INTRODUCTION

This report examines the pressure relief for the JLab Dipole helium vessel. The report defines the geometry and lists the heat flux for a quench and a loss of vacuum. The report then summarise the vent flow rate and the sizing of the relief devices.

Reference JLab Dipole 238_2 Venting Quench.xls
JLab Dipole 239_2 Relief Valve Quench.xls
JLab Dipole 240_1 Venting LOV + Quench.xls
JLab Dipole 241_1 Burst disc.xls
JLab Dipole 242_1 Vent Pipe.xls

PARAMETERS

SURFACE AREAS

Wetted surface in contact with liquid helium

Helium Vessel for Magnet	Outer cylinder	15.35	m²		
	Inner cylinder – straight length	7.84	m²		
	End piece	1.29	m²		
	End piece	1.29	m²		
	TOTAL Magnet Assembly			25.77	m²
Helium Chimney Pipe	Feed pipe	0.50	m²		
	Feed pipe – Magnet assembly	0.33	m²		
	Return pipes – all three	3.00	m²		
	TOTAL Chimney Pipes			3.83	m²
CCR	Reservoir base	0.24	m²		
	Reservoir cylinder	0.78	m²		
	Pipes	0.30	m²		
	TOTAL CCR			1.32	m²
Magnet Assembly	Coil inner surface	4.37	m²		
	Outer cylinder	14.36	m²		
	Inner cylinder – excluding coil surface	3.46	m²		
	End piece	0.96	m²		
	End piece	0.96	m²		
	TOTAL Magnet coil inner surface			3.46	m²
	TOTAL Magnet Assembly – less coil inner			19.74	m²

HELIUM INVENTORY

Magnet vessel	180	litres		
Helium feed pipe	2	litre		
Return pipes – all three	65	litres		
CCR – liquid contents	75	litres		
CCR – vapour contents	32			
TOTAL liquid helium inventory			322	litres
TOTAL vapour helium inventory			32	litres

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HEATING

Quench

Maximum surface temperature	160	K
Surface temperature for heat flux	40	K
Heat flux on quench	3.93	W / cm²
Magnet assembly surface area	4.37	m²
Heating to helium on quench	172	kW
Maximum energy released	160	MJ

The maximum surface temperature for quench with no protection resistor is 160 K which is reached after 70 seconds. At 5 seconds the temperature has reached 40 K and is climbing. Therefore the temperature at any position on the coil at this moment in time is no higher than 40 K. This temperature is used to calculate a heat flux of 3.93 W / cm² to supercritical helium at the relief pressure of 5.47 bar A. The t total heat load of 172 kW is sufficient to discharge 67% of the liquid helium inventory within 5 seconds. after this time, although the heat flux is rising the helium density and inventory is reducing so that the vent flow rate is no greater than then maximum calculated at 5 seconds.

Loss of Vacuum

Maximum surface temperature	63	K
Heat flux on LOV	0.70	W / cm²
Helium vessel wetted surface area	30.27	m²
Heating to helium on LOV	212	kW

The heat flux of 0.70 W / cm² relies on the insulating effect of a few layers of multilayer insulation or of a thin layer of Lydall Industries Cryolite on the helium vessel. For comparison the heat flux to supercritical helium on bare metal due to a loss of vacuum has been measured as 3.0 W / cm².

The total heat load for a simultaneous quench and loss of vacuum is 447 kW.

OPERATION

The objective is to use a pressure relief valve with a set pressure of 4.0 atm which is 4.05 bar G to handle the gas flow rate from a quench. At full flow the pressure will be 4.46 bar G which is 5.47 bar A.

A burst disc in conjunction with the relief valve will manage the flow from a simultaneous Loss of Vacuum (LOV) and quench at 5.0 atm which is 5.07 bar G and 6.08 bar A.

Whilst sourcing the burst disc and the relief valve, attention will be paid to the tolerances of both devices to ensure that there is no overlap of the relief valve operating at its fully open pressure plus the upper tolerance of pressure and the burst disc having a the minimum tolerance of burst pressure. If the difference in pressures is small the set pressure of the relief valve will be reduced.

