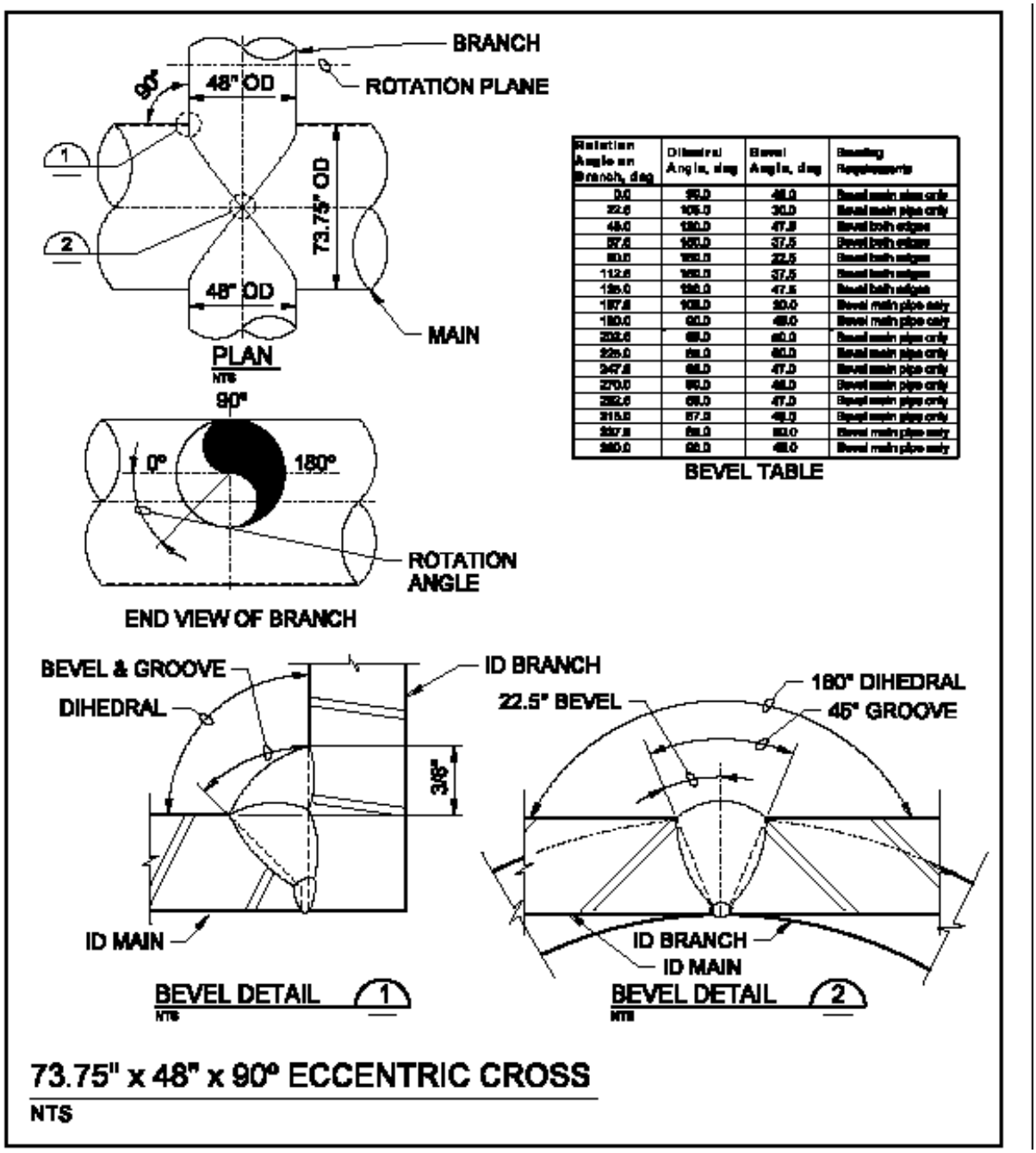
Given: 1) 73.75" x 48" x 90 deg eccentric cross & 2) 36" x 36" x 90 deg concentric cross

Find: Developed plans of main pipe and branch pipes plus welding bevels $ORIGIN \equiv 1$

Solution: program to develop 3D intersection of pipes & beveling; assume $n := 16$ angular divisions of branch



