Autodesk Inventor Engineer s Handbook

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Gears Calculation

Worm Gears Generator

[قابل توجه خوانندگان عزیز: کلیه مطالب این هندبوک از سایت شرکت Autodesk کپی برداری شده است.]

Basic geometric calculation

Input Parameters

Teeth type - common or spiral

Gear ratio and tooth numbers $i = \frac{z_2}{z_1}$

Pressure angle (the angle of tool profile) α

Module m (With ANSI - English units, enter tooth pitch p = π m)

Unit addendum ha^*

Unit clearance c^*

Unit dedendum fillet r_f^*

Face widths b_1 , b_2

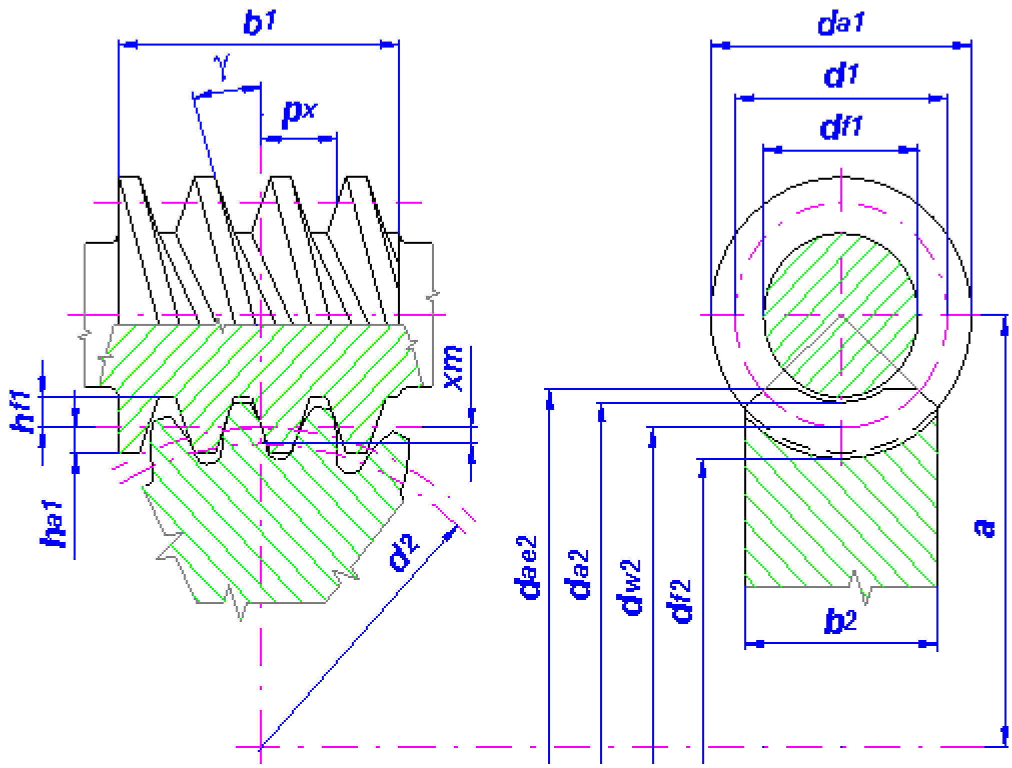
Unit worm gear correction x

Worm size can be specified using the:

- worm diameter factor q
- helix direction γ
- pitch diameter d_1

Auxiliary Geometric Calculations
Design of module, Number of teeth, Worm diameter factor and correction
Calculation of worm gear unit correction
Worm gear face width design
Worm length design
Calculation of maximum tooth root fillet

Calculated parameters



Common gearing ZN

Axial module	$m_n = m$
Normal module	$m_x = m_n \cos \gamma$
Axial pressure angle	$\alpha_x = a$
Normal pressure angle	$\alpha_n = \text{arctg} (\text{tg}\, \alpha \cos \gamma)$
Helix/lead angle	$\gamma = \arcsin z_1 / q$

Spiral gearing ZA

Axial module	$m_n = m_x / \cos \gamma$
Normal module	$m_x = m$
Axial pressure angle	$\alpha_n = \text{arctg} (\text{tg}\, \alpha \cos \gamma)$
Normal pressure angle	$\alpha_x = \alpha$
Helix/lead angle	$\gamma = \arctan z_1 / q$

