

## User inputs that affect the motor torque required to drive the FTW.

Enter the desired cycle time. This is the time to move the turret from one position to an adjacent position. The maximum number of cycles for the longest move is 8 cycles.

$$t_{\text{cycle}} := 3.75\text{sec} \quad \text{Desired cycle time}$$

Select a desired compression spring for the detent preload force.

The following spring is assumed: Associated Spring Part No. C0360-035-2500-S.

$$L_{\text{free}} := 25\text{mm} \quad \text{Free Length of spring} \quad F_{\text{max\_comp\_spr}} := 15.12 \cdot 2.97\text{N} = 44.906\text{N}$$

$$k_{\text{spr}} := 2.97 \frac{\text{N}}{\text{mm}}$$

Select a desired preload force for seating the detent into the vee-groove.

$$F_{\text{pre}} := 15\text{N} \quad \text{Desired initial preload of compression spring when the detent is seated into the vee-groove.}$$

The following two stepper motors are considered for driving the turret.

### Motor Parameters for Phytron Steppers

$$T_{\text{vss42\_max}} := 92\text{N}\cdot\text{mm} \quad \text{VSS42 Stepper motor drive (stall) torque}$$

$$T_{\text{vss32\_max}} := 32\text{N}\cdot\text{mm} \quad \text{VSS 32.200.1.2-VGPL 32 4-UHVC stepper motor (with 4:1 reduction gear box (stall) torque)}$$

$$\text{Ratio}_{\text{mot\_gearbox}} := 1$$

Select a desired gear reduction ratio between the motor and the crank of the geneva mechanism (default ratio is 3:1).

$$\text{Ratio}_{\text{mitergear}} := 3 \quad \text{Miter gear reduction ratio between stepper and crank}$$

Define crank shaft bearing friction (torque).

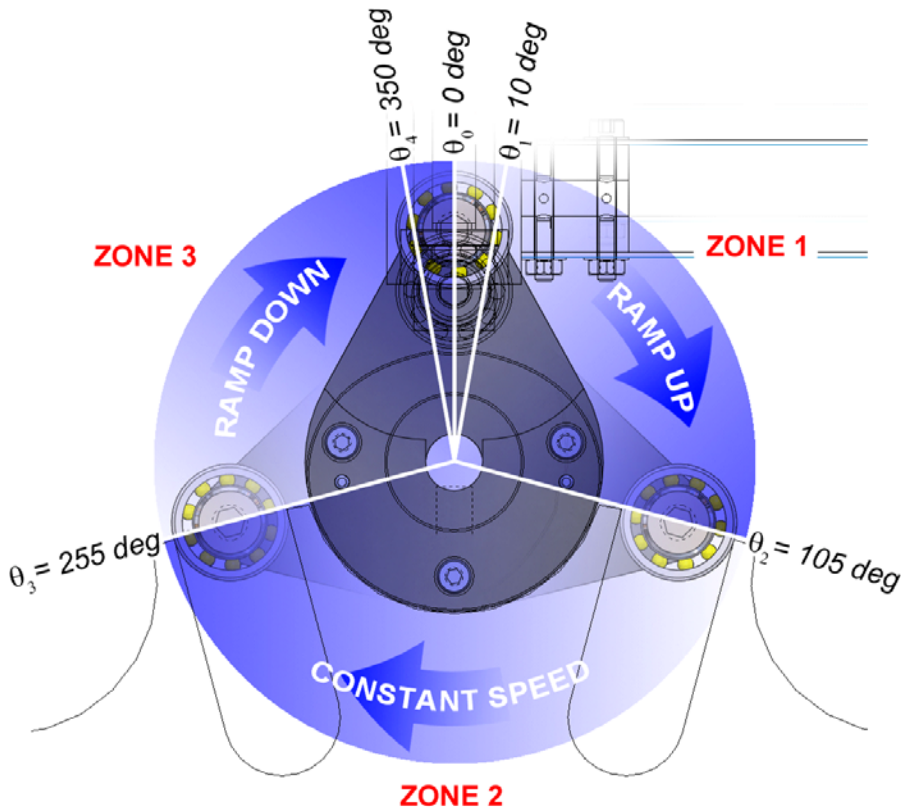
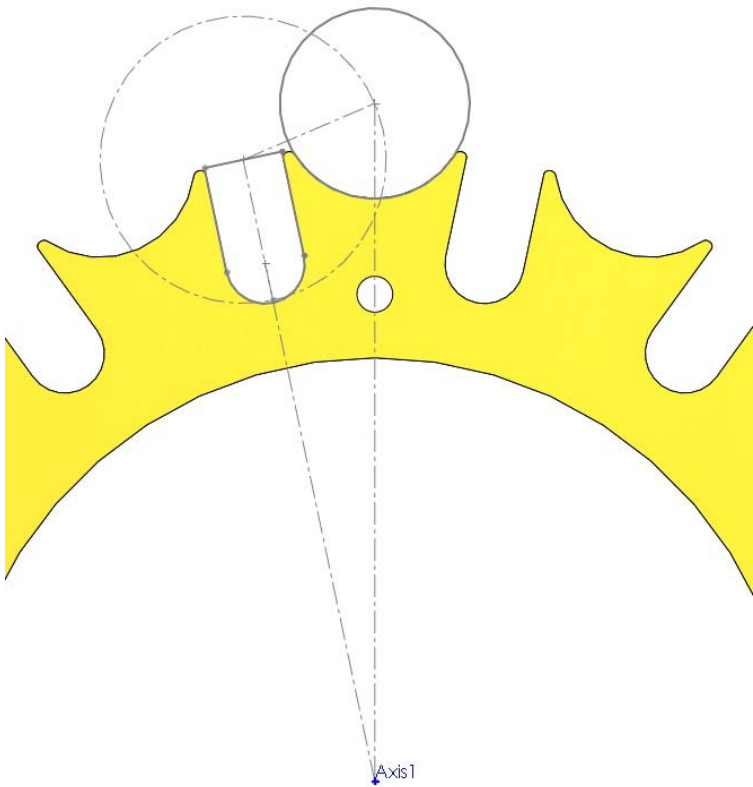
$$T_{\text{crank\_friction}} := 1\text{N}\cdot\text{mm}$$

Define motor drive shaft bearing friction (torque).

$$T_{\text{fric\_shaft1}} := T_{\text{crank\_friction}}$$

Define FTW hub bearing friction (torque).

$$T_{\text{trt\_fric}} := 10\text{N}\cdot\text{mm}$$



Part 1. Cam Move Profile Calculations

This calculations assumes a trapezoidal move profile for the Geneva crank. The crank starts at  $\theta_1= 0\text{deg}$ , which corseponds to the detent mechanism fully seated in the vee-groove. The crank acclerates from  $\theta_1$  to  $\theta_2$  with constant acceleration. From  $\theta_2$  to  $\theta_3$ , the angular velocity is constant. From  $\theta_3$  to  $\theta_4$ , the crank decelerates back to a stop, completing one cycle of the crank.

The geometry of the Geneva wheel will determine at which angle the cam drive will engage the geneva:

$R_{CG} := 64\text{mm}$ Radius of the cam drive axis to the axis of the Geneva wheel

$R_G := 60\text{mm}$  Radius of the Geneva wheel

$N_S := 15$  Number of discrete positions

$$\theta_{\text{engage}} := \frac{\pi}{2} + \text{atan}\left[\frac{\left(R_{CG} - R_G \cdot \cos\left(\frac{\pi}{N_S}\right)\right)}{R_G \cdot \sin\left(\frac{\pi}{N_S}\right)}\right] = 113.062 \cdot \text{deg}$$

Angle at which the drive engages the geneva

$$R_{CD} := \sqrt{\left(R_{CG} - R_G \cdot \cos\left(\frac{\pi}{N_S}\right)\right)^2 + \left(R_G \cdot \sin\left(\frac{\pi}{N_S}\right)\right)^2} = 13.558 \cdot \text{mm}$$

Distance from the cam axis to the drive bearing axis

$\theta_0 := 0\text{deg}$

Starting position of the crank, which corresponds to the detent mechanism seated in the vee-groove.

$\theta_1 := 10\text{deg}$

Cam angle when follower begins to lift detent off of vee-groove.

$\theta_2 := \theta_{\text{engage}} = 113.062 \cdot \text{deg}$

Position of crank when the detent mechanism completely clears the vee-groove. The crank accelerates to full speed from  $\theta_1$  to this position and begin to engage with the geneva wheel to begin cycling the turret to the next position.

$\theta_3 := 360\text{deg} - \theta_2 = 246.938 \cdot \text{deg}$

Position of crank when the geneva has completed a move of the turret to the next position. The crank rotates at constant speed from this position to  $\theta_4$ .

$\theta_4 := 360\text{deg} - \theta_1 = 350 \cdot \text{deg}$

Cam angle when follower finishes seating the detent onto the vee-groove.

