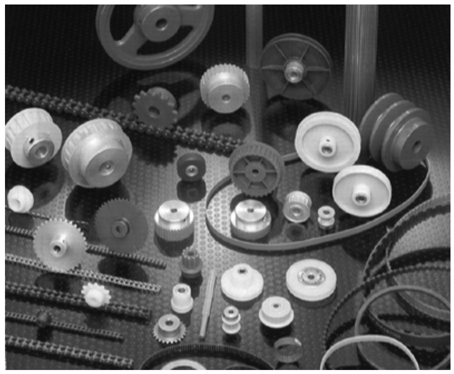
Machine Components: Power Transmission Elements



ME 72 Engineering Design Laboratory

Power Transmission Design Issues

- Power source (motor, engine, etc.)
- Power required (P = torque $\times$ velocity)
- Continuous or Intermittent Motion
- Operating conditions (start, load duration)
- Magnitude of speed (input or output)
- Speed modification (output to input, constant or variable, linear or rotary)

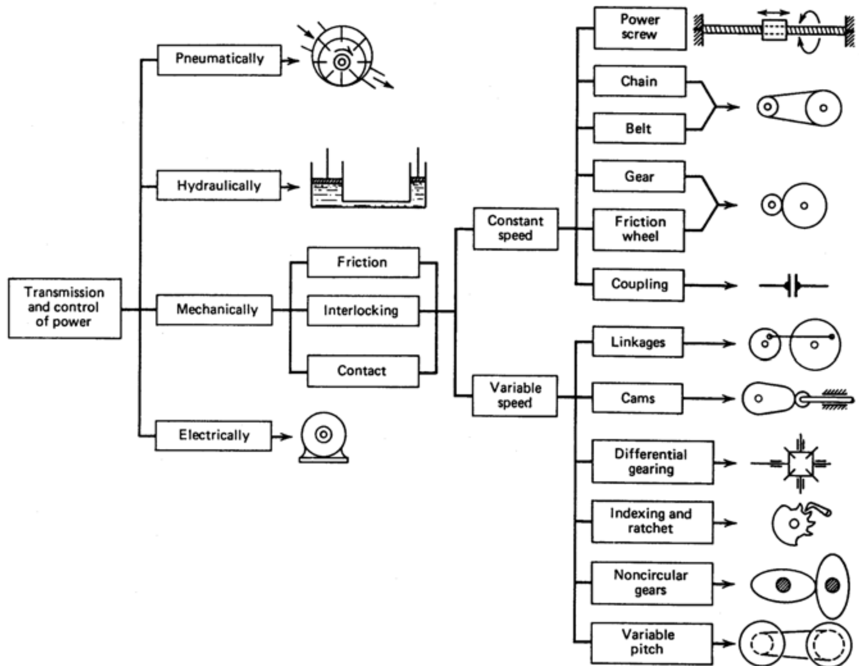
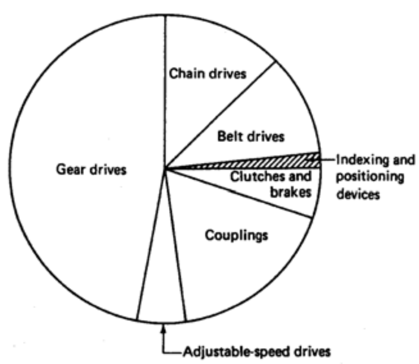


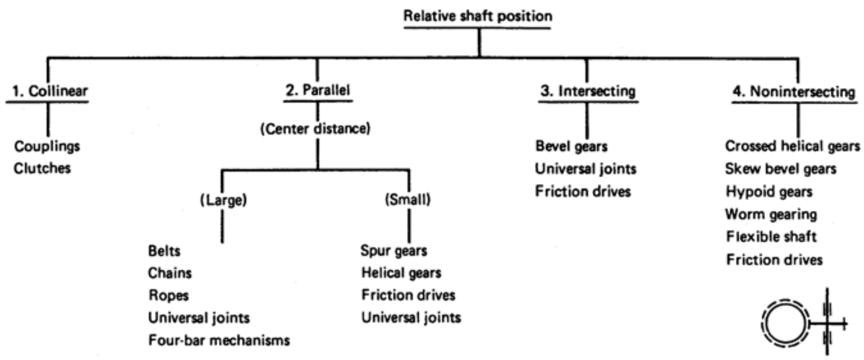
Figure 9-1 Principal means of power transmission. (Developed by Uffe Hindhede.)

