gear automation and design revised

$Backlash\_lookup_6 := 0.015$ $Backlash\_lookup_{12} := 0.009$ $Backlash\_lookup_{18} := 0.007$

$Backlash\_lookup_8 := 0.010$ $Backlash\_lookup_{14} := 0.009$ $Backlash\_lookup_{20} := 0.006$

$Backlash\_lookup_{10} := 0.010$ $Backlash\_lookup_{16} := 0.008$

Table page 68 Lynwander, Gear Drive Sysytems for backlash at various diametral values

numerical example ...

$DP := 10$ diametral_pitch middle of course range 2 .... 16 per Shigley Table 9.3

$\phi 1 := 20deg$ pressure_angle_at_pitch_radius

$N_P := 20$ number_of_pinion_teeth

$N_G := 30$ number_of_gear_teeth

$addendum := \frac{1}{DP}$

$dedendum := \frac{1.25}{DP}$

Table 9.2 Sigley for pressure angles 20, 22.5 and 25

************************************ end of input ***

$C := \frac{N_P + N_G}{2 \cdot DP}$ $C = 2.5$ center_distance $R := \frac{N_G}{N_P}$

$R_G := \frac{N_G}{DP} \cdot \frac{1}{2}$ $R_G = 1.5$ $R_P := \frac{N_P}{DP} \cdot \frac{1}{2}$ $R_P = 1$

$BL := Backlash\_lookup_{DP}$ $BL = 0.01$

$T_{P1} = T_{G1} = \frac{CP}{2} - \frac{BL}{2} = \frac{\pi}{DP \cdot 2} - \frac{BL}{2}$ allocate 1/2 backlash to each P & G $CP := \frac{\pi \cdot 2 \cdot R_P}{N_P}$ $CP = 0.314$

$T_{P1} := \frac{\pi}{DP \cdot 2} - \frac{BL}{2}$ $T_{P1} = 0.152$ $T_{G1} := T_{P1}$ $T_{G1} = 0.152$ $2 \cdot T_{P1} = 0.304$

$R_{root\_P} := R_P - dedendum$ $R_{root\_P} = 0.875$ root_radius_pinion $dedendum = 0.125$

$R_{root\_G} := R_G - dedendum$ $R_{root\_G} = 1.375$ root_radius_gear

$R_{add\_P} := R_P + addendum$ $R_{add\_P} = 1.1$ addendum_radius_pinion $addendum = 0.1$

