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INTRODUCTION

This paper describes the mechanical design of the two dimensional cross-section (Figure 1) of the base-line collider dipole magnet for the Superconducting Super Collider. The components described here are the collar laminations (Figure 5, drawing number 0102-ME-292059), the tapered keys that lock the upper and lower collars (Figure 6, drawing number 0102-MB-217851), the yoke laminations (Figure 7, drawing number 0102-ME-292123), the cold mass shell (Figure 8, drawing number 0102-MD-292156).

The collars, made from 21-6-9 stainless steel, are 17 mm wide and have an outer radius of 67.82 mm. They serve to position the conductors at the location specified by the magnetic design[1] and to provide restraint against conductor motion under excitation which might cause the field shape to change or cause premature quenching (training). As in the 40 mm dipoles[2] the upper and lower collars are locked together by tapered keys near the mid-plane and left-right pairs of collars are spot welded to give greater horizontal stiffness. The collars precompress the coil by an amount larger than the sum of the Lorentz (IxB) forces on the conductors and have sufficient bending stiffness by themselves to limit deflections to less than 0.1-0.2 mm under excitation. In addition to being a magnetic element, the yoke is used to provide additional support to the collars near the horizontal mid-plane to limit deflections under the dominantly horizontal Lorentz force. To accomplish this the collars are designed to have a small interference fit (0.08 mm) with the yoke near the horizontal mid-plane at the operating temperature of 4.35 K. The 4.95 mm thick, 340 mm O.D. 304N stainless steel cold mass shell is pretensioned by weld shrinkage to 200-250 MPa at room temperature to firmly clamp the vertically split yoke around the collared coil. Due to the larger thermal contraction of the shell than the yoke the pretension grows to 350-400 MPa with cooldown and provides adequate clamping to restrain the Lorentz force up to fields well above the design operating point. With the collars supported by the yoke the coil deflections under excitation are limited to about 0.02 mm.

We describe in detail below the shape of the outer surface of the collars, which defines the yoke-collar interface, and the shape of the collar interior, which defines the conductor placement. Other features of the collar and yoke will be described in somewhat less detail.

YOKE SPLIT DIRECTION

Because the Lorentz force is mainly horizontal in the body of the magnet, collar deflections are minimized if the yoke supports the collars near

the horizontal mid-plane. The ability to provide this support depends on the relative thermal contractions of the yoke and collar materials, the choice of yoke split direction and the details of the relative shapes of the collar outer surface and the yoke inner surface. The collars are made of 21-6-9 stainless steel which has an integrated thermal contraction[3] to 4 K of -2.9×10^{-3} and the yoke is made of low carbon steel which has an integrated thermal contraction[3] of -2.1×10^{-3}. To be inserted easily into the yoke at room temperature the collar diameter in the direction of the yoke split must be no larger than the yoke inner diameter. During cooldown the collars shrink more than the yoke and may lose contact with the yoke along the split direction.

If the yoke is split in the horizontal direction, the collared coil must be sufficiently vertically oversized that when clamped in the yoke it deflects horizontally to contact the yoke when cold. (See Figure 2a.) This design is sensitive to the magnet-to-magnet variation in collared coil vertical diameter due to prestress variation. The measured rate of deflection in the 40 mm dipoles is about 0.004 mm/MPa resulting in an expected range of 0.1-0.15 mm in vertical diameter for a preload range of ±20 MPa. Finite element calculations for the 50 mm dipole give a similar sensitivity. These calculations indicate that if there is sufficient vertical interference between the yoke and collars to ensure horizontal contact for the lowest preload coils, the mid-plane will be open by 0.05-0.1 mm at liquid helium temperature for the highest preload coils. Alternatively, if the vertical yoke-collar interference is reduced to guarantee that the yoke gap is closed for the highest prestress coils, then for the low prestress coils horizontal yoke-collar contact will be lost at 4 K and the collars will be less well supported. At room temperature a mid-plane gap is likely to exist for all coils.

In contrast, the collared coil horizontal diameter is relatively insensitive to coil prestress. (The vertical force from the coil prestress is applied at a smaller radius than the opposing force for the keys. This couple causes an inward bending of the sides of the collars that almost perfectly cancels the outward deflection due to the internal pressure of the coils.[4]) Finite element calculations and measurements[4] of 40 mm SSC dipoles show that the rate of horizontal deflection is less than 20% of that in the vertical direction; the horizontal diameter varies by $<$ 0.03 mm for the full range of expected coil preloads. If a vertically split yoke design is adopted it is relatively easy to ensure both good horizontal support to the collared coil and a closed mid-plane gap independent of the coil preload. This can be achieved with the larger thermal contraction collar material by appropriately choosing the horizontal and vertical diameters of the collars. In this case (Figure 2b) the collared coil is oversize in the horizontal direction and undersize in the vertical direction to allow easy insertion into the yoke for even the highest preload coils. Under cooldown the collars move away from the yoke at the vertical radius but positive contact is maintained at the horizontal radius. At zero field, the shell azimuthal tension is balanced primarily by a pressure between the mating surfaces of the yoke halves. As the field increases, the mid-plane progressively unloads as the horizontal Lorentz force is transferred to the yoke. Figure 3 shows the forces for the 50 mm design discussed below. As long as the shell tension exceeds the Lorentz force, the mid-plane gap remains closed and the yoke behaves as a rigid solid structure. Several 40 mm dipoles have been built and tested with a vertically split yoke and have performed as expected[5,6].

Based on the considerations above a vertically split yoke design has been chosen for the base-line 50 mm collider dipole magnet. Because this design has not been tested as extensively as the horizontally split case used for most 40 mm SSC dipoles, a backup 50 mm design with a horizontally split yoke is being built at BNL. The latter will not be described here.

DESIGN OBJECTIVES

The gross features of the yoke, in particular the inner and outer radii, are set by the magnetic design[1]. Other detailed features, for example the placement of the cooling channels and the holes for yoke-pack assembly pins, are set by a combination of mechanical and magnetic considerations. The major design objectives discussed in this section have to do with the yoke-collar and yoke-yoke interfaces and with the collar interior surface. For the yoke-collar and yoke-yoke interfaces the design should satisfy the following:

1) The yoke and collar should be in contact at the horizontal mid-plane at 4 K and zero field. A small positive loading of $\gtrsim$ 100 N/mm should be present to guarantee good transverse and axial restraint over the full excitation range. The close collar-yoke-shell fit causes the axial Lorentz force to be transferred the shell and limits the compressive loading of the coil end.

2) Yoke mid-plane gap should be closed under all circumstances at T = 4 K up to at least B = 8 T (20% in field and 45% in force above the operating point).

3) If possible, the yoke mid-plane gap should also be closed at assembly at room temperature; requirements (1) and (2) takes precedence, however.

The combination of collar deflections due to coil prestress, assembly into the yoke and cooldown must result in a coil of the design shape: round, at the correct radius and with the correct pole angles. The "target shape" for the coils, fully assembled at 4 K and zero field, is the shape specified by the magnetic design shrunk according to the thermal contraction of stainless steel. This would be the shape of the coils if the collars were infinitely rigid. Prestress causes the vertical radius to increase, yoke assembly causes the horizontal radius to decrease and the vertical radius to increase, and cooldown causes both to decrease with the vertical decreasing somewhat more. The interior surface of the undeflected collar at room temperature must therefore have a horizontal radius larger and a vertical radius smaller than nominal to arrive at the correct shape cold. (See Figure 4.)

YOKE COLLAR INTERFACE

A simple spring model was used to model the interaction among the collar, yoke, and shell and to check the sensitivity of the system to uncertainties in the parameters of the calculation and part tolerances. Values of the parameters were derived from finite element calculations described in Reference 7 and from measurements on 40 mm SSC dipoles. The precise collar dimensions used in the finite element analysis differed by up to 0.09 mm from the final dimension chosen here.

The calculation models the collars as coupled vertical and horizontal springs with effective spring constants and vertical-horizontal couplings for forces applied by coil prestress and shell tension. Because the collars are designed so that they always clear the yoke in the vertical direction, the model is insensitive to parameters relevant to the vertical radius. The finite stiffness of the yoke is not explicitly included, but since the effective spring constants come from finite element calculations that include yoke elastic properties, these effects are implicitly included. The parameters of the calculation are shown in Table Ia and the source of their values are given below.

rv and rh The vertical and horizontal collar radii relative to the yoke at room temperature are chosen to give the desired yoke-collar interaction and varied to check the effect of parts tolerances.

Shell Stress The azimuthal shell stress at 300 K and 4 K is based on measurements made at Fermilab on model magnets F3[8] and DSS012[9] and at LBL on the first QC cross section 40 mm quadrupole.[10] The shell stress near the yoke parting plane determines the clamping force and this was measured to be 175-200 MPa at room temperature and 300-350 MPa at 4 K. The low end of the range was used in both cases. In fact, the model calculates the shell tension required to close the mid-plane gap at both temperatures, so the effect of varying the shell tension can be easily seen. The measurements in References 8-10 indicate that the parting plane stress comes from the weld shrinkage and is at or near the room temperature yield strength of the shell material in the annealed state. The 50 mm aperture models will use a higher strength material 304N specified to have a minimum yield strength of 310 MPa. An analysis of the shell tension, including frictional effects and the interaction with the tooling[11,12], indicates that with the use of 304N the shell stress at the mid-plane is expected to be $>$ 210 MPa under the most pessimistic assumptions consistent with data[11]. At 4 K the shell tension should be $>$ 350 MPa.

Thermal Contraction The integrated thermal contraction of the collar and the yoke material was measured[3] at BNL to be -2.9×10^{-3} and -2.1×10^{-3} respectively. Standard tables[13] give values of -3.0×10^{-3} and -2.0×10^{-3} for stainless steel and iron. Both sets of values were tried; the final values are based on an average of the two with their difference representing the uncertainty from this source.

Nominal Radius This is the yoke inner radius for the magnetic design[1] of the W6733 cross section.

drv/drh The ratio of vertical to horizontal radius change for a horizontal force applied by the yoke was copied from the 40 mm model[14,15]. Because of the similarity of the 40 mm and 50 mm designs, the value of drv/drh should be similar. Variations of ±10% about the central value were tried. Since this effects only the vertical yoke-collar clearance it is if little importance for this design.

drv/dpr and drh/dpr The rate of change of collar vertical and horizontal radius with prestress (average of inner and outer coils) was taken from finite element calculations[7,16] and measurements of 40 mm magnets.[17] The finite element results depend on whether or not the wedges are allowed to slide relative to the adjacent conductors:

	drv/dpr	drh/dpr	
slip[7]	$1.4\text{x}10^{-3}$	$-1.8\text{x}10^{-4}$	mm/MPa
no slip[16]	$1.7\text{x}10^{-3}$	$-0.7\text{x}10^{-4}$	mm/MPa

Measured[17] vertical deflections of 40 mm collars, $2.0\text{x}10^{-3}$ mm/MPa, are somewhat larger than predicted by finite element calculations[14] $1.6\text{x}10^{-3}$ mm/MPa. Values of drv/dpr from 1.3 to $1.9\text{x}10^{-3}$ mm/MPa and of drh/dpr from 0 to $-0.4\text{x}10^{-3}$ mm/MPa were tried. Because there is no vertical yoke-collar interaction and the values of drh/dpr are small, the results are not very sensitive to these variations.

Prestress The target collared coil room temperature prestress is approximately 70 MPa. A range of ±20 MPa, somewhat larger than is expected, was tried.

Cooldown Prestress Loss To simplify the calculation of the effects of cooldown, the model separately cools the collared coil and the yoke, and then assembles them cold. This procedure is valid because the system is linear and elastic. The prestress loss with cooldown used in the model is that for a free collared coil. This has been measured in 40 mm magnets[18] to be approximately 17 and 14 MPa for the inner and outer coils respectively. Values of 15.5 and 22.5 MPa (average of inner and outer coils) were tried. Because of the similarity of the designs, the behavior of the 50 mm dipole is expected to be similar. Since this affects mainly the collared coil vertical radius it is not a very important parameter.

drh/d(Shell Stress) The rate of change of collared coil vertical radius with shell tension has two values depending on whether the collars are free to expand vertically or not. Because the collars always clear the yoke, only the first (larger) value is important. Its value, $-1.0\text{x}10^{-3}$ mm/MPa, is taken from finite element calculations[7] and is varied between -0.9 and $1.2\text{x}10^{-3}$ mm/MPa.

The results of the calculations are shown in Tables Ib-e. Tables Ib-d use the recent BNL[3] values of integrated thermal contraction. The three tables correspond to three values of collar horizontal radius representing the estimated range of 0.15 ± 0.05 mm of horizontal yoke collar interference (see below). Table Ie uses the same collar dimensions as Table Ic but shows the effect of a larger difference in yoke and collar thermal contractions. In each table the first line represents the "central values" of the parameters, which are then varied, as indicated by comments in the tables, in subsequent lines. For each set of parameters the vertical and horizontal radii of the free collared coil relative to the yoke are computed at both room temperature and 4 K. The central values of the results quoted below are an average of the central values in Tables Ic and Ie.

The room temperature yoke-collar interference in the horizontal direction is 0.14 ± 0.05 ± 0.004 ± 0.004 mm, where the first error bar is from parts tolerances, the second is from prestress variation and the third is from uncertainties in the calculation parameters. The horizontal yoke-collar interference is 0.08 ± 0.05 ± 0.005 ± 0.02 mm at 4 K. The room temperature vertical clearances before and after assembly are 0.33 ± 0.05 ± 0.03 ± 0.01 and 0.25 ± 0.05 ± 0.03 ± 0.02 mm. The vertical clearance at 4 K is about 0.1 mm larger than at 300 K.

The shell tension required to make the collar horizontal radius equal the yoke radius, that is to close the yoke mid-plane gap, is 130 ± 50 ± 7 ± 20 MPa at room temperature and 80 ± 50 ± 5 ± 20 MPa at 4 K. With a shell stress of approximately 200 MPa at room temperature the yoke gap may be barely closed under the least favorable conditions, but it is closed with a > 50% margin for the central values of the parameters. At 4 K the shell stress is ≳ 350 MPa; of this 270 ± 50 ± 5 ± 20 MPa is balanced by the pressure at the yoke mating surface and is therefore available to balance the Lorentz force. With the 4.95 mm thick shell, this is a force of 1340 ± 250 ± 25 ± 100 N/mm per quadrant. The lower bound is approximately equal to the Lorentz force of 890 N/mm per quadrant at full field. Finite element calculations[7] indicate that the collars are sufficiently stiff that only about 45% of the force is transferred to the yoke, so this design has more than a 100% margin against yoke gap opening even under the most pessimistic assumption and the yoke gap should stay closed to 10 T.

COLLAR OUTER SURFACE

The calculations above require a horizontal interference between the yoke and the undeflected collar at room temperature of 0.15 mm and vertical clearance of > 0.27 mm. The shape of the collar outer surface (Figure 5) provides for interference between 0 and 30° and and clearance between 30° and 90°. In both regions the collar radius is 0.01 mm larger than the yoke inner radius (Figure 6). (The intent was to make them equal but due to minor design errors a 0.01 mm discrepancy resulted.) Over the 0 to 30° range the center of curvature is displaced horizontally by 0.14 mm to generate the 0.15 mm interference and between 30° and 90° the center is displaced vertically by 0.46 mm to generate a vertical clearance of 0.45 mm, comfortably larger than is required. A small step occurs at the transition as shown in detail G of the collar drawing, Figure 5.

The tolerances that effect the yoke collar interface are those on the radius and horizontal offset of the collar outer surface and the radius and offset (relative to the yoke mating surface) of the yoke inner radius. Each is set to be ±0.012 mm. This value is chosen as being the best that can be achieved with current lamination stamping technology. The combined tolerance on the horizontal yoke-collar interference is ±0.05 mm as used in the calculations above. Tolerances of dimensions effecting the clearance between 30° and 90° are similar, but since the clearance is always > 0.10 mm, these tolerances are less important.

