Lesson 6: Mechanics for Motors and Generators

1

ET 332b Ac Motors, Generators and Power Systems

Lesson 6_et332b.pptx

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.
- Identify the operating point of a motor-load system

Lesson 6_et332b.pptx

2

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

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

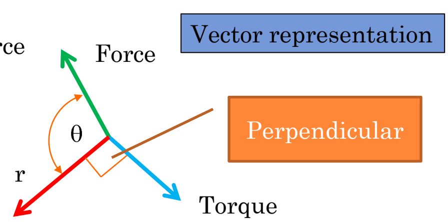
rad/sec to RPM

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

RPM to rad/sec

Force and torque

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



Lever arm

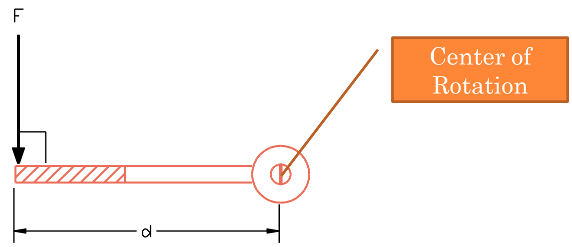
Definitions

Torque =(applied force)·(perpendicular distance)

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

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

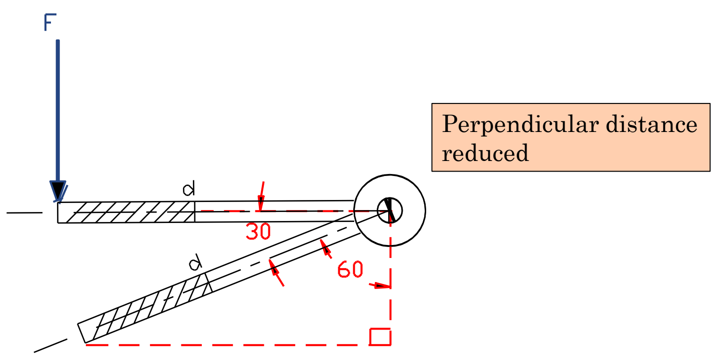
Lesson 6_et332b.pptx

5

Force and Torque Example

Example: Non-perpendicular distance

$\theta = 60^o$



r $\sin(\theta)$

d = 20 cm F = 20 N

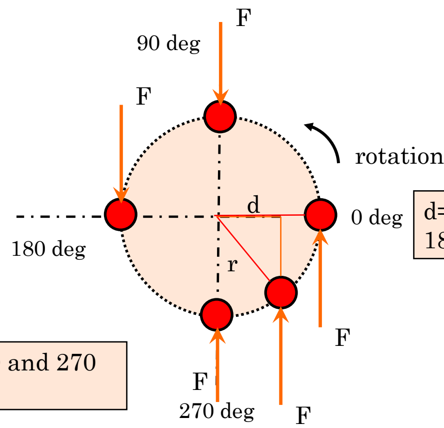
T = F(r $\sin(\theta)$) = 20 N (0.2 m $\sin(60^o)$) = 3.46 N-m

Lesson 6_et332b.pptx

6

Circular Motion and Torque

Torque changes with position in circular motion



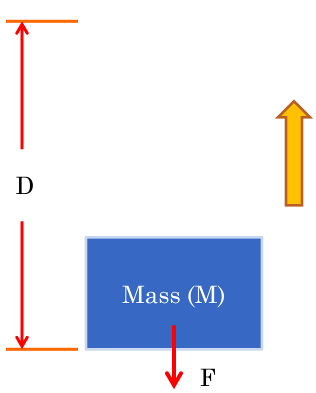
d=r and T = max at 0 180 deg θ = 90°

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)

English-SI Unit Conversions

English Units
Power = Horsepower (HP)
Torque = (lb-ft)

→

SI Units
Power = Watts or Kilowatts (W, kW)
Torque = Newton-Meters (N-m)

