TS-SSC 90-029

Design of a Vertically-Split Yoke and Associated Collar for the 40 mm Dipole

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I Yoke

1) ID and OD of yoke should remain at their nominal values and interior should remain circular to follow the magnetic design.

2) All yoke features should remain the at the same locations, again for magnetic reasons.

3) Exceptions to (2) include the bus slot, mid-plane yoke-to-yoke alignment features and the full-length fiducial. The fiducial must be moved to the vertical mid-plane for obvious assembly reasons. This requires that the bus slot be moved radially inwards enough to provide space for the fiducial bar and enough yoke material for it to interlock with. (Steve Kahn believes that moving the bus slot by the required amount will have little effect on the magnetic field quality.) This also serves to increase the bending stiffness of the yoke assembly. The yoke mid-plane alignment key must also be moved to the vertical mid-plane. This feature at the horizontal mid-plane is used to control the saturation sextapole moment, so moving it the the vertical mid-plane will degrade the field quality at high field. This will be ignored for now.

4) A taper of 2 mils on the vertical mid-plane counteracts the tendency of the gap to open at the inner radius under excitation due to yoke bending.

5) The yoke lamination is shown in Figure 1.

II Yoke-Collar Interface

1) The desired features are:

   a) Yoke mid-plane gap should be closed under all circumstances at T = 4 K up to at least B = 7.2 T.

   b) At T = 4 K, B = 0, the yoke should horizontally load the collared coil with at least 3000 lbs./(axial inch). This serves to guarantee good axial restraint and that the collars are well seated against the yoke for good horizontal support.

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

2) To achieve these requirements with a round yoke ID the collars must be horizontally elliptical. The collar horizontal radius must be sufficiently large to ensure positive loading at 4 K. The collar vertical radius must be sufficiently small that a yoke-collar gap exists at the pole under all conditions. This gap must exist for the highest preload coils which generate the largest vertical radius collared coils. (The horizontal radius depends only weakly on preload.) This is necessary to allow the collared coil to be inserted into the yoke, but more importantly to ensure closure of the yoke mid-plane. Because of requirement (b), the collared coil will be horizontally compressed by the yoke both at 300 K and at 4 K. (More at 300 K because of the smaller thermal contraction of the yoke material.) The force required for horizontal compression of the collared coil is much smaller if it is free to expand vertically. If the collars contact the yoke at the pole, the skin tension is insufficient to allow any significant further compression.

III Collar Interior

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. Prestress causes the vertical radius to increase, 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 undeflected room temperature collar must have a horizontal radius larger and a vertical radius smaller than nominal to arrive at the correct shape cold.

IV Collar Shape Calculation

1) Collar outer surface

To estimate the required collar shape the collars are modeled as a pair of coupled springs whose spring constants are derived from finite element calculations.[1] Collar deflections due to prestress, assembly into the yoke and cooldown are computed for various trial vertical and horizontal radii. To bypass the difficulties of computing the effects of cooldown (in which many things are changing at once) the model cools the collared coil and yoke separately and then assembles them at 4 K. (Assuming that the problem is linear and elastic the order in which various steps are performed does not effect the end result.) Collared coil deflections in the yoke are computed both at 300 K and 4 K with skin tensions appropriate for each temperature. A Fortran program is used to try a variety of trial collar vertical and horizontal radii for a variety of coil preloads and a variety of plausible values of collar spring and vertical-horizontal coupling constants. Tables of the calculation results are attached for the horizontal radius 6±1 mils larger than the yoke and the vertical radius 12±1 mils smaller than the yoke.