Table Ia

```
*************************************************************
********* Collared Coil In Vertically Split Yoke **********
*************************************************************


------------------ Input Parameters -----------------------
rv(Rv)            = collar(yoke) vertical   radius - nominal radius (mm)
rh(Rh)            = collar(yoke) horizontal radius - nominal radius (mm)
skin_stress       = azimuthal skin stress at 4 K (MPa)
skin_stress_300K= azimuthal skin stress at 300 K (MPa)
contract_collar = integrated thermal contraction to 4 K of collar material
contract_yoke   = integrated thermal contraction to 4 K of yoke   material
r_nominal         = nominal 300 K unstressed collar radius (mm)
drv/drh           = drv/drh for horizontal force
drv/dpr           = drv/d(prestress) (average of inner and outer) (mm/MPa)
drh/dpr           = drh/d(prestress) (average of inner and outer) (mm/MPa)
prestr            = free collared coil prestress at 300 K (average of inner and outer) (MPa)
dcool             = free collared coil cooldown prestress change (average of inner and outer) (MPa)
dh/ds1            = drh/d(skin stress) rv < Rv (mm/MPa)
dh/ds2            = drh/d(skin stress) rv > Rv (mm/MPa)

------------------ Output Parameters ----------------------
rv                = rv-Rv of free collared coil (mm)
rh                = rh-Rh of free collared coil (mm)
rh_rv0            = rh-Rh for rv = Rv (mm)
rv_rh0            = rv-Rv for rh = Rh (mm)
rh_sk             = rh-Rh for assumed skin stress (mm)
rv_sk             = rv-Rv for assumed skin stress (mm)
sk_rv0            = skin stress to make rv = Rv (MPa)
sk_rh0            = skin stress to make rh = Rh (MPa)

------------------------------------------------------------


*****************************
******* 50 mm Dipole *******
*****************************
```

Table Ib

r_nominal	=	67.82 mm
rv	=	-0.44 mm
rh	=	0.10 mm
skin_stress_300K	=	175.00 MPa
skin_stress	=	300.00 MPa
contract_collar	=	-2.90 * 1.E-3
contract_yoke	=	-2.10 * 1.E-3

							T = 300 K				T = 4 K							
drv/drh	drv/dpr	drh/dpr	prestr	dcool	dh/ds1	dh/ds2	rh	rv	rv_rh0	sk_rh0	rh	rv	rh_rv0	rv_rh0	rh_sk	rv_sk	sk_rv0	sk_rh0
-0.55	0.0017	-0.0002	70.0	-15.5	-.00100	-.00011	0.09	-0.32	-0.27	86.	0.03	-0.40	-0.70	-0.38	0.00	-0.38	-	35.
-0.55	0.0013	-0.0002	90.0	-15.5	-.00100	-.00011	0.08	-0.32	-0.28	82.	0.03	-0.40	-0.69	-0.38	0.00	-0.38	-	31.
----- Vary Coil Prestress and Cooldown Loss -----																		
-0.55	0.0017	-0.0002	90.0	-15.5	-.00100	-.00011	0.08	-0.29	-0.24	82.	0.03	-0.37	-0.64	-0.35	0.00	-0.35	-	31.
-0.55	0.0017	-0.0002	50.0	-15.5	-.00100	-.00011	0.09	-0.35	-0.31	90.	0.04	-0.44	-0.75	-0.41	0.00	-0.41	-	39.
-0.55	0.0017	-0.0002	70.0	-22.5	-.00100	-.00011	0.09	-0.32	-0.27	86.	0.04	-0.41	-0.72	-0.39	0.00	-0.39	-	36.
----- Vary dr/d(prestress) -----																		
-0.55	0.0013	-0.0002	70.0	-15.5	-.00100	-.00011	0.09	-0.35	-0.30	86.	0.03	-0.42	-0.73	-0.40	0.00	-0.40	-	35.
-0.55	0.0015	-0.0002	70.0	-15.5	-.00100	-.00011	0.09	-0.34	-0.29	86.	0.03	-0.41	-0.72	-0.39	0.00	-0.39	-	35.
-0.55	0.0019	-0.0002	70.0	-15.5	-.00100	-.00011	0.09	-0.31	-0.26	86.	0.03	-0.39	-0.68	-0.37	0.00	-0.37	-	35.
-0.55	0.0017	0.0000	70.0	-15.5	-.00100	-.00011	0.10	-0.32	-0.27	100.	0.05	-0.40	-0.68	-0.38	0.00	-0.38	-	46.
-0.55	0.0017	-0.0004	70.0	-15.5	-.00100	-.00011	0.07	-0.32	-0.28	72.	0.02	-0.40	-0.71	-0.39	0.00	-0.39	-	24.
----- Choose values that give a small and a big collared coil (vertically) -----																		
-0.55	0.0013	-0.0002	50.0	-22.5	-.00100	-.00011	0.09	-0.38	-0.33	90.	0.04	-0.46	-0.79	-0.44	0.00	-0.44	-	40.
-0.55	0.0019	-0.0002	90.0	-15.5	-.00100	-.00011	0.08	-0.27	-0.22	82.	0.03	-0.35	-0.61	-0.34	0.00	-0.34	-	31.
----- Choose values that give a small and a big collared coil (horizontally) -----																		
-0.55	0.0017	-0.0004	90.0	-15.5	-.00100	-.00011	0.06	-0.29	-0.25	64.	0.02	-0.37	-0.65	-0.36	0.00	-0.36	-	16.
-0.55	0.0017	0.0000	70.0	-15.5	-.00100	-.00011	0.10	-0.32	-0.27	100.	0.05	-0.40	-0.68	-0.38	0.00	-0.38	-	46.
----- Vary dr/d(skin stress) -----																		
-0.55	0.0017	-0.0002	70.0	-15.5	-.00080	-.00009	0.09	-0.32	-0.27	108.	0.03	-0.40	-0.70	-0.38	0.00	-0.38	-	44.
-0.55	0.0017	-0.0002	70.0	-15.5	-.00100	-.00011	0.09	-0.32	-0.27	86.	0.03	-0.40	-0.70	-0.38	0.00	-0.38	-	35.
-0.55	0.0017	-0.0002	70.0	-15.5	-.00120	-.00013	0.09	-0.32	-0.27	72.	0.03	-0.40	-0.70	-0.38	0.00	-0.38	-	29.
----- Vary drv/drh -----																		
-0.50	0.0017	-0.0002	70.0	-15.5	-.00100	-.00011	0.09	-0.32	-0.28	86.	0.03	-0.40	-0.77	-0.38	0.00	-0.38	-	35.
-0.60	0.0017	-0.0002	70.0	-15.5	-.00100	-.00011	0.09	-0.32	-0.27	86.	0.03	-0.40	-0.83	-0.38	0.00	-0.38	-	35.

Table Ic

```
------------------------------------
r_nominal          =   67.82 mm
rv                 =   -0.44 mm
rh                 =    0.15 mm
skin_stress_300K   =  175.00 MPa
skin_stress        =  300.00 MPa
contract_collar    =   -2.90 * 1.E-3
contract_yoke      =   -2.10 * 1.E-3
------------------------------------
```

							T = 300 K				T = 4 K							
drv/drh	drv/dpr	drh/dpr	prestr	dcool	dh/ds1	dh/ds2	rh	rv	rv_rh0	sk_rh0	rh	rv	rh_rv0	rv_rh0	rh_sk	rv_sk	sk_rv0	sk_rh0
-0.55	0.0017	-0.0002	70.0	-15.5	-.00100	-.00011	0.14	-0.32	-0.25	136.	0.08	-0.40	-0.65	-0.35	0.00	-0.35	-	85.
-0.55	0.0013	-0.0002	90.0	-15.5	-.00100	-.00011	0.13	-0.32	-0.25	132.	0.08	-0.40	-0.64	-0.35	0.00	-0.35	-	81.
----- Vary Coil Prestress and Cooldown Loss -----																		
-0.55	0.0017	-0.0002	90.0	-15.5	-.00100	-.00011	0.13	-0.29	-0.21	132.	0.08	-0.37	-0.59	-0.32	0.00	-0.32	-	81.
-0.55	0.0017	-0.0002	50.0	-15.5	-.00100	-.00011	0.14	-0.35	-0.28	140.	0.09	-0.44	-0.70	-0.39	0.00	-0.39	-	89.
-0.55	0.0017	-0.0002	70.0	-22.5	-.00100	-.00011	0.14	-0.32	-0.25	136.	0.09	-0.41	-0.67	-0.37	0.00	-0.37	-	86.
----- Vary dr/d(prestress) -----																		
-0.55	0.0013	-0.0002	70.0	-15.5	-.00100	-.00011	0.14	-0.35	-0.27	136.	0.08	-0.42	-0.68	-0.38	0.00	-0.38	-	85.
-0.55	0.0015	-0.0002	70.0	-15.5	-.00100	-.00011	0.14	-0.34	-0.26	136.	0.08	-0.41	-0.67	-0.37	0.00	-0.37	-	85.
-0.55	0.0019	-0.0002	70.0	-15.5	-.00100	-.00011	0.14	-0.31	-0.23	136.	0.08	-0.39	-0.63	-0.34	0.00	-0.34	-	85.
-0.55	0.0017	0.0000	70.0	-15.5	-.00100	-.00011	0.15	-0.32	-0.24	150.	0.10	-0.40	-0.63	-0.35	0.00	-0.35	-	96.
-0.55	0.0017	-0.0004	70.0	-15.5	-.00100	-.00011	0.12	-0.32	-0.25	122.	0.07	-0.40	-0.66	-0.36	0.00	-0.36	-	74.
----- Choose values that give a small and a big collared coil (vertically) -----																		
-0.55	0.0013	-0.0002	50.0	-22.5	-.00100	-.00011	0.14	-0.38	-0.30	140.	0.09	-0.46	-0.74	-0.41	0.00	-0.41	-	90.
-0.55	0.0019	-0.0002	90.0	-15.5	-.00100	-.00011	0.13	-0.27	-0.20	132.	0.08	-0.35	-0.56	-0.31	0.00	-0.31	-	81.
----- Choose values that give a small and a big collared coil (horizontally) -----																		
-0.55	0.0017	-0.0004	90.0	-15.5	-.00100	-.00011	0.11	-0.29	-0.22	114.	0.07	-0.37	-0.60	-0.33	0.00	-0.33	-	66.
-0.55	0.0017	0.0000	70.0	-15.5	-.00100	-.00011	0.15	-0.32	-0.24	150.	0.10	-0.40	-0.63	-0.35	0.00	-0.35	-	96.
----- Vary dr/d(skin stress) -----																		
-0.55	0.0017	-0.0002	70.0	-15.5	-.00080	-.00009	0.14	-0.32	-0.25	170.	0.08	-0.40	-0.65	-0.35	0.00	-0.35	-	106.
-0.55	0.0017	-0.0002	70.0	-15.5	-.00100	-.00011	0.14	-0.32	-0.25	136.	0.08	-0.40	-0.65	-0.35	0.00	-0.35	-	85.
-0.55	0.0017	-0.0002	70.0	-15.5	-.00120	-.00013	0.14	-0.32	-0.25	113.	0.08	-0.40	-0.65	-0.35	0.00	-0.35	-	71.
----- Vary drv/drh -----																		
-0.50	0.0017	-0.0002	70.0	-15.5	-.00100	-.00011	0.14	-0.32	-0.25	136.	0.08	-0.40	-0.72	-0.36	0.00	-0.36	-	85.
-0.60	0.0017	-0.0002	70.0	-15.5	-.00100	-.00011	0.14	-0.32	-0.24	136.	0.08	-0.40	-0.58	-0.35	0.00	-0.35	-	85.

Table Id

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---------------------------------------
r_nominal         =   67.82 mm
rv                =   -0.44 mm
rh                =    0.20 mm
skin_stress_300K  =  175.00 MPa
skin_stress       =  300.00 MPa
contract_collar   =   -2.90 * 1.E-3
contract_yoke     =   -2.10 * 1.E-3
---------------------------------------
```

							T = 300 K				T = 4 K							
drv/drh	drv/dpr	drh/dpr	prestr	dcool	dh/ds1	dh/ds2	rh	rv	rv_rh0	sk_rh0	rh	rv	rh_rv0	rv_rh0	rh_sk	rv_sk	sk_rv0	sk_rh0
-0.55	0.0017	-0.0002	70.0	-15.5	-.00100	-.00011	0.19	-0.32	-0.22	186.	0.13	-0.40	-0.60	-0.33	0.00	-0.33	-	135.
-0.55	0.0013	-0.0002	90.0	-15.5	-.00100	-.00011	0.18	-0.32	-0.22	182.	0.13	-0.40	-0.59	-0.33	0.00	-0.33	-	131.
----- Vary Coil Prestress and Cooldown Loss -----																		
-0.55	0.0017	-0.0002	90.0	-15.5	-.00100	-.00011	0.18	-0.29	-0.19	182.	0.13	-0.37	-0.54	-0.30	0.00	-0.30	-	131.
-0.55	0.0017	-0.0002	50.0	-15.5	-.00100	-.00011	0.19	-0.35	-0.25	190.	0.14	-0.44	-0.65	-0.36	0.00	-0.36	-	139.
-0.55	0.0017	-0.0002	70.0	-22.5	-.00100	-.00011	0.19	-0.32	-0.22	186.	0.14	-0.41	-0.62	-0.34	0.00	-0.34	-	136.
----- Vary dr/d(prestress) -----																		
-0.55	0.0013	-0.0002	70.0	-15.5	-.00100	-.00011	0.19	-0.35	-0.25	186.	0.13	-0.42	-0.63	-0.35	0.00	-0.35	-	135.
-0.55	0.0015	-0.0002	70.0	-15.5	-.00100	-.00011	0.19	-0.34	-0.23	186.	0.13	-0.41	-0.62	-0.34	0.00	-0.34	-	135.
-0.55	0.0019	-0.0002	70.0	-15.5	-.00100	-.00011	0.19	-0.31	-0.20	186.	0.13	-0.39	-0.58	-0.32	0.00	-0.32	-	135.
-0.55	0.0017	0.0000	70.0	-15.5	-.00100	-.00011	0.20	-0.32	-0.21	200.	0.15	-0.40	-0.58	-0.32	0.00	-0.32	-	146.
-0.55	0.0017	-0.0004	70.0	-15.5	-.00100	-.00011	0.17	-0.32	-0.23	172.	0.12	-0.40	-0.61	-0.33	0.00	-0.33	-	124.
----- Choose values that give a small and a big collared coil (vertically) -----																		
-0.55	0.0013	-0.0002	50.0	-22.5	-.00100	-.00011	0.19	-0.38	-0.27	190.	0.14	-0.46	-0.69	-0.38	0.00	-0.38	-	140.
-0.55	0.0019	-0.0002	90.0	-15.5	-.00100	-.00011	0.18	-0.27	-0.17	182.	0.13	-0.35	-0.51	-0.28	0.00	-0.28	-	131.
----- Choose values that give a small and a big collared coil (horizontally) -----																		
-0.55	0.0017	-0.0004	90.0	-15.5	-.00100	-.00011	0.16	-0.29	-0.20	164.	0.12	-0.37	-0.55	-0.30	0.00	-0.30	-	116.
-0.55	0.0017	0.0000	70.0	-15.5	-.00100	-.00011	0.20	-0.32	-0.21	200.	0.15	-0.40	-0.58	-0.32	0.00	-0.32	-	146.
----- Vary dr/d(skin stress) -----																		
-0.55	0.0017	-0.0002	70.0	-15.5	-.00080	-.00009	0.19	-0.32	-0.22	233.	0.13	-0.40	-0.60	-0.33	0.00	-0.33	-	169.
-0.55	0.0017	-0.0002	70.0	-15.5	-.00100	-.00011	0.19	-0.32	-0.22	186.	0.13	-0.40	-0.60	-0.33	0.00	-0.33	-	135.
-0.55	0.0017	-0.0002	70.0	-15.5	-.00120	-.00013	0.19	-0.32	-0.22	155.	0.13	-0.40	-0.60	-0.33	0.00	-0.33	-	112.
----- Vary drv/drh -----																		
-0.50	0.0017	-0.0002	70.0	-15.5	-.00100	-.00011	0.19	-0.32	-0.23	186.	0.13	-0.40	-0.67	-0.33	0.00	-0.33	-	135.
-0.60	0.0017	-0.0002	70.0	-15.5	-.00100	-.00011	0.19	-0.32	-0.21	186.	0.13	-0.40	-0.53	-0.32	0.00	-0.32	-	135.

Table Ie