$R_{add\_G} := R_G + addendum$ $R_{add\_G} = 1.6$ addendum_radius_gear

$inv(\phi) := \tan(\phi) - \phi$ involute_function

$CTT_1 := T_{P1}$ circular_tooth_thickness_at_pitch_radius

$\theta 1 := inv(\phi 1)$ involute_angle_at_pitch_radius $\theta 1 = 0.854\,deg$

geometry to determine points on involute between root and addendum R_2, B

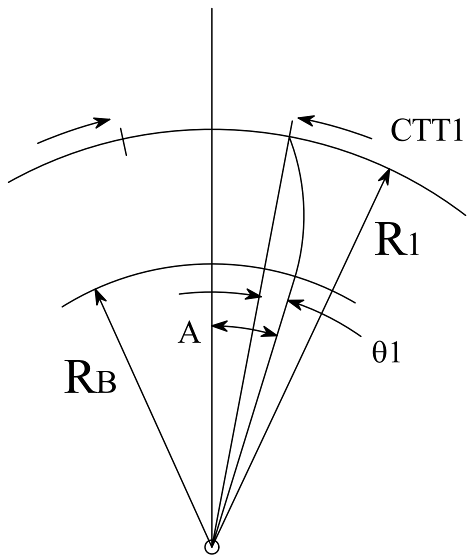


figure 2.10 page 31 Lynwander
reversed and rotated - values at pitch radius

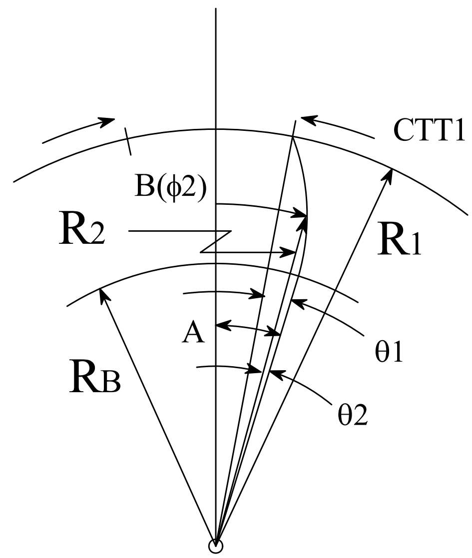


figure 2.10 page 31 Lynwander
reversed and rotated

$$A = \theta 1 + \frac{1}{2} \cdot \frac{CTT_1}{R_1}$$

CTT_1 = circular_tooth_thickness

ϕ = pressure_angle_design

$\theta 1$ = involute_of_design_pressure_angle

$$R_1 = \text{pitch\_radius} = \frac{R_B}{\cos(\phi)}$$

here consider varying ϕ from 0 to a value > design angle = $\phi 2$

$\theta 2$ = involute_of_$\phi 2$

$$B(\phi 2) = A - \theta 2$$

$$R_2 = \frac{R_B}{\cos(\phi 2)}$$

Pinion geometry

$\alpha := 0, 0.01 .. 2\cdot\pi$ α = circular_range_variable

$R_{B\_P} := R_P \cdot \cos(\phi 1)$ base_radius_pinion $R_{B\_P} = 0.94$ $R_{root\_P} = 0.875$

want to go from base to addendum radius in say 20 points

$$\phi\_add\_P := \text{acos}\left(\frac{R_{B\_P}}{R_{add\_P}}\right)$$

$\phi\_add\_P = 31.321\,\text{deg}$

$R_{root\_P} > R_{B\_P} = 0$

$N1 := 20$ N1 = number_of_points_along_involute

$i := 1 .. N1 + 1$ $\phi 2_i := \frac{\phi\_add\_P}{N1} \cdot (i - 1)$ increment_of_pressure_angle

let's put base radius to addendum in 1:n1+1

$\theta 2 := \text{inv}(\phi 2)$ involute_angle_at_local_radius

$R_{2\_P_i} := \frac{R_{B\_P}}{\cos(\phi 2_i)}$ radius_on_involute

$CTT_{2_i} := 2 \cdot R_{2\_P_i} \cdot \left(\frac{CTT_1}{2 \cdot R_P} + \theta 1 - \theta 2_i\right)$ thickness_at_location number of teeth $j := 1 .. N_P$ $B\_del_j := (j-1)\cdot\frac{2\pi}{N_P}$ angular increment for teeth (offset to angle B)

$B = angle\_relative\_to\_tooth\_center = \frac{thickness}{2\cdot radius\_at\_location}$ r,l = right,left side of tooth

$i = range\_variable\_along\_involute$

$Bl\_P_{i,j} := \frac{CTT2_i}{2\cdot R_{2\_P_i}} + B\_del_j$ $Br\_P_{i,j} := B\_del_j - \frac{CTT2_i}{2\cdot R_{2\_P_i}}$ $j = tooth\_number$

adding a point at the root radius so we need to add two values of R_{root} and one each of Br and Bl. these are the first points

$R_{2\_P_0} := R_{root\_P}$ $Bl\_P_{0,j} := Bl\_P_{1,j}$ $Br\_P_{0,j} := Br\_P_{1,j}$

now i needs to go from 0 to N1 + 1 $N1 := N1 + 1$ $i := 0 .. N1$

put into vector of R and θ for polar plot effectiveness
N1+2 points from i up and down. radius up across then down across connecting the dots ...

$R\_plot\_P_{i+(N1+1)\cdot 2\cdot(j-1)} := R_{2\_P_i}$ $R\_plot\_P_{i+(N1+1)\cdot[2\cdot(j-1)+1]} := R_{2\_P_{N1-i}}$