Constant Speed Mechanical Transmission Elements

- Gears
- Friction wheels
- Power Screws
- Belts and Chains
- Wire Rope
- Couplings
- Clutches and Brakes



Relative Shaft Position



Relative Size

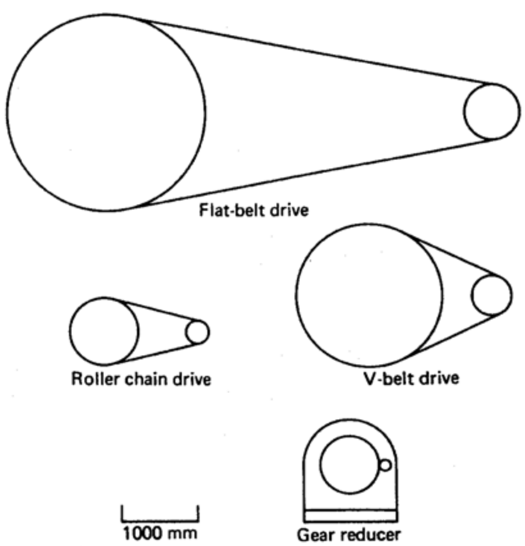


TABLE 9-1 Limits and Characteristics of Constant-Speed Drives

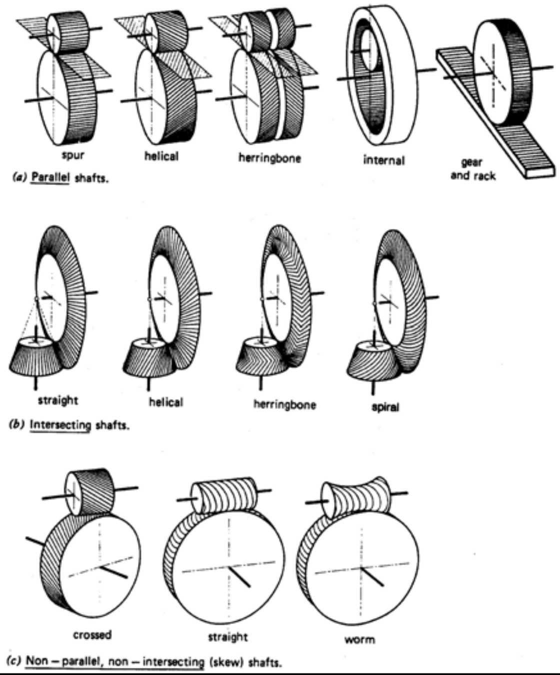
Type of Drive	Speed Ratio (one step)	Power (per mesh)	Maximum Speed	Peripheral Speed	Efficiency (including bearings)	Shaft Center Distance (a measure of space occupied)	Relative Shaft Position (reducer)	Mass Relative to Power	Initial Cost (spur gear =100%)	Noise Level	Life (relative)	Damping
Nomenclature rate, etc.	m_w	P, kW	n_{max}, rpm	v, m/s	e, %	C, m			%			
Straight Spur	<5	3,000		<50			Parallel			High	Average	
Parallel gear	<8			<100	99–97	0.1–0.63	Collinear	Average	100			Poor
helical drive	(20)*	(20,000)	100,000	(200)						Average	Long	
Straight Bevel	<8			<25	99–97	—				High	Average	
gear	<8	4,000	15,000	<50			Inter-	Small	150			Poor
Spiral drive	(15+)			(200)	99–97	—	secting			Average	Long	
Crossed helical gearing	<100	<8	25,000	<50	95–50	0.1–0.4	Non-parallel,	Very large:	100	Low	Moderate	Poor
Worm gearing	<60 (100)	<150 (1,000)	30,000	<70	97–50	0.05–0.5	Non-intersecting	Small	<100	Low	Short	Moderate
Friction wheel drive	6 (10)	20 (150)	10,000	<20	98–95	0.1–0.5	All positions	Average	50	Very low	Short	Moderate to good
Flat	5 (20)	300 (1,600)	18,000	<100	98–96	$(0.5–3)x(d_1+d_2)$	Arbitrary	Average	65	Low	Average	Moderate to good
V-type Belt drives	8 (40)	220 (1,100)	10,000	<60	97–95	$>1_i(2–3)$	Parallel	Average	65	Very low	Moderate	Good
Synchronous	8 (15)	200 (1,200)	5,000	<60	98–95	$>1_i(2–3)$	Parallel	Average	65	Low	Moderate	Good
Roller	<6	700						Average	85	High	Moderate	Poor
Chain	(14)	(4,000)	5,000	<17	97–95							
Silent drives	<8					0.3–3	Parallel	to large	125	Low	Average	Poor
	(12)	(900)		<30	99–97							

*( ) Refers to maximum value.