The results indicate the following for these collar dimensions and a preload window of 10±3 kpsi:

a) The skin tension required to close the mid-plane at T = 300 K is 22±4 kpsi. Since the measured 300 K skin stress is 25-30 kpsi, the yoke mid-plane is just closed.

b) At 4 K, B = 0, the skin stress required to close the mid-plane is 14±6 kpsi, so the horizontal yoke-collar clamping force is 5±2 klbs./(axial inch). Assuming that the effective coefficient of friction between the collars and the yoke is on the order of 1 and that no bending of collar or yoke laminations occurs in the axial direction then the axial Lorentz force will be transferred to the skin within a few inches.

c) The measured skin tension at 4 K is 45-50 kpsi. 14±6 kpsi is used to compress the collared coil and close the mid-plane, so 33±8 kpsi or 12±3 klbs/(axial inch) remains to oppose the horizontal Lorentz force. The Lorentz force at 6.6 T is 8 klbs/inch. If all of this appears in the skin (assuming none goes into collar and yoke bending), the skin has sufficient stress to maintain the mid-plane gap closed up to 8.1(+0.9/-1.1) T. In fact, even with the mid-plane gap closed some yoke and collar bending occurs. This reduces the fraction of the Lorentz force that appears in the skin and increases the safety margin. Finite element calculations [2] show that only about one half of the Lorentz force is transmitted to the yoke, so this design has more than a factor of two mechanical margin.

The "error bars" in the above discussion include the variation in preload, a tolerance of ±1 mil on the relative collar and yoke radii and reasonable uncertainties in the values of parameters used in the coupled spring model calculation.

The proposed collar has an outer horizontal radius 6 mils larger and a vertical radius 12 mils smaller than the yoke inner radius. This may be achieved by specifying an elliptical surface. An alternate method, which will yield an almost equivalent surface, is to specify a circular surface with a radius 6 mils larger than nominal which is centered 18 mils "below" the nominal center.

The collars are "flattened" in the neighborhood of the keys and do not make contact until about 0.4" above the mid-plane. The actual collar (Figure 2) is designed to generate 6 mils of horizontal interference at a distance of 0.5" from the mid-plane. [3]

2) Collar Inner Surface

The "target shape" for the coils, fully assembled at 4 K, is the shape in the horizontally split yoke case. There is 360° contact between the horizontally split yoke and the collars. Therefore the collar outer and inner surfaces are round and concentric. The assembled collars have been expanded by the coil preload from their undeflected size to fill the yoke and are therefore 2 mils larger in radius than a free collar at 4 K. To compute the shape of the inner surface of the collars for the vertically split yoke we start by defining them to have the desired shape assembled at 4 K and then

work backwards to determine the shape of the free collars at 300 K that will generate the final shape. As before, we un-yoke the collared coil at 4 K to simplify the calculation of thermal expansion effects. In the table below all deflections are relative to a free collar at the particular temperature. (That is, we work in a coordinate system that varies with the thermal expansion of stainless steel.)

	Δrh (mils)	Δrv (mils)
4 K, assembled (final state)	+2	+2
Un-yoked (at 4 K)	+3.5	-1.9
Warmup (effects of prestress increase only)	-0.1	+1.3
Uncollared (at 300 K)	+0.5	-5.6
Net deflection	+5.9	-4.2

That is, the collar interior should have a horizontal radius 6 mils larger and a vertical radius 4 mils smaller than called for by the nominal magnet design. This is achieved, as before, by increasing the radius by 6 mils and displacing the center by -10 mils.

The pole surfaces are defined by setting the circumferences at the inner and outer radii of the two coil cavities to be the same as for the vertically ovalized collars for the horizontally split yoke. Details of the calculation are given in Figure 3.

Notes

[1] For more details of this model as applied to the horizontally split yoke case see J. Strait, "Calculation of Desired Vertical Ovality of SSC Collars," in minutes of the MSIM, October, 1989.

[2] J. R. Turner, private communication.

