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SDC
SOLENOIDAL DETECTOR NOTES

SDC ENDPLUG CALORIMETER-WBS 2.2.10 ABSORBER PLATE FLATTENING FORCES

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Introduction

This note provides estimates of the maximum forces which would have to be applied to the endplug absorber plates to force them "flat" (for welding the second end of tie-rods) assuming they were initially crowned, but *well below* the limits of U. S. commercial steel plate flatness tolerances. These estimates are believed to be good approximations of maximum loads which will be encountered during fabrication if we use a *restricted set* of commercial stock absorber plate blanks with no subsequent surface machining or blanchard grinding.

Endplug Design Objective

The design objective of the SDC Endplug is a configuration which meets all important requirements at minimum cost. Part of our plan toward achieving that objective is to use stock absorber plates (no surface machining or grinding) wherever possible. If the plates are not flat, we will need to flatten them during assembly welding. What are the required loads?

Commercial Plate Flatness

The flatness of commercial steel plate provides a measure of the degree of difficulty in meeting our objectives. **Table 1** lists these flatness tolerances for the range of absorber plate sizes needed for the endplug.

We don't need a computer to see that the loads required to remove these kind of "distortions" would be quite high for 42 mm (1.654 inch) thick plates. Consequently, LBL endplug absorber plate fabrication drawings limit the degree of out-of-flatness with a "stock flatness specification" which typically limits the long-wave curvature sagitta of flame-cut blanks to about 0.1 inch, and the short-wave deviation to about 10 mills in 12 inches. The question addressed herein is: "Is this a reasonable spec from a loads point of view?"

Table 1 U. S. Commercial Steel Plate Flatness Tolerances (Ref. 1,2)

Stock thkns t_s,(in)	Maximum Plate Width (in) $108 \le W \le 120$	$120 \le W \le 144$	$144 \le W \le 168$
$0.50 \le t_s \le 0.75$	**1.00**	**1.12**	**1.50**
$0.75 \le t_s \le 1.00$	**0.88**	**1.00**	**1.38**
$1.00 \le t_s \le 2.00$	**0.63**	**0.69**	**1.12**

Plate Curvature Assumptions

First I assume the "worst", as received "commercial plates" are distorted with *cylindrical* curvature, with a peak sagitta of $(y_o)_{max} = 0.1$ inch for a 120 inch wide (W_r) *reference plate* under self-weight loading. This reference plate would have a radius of curvature, $R_c \approx 18{,}000$ inches calculated from: $((y_o)_{max})^2 - 2\,R_c\,(y_o)_{max} + (W_r/2)^2 = 0$.

I further assume that *all of our worst plates* of a given size and thickness used in the endplug have this same initial minimum radius of curvature.

Analysis Assumptions

Given the forgoing, the analysis herein assumes these annular plates have *spherical curvature*, with $R_s = R_c$, and approximates their stiffness to lateral loads using *flat plates formulas* from Ref. 3.

As these annular plates (outer radius, a, inner radius, b) are stacked in the endplug absorber structure's assembly/welding process, I assume they are placed concave downward, with continuous line contact from the plate beneath at **r** = a.

Table 2 provides plate dimensions for 4 regions in the endplug. Ymax is the sagitta the plate would have at it's centerline for $R_s \approx 18000$ inches, and yb is the height of the inner edge at r = b (which is removed in **Case 1** loading).

Table 2 Plate Dimensions

Absorber Plate	t (mm)	a (in)	b (in)	ymax (in)	yb (in)	≈weight Wt (lbs)
hac1 front	18	52.04	18.84	.075	.0654	1482
hac1 rear	18	61.94	22.42	.106	.0926	2100
hac2 front	42	61.94	22.42	.106	.0926	4900
hac2 rear	42	73.40	26.57	.150	.1300	6882

Loading Scenario and Flattening Force Results

There are 3 rings of tie-rods to be welded as each plate is added to the stack. The loading sequence assumes we pull the inner plate edge (r = b) down first (**Case 1**), and weld the inner-most ring of tie-rods. Then loads are applied near the middle of the annulus (**Case 2**) at r = (a + b)/2, and the middle ring of rods are welded.

Case 1 assumes the annular plates are *spherically crowned.* I approximate this situation with Case 1a of Table 24 of Reference 3 (outer edge supported, with an annular line load, w, applied at inner plate edge, ro = b) for the first ring of tie-rod welding. I calculate the line load, w(ro), at r = ro = b for y(ro) = Δy_1 = yb (using values from **Table 2**). The results of this first plate loading case are shown in **Table 3**, where W = 2 π ro w.

