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OCH SPACER DESIGN

C.H. Kurita

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Approved:

A handwritten signature in cursive script, appearing to read "R. J. Kempf", is written over a horizontal line.

INTRODUCTION

The purpose of the OCH module spacers is to keep the given dimension of .224" between the 1.83" absorber plates. This distance is determined by two liquid argon gaps of .09" each and a readout board of .044". The spacer should be made out of a material that would give a minimum thermal contraction movement. Also the dimension of the spacer will be determined dependent upon the load applied to the spacers and the strength of the material chosen.

SPACER POSITIONING

The load placed on the spacers throughout the plane of the copper plates cannot be assumed to be evenly distributed due to variations in the flatness of the plate. Such variations can cause some spacers to receive more of the load than others, which can in turn, lead to their yielding. By making the spacers larger, and thus increasing their strength, the effective area of the plates and readout boards would also be decreased. Instead, four load bearing spacers shall be used, one near each of the corners of the plate. The spacers shall be placed about 1" in from the corners to allow room for the notches needed for wiring. While the purpose of the spacers is to maintain a given dimension between the copper plates, and thus have a certain thermal contraction, because of their positioning, it is also very important that they are made of a material strong enough to bear the imposed load.

THERMAL CONTRACTION

The spacers need to be made out of a material that minimizes thermal contraction when the module is cooled down. The absorber plates are made out of 1.83" copper, and the end plates, intermediate plates, and skin, which hold the module together, are made out of SS304. Thus, on a per cell basis, the dimension of the copper involved in each cell is 1.83" (.915" from each plate on either side), and the SS304 dimension is 2.054", see Fig. 1, next page.

Fig. 1 Unit cell

Referring to the Brookhaven National Laboratory Selected Cryogenic Data Notebook for thermal expansion values, it is found that the thermal expansion for copper in going from ambient temperature (294.1 K) to that of liquid argon (87 K) is 308.57×10^{-5} . Therefore, for the given dimension of copper, there is a contraction of $0.00564683"$. For SS304, the thermal expansion is 285.87×10^{-5} , and its corresponding contraction is $0.00587177"$.

The displacement of the copper is less than that of the SS304, so it is therefore desirable to have the spacers made out of a material with a thermal contraction which, when added to that of the copper, compensates for the difference between the contractions of the copper and the SS304. Improper contraction of the spacers could result in the loosening or tightening of the copper plates and readout boards in the module. The desired thermal contraction for the spacer material is 100.42×10^{-5} . Invar-36 has a thermal contraction of 51.22×10^{-5} for the transition between ambient temperature and liquid argon temperature, and it would be a suitable material from which to construct the spacers, provided that its yielding point is high enough to handle the stresses applied when it is loaded, and it is at 35,000 PSI. However, since the thermal contraction of Invar-36 is less than that desired for zero displacement, if used alone, there would still be a difference in displacements of $0.00011473"$, about 51% of the original displacement. While an alloy of Invar could probably be found, which would have a closer thermal contraction, there is another alternative. This remaining displacement could be compensated for by the addition of a SS304 washer between the Invar-36 spacer and the

copper plate. With the dimension of the total gap to be filled and the thermal contraction of both Invar-36 and SS304 known, the proper dimension of each material needed for zero displacement can be calculated. It is found that the Invar-36 spacer should be 0.15394250", and the thickness of the SS304 washer 0.07005750". See Appendix A for calculations.

SPACER DIMENSION

In order to determine the dimension of the spacers, it is necessary to find the maximum force and allowable stress of the spacer. By using the cantilever beam for an example of creating the greatest moment at the end of the beam while being supported, this moment is found to be 318,671 lb-in when the applied load is 11,465.19 lbs. To counteract this moment, there is a tensile force present at the top of the beam and a compressive force at the bottom which form a couple that equalizes the moment produced by the load of the beam.

Looking at a cross section of the beam to determine the force acting on the spacers, it can be seen that these forces are probably not equally distributed amongst the four spacers because, when looked at symmetrically, the top spacers will separate when a tensile force is applied since they are only attached to one side of the plate. The skin at the top will then take all of the tensile load, while at the bottom, the spacers will also be subject to some of the compressive load in addition to the skin. At the bottom, the load per spacer would be 6,404.9 lbs, independent of which edge of the trapezoid, the longer of the shorter, is placed on top, see Fig. 2. Although the neutral axis does not lie at the intersection of the midpoints of the trapezoid, its positioning does not effect the magnitude of the forces at the top and bottom of the plates because these forces are found to be equal. The load per spacer is only dependent upon the overall distance from the top to the bottom of the plate, normal to the line of the neutral axis.

Fig. 2

However, if the beam is positioned as in Fig. 3, only one spacer will essentially see the load because the top one will separate in tension, and the other two will basically cancel each other out. In this manner, the load per spacer is 8,756.6 lbs, again independent of which edge of the trapezoid is on top.