```
------------------------------------
r_nominal         =   67.82 mm
rv                =   -0.44 mm
rh                =    0.15 mm
skin_stress_300K  =  175.00 MPa
skin_stress       =  300.00 MPa
contract_collar   =   -3.00 * 1.E-3
contract_yoke     =   -2.00 * 1.E-3
------------------------------------
```

							T = 300 K				T = 4 K							
drv/drh	drv/dpr	drh/dpr	prestr	dcool	dh/ds1	dh/ds2	rh	rv	rv_rh0	sk_rh0	rh	rv	rh_rv0	rv_rh0	rh_sk	rv_sk	sk_rv0	sk_rh0
-0.55	0.0017	-0.0002	70.0	-15.5	-.00100	-.00011	0.14	-0.32	-0.25	136.	0.07	-0.42	-0.68	-0.38	0.00	-0.38	-	71.
-0.55	0.0013	-0.0002	90.0	-15.5	-.00100	-.00011	0.13	-0.32	-0.25	132.	0.07	-0.41	-0.68	-0.37	0.00	-0.37	-	67.
----- Vary Coil Prestress and Cooldown Loss -----																		
-0.55	0.0017	-0.0002	90.0	-15.5	-.00100	-.00011	0.13	-0.29	-0.21	132.	0.07	-0.38	-0.63	-0.34	0.00	-0.34	-	67.
-0.55	0.0017	-0.0002	50.0	-15.5	-.00100	-.00011	0.14	-0.35	-0.28	140.	0.08	-0.45	-0.74	-0.41	0.00	-0.41	-	75.
-0.55	0.0017	-0.0002	70.0	-22.5	-.00100	-.00011	0.14	-0.32	-0.25	136.	0.07	-0.43	-0.70	-0.39	0.00	-0.39	-	73.
----- Vary dr/d(prestress) -----																		
-0.55	0.0013	-0.0002	70.0	-15.5	-.00100	-.00011	0.14	-0.35	-0.27	136.	0.07	-0.44	-0.72	-0.40	0.00	-0.40	-	71.
-0.55	0.0015	-0.0002	70.0	-15.5	-.00100	-.00011	0.14	-0.34	-0.26	136.	0.07	-0.43	-0.70	-0.39	0.00	-0.39	-	71.
-0.55	0.0019	-0.0002	70.0	-15.5	-.00100	-.00011	0.14	-0.31	-0.23	136.	0.07	-0.40	-0.66	-0.37	0.00	-0.37	-	71.
-0.55	0.0017	0.0000	70.0	-15.5	-.00100	-.00011	0.15	-0.32	-0.24	150.	0.08	-0.42	-0.67	-0.37	0.00	-0.37	-	82.
-0.55	0.0017	-0.0004	70.0	-15.5	-.00100	-.00011	0.12	-0.32	-0.25	122.	0.06	-0.42	-0.69	-0.38	0.00	-0.38	-	60.
----- Choose values that give a small and a big collared coil (vertically) -----																		
-0.55	0.0013	-0.0002	50.0	-22.5	-.00100	-.00011	0.14	-0.38	-0.30	140.	0.08	-0.47	-0.78	-0.43	0.00	-0.43	-	77.
-0.55	0.0019	-0.0002	90.0	-15.5	-.00100	-.00011	0.13	-0.27	-0.20	132.	0.07	-0.37	-0.60	-0.33	0.00	-0.33	-	67.
----- Choose values that give a small and a big collared coil (horizontally) -----																		
-0.55	0.0017	-0.0004	90.0	-15.5	-.00100	-.00011	0.11	-0.29	-0.22	114.	0.05	-0.38	-0.64	-0.35	0.00	-0.35	-	52.
-0.55	0.0017	0.0000	70.0	-15.5	-.00100	-.00011	0.15	-0.32	-0.24	150.	0.08	-0.42	-0.67	-0.37	0.00	-0.37	-	82.
----- Vary dr/d(skin stress) -----																		
-0.55	0.0017	-0.0002	70.0	-15.5	-.00080	-.00009	0.14	-0.32	-0.25	170.	0.07	-0.42	-0.68	-0.38	0.00	-0.38	-	89.
-0.55	0.0017	-0.0002	70.0	-15.5	-.00100	-.00011	0.14	-0.32	-0.25	136.	0.07	-0.42	-0.68	-0.38	0.00	-0.38	-	71.
-0.55	0.0017	-0.0002	70.0	-15.5	-.00120	-.00013	0.14	-0.32	-0.25	113.	0.07	-0.42	-0.68	-0.38	0.00	-0.38	-	59.
----- Vary drv/drh -----																		
-0.50	0.0017	-0.0002	70.0	-15.5	-.00100	-.00011	0.14	-0.32	-0.25	136.	0.07	-0.42	-0.76	-0.38	0.00	-0.38	-	71.
-0.60	0.0017	-0.0002	70.0	-15.5	-.00100	-.00011	0.14	-0.32	-0.24	136.	0.07	-0.42	-0.62	-0.37	0.00	-0.37	-	71.

COLLAR INNER SURFACE

The interior shape of the collar determines the conductor placement which in turn determines the field shape. The "target shape" for the coils, fully assembled at 4 K and zero field, is the shape specified by the magnetic design shrunk according to the thermal contraction of stainless steel. The design method begins with a collar which, in its undeflected state at room temperature, has the dimensions given by the magnetic design. Finite element calculations[7] are done to determine the net deflection of the collar due to assembly and cooldown. The deflections returned by the finite element calculations include both mechanical deflections due to the stresses on the collar and the thermal contraction of the stainless steel from which the collar is made. The difference between the shape of the undeflected collar at 4 K (which is the target shape) and final shape from the finite element calculations is determined. This difference is then added to the appropriate dimensions of the original (nominal) collar design. The result is a shape which, after all deflections have occurred, has the correct shape at 4 K.

The nominal collar shape was determined by taking the profile of the insulated conductors from the magnetic design (Figure 9, drawing MB-292000) and adding to it the nominal thickness of the ground wrap insulation. (See Figure 10, drawing MB-292047. All Kapton layers and the strip heater package are 0.13 mm thick and the collaring shoe is 0.38 mm thick.) It is specified by the radii of the inner surfaces of the collar (the outer surface of the outer coil plus ground wrap and collaring shoe, the outer surface of the inner coil plus ground wrap and the inner surface of the inner coil) and the distance from the vertical center line of the intersections of the inner and outer coil pole surfaces plus ground wrap with the collar surfaces at the inner and outer coil radii. These dimensions are shown in Table II.

Table II
Nominal Collar Shape From the Magnetic Design
(all dimensions are mm)

Location	r	x	y
Outer Midplane	50.76	50.76	0.00
Outer Pole Outer Edge	50.76	34.19	37.52
Outer Pole Inner Edge	37.84	23.94	29.30
Inner Pole Outer Edge	37.84	9.88	36.53
Inner Pole Inner Edge	24.78	5.86	24.08

Finite element calculations were performed for the case in which both the inner and the outer coil prestresses were 70 MPa and the horizontal yoke-collar interference was 0.17 mils. The net deflection to 4 K of five points on the interior of the collar were tabulated. The results are shown in Table III.