Mechanical Power Conversion- Watts to Hp

Conversion factor: 1 hp = 746 watts

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

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

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

Lesson 6_et332b.pptx

11

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

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

Lesson 6_et332b.pptx

12

Unit Conversion Examples

<u>Example 6-1:</u> 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

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

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

Lesson 6_et332b.pptx

13

Unit Conversion Examples

<u>Example 6-2:</u> 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

$$T = \frac{7.04 \cdot P}{n} \quad \text{or} \quad T = \frac{5252 \cdot P}{n}$$

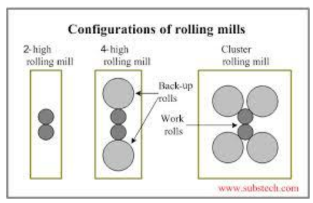
Lesson 6_et332b.pptx

14

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)



Mechanical Loads for Motors

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

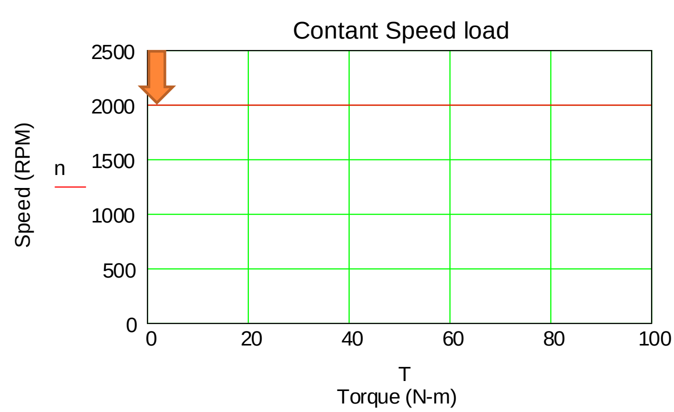
Examples: Hoisting, conveyors

Mechanical Loads for Motors

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

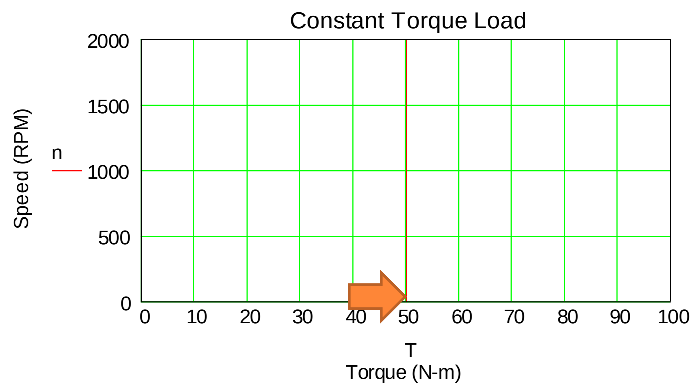
Example: Winding operations (cable, wire)