$\theta_5 := 360\text{deg}$

Ending position of the crank, which corresponds to the detent mechanism seated in the vee-groove.

$\theta := \theta_0, .1 \cdot \text{deg} .. \theta_5$

Define range for crank angle.

Calculate the corresponding times for the angular positions above.

$$\omega_{\text{crank\_max}} := \frac{1}{t_{\text{cycle}}}\left(2\theta_5 - \theta_3 + \theta_2\right) = 26.05 \cdot \frac{\text{rev}}{\text{min}}$$

Calculated maximum crank velocity for the desired cycle time

$$t_2 := 2 \cdot \frac{\left(\theta_2\right)}{\omega_{\text{crank\_max}}} = 1.447 \text{ s}$$

Calculated time to get to the  $\theta_2$  position.

$$t_1 := \sqrt{\frac{2t_2 \cdot \theta_1}{\omega_{\text{crank\_max}}}} = 0.43 \text{ s}$$

$$t_3 := t_2 + \frac{\left(\theta_3 - \theta_2\right)}{\omega_{\text{crank\_max}}} = 2.303 \text{ s}$$

Calculated time to get to the  $\theta_3$  position.

$$t_5 := t_3 + 2 \cdot \left(\frac{\theta_5 - \theta_3}{\omega_{\text{crank\_max}}}\right) = 3.75 \text{ s}$$

Calculated time to get to the  $\theta_5$  position.

$$t_4 := t_5 - t_1 = 3.32 \text{ s}$$

Calculate angular position of crank as a function of time.

$t := 0\text{s}, .01\text{s} .. t_5$

Define time range

$$\theta_x(t) := \text{if}\left[t < t_2, \frac{\omega_{\text{crank\_max}}}{2t_2} \cdot t^2, \frac{\omega_{\text{crank\_max}}}{2} \cdot t_2 + \omega_{\text{crank\_max}} \cdot \left(t - t_2\right)\right]$$

$$\theta_{\text{crank}}(t) := \text{if}\left[t < t_3, \theta_x(t), \frac{\omega_{\text{crank\_max}}}{t_5 - t_3} \cdot \left(t_5 \cdot t - \frac{1}{2} \cdot t^2\right) + \theta_5 - \frac{\omega_{\text{crank\_max}}}{t_5 - t_3} \cdot \frac{t_5^2}{2}\right]$$

Calculate angular velocity of crank as a function of time.

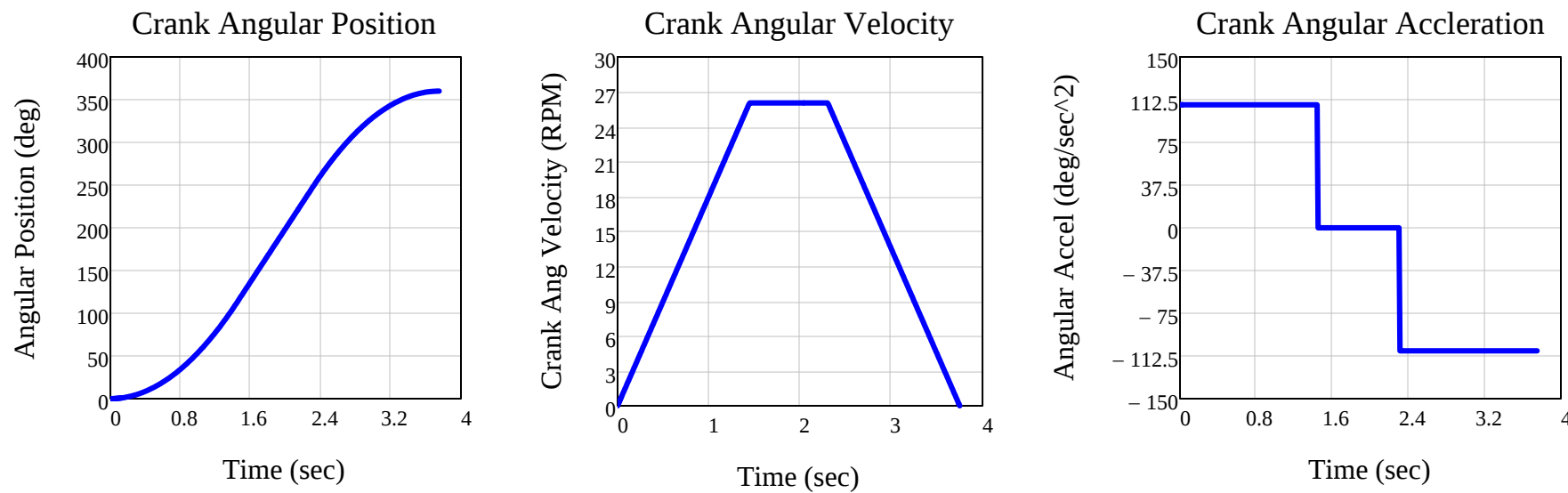
$$\omega_t(t) := \text{if}\left[t < t_2, \omega_{\text{crank\_max}} \cdot \frac{t}{\left(t_2\right)}, \omega_{\text{crank\_max}}\right]$$

$$\omega_{\text{crank}}(t) := \text{if}\left[t < t_3, \omega_t(t), \omega_{\text{crank\_max}} \cdot \frac{\left(t_5 - t\right)}{\left(t_5 - t_3\right)}\right]$$

Calculate angular acceleration of crank as a function of time.

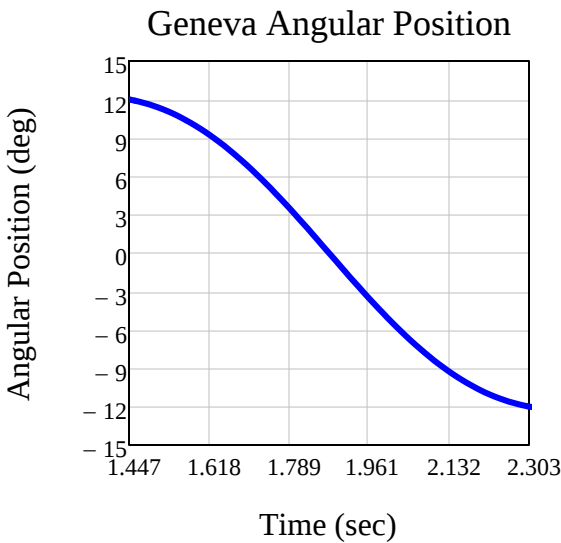
$$\alpha_{\text{crank}}(t) := \frac{d}{dt} \omega_{\text{crank}}(t)$$

Crank angular acceleration.



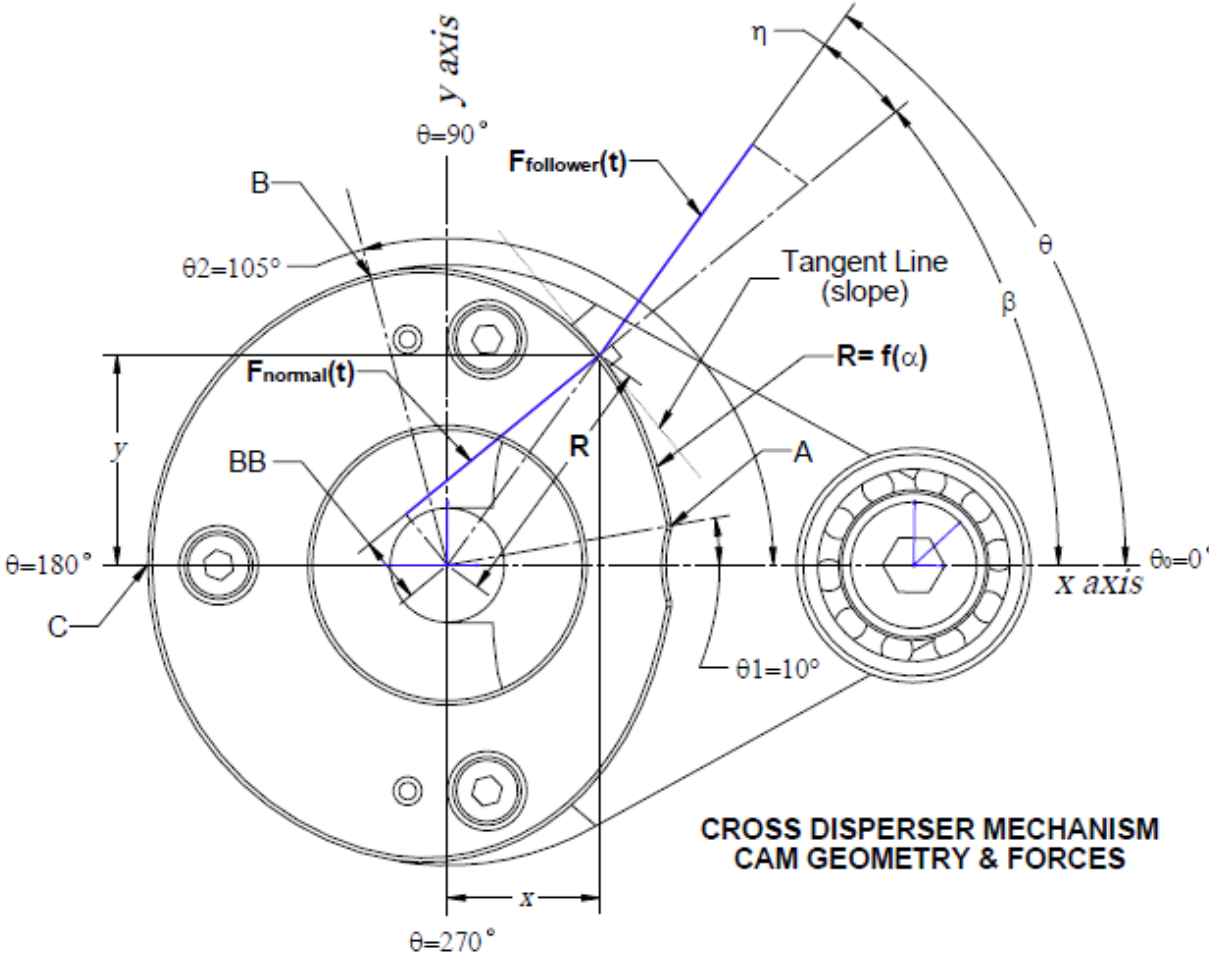
Angle of the geneva in function of the angle of the cam:

