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Crossed helical gearing a.k.a. screw gears

How using different helix angles can produce unique gear combinations.

A common refrain from my childhood was "if you keep crossing your eyes, they are going to get stuck like that!" It never did happen, but it was a real-life example of what nonparallel meant. In gearing, the axis of the pair is usually parallel, or they are intersecting. Crossed helical gears, also known as screw gears, are both nonparallel and nonintersecting. They allow for some very unique designs.

The term screw gearing includes various types of gears used to drive nonparallel and nonintersecting shafts where the teeth of one or both members of the pair are helical in nature. The Figure 1 below shows the meshing of screw gears where the pitch and pressure angles are the same but the helix angle of the teeth on each gear is different.

Two screw gears can only mesh together under the conditions that normal modules (m_{n1}) and (m_{n2}) and normal pressure angles (α_{n1}, α_{n2}) are the same.

If we set a pair of screw gears to have the shaft angle Σ and helix angles β_1 and β_2:

If they are the same hand (both left hand or both right hand), then

$$\Sigma = \beta_1 + \beta_2$$

If they are the opposite hand (one left hand and the other right hand), then

$$\Sigma = \beta_1 - \beta_2 \quad \text{or} \quad \Sigma = \beta_2 - \beta 1$$

If these screw gears are profile shifted, then the meshing would become a little more complex. If we let β_{w1} and β_{w2} represent the working pitch cylinders:

If they are the same hand (both left hand or both right hand), then

$$\Sigma = \beta_{w1} + \beta_{w2}$$

If they are the opposite hand (one left hand and the other right hand), then

$$\Sigma = \beta_{w1} - \beta_{w2} \quad \text{or} \quad \Sigma = \beta_{w2} - \beta_{w1}$$

The unique situation of crossed axis helical gears is that if you set the helix angles β_1 and β_2 to 45 degrees and both gears are of the same hand, then the resulting shaft angle Σ becomes 90 degrees and the gear pair will operate as a right angle drive. However, if the same gears are opposite in hand and the helix angles β_1 and β_2 are 45 degrees, then the resulting shaft angle Σ becomes 0 degrees and the gear pair will operate as a set of regular helical gears. For all configurations of crossed helical gears, the speed ratio of the gear pair is equal to z_2/z_1. Thus the speed ratio of these gear pairs is limited by the size of the larger gear and practically speaking are usually less than 6:1.

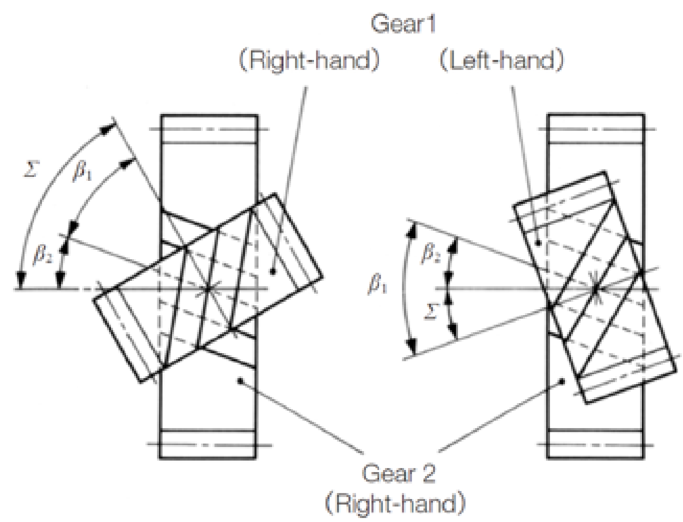

Figure 1: Screw gears of nonparallel and nonintersecting axes.

Table 1 presents the equations for a profile shifted screw gear pair. When the normal profile shift coefficients $x_{n1} = x_{n2} = 0$, the equations and calculations are the same as for standard helical gears and the following apply:

$$d_{w1} = d_1 \qquad d_{w2} = d_2$$

$$\beta_{w1} = \beta_1 \qquad \beta_{w2} = \beta_2$$

For all screw gears, the proper thrust bearings must be selected so that they absorb the thrust loads imparted by the helix angle.

Although the most popular helix angle for screw gears is 45 degrees, any helix angle greater than zero degrees is possible. The ability to mix helix angles allows for screw gears to be used in unique applications where the input and output shafts are neither intersecting nor parallel and when combined with profile shifting, they also allow for a variety of center distances. These features are not found in any other form of gearing.

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No.	Item	Symbol	Formula	Example: Pinion (1)	Example: Gear (2)
1	Normal module	m_n	Chosen Values	3	
2	Normal pressure angle	α_n		20°	
3	Reference cylinder helix angle	β		20°	30°
4	Number of teeth & helical hand	z		15 (R)	24 (R)
5	Normal profile shift coefficient	x_n		0.4	0.2
6	Number of teeth of an Equivalent spur gear	z_v	$\frac{z}{\cos^3 \beta}$	18.0773	36.9504
7	Transverse pressure angle	α_t	$\tan^{-1}\left(\frac{\tan \alpha_n}{\cos \beta}\right)$	21.1728°	22.7959°
8	Involute function α_{wn}	$\mathrm{inv}\alpha_{wn}$	$2 \tan \alpha_n \left(\frac{x_{n1} + x_{n2}}{z_{v1} + z_{v2}}\right) + \mathrm{inv}\, \alpha_n$	0.0228415	
9	Normal working pressure angle	α_{wn}	Find from involute function table	22.9338°	
10	Transverse working pressure angle	α_{wt}	$\tan^{-1}\left(\frac{\tan \alpha_{wn}}{\cos \beta}\right)$	24.2404°	26.0386°
11	Center distance modification coefficient	y	$\frac{1}{2}(z_{v1} + z_{v2})\left(\frac{\cos \alpha_n}{\cos \alpha_{wn}} - 1\right)$	0.55977	
12	Center distance	a	$\left(\frac{z_1}{2 \cos \beta_1} + \frac{z_2}{2 \cos \beta_2} + y\right) m_n$	67.1925	
13	Reference diameter	d	$\frac{z m_n}{\cos \beta}$	47.8880	83.1384
14	Base diameter	d_b	$d \cos \alpha_t$	44.6553	76.6445
15	Working pitch diameter	d_{w1} d_{w2}	$2a \frac{d_1}{d_1 + d_2}$ $2a \frac{d_2}{d_1 + d_2}$	49.1155	85.2695
16	Working helix angle	β_w	$\tan^{-1}\left(\frac{d_w}{d} \tan \beta\right)$	20.4706°	30.6319°
17	Shaft angle	Σ	$\beta_{w1} + \beta_{w2}$ or $\beta_{w1} - \beta_{w2}$	51.1025°	
18	Addendum	h_{a1} h_{a2}	$(1 + y - x_{n2}) m_n$ $(1 + y - x_{n1}) m_n$	4.0793	3.4793
19	Tooth depth	h	$\{2.25 + y - (x_{n1} + x_{n2})\} m_n$	6.6293	
20	Tip diameter	d_a	$d + 2h_a$	56.0466	90.0970
21	Root diameter	d_f	$d_a - 2h$	42.7880	76.8384

Table 1: The equations for a screw gear pair on nonparallel and nonintersecting axes in the normal system.