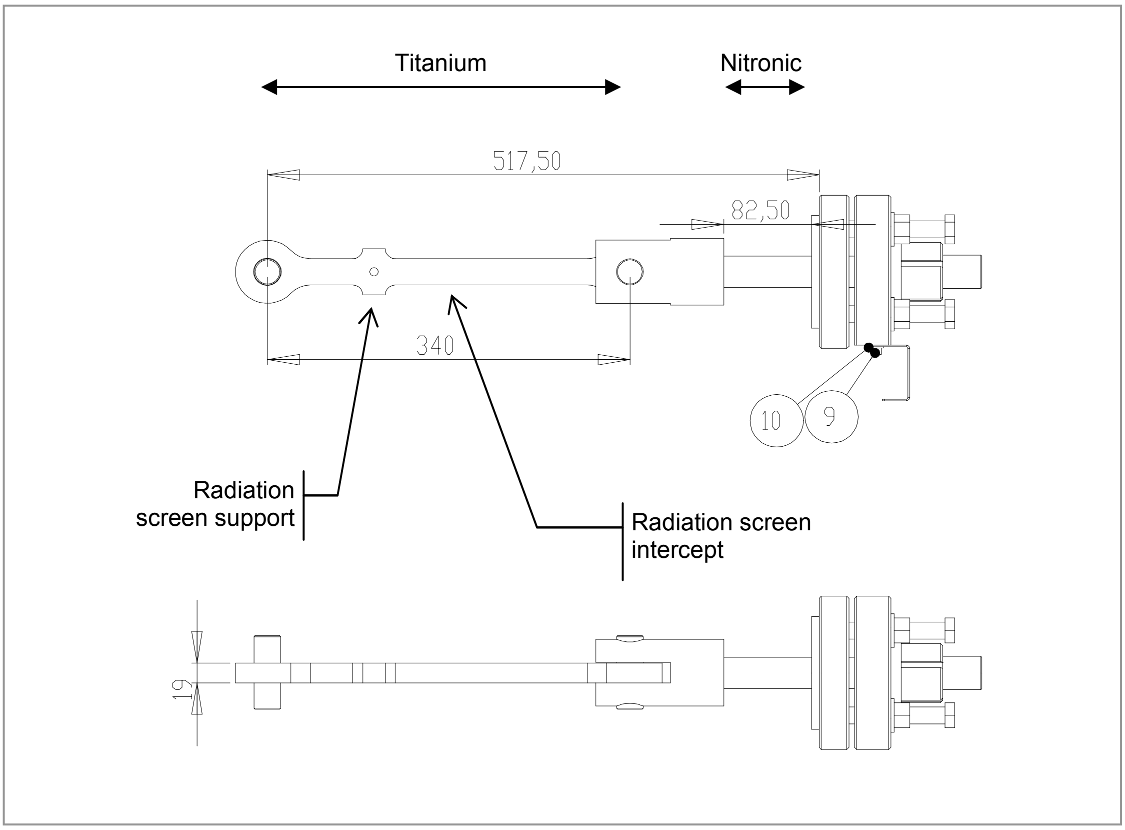
MAGNET SUPPORT STRUTS

This design note summarises the design of the magnet support struts.



The radiation screen will be supported on a pin located on the titanium strut.

There will be a thermal intercept at a warmer position which will be linked to the radiation screen by a copper braid.

The design logic considers that the pins supporting the radiation screen will provide poor thermal contact with the titanium strut compared to the thermal intercept. The worst case option is that the pin will hold the strut at 78 K and the thermal intercept will do the same. Effectively this will shorten the length of the titanium strut

This report uses calculations in the spreadsheet “JLab Dipole 210_4 Supports & Ti props.xls” to review this.

