Tribhuvan University
Institute of Engineering
Pulchowk Campus
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Unit: I- Introduction to Electric Drives

Class-02:
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Presented by
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Subject Name
EE: Modelling and Control of Electric Drives

Discussed in the Previous Class

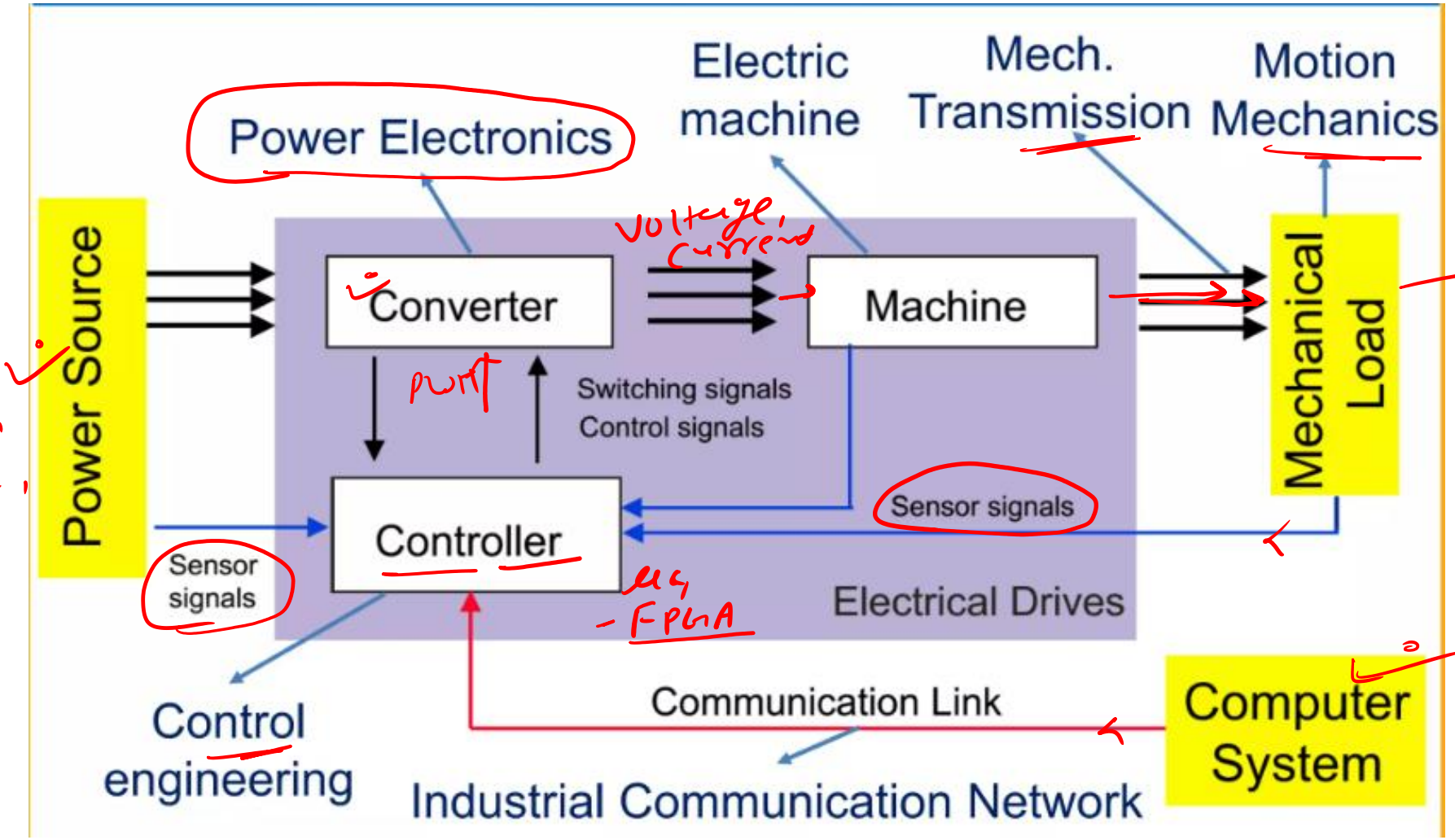
In the previous class discussed the following topics:

- Syllabus
- Course Evolution Scheme
- Introduction to Electrical Machines and Drives