$$\gamma_{\text{geneva}}(t) := \text{atan} \left( \frac{R_{\text{CD}} \cdot \cos \left( \theta_{\text{crank}}(t) - \frac{\pi}{2} \right)}{R_{\text{CG}} - R_{\text{CD}} \cdot \sin \left( \theta_{\text{crank}}(t) - \frac{\pi}{2} \right)} \right)$$



| t =        | θ <sub>crank</sub> (t) =   | γ <sub>geneva</sub> (t) =  |
|------------|----------------------------|----------------------------|
| 0.000000 s | 0.000000                   | 0.000000 ·deg              |
| 0.010000   | 5.401816 ·10 <sup>-3</sup> | 9.443124 ·10 <sup>-4</sup> |
| 0.020000   | 0.021607                   | 3.777250 ·10 <sup>-3</sup> |
| 0.030000   | 0.048616                   | 8.498811 ·10 <sup>-3</sup> |
| 0.040000   | 0.086429                   | 0.015109                   |
| 0.050000   | 0.135045                   | 0.023608                   |
| 0.060000   | 0.194465                   | 0.033995                   |
| 0.070000   | 0.264689                   | 0.046271                   |
| 0.080000   | 0.345716                   | 0.060436                   |
| 0.090000   | 0.437547                   | 0.076489                   |
| 0.100000   | 0.540182                   | 0.094430                   |
| 0.110000   | 0.653620                   | 0.114260                   |
| 0.120000   | 0.777862                   | 0.135979                   |
| 0.130000   | 0.912907                   | 0.159585                   |
| 0.140000   | 1.058756                   | 0.185080                   |
| ...        | ...                        | ...                        |

## Cam Follower Path Calculations



**This calculation uses a sinusoidal cam follower path for a smooth transition between the seated to unseated positions of the detent mechanism.**

Lift := 7mm      Cam lift (distance from detent fully seated to fully disengaged).

$R_2 := 15 \cdot \text{mm}$  Radius of cam when detent is fully disengaged.

$$R_1 := R_2 - \text{Lift} \quad \text{Radius of cam when detent is seated.}$$

**Define cam radius equation for three segments of cam from 0 deg to  $\theta_2$ , &  $\theta_2$  to 180 deg.**

$$R_{\text{zone1}}(\theta) := \text{if} \left[ \theta < \theta_1, R_1, R_1 + \left( \frac{R_2 - R_1}{2} \right) \cdot \left[ 1 + \sin \left[ \left( \frac{180 \text{deg}}{\theta_2 - \theta_1} \right) \cdot (\theta - \theta_1) - 90 \text{deg} \right] \right] \right]$$

Radius of cam path in zone 1.

$$R_{\text{zone}12}(\theta) := \text{if}(\theta < \theta_2, R_{\text{zone}1}(\theta), R_2)$$

Radius of cam path in zones 1 & 2.

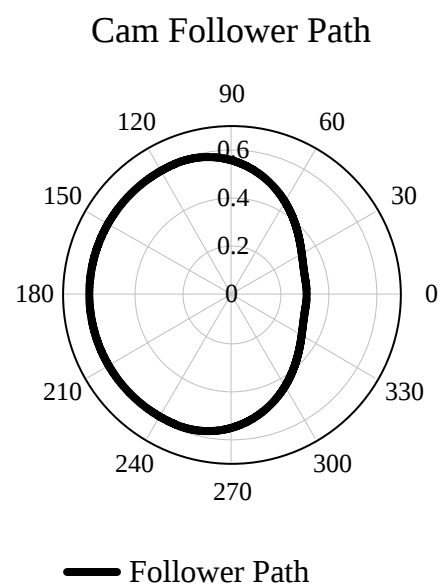
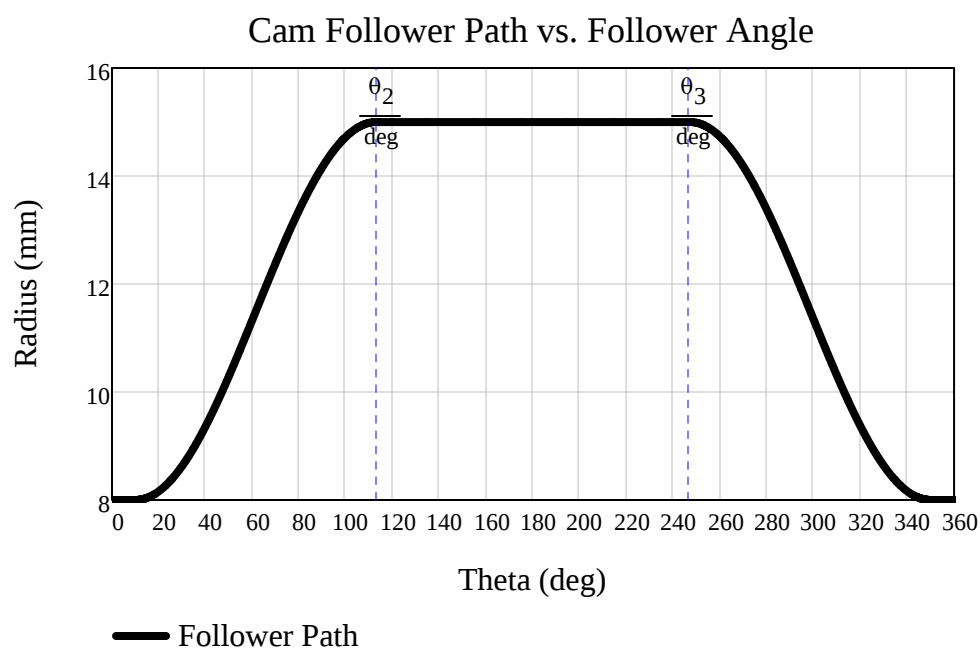
$$R_{\text{zone123}}(\theta) := \text{if} \left[ \theta < \theta_3, R_{\text{zone12}}(\theta), R_1 + \left( \frac{R_2 - R_1}{2} \right) \cdot \left[ 1 + \sin \left[ \left( \frac{180 \text{deg}}{\theta_4 - \theta_3} \right) \cdot (\theta - \theta_3) + 90 \text{deg} \right] \right] \right]$$

Radius of cam path in zones 1, 2 & 3.

$$R_{\text{zone1234}}(\theta) := \text{if}(\theta < \theta_4, R_{\text{zone123}}(\theta), R_1)$$

Radius of cam path in zones 1, 2, 3 & 4.

$$R_{\text{cam}}(\theta) := R_{\text{zone1234}}(\theta)$$



$$R_{z1}(t) := \text{if} \left[ t < t_1, R_1, R_1 + \left( \frac{R_2 - R_1}{2} \right) \cdot \left[ 1 + \sin \left[ \left( \frac{180 \text{deg}}{\theta_2 - \theta_1} \right) \cdot (\theta_{\text{crank}}(t) - \theta_1) - 90 \text{deg} \right] \right] \right]$$

Radius of cam path in zone 1.

$$R_{z12}(t) := \text{if} \left( t < t_2, R_{z1}(t), R_2 \right)$$

Radius of cam path in zones 1 & 2.