Table 3 Flattening Forces

Case No.	Absorber Plate	Δy (in)	unit line load w(ro) (lb/in)	total applied load, W (lb)	≈W/Wt (Ref.)
1-1	hac1 front	.0654	2.98	353	0.238
1-2	hac1 rear	.0926	2.50	353	0.168
1-3	hac2 front	.0926	31.8	4482	0.915
1-4	hac2 rear	.1300	26.8	4482	0.651
2-1	hac1 front	.00822	11.17	2487	1.678
2-2	hac1 rear	.01165	9.38	2487	1.184
2-3	hac2 front	.01165	119.2	31590	6.447
2-4	hac2 rear	.01636	100.6	31590	4.590

Case 2 assumes that the inner ring of tie-rods have been welded (using the **Case 1** conditions), and now the plates are *torrispherically crowned,* (e.g. like a thin slice through the face of a doughnut) with a peak sagitta, Δy_2, calculated from **Case 1** results. I approximated the **Case 2** situation using Case 1c of Table 24 (inner and outer plate edges supported with the line load, w(ro), applied at ro = (a + b)/2. Again, I calculate the line load, w(ro), for a given displacement, y(ro) = Δy_2. The results of the **Case 2** loading are also listed in **Table 3.**

The sagitta, Δy_2, at r = ro = (a + b)/2, for **Case 2** was calculated from home-built, **Case 1** post-processing to the Roark and Young on TK Solver (Ref. 3) routines (see TK Variable Sheets and Rule Sheets, attached) using the original plate radius, R_S, and an *approximate radius,* ρbar, (*assumed constant for* $b \leq r \leq a$) computed from **Case 1** bending moment data. First I computed a constant, average bending moment, Mrbar, using every 5th value of TK's 35 stored Mr(r) values. The approximate ρbar was then calculated from: ρbar = D/Mrbar, where, D, is the plate constant: $D = E\, t^3/(12\,(1-\mu^2))$, E is Young's Modulus, and μ is Poisson's ratio.

Finally, the annular plate's approximate torrispherical radius for **Case 2** was calculated from; $1/R_2 = 1/R_S + 1/\rho bar$, and Δy_2 (see **Table 3, Case 2**) was calculated from; $\Delta y_2 = (a^2 - 2\,a\,b + b^2)/(8\,R_2)$.

Conclusions

The required externally applied loads for bringing the inner edge of absorber plates flat for welding the inner-most ring of tie-rods are small ($W \leq 5000$ lbs) if we limit the allowed curvature of endplug stock plates with a tight flatness tolerance on purchased blanks (as on current LBL fabrication drawings). These **Case 1** loads should present no fabrication difficulties, or require special fixtures.

Maximum loads to flatten the hac 2 plates for subsequent welding of the middle ring of tie-rods (**Case 2**), however, are the order of 32,000 lbs, and will require a special fixture.

This fixture could consist of 2 stiff plates, and a central (vertical), threaded "loading rod" (≈ 2 - 2.5 inch diam.) and nut, which would be torqued from the top of the stack. The left-over, flame-cut central blank from the Endplug Adapter Ring (20M6133) could be used (under the stack) for the bottom loading fixture plate, and the blank from the Endplug Support Flange (20M6143) could be used for the top loading fixture plate (with ≈ 16 suitable, short vertical "columns" attached for welder access).

Because the sagitta for **Case 2** loading (Δy_2) is very small, we expect the subsequent (final) plate sagitta's between the 3 rings of welded tie-rods to be *extremely small,* and therefor of no consequence in the axial tolerance build-up in the endplug due to fabrication from "selected stock", commercial plates. However, the stock plate's *thickness tolerance* (build-up) will need to be reviewed by project physicists to verify acceptability.

We will undoubtedly pay a premium price for burned blanks with the nominal 0.1 inch flatness specification in the current design, but we should save a "ton" if we can avoid grinding--Approx. grinding cost: 2 plugs x 100 tonne/plug x 2204.6 lb/tonne x 1.25 $/lb ≈ $ 550 K, *assuming average $/lb for grinding (and handling) of smaller* absorber plates recently quoted to ANL for hadronic endcap modules (Ref. 4).

References

Ref. 1 Standard Mill Practices, Carbon Steel, Sheared and Universal Mill Plates, Flatness, pg. 93, data sheet excerpted from "Shapes and Plates" catalog, United States Steel, Oct. 1968.

Ref. 2 (similar flatness data from pg. 57, American Steel catalog, no date)

Ref. 3 TK Solver System : Roark & Young Application, Universal Technical Systems, Inc., Rockford, Illinois, July 1989.