Lecture Outcomes

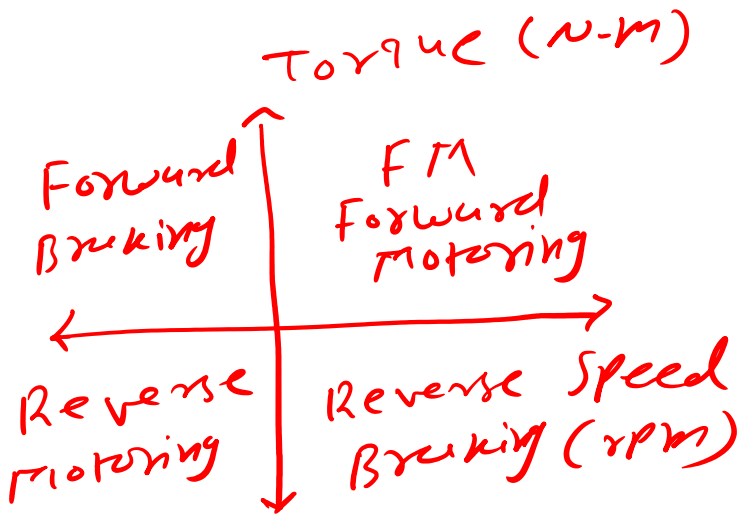
- Block Diagram of Electric Drives
- Classifications of Electric Drives
- Concepts and Elements of Electric Drives
- Torque-Speed Characteristics Curves
- Lecture remarks: Key points of today's class

Block Diagram of Electric Drive



Advantages of Electric Drive

- Very large range torque, speed, and power
- Free from pollution
- It can operate on all the quadrants of speed torque plane side
- Working is independent of the environment condition
- The efficiency of the drive is high
- No starting problem easily start so not require any refueling



Direction & Speed

FB, RB, FM, RM

Classifications of Electric Drives

- Adjustability of the speed: fixed, variable, servo
  - Fixed-speed drives
  - Variable-speed drives
  - Servo drives: positioning system
- Motor type and drive controller
  - DC drive
  - AC drive
- Motor Power
  - Small power, medium, large, very large power
- Motor rated data
- Controller rated data

Concepts and Elements of Electric Drives

Power Source:

- Alternative Current
  - Single phase or Multiphase
  - 50Hz or 60 Hz
- Direct Current:
  - Battery
  - Fuel Cell
  - Solar Cell

Concepts and Elements of Electric Drives

Power Processing Unit:

- Convert the fixed voltage/frequency inputs into outputs with appropriate forms (in frequency, amplitude, number of phase) that optimally suited the load requirements.

- Four types:
  - Controlled rectifiers (AC to DC converters)
  - DC choppers (DC to DC converters)
  - AC voltage controllers (AC to AC converters)
  - Inverters (DC to AC converters)

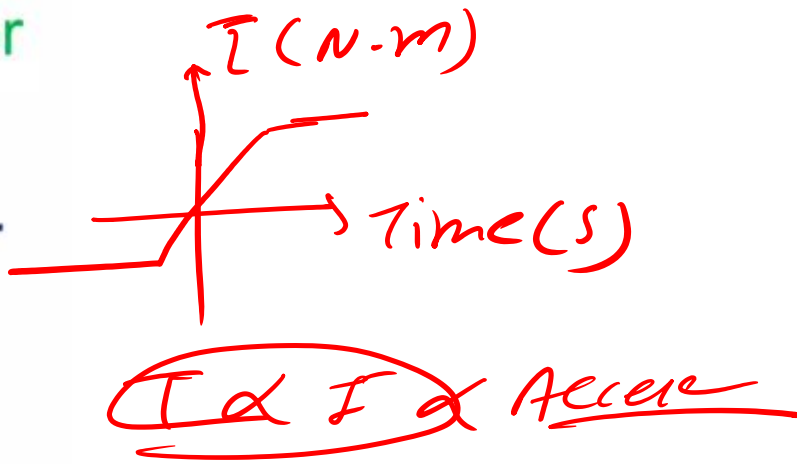
Concepts and Elements of Electric Drives

Controller

- Governing the load and motor characteristics and their interaction
- To match the load and motor through the power converter.