[3] J. Kerby, "Center Offset of Outside Radius of 40 mm Ovalized Collars", TS-SSC 90-023

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*********************************************************
********* Collared Coil In Vertically Split Yoke **********
*********          40 mm SSC Dipole            **********
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------------------ Input Parameters ----------------------
rv(Rv)           = collar(yoke) vertical   radius - nominal radius (mils)
rh(Rh)           = collar(yoke) horizontal radius - nominal radius (mils)
skin_stress      = azimuthal skin stress at 4 K (kpsi)
skin_stress_300K= azimuthal skin stress at 300 K (kpsi)
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 (inches)
drv/drh          = drv/drh for horizontal force
drv/dpr          = drv/d(prestress) (average of inner and outer) (mils/kpsi)
drh/dpr          = drh/d(prestress) (average of inner and outer) (mils/kpsi)
prestr           = free collared coil prestress at 300 K (average of inner and outer) (kpsi)
dcool            = free collared coil cooldown prestress change (average of inner and outer) (kpsi)
dh/ds1           = drh/d(skin stress) rv < Rv (mils/kpsi)
dh/ds2           = drh/d(skin stress) rv > Rv (mils/kpsi)

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

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r_nominal        =   2.183 inches
rv               = -11.000 mils
rh               =   7.000 mils
skin_stress_300K =  25.000 kpsi
skin_stress      =  45.000 kpsi
contract_collar  =  -0.003
contract_yoke    =  -0.002
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```

							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
-0.54	0.56	-0.05	10.00	-2.25	-0.25	-0.03	6.5	-5.4	-1.9	26.4	4.4	-8.8	-12.0	-6.5	0.0	-6.5	-	18.
----- Vary Coil Prestress and Cooldown Loss -----																		
-0.54	0.56	-0.05	13.00	-2.25	-0.25	-0.03	6.3	-3.7	-0.3	25.8	4.3	-7.2	-9.0	-4.9	0.0	-4.9	-	17.
-0.54	0.56	-0.05	7.00	-2.25	-0.25	-0.03	6.6	-7.1	-3.5	27.0	4.6	-10.5	-14.9	-8.1	0.0	-8.1	-	19.
-0.54	0.56	-0.05	10.00	-3.25	-0.25	-0.03	6.5	-5.4	-1.9	26.4	4.5	-9.4	-12.9	-7.0	0.0	-7.0	-	18.
----- Vary dr/d(prestress) -----																		
-0.54	0.44	-0.05	10.00	-2.25	-0.25	-0.03	6.5	-6.6	-3.1	26.4	4.4	-9.8	-13.7	-7.4	0.0	-7.4	-	18.
-0.54	0.56	0.00	10.00	-2.25	-0.25	-0.03	7.0	-5.4	-1.6	28.5	4.8	-8.8	-11.6	-6.2	0.0	-6.2	-	20.
----- Choose values that give a small collared coil -----																		
-0.54	0.44	-0.05	7.00	-3.25	-0.25	-0.03	6.6	-7.9	-4.3	27.0	4.6	-11.5	-16.7	-9.0	0.0	-9.0	-	19.
----- Vary dr/d(skin stress) -----																		
-0.54	0.56	-0.05	10.00	-2.25	-0.32	-0.03	6.5	-5.4	-1.9	20.3	4.4	-8.8	-12.0	-6.5	0.0	-6.5	-	14.
-0.54	0.56	-0.05	10.00	-2.25	-0.25	-0.05	6.5	-5.4	-1.9	26.4	4.4	-8.8	-12.0	-6.5	0.0	-6.5	-	18.
-0.54	0.56	-0.05	10.00	-2.25	-0.32	-0.05	6.5	-5.4	-1.9	20.3	4.4	-8.8	-12.0	-6.5	0.0	-6.5	-	14.
----- Vary drv/drh -----																		
-0.46	0.56	-0.05	10.00	-2.25	-0.25	-0.03	6.5	-5.4	-2.4	26.4	4.4	-8.8	-14.8	-6.8	0.0	-6.8	-	18.
-0.64	0.56	-0.05	10.00	-2.25	-0.25	-0.03	6.5	-5.4	-1.2	26.4	4.4	-8.8	-9.4	-6.0	0.0	-6.0	-	18.

