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ENERGY DOUBLER/SAVER SAFETY LEADS

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Summary

A special type of cryogenic current lead is described and its thermal evaluation is presented. This high voltage insulated lead was designed for heavy electrical conduction only during the quench of a superconducting magnet and for minimal heat leak.

Introduction

One of the protection schemes[1] for the Energy Doubler is based on one safety lead per bending magnet for dumping the magnet energy in the event of a quench. Although the safety leads are designed to carry no electric current during normal operation, they present a source of heat that has to be taken into account in the specification of the refrigeration system. Here we describe and report measurements made on the present model of one such lead.

Description

Figure 1 presents the model tested. It is a gas cooled lead which doubles as a pressure relief pipe. Two gravity action check valves control the flow of the gas: the lower one prevents pressure oscillations and the upper one keeps the normal condition cooling gas flowing through an annular path for better heat exchange with the current-carrying external pipe.

Thermal Evaluation

In the test setup, the low temperature feedthrough was not used and the lead was soldered to one end of a specially designed copper piece, the other end of which was immersed in liquid helium. This copper piece has in it a 1.905 cm diameter, 18.10 cm long solid cylindrical body, R, thermal guarded by a copper tube attached to the lower part of the piece. Two carbon thermometers, T_2 and T_1, measured the temperature drop across R caused by the heat current, $\dot{Q}_1$, from the safety lead to the helium bath.

Figure 2 shows the test setup. The end of the copper piece that is soldered to the lead is provided with an electric heater, H1, and a 52 cm long, .79 mm i.d., .102 mm wall, stainless steel capillary which brings liquid helium from the bath to the lead. A set of cuts between the lead and the cylindrical body allow for some flexibility on this otherwise rigid heat path. The capillary, even when filled with stationary liquid, conducts a negligible part of the heat to the bath.

The thermal circuit can therefore be indicated by Figure 3. Four relevant heat currents are indicated: $\dot{Q}_1$ - the heat flowing from the environment and room temperature walls into the lead; $\dot{Q}_2$ - the calibrated heat introduced by means of the electric heater H1; $\dot{Q}_3$ - the heat current that the lead delivers to the liquid helium bath (through the copper cylinder R); and $\dot{Q}_4$ - the heat current transferred to the helium gas flow. Of these only $\dot{Q}_1$ is not measured. $\dot{Q}_2$ is the simplest to measure and control, using a 4-lead technique and regulated electric current supply. $\dot{Q}_3$ is obtained from the temperature drop T_1-T_2 across the cylinder R, which was calibrated using $\dot{Q}_2$ without the safety lead. $\dot{Q}_4$ is calculated by measuring the mass flow rate, $\dot{m}$, the temperature of the gas flowing out of the lead, T_t, and finding[2] the enthalpy increase from the liquid state and therefore $\dot{Q}_4$ is the power absorbed by the flowing helium in a steady state condition.