Rotation Angle on Branch, deg	Dihedral Angle, deg	Bevel Angle, deg	Beveling Requirements
0.0	90.0	45.0	Bevel main pipe only
22.5	105.0	30.0	Bevel main pipe only
45.0	120.0	47.5	Bevel both edges
67.5	165.0	37.5	Bevel both edges
90.0	180.0	22.5	Bevel both edges
112.5	165.0	37.5	Bevel both edges
135.0	120.0	47.5	Bevel both edges
157.5	105.0	30.0	Bevel main pipe only
180.0	90.0	45.0	Bevel main pipe only
202.5	105.0	30.0	Bevel main pipe only
225.0	120.0	60.0	Bevel main pipe only
247.5	165.0	47.5	Bevel main pipe only
270.0	90.0	45.0	Bevel main pipe only
292.5	65.0	47.5	Bevel main pipe only
315.0	67.5	45.0	Bevel main pipe only
337.5	90.0	60.0	Bevel main pipe only
360.0	90.0	45.0	Bevel main pipe only

BEVEL TABLE

1) 73.75" x 48" x 90 deg eccentric cross;

$D_b := 73.75 \cdot in$ $D_s := 48 \cdot in$ $\Delta := 90 \cdot deg$ $off := 4 \cdot ft$ offset of ref. line on branch

$fff(D_b, D_s, \Delta) :=$

$R_b \leftarrow \frac{D_b}{2}$

$R_s \leftarrow \frac{D_s}{2}$

for $i \in 1 .. n + 1$

$\alpha_i \leftarrow \frac{2\pi}{n} \cdot (i - 1)$

$xb_1 \leftarrow \sqrt{R_b^2 - \left[R_b - R_s \cdot \left(1 + \sin(\alpha_1)\right)\right]^2}$

$P1 \leftarrow \begin{bmatrix} \sqrt{R_b^2 - \left[R_b - R_s \cdot \left(1 + \sin(\alpha_i)\right)\right]^2} \\ \frac{R_s \cdot \left(1 - \cos(\alpha_i)\right)}{\sin(\Delta)} + \left[\frac{xb_1 - \sqrt{R_b^2 - \left[R_b - R_s \cdot \left(1 + \sin(\alpha_i)\right)\right]^2}}{\tan(\Delta)}\right] \\ R_s \cdot \left(1 + \sin(\alpha_i)\right) \end{bmatrix}$

$L' \leftarrow off - \frac{\sqrt{R_b^2 - \left[R_b - R_s \cdot \left(1 + \sin(\alpha_i)\right)\right]^2}}{\sin(\Delta)} - R_s \cdot \cos(\alpha_i) \cdot \tan\left(\frac{\pi}{2} - \Delta\right)$

$arcb \leftarrow R_b \cdot \left[\operatorname{asin}\left[\frac{R_s \cdot \left(1 + \sin(\alpha_i)\right) - R_b}{R_b}\right] + \frac{\pi}{2}\right]$