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r_nominal        =   2.183 inches
rv               = -11.000 mils
rh               =   5.000 mils
skin_stress_300K =  25.000 kpsi
skin_stress      =  45.000 kpsi
contract_collar  =  -0.003
contract_yoke    =  -0.002
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							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
-0.54	0.56	-0.05	10.00	-2.25	-0.25	-0.03	4.5	-5.4	-3.0	18.3	2.4	-8.8	-14.0	-7.5	0.0	-7.5	-	10.
----- Vary Coil Prestress and Cooldown Loss -----																		
-0.54	0.56	-0.05	13.00	-2.25	-0.25	-0.03	4.3	-3.7	-1.4	17.6	2.3	-7.2	-11.0	-5.9	0.0	-5.9	-	9.
-0.54	0.56	-0.05	7.00	-2.25	-0.25	-0.03	4.6	-7.1	-4.6	18.9	2.6	-10.5	-16.9	-9.1	0.0	-9.1	-	10.
-0.54	0.56	-0.05	10.00	-3.25	-0.25	-0.03	4.5	-5.4	-3.0	18.3	2.5	-9.4	-14.9	-8.1	0.0	-8.1	-	10.
----- Vary dr/d(prestress) -----																		
-0.54	0.44	-0.05	10.00	-2.25	-0.25	-0.03	4.5	-6.6	-4.2	18.3	2.4	-9.8	-15.7	-8.5	0.0	-8.5	-	10.
-0.54	0.56	0.00	10.00	-2.25	-0.25	-0.03	5.0	-5.4	-2.7	20.3	2.8	-8.8	-13.6	-7.3	0.0	-7.3	-	11.
----- Choose values that give a small collared coil -----																		
-0.54	0.44	-0.05	7.00	-3.25	-0.25	-0.03	4.6	-7.9	-5.4	18.9	2.6	-11.5	-18.7	-10.1	0.0	-10.1	-	11.
----- Vary dr/d(skin stress) -----																		
-0.54	0.56	-0.05	10.00	-2.25	-0.32	-0.03	4.5	-5.4	-3.0	14.0	2.4	-8.8	-14.0	-7.5	0.0	-7.5	-	8.
-0.54	0.56	-0.05	10.00	-2.25	-0.25	-0.05	4.5	-5.4	-3.0	18.3	2.4	-8.8	-14.0	-7.5	0.0	-7.5	-	10.
-0.54	0.56	-0.05	10.00	-2.25	-0.32	-0.05	4.5	-5.4	-3.0	14.0	2.4	-8.8	-14.0	-7.5	0.0	-7.5	-	8.
----- Vary drv/drh -----																		
-0.46	0.56	-0.05	10.00	-2.25	-0.25	-0.03	4.5	-5.4	-3.3	18.3	2.4	-8.8	-16.8	-7.7	0.0	-7.7	-	10.
-0.64	0.56	-0.05	10.00	-2.25	-0.25	-0.03	4.5	-5.4	-2.5	18.3	2.4	-8.8	-11.4	-7.3	0.0	-7.3	-	10.

