BRAYEBROOK OBSERVATORY - GP-DX

CALCULATION SHEET 1 of 4

TORQUE REQUIREMENTS for SLEWING MOTORS:

Efficiency of worm drive: $\eta = \dfrac{\cos\vartheta - \mu\tan\lambda}{\cos\vartheta + \mu\cot\lambda}$

empirical formulae for coefficient of dry friction - stainless worm on bronze wheel:

$\mu = 0.193 v^{-0277}$ where v is rubbing speed in ft/min

rubbing speed at slewing rate is 8.189 ft. per min

$$v = \frac{n\pi d}{12\cos\lambda}$$

$$\& \quad \tan\lambda = \frac{l}{\pi d}$$

where l = linear lead of worm screw
λ= helix lead angle
d = worm dia. [effective]

$$\tan\vartheta = \tan\vartheta_x \cos\lambda$$

for ISO metric screw thread form of worm:

$$\vartheta_x = 30^{o} \ \vartheta_x = threadform\ semi-angle$$

$$\theta = 29^{\circ}.978$$

$$\lambda = 2^{\circ}.430$$

$$\mu = 0.108$$

$$\eta = 0.253$$

Consider case where telescope is accelerated from rest to 2.5°/sec in 9 seconds:

$$\omega_f = 2.5^{\circ} s^{-1} = 0.04363\, rads.s^{-1}$$

About Hour Axle _ $\omega_{\circ} = 0$

$$\therefore \alpha = \frac{(\omega_f - \omega_{\circ})}{t} = \frac{0.04363}{9} = 4.84814 \times 10^{-3}\ rads.s^{-2}$$

Torque at worm _ $T_{\circ} = \dfrac{J_m.\alpha}{120.\eta} = \dfrac{0.4367 \times 4.84814 \times 10^{-3}}{120 \times 0.253} = 0.06974 \times 10^{-3}\ ftlbs$

$$T_{\circ} = 0.837 \times 10^{-3}\ inlbs \quad [0.095 mNm]$$

[Jm in ftlbssec^2]

Polar moment of inertia about Hour Axle is 0.4367 ftlbssec^2

RA wormwheel drive ratio is 120:1

for Jm calculation see <GP-DX Jm calc.pdf>

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$$\omega_f = 2.5^\circ s^{-1} = 0.04363\, rads.s^{-1}$$

About Dec Axle _ $\omega_\circ = 0$

$$\therefore \alpha = \frac{(\omega_f - \omega_\circ)}{t} = \frac{0.04363}{9} = 4.84814 \times 10^{-3}\ rads.s^{-2}$$

Torque at worm _

$$T_\circ = \frac{J_m.\alpha}{120.\eta} = \frac{0.691 \times 4.84814 \times 10^{-3}}{120 \times 0.253} = 0.1103 \times 10^{-3}\ ftlbs$$

$$T_\circ = 1.324 \times 10^{-3}\ inlbs \quad [0.15 mNm]$$

[Jm in ftlbssec^2]
Polar moment of inertia about Dec Axle is 0.691 ftlbssec^2
DEC wormwheel drive ratio is 120:1

TAKING WORST CASE SCENARIO @ WORM:

Limiting strength torque _

$$= \frac{5}{8}.8500 \times \frac{1}{3} \times \frac{3}{8} \times \frac{1}{\pi} \times \frac{1}{12} \times \frac{1}{2}.\cos 2^\circ.430$$

$$= 8.8\ inlbs = 1.0 Nm$$

[8500 lbsf/ in^2 shear strength of PB2 bronze]

Angular velocity of RA worm: $\omega_f = 50\ revs/\min \quad [5.236\ rads/\sec]$
Angular velocity of DEC worm: $\omega_\circ = 50\ revs/\min \quad [5.236\ rads/\sec]$

STEPPER MOTOR NIPON PF42-48 _
WORST CASE SCENARIO:-
2 phase @ 7º.5 step angle [48 steps / rev]

Nº. of steps to accelarate HOUR axle to 2.5º/ sec in 9 seconds (x600):

$$\omega = 2.5^\circ s^{-1} = 300^\circ.s^{-1} @\ worm = 0.833\ revs/\sec$$

$$@7^\circ.5\ step\ angle = 40\ steps/\sec$$

$$\therefore N_\omega = 360\ steps$$

max start up frequency:

$$f_1 = \frac{f_s}{\sqrt{1 + \frac{J_L}{J_O}}} = \frac{320}{\sqrt{1 + \frac{0.4367}{9.441 \times 10^{-7}}}} = \frac{320}{680}$$

$$\therefore f_1 = 0.47\ Hz$$

ABOUT HOUR. AXLE _

$$J_L = 0.4367\ ftlbs\sec^2 \qquad J_0 = 9.441 \times 10^{-7}\ ftlbs\sec^2$$

$$= 0.4367 \times 32.2 = 14.06\ lbsft^2 \qquad = 9.441 \times 10^{-7} \times 32.2 = 0.03 \times 10^{-3} lbsft^2$$