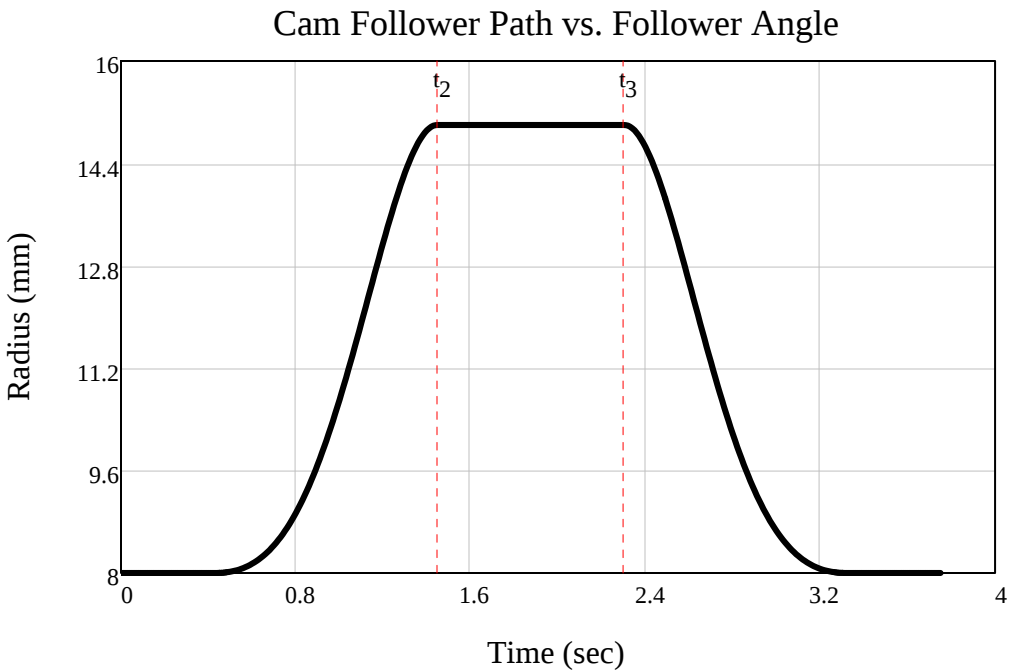
$$R_{z123}(t) := \text{if} \left[ t < t_3, R_{z12}(t), R_1 + \left( \frac{R_2 - R_1}{2} \right) \cdot \left[ 1 + \sin \left[ \left( \frac{180 \text{deg}}{\theta_4 - \theta_3} \right) \cdot (\theta_{\text{crank}}(t) - \theta_3) + 90 \text{deg} \right] \right] \right]$$

Radius of cam path in zones 1, 2 & 3.

$$R_{z1234}(t) := \text{if} \left( t < t_4, R_{z123}(t), R_1 \right)$$

$$R_{\text{cm}}(t) := R_{z1234}(t)$$

Radius of cam path in zones 1, 2, 3 & 4.



Convert cam follower path to cartesian coordinates

$$x(\theta) := R_{\text{cam}}(\theta) \cdot \cos(\theta)$$

x coordinate

$$y(\theta) := R_{\text{cam}}(\theta) \cdot \sin(\theta)$$

y coordinate

$$x_t(t) := R_{\text{cam}}(\theta_{\text{crank}}(t)) \cdot \cos(\theta_{\text{crank}}(t))$$

x coordinate

$$y_t(t) := R_{\text{cam}}(\theta_{\text{crank}}(t)) \cdot \sin(\theta_{\text{crank}}(t))$$

y coordinate

|                            |     |               |     |                          |     |
|----------------------------|-----|---------------|-----|--------------------------|-----|
| $R_{\text{cam}}(\theta) =$ |     | $x(\theta) =$ |     | $y(\theta) =$            |     |
| 0.314961                   | ·in | 0.314961      | ·in | 0                        | ·in |
| 0.314961                   |     | 0.31496       |     | $5.497097 \cdot 10^{-4}$ |     |
| 0.314961                   |     | 0.314959      |     | $1.099418 \cdot 10^{-3}$ |     |
| 0.314961                   |     | 0.314956      |     | $1.649122 \cdot 10^{-3}$ |     |
| 0.314961                   |     | 0.314953      |     | $2.198822 \cdot 10^{-3}$ |     |
| ...                        |     | ...           |     | ...                      |     |

Calculate angle beta. See figure of cam geometry above.

$$\beta(\theta) := \text{if} \left[ \left( \theta < \theta_2 \right), 90 \text{deg} + \text{atan} \left( \frac{\frac{\text{d}}{\text{d}\theta} y(\theta)}{\frac{\text{d}}{\text{d}\theta} x(\theta)} \right), \theta \right]$$

$$\beta_{1t}(t) := \text{if} \left[ \left( t < t_2 \right), 90 \text{deg} + \text{atan} \left( \frac{\frac{\text{d}}{\text{d}t} y_t(t)}{\frac{\text{d}}{\text{d}t} x_t(t)} \right), \theta_{\text{crank}}(t) \right]$$

$$\beta_t(t) := \text{if} \left[ \left( t < t_3 \right), \beta_{1t}(t), 270 \text{deg} + \text{atan} \left( \frac{\frac{\text{d}}{\text{d}t} y_t(t)}{\frac{\text{d}}{\text{d}t} x_t(t)} \right) \right]$$

Calculate angle η.

$$\eta(\theta) := \theta - \beta(\theta)$$

$$\eta_t(t) := \theta_{\text{crank}}(t) - \beta_t(t)$$

Calculate moment arm BB

$$BB(\theta) := R_{\text{cam}}(\theta) \cdot \sin(\eta(\theta))$$

$$BB_t(t) := R_{\text{cm}}(t) \sin(\eta_t(t))$$

Moment arm length.

Motor & Drive Inertias

$$I_{\text{vss32rotor}} := 1000 \text{gm} \cdot \text{mm}^2$$

$$I_{\text{shaft1}} := 2218 \text{gm} \cdot \text{mm}^2$$

$$I_{\text{crank}} := 8763 \text{gm} \cdot \text{mm}^2$$

$$I_{\text{ftw}} := 1769112 \text{gm} \cdot \text{mm}^2$$

$$I_{\text{mot\_gearbox}} := 0$$

# Calculate loads on crank in Zone 1 & Zone 3. (Cam angle from 0 degrees to $\theta_2$ and $\theta_3$ to $\theta_5$ ).

The crank is subjected to the following loads in zones 1 & 3.

1. Flex Pivot loads from detent mechanism.
2. Preload force from detent mechanism compression spring.
3. Inertial forces caused by accelerating mass of detent mechansim when crank is moving.
4. Inertial force (torque) on crank shaft from accelerating crank ( $I \times \alpha$ ).
5. Frictional forces (torque) from bearings.

## 1. Calculate Flex Pivot Load.

$$L_{\text{arm}} := 107.561 \text{ mm}$$
$$\alpha_{\text{detent}}(t) := \text{asin} \left[ \frac{(R_{\text{cm}}(t) - R_1)}{L_{\text{arm}}} \right] \quad k_{\text{fp}} := 0.0286 \text{ in} \frac{\text{lbf}}{\text{deg}}$$
$$F_{\text{fp\_at\_cam}}(t) := k_{\text{fp}} \cdot \frac{\alpha_{\text{detent}}(t)}{L_{\text{arm}}} \quad \text{Component of detent spring force provided by the parallel spring flexure.}$$

## 2. Calculate detent mechanism preload compression spring forces.

$$L_{\text{arm\_at\_detent}} := 60 \text{ mm}$$
$$L_{\text{arm\_at\_spring}} := 48 \text{ mm}$$
$$L_{\text{preload}} := L_{\text{free}} - \frac{F_{\text{pre}} \cdot \frac{L_{\text{arm\_at\_detent}}}{L_{\text{arm\_at\_spring}}}}{k_{\text{spr}}} = 18.687 \cdot \text{mm} \quad \text{Length at initial preload (seated in vee-groove).}$$
$$L_{\text{maxcomp}} := L_{\text{preload}} - \text{Lift} \cdot \frac{L_{\text{arm\_at\_spring}}}{L_{\text{arm}}} = 15.563 \cdot \text{mm} \quad \text{Length at max compression (unseated)}$$
$$F_{\text{comp}}(t) := F_{\text{pre}} \cdot \frac{L_{\text{arm\_at\_detent}}}{L_{\text{arm}}} + (k_{\text{spr}}) \cdot (R_{\text{cm}}(t) - R_1) \cdot \frac{L_{\text{arm\_at\_spring}}}{L_{\text{arm}}} \quad \text{Component of detent spring force provided by the compression spring.}$$