$v_{i,1} \leftarrow i$

$v_{i,2} \leftarrow \frac{P1_1}{in}$

$v_{i,3} \leftarrow \frac{P1_2}{in}$

$v_{i,4} \leftarrow \frac{P1_3}{in}$

$v_{i,5} \leftarrow \frac{-P1_1}{in}$

$v_{i,6} \leftarrow \frac{P1_2}{in}$

$v_{i,7} \leftarrow \frac{R_s \cdot \alpha_i}{in}$

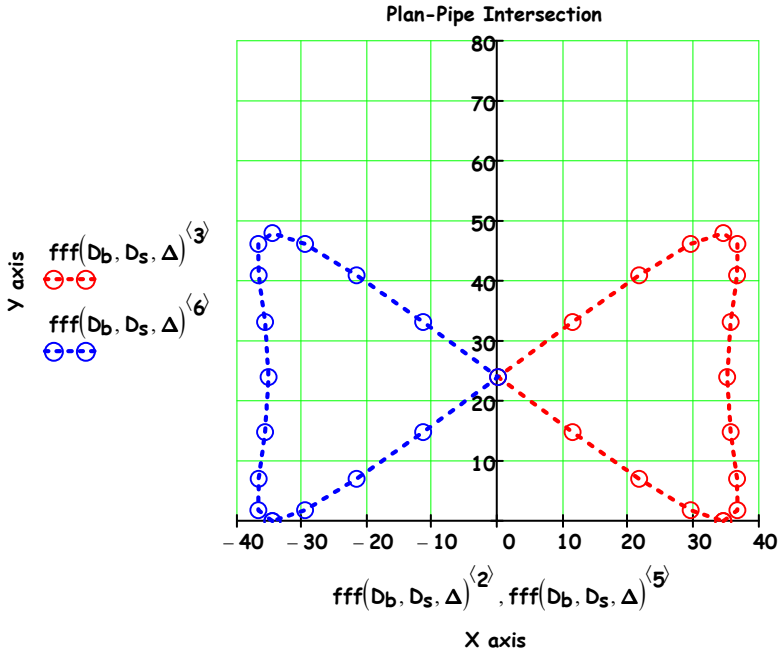
$v_{i,8} \leftarrow \frac{L'}{in}$

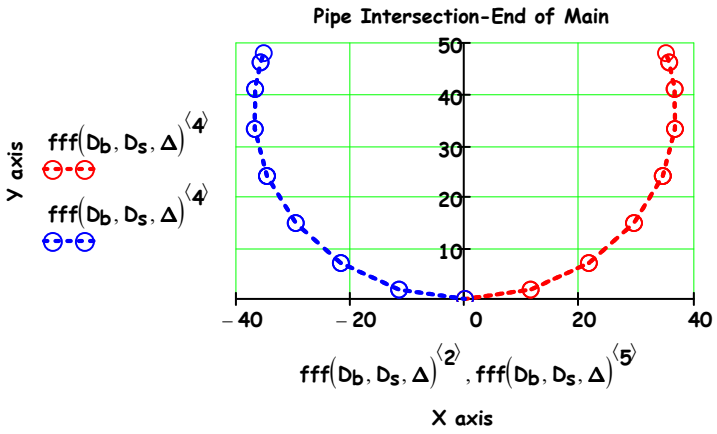
$v_{i,9} \leftarrow \frac{arcb}{in}$

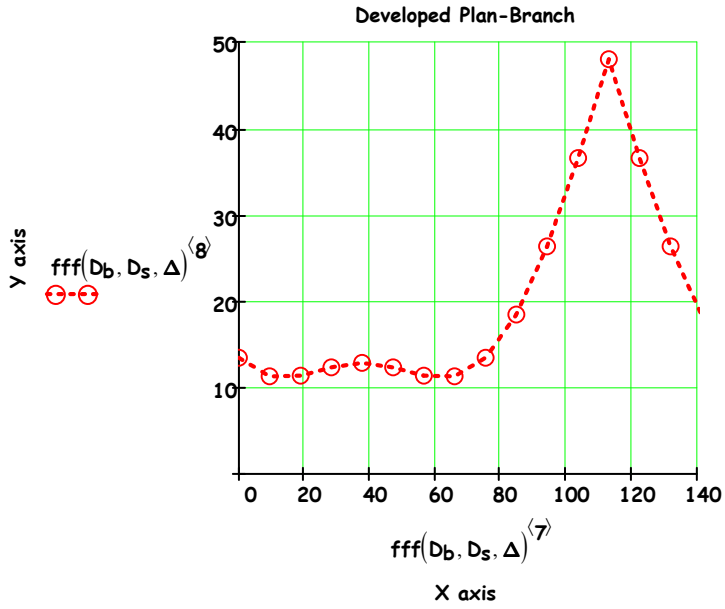
1) 73.75" x 48" x 90 deg eccentric cross;

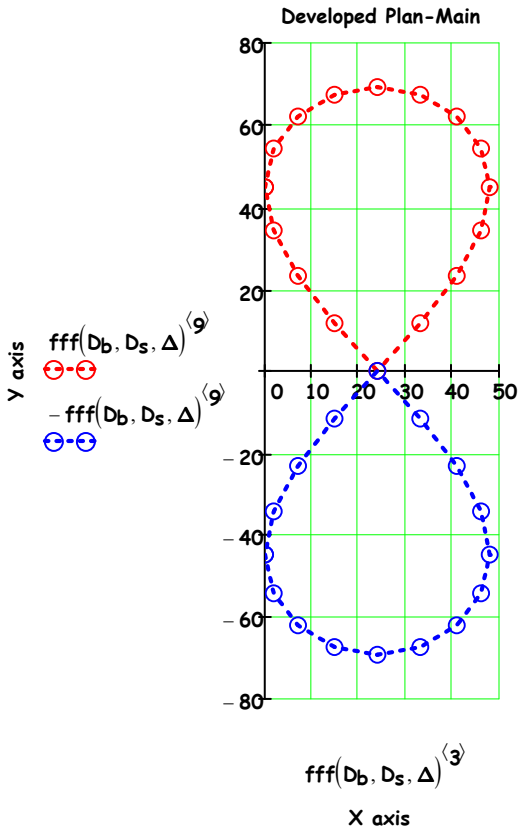
$D_b = 73.75\,in$ $D_s = 48.00\,in$ $\Delta = 90.00\,deg$ $off = 4.00\,ft$ offset of ref. line on branch