Fig. 3

In addition to the load applied by the weight of the module itself, there is also a compressive force produced at the time when the skins are welded together. This force can be calculated from the strain measurement of 0.000193 PSI in the skin and is found to be 10,036.6 lbs. This compressive force seen by the spacers is a tensile force to the skins. When compressively loaded, the skin, which is in tension, will become less tense the more that it is loaded until it reaches a point where it will begin to go into compression. However, because this "pre-load" tension caused by the welding of the skins is greater than the worst possible case of loading due to the weight of the module, which is 8,756.6 lbs (the case in Fig. 3), the tension in the skins will counteract with the cantilever force and the spacers should not have to bear any additional compressive load other than the pre-load compressive force. Using this pre-load value of 10,036.6 lbs and the desired value for stress when there is a safety factor of 2, the area of the spacer can be calculated, and its proper dimension can be found. The yield stress of both Invar-36 and SS304 is 35,000 PSI, and the desired stress for the spacers is 50% of that, or 17,500 PSI. The calculated area is 0.57352000 in^2 , and the needed diameter of the spacer is therefore 0.85453399". See Appendix B for calculations of the neutral axis of the trapezoid, largest possible moment, force per spacer, and dimension of spacer.

CONCLUSION

Considering both thermal contraction and yield strength, it is found that Invar-36 would be a suitable material from which to make the spacers for the OCH module, provided that SS304 washers are used in conjunction with the spacers. The spacers would be positioned about 1" from the corners of each of the copper plates, and would have a diameter of about 0.85453399". The thickness of the Invar spacer would be 0.15394250" and that of the SS304 would be 0.07005750". This combination of materials used for spacing purposes should result in zero displacement due to thermal contraction and no buckling due to overloading. The actual design of the spacer can be found in DWG. 3740.222-MB-223758.

$\pm .001$
→ .164 ←

.875 DIA.
STOCK

$\frac{1}{32} \times 45^\circ$ CHAMFER

REV.	DESCRIPTION	DRAWN	DATE
		APPD.	DATE
A	ADD CHAMFER	JM	2/13/87
		G.D	3/13/87

UNLESS OTHERWISE SPECIFIED			OPERATOR	KRAMPETZ	
FRACTIONS	DECIMALS	ANGLES	DRAWN	MATESEI	2-3-87
2. <i>1/64</i>	<i>.005</i>	<i>1/16</i>	CHECKED	K. WEBER	2-12-87
1. BREAK ALL SHARP EDGES 1/64 MAX.			APPROVED	R. LUTHER	2-10-87
2. DO NOT SCALE DWG.			USED ON 3740.222-ME-223756		
3. DIMENSIONING IN ACCORD WITH ANSI Y14.5 STD's.			MATERIAL INVAR 36		
✓ MAX. ALL MACHINED SURFACES
FERMI NATIONAL ACCELERATOR LABORATORY U.S. DEPARTMENT OF ENERGY					
DP DETECTOR END CALORIMETER - O.H. MODULE INVAR-COLL B SPACER BUTTON					
SCALE	PLANS	DRAWING NUMBER	REV.		
4:1		3740.222-MB-223758	A		

APPENDIX A**THERMAL CONTRACTION (per unit cell)**

length of copper in unit cell= $L_{Cu}=1.83"$

length of SS304 in unit cell= $L_{SS}=1.83"+.224"=2.054"$

length of gap between plates= $L_g=.224"$

number of copper plates=number of unit cells=20

number of gaps = 23

number of extra gaps not included in unit cells=3

thermal contraction, $e_t=\Delta L/L$

ambient temperature: 70 F=21.1 C=294.1 K

liquid argon temperature: 87 K

Interpolating from referenced tables:

Cu

at 294.1 K: $e_t=(300-294.1)/(300-293)*(-11-0)+0=-9.27$

(*e-5)

at 87 K: $e_t=(90-87)/(90-80)*(293-302)+302=299.3$

$\Delta e_{tCu}=308.57e-5$

SS304

at 294.1 K: $e_t=(300-294.1)/(300-293)*(-11-0)+0=-9.27$

(*e-5)

at 87 K: $e_t=(90-87)/(90-80)*(271-279)+279=276.6$

$\Delta e_{tss}=285.87e-5$

Invar-36

$$\text{at } 294.1 \text{ K: } e_t = (300 - 294.1) / (300 - 293) * (-1.8 - 0) + 0 = -1.52$$