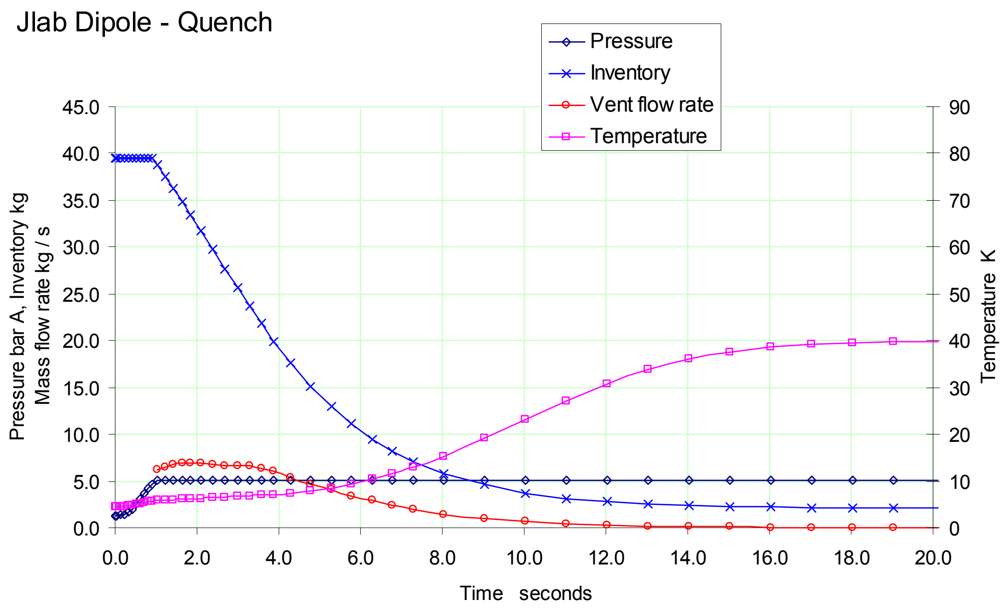
ANALYSIS

The analysis uses a numerical analysis which calculates the heat input for an increment of time and the resultant change in the helium conditions.

~ Initially there is no venting and the helium conditions are evaluated for an increase in internal energy at a constant density. This will give a rise in pressure until the relief valve lifts. As a simplification this is taken as the full flow vent pressure for the relief valve.

~ From this point the helium conditions are calculated for an increase in enthalpy at a constant pressure. The volume increase above the cryostat internal volume gives the vent flow rate.

QUENCH



The chart shows the pressure rise as the dark blue line (diamonds), the temperature as the purple line (squares), the vent mass flow rate as the red line (circles) and the retained mass or inventory as the light blue line (crosses).

The maximum vent flow rate is calculated to be 6.97 kg / s which is 25 100 kg / hr.

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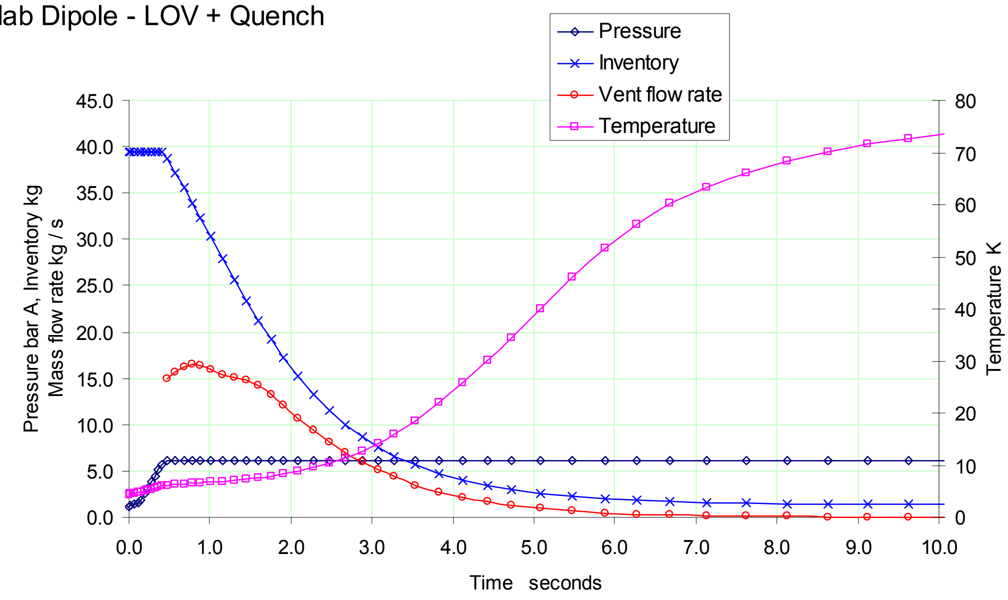
QUENCH + LOSS OF VACUUM