Point No.	Side #1			Side #2		Arc Length on Branch, in	Offset Along Branch, in	Arc Length on Main, in
	x	y	z	x	y			
1.0	34.6	0.0	24.0	-34.6	0.0	0.0	13.4	44.8
2.0	36.7	1.8	33.2	-36.7	1.8	9.4	11.3	54.2
3.0	36.6	7.0	41.0	-36.6	7.0	18.8	11.4	62.0
4.0	35.7	14.8	46.2	-35.7	14.8	28.3	12.3	67.3
5.0	35.2	24.0	48.0	-35.2	24.0	37.7	12.8	69.2
6.0	35.7	33.2	46.2	-35.7	33.2	47.1	12.3	67.3
7.0	36.6	41.0	41.0	-36.6	41.0	56.5	11.4	62.0
8.0	36.7	46.2	33.2	-36.7	46.2	66.0	11.3	54.2
9.0	34.6	48.0	24.0	-34.6	48.0	75.4	13.4	44.8
10.0	29.5	46.2	14.8	-29.5	46.2	84.8	18.5	34.3
11.0	21.7	41.0	7.0	-21.7	41.0	94.2	26.3	23.1
12.0	11.5	33.2	1.8	-11.5	33.2	103.7	36.5	11.7
13.0	0.0	24.0	0.0	0.0	24.0	113.1	48.0	0.0
14.0	11.5	14.8	1.8	-11.5	14.8	122.5	36.5	11.7
15.0	21.7	7.0	7.0	-21.7	7.0	131.9	26.3	23.1
16.0	29.5	1.8	14.8	-29.5	1.8	141.4	18.5	34.3
17.0	34.6	0.0	24.0	-34.6	0.0	150.8	13.4	44.8









Bevels on both sides;

$$\psi - \text{Groove} - 2\cdot\left(\frac{\pi}{2} - \text{Bevel}\right) \text{ solve, Bevel} \rightarrow \frac{\pi}{2} + \frac{\text{Groove}}{2} - \frac{\psi}{2}$$

$$\text{Bevel} = \frac{1}{2}(\pi + \text{Groove} - \psi)$$

Bevels on one side (main pipe only);

$$\psi - \text{Groove} - \left(\frac{\pi}{2} - \text{Bevel}\right) \text{ solve, Bevel} \rightarrow \frac{\pi}{2} + \text{Groove} - \psi$$

$$\text{Bevel} = \frac{\pi}{2} + \text{Groove} - \psi$$

$Groove := 45 \cdot deg$

the following equations are from a Shell Oil document that supports Annex G, Local Dihedral Angle of AWS D1.1, Structural Welding Code-Steel. Shell Oil internal report on the findings of this project. Also, published in AWS Journal Article Name: Local Dihedral Angle Equations for Tubular Joints and Related Applications Author: W.H. Luyties J.W. Post Page: 51 Date: Apr. 1988 The report designation is CE77 and was published in September 1986...Figure 22, 90 deg intersection, Beta=.50, AOFF/RCHORD=.50

$\Delta := 90 \cdot deg$

note: $\frac{Ds}{Db} = 0.65$ thus interpolation of Fig. 22 is req'd....or write a program using equations in ref.

weld axis vector;

$$V_1 = \begin{bmatrix} (-TMPLT2 + TMPLT1) \\ r \cdot \sin(x + \Delta x) - r \cdot \sin(x - \Delta x) \\ -r \cdot \cos(x + \Delta x) + r \cdot \cos(x - \Delta x) \end{bmatrix}$$

weld axis vector; transformed to main pipe coordinate system

$$N_1 = \begin{bmatrix} \cos(\theta) \cdot (-TMPLT2 + TMPLT1) - \sin(\theta) \cdot (-r \cdot \cos(x + \Delta x) + r \cdot \cos(x - \Delta x)) \\ r \cdot \sin(x + \Delta x) - r \cdot \sin(x - \Delta x) \\ \sin(\theta) \cdot (-TMPLT2 + TMPLT1) - \cos(\theta) \cdot (-r \cdot \cos(x + \Delta x) + r \cdot \cos(x - \Delta x)) \end{bmatrix}$$