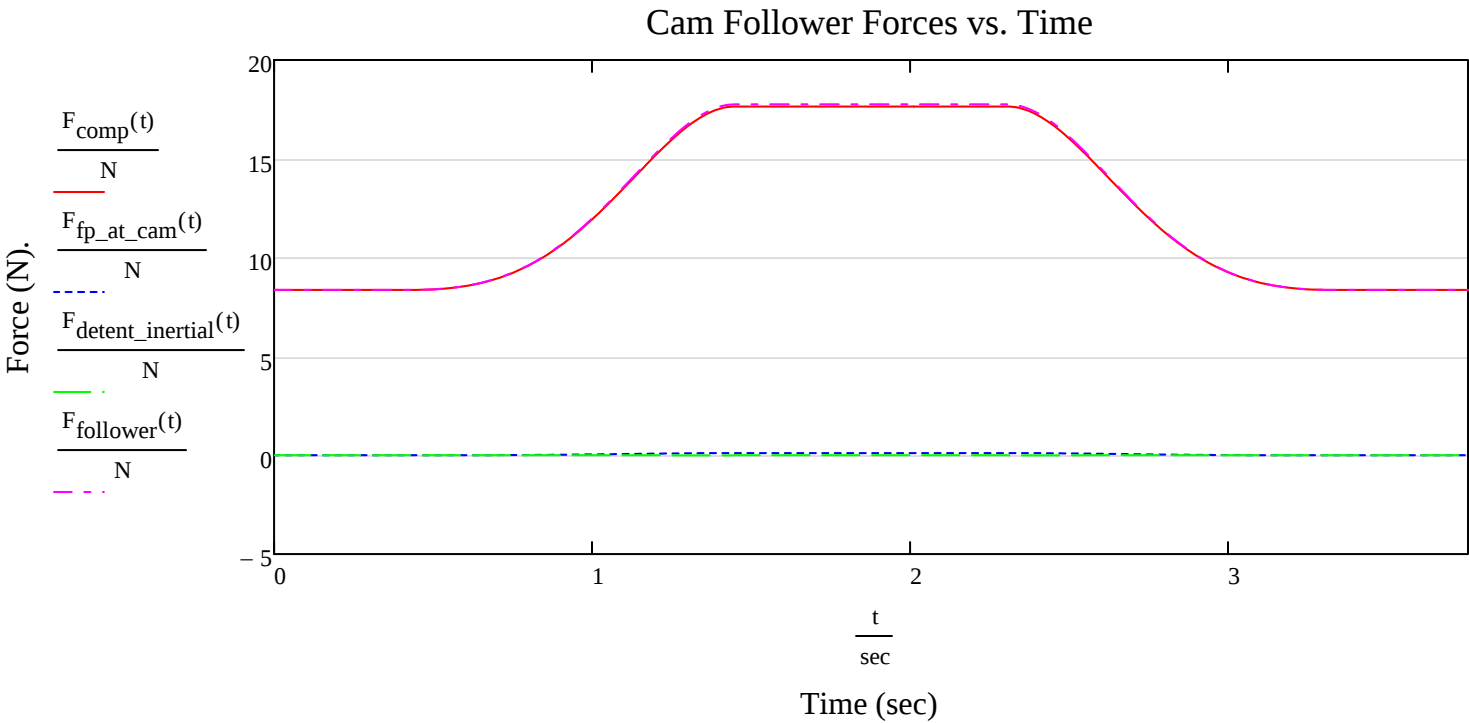
## 3. Calculate the inertial forces caused by accelerating mass of detent mechansim when crank is moving.

$$v_{\text{detent}}(t) := \left( \frac{d}{dt} R_{\text{cm}}(t) \right) \quad \text{Linear velocity of detent arm when climbing the cam.}$$
$$a_{\text{detent}}(t) := \left( \frac{d^2}{dt^2} R_{\text{cm}}(t) \right) \quad \text{Linear acceleration of detent arm when climbing the cam.}$$
$$M_{\text{detent}} := 42.75 \text{ gm} \quad \text{Mass of moving portion of detent arm.}$$
$$F_{\text{detent\_inertial}}(t) := M_{\text{detent}} \cdot a_{\text{detent}}(t) \quad \text{Force component of detent arm due to the acceleration when climbing cam.}$$

## Calculate total force on cam from follower loads.

$$F_{\text{follower}}(t) := F_{\text{comp}}(t) + F_{\text{fp\_at\_cam}}(t) + F_{\text{detent\_inertial}}(t) \quad \text{Total detent spring force.}$$

$$F_{\text{normal}}(t) := \frac{F_{\text{follower}}(t)}{\cos(\eta_t(t))} \quad \text{Reaction force to the spring in the normal direction}$$



## Calculate motor speed and acceleration

$$\omega_{\text{shaft1}}(t) := \omega_{\text{crank}}(t) \cdot \text{Ratio}_{\text{mitergear}} \quad \alpha_{\text{shaft1}}(t) := \text{Ratio}_{\text{mitergear}} \cdot \alpha_{\text{crank}}(t)$$

$$\omega_{\text{motor}}(t) := \omega_{\text{shaft1}}(t) \cdot \text{Ratio}_{\text{mot\_gearbox}} \quad \alpha_{\text{motor}}(t) := \alpha_{\text{shaft1}}(t) \cdot \text{Ratio}_{\text{mot\_gearbox}}$$

# Calculate loads on crank in Zone 2 (Cam angle from $\theta_2$ to $\theta_3$ ).

The crank is subjected to the following loads in zone 2..

1. Inertial force (torque) of accelerating turret ( $I \times \alpha$ ) as is cycles from one position to the next.
2. Frictional forces (torque) from turret bearings.

$R_{\text{crank}} := 25.88190451\text{mm}$

Radius of Geneva crank

$D_{\text{ctr}} := 100\text{mm}$

Distance between centers of Geneva wheel and crank

$$\theta_{\text{gen2}}(t) := \text{if} \left( t < t_2, \text{atan} \left( \frac{R_{\text{crank}} \cdot \sin(180\text{deg} - \theta_2)}{D_{\text{ctr}} - R_{\text{crank}} \cdot \cos(180\text{deg} - \theta_2)} \right), \text{atan} \left( \frac{R_{\text{crank}} \cdot \sin(180\text{deg} - \theta_{\text{crank}}(t))}{D_{\text{ctr}} - R_{\text{crank}} \cdot \cos(180\text{deg} - \theta_{\text{crank}}(t))} \right) \right)$$

$$\theta_{\text{geneva}}(t) := \text{if} \left( t < t_3, \theta_{\text{gen2}}(t), \text{atan} \left( \frac{R_{\text{crank}} \cdot \sin(180\text{deg} - \theta_3)}{D_{\text{ctr}} - R_{\text{crank}} \cdot \cos(180\text{deg} - \theta_3)} \right) \right)$$

$$R_{\text{geneva}}(t) := \frac{R_{\text{crank}} \cdot \sin(180\text{deg} - \theta_{\text{crank}}(t))}{\sin(\theta_{\text{geneva}}(t))}$$

Geneva radius as a function of time

$$\omega_{\text{geneva}}(t) := \frac{d}{dt} \theta_{\text{geneva}}(t)$$

$$\alpha_{\text{geneva}}(t) := \frac{d^2}{dt^2} \theta_{\text{geneva}}(t)$$

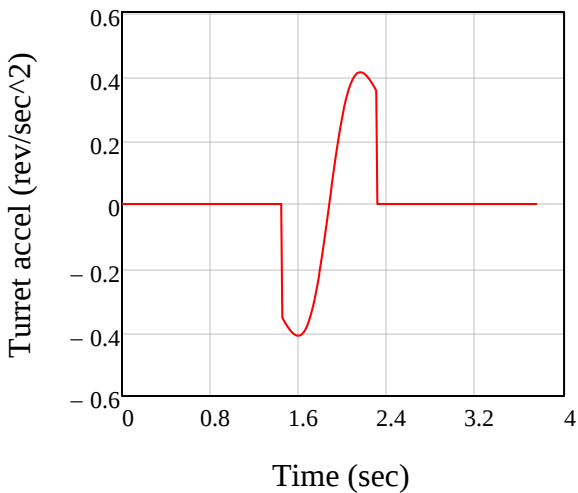
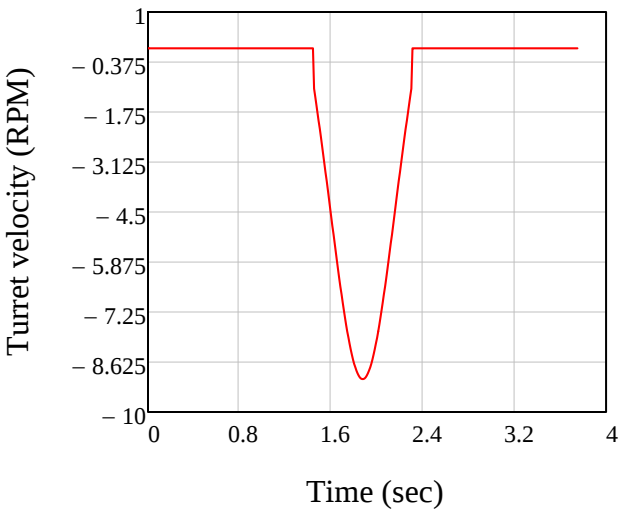
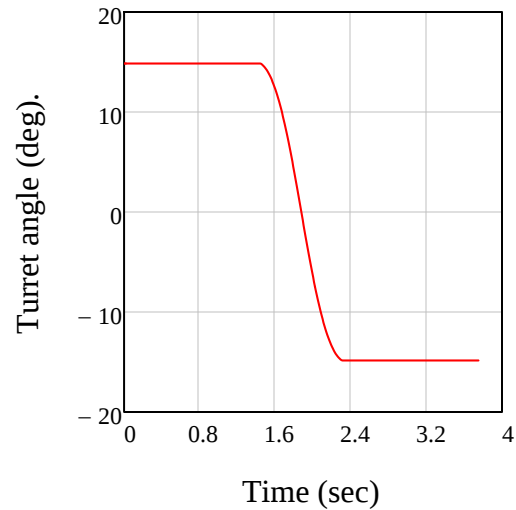
$$T_{\text{ftw}}(t) := I_{\text{ftw}} \cdot \alpha_{\text{geneva}}(t) + T_{\text{trt\_fric}}$$