put right data first
alternate by and "right" and "left" in sequence

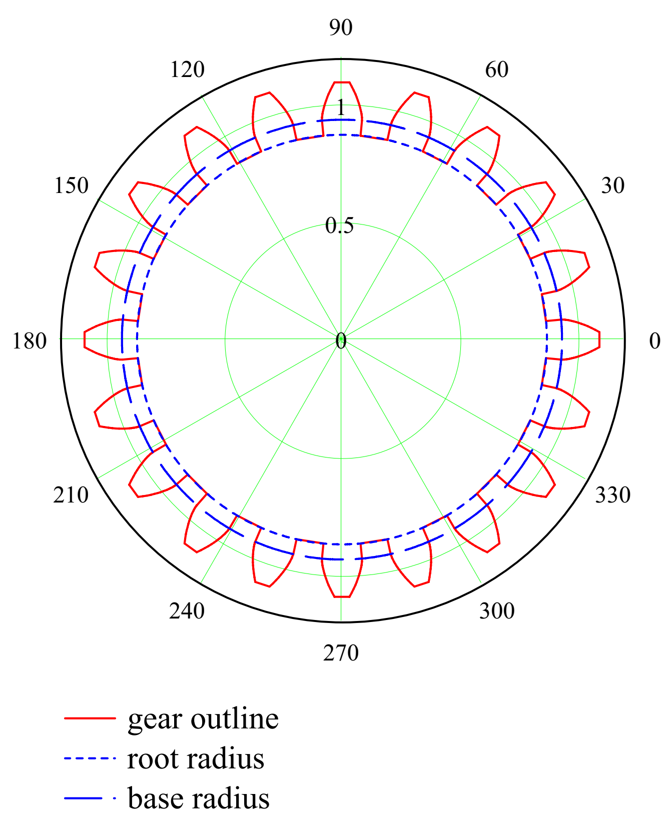
$B\_plot\_P_{i+(N1+1)\cdot 2\cdot(j-1)} := Br\_P_{i,j}$ $B\_plot\_P_{i+(N1+1)\cdot[2\cdot(j-1)+1]} := Bl\_P_{N1-i,j}$

$bug := rows(R\_plot\_P)$ $R\_plot\_P_{bug} := R\_plot\_P_0$ $B\_plot\_P_{bug} := B\_plot\_P_0$ close curve $krhs := 1$

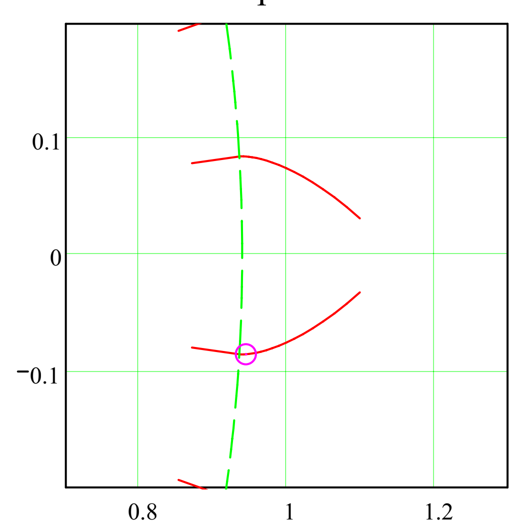
convert to X, Y coordinates to allow a closeup of one tooth, cannot restrain θ in polar plot

$Xr\_P_{i,j} := R_{2\_P_i}\cdot\cos(Br\_P_{i,j})$ $Xl\_P_{i,j} := R_{2\_P_i}\cdot\cos(Bl\_P_{i,j})$

$Yr\_P_{i,j} := R_{2\_P_i}\cdot\sin(Br\_P_{i,j})$ $Yl\_P_{i,j} := R_{2\_P_i}\cdot\sin(Bl\_P_{i,j})$



closeup of tooth



Gear geometry

$\phi 2 := \text{reset}$ reset ϕ2 to avoid extra values in gear

$R_{B\_G} := R_G \cdot \cos(\phi 1)$ base_radius_gear $R_{B\_G} = 1.41$ $N2 := 24$ $R_{root\_G} = 1.375$

want to go from base to addendum radius in say 20 points retained separate number N2

$\phi\_add\_G := \text{acos}\left(\frac{R_{B\_G}}{R_{add\_G}}\right)$ $\phi\_add\_G = 28.241\ \text{deg}$

$N2 := 20$ N2 = number_of_points_along_involute

$R_{root\_G} > R_{B\_G} = 0$ $\phi\_ded\_G := \text{acos}\left(\frac{R_{B\_G}}{R_{root\_G}}\right)$ $\phi\_ded\_G = 12.816i\ \text{deg}$

$\phi\_root\_G := \text{if}(R_{root\_G} > R_{B\_G}, \phi\_ded\_G, 0)$ if root is > base, start involute at root not base. to allow the pposite, insert extra point as in pinion.

