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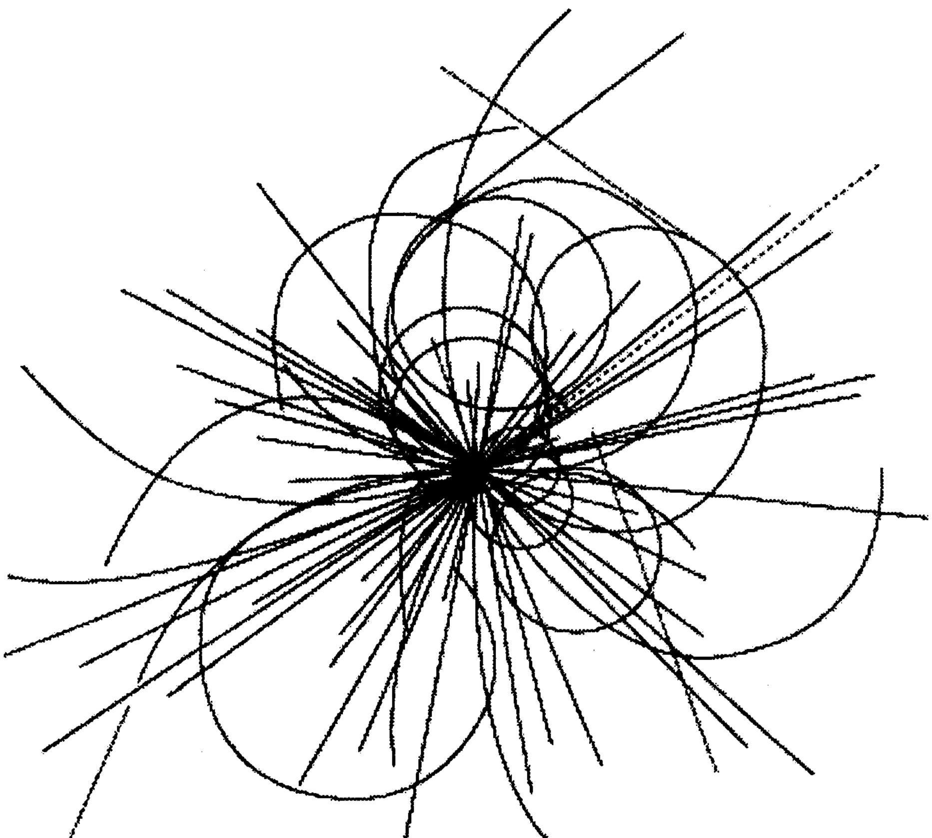

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COLLIDER QUADRUPOLE MAGNET (CQM) OPTICAL ALIGNMENT WINDOW HEAT LEAK PREDICTION

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SUMMARY

The additional static heat leak to the cryogenic refrigeration systems of an SSC Collider Quadrupole Magnet (CQM) due to the Optical Alignment Window apparatus was calculated for three configurations: (1) panes in the 20K shield, 80K shield, and vacuum vessel, (2) empty aperture in the 20K shield and panes in the 80K shield and vacuum vessel, and (3) empty apertures in both the 20K and 80K shields and a pane in the vacuum vessel only. In addition, two cases for pane infrared optical coating configuration were simulated: (1) coating on both sides of a pane and (2) coating on the top side of a pane only. For a four windows per magnet design, the results of the analysis show that the 4K and the 20K total static heat leak budgets will be exceeded only for the empty apertures in both of the shields configuration. This result applies for a single side or double sided coated pane. The existing baseline configuration (no 20K shield pane, pane in 80K shield, pane top side coated) is sufficient to meet the CQM total static heat leak budget.

There is not enough difference between the thermal performance of the windows with both sides or only one side of the panes coated to affect whether or not the heat leak exceeds budget due to the windows, therefore it will not necessary to coat both sides of the panes to meet the existing CQM static heat leak budget. Since the 4K static heat leak for the configuration without a pane in the 80K shield grossly exceeds budget, the optical window assembly will have to include a pane in the 80K shield.

