Lesson 5: Mechanics for Motors and Generators

ET 332a

Dc Motors, Generators and Energy Conversion Devices

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Learning Objectives

After this presentation you will be able to:

- Explain how torque and speed is represented.
- Convert power, torque and speed units from SI to English Units
- Perform simple mechanical calculations.
- Identify common mechanical loads for electrical machines.

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Speed Definitions and Unit conversions

Angular speed (radians/second)

rad/sec used in calculations $\omega = \dfrac{d\theta}{dt}$

ω = angular speed (radians/sec)
θ = arc length (radians)

Standard for motors and generators
Revolutions per minute (RPM)

Conversions

$$n = \left(\frac{60}{2\pi}\right)\cdot\omega$$

rad/sec to RPM

$$\omega = \left(\frac{2\pi}{60}\right)\cdot n$$

RPM to rad/sec

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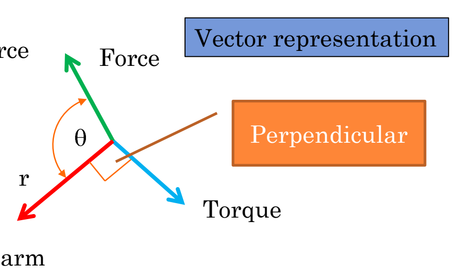
Force and torque

Torque –"twisting force
Units SI (N-m)
English (ft-lb)



Definitions

Torque =(applied force)·(perpendicular distance)

$$T = F\cdot(r\cdot\sin(\theta))$$

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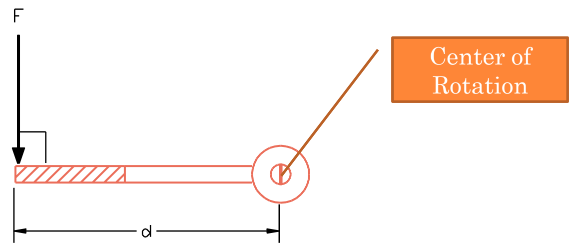
Force and Torque Example

Example: torque wrench



F = 20 N

d = 20 cm

$\theta = 90^{o}$

T = 20 N (0.2 m sin(90^{o})) = 4.0 N-m

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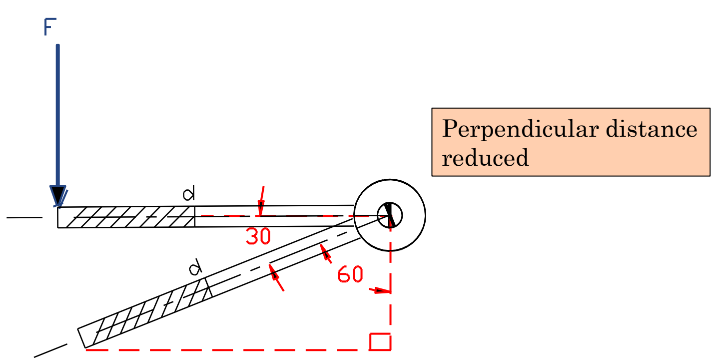
Force and Torque Example

Example: Non-perpendicular distance

$\theta = 60^{o}$



r sin(θ)

d = 20 cm   F = 20 N

T = F(r sin(θ)) = 20 N (0.2 m sin(60^{o})) = 3.46 N-m

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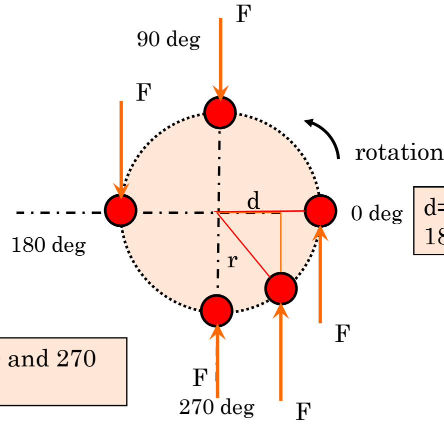
CIRCULAR MOTION AND TORQUE

Torque changes with position in circular motion



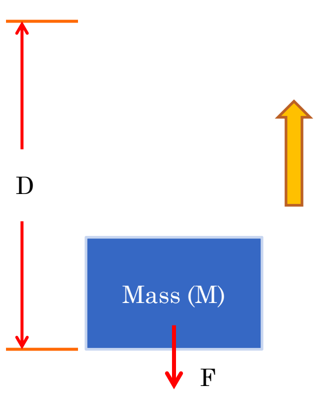
d=r and T = max at 0
180 deg θ = 90°

d =0 T = 0 at 90 and 270
deg θ = 0°

WORK AND POWER

Energy dissipates and work occurs when a force acts on a mass

Lifting a weight requires work
and dissipates energy



Work = (Force)(Distance) Linear Systems

W (Joules) = F (Newtons) X D (Meters)