In Table IV these deflections are compared with the deflections due to thermal contraction of stainless steel alone. An integrated thermal contraction to 4 K of -3.0×10^{-3} is assumed here as was the finite element model. These are shown in the columns labeled "Thermal Contraction". The differences between the total deflection and the thermal contraction are displayed in the next two columns labeled "Deflection rel. to free collar at 4K". These are the deflections of the collars at 4 K due to mechanical stresses. These are then corrected for the fact that the design calls for 0.15 mm of horizontal yoke-collar interference while the finite element calculations assumed 0.17 mm. The correction is done by adding 0.02 mm to the x deflection at the horizontal mid-plane and decreasing the other x deflections by the same proportion. The y deflection nearest to the pole is decreased by 0.01 mm. (The vertical radius changes by about minus one-half the change in horizontal radius for a horizontally applied force. See the section on the yoke-collar interface.) The other y deflections are decreased by the same proportion. The results are in the columns labeled "Corr. to design yoke-collar interference".

Table III
Collar displacements (mm) due to assembly and cooldown

Location	dx	dy
Outer Midplane	-0.26	0.00
Outer Pole Outer Edge	-0.12	-0.03
Outer Pole Inner Edge	-0.09	0.03
Inner Pole Outer Edge	-0.04	0.01
Inner Pole Inner Edge	-0.02	0.05

Table IV
Corrected Collar Deflections (mm)

Location	Thermal Contraction dx	Thermal Contraction dy	Deflection rel. to free collar at 4K dx	Deflection rel. to free collar at 4K dy	Corr. to design yoke-collar interference dx	Corr. to design yoke-collar interference dy
Outer Midplane	-0.15	0.00	-0.11	0.00	-0.09	0.00
Outer Pole Outer Edge	-0.10	-0.11	-0.02	0.09	-0.02	0.08
Outer Pole Inner Edge	-0.07	-0.09	-0.02	0.12	-0.01	0.11
Inner Pole Outer Edge	-0.03	-0.11	0.00	0.12	0.00	0.11
Inner Pole Inner Edge	-0.02	-0.07	0.00	0.12	0.00	0.11

The desired collar shape, undeflected at room temperature, is gotten by subtracting dx and dy in the last two columns in Table IV from the x and y coordinates in Table II. This sets the coordinates at the five locations listed. The rest of the collar surfaces are made circular with radii and centers chosen to pass through these five points. Because the cable width is preserved by the deflections, the radii must all be changed by the same amount and they must remain concentric. The radii are increased by 0.09 mm to generate the required increase in x at the horizontal mid-plane. The centers of curvature are offset vertically by -0.20 mm relative to the horizontal center line. This value was chosen to give the best fit to the design values of y-dy at the design values of x+dx from Tables II and IV. In the collar drawing (Figure 5) the radius r and center offset of each surface and the distance 2x between corresponding corners on the left and right sides are specified. (Note that in the coordinate system defined in this discussion positive y is down on the collar drawing.) Table V shows the values of r, offset and x and the values of y at the corners derived from them. It also shows the differences between the y values so generated and those derived from y and dy in Tables II and IV.

Table V
Design Collar Dimensions (mm)

Location	r	offset	x	y	y-deviation
Outer Midplane	50.85	-0.20	50.85	0.00	-
Outer Pole Outer Edge	50.85	-0.20	34.21	37.42	-0.02
Outer Pole Inner Edge	37.93	-0.20	23.95	29.21	0.02
Inner Pole Outer Edge	37.93	-0.20	9.88	36.42	0.01
Inner Pole Inner Edge	24.87	-0.20	5.86	23.97	0.00

The coordinates that actually appear on the collar drawing differ from these by a small amount for several reasons. First, the original calculations on the basis of which the drawing was originally made assumed 0.14 mm of horizontal yoke-collar interference rather than 0.15 mm. The 0.01 mm discrepancy is the same one mentioned in the discussion of the collar outer surface. Second, the original calculation was done based on an earlier cross-section which differed from the one currently in use by up to 0.2 mm due to changes in the cable dimensions. The collar drawing was corrected for these cross section changes but the calculations discussed in this paper were not re-done. For reasons not understood additional discrepancies up to 0.05 mm have appeared from this cause. Table VI shows the actual coordinates from the drawing. The numbers in parentheses are the differences between the actual values and those in Table V. The discrepancies are all very small, the largest being a displacement of the outer coil pole surface azimuthally towards the mid-plane by 0.06 mm.

Table VI
Actual Collar Dimensions (mm)

Location	r	offset	x	y
Outer Midplane	50.83(-.02)	-0.18(.02)	50.83(-.02)	-
Outer Pole Outer Edge	50.83(-.02)	-0.18(.02)	34.25(0.04)	37.38(-.04)
Outer Pole Inner Edge	37.92(-.01)	-0.18(.02)	24.00(0.05)	29.18(-.03)
Inner Pole Outer Edge	37.92(-.01)	-0.18(.02)	9.88(0.00)	36.43(0.01)
Inner Pole Inner Edge	24.87(0.00)	-0.18(.02)	5.85(-.01)	23.99(0.01)

OTHER COLLAR FEATURES