normal to plane of tangency of main pipe;

$$N2 = \begin{pmatrix} 0 \cdot in \\ r \cdot \sin(x) + AOFF \\ A \end{pmatrix} \qquad A = \sqrt{R^2 - (r \cdot \sin(x) + AOFF)^2}$$

vector in the plane tangent to the main pipe and perp to weld axis; $N3 = N1 \times N2$

normal to plane of tangency of branch

$$V_4 = \begin{pmatrix} 0 \cdot in \\ r \cdot \sin(x) \\ -r \cdot \cos(x) \end{pmatrix}$$

normal to plane of tangency of branch pipe; transformed to main

$$N4 = \begin{bmatrix} \cos(\theta) \cdot (0 \cdot in) - \sin(\theta) \cdot (-r \cdot \cos(x)) \\ r \cdot \sin(x) \\ \sin(\theta) \cdot (0 \cdot in) - \cos(\theta) \cdot (-r \cdot \cos(x)) \end{bmatrix}$$

vector in the plane tangent to the branch pipe and perp to weld axis; $N5 = N4 \times N1$

local dihedral angle using dot product of vectors N3 & N5 $\psi = \operatorname{acos}\left(\frac{N5 \cdot N3}{|N5| \cdot |N3|}\right)$

$Db = 73.75\,in$ $Ds = 48.00\,in$ $R := \frac{Db}{2}$ $R = 36.88\,in$ $r := \frac{Ds}{2}$ $r = 24.00\,in$ $\theta := \Delta$ $\theta = 90.00\,deg$

$off = 48.00\,in$ $\Delta x := 1 \cdot deg$ $n = 16.00$ $AOFF := R - r$ $AOFF = 12.88\,in$ note: inverts match

$$f(D_b, D_s, \Delta) :=$$

$R \leftarrow \frac{D_b}{2}$

$r \leftarrow \frac{D_s}{2}$

$\theta \leftarrow \Delta$

$AOFF \leftarrow R - r$

for $i \in 1 .. n + 1$

$x \leftarrow \frac{2 \cdot \pi}{n} \cdot (i - 1)$

$TMPLT2 \leftarrow off - \frac{\sqrt{R^2 - [R - r \cdot (1 + \sin(x + \Delta x))]^2}}{\sin(\theta)} - r \cdot \cos(x + \Delta x) \cdot \tan\left(\frac{\pi}{2} - \theta\right)$

$TMPLT1 \leftarrow off - \frac{\sqrt{R^2 - [R - r \cdot (1 + \sin(x - \Delta x))]^2}}{\sin(\theta)} - r \cdot \cos(x - \Delta x) \cdot \tan\left(\frac{\pi}{2} - \theta\right)$

$A \leftarrow \sqrt{R^2 - (r \cdot \sin(x) + AOFF)^2}$

$$N1 \leftarrow \begin{bmatrix} \cos(\theta) \cdot (-TMPLT2 + TMPLT1) - \sin(\theta) \cdot (-r \cdot \cos(x + \Delta x) + r \cdot \cos(x - \Delta x)) \\ r \cdot \sin(x + \Delta x) - r \cdot \sin(x - \Delta x) \\ \sin(\theta) \cdot (-TMPLT2 + TMPLT1) - \cos(\theta) \cdot (-r \cdot \cos(x + \Delta x) + r \cdot \cos(x - \Delta x)) \end{bmatrix}$$

$$N2 \leftarrow \begin{pmatrix} 0 \cdot in \\ r \cdot \sin(x) + AOFF \\ A \end{pmatrix}$$

$N3 \leftarrow N1 \times N2$

$$N4 \leftarrow \begin{bmatrix} \cos(\theta) \cdot (0 \cdot in) - \sin(\theta) \cdot (-r \cdot \cos(x)) \\ r \cdot \sin(x) \\ \sin(\theta) \cdot (0 \cdot in) - \cos(\theta) \cdot (-r \cdot \cos(x)) \end{bmatrix}$$

$N5 \leftarrow N4 \times N1$

$\psi \leftarrow \operatorname{acos}\left(\frac{N5 \cdot N3}{|N5| \cdot |N3|}\right)$