Ref. 4 Private phone conversation with Norm Hill, 9/10/92--based on 2 bids only, which differed by a factor of ≈ 3.5.

"TK Variable Sheet"

Example: hac2 rear

Case 1

St	Input	Name	Output	Unit	Comment
					This file computes the uniform line that must be applied at the plate's inner radius to bring it flat from an initial edge height of ybb, and ests the crown height of the torrispher seg for the middle rod ring load set (y2)
					•••••••••••••••••••••••••••••••••••••
					--improved version of Case 1----
					this is my CASE 3--see note--this requires simultaneous iteration (guess) of w & delb to get a solution--
					--use about .01 for a first guess of delb. Use y2=(a^2-2ab+b^2)/(8 Rad2) as input y for CASE 2 (see note)
					•••••••••••••••••••••••• wlp 9/3/92
					Case 1 - Annular plate with a uniform annular line load - Page 400
		delb	.01961531	in	ybb+delb=ymax
L		w	-26.842	lb/in	Uniform annular line load
L	26.5735	r0		in	Radius to annular line load
					Table 24 - Roark & Young (6 ed) Formulas for flat circular plates of constant thickness
		case	'Case_1a		••••• Reference number
		caution	'_		Caution Message
		caution	'_		
		matl#			Material Number (See Material Table)
		matl			Material name
		plot	'y		Generate plots? 'n=no (Default=yes)
	3E7	E		psi	Young's Modulus
	.3	nu			Poisson's ratio
L	73.3997	a		in	Outer Radius
L	26.5735	b		in	Inner Radius
L	1.6535	t		in	Plate Thickness
		D	12420679	in-lb	Plate Constant
					AT RADIUS:
L	26.5735	r		in	Radius
L	.130038	y		in	Deflection
		th	-.003136	rad	Radial Slope Angle
		Mr	0	in-lb/in	Radial Bending Moment
		Mt	-1333.868	in-lb/in	Tangential Bending Moment
		Q	0	lb/in	Shear Force
		sigma_r	0	psi	Radial Bending Stress
		sigma_t	-2927.07	psi	Tangential Bending Stress
					AT OUTER EDGE:
		ya	0	in	Deflection
		tha	-.0025441	rad	Radial Slope Angle
		Mra	0	in-lb/in	Radial Bending Moment
		Qa	9.718	lb/in	Shear Force
					AT INNER EDGE:
		yb	.130038	in	Deflection

St	Input	Name	Output	Unit	Comment
		thb	-.003136	rad	Radial Slope Angle
		Mrb	0	in-lb/in	Radial Bending Moment
		Qb	0	lb/in	Shear Force
	188.73	zo		in	approx ip dis to h1 front pl
		theti	.09949199		
		theto	.26903599		
	3	etai			
	2	etao			
		zh1f	188.73		
		zh1b	224.63551		
	.70866142	th1p			
	.23622047	tw			
		zh2f	224.63551		
		zh2b	266.21031		
	1.6535433	th2p			
		roh1f	52.036742		
		rih1f	18.839325		
		roh1b	61.93663		
		rih1b	22.423469		
		roh2f	61.93663		
		rih2f	22.423469		
		roh2b	73.399658		
		rih2b	26.573532		
		a1	52.036742		
		a2	61.93663		
		a3	61.93663		
		a4	73.399658		
		b1	18.839325		
		b2	22.423469		
		b3	22.423469		
		b4	26.573532		
		t1	.70866142		hac1 plate thickness
		t2	.70866142		"
		t3	1.6535433		hac2 plate thickness
		t4	1.6535433		"
		ro1	18.839325		
		ro2	22.423469		
		ro3	22.423469		
		ro4	26.573532		
L		ymax	.14965326	in	assumed max init. out-of-flat
		Ftot	-4481.693	lb	tot. reqd flattening force
	120	W120		in	Width of reference plate
	.1	yomax		in	sagitta of reference plate
		Rad	18000.05	in	initial rad of curvature spher. cap (RUFF rad of curvat. for 2nd load set)
L		ybb	.13003795	in	height at b for yomax=0.1
					..... plate curvature due to this loading .....
		apMrmx	112.61407	in-lb/in	apMrmx=max(abs('Mrp[10]),abs('Mrp[13])
		apMrmn	37.538024	in-lb/in	apMrmn=1/3*(apMrmx)-FAIR aprox.mean Mr
		rho2	330882.6	in	rho2=1/(apMrmn/D)-avg rad of curvature for 2nd load set--FAIR Approx .....
		rhobar	242952.74	in	rhobar=1/Mrbar/D--GOOD APPROX