Source. Adapted from G. Reitor and K. Hohmann, *Grundlagen des Konstruieren*. Essen: Verlag W. Girardet, 1976.

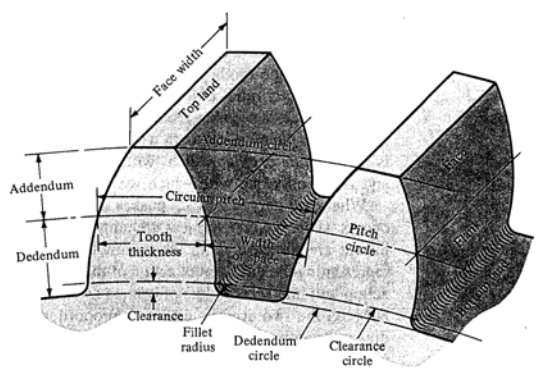
Gear Design Issues

- Types of Gears: spur, helical, herringbone, internal, rack, bevel, and worm
- Angular Velocity Ratio (gear ratio)
- Power Requirements (speed and torque)
- Gear Tooth Loads
- Gear Tooth Stresses



Gear Terminology

- Pitch Circle (radius or diameter)
- Circular Pitch
- Number of Teeth
- Pressure Angle
- Face Width



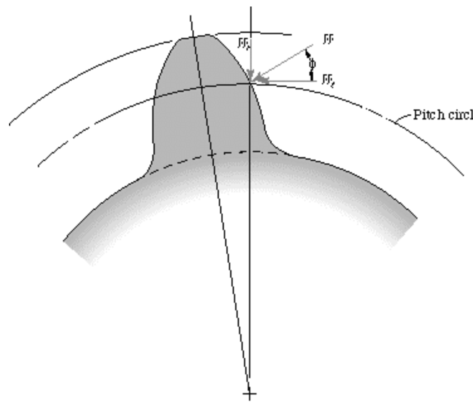
Spur Gears: Force Analysis

- W is the resultant force
- W_t and W_r are tangential and radial components
- d is the pitch diameter
- ϕ is the pressure angle
- τ is the applied torque

$$W_t = \frac{2\tau}{d}$$

$$W = \frac{W_t}{\cos\phi}$$

$$W_r = W_t \tan\phi$$



Helical Gears: Force Analysis

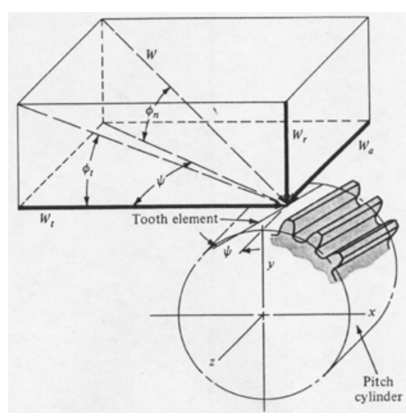
- W_t, W_r and W_a are tangential and radial and axial components
- ϕ_n is the normal pressure angle
- ϕ_t is the tangent pressure angle
- ψ is the helix angle

$$W_t = \frac{2\tau}{d}$$

$$W_r = W\sin\phi_n = W_t\tan\phi_t$$

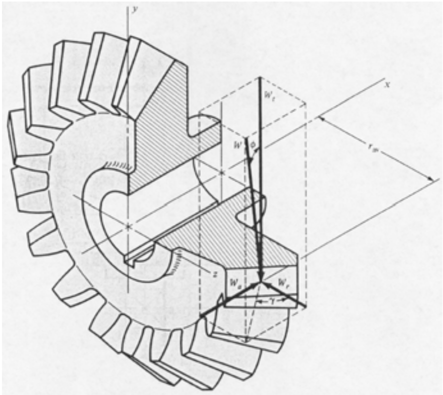
$$W_t = W\cos\phi_n\cos\psi$$

$$W_a = W\cos\phi_n\sin\psi = W_t\tan\psi$$



Bevel Gears: Force Analysis

- W_t, W_r and W_a are tangential and radial and axial components
- ϕ is the pressure angle
- γ is the bevel angle
- r_{av} is the average pitch radius