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r_nominal        =   2.183 inches
rv               = -13.000 mils
rh               =   6.000 mils
skin_stress_300K =  25.000 kpsi
skin_stress      =  45.000 kpsi
contract_collar  =  -0.003
contract_yoke    =  -0.002
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							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
-0.54	0.56	-0.05	10.00	-2.25	-0.25	-0.03	5.5	-7.4	-4.4	22.3	3.4	-10.8	-16.7	-9.0	0.0	-9.0	-	14.
----- Vary Coil Prestress and Cooldown Loss -----																		
-0.54	0.56	-0.05	13.00	-2.25	-0.25	-0.03	5.3	-5.7	-2.8	21.7	3.3	-9.2	-13.7	-7.4	0.0	-7.4	-	13.
-0.54	0.56	-0.05	7.00	-2.25	-0.25	-0.03	5.6	-9.1	-6.0	22.9	3.6	-12.5	-19.6	-10.6	0.0	-10.6	-	15.
-0.54	0.56	-0.05	10.00	-3.25	-0.25	-0.03	5.5	-7.4	-4.4	22.3	3.5	-11.4	-17.6	-9.5	0.0	-9.5	-	14.
----- Vary dr/d(prestress) -----																		
-0.54	0.44	-0.05	10.00	-2.25	-0.25	-0.03	5.5	-8.6	-5.6	22.3	3.4	-11.8	-18.4	-9.9	0.0	-9.9	-	14.
-0.54	0.56	0.00	10.00	-2.25	-0.25	-0.03	6.0	-7.4	-4.2	24.4	3.8	-10.8	-16.3	-8.8	0.0	-8.8	-	16.
----- Choose values that give a small collared coil -----																		
-0.54	0.44	-0.05	7.00	-3.25	-0.25	-0.03	5.6	-9.9	-6.9	22.9	3.6	-13.5	-21.4	-11.6	0.0	-11.6	-	15.
----- Vary dr/d(skin stress) -----																		
-0.54	0.56	-0.05	10.00	-2.25	-0.32	-0.03	5.5	-7.4	-4.4	17.2	3.4	-10.8	-16.7	-9.0	0.0	-9.0	-	11.
-0.54	0.56	-0.05	10.00	-2.25	-0.25	-0.05	5.5	-7.4	-4.4	22.3	3.4	-10.8	-16.7	-9.0	0.0	-9.0	-	14.
-0.54	0.56	-0.05	10.00	-2.25	-0.32	-0.05	5.5	-7.4	-4.4	17.2	3.4	-10.8	-16.7	-9.0	0.0	-9.0	-	11.
----- Vary drv/drh -----																		
-0.46	0.56	-0.05	10.00	-2.25	-0.25	-0.03	5.5	-7.4	-4.9	22.3	3.4	-10.8	-20.1	-9.3	0.0	-9.3	-	14.
-0.64	0.56	-0.05	10.00	-2.25	-0.25	-0.03	5.5	-7.4	-3.9	22.3	3.4	-10.8	-13.5	-8.7	0.0	-8.7	-	14.

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r_nominal        =   2.183 inches
rv               = -13.000 mils
rh               =   7.000 mils
skin_stress_300K =  25.000 kpsi
skin_stress      =  45.000 kpsi
contract_collar  =  -0.003
contract_yoke    =  -0.002
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```

							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
-0.54	0.56	-0.05	10.00	-2.25	-0.25	-0.03	6.5	-7.4	-3.9	26.4	4.4	-10.8	-15.7	-8.5	0.0	-8.5	-	18.
----- Vary Coil Prestress and Cooldown Loss -----																		
-0.54	0.56	-0.05	13.00	-2.25	-0.25	-0.03	6.3	-5.7	-2.3	25.8	4.3	-9.2	-12.7	-6.9	0.0	-6.9	-	17.
-0.54	0.56	-0.05	7.00	-2.25	-0.25	-0.03	6.6	-9.1	-5.5	27.0	4.6	-12.5	-18.6	-10.1	0.0	-10.1	-	19.
-0.54	0.56	-0.05	10.00	-3.25	-0.25	-0.03	6.5	-7.4	-3.9	26.4	4.5	-11.4	-16.6	-9.0	0.0	-9.0	-	18.
----- Vary dr/d(prestress) -----																		
-0.54	0.44	-0.05	10.00	-2.25	-0.25	-0.03	6.5	-8.6	-5.1	26.4	4.4	-11.8	-17.4	-9.4	0.0	-9.4	-	18.
-0.54	0.56	0.00	10.00	-2.25	-0.25	-0.03	7.0	-7.4	-3.6	28.5	4.8	-10.8	-15.3	-8.2	0.0	-8.2	-	20.
----- Choose values that give a small collared coil -----																		
-0.54	0.44	-0.05	7.00	-3.25	-0.25	-0.03	6.6	-9.9	-6.3	27.0	4.6	-13.5	-20.4	-11.0	0.0	-11.0	-	19.
----- Vary dr/d(skin stress) -----																		
-0.54	0.56	-0.05	10.00	-2.25	-0.32	-0.03	6.5	-7.4	-3.9	20.3	4.4	-10.8	-15.7	-8.5	0.0	-8.5	-	14.
-0.54	0.56	-0.05	10.00	-2.25	-0.25	-0.05	6.5	-7.4	-3.9	26.4	4.4	-10.8	-15.7	-8.5	0.0	-8.5	-	18.
-0.54	0.56	-0.05	10.00	-2.25	-0.32	-0.05	6.5	-7.4	-3.9	20.3	4.4	-10.8	-15.7	-8.5	0.0	-8.5	-	14.
----- Vary drv/drh -----																		
-0.46	0.56	-0.05	10.00	-2.25	-0.25	-0.03	6.5	-7.4	-4.4	26.4	4.4	-10.8	-19.1	-8.8	0.0	-8.8	-	18.
-0.64	0.56	-0.05	10.00	-2.25	-0.25	-0.03	6.5	-7.4	-3.2	26.4	4.4	-10.8	-12.5	-8.0	0.0	-8.0	-	18.