ANALYSIS

The CQM Optical Alignment Window configuration consists of a polished stainless steel alignment mirror affixed to the Cold Mass, above which is located a single circular aperture in each of the 20K shield, 80K shield, and vacuum vessel cryostat components. The apertures allow the mirror to be viewed by the alignment instrument outside of the vacuum vessel. The baseline design calls for a total of four such windows in each CQM. The shields do not have to contain a pane to meet any vacuum quality or integrity requirements, thus a

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simple empty aperture cut through the shields would suffice, unless required to minimize heat leak. The current baseline design [1] specifies a pane in the 80K shield but not in the 20K shield. Where a pane is present, it will consist of ordinary optical quartz window glass with an infrared reflecting, visibly transmitting optical coating of indium-tin oxide (ITO) applied over the entire top surface of the pane. The total hemispherical emissivity of the coated surface of the glass used by the optics consultant, Precision Optics, in their analysis is 0.15, and of the uncoated surface is 0.5. These emissivity values were used in this heat leak analysis. The vacuum vessel aperture is 4 cm diameter, the shield apertures are 5 cm diameter, and the Cold Mass mirror is 4 cm diameter. The cryostat configuration for the LBL 40mm Quadrupole was used as the magnet baseline for this analysis.

A diagram of the thermal model of a single window is shown in Figure 1. The additional heat leak due to the presence of the optical alignment window is due primarily to the increase in thermal radiation heat transfer from glass panes in a higher temperature cryostat component to the adjacent lower temperature cryostat components and pane, and from the direct thermal radiation between non-adjacent components (such as the 80K shield and Cold Mass) possible where an empty aperture permits such surfaces to see each other. The thermal radiation between adjacent components, such as the vacuum vessel and the 80K shield, increases over that for a configuration without windows since the emissivity of the coated or uncoated glass is higher than that of the metal surfaces (aluminum or stainless steel) which it replaces at an aperture. Ordinary optical window glass has a narrow band of high (0.9) transmittance from 0.2 μm to 3 μm which covers the visible and near infrared bands. The transmittance of glass in the far-infrared beyond 3 μm, where 99.99% of the total thermal radiation energy for bodies below 310 K is emitted, is essentially zero, so that the glass panes simply appear as higher emissivity patches on the shields for purposes of thermal radiation modeling. However, where an empty aperture appears, thermal radiation from a higher temperature cryostat component beyond the aperture is allowed to pass through the hole and fall on a surface which would normally be protected by the adjacent apertureless surface, in the windowless configuration.