$i := 1 .. N2 + 1$

$\phi 2_i := \phi\_root\_G + \frac{\phi\_add\_G - \phi\_root\_G}{N2} \cdot (i - 1)$ increment_of_pressure_angle

$\theta 2 := \text{inv}(\phi 2)$ involute_angle_at_local_radius $R_{2\_G} := \frac{R_{B\_G}}{\cos(\phi 2)}$ radius_on_involute

$CTT_{2_i} := 2 \cdot R_{2\_G_i} \cdot \left(\frac{CTT_1}{2 \cdot R_G} + \theta 1 - \theta 2_i\right)$ thickness_at_location

$j := 1 .. N_G$ $B\_del_j := (j - 1) \cdot \frac{2\pi}{N_G}$ angular increment for teeth (offset to angle B)

$B = \text{angle\_relative\_to\_tooth\_center} = \frac{\text{thickness}}{2 \cdot \text{radius\_at\_location}}$ r,l = right,left side of tooth

$Bl\_G_{i,j} := \frac{CTT_{2_i}}{2 \cdot R_{2\_G_i}} + B\_del_j$ $Br\_G_{i,j} := B\_del_j - \frac{CTT_{2_i}}{2 \cdot R_{2\_G_i}}$

i = range_variable_along_involute

j = tooth_number

adding a point at the root radius, R_{root} is max(R_B,R_{root}) and one each of Br and Bl. these are the first points. in either case, added point is R_{root_G}.

$R_{2\_G_0} := R_{root\_G}$ $Bl\_G_{0,j} := Bl\_G_{1,j}$ $Br\_G_{0,j} := Br\_G_{1,j}$

put into vector of R and θ for polar plot effectiveness

now i needs to go from 0 to N2 + 1 $N2 := N2 + 1$ $i := 0 .. N2$

N2 points from i up and down. radius up across then down across connecting the dots ...

$R\_plot\_G_{i+(N2+1)\cdot 2\cdot(j-1)} := R_{2\_G_i}$ $R\_plot\_G_{i+(N2+1)\cdot[2\cdot(j-1)+1]} := R_{2\_G_{N2-i}}$

put right data first, alternate by and "right" and "left" in sequence

$B\_plot\_G_{i+(N2+1)\cdot 2\cdot(j-1)} := Br\_G_{i,j}$ $B\_plot\_G_{i+(N2+1)\cdot[2\cdot(j-1)+1]} := Bl\_G_{N2-i,j}$

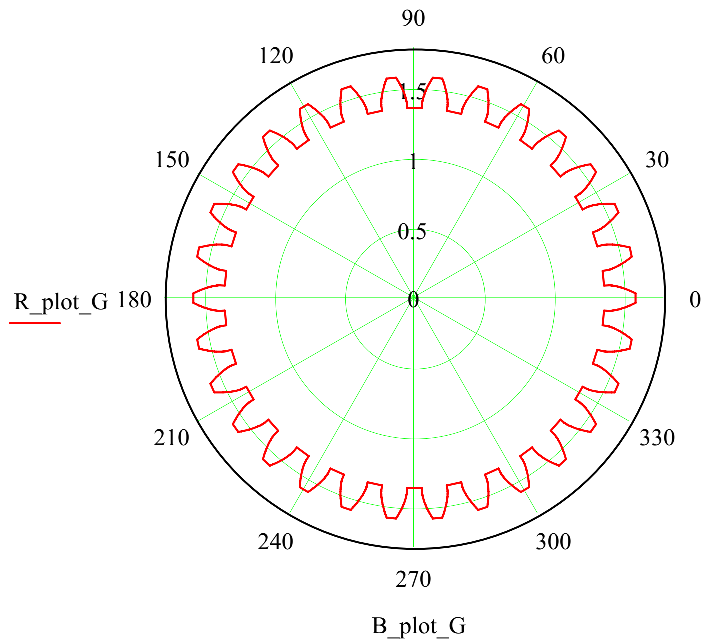
$bug := \text{rows}(R\_plot\_G)$ $R\_plot\_G_{bug} := R\_plot\_G_0$ $B\_plot\_G_{bug} := B\_plot\_G_0$ close curve