$$F_{\text{tan\_trt\_1}}(t) := \text{if} \left( t < t_2, 0\text{lbf}, \frac{T_{\text{ftw}}(t)}{R_{\text{geneva}}(t)} \right)$$

$$F_{\text{tan\_turret}}(t) := \text{if} \left( t < t_3, F_{\text{tan\_trt\_1}}(t), 0\text{lbf} \right)$$

$$F_{\text{tan\_crank}}(t) := F_{\text{tan\_turret}}(t) \cdot \sin(\theta_{\text{crank}}(t) - \theta_{\text{geneva}}(t) - 90\text{deg})$$

$$T_{\text{crank\_z2}}(t) := F_{\text{tan\_crank}}(t) \cdot R_{\text{crank}}$$

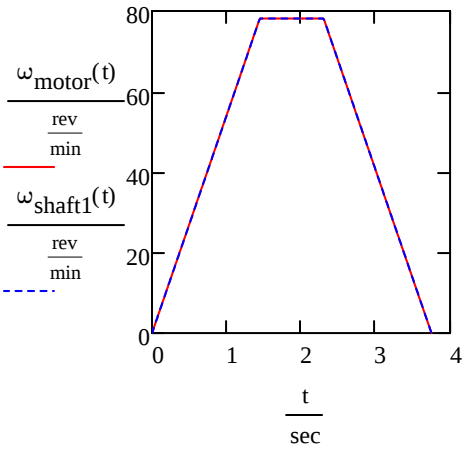


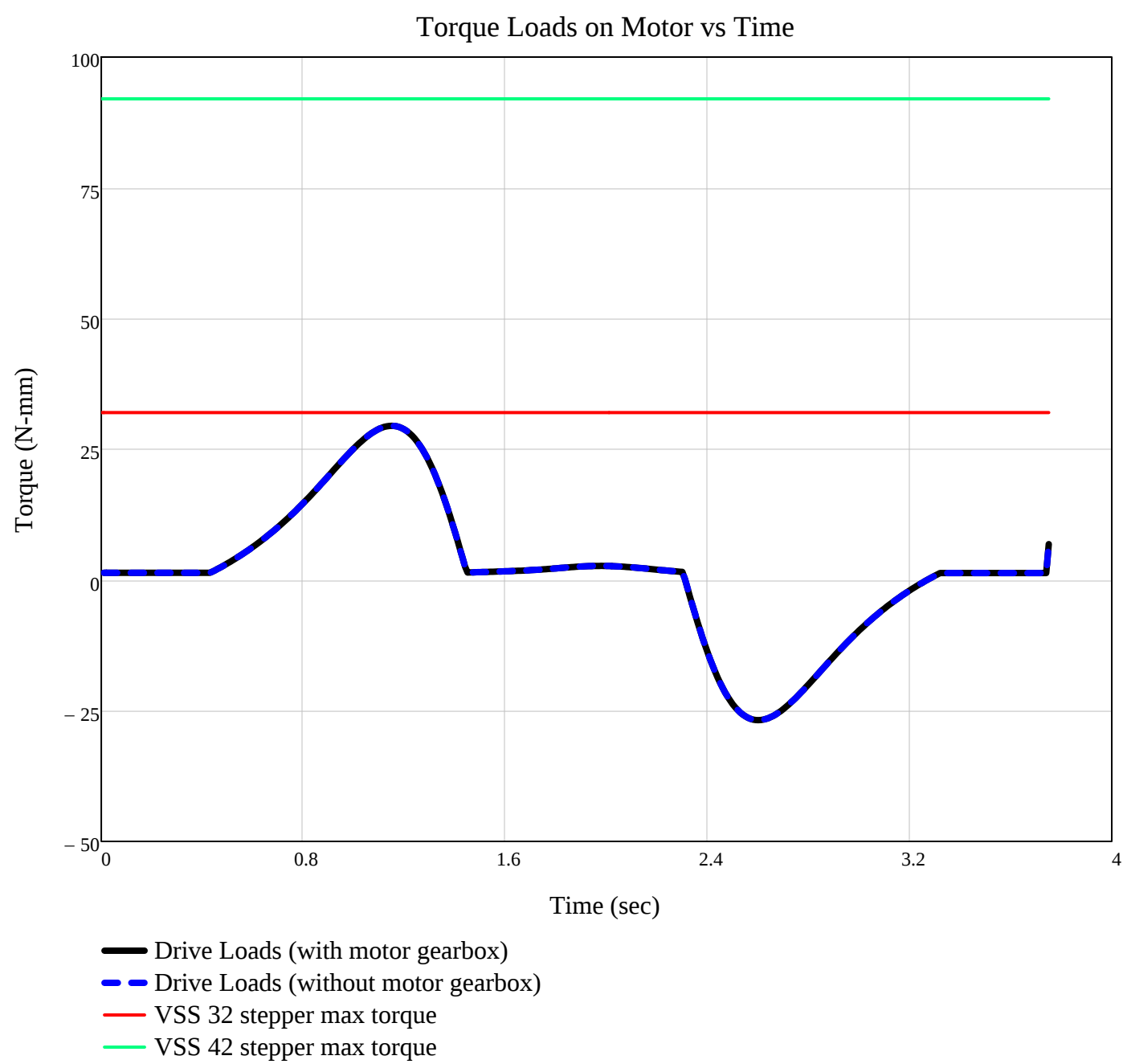
$$T_{\text{crank}}(t) := F_{\text{normal}}(t) \cdot BB_t(t) + (I_{\text{crank}}) \cdot \alpha_{\text{crank}}(t) + T_{\text{crank\_friction}} + F_{\text{tan\_crank}}(t) \cdot R_{\text{crank}}$$

$$T_{\text{shaft1}}(t) := (I_{\text{shaft1}} + I_{\text{mot\_gearbox}}) \cdot \alpha_{\text{shaft1}}(t) + \frac{T_{\text{crank}}(t)}{\text{Ratio}_{\text{mitergear}}} + T_{\text{fric\_shaft1}}$$

$$T_{\text{mot\_gearbox}}(t) := I_{\text{vss32rotor}} \cdot \alpha_{\text{motor}}(t) + \frac{T_{\text{shaft1}}(t)}{\text{Ratio}_{\text{mot\_gearbox}}}$$

$$T_{\text{mot\_nogrbx}}(t) := I_{\text{vss32rotor}} \cdot \alpha_{\text{shaft1}}(t) + T_{\text{shaft1}}(t)$$