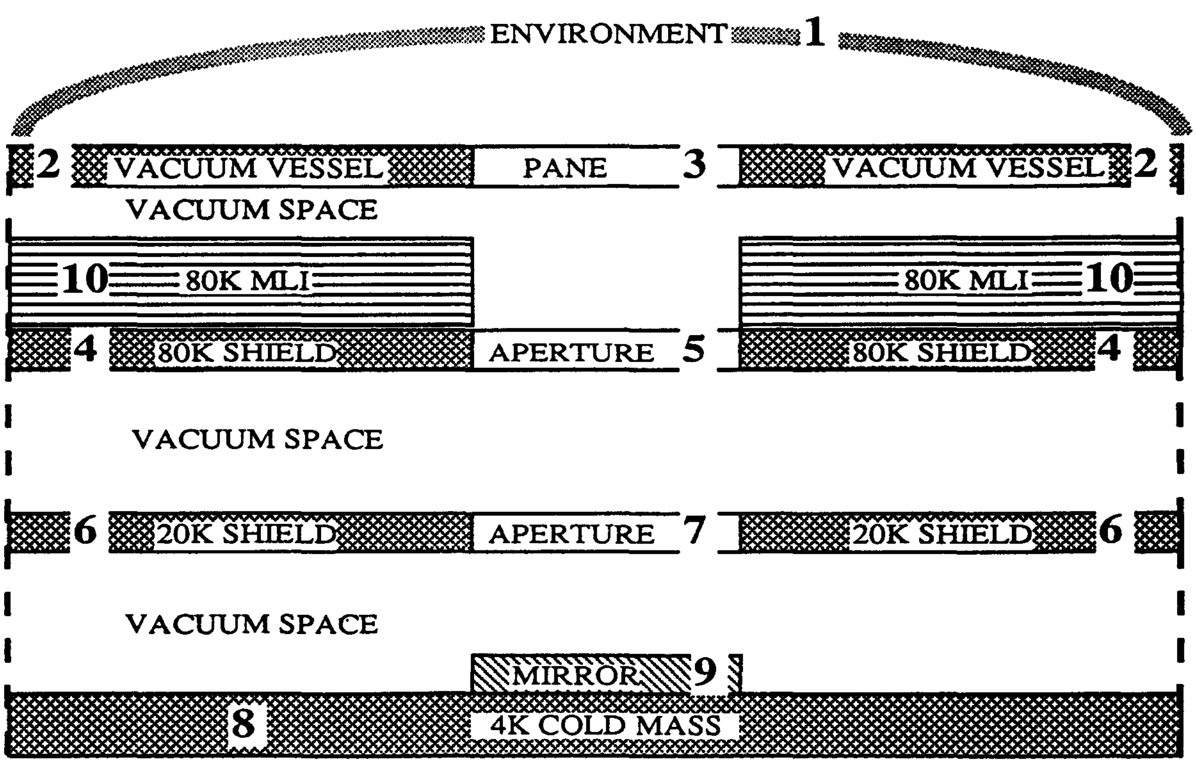

Figure 1: CQM Optical Alignment Window Thermal Model Configuration

The increase in heat leak due to the presence of the window from residual gas conduction is insignificant above 20K since residual gas conduction at collider vacuum design levels (1E-6 torr) is insignificant compared to radiation. The increase in the 4K total static heat leak due to residual gas conduction between the 80K shield and the Cold Mass through the empty aperture in the 20K shield was ignored in this analysis since it is also not significant compared to the thermal radiation.

The additional heat leak for each of the three cryogenic systems due to the optical alignment window from thermal radiation was calculated on a per window and per CQM basis for Collider operational conditions using an Excel spreadsheet. The Quadrupole Thermal Model was not needed for the calculation. The temperature of the vacuum vessel, 80K shield, 20K shield, and 4K Cold Mass were fixed at 310, 84, 20, and 4.2 K for purposes of this analysis, based on previous results from the full Quadrupole Thermal Model [2]. The temperature of the glass panes, where present, was assumed to be the same as that of the cryostat component in which they were emplaced, based on results of the pane thermal analysis [1] which showed that the maximum difference in pane to structure temperature would only be 6 K where the ITO coating was used.

RESULTS

The predicted total static heat leaks per CQM with 4 windows (<u>not</u> per window) due to the Optical Alignment Windows are shown in Table 1. Table 1 pertains to the baseline case of panes coated on the top side only, except for the entries showing the heat leak due to the windows for the both sides coated case as identified. Table 1 displays the design heat leak for each system both with and without the windows and compares the design with the budget heat leak. The comparison values apply only to the top side coated case only.

The results presented in Table 1 for the CQM with four Windows show that none of the heat leaks will exceed budget for either the baseline configuration (no pane in 20K shield) or the configuration with a pane in both shields, for either the top or both sides of the panes coated. There is no significant difference in the design to budget heat leak margin between these two acceptable configurations. The heat leak for both pane sides coated is always less than that for the top pane side only coated as expected. There is no need for further consideration of a pane in the 20K shield to meet heat leak requirements, as the current baseline is sufficient. In fact, the number of windows per magnet could be increased. In addition, the ITO coating on the top surface of the panes is also sufficient, and coating of both sides of the panes will not be necessary to meet static heat leak requirements for either of the acceptable configurations.