$v_{i,1} \leftarrow \frac{x}{deg}$

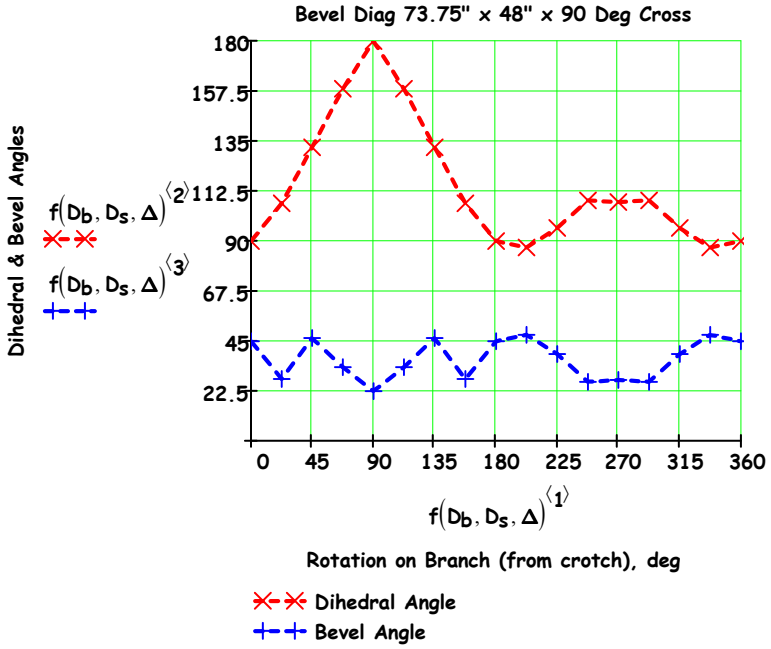
$v_{i,2} \leftarrow \frac{\psi}{deg}$

$bev \leftarrow \begin{cases} \frac{1}{2}(\pi + Groove - \psi) & \text{if } 130 \cdot deg \le \psi \le 180 \cdot deg \\ \frac{\pi}{2} + Groove - \psi & \text{otherwise} \end{cases}$

$v_{i,3} \leftarrow \frac{bev}{deg}$

$v_{i,4} \leftarrow \begin{cases} \text{"bevel both edges"} & \text{if } 130 \cdot deg \le \psi \le 180 \cdot deg \\ \text{"bevel main pipe only"} & \text{otherwise} \end{cases}$

v



Bevel Table;

Rotation Angle on Branch,	Dihedral Angle, deg	Bevel, deg	Beveling Requirements
0.0	90.0	45.0	bevel main pipe only
22.5	107.0	28.0	bevel main pipe only
45.0	132.2	46.4	bevel both edges
67.5	158.5	33.2	bevel both edges
90.0	180.0	22.5	bevel both edges
112.5	158.5	33.2	bevel both edges
135.0	132.2	46.4	bevel both edges
157.5	107.0	28.0	bevel main pipe only
180.0	90.0	45.0	bevel main pipe only
202.5	87.1	47.9	bevel main pipe only
225.0	95.8	39.2	bevel main pipe only
247.5	108.4	26.6	bevel main pipe only
270.0	107.6	27.4	bevel main pipe only
292.5	108.4	26.6	bevel main pipe only
315.0	95.8	39.2	bevel main pipe only
337.5	87.1	47.9	bevel main pipe only
360.0	90.0	45.0	bevel main pipe only

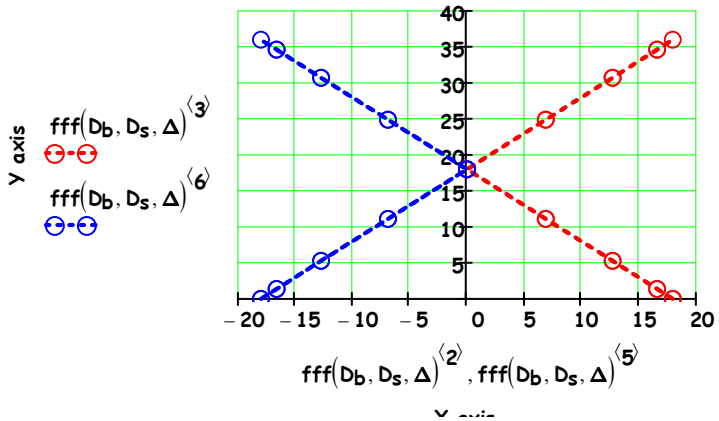
2) 36" x 36" x 90 deg concentric cross;