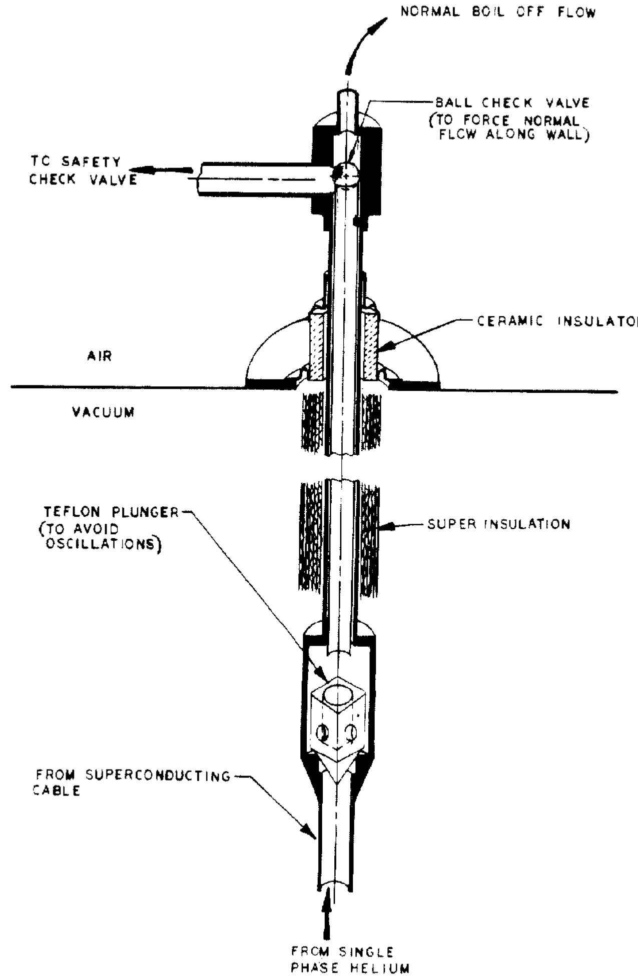

Figure 1. Safety Lead

The mass flow rate $\dot{m}$ was adjusted by a control valve after the gas was warmed up and measured by means of a wet test meter and a clock under known pressure and temperature near room values. The temperature, T_t, was

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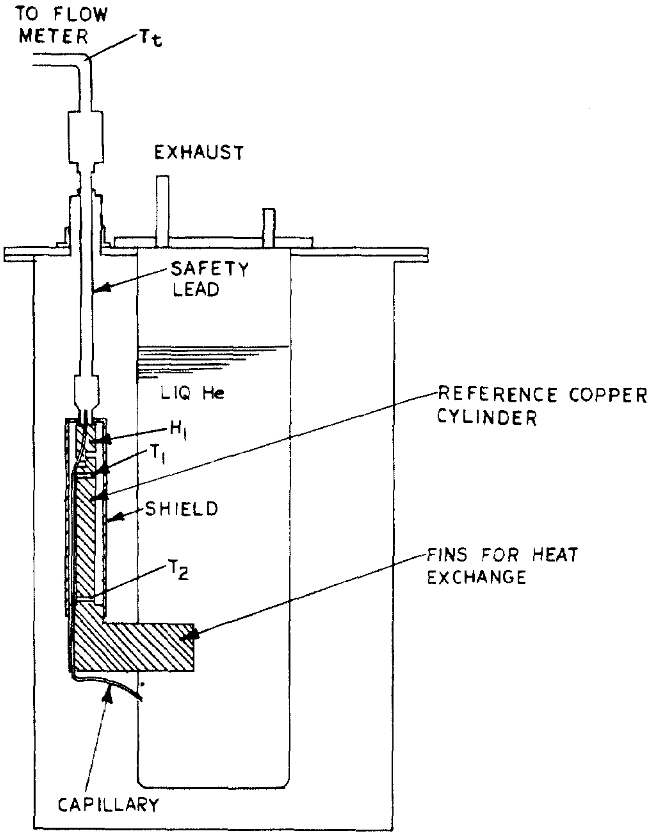

Figure 2. Experimental Setup

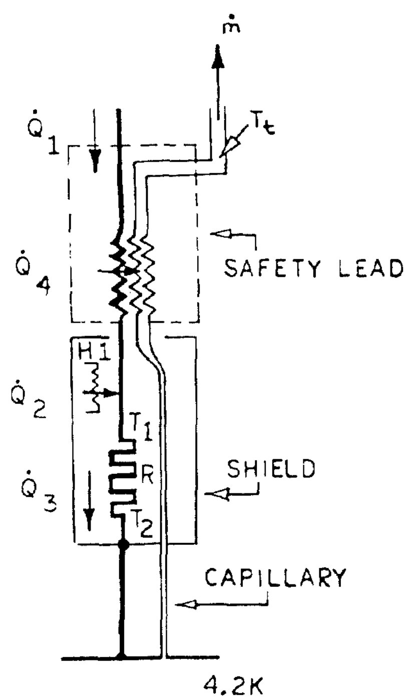

Figure 3. Thermal circuit of the experimental setup

measured with a thermistor immersed in the gas flow at the top of the safety lead.