Concepts and Elements of Electric Drives

- Controller - Input
  - Torque, flux, speed, and/or position commands and their rate of variation
  - Measured torque, flux, speed, and/or position for feedback control
  - Limiting value of torque, currents, acceleration...
  - Temperature feedback and instantaneous currents and/or voltage in the motor and/or converter
  - The constant in the speed and position controller



Concepts and Elements of Electric Drives

- **Controller - Output**
  - Control signal for voltage magnitude: v_c
  - Control signal for determining frequency: f_c
  - Control signals for the bases/gates of the converters
  - Protection and other monitoring function
- **Controller - Realization**
  - Analog or integrated circuit
  - Microprocessor, single-chip μC, DSP, VLSI, FPGA ⇒ Clock frequency
  - Complex control algorithm can be implemented

$f = \frac{1}{Time}$

Concepts and Elements of Electric Drives

Mechanical Load

$$T_L = T_0 + C T_r \left(\frac{n}{n_r}\right)^k$$

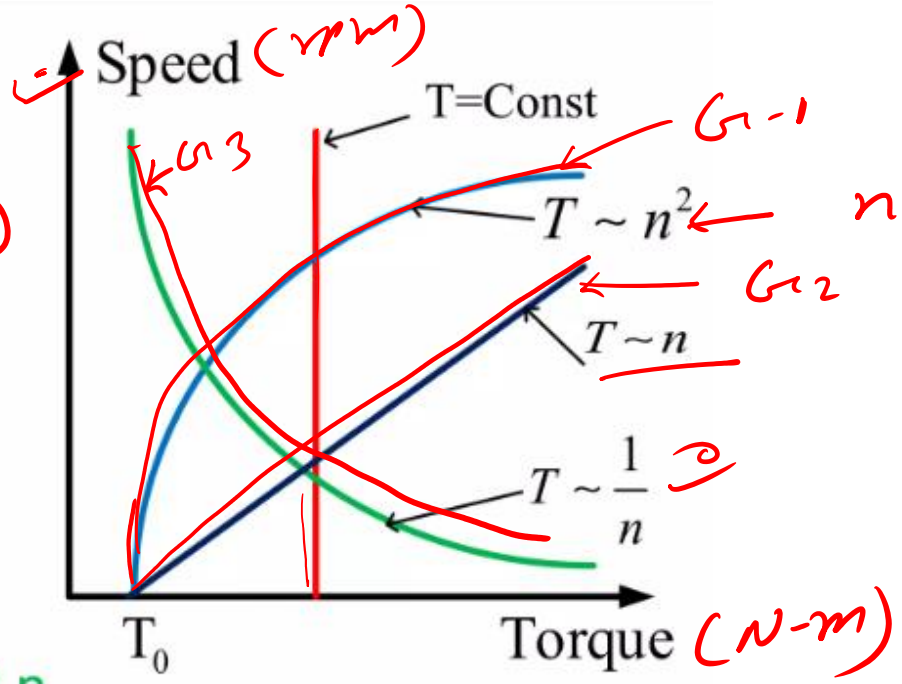
T_0: Load torque at zero speed

C: constant

T_r: load torque at the rated speed n_r

n: operating speed

k: exponential coefficient



n = speed (rps)

$T \propto n^2$

$T \propto n$

$T \propto \frac{1}{n}$

T = constant

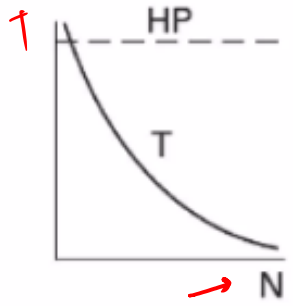
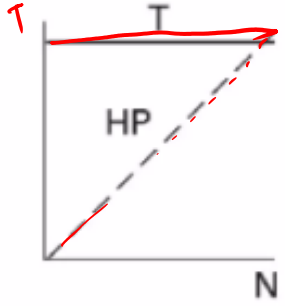
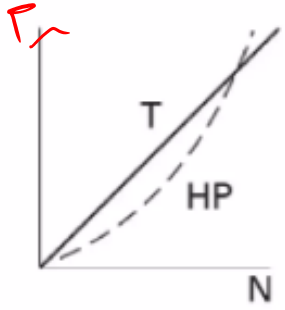
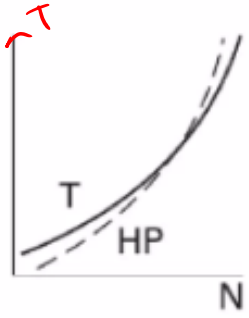
Speed vs Torque

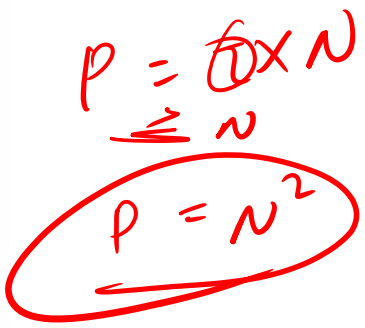
n = speed (rps)

N = speed (rpm)

Concepts and Elements of Electric Drives

Mechanical Load

$T \approx \frac{1}{N}$	$T = \text{Constant}$	$T \approx N$	$T \approx N^2$
$HP = \text{Constant}$	$HP \approx N$	$HP \approx N^2$	$HP \approx N^3$
			