(*e-5)

$$\text{at } 87 \text{ K: } e_t = (90 - 87) / (90 - 80) * (49 - 50) + 50 = 49.7$$

$$\Delta e_{tI} = 51.22e-5$$

$$\Delta L = e_t L$$

$$\Delta L_{Cu} = (308.57e-5)(1.83") = 0.00564683"$$

$$\Delta L_{SS} = (285.87e-5)(2.054") = 0.00587177"$$

$$\Delta L_g = 0.00022454"$$

$$e_{tg} = (0.00022494") / (.224") = 0.00100420 = 100.42e-5$$

$$e_{tg} = 100.42e-5$$

if Invar-36 only:

$$\Delta L_I = (51.22e-5) * (.224") = 0.00011473"$$

$$(0.00011473") / (0.00022494") * (100) = 51\%$$

length of Invar-36 spacer = L_I length of SS304 washer = L_W number of plates = N

$$(N * L_{Cu} * e_{tCu}) + (N * L_W * e_{tW}) + (N * L_I * e_{tI}) = N * L_{SS} * e_{tSS}$$

$$L_W + L_I = L = .224", L_W = .224" - L_I$$

$$(20*1.83*308.57e-5)+(23*(.224-L_1)*285.87e-5)+(23*L_1*51.22e-5)=$$

$$(20*2.054*285.85e-5)+(3*.224*285.87e-5)$$

$$L_1=((20*2.054*285.87e-5)+(3*.224*285.87e-5)-(20*1.83*308.57e-5)$$

$$-(23*.224*285.87e-5))/(23*(51.22e-5-285.87e-5))$$

$$L_1=0.15394250"$$

$$L_w=.224-0.15394250=0.07005750"$$

$$L_w=0.07005750"$$

APPENDIX A**NEUTRAL AXIS OF COPPER PLATE/SPACER DIMENSION**

$$a=4.964''$$

$$b=34.538''$$

$$c=24.610''$$

$$d=28.025''$$

$$yl=(d/3)*(2*b+c)/(b+c)$$

$$ym=(2*b^2+2*b*c-a*b-2*a*c-c^2)/(3*(b+c))$$

$$yl=14.7965''$$

$$ym=17.269''$$

force due to the tightening of the skins when welded= F_t

thickness of skin= $0.0625''$

strain in skin= $e=0.000193$ PSI

modulus of elasticity for SS304= $E=29e6$

area of skin in cross section= A_s

$$A_s=((d/2)*(b+c))-(((d-0.125)/2)*((b-0.125)+(c-0.125)))$$

$$A_s=7.173 \text{ in}^2$$

$$Q = E * e$$

$$Q = (29e6) * (0.000193 \text{ PSI}) = 5,597 \text{ PSI}$$

$$Q = 5,597 \text{ PSI}$$

$$F_t = Q * A_s$$

$$F_t = (5,597 \text{ PSI}) * (7.173 \text{ in}^2)$$

$$F_t = 40,146.7 \text{ lbs} / 4 \text{ spacers}$$

$$F_t = 10,036.7 \text{ lbs} / \text{spacer}$$

$$\text{load from weight} = W = 11,465.19 \text{ lbs}$$

$$D = 55.605^\circ / 2 = 27.8025^\circ$$

$$M = W * D$$

$$M = (11,465.19 \text{ lbs}) / (27.8025^\circ)$$

$$M = 318,671 \text{ lb-in}$$

$$M = F_a * D_a + F_b * D_b$$

$$\sum F_x = 0 = F_b - F_a$$

$$F_a = F_b = F$$

$$M = F * (D_a + D_b)$$

$$D_a + D_b = D$$

$$M = F * D, F = M / D$$

1

$$D1 = (\cos 27.419^\circ \times 28.025'')$$

$$D1 = 24.877''$$

$$F1 = M1/D1$$

$$F1 = (318,671 \text{ lb-in}) / 24.877''$$

$$F1 = 12,809.9 \text{ lbs} / 2 \text{ spacers}$$

$$F1 = 6,404.9 \text{ lbs/spacer}$$

2

$$D2 = (\cos 27.419^\circ \times 40.9979'')$$

$$D2 = 36.392''$$

$$F2 = M/D2$$

$$F2 = (318,671 \text{ lb-in}) / (36.392'')$$

$$F2 = 8,756.6 \text{ lbs/spacer}$$

worst case

yield stress of Invar-36 = yield stress of SS304 = $\sigma_y = 35,000 \text{ PSI}$

safety factor = 2, desired stress = $\sigma_p = .5\sigma_y$

$$\sigma_p = .5 \times (35,000 \text{ PSI}) = 17,500 \text{ PSI}$$

$$\sigma = F/A, A = F/\sigma$$

$$A = (10,036.7 \text{ lbs}) / 17,500 \text{ PSI} = 0.57352000 \text{ in}^2$$

$$A = (\pi D^2) / 4, D = (4A/\pi)^{1/2}$$

$$D = (4 \times (0.57352000 \text{ in}^2) / \pi)^{1/2} = 0.85753399''$$

$$D = 0.85753399''$$