Rev	Date	Description

DESIGN METHOD

The analysis assumes the following:

1. The Nitronic section has the same conductivity as stainless steel.
2. The temperature between the titanium section and the nitronic section is adjusted until the heat load of each section is balanced.
3. The large diameter Nitronic section into which is pinned the warm end of titanium support is at a uniform temperature.
4. The Nitronic section has a diameter of 30 mm and a length of 82.5 mm.
5. The titanium strut has a rectangular section of 25 mm by 19 mm. The length depends on the position of the thermal intercept and the mechanical support of the radiation screen.
6. There is a temperature offset between the radiation screen and the titanium strut to allow for the temperature drop in the copper braid and the temperature drop across the contact interfaces.
7. It is not practical to change the position of the mechanical support for the liquid nitrogen radiation screen without significant design changes and cost.

ANALYSIS

Five cases are studied and the results compared.

Case 1	There is no thermal intercept. The heat load from room temperature is loaded onto the 4 K surfaces.
Case 2	The thermal intercept, which is connected to the liquid nitrogen cooled radiation screen, is located on the strut where the temperature is 84 K. This position is between the radiation screen support pin and the cold end at 4 K.
Case 3	The thermal intercept, which is connected to the liquid nitrogen cooled radiation screen, is located at the pin which supports the radiation screen.
Case 4	The thermal intercept is moved towards the warm end of the support. This point becomes grounded at 84 K. There is no heat load into the support at the mechanical support of the radiation screen.
Case 5	The thermal intercept is moved towards the warm end of the support. This point becomes grounded at 84 K. However the mechanical support becomes grounded at the temperature of the liquid nitrogen radiation screen.

In practise the heat load will lie between the results for Cases 4 & 5.

CASE 1 NO THERMAL INTERCEPT

		Nitronic	Titanium	
Nitronic	effective length	82.5	300	mm
	heat flux area	707	475	mm²
	hot temperature	295	278	K
	cold temperature	278	5	K
	integrated thermal conductivity	232	1255	W / m.K
	Single support heat load	1.99	1.99	W
	Liquid nitrogen heat load		n-a	
	Single support liquid helium heat load		1.99	W per strut

CASE 2 THERMAL INTERCEPT COINCIDES WITH THE 84 K POINT ON THE STRUT

Warm Length		Nitronic	Titanium	
	effective length	82.5	237	mm
	heat flux area	707	475	mm²
	hot temperature	295	276	K
	cold temperature	276	84	K
	integrated thermal conductivity	250	1066	W / m.K
	Single support heat load	2.14	2.14	W

Cold Length		Titanium	
	effective length	45	mm
	heat flux area	475	mm²
	hot temperature	84	K
	cold temperature	5	K
	integrated thermal conductivity	179	W / m.K
	Single support heat load	1.98	W
	Liquid nitrogen heat load	0.16	W per strut
	Liquid helium heat load	1.98	W per strut

Case 3 Thermal Intercept & Radiation Screen Support Together

Warm Length	Nitronic	Titanium	
effective length	82.5	210	mm
heat flux area	707	475	mm²
hot temperature	295	274	K
cold temperature	274	84	K
integrated thermal conductivity	278	1051	W / m.K
Single support heat load	2.38	2.38	W

Cold Length	Titanium	
effective length	70	mm
heat flux area	475	mm²
hot temperature	84	K
cold temperature	5	K
integrated thermal conductivity	179	W / m.K
Single support heat load	1.22	W

Liquid nitrogen heat load	1.16	W per strut
Liquid helium heat load	1.22	W per strut

Case 4 Thermal Intercept moved towards the Warm End
No Heating from the Radiation Screen Mechanical Support

Warm Length	Nitronic	Titanium	
effective length	82.5	140	mm
heat flux area	707	475	mm²
hot temperature	295	265	K
cold temperature	265	84	K
integrated thermal conductivity	392	989	W / m.K
Single support heat load	3.36	3.36	W

Cold Length	Titanium	
effective length	120	mm
heat flux area	475	mm²
hot temperature	84	K
cold temperature	5	K
integrated thermal conductivity	179	W / m.K
Single support heat load	0.71	W

Liquid nitrogen heat load	2.65	W per strut
Liquid helium heat load	0.71	W per strut

CASE 5 THERMAL INTERCEPT MOVED TOWARDS THE WARM END
THE RADIATION SCREEN MECHANICAL SUPPORT AT 84 K

Warm Length	Nitronic	Titanium	
effective length	82.5	140	mm
heat flux area	707	475	mm²
hot temperature	295	265	K
cold temperature	265	84	K
integrated thermal conductivity	392	989	W / m.K
Single support heat load	3.36	3.36	W

Cold Length	Titanium	
effective length	70	mm
heat flux area	475	mm²
hot temperature	84	K
cold temperature	5	K
integrated thermal conductivity	179	W / m.K
Single support heat load	1.22	W
Liquid nitrogen heat load	2.14	W per strut
Liquid helium heat load	1.22	W per strut

These results are summarised in the following table.