The small tab on the side of the collar (detail A, Figure 5) is used to center the collared coil vertically in the yoke. It has a ±8.5° taper to ease insertion into the yoke. The flats on the side of the collar and the yoke in the region of the tapered keys are, in the undeflected parts, at the identical distance from the vertical center-line. However, because of the 0.15 mm mils of interference just above the tapered keys, after assembly the collars are deflected so that there is 0.15 ± 0.08 mm of clearance between the yoke and collars at the base of the alignment tab. The lower bound of the tolerance band on the yoke slot width is equal to the upper bound of that on the collar tab. However, because the collar is displaced 0.15 mm radially inwards at assembly, there is a clearance of between 0.01 and 0.06 mm on either side of the alignment tab for the full range of the relevant part tolerances. This may allow the coil to be vertically off-center in the yoke by up to ±0.06 mm, which will in turn generate a skew quadrupole moment a_1 of up to ±0.6 units[19]. In fact, it is unlikely that the parts tolerances will conspire so as to give this maximum allowable vertical clearance over the entire manufacturing run so the expected contribution to $\sigma(a_1)$ is considerably smaller than this. (The effect on other harmonics of vertical off-centering is negligible[19] with respect to their specified tolerances.)

The slots for the tapered keys (detail A of Figure 5) are 0.30 mm larger than the tapered keys themselves (Figure 7). Only the "upper" surfaces of the key slots on the drawing contact the keys so a considerable tighter tolerance (0.02 mm) has been specified for them than for the opposite surfaces. The "active" surfaces have been placed so that for nominal dimensions the center lines of the upper and lower collars are coincident. The key slots are oversized for two reasons: 1) to ease insertion of the keys if the keys are placed rather than driven into the slots ("square key" method) and 2) to allow, by procurement of slightly larger keys, for up to 0.03 mm of "anti-ovalization" if it is decided to drive the keys into the slots ("tapered key" method). The latter process has been observed[16] in 40 mm magnets to result in an additional vertical deflection of the collars of 0.03-0.05 mm on the radius due to scoring of the keys or local yielding of the collars near the key slots. It is currently planned to use the square key method, but both the tooling and the collar + key design allow use of the tapered key method.

The small notches in the outer surface are used for lifting the collared coil assembly in either "upright" or 90° rotated orientations. (The later is required for insertion into the vertically-split yoke) and for azimuthal alignment within the collaring tooling. The notch on the outer surface at the pole is for routing instrumentation wires. Its width and placement are not particularly important for the collar design but tighter tolerances have been applied as this is the most convenient datum to define the vertical center line for inspection.

OTHER YOKE FEATURES

As noted above the yoke inner and outer radii are part of the magnetic design[1]. Most other features effect the saturation characteristics of the magnet so, although their sizes and locations are set mostly by mechanical considerations, magnetic effects were also considered. The square hole on the horizontal mid-plane is used to control the effect of iron saturation on b_2 and its size and location was chosen[1] based on the magnetic effects of the other features.

The cooling channel diameter of 29.1 mm was copied from the 40 mm magnet. The precise size that is desirable from a cryogenic system standpoint depends somewhat on the magnet cooling method. The size was set before the cooling method was chosen and is believed to be sensible[20] if the beam pipe is small enough to allow about 10% of the helium flow to go through the beam tube annulus. Presently the beam tube annular space is only 1.6 mm allowing only 1-2% of the helium to flow near the coil. Therefore larger cooling channels may be appropriate in the final design.

The bus slot and the cooling channels have been set to the largest radius at which they will fully clear the 19 mm wide end clamp filler pack (Figure 11, drawing MD-292141) which is used to support the shell at the end of the magnet. The cooling channel is placed as close to the vertical center-line as possible while still maintaining enough material between it and the bus slot to ensure the mechanical integrity of the lamination.

Four 12.88 mm diameter holes are used for pins to make yoke packs. The two nearer the horizontal center-line are placed at as large a radius possible and the others are placed as close to the vertical parting plane as possible to minimize their effects on iron saturation.

The notch at the outer radius at the vertical parting plane interlocks with the alignment key (Figure 12, drawing MB-292155). The alignment key interlocks to the yoking tooling to hold the magnet in a straight, twist-free state as the shell is welded, and it also serves as a fiducial feature for later alignment of the cold mass in the cryostat. As such the tolerance on the yoke notch and alignment key are name quite tight (0.025 mm full range on the key width and on the slot full width). The tolerance bands are set so that the fit between the yoke and the key varies from 0 to 0.05 mm clearance. At the yoke radius of 165.05 mm this implies an angular uncertainty of 0.3 mrad. The depth of the notch and the thickness of the key are set so that at minimum clearance the shoulder of the key is flush with the corner of the yoke notch and at maximum clearance it is 0.10 mm below the yoke.

