \times 10^6 \text{ joules}$$

From liquid helium we obtain:

$$1550 \times 125 = 193{,}750 \text{ joules/liter}$$

If we use liquid helium, we need:

$$\frac{39.95 \times 10^6}{.19375 \times 10^6} = 206.2 \text{ liters}$$

With a stream of 50 liters/hr cool the magnet in 4 hrs. This stream needs to flow through the single-phase channel primarily.

5. To control temperature accurately and to provide a long time constant, flow liquid helium through a small transfer line equipped with heater and control into a 500 liter dewar. This dewar will have a bleed controlled by a pressure controller to take excess flow to vent on liquefier return. The gas to the magnet will be taken from the dewar through a vacuum-jacketed transfer line of small size. This line will be shielded by gas of the same temperature to make heat leak zero.

Some numbers are instructive:

a) At 1.4 atm (5.88 psig) and 10°K the dewar contains 3,556 grams of gas (V_s = 140.6 cc/gr).

b) A flow rate of 1 g/sec of liquid to the dewar requires 64.25 - 11.91 = 52.34 W of heat to become gas of 10°K. Variation of flow rate by 10% will change gas temperature into the dewar by $\pm$.95°K, unless heater is controlled by temperature measurement.

c) A sealed 500 liter dewar with a nominal heat leak resulting in boil-off of 10 liters/day will build pressure slowly. Heat leak is approximately .3 W.

Enthalpy gain in 24 hrs is $\frac{25000}{3556}$ = 7.03 J/gr.

Internal energy changes from 44.31 to 51.34 J/gr.

Specific volume remains the same. Pressure changes from 1.4 to approximately 1.75 atm. $\frac{dP}{dT} = .21$ psig/hr

d) The effect of a temperature variation of the inlet gas on the temperature of the gas leaving to the magnet may be evaluated as follows:

Assume that mixing is complete. Then for constant specific heat:

$$M \frac{d\,(T - T_o)}{dt} = (T - T_o)\ \dot{m}$$

Where: M = mass in dewar (gram)

T = temperature of gas flowing in

T_o = temperature of mass in dewar at time zero

t = time (sec)

$\dot{m}$ = mass flowing in and out of dewar (g/sec)

$$(T - T_o) = (T - T_o)_o \quad e^{\left(-\frac{\dot{m}}{M} t\right)}$$

$$\frac{\dot{m}}{M} = .00028$$

$$(T - T_o)_o = 1°K$$

$$T - T_o = e^{-.00028\ t}$$

$$t = 3600 \text{ sec}$$

$$T - T_o = .363°K$$

e) The time constant of the magnet is small compared to that of the dewar, since mass in the magnet at 1.4 atm and 10°K (20,000 cc) is 142.24 grams.

Also, there is no mixing in the magnet, and as a result, the temperature wave moves through in a period of approximately 2-1/2 min with a flow rate of 1 g/sec. Over this period, inlet temperature will not change by more than .04°K, if temperature to the dewar has changed by 1°K.

6. Flow Sheet of the System:

Drawing No. 1650-MD-107086 shows the flow sheet of the proposed system. In order to implement the system, major modifications to the system need to be made and it is likely that the present test stands cannot be used for the heat leak measurement. For this reason, some alternate methods should be considered.

Method II

Heat Leak Measurement by Evaluating Rate of Rise of Pressure of the Single-phase System:

A reasonably good indication of magnet heat leak may possibly be obtained by observing the rate of rise of pressure in the single-phase system of the magnet in the sealed-off condition. The measurement starts when all of the liquid has been removed from the single and two-phase systems and both systems are filled with cold helium gas.

It turns out that at constant heat flux into a closed system filled with helium gas at 5°K (time zero), rate of pressure rise is initially proportional to the heat input. For instance, a volume of 20,000 cc filled with helium gas of 5°K at a pressure of 1.4 atm will contain 380.7 grams.

A heat input of 6 W will provide pressure, temperature (average) as a function of temperature as shown in Table I:

TABLE I

Time Seconds	Pressure Psig	Temperature °K	Int. Energy Joules/gr
-0-	5.88	5.0	26.23
191	11.76	5.94	29.24
383	17.64	6.9	32.27
570	23.52	7.85	35.22

It is not important to know the exact temperature at the time when the volume is locked up. For instance, at an initial temperature of 6°K, mass contained in the volume is 271.6 grams at 1.4 atm. The rate of rise for a heat input of 6 W is as shown in Table II:

TABLE II

Time Seconds	Pressure Psig	Temperature °K	Int. Energy Joules/gr
-0-	5.88	6.0	30.53
182	11.76	7.3	34.56
366	17.64	8.72	38.62
574	23.52	10.08	43.22
765	29.40	11.44	47.44

In order to make the measurement a more or less absolute measurement, it is necessary to evaluate the contribution of the external parts connected to the single-phase system of the magnet. A large effect is obtained from electrical leads, especially when they are not cooled and are closely coupled to the single-phase system. If they are loosely coupled; that is, when there is some distance between cold end of lead and single-phase system, effect of lead heating is relatively small, because of the long gas column with temperature gradient.

In order to calibrate the existing system of lead box, magnet, and turnaround box in the magnet test facility, it is proposed to use a dummy magnet cryostat with the following characteristics:

a) Dummy cryostat volume is the same as that of the single-phase system of energy doubler magnet cryostats.

b) Provide perfect insulation for the dummy cryostat by proper shielding with the two-phase connections in the boxes connected to an insulating shield.

c) Provide a variable heater in the dummy cryostat.

d) Provide a temperature sensor in the dummy cryostat.

After installation of the dummy cryostat on a test stand, the heat leak of the lead box and turnaround box will be determined by doing the following:

a) Flow cold helium gas through the system by using the heater in the lead box to vaporize liquid helium.

b) Once the system is filled with cold gas ($T = 5\text{-}6°K$), close valves at both ends of the single-phase system containing the dummy magnet cryostat.

c) Measure rate of pressure rise versus time.

d) Repeat Steps a), b), and vary c) by adding known increments of heat to the dummy magnet reservoir.