$D_b := 36 \cdot in$ $D_s := 36 \cdot in$ $\Delta := 90 \cdot deg$ $off = 48.00 in$

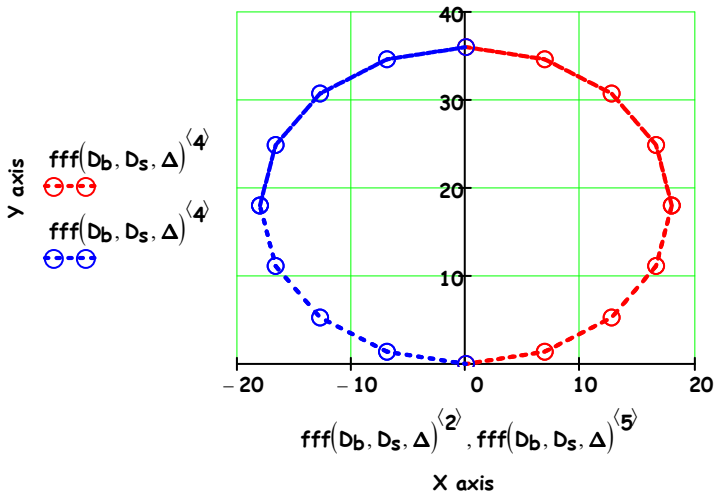
fff' :=

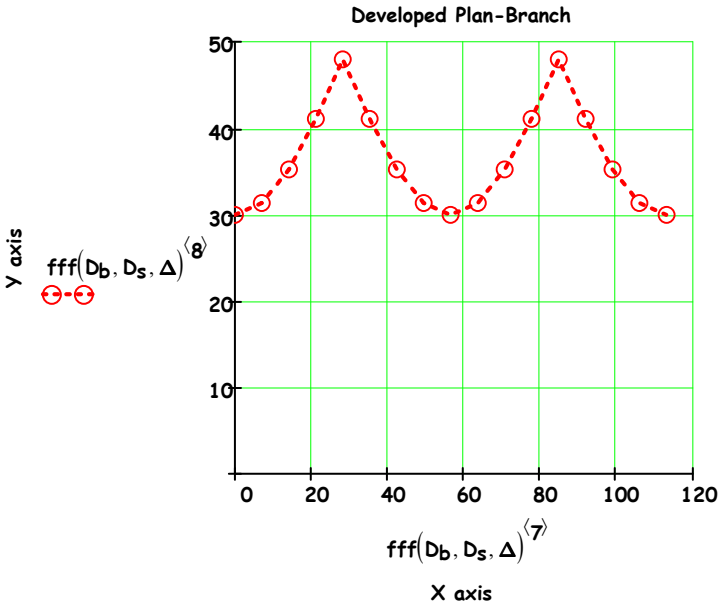
Point No.	Side #1			Side #2		Arc Length on Branch, in	Offset Along Branch, in	Arc Length on Main, in
	x	y	z	x	y			
1.0	18.0	0.0	18.0	-18.0	0.0	0.0	30.0	28.3
2.0	16.6	1.4	24.9	-16.6	1.4	7.1	31.4	35.3
3.0	12.7	5.3	30.7	-12.7	5.3	14.1	35.3	42.4
4.0	6.9	11.1	34.6	-6.9	11.1	21.2	41.1	49.5
5.0	0.0	18.0	36.0	0.0	18.0	28.3	48.0	56.5
6.0	6.9	24.9	34.6	-6.9	24.9	35.3	41.1	49.5
7.0	12.7	30.7	30.7	-12.7	30.7	42.4	35.3	42.4
8.0	16.6	34.6	24.9	-16.6	34.6	49.5	31.4	35.3
9.0	18.0	36.0	18.0	-18.0	36.0	56.5	30.0	28.3
10.0	16.6	34.6	11.1	-16.6	34.6	63.6	31.4	21.2
11.0	12.7	30.7	5.3	-12.7	30.7	70.7	35.3	14.1
12.0	6.9	24.9	1.4	-6.9	24.9	77.8	41.1	7.1
13.0	0.0	18.0	0.0	0.0	18.0	84.8	48.0	0.0
14.0	6.9	11.1	1.4	-6.9	11.1	91.9	41.1	7.1
15.0	12.7	5.3	5.3	-12.7	5.3	99.0	35.3	14.1
16.0	16.6	1.4	11.1	-16.6	1.4	106.0	31.4	21.2
17.0	18.0	0.0	18.0	-18.0	0.0	113.1	30.0	28.3