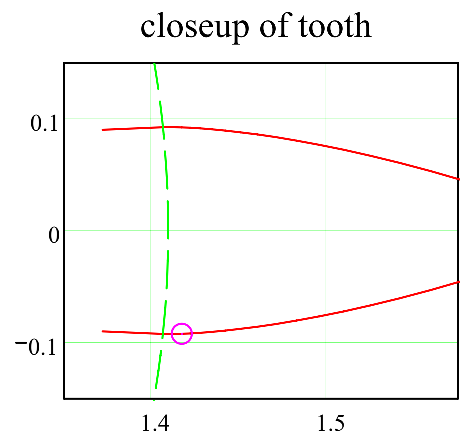
convert to X, Y coordinates to allow a closeup of one tooth, cannot restrain θ in polar plot

$krhs := 1$

$Xr\_G_{i,j} := R_{2\_G_i} \cdot \cos(Br\_G_{i,j})$ $Xl\_G_{i,j} := R_{2\_G_i} \cdot \cos(Bl\_G_{i,j})$

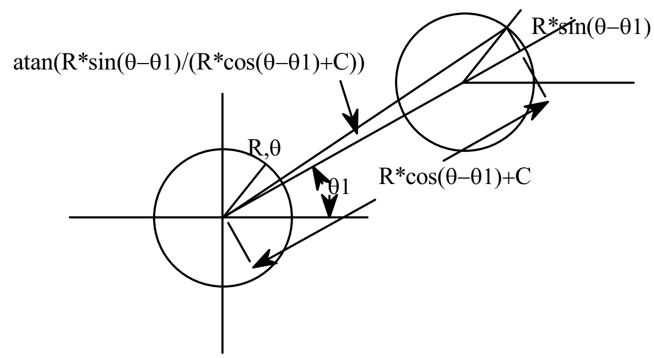
$Yr\_G_{i,j} := R_{2\_G_i} \cdot \sin(Br\_G_{i,j})$ $Yl\_G_{i,j} := R_{2\_G_i} \cdot \sin(Bl\_G_{i,j})$





geometry to shift gear to appropriate center

relationships to shift a circle R,θ from center at 0,0 to C,0



$$R_{21}(R,\theta,C,\theta 1) := \sqrt{\left(R\cdot\cos(\theta-\theta 1)+C\right)^2+\left(R\cdot\sin(\theta-\theta 1)\right)^2}$$

$\theta 1 = \text{angle\_circle\_center\_rotated}$

$$\theta_{21}(R,\theta,C,\theta 1) := \left(\operatorname{atan}\left(\frac{R\cdot\sin(\theta-\theta 1)}{R\cdot\cos(\theta-\theta 1)+C}\right)+\theta 1\right)$$

shift gear a distance C, no rotation of center but rotate gear (B_P) by 1/2 circular pitch angle to mesh

Gear $\quad i := 0 .. \text{rows(R\_plot\_G)} - 1 \quad B\_shift := \frac{\pi}{N_G} \quad B\_shift = 6\,\text{deg}$

add rotation dependent on FRAME start at 1/2 -CP go to CP/2 ??

$$B\_rot := -B\_shift + 2\cdot\frac{B\_shift}{100}\cdot FRAME$$

$B\_rot = -6\,\text{deg}$

and finally ... remove BL for meshing, applying half thedistance on each of pinion and gear pinion is rotating CCW so adjust BL/4*R_P and gear is CW so add BL/4*RG (CCW) to gear

$B\_adj\_P := \frac{BL}{4\cdot R_P}$

$B\_shift - B\_rot + B\_adj\_G = \text{total\_rotation\_of\_gear}$

applied before translation

$B\_adj\_G := \frac{BL}{4\cdot R_G}$

$R\_plot\_G\_1_i := R_{21}\left(R\_plot\_G_i, B\_plot\_G_i + B\_shift - B\_rot + B\_adj\_G, C, 0\right)$