In calibration runs for R, the temperatures T_1 and T_2 were used only as parameters to compare $\dot{Q}_2$ with $\dot{Q}_3$ and carbon resistors were used as thermometers.

Conclusion

The data of one of the final runs are presented in Table I. Several runs were needed to debug and calibrate the system, get all relevant variables controlled and become familiar with the equilibrium time constants. Several points with non-zero values of $\dot{Q}_2$ were included, they reflect a correct performance for the measuring method involved which is a rather uncommon one. These points also give an idea of the scattering in the results.

TABLE I

THERMAL MEASUREMENT DATA

DATA #	T_1	T_2	T_t	$\dot{m}$	$\dot{Q}_2$	$\dot{Q}_3$	$\dot{Q}_4$	$\dot{Q}_1$
27 A	6.705 K	5.193 K	-	0 mg/sec	0 W	3.92W	0W	4.06W
B	6.914	5.271	-	0	.300	4.38	0	4.19
C	7.064	5.354	-	0	.597	4.62	0	4.15
D	7.302	5.463	-	0	.917	5.08	0	4.31
E	7.387	5.482	-	0	1.216	5.32	0	4.24
31 A	4.449	4.512	194.1 K	12.42	0	.01	12.59	12.60
B	4.689	4.546	194.3	12.23	.298	.31	12.41	12.42
C	4.865	4.586	195.1	12.48	.584	.58	12.71	12.71
D	5.061	4.651	193.9	12.33	.9198	.86	12.48	12.42
E	5.236	4.718	193.3	12.52	1.225	1.13	12.64	12.55
32 A	4.692	4.528	210.5	9.30	0	.36	10.22	10.58
B	4.901	4.603	212.2	9.40	.298	.62	10.41	10.73
C	5.084	4.662	212.0	9.35	.599	.89	10.35	10.64
D	5.270	4.727	212.7	9.54	.924	1.20	10.59	10.87
E	5.451	4.797	212.1	9.41	1.24	1.48	10.42	10.66
33 A	5.102	4.666	231.7	6.24	0	.93	7.54	8.47
B	5.293	4.751	234.1	6.36	.3	1.19	7.77	8.66
C	5.446	4.804	233.8	6.35	.604	1.44	7.74	8.58
D	5.646	4.864	234.4	6.20	.898	1.85	7.58	8.53
E	5.839	4.930	235.0	6.15	1.295	2.20	7.54	8.45

The main result (mass flow rate as a function of heat load) for two leads that differed only on the material of the main tube is plotted in Figure 4. Our rule of thumb for overall refrigeration economy (3W vs 1ℓ/hr) is plotted as a load line. Its crossing point with the other curves indicates the flow rates to be used for best performance.

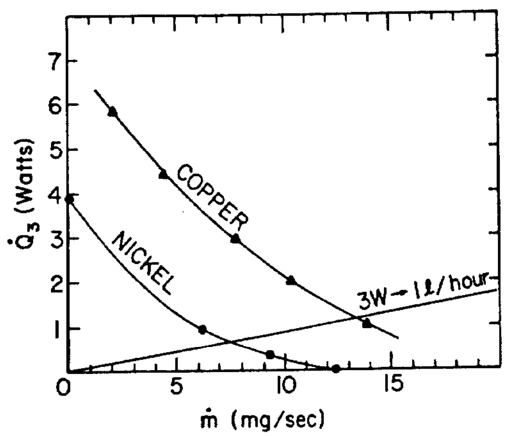

Figure 4. Safety lead heat load as function of gas flow

Acknowledgements

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2. R.D.McCarty, Thermophysical Properties of Helium-4, NBS Technical Note 631.