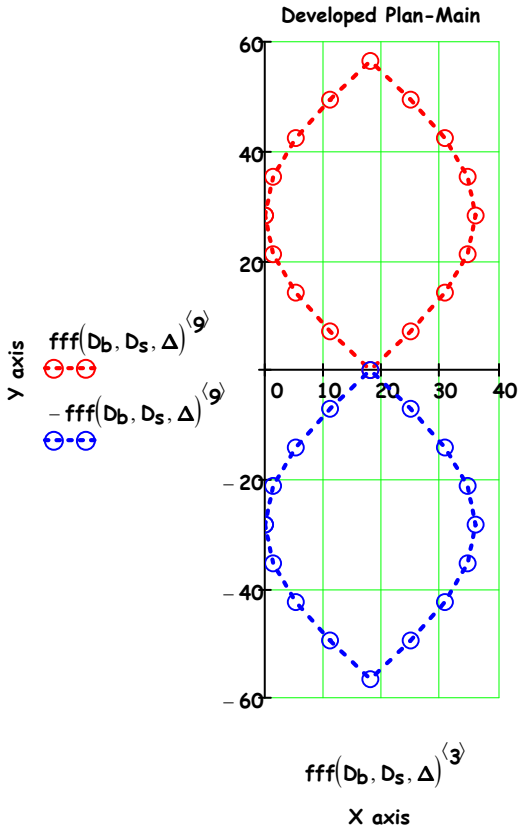
Plan-Pipe Intersection

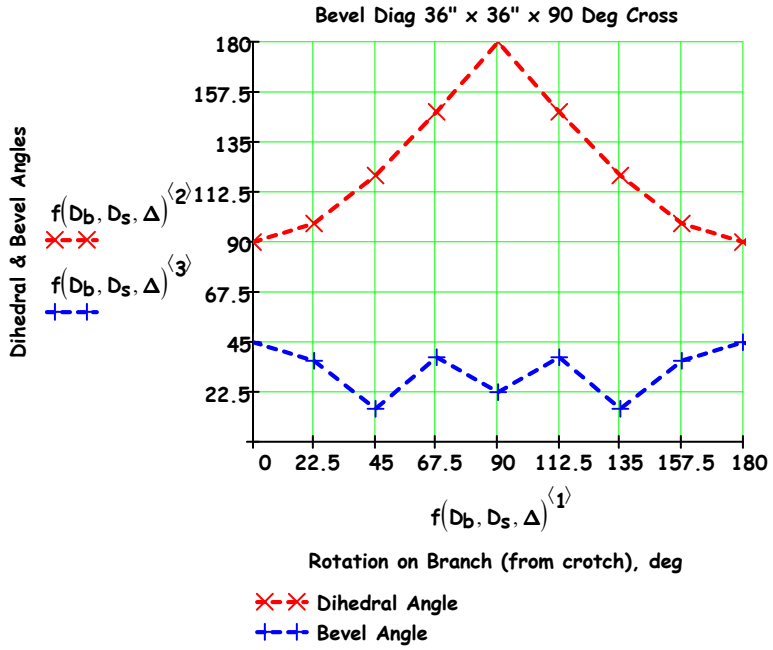


Pipe Intersection-End of Main




Developed Plan-Branch
y axis
fff(Db, Ds, Δ)⟨8⟩
50
40
30
20
10
0
20
40
60
80
100
120
fff(Db, Ds, Δ)⟨7⟩
X axis


Developed Plan-Main
y axis
fff(Db, Ds, Δ)⟨9⟩
– fff(Db, Ds, Δ)⟨9⟩
60
40
20
– 20
– 40
– 60
0
10
20
30
40
fff(Db, Ds, Δ)⟨3⟩
X axis



Bevel Table;

Rotation Angle on Branch,	Dihedral Angle, deg	Bevel, deg	Beveling Requirements
0.0	90.0	45.0	bevel main pipe only
22.5	98.4	36.6	bevel main pipe only
45.0	120.0	15.0	bevel main pipe only
67.5	148.6	38.2	bevel both edges
90.0	180.0	22.5	bevel both edges
112.5	148.6	38.2	bevel both edges
135.0	120.0	15.0	bevel main pipe only
157.5	98.4	36.6	bevel main pipe only
180.0	90.0	45.0	bevel main pipe only