Pulse speed: $f_2 = 40\ Hz @ 48\ steps/rev$

Acceleration Torque:

$$T_a = \frac{\eta\left(J_O + J_L\right).\pi.\vartheta_s.\left(f_2 - f_1\right)}{180.t_1}$$

$$= \frac{0.253\left(0.03\times10^{-3} + 14.06\right).\pi.7^\circ.5\left(40 - 0.47\right)}{180\times9}$$

$$= 2.045\, ftlbs = 2.773 Nm$$

@ RA worm: $T_{aw} = \frac{T_a}{120} = 0.023Nm = 23mNm$

inertia ratio of telescope about hour axle to motor rotor inertia:

$$J_\rho = \frac{J_L}{J_O.120^2} = 32.5$$

N°. of steps to accelarate DEC axle to 2.5°/ sec in 9 seconds (x600):

$$\omega = 2.5^\circ s^{-1} = 300^\circ.s^{-1} \text{ @ } worm = 0.833\, revs/\sec$$

$$@7^\circ.5\ step\ angle = 40\ steps/\sec$$

$$\therefore N_\omega = 360\ steps$$

max start up frequency:

$$f_1 = \frac{f_s}{\sqrt{1 + \frac{J_L}{J_O}}} = \frac{320}{\sqrt{1 + \frac{0.676}{9.441\times10^{-7}}}} = \frac{320}{846}$$

$$\therefore f_1 = 0.38\ Hz$$

ABOUT DEC. AXLE _

$J_L = 0.676\ ftlbs\sec^2$ $\quad J_0 = 9.441\times10^{-7}\ ftlbs\sec^2$

$= 0.676\times32.2 = 21.77\ lbsft^2$ $\quad = 9.441\times10^{-7}\times32.2 = 0.03\times10^{-3} lbsft^2$

Pulse speed: $f_2 = 40\ Hz \text{ @ } 48\ steps/rev$

Acceleration Torque:

$$T_a = \frac{\eta\left(J_O + J_L\right).\pi.\vartheta_s.\left(f_2 - f_1\right)}{180.t_1}$$

$$= \frac{0.253\left(0.03\times10^{-3} + 21.77\right).\pi.7^\circ.5\left(40 - 0.38\right)}{180\times 9}$$

$$= 3.174\,ftlbs = 4.303Nm$$

@ Dec worm: $T_{aw} = \frac{T_a}{120} = 0.036Nm = 36mNm$

inertia ratio of telescope about Dec axle to motor rotor inertia:

$$J_\rho = \frac{J_L}{J_O.120^2} = 50.4$$

From the Nipon PF42 data sheet, the PF42-48 when wired bi-polar and driven at full step, the holding torque is 54mNm the pull out torque @ 12VDC @ 40pps is about 35mNm, which indicates the Dec motor may stall. However you have to bear in mind these calculations are approximate. The worm efficiency assumes dry contact between worm and wheel, whereas it is greased, so the efficiency will be slightly higher. The pull out and slewing pulse rates are also eight times that required to slew at 2.5°/sec (310pps & 320pps).

The ss2K handset permits the acceleration time to be set up to 9s and the slew speed up to x1999, so if it does stall the slew rate could be lowered.

The GP-DX rated load is only 20lbsf, but this does not include the Dec c/wts. My GP-DX carries 43lbsf of equipment & 32.5lbsf c/wts. To make the mount as rigid as possible all the pillar joints are sealed with epoxy metal putty. This includes the tripod head. There is minimal motion between the pillar and the tripod head, or the equatorial head. The tripod is a Nikon mahogany surveyor's tripod, not a Vixen tripod. It is very heavy duty and resists the twisting reaction of the slewing drive effectively.

I have compiled an Xcel Mac 2001 spreadsheet <SLEWING TORQUE for GP-DX> Input slew time into cell B3 & the Jm values about the hour & Dec axes into cells C20 & C21. I have marked columns X & AB in red. The slew cut off rate is where the torque value exceeds 35mNm.