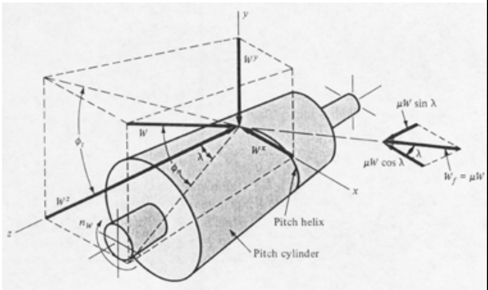
$$W_t = \frac{\tau}{r_{\mathrm{av}}}$$

$$W_r = W_t \tan\phi \cos\gamma$$

$$W_a = W_t \tan\phi \sin\gamma$$

Worm Gears: Force Analysis

- W_t, W_r and W_a are tangential and radial and axial components
- ϕ_n is the normal pressure angle
- λ is the worm lead angle
- d_{worm} is the pitch diameter of the worm



$$W_t = \frac{2\tau}{d_{\mathrm{worm}}}$$

$$W^x = W_t = W \cos\phi_n \sin\lambda$$

$$W^y = W_r = W \sin\phi_n$$

$$W^z = W_a = W \cos\phi_n \cos\lambda$$

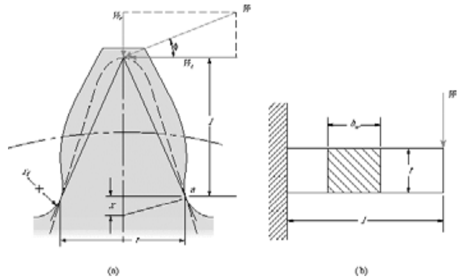
Stresses in Gears: Lewis Formula

$$\sigma_b = \frac{Mc}{I} = \frac{W_t l\left(\frac{t}{2}\right)}{\frac{b_w t^3}{12}} = \frac{6W_t l}{b_w t^2}$$

$$l = \frac{t^2}{4x}$$

$$\sigma_b = \frac{3W_t}{2b_w x} = \frac{3W_t p_d}{2b_w p_d x} = \frac{W_t p_d}{b_w Y}$$

$$Y = \frac{2p_d x}{3} = \text{Lewis Form Factor}$$



Stresses in Gears: AGMA Formula

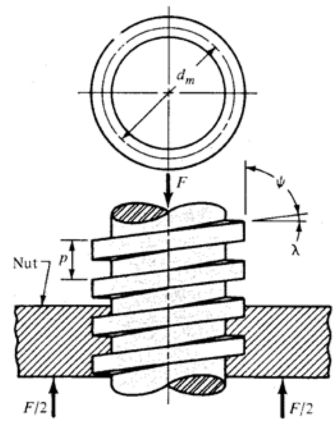
- Assumptions
  - Contact ratio is 1-2
  - No interference or undercutting
  - No pointed teeth
  - Nonzero backlash
  - Standard root fillets
  - Friction neglected

- σ_b=bending stress
- W_t=tangential force
- p_d = pitch diameter
- b_w=face width
- J=geometry factor
- K_a=application factor
- K_m= load distribution factor
- K_s=size factor
- K_v=dynamic factor

$$\sigma_b = \frac{W_t p_d}{b_w J} \frac{K_a K_m K_s}{K_v}$$

Power Screws

- Consists of a threaded shaft and nut
- Used to convert rotary to linear motion
- Can be designed for high precision
- Often have multiple threads
- Non backdrivable



Power Screw Force Balance

- Basic force balance

$$\sum F_x = F - \mu N \cos\lambda - N \sin\lambda = 0$$
$$F = N(\mu \cos\lambda + \sin\lambda)$$

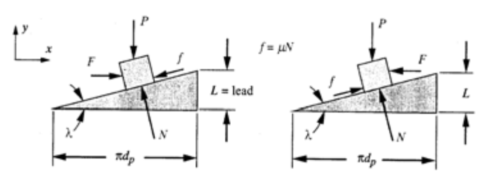
$$\sum F_y = N \cos\lambda - \mu N \sin\lambda = 0$$
$$N = \frac{P}{(\cos\lambda - \mu \sin\lambda)}$$

$$F = P\frac{(\mu \cos\lambda + \sin\lambda)}{(\cos\lambda - \mu \sin\lambda)}$$

$$T = \frac{Pd_p}{2}\frac{(\mu \cos\lambda + \sin\lambda)}{(\cos\lambda - \mu \sin\lambda)}$$