The maximum vent flow rate is 16.50 kg / s which is 59 400 kg / hr.

RELIEF VALVE

The relief valve for the quench condition is based on the valve proposed in the JLab report “safety_analysis_Dec_2010.pdf”.

	Manufacturer		Anderson Greenwood		
	Type		Pilot operated relief valve		
	Part number		25905K34 / S		
	Orifice diameter	38.9	mm		
	Orifice area	1186	mm²	1.287	in²
	Effective nozzle coefficient of discharge	0.975			
	Set pressure	4.05	bar G	4.00	atm
	Fully open pressure	5.47	bar A	79.4	psi A
Gas conditions	Fluid		Helium		
	Molar mass	4.003	kg / kgmol		
	Pressure	5.472	bar A	79.4	psi A
	Temperature	6.5	K	11.7	R
	Isentropic coefficient	3.87			
	Compressibility factor	0.9244			
	Density	86.42	kg / m³	5.395	lb / ft³
	Compressibility function	480.2			
	Back pressure correction factor	1.000			
	Relieving capacity	26460	kg / hr	58340	lb / hr

BURST DISC

The burst disc is mounted on a 4.000" nb 10s pipe which has an inside diameter of 108.2 mm and a length of 790 mm. The pipe includes a non return valve. The Kv value for this device is estimated as 150. The design figure for this valve should be advised by JLab.

The pressure drop across the burst disc is calculated as follows.

	Manufacturer		FIKE		
	Type		AXIUS Low Pressure		
	Orifice area	8194	mm²	12.7	in²
	Orifice diameter	102.8	mm	4.02	in
	K_R	0.45			
Gas conditions	Fluid		Helium		
	Molar mass	4.003	kg / kgmol		
	Pressure	6.08	bar A		
	Temperature	8.0	K		
	Density	36.59	kg / m³		
	Mass flow rate	16.50	kg / s		
	Pressure drop	249	mbar		

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The pressure drop for the vent pipe passing 16.5 kg / s is therefore listed as follows:

Entry contraction loss	65.6	mbar
Pipe loss130 mm at 4.7 mbar per metre	0.6	mbar
Non-Return Valve (Kv of 150)	1380	mbar
Pipe loss660 mm at 5.0 mbar per metre	3.3	mbar
Burst disc	249	mbar

Therefore the total pressure drop from the reservoir to the downstream side of the burst disc is 1.7 bar. Since the internal pressure is 5.08 bar G, this leaves sufficient pressure to move the gas through the pipe which will be downstream of the burst disc. (Any changes in section should be gradual and the pipe should be insulated to reduce the effect of air condensation.)

The gas velocity in the pipe is 16 m / s before the non-return valve and 17 m / s downstream of the non-return valve.

CONCLUSIONS

The vent flow rate at a pressure of 5.47 bar A for a quench is conservatively estimated as 25 100 kg / hr. A relief valve 25905J34 / S from Anderson Greenwood has a flow capacity of 26 500 kg / hr.

The vent flow rate for a quench and a loss of vacuum at a pressure of 6.08 bar A is estimated as 59 400 kg / hr. The vent pipe with the burst disc will pass this flow with a pressure drop of 1 700 mbar.

The flow capacity of the non-return valve in the CCR vent pipe should be confirmed by JLab.

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