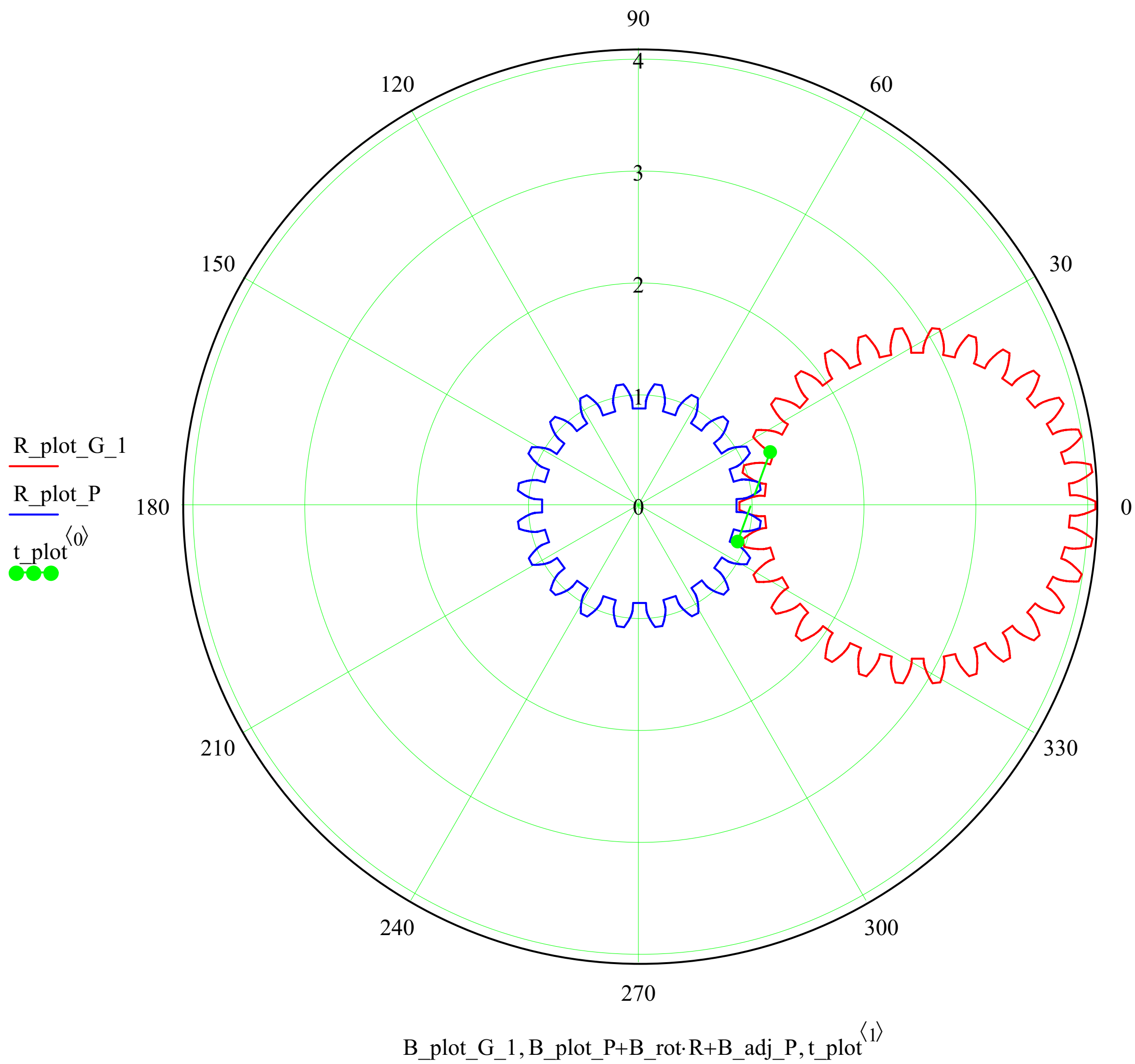
$B\_plot\_G\_1_i := \theta_{21}\left(R\_plot\_G_i, B\_plot\_G_i + B\_shift - B\_rot + B\_adj\_G, C, 0\right)$

now add tangent to the mix ... pinion is rotating ccw therefore tangent is at: $R_{B\_P}, -\phi 1$

gear is rotating cw therefore tangent before shift is at: $R_{B\_G}, \pi - \phi 1$

and we need to translate it $R_{tan\_G} := R_{21}\left(R_{B\_G}, \pi - \phi 1, C, 0\right)$ $\theta_{tan\_G} := \theta_{21}\left(R_{B\_G}, \pi - \phi 1, C, 0\right)$

so tangent plot is $t\_plot := \begin{pmatrix} R_{B\_P} & -\phi 1 \\ R_{tan\_G} & \theta_{tan\_G} \end{pmatrix}$ $t\_plot = \begin{pmatrix} 0.94 & -0.349 \\ 1.27 & 0.389 \end{pmatrix}$