Normal tooth pitch

$p_n = \pi m_n$

Axial tooth pitch

$p_x = \pi_x$

Basic tooth pitch

$p_b = p_x \cos \alpha_x$

Lead

$p_z = z_1 p_x$

Virtual/alternate number of teeth

$$z_{u2} = \frac{z_2}{\cos^3 \gamma}$$

Helix angle at basic cylinder

$\sin \gamma_b = \sin \gamma \cos \alpha_n$

Worm pitch cylinder diameter

$d_1 = q\,m$

Worm gear pitch circle diameter

$d_2 = z_2 m_x$

Worm outside cylinder diameter

$d_{a1} = d_1 + 2mh_a^*$

Worm gear outside circle diameter

$d_{a2} = d_2 + 2m\,(h_a^* + x)$

Worm root cylinder diameter

$$d_{f1} = d_1 - 2m\,(h_a^{*} + c^{*})$$

Worm gear root circle diameter

$$d_{f2} = d_2 - 2m\,(h_a^{*} + c^{*} - x)$$

Worm rolling(work) circle diameter

$$d_{w1} = d_1 + 2xm$$

Worm gear rolling(work) circle diameter

$$d_{w2} = d_2$$

Worm gear root circle diameter

$$d_{b2} = d_2 \cos \alpha_x$$

Center distance

$$a = \frac{d_{w1} + d_{w2}}{2}$$

Chamfer angle of worm gear rim

$$\sin\varphi = \frac{b_2}{d_{a1}}$$

Worm tooth thickness in normal plane

$$s_1 = \frac{p_n}{2}$$

Worm gear tooth thickness in normal plane

$$s_2 = \frac{p_n}{2} + 2xmtg\alpha$$

Worm tooth thickness in axis plane

$s_{x1} = s_1 / \cos\gamma$

Worm gear tooth thickness in axis plane

$s_{x2} = s2 / \cos\gamma$

Work face width

$b_w = \min(b_1, b_2)$

Contact ratio

$\varepsilon_\gamma = \varepsilon_\alpha + \varepsilon_\beta$

where:

$$\varepsilon_\alpha = \frac{\sqrt{d_{a2}^2 - d_{b2}^2} + \frac{2m_x}{\sin\alpha_x} - d_2\sin\alpha_x}{2p_b}$$

$$\varepsilon_\beta = \frac{b_2\sin\gamma}{p_n}$$

Minimum worm gear tooth correction

$$x_{min} = h_{a0}^* - \frac{z_{v2}}{2}\left(1 + \frac{\chi}{h_a^*}\right)\sin^2\alpha$$

where:

$h_a{}^*{}_0 = h_a{}^* + c^* - r_f{}^*(1 - \sin\alpha)$

$c = 0.3$ for $\alpha = 20$ degrees

$c = 0.2$ for $\alpha = 15$ degrees

Design of module, number of teeth, worm diameter factor and correction

Used Calculation

The calculation of wormgear unit corrections for all combinations of modules and worm diameter factors, for which the resulting correction is in the range from - 0.5 to 1.

Unit Correction Design:

Used Calculation

$$x = \frac{2a - d_1 - d_2}{2m}$$

Worm Gear Face Width Design:

Metric units

$$b_2 = 2m\left(0.5 + \sqrt{q + 1}\right)$$

ANSI with English units

$$b_2 = 1.125\sqrt{\left(d_{a1} + 2c^* m\right)^2 - \left(d_{a1} - 4h_a^* m\right)^2}$$

Worm Length Design:

Metric units

$$b_1 = 2.5m\sqrt{z_2 + 1}$$

Calculation of strength proportions

Input values:

Gearing ratio i

Driving worm

Input power P_1

Input speed n_1

Driven worm gear

Input power P_2

Input speed n_2

Calculated values

a) Driving worm Output speed: $n_2 = \frac{n_1}{i}$

b) Driving worm gear Output speed: $n_1 = n_2 i$

Metric units

Worm circumferential speed

$$v_1 = \frac{\pi d_1 n_1}{60000} [m/s]$$

ANSI with English units

Worm circumferential speed

$$v_1 = \frac{\pi d_1 n_1}{720} [ft/s]$$

Worm gear circumferential speed

$$v_2 = v_1 \frac{z_1}{q}$$

Sliding speed

$v_k = v_1 / \cos \gamma$

Friction factor in gear

$$\mu_z = 0.02 + \frac{0.03}{v_k [m/s]}$$

Friction angle

$tg\, \rho_z = \mu_z$

a) Driving worm

Gear efficiency:

$$\eta_z = \frac{tg\, \gamma}{tg(\gamma + \rho_z)}$$

Output power:

$P_2 = P_1 \eta$

Metric units

Input moment:

$$T_1 = \frac{60000\, P_1}{2 \pi n_1} [Nm]$$

Tangential/circumferential force:

$$F_{t1} = \frac{2000\ T_1}{d_{w1}} [N]$$

ANSI with English units

Input moment:

$$T_1 = 550 \frac{60 P_1}{2\pi n_1} [lbft]$$

Tangential/circumferential force:

$$F_{t1} = \frac{24\ T_1}{d_{w1}} [lb]$$

Output moment:

$$T_2 = T_1\, i\, \eta$$

b) Driving worm gear

Gear efficiency:

$$\eta_Z = \frac{tg(\gamma - \rho_Z)}{tg\,\gamma}$$

Output power:

$$P_1 = P_2\, \eta$$

Metric units

Input moment:

$$T_2 = \frac{60000\, P_2}{2\pi n_2}\,[Nm]$$

Tangential/circumferential force:

$$F_{t1} = \frac{2000\ T_2}{i\, d_{w2}}\,[N]$$

ANSI with English units

Input moment:

$$T_2 = 550\,\frac{60\, P_2}{2\pi n_2}\,[lbft]$$

Tangential/circumferential force:

$$F_{t1} = \frac{24\ T_2}{i\, d_{w2}}\,[lb]$$

Output moment:

$$T_1 = \frac{T_2}{i}\,\eta$$

Tangential/circumferential force

$$F_{t2} = F_{t1}\, i\, \eta\, \frac{d_{w1}}{d_{w2}}$$

Axial force

$F_{a1,2} = F_{t2,1}$

Radial force

$$F_r = F_{t1}\frac{\tan\alpha_n \cos\rho_Z}{\sin(\gamma + \rho_Z)}$$

Normal force

$$F_n = \sqrt{\cos^2\rho_Z\left(F_{t1}^2 + F_a^2\right) + F_r^2}$$

Strength calculation with CSN 01 4686

Based on the fixed-end beam calculation. Includes the majority of effects.

Safety factor of contact fatigue

$$S_{H2} = \frac{\sigma_{Hlim\,2} \cdot Z_{N2} \cdot Z_L \cdot Z_v}{Z_E \cdot Z_H \cdot Z_\varepsilon \cdot \sqrt{\dfrac{F_{t2} \cdot K_H}{b_2 \cdot d_{w2}}}}$$

where:

σ_{Hlim}	contact fatigue limit (material value)
F_t	tangential force acting at teeth
b_w	operating facewidth

Safety factor of bending fatigue

$$S_{F2} = \frac{\sigma_{F\,lim\,2} \cdot Y_A \cdot Y_{N2} \cdot Y_X}{Y_F \cdot Y_\beta \cdot Y_\varepsilon \cdot \dfrac{F_{t2} \cdot K_F}{b_2 \cdot m}}$$

where:

σ_{Flim} bending fatigue limit (material value)

Increase of Temperature Check

Safety against overheating: $Q_{od} \geq P_z$

where:

$Q_{od} = \vartheta_D A k$	heat conducted away in oil
$\vartheta_D = t_{max} - t_0 =$ 60o	available temperature drop

A	gearbox surface, which conducts away the heat, $A \approx 9 \cdot 10^{-5} a^{1.85}$ for well ribbed gearbox
k	transfer of heat factor, $k \approx 6.6.10^{-3} (1 + 0.4 n_1^{0.75})$ for the gearbox with fan and bottom worm

Deflection Check of Worm Shaft

Resultant deflection if the worm is symmetrically mounted and has the length $l = 2.5\, b_1$:

$$y = \frac{l_1^3 \sqrt{F_r^2 + F_{t1}^2}}{48EJ}$$

where:

$$J = \frac{\pi d_1^4}{64}$$ moment of inertia

Allowable deflection:

$y_D \approx 0.004$m shaft with hardened worm

$y_D \approx 0.01$m shaft with heat-treated worm

Factor calculations

Z_N ... service life (for contact)

$$Z_{N2} = q_H \sqrt{\frac{N_{H\lim 2}}{N_{K2}}}$$

$1 \le ZN \le 1.8$

Y_N ... service life (for bending)

$$Y_{N2} = q_F \sqrt{\frac{N_{F\lim 2}}{N_{K2}}}$$

$1 \le ZN \le 1.85$

N_{Hlim}, N_{Flim} ... base number of load cycles (material value)

$N_{K1,2}$ ... required number of load cycles (speed)

$N_{K2} = 60\, L_h\, n_2$

Z_L ... lubricant

Z_v ... circumferential speed

Z_E ... material mechanical properties

$$Z_E = \sqrt{\frac{1}{\pi \cdot \left(\frac{1-\mu_1^2}{E_1} + \frac{1-\mu_2^2}{E_2}\right)}}$$

where:

μ Poisson's ratio (material value)

E modulus of elasticity (material value)

Z_H ... mating teeth shape

$$Z_H = \sqrt{\frac{4 \cdot \cos\gamma}{\sin 2\alpha_n}}$$

Z_ε ... length of contact curves

$$Z_\varepsilon = \sqrt{\frac{\cos\gamma}{\varepsilon_\alpha}}$$

Y_ε ... profile mesh effect

for $\varepsilon_\beta < 1$:

$$Y_\varepsilon = 0.2 + \frac{0{,}8}{\varepsilon_\alpha}$$

for $\varepsilon_\beta \geq 1$:

$$Y_\varepsilon = \frac{1}{\varepsilon_\alpha}$$

Y_β ... helix direction

$$Y_\beta = 1 - \varepsilon_\beta \frac{\gamma}{120°} \geq Y_{\beta min}$$

where:

$Y_{\beta\, min} = 1 - 0.25\, \varepsilon_\beta \geq 0.75$

Y_F ... tooth shape (table value)

Z_V	Y_F
20	1.98
22	1.93
25	1.95
27	1.8
30	1.76
33	1.7
36	1.62
40	1.55
45	1.48
50	1.45
60	1.4
80	1.34
100	1.3
150	1.27
300	1.24

K_H ... additional loads (for contact)

$K_H = K_A K_{Hv} K_{H\beta} K_{H\alpha}$

K_F ... additional loads (for bending)

$K_F = K_A K_{Fv} K_{F\beta} K_{F\alpha}$

K_A ... outside dynamic forces

where:

$K_{Hv} = K_{Fv}$ table values

$$K_{H\alpha} = K_{F\alpha} = \frac{1}{0.75\,\varepsilon_\alpha}$$ portion of single tooth loading

$$K_{H\beta} = 1 + \left(\frac{Z_2}{\Theta}\right)^3 (K_A - 1)0.6$$ loading non uniform teeth along the width (for contact)

Θ worm deformation (table value)

$$K_{F\beta} = (K_{H\beta})^{NF}$$ loading non uniform teeth along the width (for bending)

$$NF = \frac{(b_w/h)^2}{(b_w/h)^2 + (b_w/h) + 1}$$

$h = 2$ m

Strength calculation with ANSI

Based on the fixed-end beam calculation. Includes the majority of effects.

Dynamic Load

$F_d = F_{t2} K_v$

where:

F_{t2}	Poisson's ratio (material value)
$K_v = \frac{1200 + v_2}{1200}$	circumferential force factor
v_2	gear circumferential speed [ft/min]

Allowable Bending Force

$F_s = S_n b_2 p\ y \geq F_d$

where:

S_n limiting bending strength (material value)

b_2 gear width

p gear pitch

y form factor (Lewis factor)

Allowable Contact Force

$F_w = d_2 b_2 K_w \geq F_d$

where:

K_w limiting contact strength (material value)

b_2 gear width

d_2 gear pitch diameter

Increase of Temperature Check

$Q_{max} \geq P_z$

where:

$P_z = P (1 - \eta + 0.3)$	lost power
$Q_{max} = C A (t_{max} - t_0) / 33000$	heat conducted away in oil
$t_{max} - t_0$ = 120° F	allowable temperature drop
A	gearbox surface, which conducts away the heat, $A \approx 0.3 a^{1.7}$ for well ribbed gearbox
C	transfer of heat factor, $C \approx 0.0356 n_1 + 20$ for the gearbox with fan and bottom worm

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