Load Type Plots-Constant Speed



Speed, n, remains constant over a wide range of torques

Load Type Plots-Constant Torque

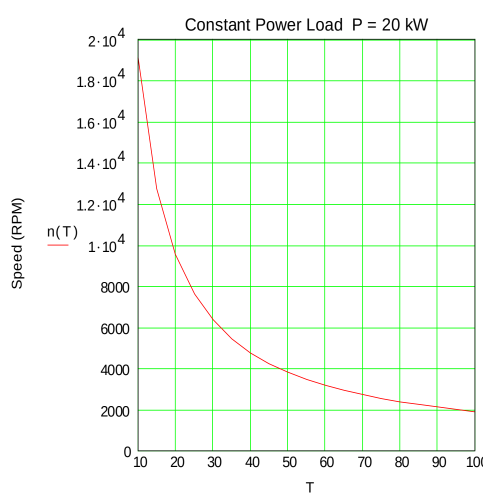


Toque, T, remains constant over a wide range of speeds

19

Lesson 6_et332b.pptx

Load Type Plots-Constant Power



Constant power load
P=20 kW

$$20{,}000 = T \cdot \left(\frac{2\pi}{60}\right) \cdot n$$

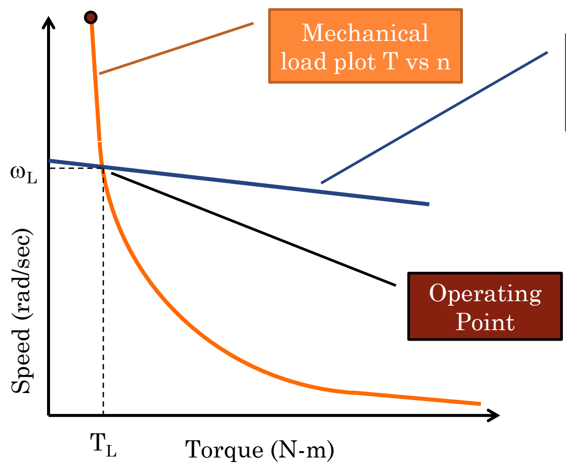
$$n(T) = \left(\frac{P}{T}\right) \cdot \left(\frac{2\pi}{60}\right) = \left(\frac{20{,}000}{T}\right) \cdot \left(\frac{2\pi}{60}\right)$$

20

Lesson 6_et332b.pptx

Motor-Load Operating Point

Motor only delivers the power a mechanical load requires to operate at a given speed.



$P_L = T_L \cdot \omega_L$ (Watts)

Where:

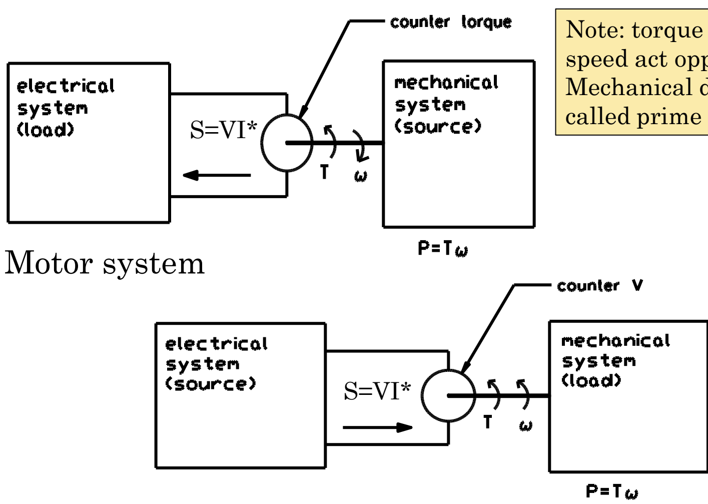
P_L = load power
T_L = load torque
ω_L = load speed

Lesson 6_et332b.pptx

21

Motor-Generator Systems

Alternator system



Note: torque and speed act opposite. Mechanical drive called prime mover

Lesson 6_et332b.pptx

22

Power Losses and Efficiency in Electromechanical Systems

$$\text{efficiency} = \left(\frac{\text{output power}}{\text{input power}}\right) \cdot 100\%$$

$$\eta = \left(\frac{P_0}{P_{in}}\right) \cdot 100\%$$

Must be in same units

For motors: P_o = mechanical power in HP
P_{in} = electric power in W

For Alternators/Generators:
P_o = electric power W
P_{in} = mechanical power

Mechanical power source for alternators/generators called prime mover (turbine (gas steam) diesel engine)

Lesson 6_et332b.pptx

23

Power Losses and Efficiency in Electromechanical Systems

For transformers input and output power are both electrical

$$\eta = \frac{P_0}{P_{in}} \cdot 100\,\%$$

$$P_{in} = P_0 + P_{losses}$$

Losses include: hysteresis
eddy currents
friction and windage
stray losses
field losses

Typical good efficiency 90-98% depends on device

Lesson 6_et332b.pptx

24

END LESSON 6: MECHANICS FOR MOTORS AND GENERATORS

ET 332b Ac Motors, Generators and Power Systems