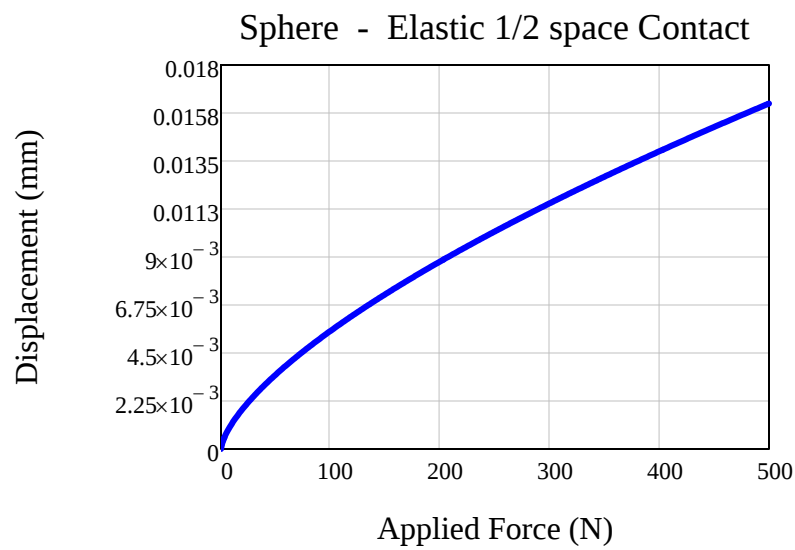




Detent Ball Contact, Deformations and Friction:

|                                                              |                                   |
|--------------------------------------------------------------|-----------------------------------|
| $F_{\text{detball}} := 0.\text{N}, 1.\text{N}.. 500\text{N}$ |                                   |
| $R_{\text{ball}} := 6\text{mm}$                              | Detent Ball Radius                |
| $E_{\text{ball}} := 2 \cdot 10^{11}\text{Pa}$                | Detent Ball Young's Modulus       |
| $\nu_{\text{ball}} := 0.3$                                   | Detent Ball Poisson's Coefficient |
| $E_{\text{vgroove}} := 1 \cdot 10^{11}\text{Pa}$             | V-Groove Young's Modulus          |
| $\nu_{\text{vgroove}} := 0.33$                               | V-Groove Poisson's Coefficient    |

$$d(F_{\text{detball}}) := \left[ \frac{\frac{3}{4} \cdot \left[ \frac{\left(1 - \nu_{\text{vgroove}}^2\right)}{E_{\text{vgroove}}} + \frac{\left(1 - \nu_{\text{ball}}^2\right)}{E_{\text{ball}}} \right] \cdot F_{\text{detball}}}{\left(\sqrt{R_{\text{ball}}}\right)} \right]^{\left(\frac{2}{3}\right)}$$



Ball / V-groove friction:

Static Friction Coefficients:

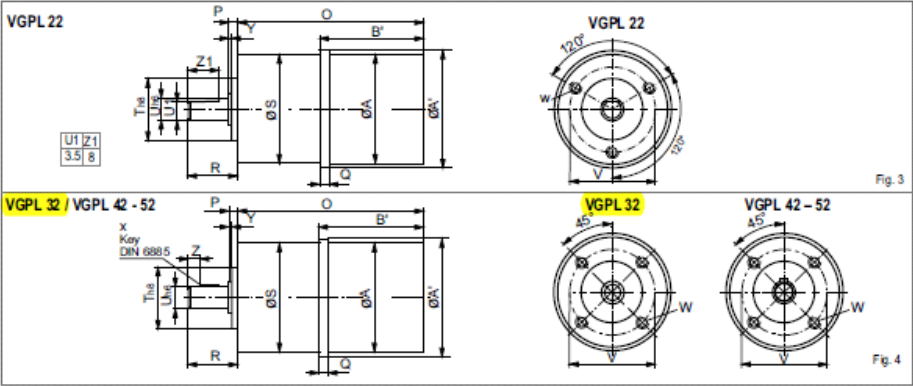
|                           |                  |
|---------------------------|------------------|
| $\mu_{\text{as}} := 0.61$ | Aluminum / Steel |
| $\mu_{\text{bs}} := 0.51$ | Brass / Steel    |
| $\mu_{\text{ss}} := 0.8$  | Steel / Steel    |

V-groove angle:

$$\alpha_{\text{vgroove}} := 45\text{deg}$$
$$F_{\text{fas}} := 100 \cdot \cos\left(\frac{\pi}{2} - \alpha_{\text{vgroove}}\right) \cdot \mu_{\text{as}} = 43.134$$

| Size                                                                                                                                                                                                                                                                                                                                                                                         | Standard Part<br>200 steps/rev. | Electrical Characteristics                   |       |      |                              |      |      |                                       |      |      | Mechanical Characteristics                                                                                               |                  |                    |       |      |        |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|----------------------------------------------|-------|------|------------------------------|------|------|---------------------------------------|------|------|--------------------------------------------------------------------------------------------------------------------------|------------------|--------------------|-------|------|--------|
|                                                                                                                                                                                                                                                                                                                                                                                              |                                 | Parallel Windings <sup>6)</sup><br>(4 leads) |       |      | Series Windings<br>(4 leads) |      |      | Unipolar Connection<br>(5 or 6 leads) |      |      | 4) 5)                                                                                                                    | 5)               | Loads              |       | Mass |        |
|                                                                                                                                                                                                                                                                                                                                                                                              |                                 | 1)                                           | 2)    | 3)   | 1)                           | 2)   | 3)   | 1)                                    | 2)   | 3)   | Holding<br>Torque                                                                                                        | Detent<br>Torque | Rotor<br>Inertia   | axial |      | radial |
|                                                                                                                                                                                                                                                                                                                                                                                              |                                 | I/Ph                                         | R/Ph  | L/Ph | I/Ph                         | R/Ph | L/Ph | I/Ph                                  | R/Ph | L/Ph |                                                                                                                          |                  |                    |       |      |        |
|                                                                                                                                                                                                                                                                                                                                                                                              |                                 | A                                            | Ω     | mH   | A                            | Ω    | mH   | A                                     | Ω    | mH   | mNm                                                                                                                      | mNm              | kg cm <sup>2</sup> | N     | N    | kg     |
| 19                                                                                                                                                                                                                                                                                                                                                                                           | VSS 19.200.0.3                  | 0.3                                          | 6     | 2.2  | 0.15                         | 24   | 8.8  | 0.21                                  | 12   | 2.2  | 3.4                                                                                                                      | 0.9              | 0.0009             | 3     | 3    | 0.05   |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 19.200.0.6                  | 0.6                                          | 2.1   | 0.55 | 0.3                          | 8.4  | 2.2  | 0.42                                  | 4.2  | 0.55 |                                                                                                                          |                  |                    |       |      |        |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 19.200.1.2                  | 1.2                                          | 0.625 | 0.15 | 0.6                          | 2.5  | 0.6  | 0.84                                  | 1.25 | 0.15 |                                                                                                                          |                  |                    |       |      |        |
| 25                                                                                                                                                                                                                                                                                                                                                                                           | VSS 25.200.0.3                  | 0.3                                          | 12    | 6    | 0.15                         | 48   | 24   | 0.21                                  | 24   | 6    | 12                                                                                                                       | 2                | 0.002              | 5     | 5    | 0.08   |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 25.200.0.6                  | 0.6                                          | 3.25  | 1.5  | 0.3                          | 13   | 6    | 0.42                                  | 6.5  | 1.5  |                                                                                                                          |                  |                    |       |      |        |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 25.200.1.2                  | 1.2                                          | 0.95  | 0.4  | 0.6                          | 3.8  | 1.6  | 0.84                                  | 1.9  | 0.4  |                                                                                                                          |                  |                    |       |      |        |
| 32                                                                                                                                                                                                                                                                                                                                                                                           | VSS 32.200.0.6                  | 0.6                                          | 4.6   | 5.3  | 0.3                          | 18.4 | 21.2 | 0.42                                  | 9.2  | 5.3  | 45                                                                                                                       | 3                | 0.01               | 5     | 15   | 0.17   |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 32.200.1.2                  | 1.2                                          | 1.25  | 1.2  | 0.6                          | 5.0  | 4.8  | 0.84                                  | 2.5  | 1.2  |                                                                                                                          |                  |                    |       |      |        |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 32.200.2.5                  | 2.5                                          | 0.3   | 0.3  | 1.25                         | 1.2  | 1.2  | 1.75                                  | 0.6  | 0.3  |                                                                                                                          |                  |                    |       |      |        |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 33.200.0.6                  | 0.6                                          | 7.5   | 9.3  | 0.3                          | 30   | 37.2 | 0.42                                  | 15   | 9.3  | 68                                                                                                                       | 3.3              | 0.018              | 5     | 15   | 0.26   |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 33.200.1.2                  | 1.2                                          | 1.9   | 2.2  | 0.6                          | 7.4  | 8.8  | 0.84                                  | 3.8  | 2.2  |                                                                                                                          |                  |                    |       |      |        |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 33.200.2.5                  | 2.5                                          | 0.47  | 0.6  | 1.25                         | 1.88 | 2.4  | 1.75                                  | 0.94 | 0.6  |                                                                                                                          |                  |                    |       |      |        |
| 42                                                                                                                                                                                                                                                                                                                                                                                           | VSS 42.200.0.6                  | 0.6                                          | 7.25  | 11   | 0.3                          | 29   | 44   | 0.42                                  | 14.5 | 11   | 130                                                                                                                      | 5                | 0.045              | 20    | 40   | 0.35   |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 42.200.1.2                  | 1.2                                          | 1.7   | 3    | 0.6                          | 6.8  | 12   | 0.84                                  | 3.4  | 3    |                                                                                                                          |                  |                    |       |      |        |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 42.200.2.5                  | 2.5                                          | 0.34  | 0.7  | 1.25                         | 1.36 | 2.8  | 1.75                                  | 0.68 | 0.7  |                                                                                                                          |                  |                    |       |      |        |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 43.200.0.6                  | 0.6                                          | 9.5   | 22.9 | 0.3                          | 38   | 91.6 | 0.42                                  | 19   | 22.9 | 235                                                                                                                      | 7                | 0.077              | 20    | 40   | 0.52   |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 43.200.1.2                  | 1.2                                          | 2.6   | 5.2  | 0.6                          | 10.4 | 20.8 | 0.84                                  | 5.2  | 5.2  |                                                                                                                          |                  |                    |       |      |        |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 43.200.2.5                  | 2.5                                          | 0.5   | 1.2  | 1.25                         | 2    | 4.8  | 1.75                                  | 1    | 1.2  |                                                                                                                          |                  |                    |       |      |        |
| 52                                                                                                                                                                                                                                                                                                                                                                                           | VSS 52.200.1.2                  | 1.2                                          | 2.65  | 7    | 0.6                          | 10.6 | 28   | 0.84                                  | 5.3  | 7    | 405                                                                                                                      | 13               | 0.15               | 25    | 70   | 0.72   |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 52.200.2.5                  | 2.5                                          | 0.6   | 1.6  | 1.25                         | 2.4  | 6.4  | 1.75                                  | 1.2  | 1.6  |                                                                                                                          |                  |                    |       |      |        |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 52.200.5                    | 5                                            | 0.165 | 0.4  | 2.5                          | 0.66 | 1.6  | 3.5                                   | 0.33 | 0.4  |                                                                                                                          |                  |                    |       |      |        |
| 56                                                                                                                                                                                                                                                                                                                                                                                           | VSS 57.200.1.2                  | 1.2                                          | 3.9   | 9.5  | 0.6                          | 15.6 | 38   | 0.84                                  | 7.8  | 9.5  | 630                                                                                                                      | 50               | 0.24               | 40    | 80   | 0.99   |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 57.200.2.5                  | 2.5                                          | 0.8   | 2.4  | 1.25                         | 3.2  | 9.6  | 1.75                                  | 1.6  | 2.4  |                                                                                                                          |                  |                    |       |      |        |
|                                                                                                                                                                                                                                                                                                                                                                                              | VSS 57.200.5.0                  | 5                                            | 0.25  | 0.8  | 2.5                          | 1    | 3.2  | 3.5                                   | 0.5  | 0.8  |                                                                                                                          |                  |                    |       |      |        |
| 1) I/Ph: Phase current<br>2) R/Ph: Phase resistance<br>3) L/Ph: Phase inductance<br>4) Holding torque in bipolar mode with parallel windings, 2 phases ON at rated current<br>5) 7 mNm ~ 1 inoz<br>6) Standard wiring at delivery (if no wiring mode was given in the order)<br>Design voltage 42 V <sub>DC</sub> (operation with SELV type supply)<br><b>Bold letters = Preferred types</b> |                                 |                                              |       |      |                              |      |      |                                       |      |      |                                                                                                                          |                  |                    |       |      |        |
|                                                                                                                                                                                                                                                                                                                                                                                              |                                 |                                              |       |      |                              |      |      |                                       |      |      | <b>Important:</b><br>All values given above were measured at room temperature of 25 °C (77 °F) and atmospheric pressure. |                  |                    |       |      |        |