St	Input	Name	Output	Unit	Comment
		Mrbar	51.123848	in-lb/in	avg. Mr-using 8 ea. Mr(r) terms--GOOD APPROX Avg. Mr(r) for 2nd load set--
					••••••

"TK Variable sheet"

Example: hac2 rear

Case 2

St	Input	Name	Output	Unit	Comment
					This file computes the uniform line that must be applied at the plate's mean radius to bring it flat from an initial crown height of ydef
					.....
					this is my CASE 2--see note
					..... wlp 9/3/92
					Case 1 - Annular plate with a uniform annular line load - Page 400
L		w	-100.58	lb/in	Uniform annular line load
L	49.9866	r0		in	Radius to annular line load
					Table 24 - Roark & Young (6 ed) Formulas for flat circular plates of constant thickness
		case	'Case_1c		Reference number
		caution	'_		Caution Message
		caution	'_		
		matl#			Material Number (See Material Table)
		matl			Material name
		plot	'y		Generate plots? 'n=no (Default=yes)
	3E7	E		psi	Young's Modulus
	.3	nu			Poisson's ratio
L	73.3997	a		in	Outer Radius
L	26.5735	b		in	Inner Radius
	1.6535	t		in	Plate Thickness
		D	12420679	in-lb	Plate Constant
					AT RADIUS:
L	49.9866	r		in	Radius
L	.0163551	y		in	Deflection
		th	-.000101	rad	Radial Slope Angle
		Mr	-1102.827	in-lb/in	Radial Bending Moment
		Mt	-353.682	in-lb/in	Tangential Bending Moment
		Q	-48.056	lb/in	Shear Force
		sigma_r	-2420.067	psi	Radial Bending Stress
		sigma_t	-776.127	psi	Tangential Bending Stress
					AT OUTER EDGE:
		ya	0	in	Deflection
		tha	-.0009435	rad	Radial Slope Angle
		Mra	0	in-lb/in	Radial Bending Moment
		Qa	35.77	lb/in	Shear Force
					AT INNER EDGE:
		yb	0	in	Deflection
		thb	.0012146	rad	Radial Slope Angle
		Mrb	0	in-lb/in	Radial Bending Moment
		Qb	-90.397	lb/in	Shear Force
	188.73	zo		in	approx ip dis to h1 front pl
		theti	.09949199		
		theto	.26903599		

St	Input	Name	Output	Unit	Comment
	3	etai			
	2	etao			
		zh1f	188.73		
		zh1b	224.63551		
	.70866142	th1p			
	.23622047	tw			
		zh2f	224.63551		
		zh2b	266.21031		
	1.6535433	th2p			
		roh1f	52.036742		
		rih1f	18.839325		
		roh1b	61.93663		
		rih1b	22.423469		
		roh2f	61.93663		
		rih2f	22.423469		
		roh2b	73.399658		
		rih2b	26.573532		
		a1	52.036742		plate outer radius
		a2	61.93663		"
		a3	61.93663		"
		a4	73.399658		"
		b1	18.839325		plate inner radius
		b2	22.423469		"
		b3	22.423469		"
		b4	26.573532		"
		t1	.70866142		hac1 plate thickness
		t2	.70866142		"
		t3	1.6535433		hac2 plate thickness
		t4	1.6535433		"
		ro1	35.438034		radial location for applied load, w
		ro2	42.18005		"
		ro3	42.18005		"
		ro4	49.986595		"
L		ydef	.01635509	in	assumed init. out-of-flat
		Ftot	-31589.72	lb	tot. reqd flattening force