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r_nominal        =   2.183 inches
rv               = -13.000 mils
rh               =   5.000 mils
skin_stress_300K =  25.000 kpsi
skin_stress      =  45.000 kpsi
contract_collar  =  -0.003
contract_yoke    =  -0.002
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```

							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
-0.54	0.56	-0.05	10.00	-2.25	-0.25	-0.03	4.5	-7.4	-5.0	18.3	2.4	-10.8	-17.7	-9.5	0.0	-9.5	-	10.
----- Vary Coil Prestress and Cooldown Loss -----																		
-0.54	0.56	-0.05	13.00	-2.25	-0.25	-0.03	4.3	-5.7	-3.4	17.6	2.3	-9.2	-14.7	-7.9	0.0	-7.9	-	9.
-0.54	0.56	-0.05	7.00	-2.25	-0.25	-0.03	4.6	-9.1	-6.6	18.9	2.6	-12.5	-20.6	-11.1	0.0	-11.1	-	10.
-0.54	0.56	-0.05	10.00	-3.25	-0.25	-0.03	4.5	-7.4	-5.0	18.3	2.5	-11.4	-18.6	-10.1	0.0	-10.1	-	10.
----- Vary dr/d(prestress) -----																		
-0.54	0.44	-0.05	10.00	-2.25	-0.25	-0.03	4.5	-8.6	-6.2	18.3	2.4	-11.8	-19.4	-10.5	0.0	-10.5	-	10.
-0.54	0.56	0.00	10.00	-2.25	-0.25	-0.03	5.0	-7.4	-4.7	20.3	2.8	-10.8	-17.3	-9.3	0.0	-9.3	-	11.
----- Choose values that give a small collared coil -----																		
-0.54	0.44	-0.05	7.00	-3.25	-0.25	-0.03	4.6	-9.9	-7.4	18.9	2.6	-13.5	-22.4	-12.1	0.0	-12.1	-	11.
----- Vary dr/d(skin stress) -----																		
-0.54	0.56	-0.05	10.00	-2.25	-0.32	-0.03	4.5	-7.4	-5.0	14.0	2.4	-10.8	-17.7	-9.5	0.0	-9.5	-	8.
-0.54	0.56	-0.05	10.00	-2.25	-0.25	-0.05	4.5	-7.4	-5.0	18.3	2.4	-10.8	-17.7	-9.5	0.0	-9.5	-	10.
-0.54	0.56	-0.05	10.00	-2.25	-0.32	-0.05	4.5	-7.4	-5.0	14.0	2.4	-10.8	-17.7	-9.5	0.0	-9.5	-	8.
----- Vary drv/drh -----																		
-0.46	0.56	-0.05	10.00	-2.25	-0.25	-0.03	4.5	-7.4	-5.3	18.3	2.4	-10.8	-21.1	-9.7	0.0	-9.7	-	10.
-0.64	0.56	-0.05	10.00	-2.25	-0.25	-0.03	4.5	-7.4	-4.5	18.3	2.4	-10.8	-14.5	-9.3	0.0	-9.3	-	10.