Table 1 shows that the 20K heat leak and the 4K heat leak will be significantly, exceeded for the configuration with no pane in both of the shields, for either the top or both sides of the vacuum vessel pane coated. The large increase in 4K heat leak is due entirely to direct exposure to the 310 K vacuum vessel and pane when the 80K shield pane is removed, as a consequence of the absolute temperature to the 4th power nature of thermal radiation heat transfer. The heat leak per window (not shown) also exceeds the 4K total static budget significantly, so that a reduction in the number of windows per CQM would not allow the removal of the 80K shield pane from the design. The configuration without an 80K shield pane is unacceptable since it exceeds the 4K heat leak requirements and should not be considered further.

The small net decrease in 80K heat leak for the configuration without an 80K pane is attributable to several phenomena. The increase in 80K heat leak for the other two configurations was entirely due to the higher emissivity of the pane than the shield which it replaced, coupled with the fact that the 80K shield is covered with MLI. The increase in 80K heat leak with an 80K pane was entirely localized in the pane, rather than over the entire shield surface, since it was covered in MLI. In contrast, the increase in 20K and 4K heat leak per window is not localized to the 20K shield pane or 4K Cold Mass and mirror since all of these surfaces can exchange heat with the higher temperature surfaces above, and not just the window components. When the 80K pane is not present, there is no 80K surface to absorb thermal radiation from the vacuum vessel wall and pane, and this heat is transferred entirely to the 20K and 4K surfaces below, decreasing the 80K heat leak in comparison with no window present.

Table 1. Predicted CQM Heat Leaks with Optical Alignment Windows

Heat Leak Parameter [All in Watts except Relative Difference]	Pane in 20K and 80K Shields	Baseline: No Pane in 20K Shield	No Pane in 20K or 80K Shield
80K Total Static Design Heat Leak w/o Windows	13.705	13.705	13.705
80K Static Heat Leak due to Windows, Top Coated	**0.866**	**0.854**	**-0.016**
80K Static Heat Leak due to Windows, Both Coated	**0.721**	**0.711**	**-0.020**
80K Total Static Design Heat Leak With Windows	14.571	14.559	13.689
80K Total Static Budget Heat Leak	14.970	14.970	14.970
80K Total Static Heat Leak Design - Budget	-0.399	-0.412	-1.281
Relative Difference, Design vs. Budget	-2.7%	-2.7%	-8.6%
80K Heat Leak Budget Status	**UNDER**	**UNDER**	**UNDER**
20K Total Static Design Heat Leak w/o Windows	1.068	1.068	1.068
20K Static Heat Leak due to Windows, Top Coated	**0.012**	**0.006**	**1.794**
20K Static Heat Leak due to Windows, Both Coated	**0.006**	**0.002**	**1.633**
20K Total Static Design Heat Leak With Windows	1.080	1.074	2.862
20K Total Static Budget Heat Leak	2.081	2.081	2.081
20K Total Static Heat Leak Design - Budget	-1.001	-1.007	0.781
Relative Difference, Design vs. Budget	-48.1%	-48.4%	37.5%
20K Heat Leak Budget Status	**UNDER**	**UNDER**	**OVER**
4K Total Static Design Heat Leak w/o Windows	0.086	0.086	0.086
4K Static Heat Leak due to Windows, Top Coated	**0.000**	**0.018**	**2.001**
4K Static Heat Leak due to Windows, Both Coated	**0.000**	**0.014**	**1.804**
4K Total Static Design Heat Leak With Windows	0.086	0.104	2.087
4K Total Static Budget Heat Leak	0.232	0.232	0.232
4K Total Static Heat Leak Design - Budget	-0.146	-0.128	1.855
Relative Difference, Design vs. Budget	-62.9%	-55.0%	798.9%
4K Heat Leak Budget Status	**UNDER**	**UNDER**	**OVER**

In conclusion, the results of the thermal analysis showed that the baseline configuration of a pane in the 80K shield and no pane in the 20K shield with top side of the pane only coated would not introduce sufficient additional heat leak into the cryostat to exceed the present CQM static heat leak budgets.

ACKNOWLEDGMENTS

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