– Rewrite in terms of L using:

$$\tan\lambda = \frac{L}{\pi d_p}$$



(a) Lifting the load up the plane

(b) Lowering the load down the plane

$$T_{up} = \frac{Pd_p}{2}\frac{(\mu \pi d_p + L)}{(\pi d_p - \mu L)} \qquad T_{down} = \frac{Pd_p}{2}\frac{(\mu \pi d_p - L)}{(\pi d_p + \mu L)}$$

Belt Drives

- Belt drives are used when large distances between shafts make gears impractical or when designated speed is too high for chain drives.
- Belts are used with pulleys or sheaves to transmit power.
- Belts require tensioning, and are prone to slip under high loads.

Types of Belts

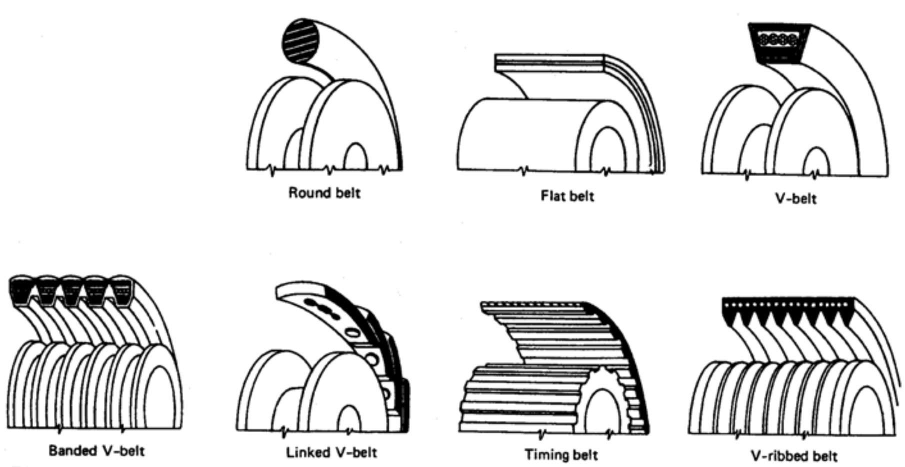
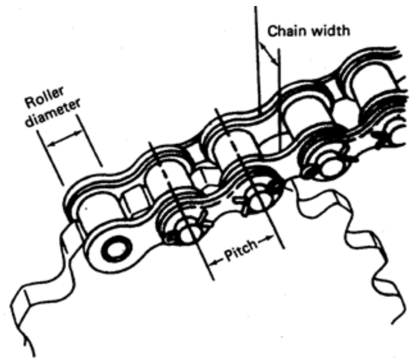


Figure 11-6 Types of belts. (Courtesy Deere and Company Technical Services.)

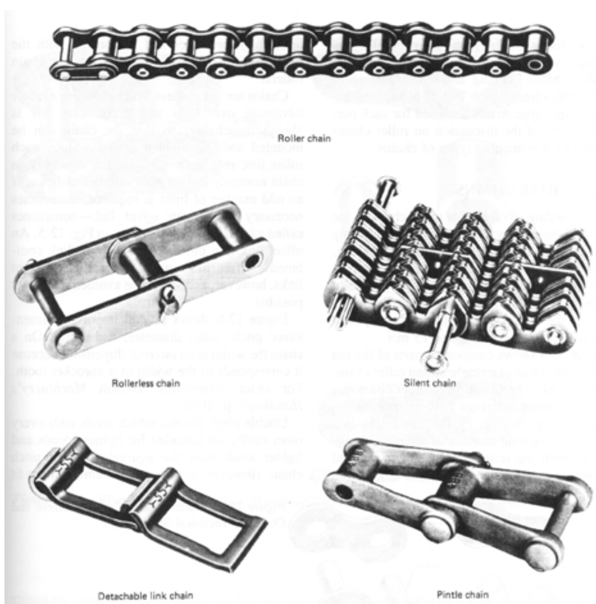
Chain Drives

- Chains transmit power through interlocking links wrapping on a sprocket.
- Chain drives have a high load capacity.
- They can be used to transmit power or impart timed linear motion.