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5. J. Strait, et al., "Experimental Evaluation of Vertically Versus Horizontally Split Yokes for SSC Dipole Magnets," Proceedings of the Second International Industrial Symposium of the Super Collider, 731 (1990) M. McAshan, ed.

6. W. Koska, et al., "Tests of 40 mm SSC Dipole Model Magnets with Vertically Split Yokes," submitted to the 1991 IEEE Particle Accelerator Conference, San Francisco, CA, May 6-9, 1991.

7. J. Kerby, Mechanical Analysis of the Vertically Split Yoke 50 mm SSC Dipole, Fermilab Technical Support Section internal note TS-SSC 91-001, 12/13/90.

8. J. Strait, FNAL Short Magnet Program, Minutes of the SSC Magnet Systems Integration Meeting (MSIM), 11/9-20/88.

9. J. Strait, Status of FNAL Short Magnet Program, Minutes of the MSIM, 4/13-14/89.

10. C. Taylor, LBL Quadrupole Program, Minutes of the MSIM, 6/12/90.

11. J. Strait, Analysis of Yoke-Skin Interaction, TS-SSC 90-040, 6/28/90.

12. J. Strait, Evaluation of Yoking Tooling Design, TS-SSC 90-059, 9/10/90.

13. Brookhaven National Laboratory Selected Cryogenic Data Notebook, BNL 10200-R, August, 1980, J.E. Jensen, et al., eds.

14. J. Cortella, private communications. Some of the relevant finite element calculation results for the 40 mm dipole are summarized in Ref. 16.

15. J. Strait, Design of a Vertically-Split Yoke and Associated Collar for the 40 mm Dipole, TS-SSC 90-029, 6/11/90.

16. J. R. Turner, Mechanical Analysis of the W6733H Cross Section, SSCL Magnet Systems Division internal note MD-TA-143.

17. J. Strait, Notes on Collared Coil Mechanics and Sextupole Moment, Minutes of the MSIM, 7/11-12/90.

18. J. Strait, Calculation of Desired Vertical Ovality of SSC Collars, Minutes of the MSIM, 10/10-11/89.

19. A. Mokhtarani, Effect of Manufacturing Errors on Harmonics in 5 cm SSC Magnets, TS-SSC 91-038, 1/7/91.

20. M. McAshan, private communication.

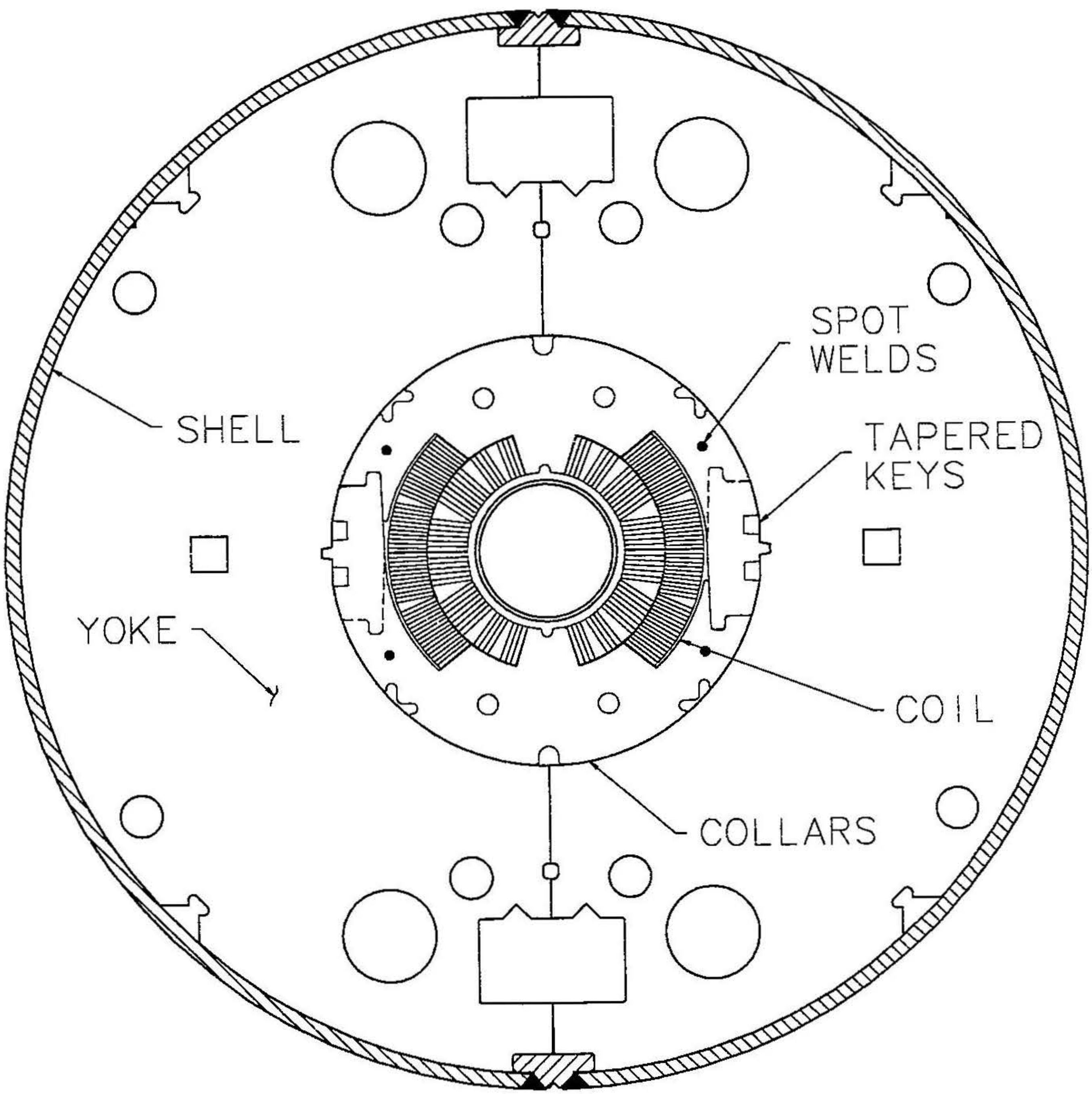


Figure 1
SSC Collider Dipole Magnet Cross Section

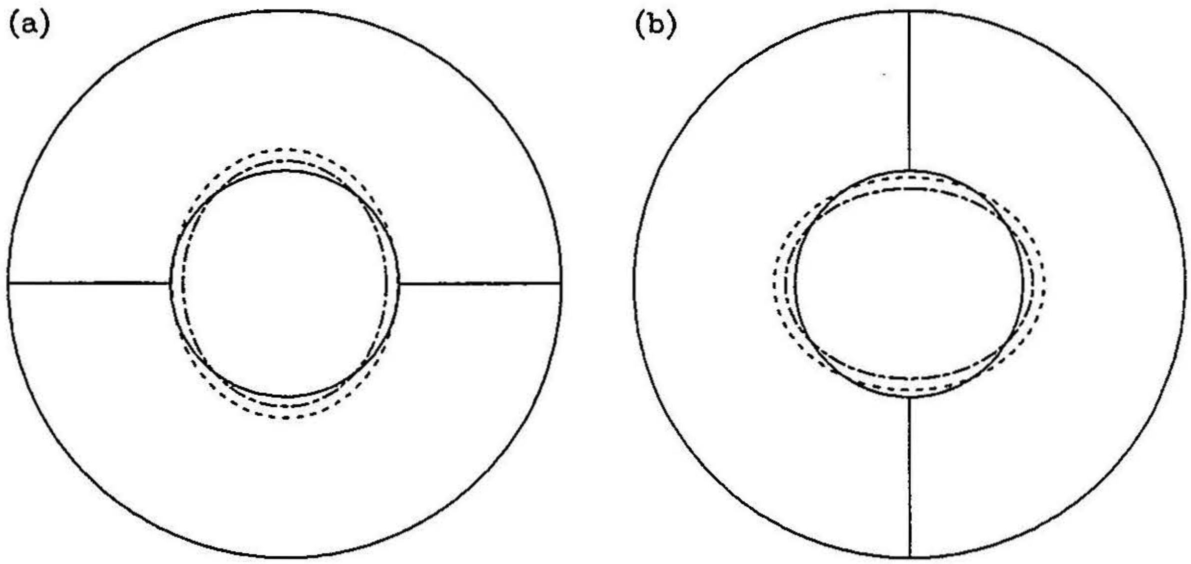


Figure 2
Horizontally split (a) and vertically split (b) yoke configurations.
The solid lines represent the yoke laminations, the dotted lines represent the free collared coil at T=300 K and the dot–dashed lines represent the free collared coil at T=4 K. (The collared coil distortions relative to to the yoke are greatly exaggerated.)

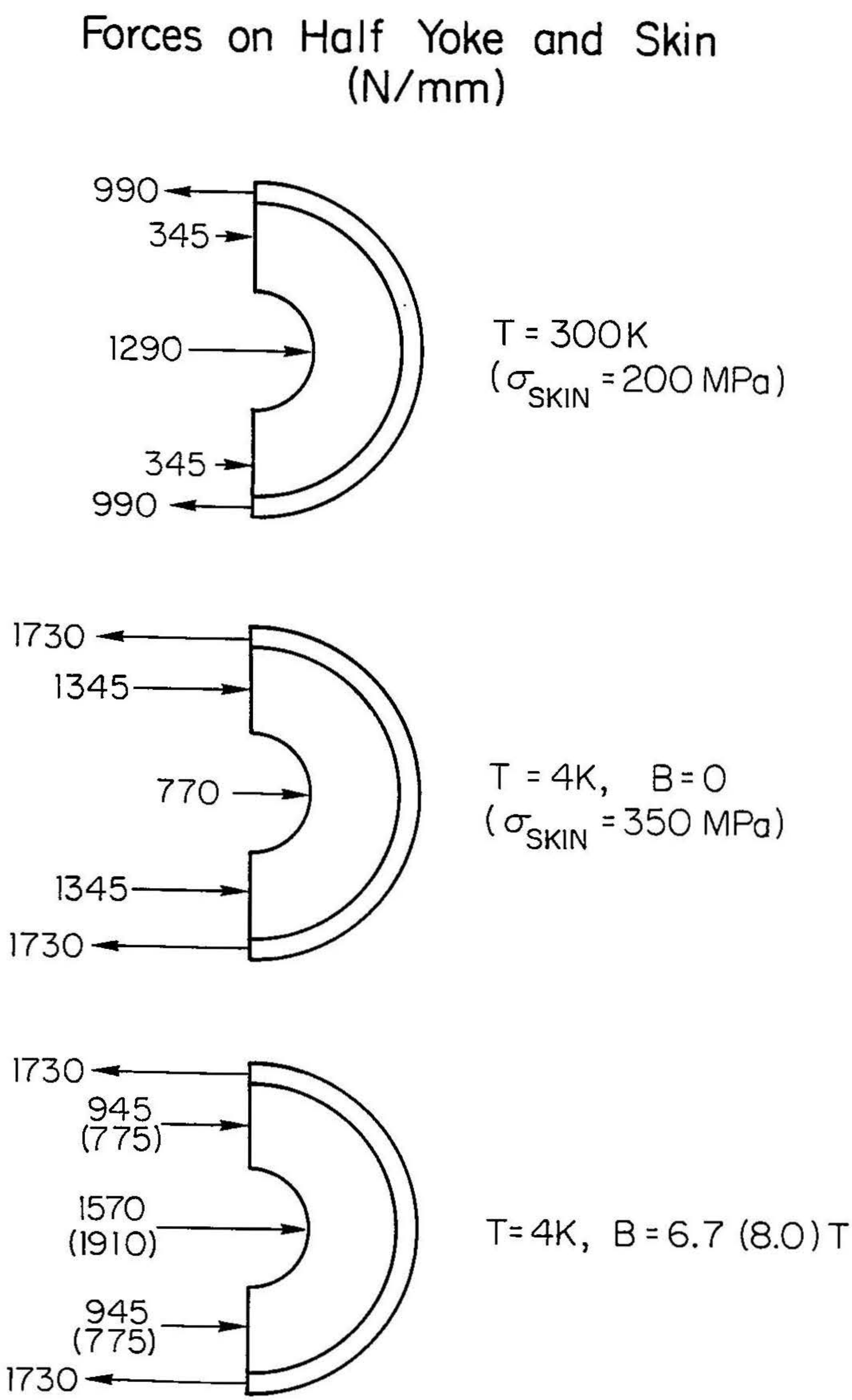


Figure 3

Forces (N/mm) on the a half yoke and shell due to shell azimuthal stress, yoke-yoke parting plane pressure, and the reaction of the collared coil. The force due to the collared coil includes the elastic effects of the yoke-collar interference fit and of the Lorentz force.

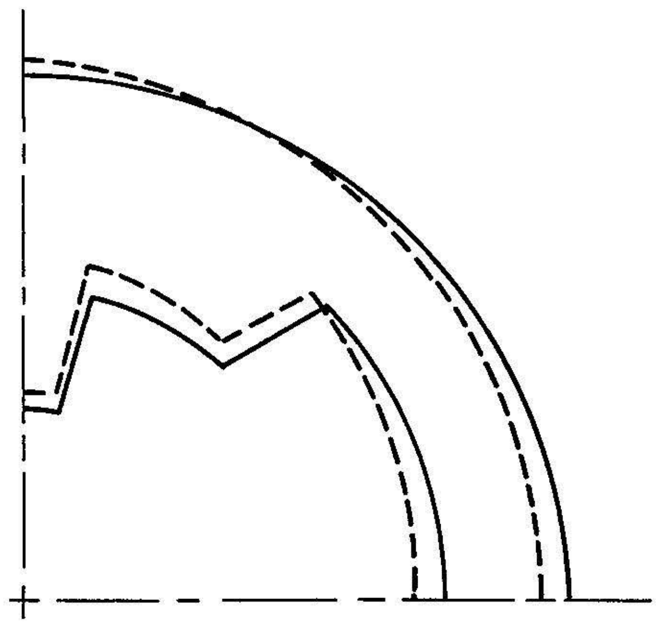
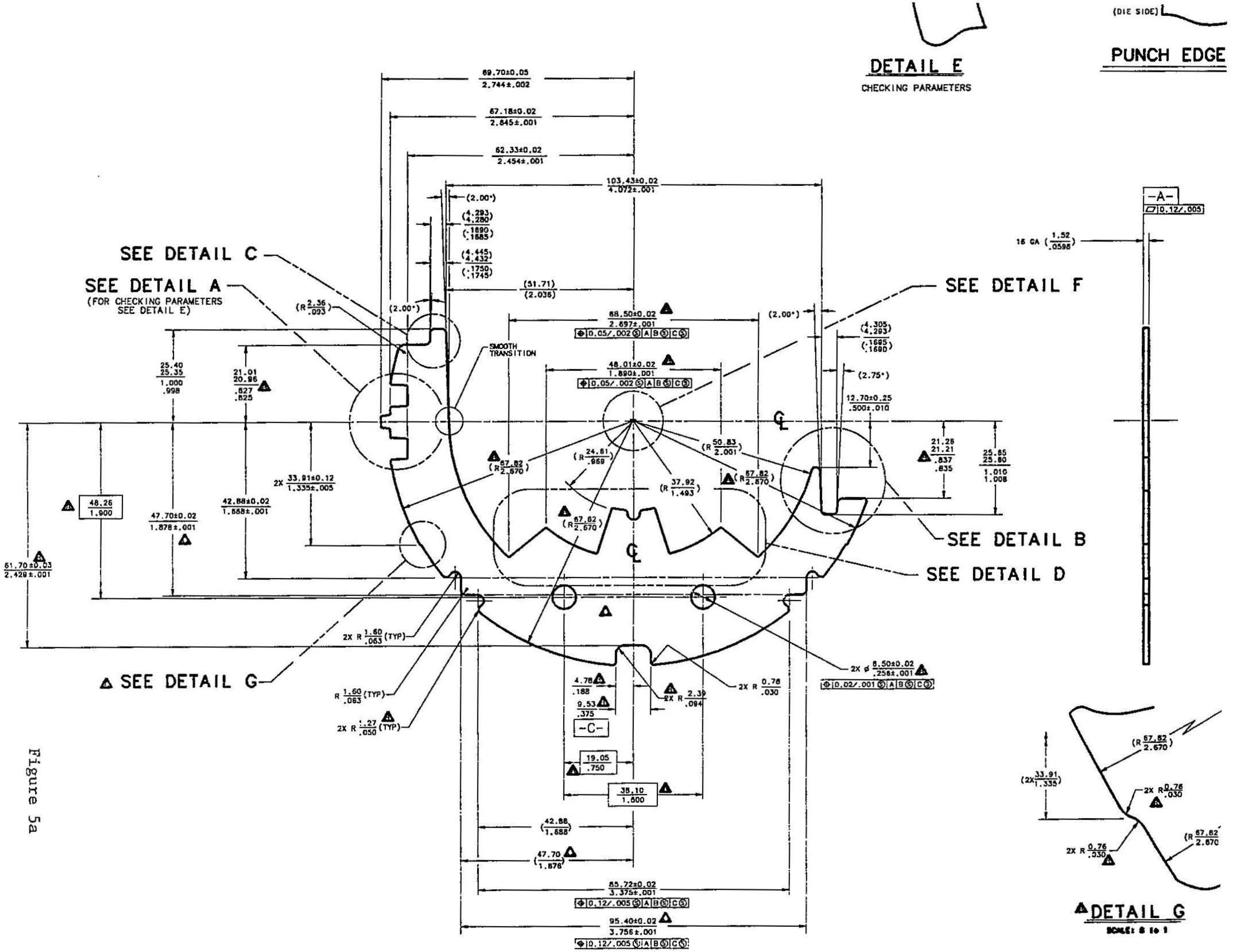


Figure 4
Relation between the free (solid line) and deflected (dashed-line) collar at 4 K.



DETAIL E
CHECKING PARAMETERS
(DIE SIDE)
PUNCH EDGE
69.70±0.05
2.744±.002
67.18±0.02
2.645±.001
62.33±0.02
2.454±.001
103.43±0.02
4.072±.001
(2.00°)
(4.293/4.280)
(.1690/.1685)
(4.445/4.432)
(.1750/.1745)
(51.71)
(2.036)
SEE DETAIL C
SEE DETAIL A
(FOR CHECKING PARAMETERS SEE DETAIL E)
(R 2.36/.093)
SMOOTH TRANSITION
68.50±0.02
2.697±.001
0.05/.002 Ⓢ A B Ⓢ C Ⓢ
48.01±0.02
1.890±.001
0.05/.002 Ⓢ A B Ⓢ C Ⓢ
SEE DETAIL F
(4.305/4.293)
(.1695/.1690)
(2.75°)
12.70±0.25
.500±.010
-A-
0.12/.005
16 GA (1.52/.0598)
25.40/25.35
1.000/.998
21.01/20.96
.827/.825
(R 24.61/.969)
(R 50.83/2.001)
(R 67.82/2.670)
(R 37.92/1.493)
21.26/21.21
.837/.835
25.65/25.60
1.010/1.008
2X 33.91±0.12
1.335±.005
48.26
1.900
47.70±0.02
1.878±.001
42.88±0.02
1.688±.001
61.70±0.03
2.429±.001
SEE DETAIL B
SEE DETAIL D
2X R 1.60/.063 (TYP)
R 1.60/.063 (TYP)
2X R 1.27/.050 (TYP)
SEE DETAIL G
4.78
.188
9.53
.375
-C-
2X R 2.39/.094
2X R 0.76/.030
2X ⌀ 6.50±0.02
.256±.001
0.02/.001 Ⓢ A B Ⓢ C Ⓢ
19.05
.750
38.10
1.500
(42.88/1.688)
(47.70/1.878)
85.72±0.02
3.375±.001
0.12/.005 Ⓢ A B Ⓢ C Ⓢ
95.40±0.02
3.756±.001
0.12/.005 Ⓢ A B Ⓢ C Ⓢ
(2X 33.91/1.335)
DETAIL G
SCALE: 8 to 1

Figure 5a

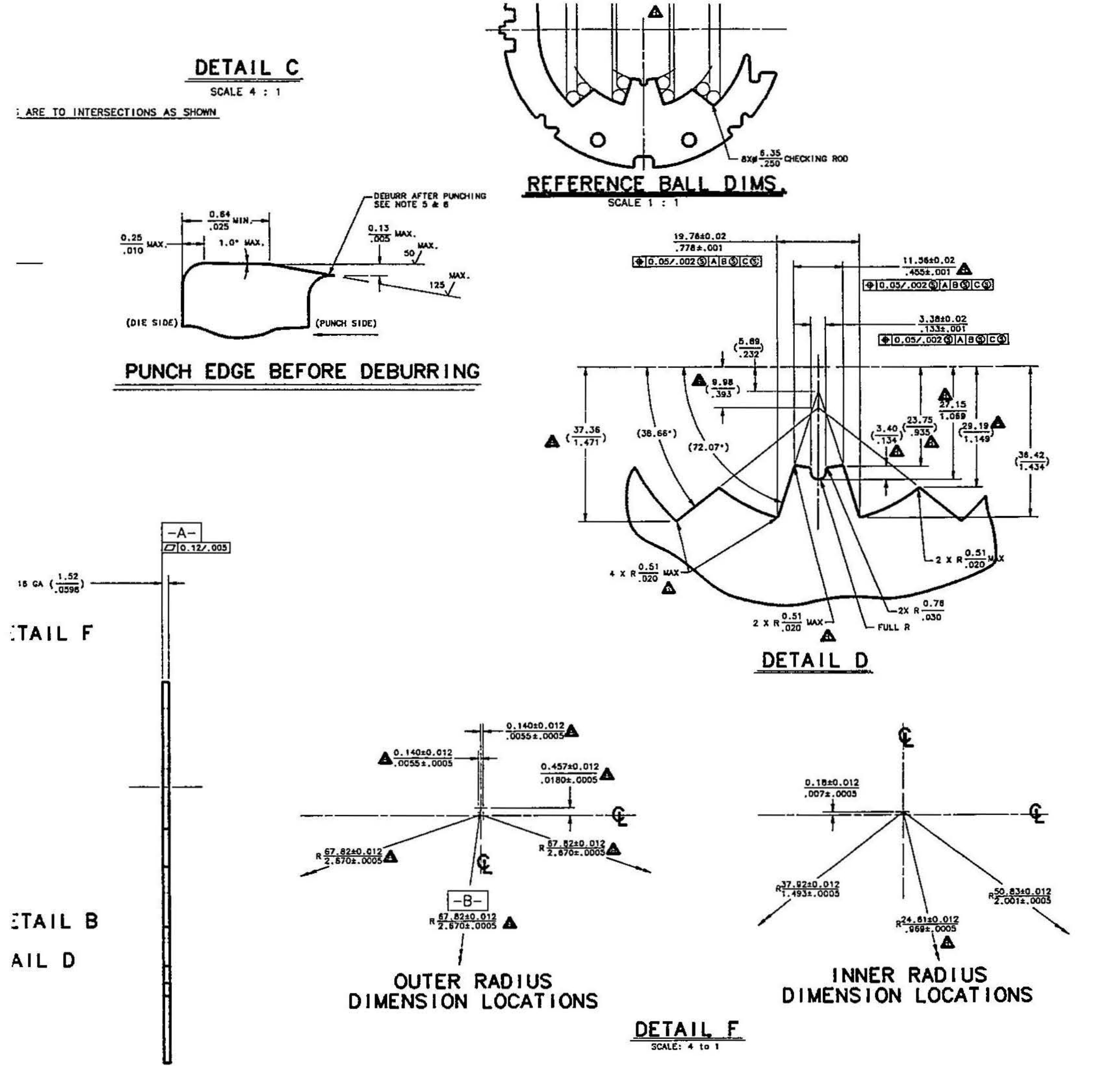
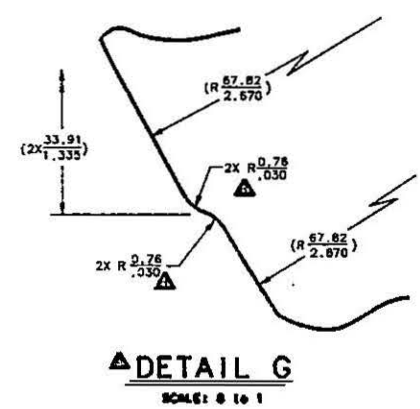


Figure 5b



NOTES:

1-MATERIAL: #16GA.(.0598)NITRONIC-40 ASTM A-412 GR.XM-11.
2-ALL DIMENSIONS ARE TO TRUE CORNER INTERSECTIONS
3-DIMENSIONS SHOWN ARE ON DIE SIDE.
4-TOLERANCES ARE NON-CUMULATIVE.
5-TUMBLE TO REMOVE ALL SHARP EDGES AND BURRS.
6-FINISHED LAM. MUST BE FREE OF ALL FOREIGN MATTER, OIL, GREASE, METAL PARTICLES, ETC. PRODUCED DURING DIE PUNCHING OR TUMBLING.
7-THIS COLLAR IS MADE TO BE USED WITH VERTICALLY SPLIT YOKE LAMINATION #0102-ME-292123
8-ALL TOLERANCES ±.12mm (.005 inch) UNLESS OTHERWISE SPECIFIED; ANGLES ±.25°.

ITEM	PART NO.	DESCRIPTION OR SIZE	QT

PARTS LIST

UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS ARE IN MILLIMETERS.
2. TOLERANCES: SEE NOTE 8.
3. DIMENSIONS BASED UPON ANSI Y14.5M-1982.
4. INCH DIMENSIONS ARE FOR REFERENCE ONLY.
5. BREAK ALL SHARP EDGES.
6. DO NOT SCALE DRAWING.
7. MAX. ALL MACH. SURFACES 125
8. DIMENSION IDENTIFICATION: MILLIMETER/INCH : MILLIMETER/INCH

ORIGINATOR	J. STRAIT	
DRAWN	RICK DIXON	5/23/
CHECKED	J. Brondt	7/17/
APPROVED	R. Bossert	7/17/
USED ON		
MATERIAL	SEE NOTE 1	

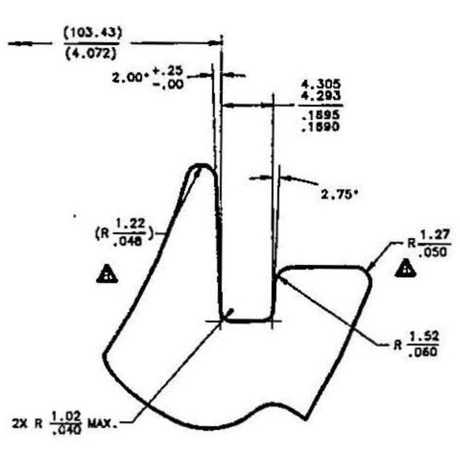
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
SSC

SSC 50mm DIPOLE COLD MASS
COLLAR LAMINATION W/O SHIMS
FOR VERTICALLY SPLIT YOKE

SCALE	FILMED	DRAWING NUMBER
2 : 1 AND NOTED		0102-ME-292059

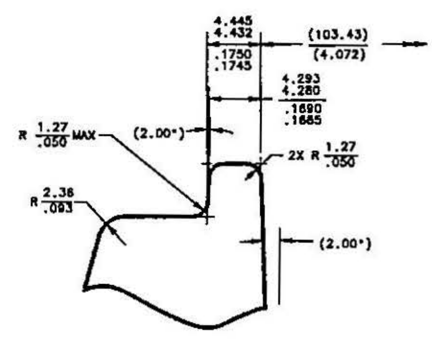
CREATED WITH I-DEAS 5.0 | USER NAME: NancyB