$X\_G := \text{reset}$ $Y\_G := \text{reset}$ shift to X,Y so can get closeup of mesh in animation $j := 0 .. \text{rows}(R\_plot\_P) - 1$

$X\_G_i := R\_plot\_G\_1_i \cdot \cos(B\_plot\_G\_1_i)$

$X\_P_j := R\_plot\_P_j \cdot \cos(B\_plot\_P_j + B\_rot \cdot R + B\_adj\_P)$

$Y\_G_i := R\_plot\_G\_1_i \cdot \sin(B\_plot\_G\_1_i)$

$Y\_P_j := R\_plot\_P_j \cdot \sin(B\_plot\_P_j + B\_rot \cdot R + B\_adj\_P)$

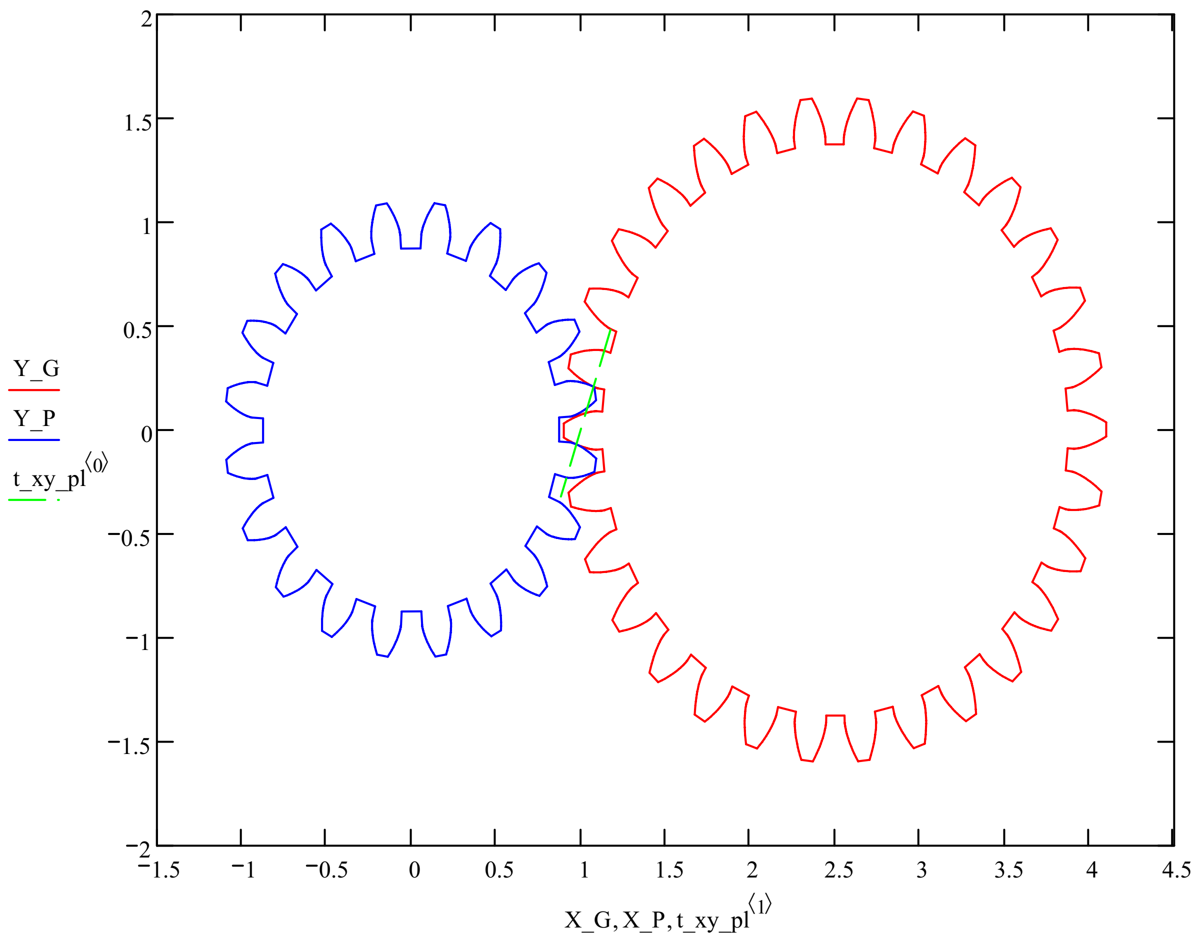
$X\_tan\_G := R_{tan\_G} \cdot \cos(\theta_{tan\_G})$