TK Rule Sheet, Case 1


```
S Rule
  if or(b<=0,r0<b,r0>a,a<=b,r<b,r>a) then caution1='Dim_Err else caution1='_
  if t>(a-b)/4 then caution2='t_Thick else caution2='_
  D=E*t^3/(12*(1-nu^2))
  call get_tab(matl#,matl,E,nu)
  call case(a,D,nu,b,r0,r;ya,yb,Mra,Mrb,Qa,Qb,tha,thb,case)
  call load(nu,r0,a,b,r,D,Mra,Mrb,tha,thb,Qa,Qb,ya,yb;y,th,Mr,Mt,Q)
  sigma_r=6*Mr/(t^2)
  sigma_t=6*Mt/(t^2)
  call clear()
  plot=given('plot,plot,'y)
  if and (solved(),plot<>'n) then call genplot()
  theti=2*atan(exp(-etai))
  theto=2*atan(exp(-etao))
  etai=3
  etao=2
  zh1f=zo
  zh1b=zo+19*2*(th1p+tw)
  zh2f=zh1b
  zh2b=zh2f+11*2*(th2p+tw)
  roh1f=zo*tan(theto)
  rih1f=zo*tan(theti)
  roh1b=zh1b*tan(theto)
  rih1b=zh1b*tan(theti)
  roh2f=roh1b
  rih2f=rih1b
  roh2b=zh2b*tan(theto)
  rih2b=zh2b*tan(theti)
  a1=roh1f
  a2=roh1b
  a3=roh2f
  a4=roh2b
  b1=rih1f
  b2=rih1b
  b3=rih2f
  b4=rih2b
  t1=th1p
  t2=th1p
  t3=th2p
  t4=th2p
  ro1=b1
  ro2=b2
  ro3=b3
  ro4=b4
  r=r0
  ymax^2-2*Rad*ymax+a^2=0
  Ftot=2*pi()*r0*w
C yomax=0.1
  yomax^2-2*Rad*yomax+(W120/2)^2=0
  delb^2-2*Rad*delb+b^2=0
  ybb+delb=ymax
  y=ybb
  if rhobar > 0 then 1/Rad2=1/Rad+1/rhobar
  if rhobar > 0 then y2=(a^2-2*a*b+b^2)/(8*Rad2)
  if and (solved(),plot<>'n) then apMrmx=max(abs('Mrp[10]),abs('Mrp[13]),abs('M
  apMrmn=1/3*(apMrmx)
  rho2=1/(apMrmn/D)
  if and (solved(),plot<>'n) then Mrbar=1/8*(abs('Mrp[5])+abs('Mrp[10])+abs('Mr
  if and (solved(),plot<>'n) then rhobar=D/Mrbar
  Weight=0.283*pi()*(a^2-b^2)*t
```

TK Rule Sheet, Case 2

```
S Rule
C if or(b<=0,r0<b,r0>a,a<=b,r<b,r>a) then caution1='Dim_Err else caution1='_
C if t>(a-b)/4 then caution2='t_Thick else caution2='_
C D=E*t^3/(12*(1-nu^2))
* call get_tab(matl#,matl,E,nu)
C call case(a,D,nu,b,r0,r;ya,yb,Mra,Mrb,Qa,Qb,tha,thb,case)
C call load(nu,r0,a,b,r,D,Mra,Mrb,tha,thb,Qa,Qb,ya,yb;y,th,Mr,Mt,Q)
C sigma_r=6*Mr/(t^2)
C sigma_t=6*Mt/(t^2)
C call clear()
C plot=given('plot,plot,'y)
C if and (solved(),plot<>'n) then call genplot()
  theti=2*atan(exp(-etai))
  theto=2*atan(exp(-etao))
  etai=3
  etao=2
  zh1f=zo
  zh1b=zo+19*2*(th1p+tw)
  zh2f=zh1b
  zh2b=zh2f+11*2*(th2p+tw)
  roh1f=zo*tan(theto)
  rih1f=zo*tan(theti)
  roh1b=zh1b*tan(theto)
  rih1b=zh1b*tan(theti)
  roh2f=roh1b
  rih2f=rih1b
  roh2b=zh2b*tan(theto)
  rih2b=zh2b*tan(theti)
  a1=roh1f
  a2=roh1b
  a3=roh2f
  a4=roh2b
  b1=rih1f
  b2=rih1b
  b3=rih2f
  b4=rih2b
  t1=th1p
  t2=th1p
  t3=th2p
  t4=th2p
  ro1=(b1+a1)/2
  ro2=(b2+a2)/2
  ro3=(b3+a3)/2
  ro4=(b4+a4)/2
  r=r0
  y=ydef
  Ftot=2*pi()*r0*w
  if or(b<=0,r0<b,r0>a,a<=b,r<b,r>a) then caution1='Dim_Err else caution1='_
  if t>(a-b)/4 then caution2='t_Thick else caution2='_
  D=E*t^3/(12*(1-nu^2))
* call get_tab(matl#,matl,E,nu)
  call case(a,D,nu,b,r0,r;ya,yb,Mra,Mrb,Qa,Qb,tha,thb,case)
  call load(nu,r0,a,b,r,D,Mra,Mrb,tha,thb,Qa,Qb,ya,yb;y,th,Mr,Mt,Q)
  sigma_r=6*Mr/(t^2)
  sigma_t=6*Mt/(t^2)
  call clear()
  plot=given('plot,plot,'y)
  if and (solved(),plot<>'n) then call genplot()
```