REV.	DESCRIPTION.	DRAWN / APPD.	DATE
A	OUTER RADIUS WAS 68.07/2.680 IS KNOW 67.82/2.670 WITH NEW OFFSETS AND NEW RADIUS CENTER LOCATIONS. SEE DETAIL G FOR THESE NEW OFFSETS. SEE DETAIL F FOR NEW OUTER RADIUS DIMENSION LOCATIONS. 2X ø6.50/.256 WAS ø6.35/.250 THRU HOLE. ø6.50/.256 HOLE LOCATION HAS CHANGED. 48.26/1.900 WAS 53.87/2.121. 19.05/.750 WAS 22.23/.875 AND 38.10/1.500 WAS 44.75/1.750. SHOULDER DIM. OF 21.01-20.96/.827-.825 AND 21.26-21.21/.837-.835 WERE 21.08-21.07/.8300-.8295 AND 21.25-21.2?/.8365-.8360 RESPECTIVELY. NOTE 6 WAS ADDED. OUTER COIL POLE FACES WAS CHANGED BY .005. THE FOLLOWING DIM. HAVE CHANGED. 68.50/2.697 WAS 68.33/2.690, 48.01/1.890 WAS 47.83/1.883, 37.36/1.471 WAS 37.47/1.475, 29.19/1.149 WAS 29.26/1.152, 9.98/.393 WAS 10.13/.399, 74.47/2.932 WAS 74.30/2.925, 64.16/2.526 WAS 64.01/2.520.	R. DIXON / RB	7/9/90 / 7/17/90
B	REVISED RADII TO IMPROVE DIE WEAR: INCREASED NOTCH FOR STRAIN GAGE WIRES.	NWBARTLETT / RB	1/17/9 / 1/17/9
C	1.878 WAS 1.875: (1.878) WAS (1.875); 3.756 WAS 3.750. REMOVED PART NO. STAMP.	NWBARTLETT	3/08/9



DETAIL B

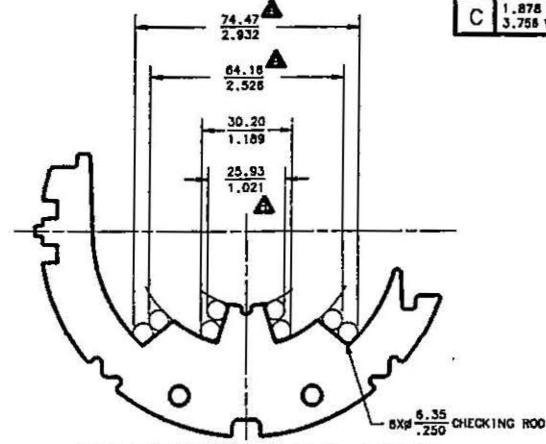
SCALE 4 : 1



DETAIL C

SCALE 4 : 1

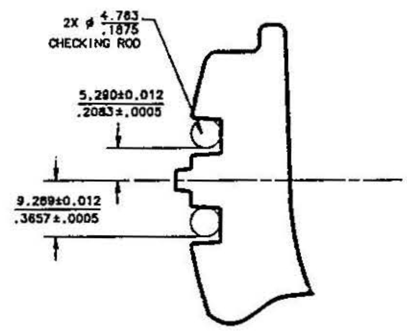
DIMENSIONS ARE TO INTERSECTIONS AS SHOWN



REFERENCE BALL DIMS.

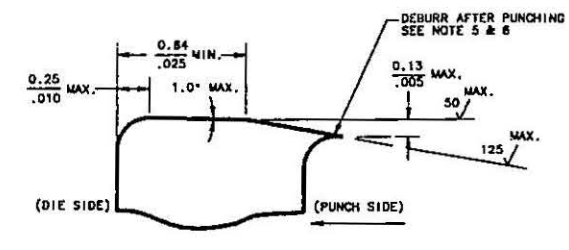
SCALE 1 : 1

Figure 5c

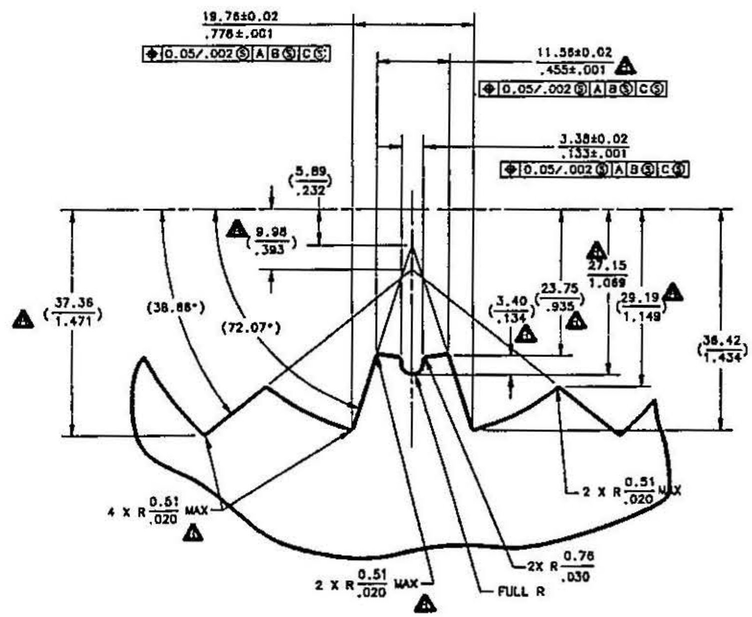


DETAIL E

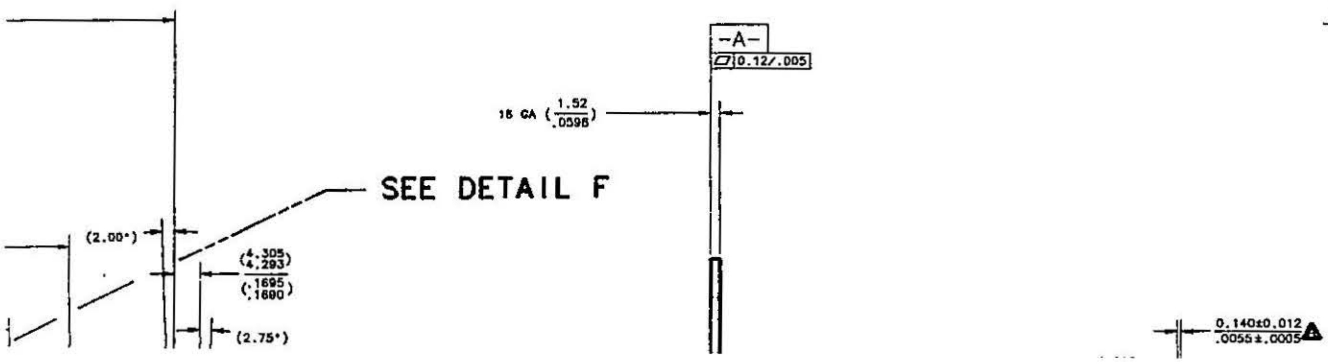
CHECKING PARAMETERS



PUNCH EDGE BEFORE DEBURRING



DETAIL D



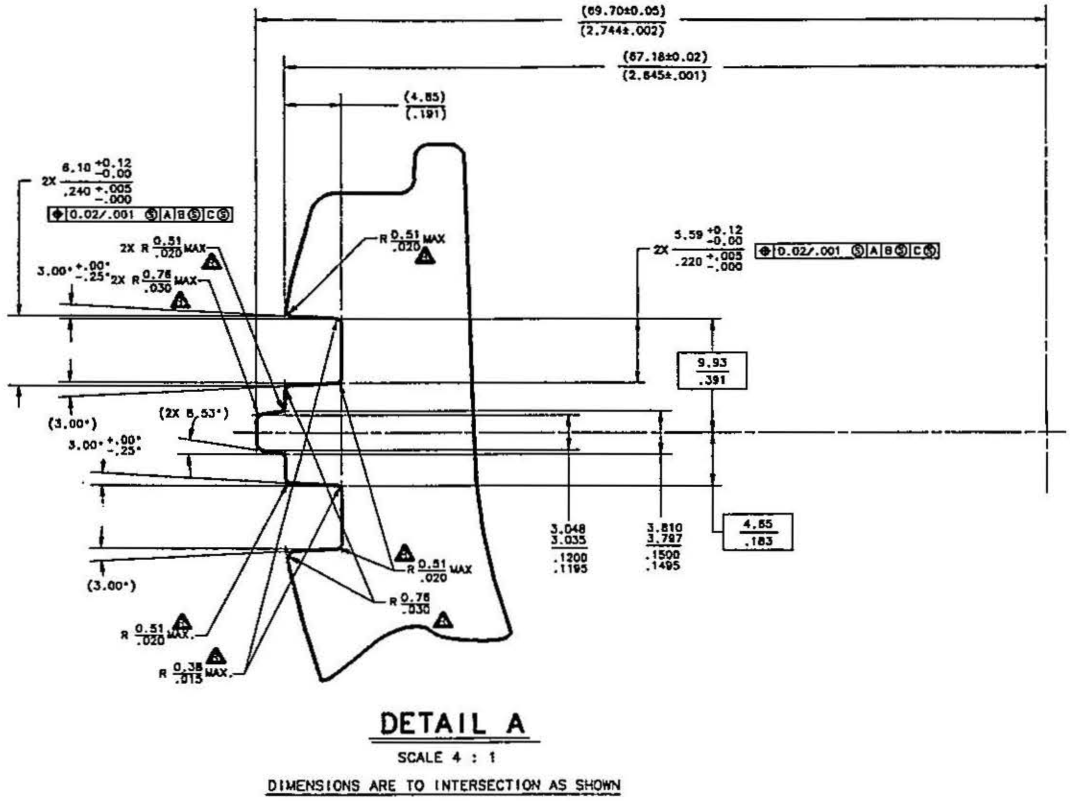
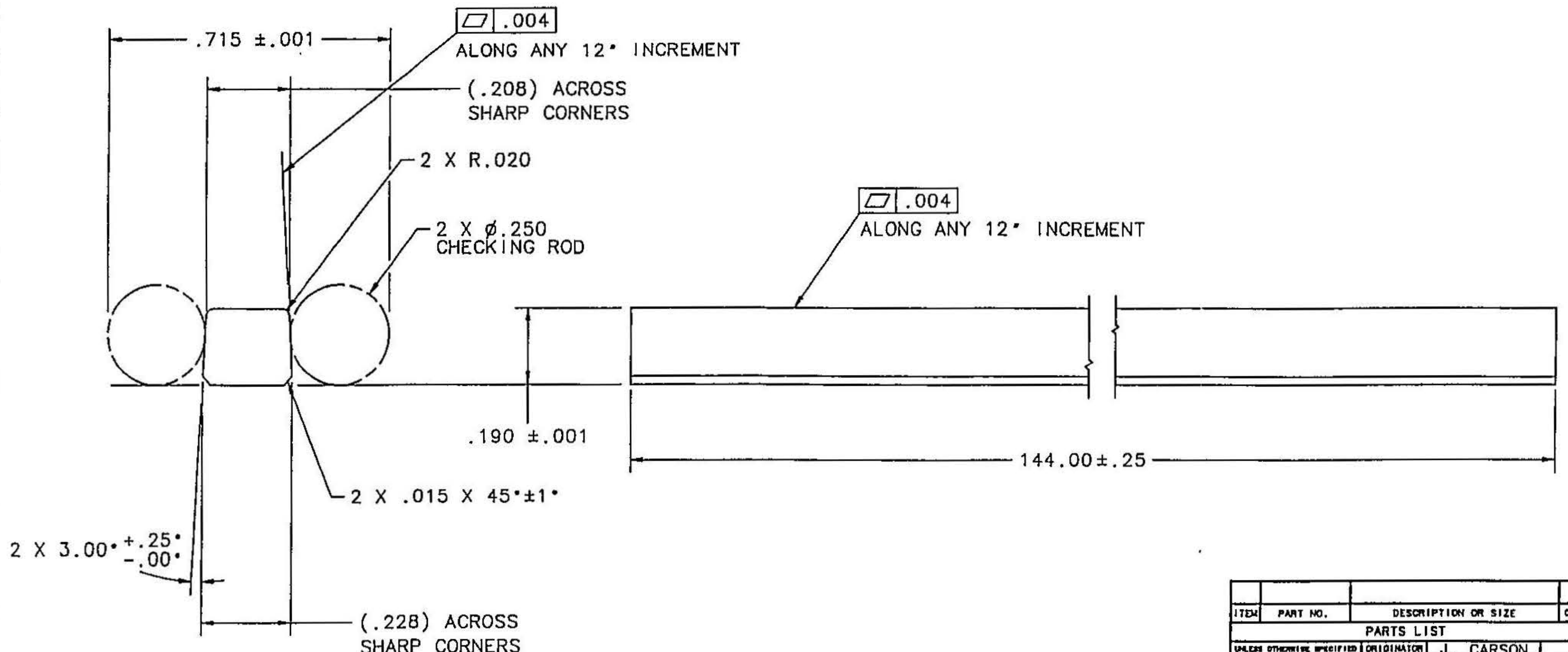

(69.70±0.05)
(2.744±.002)
(67.18±0.02)
(2.645±.001)
(4.85)
(.191)
DETAIL A
SCALE 4 : 1
DIMENSIONS ARE TO INTERSECTION AS SHOWN

Figure 5d

REV.	DESCRIPTION	DRAWN / APPD.	DATE / DATE
B	REVISED MATERIAL; ADDED NOTE 1.	NWB	11/27/81



ACTUAL SIZE

NOTES:

1. MATERIAL: PHOSPHOR BRONZE, 5% GRADE A, FULL HARD, ASTM B139 ALLOY 3/8 DIA. ROUND.
2. THIS PART IS INTERCHANGEABLE WITH BNL PART NO. 22-529.05-2 TAPERED KEY- STANDARD.

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.
PARTS LIST			

UNLESS OTHERWISE SPECIFIED			ORIGINATOR	J. CARSON	
.XX	.XXX	ANGLES	DRAWN	J. CAHILL	7-28-89
±.02	±.005	± NA	CHECKED	R. Bossert	11-27-89
1. BREAK ALL SHARP EDGES .03 MAX. 2. DO NOT SCALE DRAWING. 3. DIMENSIONS BASED UPON ANSI Y14.5M-1982 4. MAX. ALL MACH. SURFACES			APPROVED	R. Bossert	11-27-89
			USED ON	0102-ME-217916 0102-ME-217917	
			MATERIAL	SEE NOTE 1	

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

SSC MAGNET, DIPOLE
C358D CROSS SECTION
TAPERED KEY

SCALE	FILMED	DRAWING NUMBER	REV.
4:1		0102-MB-217851	B

CREATED WITH I-DEAS 4.1 | USER NAME: NANCYR

Figure 6

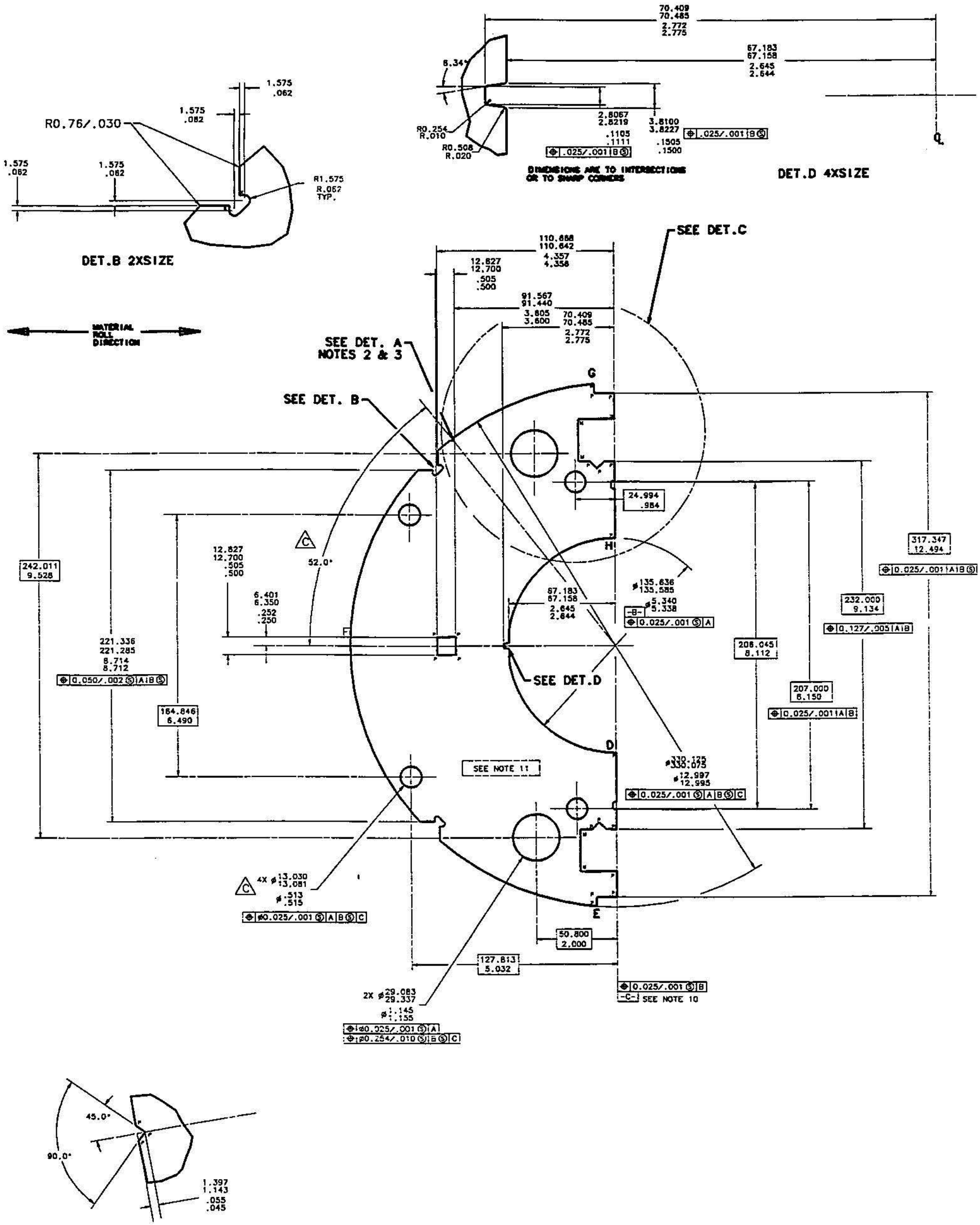
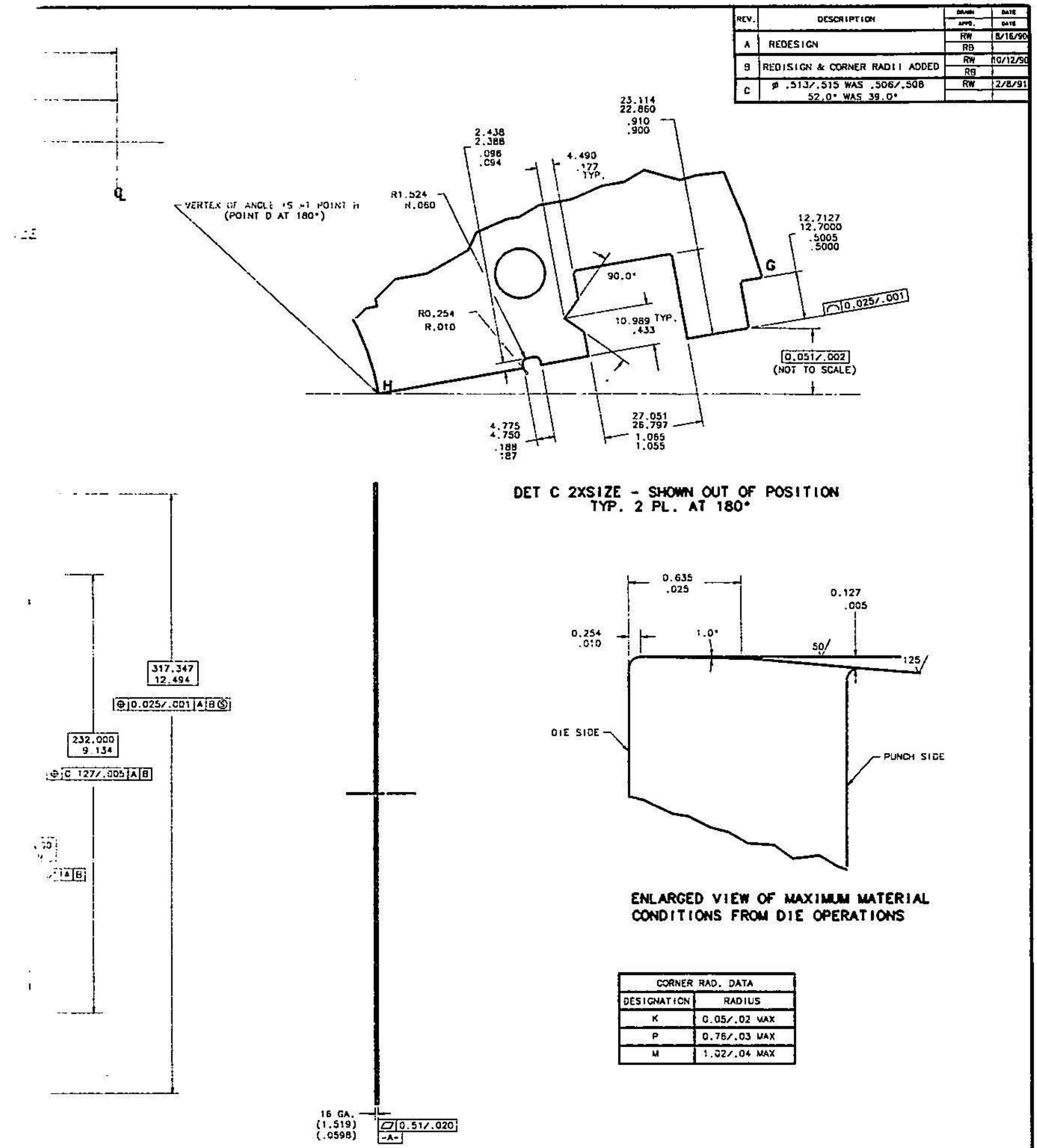

DET.B 2XSIZE
R0.76/.030
DET.D 4XSIZE
DIMENSIONS ARE TO INTERSECTIONS OR TO SHARP CORNERS
MATERIAL ROLL DIRECTION
SEE DET. A NOTES 2 & 3
SEE DET. B
SEE DET.C
SEE DET.D
SEE NOTE 11
SEE NOTE 10
DET.A 4XSIZE

Figure 7a



REV.	DESCRIPTION	DRAWN / APPD.	DATE
A	REDESIGN	RW / RB	8/16/90
B	REDISIGN & CORNER RADII ADDED	RW / RB	10/12/90
C	ø .513/.515 WAS .506/.508 52.0° WAS 39.0°	RW	2/8/91

CORNER RAD. DATA	
DESIGNATION	RADIUS
K	0.05/.02 MAX
P	0.76/.03 MAX
M	1.02/.04 MAX

Figure 7b

NOTES.

1. MATERIAL: EXTRA LOW CARBON MAGNET STEEL AS PER SPEC NO. SSC-MAG-M-4341
2. THIS NOTCH TO BE INCORPORATED INTO ALL LAMINATIONS.
3. ALL LAMINATIONS TO BE DIE PUNCHED WITH THE MAXIMUM MATERIAL THICKNESS COINCIDENTAL WITH THE EDGE DEFINED BY POINTS F,H,& G.
4. ALL DIMENSIONS WILL BE MEASURED AND INSPECTED TO HIGHEST POINT ON EDGE PROFILE.
5. USE WATER SOLUABLE STAMPING LUBRICANT ('ECK' DRAWING COMPOUND OR EQUIVALENT).
6. WT. PER LAMINATION = .83 LBS APPROX.
7. THIS YOKE LAMINATION IS MADE TO BE USED WITH ELLIPTICAL COLLAR LAMINATION DWG.NO. 0102-ME-292059
8. ALL DIMENSIONS ARE SYMETRICAL ABOUT CENTERLINE EXCEPT AS NOTED.
9. UNLESS OTHERWISE SPECIFIED, ALL TOLERANCES ARE ±.13MM /.005".
10. DATUM C IS DEFINED AS A LINE WHICH INTERSECTS THE THEORETICAL SQUARE CORNERS AT POINTS H & D.
11. STAMP OR COIN 'ME-292123C' ON PART WITH NO UPSET OR INDENTATION - CHARACTER HEIGHT = .125"

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.

PARTS LIST

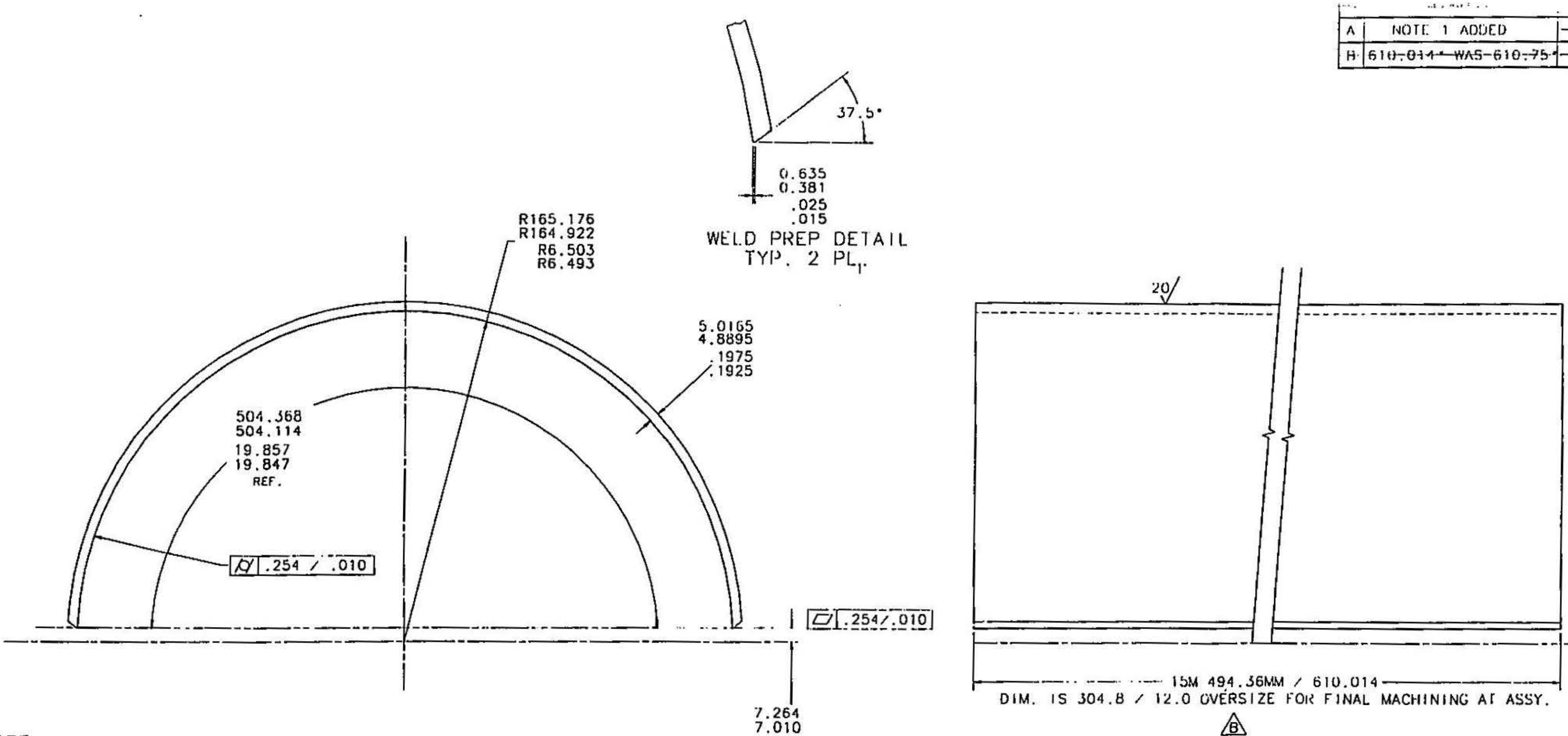
UNLESS OTHERWISE SPECIFIED:			
1. ALL DIMENSIONS ARE IN MILLIMETERS. 3. DIMENSIONS BASED UPON ANSI Y14.5M-1982. 4. INCH DIMENSIONS ARE FOR REFERENCE ONLY. 5. BREAK ALL SHARP EDGES. 6. DO NOT SCALE DRAWING. 7. MAX. ALL MACH. SURFACES 8. DIMENSION IDENTIFICATION: MILLIMETER/INCH	ORIGINATOR	J. STRAIT	
	DRAWN	ROGER ZINK	8/28/90
	CHECKED	M. GORDON	
	APPROVED	R. BOSSERT	
	USED ON		
	MATERIAL	AS NOTED	

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
SSC

SSC (50mm) SHORT/LONG COLD MASS
W6733 CROSS SECTION
VERTICAL SPLIT YOKE LAMINATION

SCALE	FILMED	DRAWING NUMBER	REV
1:1		0102-ME-292123	C

A	NOTE 1 ADDED	RR	
B	~~610.014~~ WAS 610.75	RB	



NOTE:

1. CLEAN AND HANDLE PER FERMI SPEC. #ES-107222
2. THE INSPECTION OF THE SKINS WILL BE DONE IN A CONSTRAINED CONDITION. THE DIMENSIONS ON THIS DRAWING PERTAIN TO THAT CONSTRAINED CONDITION AND WILL NOT BE INSPECTED IN ANY OTHER MANNER. WHEN REFERING TO THE CONSTRAINED CONDITION IT IS DEFINED BY THE FOLLOWING: THE SKIN WILL BE CONSTRAINED IN THE SAME CONDITION THAT IT WILL HAVE WHEN CLAMPED TO THE 1 PHASE IRON, THIS CONSTRAINING WILL IN NO WAY FORCE THE SKIN INTO A CONFIGURATION OTHER THAN IT'S OWN. IN OTHER WORDS IT IS NOT ACCEPTABLE TO FORCE OR INDUCE A TWIST TO ACHIEVE THE ABOVVE DIMENSIONS.