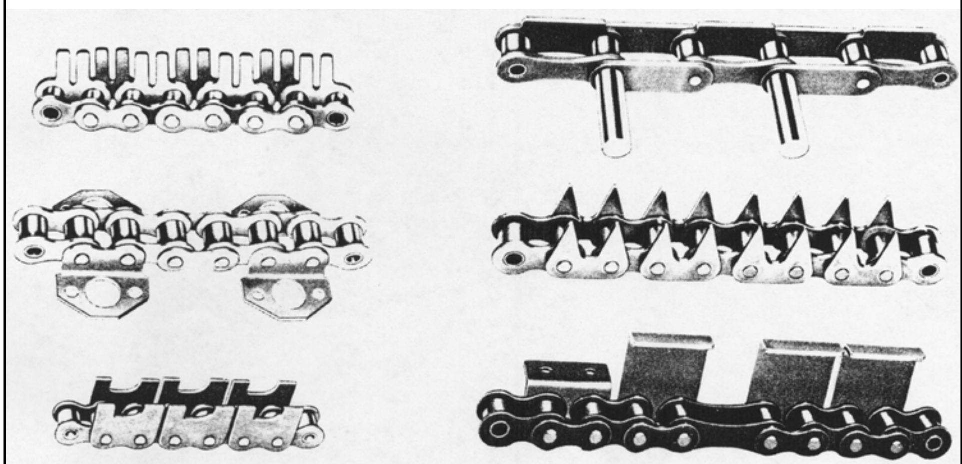


Standard or single pitch

Types of Chains



Chain Attachments



Belt/Chain Length

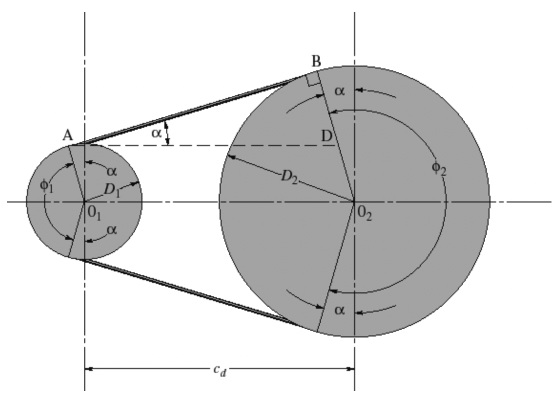
$$\overline{AB}^2 = c_d^{\,2} - \left(\tfrac{D_2 - D_1}{2}\right)^2$$

$$AB = \tfrac{1}{2}\sqrt{c_d^{\,2} - \left(D_2 - D_1\right)^2}$$

$$\phi_1 = \pi - 2\alpha$$

$$\phi_2 = \pi + 2\alpha$$

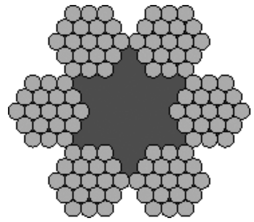
$$\alpha = \sin^{-1}\left(\tfrac{D_2 - D_1}{2c_d}\right)$$

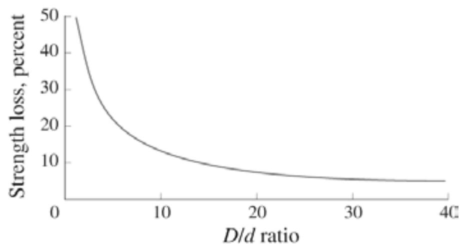


$$L = 2\overline{AB} + \tfrac{D_1}{2}\phi_1 + \tfrac{D_2}{2}\phi_2$$

Wire Rope

- Wire rope can also be used to transmit power.
- It is characterized by the number of bundles and wires/bundle.
- The critical design parameter is the pulley to rope diameter ratio.





Summary

- Gears transmit power between a variety of intersecting and non-intersecting shafts.
- Gear forces and tooth stresses are key design parameters for gear trains.
- Power screws convert rotary to linear motion and produce high forces from small torques.
- Belts and Chains transmit power through larger distances than gears.
- Wire rope (or cable) can provide backlash-free power transmission for a limited range of motion.

References

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- Shigley, J., and Mischke, C., *Mechanical Engineering Design*, 5th Ed., San Francisco: McGraw-Hill Inc., 1989.
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