Collar for Vertically Split Yoke

$r_1 = 1.604$ $\quad \tilde{s}_1 = \tilde{s}_1(\text{H-split}) - \Delta y = 1.287 - (-.010) = 1.297$

$\theta_1 = \tilde{s}_1 / r_1 = 0.8086 \text{ rad} = 46.33°$

$x_1 = r_1 \cos\theta_1 = 1.108$ $\quad 2x_1 = 2.215$

$r_2 = 1.187$ $\quad \tilde{s}_2 = 1.039 + .010 = 1.049$

$\theta_2 = 0.8837 = 50.63°$

$x_2 = 0.753$ $\quad 2x_2 = 1.506$

$r_3 = 1.187$ $\quad \tilde{s}_3 = 1.538 + .010 = 1.548$

$\theta_3 = 1.304 = 74.72°$

$x_3 = 0.313$ $\quad 2x_3 = 0.626$

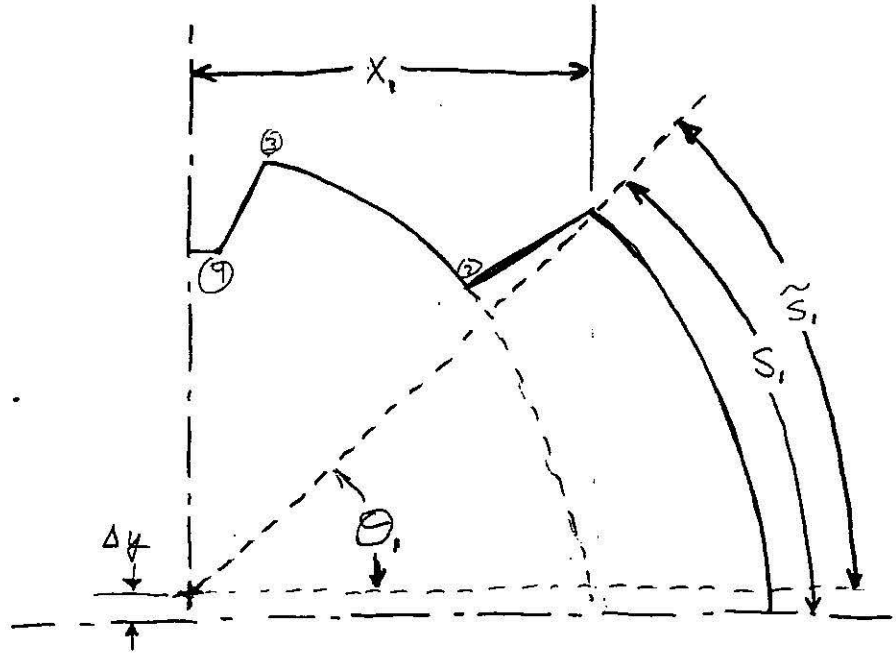
$r_4 = 0.788$ $\quad \tilde{s}_4 = 1.041 + .010 = 1.051$

$\theta_4 = 1.334 = 76.42°$

$x_4 = 0.185$ $\quad 2x_2 = 0.370$

Fig. 3b

Collar for Horizontally Split Yoke



$r_1 = 1.598 \quad \theta_1 = 46.08^\circ = .8042 \text{ rad}$

$S_1 = \tilde{S}_1 + \Delta y = r_1 \theta_1 + \Delta y = 1.285 + .002 = 1.287$

$r_2 = 1.181 \quad \theta_2 = 50.32^\circ = .8783 \text{ rad}$

$\rightarrow S_2 = 1.037 + .002 = 1.039$

$r_3 = 1.181 \quad \theta_3 = 74.51^\circ = 1.300 \text{ rad}$

$\rightarrow S_3 = 1.536 + .002 = 1.538$

$r_4 = 0.782 \quad \theta_4 = 76.09^\circ = 1.328 \text{ rad}$

$\rightarrow S_4 = 1.039 + .002 = 1.041$

Fig. 3a