Power is how fast work is done

Rate of energy consumption

Power = Work/Time

P (Watts) = W (Joules)/ t (seconds)

Force = (Mass)(Acceleration of gravity) = Weight

Work and Power in Rotating Systems

Work in rotating system

$W = T \cdot \theta$

T = torque (N-m)
θ = angular distance (m)

Power in rotating system

$P = T \cdot \omega$

P = power (Watts, W)
T = torque (N-m)
ω = angular speed (rad/sec)

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English-SI Unit Conversions

English Units		SI Units
Power = Horsepower (HP) Torque = (lb-ft)	→	Power = Watts or Kilowatts (W, kW) Torque = Newton-Meters (N-m)

Mechanical Power Conversion- Watts to Hp

Conversion factor: 1 hp = 746 watts

$$P\,(\text{hp}) = \frac{P\,(\text{W})}{746\ \text{W/hp}} \quad \text{Watts to hp}$$

$$P\,(\text{W}) = P\,(\text{hp}) \cdot 746\ \text{W/hp} \quad \text{hp to Watts}$$

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English-SI Unit Conversions

Power (HP) to Torque (lb-ft) in English Units

$$T = \frac{5252 \cdot P}{n}$$

Where: T = torque in lb-ft
P = power in horsepower (hp)
n = speed in rpm

Torque with mixed SI and English units

$$T = \frac{7.04 \cdot P}{n}$$

Where: T = torque in lb-ft
P = power in Watts
n = speed in rpm

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English-SI Unit Conversions

Torque in SI Units. Remember the definition of power…

$$P = T \cdot \omega$$

$$T = \frac{P}{\omega}$$

T = torque (N-m)
P = Watts (W)
ω = angular speed (radians/s)

Solve torque equations for speed

English Units $$n = \frac{P}{5252 \cdot T}$$

SI Units $$\omega = \frac{P}{T}$$

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UNIT CONVERSION EXAMPLES

Example 1: A motor develops 25 Hp at the shaft at a speed of 1750 rpm. Find the torque (N-m) developed and the power output in Watts

Make power unit conversion. HP=25 hp

$$P = 746\ \text{W/hp} \cdot HP = 746\ \text{W/hp} \cdot 25\ \text{hp} = \boxed{18{,}650\ \text{W}}$$

Find torque by converting n in rpm to ω in radians /second

$$\omega = \left(\frac{2\pi}{60}\right) \cdot 1750\ \text{rpm} = 183.17\ \text{rad/s}$$

$$T = \frac{P}{\omega} = \frac{18{,}650\ \text{W}}{183.17\ \text{rad/s}} = \boxed{101.8\ \text{N-m}}$$

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UNIT CONVERSION EXAMPLES

Example 2: A generator delivers 50 kW of power at 170 rad/s. What horsepower and torque (ft-lb) should the drive engine have.

Convert power in watts to hp. Remember 50 kW = 50,000 W

$$HP = \frac{P}{746\ \text{W/hp}} = \frac{50{,}000\ \text{W}}{746\ \text{W/hp}} = 67\ \text{hp}$$

$$T = \frac{7.04 \cdot 50{,}000\ \text{W}}{1624.2\ \text{rpm}} = 216.7\ \text{lb-ft}$$

$$T = \frac{5252 \cdot 67\ \text{hp}}{1624.7\ \text{rpm}} = 216.7\ \text{lb-ft}$$

To find torque in lb-ft, convert the speed into rpm

$$n = \omega \cdot \left(\frac{60}{2\pi}\right) = 170\ \text{rad/s} \cdot \left(\frac{60}{2\pi}\right) = 1624.2\ \text{rpm}$$

Now you can find torque with these two equations $T = \dfrac{7.04 \cdot P}{n}$ or $T = \dfrac{5252 \cdot P}{n}$

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Mechanics for Motors and Generators

Power is conserved in a lossless mechanical system.
(Need consistent units)

In a rotational motion system

$$P = T \cdot \omega$$

In a linear motion system

$$P = F \cdot v$$

Where: F = force in Newtons (N)
v = velocity in meters/second (m/s)
T = torque in N-m
ω = angular velocity (rad/s)

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Since power is conserved $T \cdot \omega = F \cdot v$

Mechanics for Motors and Generators

Example 3: A small electric locomotive develops 620 N-m of torque at 900 rpm as it moves at a speed of 15 mph. Determine the power, in horsepower, and Watts this requires. Also compute the force opposing the locomotive.