Stepper Motor with VGPL Gear



|                               |               | Dimensions in mm |                          |                |                        |                  |              |              |                 |       |       |        |       |    |         |       | Mass (motor + gear) |        |      |      |      |
|-------------------------------|---------------|------------------|--------------------------|----------------|------------------------|------------------|--------------|--------------|-----------------|-------|-------|--------|-------|----|---------|-------|---------------------|--------|------|------|------|
| Gear                          | Stepper Motor |                  |                          | 1 2 3          |                        |                  |              |              |                 |       |       |        |       |    |         |       |                     | 1      | 2    | 3    |      |
|                               |               |                  |                          | stages         |                        |                  |              |              |                 |       |       |        |       |    |         |       |                     | stages |      |      |      |
|                               |               | A                | A'                       | B'             | O                      |                  |              | P            | Q               | R     | S     | T      | U     | V  | W       | X     | Y                   | Z      | lg   |      |      |
| VGPL 22                       | VSS 19        | 19               | 22                       | 29             | 50                     | 57               | 64           | 3            | 4.5             | 15    | 22    | 12     | 4     | 16 | M 2.5x4 | -     | 1                   | -      | 0.1  | 0.13 | 0.15 |
|                               | VSS 25        | 25               | 25.5                     | 33.5           | 53.5                   | 60.5             | 67.5         | 3            | 5               |       |       |        |       |    |         |       |                     | 0.13   | 0.15 | 0.18 |      |
| VGPL 32                       | VSS 32        | 32               | 33                       | 40.5           | 69.5                   | 78.5             | 87.5         | 4            | 5               | 20    | 32    | 20     | 6     | 26 | M 3x5   | -     | 1                   | -      | 0.31 | 0.35 | 0.42 |
|                               | VSS 33        | 32               | 33                       | 59.5           | 88.5                   | 97.5             | 106.5        |              |                 |       |       |        |       |    |         |       |                     | 0.39   | 0.44 | 0.51 |      |
| VGPL 42                       | VSS 42        | 42               | 43                       | 58             | 93                     | 105.5            | 118          |              |                 |       |       |        |       |    |         |       |                     | 0.63   | 0.7  | 0.8  |      |
|                               | VSS 43        | 42               | 43                       | 73             | 108                    | 120.5            | 133          | 4            | 7               | 22.5  | 42    | 25     | 8     | 32 | M 4x8   | 3x3x4 | 1                   | 2.25   | 0.8  | 0.85 | 0.93 |
| VGPL 52                       | VSS 52        | 52               | 53                       | 68.5           | 109.5                  | 124              | 138.5        | 4            | 6.7             | 24    | 52    | 32     | 12    | 40 | M 5x8   | 4x4x6 | 1                   | 2      | 1.2  | 1.4  | 1.5  |
|                               | VSS 57        | 56.4             | 57                       | 78             | 119                    | 133.5            | 148          | 4            | 9               |       |       |        |       |    |         |       |                     | 1.4    | 1.5  | 1.6  |      |
| Mechanical Characteristics    |               |                  |                          |                |                        |                  |              |              |                 |       |       |        |       |    |         |       |                     |        |      |      |      |
| Gear                          | Stepper Motor | Stages           | Gear 1) backlash arc-min | Max. torque Nm | Gear inertia 2) kg cm² | Radial load 2) N | Axial load N | Efficiency % | Reduction ratio |       |       |        |       |    |         |       |                     |        |      |      |      |
|                               |               |                  |                          |                |                        |                  |              |              |                 |       |       |        |       |    |         |       |                     |        |      |      |      |
| VGPL 22                       | VSS 19        | 1                | 20'                      | 0.1            | 0.005                  | 30               | 24           | 94           | 4:1             | 5:1   | 7:1   | 35:1   | 49:1  |    |         |       |                     |        |      |      |      |
|                               | VSS 25        | 2                | 35'                      | 0.5            | 0.015                  |                  |              | 85           | 16:1            | 20:1  | 28:1  |        |       |    |         |       |                     |        |      |      |      |
| VGPL 32                       | VSS 32        | 1                | 6'                       | 0.4            | 0.025                  | 80               | 65           | 94           | 4:1             | 4.5:1 | 5.2:1 | 6.25:1 | 8:1   |    |         |       |                     |        |      |      |      |
|                               | VSS 33        | 2                | 10'                      | 2              | 0.04                   |                  |              | 85           | 16:1            | 18:1  | 25:1  | 32:1   | 50:1  |    |         |       |                     |        |      |      |      |
| VGPL 42                       | VSS 42        | 1                | 6'                       | 0.7            | 0.05                   | 150              | 120          | 94           | 4:1             | 5:1   | 6:1   | 120:1  | 184:1 |    |         |       |                     |        |      |      |      |
|                               | VSS 43        | 2                | 10'                      | 4              | 0.08                   |                  |              | 85           | 14:1            | 16:1  | 20:1  |        |       |    |         |       |                     |        |      |      |      |
| VGPL 52                       | VSS 52        | 1                | 6'                       | 1.5            | 0.1                    | 250              | 200          | 94           | 4:1             | 4.5:1 | 5.2:1 | 6.25:1 | 8:1   |    |         |       |                     |        |      |      |      |
|                               | VSS 57        | 2                | 10'                      | 10             | 0.2                    |                  |              | 85           | 16:1            | 25:1  | 29:1  | 36:1   | 50:1  |    |         |       |                     |        |      |      |      |
|                               |               | 3                | 15'                      | 30             | 0.25                   |                  |              | 80           | 72:1            | 100:1 | 130:1 | 200:1  | 256:1 |    |         |       |                     |        |      |      |      |
| 1) no load 2) center of shaft |               |                  |                          |                |                        |                  |              |              |                 |       |       |        |       |    |         |       |                     |        |      |      |      |