	Description	Heat Load to Screen		Heat load to Helium Vessel	
		Gross	Net		
Case 1	No intercept	n-a	n-a	2.0	W
Case 2	Thermal intercept coincides with the 84 K point on the strut	2.14	0.16	1.98	W
Case 3	Intercept & screen support at the same position	2.38	1.16	1.22	W
Case 4	Intercept at a warmer position compared to the screen support	3.36	2.65	0.71	W
Case 5	Intercept at a warmer position. The mechanical support of the radiation screen warms the strut.	3.36	2.14	1.22	W

The simple design with no intercept (Case 1) offers an advantage that no "effective length" is lost from the strut to accommodate clamps or pins. The entire length is be used to provide thermal isolation. However without a thermal intercept the heat load to the 4 K surface is high.

In Case 2 the thermal intercept coincides with the position on the strut which is 84 K. Therefore the liquid nitrogen screen does no effective cooling and the reduction of the heat load to the helium vessel is negligible.

In Case 3 the intercept is moved towards the warm end and onto the mechanical support of the radiation screen. The liquid nitrogen radiation screen is now cooling the strut and there is a reduction in the heat load to the helium vessel.

When the intercept is moved to a warmer position (Case 4) there is more cooling provided by the liquid nitrogen radiation screen and a more significant reduction in the heat load to the helium vessel. This assumes that the radiation screen support provides no heating to the strut.

If the mechanical support of the radiation screen does warms the titanium strut, then the heat load onto the helium vessel will increase to 1.22 W. In other words it reverts to the heat load on the helium surfaces of Case 3 and the heat load on the radiation screen of Case 4 which is the worst of both Cases 3 & 4.

Therefore the up-side is a heat load as low as 0.7 W on the helium vessel; the down-side is a heat load on the helium vessel of 1.2 W which is still lower than the original design of 2.0 W but a higher heat load on the liquid nitrogen cooled radiation screen of 3.4 W instead of 2.4 W. The extra heat load on the liquid nitrogen cooled radiation screen is not significant compared to the potential saving in the liquid helium heat load.

In this context the thermal intercept should be located at the warmer position as for Case 4

COPPER BRAID

Taking the results of Case 4 the braid has to carry a heat load of 2.7 W. Assume that the braid has a cross sectional area of 20 mm by 15 mm and that that the filling factor is 60% so that the copper area is 180 mm². At a length of 120 mm and a thermal conductivity of 764 W / m.K for Oxygen Free High Conductivity Copper (C103) then the temperature drop on the braided length is 2.3 K which is acceptable. Electrolytic Tough Pitch Copper (C101) has a thermal conductivity of 820 W / m.K and will give a comparable result. Phosphorous De-Oxidised Copper (C103) has a thermal conductivity of 135 W / m.K and, will give a temperature drop which is about 5 times higher and therefore should not be used.

CLAMPING THE BRAID TO THE STRUT

The braid should be formed into a solid block at the ends where the clamping joints are made either by brazing or be some other valid technique.

CLAMPING FORCE

With reference to the paper “The effect of solid interaction on thermal contact resistance at low temperature”, Advances in Cryogenic Engineering Volume 43, a simple correlation has been made for the heat conductance across a joint as a function of modulus, thermal conductivity, roughness and clamping force. A Belville washer on a 6 mm fastener should be used to impose a clamping force of about 300 N. Using the properties of Oxygen Free High Conductivity Copper the temperature drop at a heat load of 2.6 W is predicted to be 0.2 K on each contact surface which is acceptable.

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