$X\_tan\_P := R_{B\_P} \cdot \cos(-\phi 1)$

$Y\_tan\_G := R_{tan\_G} \cdot \sin(\theta_{tan\_G})$

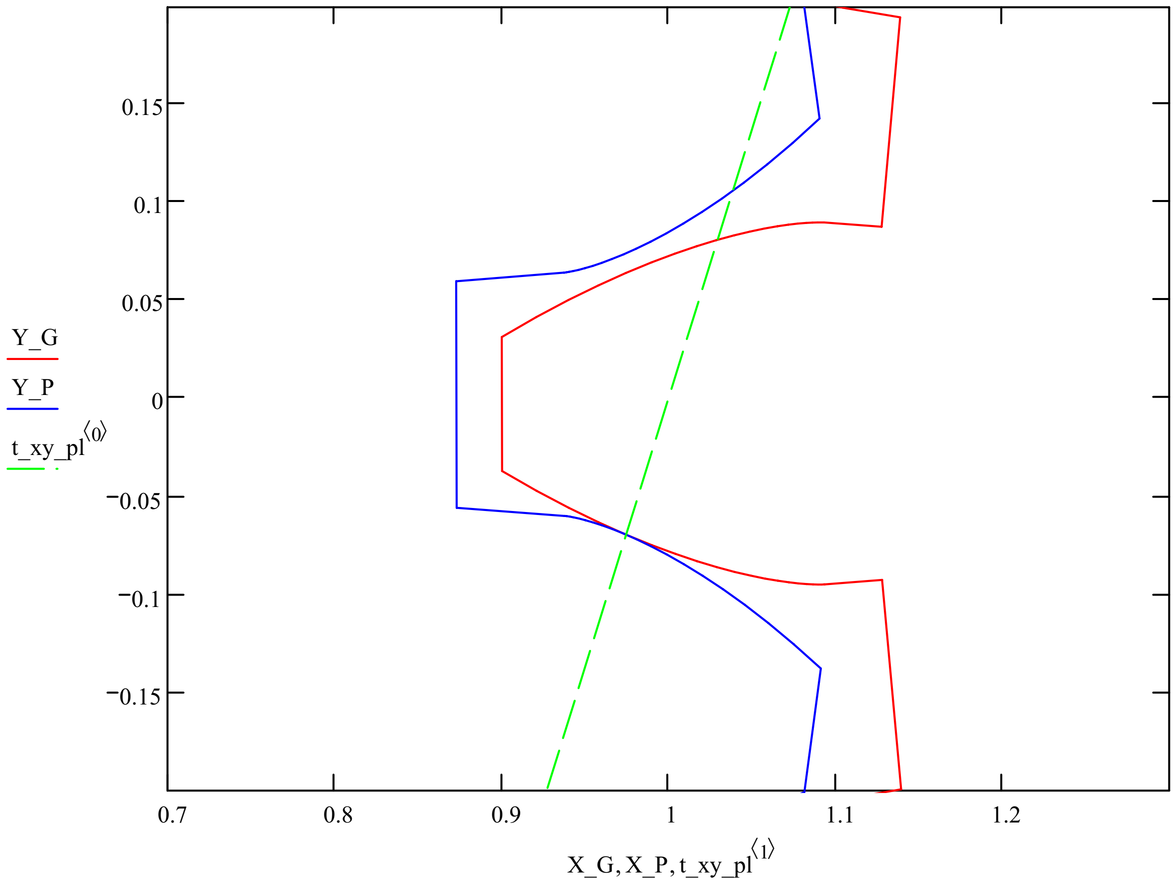
$Y\_tan\_P := R_{B\_P} \cdot \sin(-\phi 1)$

$t\_xy\_pl := \begin{pmatrix} Y\_tan\_G & X\_tan\_G \\ Y\_tan\_P & X\_tan\_P \end{pmatrix}$



$B\_rot \cdot R = -9 \text{ deg}$

$R = 1.5$ $N_P = 20$ $N_G = 30$



These last two figures are animated in gear mesh video revised. In animating, the variable FRAME is incremented from 0 : 100, the calculations highlighted above are carried out and plotted, the plots updated and a video screen captured.