Figure 8

ITEM	PART NO.	DESCRIPTION OR SIZE
	PARTS LIST	
	ORIGINATOR	J. CARSON
	DRAWN	R. WEGFORTH
	CHECKED	
	APPROVED	
	USED ON	
	MATERIAL	304LN S.S.

FERMI NATIONAL ACCELERATOR LABORAT
UNITED STATES DEPARTMENT OF ENERGY
SSC

SSC 50MM LONG COLD MASS
FINAL ASSEMBLY
SKIN

SCALE 1:1 — DRAWING NUMBER 0102-MD-292156

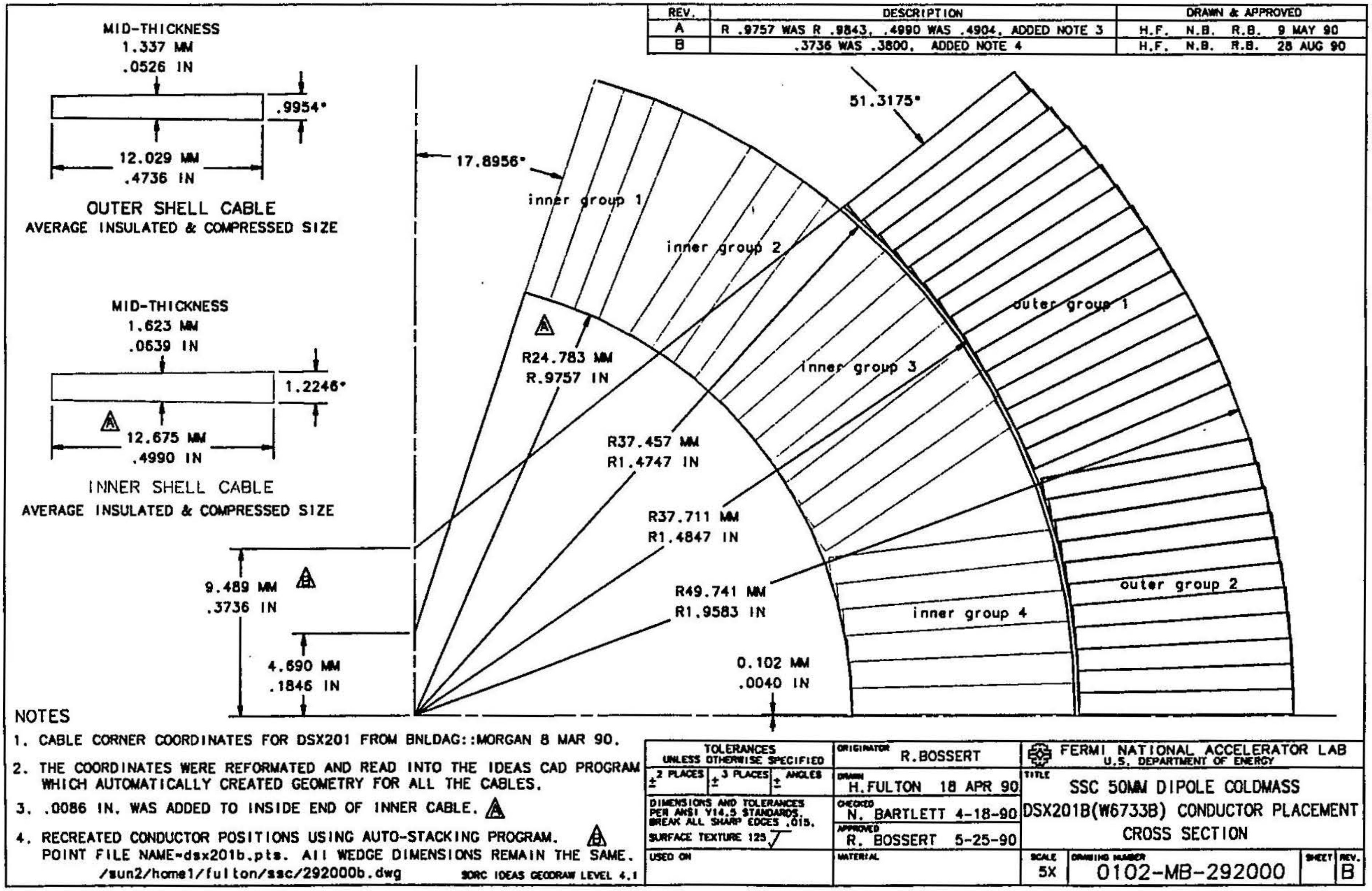

REV.
DESCRIPTION
DRAWN & APPROVED
A
R .9757 WAS R .9843, .4990 WAS .4904, ADDED NOTE 3
H.F. N.B. R.B. 9 MAY 90
B
.3736 WAS .3800, ADDED NOTE 4
H.F. N.B. R.B. 28 AUG 90
MID-THICKNESS
1.337 MM
.0526 IN
.9954°
12.029 MM
.4736 IN
OUTER SHELL CABLE
AVERAGE INSULATED & COMPRESSED SIZE
MID-THICKNESS
1.623 MM
.0639 IN
1.2246°
12.675 MM
.4990 IN
INNER SHELL CABLE
AVERAGE INSULATED & COMPRESSED SIZE
9.489 MM
.3736 IN
4.690 MM
.1846 IN
17.8956°
51.3175°
inner group 1
inner group 2
inner group 3
inner group 4
outer group 1
outer group 2
R24.783 MM
R.9757 IN
R37.457 MM
R1.4747 IN
R37.711 MM
R1.4847 IN
R49.741 MM
R1.9583 IN
0.102 MM
.0040 IN
NOTES
1. CABLE CORNER COORDINATES FOR DSX201 FROM BNLDAG::MORGAN 8 MAR 90.
2. THE COORDINATES WERE REFORMATED AND READ INTO THE IDEAS CAD PROGRAM WHICH AUTOMATICALLY CREATED GEOMETRY FOR ALL THE CABLES.
3. .0086 IN. WAS ADDED TO INSIDE END OF INNER CABLE. A
4. RECREATED CONDUCTOR POSITIONS USING AUTO-STACKING PROGRAM. B
POINT FILE NAME-dsx201b.pts. All WEDGE DIMENSIONS REMAIN THE SAME.
/sun2/home1/fulton/ssc/292000b.dwg
SDRC IDEAS GEODRAW LEVEL 4.1
TOLERANCES UNLESS OTHERWISE SPECIFIED
2 PLACES ± 3 PLACES ± ANGLES ±
DIMENSIONS AND TOLERANCES PER ANSI Y14.5 STANDARDS. BREAK ALL SHARP EDGES .015.
SURFACE TEXTURE 125
USED ON
ORIGINATOR R.BOSSERT
DRAWN H.FULTON 18 APR 90
CHECKED N. BARTLETT 4-18-90
APPROVED R. BOSSERT 5-25-90
MATERIAL
FERMI NATIONAL ACCELERATOR LAB
U.S. DEPARTMENT OF ENERGY
TITLE
SSC 50MM DIPOLE COLDMASS
DSX201B(W6733B) CONDUCTOR PLACEMENT
CROSS SECTION
SCALE 5X
DRAWING NUMBER 0102-MB-292000
SHEET
REV. B

Figure 9

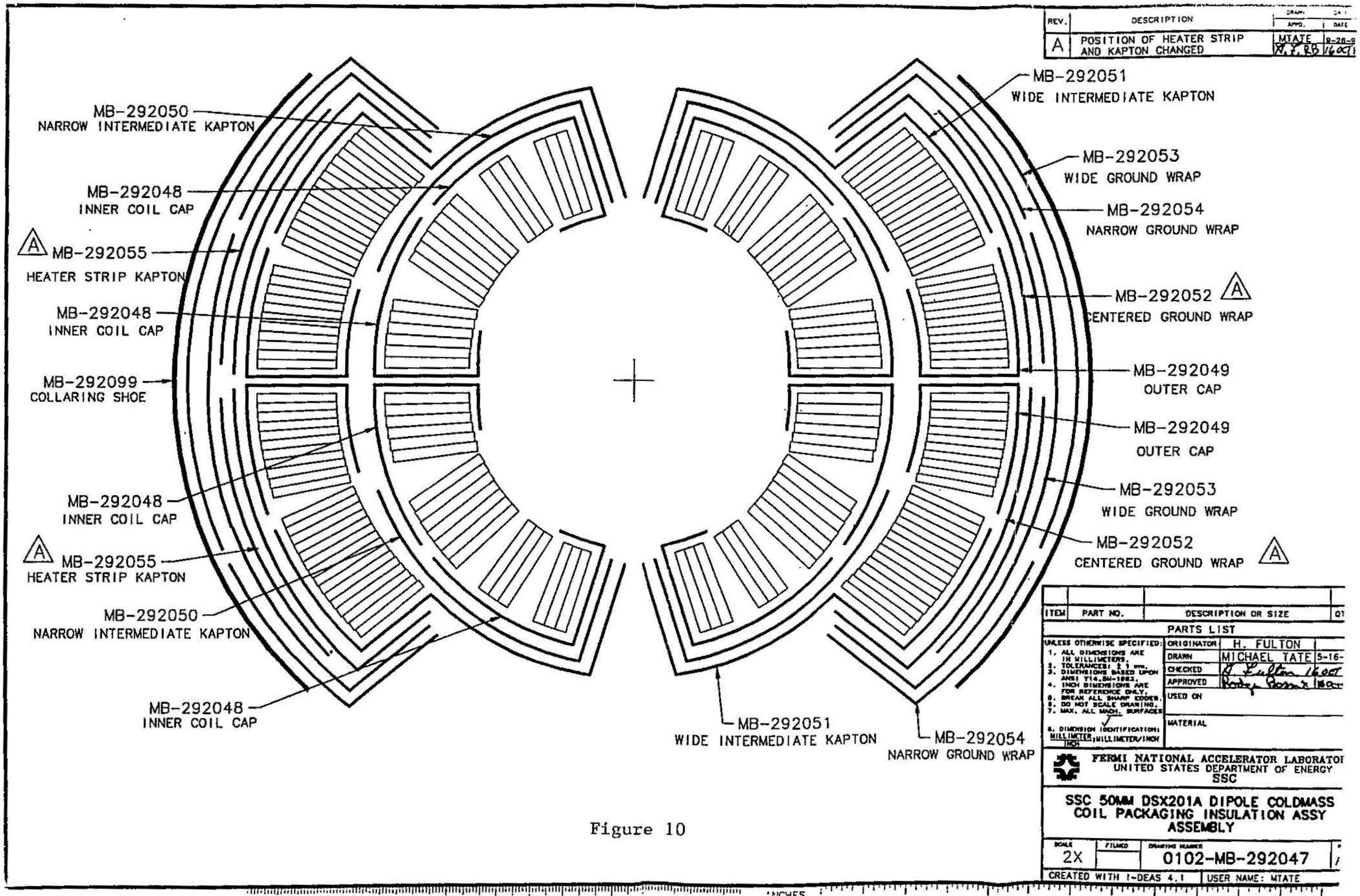
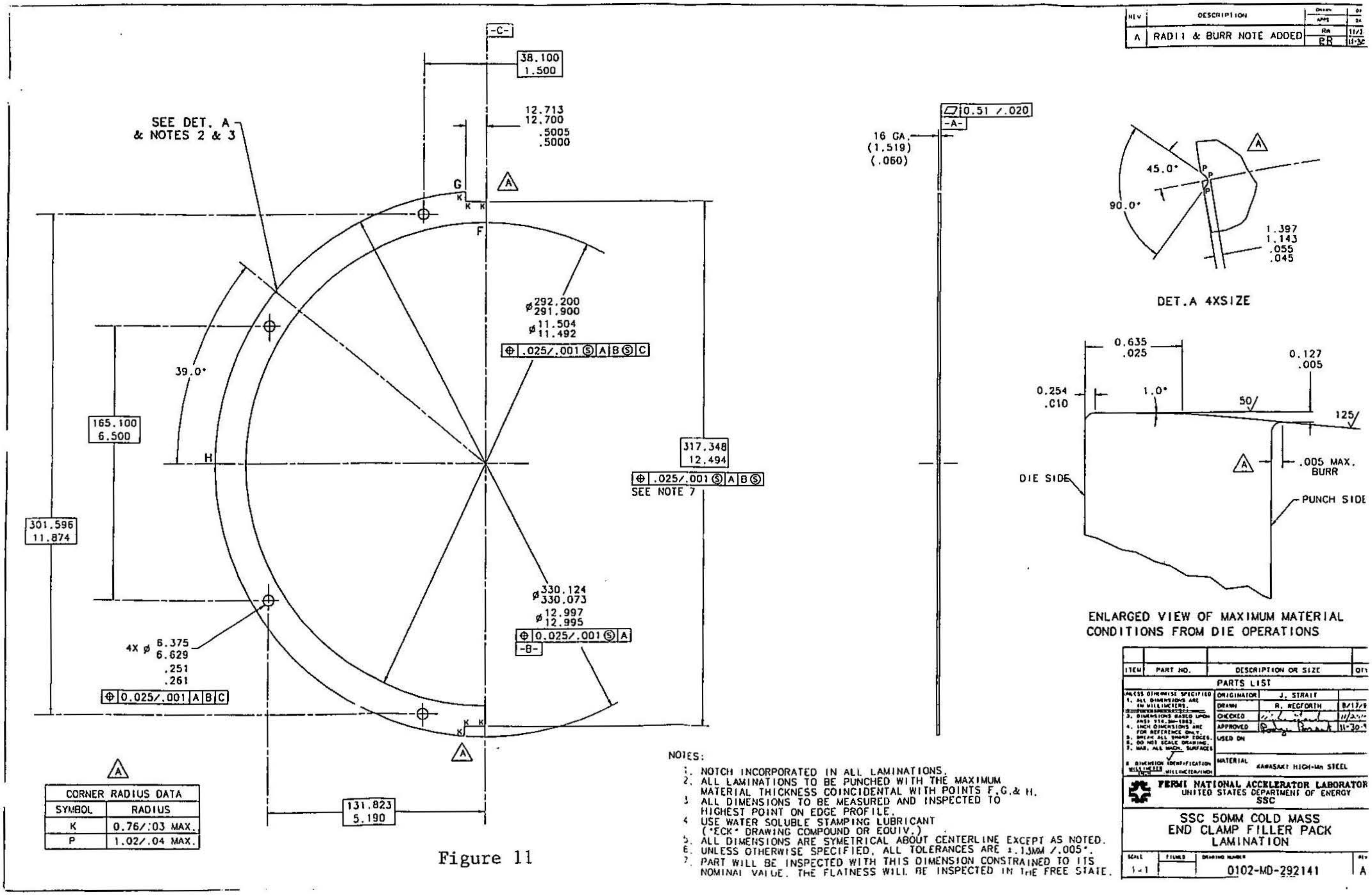

REV.
DESCRIPTION
A
POSITION OF HEATER STRIP AND KAPTON CHANGED
MTATE
MB-292050
NARROW INTERMEDIATE KAPTON
MB-292048
INNER COIL CAP
MB-292055
HEATER STRIP KAPTON
MB-292048
INNER COIL CAP
MB-292099
COLLARING SHOE
MB-292048
INNER COIL CAP
MB-292055
HEATER STRIP KAPTON
MB-292050
NARROW INTERMEDIATE KAPTON
MB-292048
INNER COIL CAP
MB-292051
WIDE INTERMEDIATE KAPTON
MB-292054
NARROW GROUND WRAP
MB-292051
WIDE INTERMEDIATE KAPTON
MB-292053
WIDE GROUND WRAP
MB-292054
NARROW GROUND WRAP
MB-292052
CENTERED GROUND WRAP
MB-292049
OUTER CAP
MB-292049
OUTER CAP
MB-292053
WIDE GROUND WRAP
MB-292052
CENTERED GROUND WRAP
ITEM
PART NO.
DESCRIPTION OR SIZE
PARTS LIST
ORIGINATOR
H. FULTON
DRAWN
MICHAEL TATE
CHECKED
APPROVED
USED ON
MATERIAL
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
SSC
SSC 50MM DSX201A DIPOLE COLDMASS
COIL PACKAGING INSULATION ASSY
ASSEMBLY
SCALE
2X
DRAWING NUMBER
0102-MB-292047
CREATED WITH I-DEAS 4.1
USER NAME: MTATE
INCHES

Figure 10



REV | DESCRIPTION
A | RADII & BURR NOTE ADDED
SEE DET. A & NOTES 2 & 3
38.100 1.500
12.713 12.700 .5005 .5000
-C-
ø292.200 291.900 ø11.504 11.492
.025/.001 Ⓢ A B Ⓢ C
39.0°
165.100 6.500
317.348 12.494
.025/.001 Ⓢ A B Ⓢ
SEE NOTE 7
301.596 11.874
ø330.124 330.073 ø12.997 12.995
0.025/.001 Ⓢ A
-B-
4X ø 6.375 6.629 .251 .261
0.025/.001 A B C
131.823 5.190
CORNER RADIUS DATA
SYMBOL | RADIUS
K | 0.76/.03 MAX.
P | 1.02/.04 MAX.
0.51 /.020
-A-
16 GA. (1.519) (.060)
45.0°
90.0°
1.397 1.143 .055 .045
DET.A 4XSIZE
0.635 .025
0.127 .005
0.254 .010
1.0°
50
125
.005 MAX. BURR
DIE SIDE
PUNCH SIDE
ENLARGED VIEW OF MAXIMUM MATERIAL CONDITIONS FROM DIE OPERATIONS
NOTES:
1. NOTCH INCORPORATED IN ALL LAMINATIONS.
2. ALL LAMINATIONS TO BE PUNCHED WITH THE MAXIMUM MATERIAL THICKNESS COINCIDENTAL WITH POINTS F,G,& H.
3. ALL DIMENSIONS TO BE MEASURED AND INSPECTED TO HIGHEST POINT ON EDGE PROFILE.
4. USE WATER SOLUBLE STAMPING LUBRICANT ("ECK" DRAWING COMPOUND OR EQUIV.)
5. ALL DIMENSIONS ARE SYMETRICAL ABOUT CENTERLINE EXCEPT AS NOTED.
6. UNLESS OTHERWISE SPECIFIED, ALL TOLERANCES ARE ±.13MM /.005".
7. PART WILL BE INSPECTED WITH THIS DIMENSION CONSTRAINED TO ITS NOMINAL VALUE. THE FLATNESS WILL BE INSPECTED IN THE FREE STATE.
PARTS LIST
ORIGINATOR J. STRAIT
DRAWN R. RECFORTH
MATERIAL KAWASAKI HIGH-Mn STEEL
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
SSC
SSC 50MM COLD MASS END CLAMP FILLER PACK LAMINATION
0102-MD-292141

Figure 11

REV	DESCRIPTION	APPD	DATE
A	NOTE 3 ADDED	RW RR	10/17/ 10-22-(

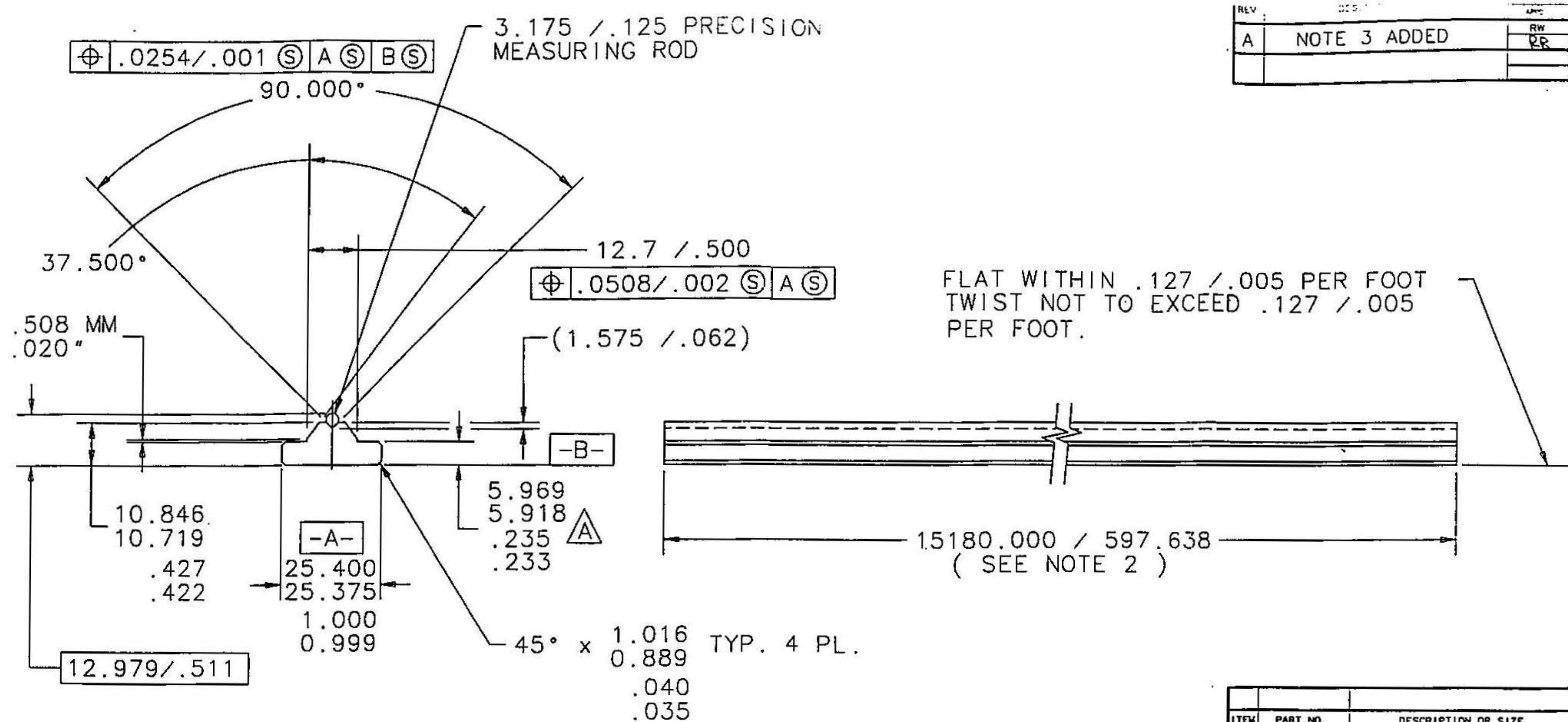


Figure 12

NOTE:

1. ALL CORNER RADII TO BE .254/.381 -.010/.015 UNLESS OTHERWISE SPECIFIED.
2. OPTIONAL - 3657.6 MM / 12'-0" LG'S. TO MAKE UP O.A.LG.
3. CLEAN AND HANDLE PER FERMI SPEC. #ES-107222

ITEM	PART NO.	DESCRIPTION OR SIZE	QT

PARTS LIST

UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS ARE IN MILLIMETERS.
2. TOLERANCES: ± 1 mm.
3. DIMENSIONS BASED UPON ANSI Y14.5M-1982.
4. INCH DIMENSIONS ARE FOR REFERENCE ONLY.
5. BREAK ALL SHARP EDGES.
6. DO NOT SCALE DRAWING.
7. MAX. ALL MACH. SURFACES √
8. DIMENSION IDENTIFICATION: MILLIMETER/INCH ; MILLIMETER/INCH

ORIGINATOR	J. CARSON	
DRAWN	R. WEGFORTH	10/2/
CHECKED	M. Gordon	10/22
APPROVED	Rodger Bossert	10-22-
USED ON		
MATERIAL	304LN S.S.	

FERMI NATIONAL ACCELERATOR LABORATOR
UNITED STATES DEPARTMENT OF ENERGY
SSC

SSC 50MM LONG COLD MASS
FINAL ASSEMBLY
ALIGNMENT KEY

SCALE	FILMED	DRAWING NUMBER	REV
1=1		0102-MB-292155	A

CREATED WITH I-DEAS 4.1 | USER NAME: WEGFORTH