Compute rotational power

$$P = T \cdot \omega = 620\ \text{N-m} \cdot \left(\frac{2\pi}{60}\right) \cdot \left(900\ \text{rpm}\right)$$

$$P = \boxed{58{,}434\ \text{W}}$$

Convert to horsepower

$$HP = P \cdot \left(\frac{1\ \text{hp}}{746\ \text{W}}\right) = 58{,}434\ \text{W} \cdot \left(\frac{1\ \text{hp}}{746\ \text{W}}\right) = \boxed{78.3\ \text{hp}}$$

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Mechanics for Motors and Generators

Example 3 continued

Since power is conserved $P = T \cdot \omega = F \cdot v$

Convert velocity to m/s

$$v = (15\ \cancel{\text{mi}}/\cancel{\text{hr}}) \cdot \left(\frac{1609\ \text{m}}{1\ \cancel{\text{mi}}}\right) \cdot \left(\frac{1\ \cancel{\text{hr}}}{3600\ \text{s}}\right) = 6.704\ \text{m/s}$$

From previous calculations $P = 58{,}434\ \text{W}$

$$P = F \cdot v$$

$$F = \frac{P}{v} = \frac{58{,}434\ \text{W}}{6.704\ \text{m/s}} = \frac{58{,}434\ \text{N-m/s}}{6.704\ \text{m/s}} = \boxed{8716.3\ \text{N}}$$

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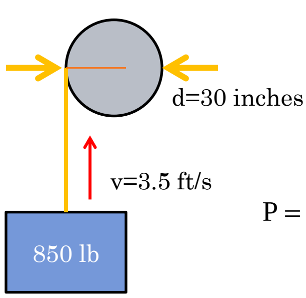
Mechanics for Motors and Generators

<u>Example 4:</u> An electric hoist lifts an 850 lb (force) at a speed of 3.5 ft/sec. The hoist drum has a diameter of 30 inches. Calculate the torque (lb-ft) and the speed of the motor performing this lift. What horsepower must the motor develop to make this lift?



Compute translational power

$$P = F \cdot v = (850\ \text{lb})(3.5\ \text{ft/s}) = 2975\ \text{lb-ft/s}$$

Convert this to horsepower using
1 hp = 550 lb-ft/s

$$P = (2975\ \text{lb-ft/s}) \cdot \left(\frac{1\ \text{hp}}{550\ \text{lb-ft/s}}\right) \boxed{= 5.409\ \text{hp}}$$

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MECHANICS FOR MOTORS AND GENERATORS

Example 4 continued

Remember the torque definition $T = F \cdot d$

Where d is distance to center of rotation (half the diameter)

$$d = \frac{30\ \text{in}}{2} = 15\ \text{in}$$

$$T = (350\ \text{lb})\left(\frac{15\text{in}}{12\ \text{in/ft}}\right) = \boxed{1062.5\text{lb-ft}}$$

Find the speed from $T = \frac{5252 \cdot P}{n}$ Solve this for n, speed in rpm

$$\frac{T}{5252 \cdot P} = \frac{1}{n} \Rightarrow \frac{5252 \cdot P}{T} = n \qquad \frac{5252 \cdot (5.409\ \text{hp})}{1062.5\ \text{lb-ft}} = n$$

$$\boxed{26.74\ \text{rpm} = n}$$

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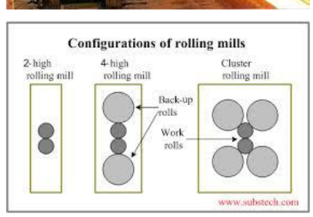
MECHANICAL LOADS FOR MOTORS

Constant Speed - motor must maintain constant speed over wide range of torque loading.

Examples: machine tools (lathes, Mills etc) rolling mills (steel production)



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Mechanical Loads for Motors

Constant Torque - motor works against constant force. Weight of load does not change.

Examples: Hoisting, conveyors

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Mechanical Loads for Motors

Constant Power - Mechanical characteristic of the load change (size, weight). Torque and speed change

Example: Winding operations (cable, wire)

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END LESSON 5: MECHANICS FOR MOTORS AND GENERATORS

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