Winders Facing lathes Rotary cutting machines	Hoisting gear Belt conveyors Process machines involving forming Rolling mills Planers	Calenders with viscous friction Eddy-current brakes	Pumps Fans Centrifuges



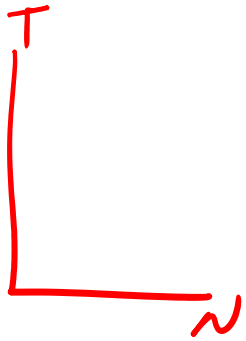
Concepts and Elements of Electric Drives

- **Active load torque:**
  - Always effect on the motor shaft, even when the system is in static state.
  - Direction remain unchanged.
  - Example: potential energy load, load caused by compressive forces, elastic forces ...
- **Passive load torque:**
  - Counteract the movement of systems.
  - Reverse direction of the rotating speed.
  - Example: friction loads, load of cutting machines

Torque-Speed Characteristics Curves

❖ Definition:

- Load's TSC: the relationship between torque and speed of a load.
- Motor's TSC: the relationship between torque and speed of a motor.
- The natural TSC: the motor torque-speed curve when it is working in nominal/rated condition.
- The controlled TSCs: achieved by adjusting one or several electrical input parameters: each motor has a family of curve



$T \propto I$

$N \propto V$

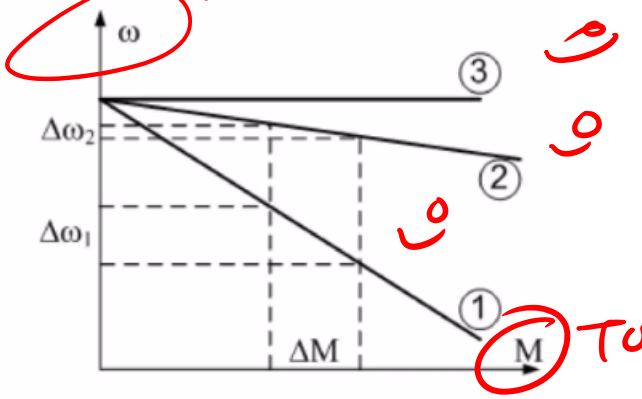
Torque-Speed Characteristics Curves

- The hardness of the TSC

$$\beta = \frac{\partial T}{\partial \omega} \approx \frac{\Delta T}{\Delta \omega}$$

- Range of speed control

$$D = \frac{\omega_{max}}{\omega_{min}}$$



- Smoothness of speed control

$$\gamma = \frac{\omega_{i+1}}{\omega_i}$$

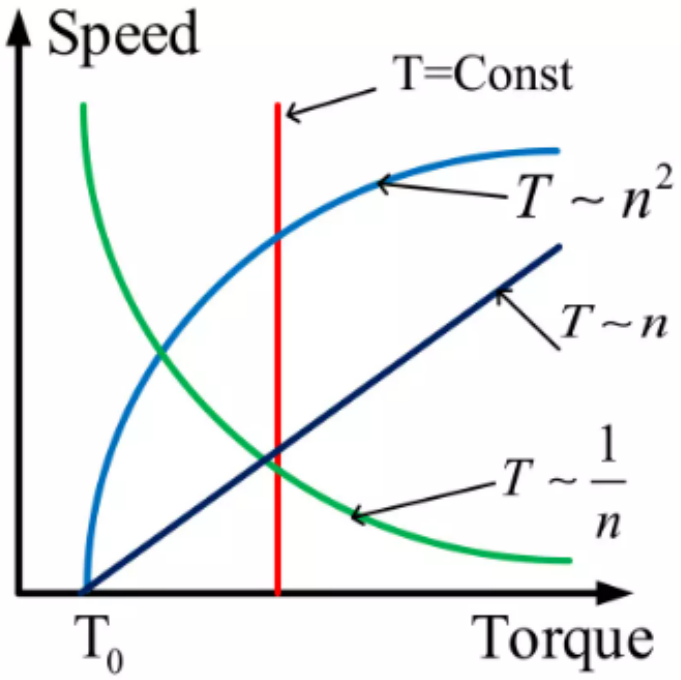
i = Time interval
ω = speed rad/sec

i = time instant
i = 5 sec ⇒ 1000 rpm
i = 10 sec ⇒ 1500 rpm

Torque-Speed Characteristics Curves

❖Mechanical Load

$$T_L = T_0 + CT_r\left(\frac{n}{n_r}\right)^k$$



T_0: Load torque at zero speed
C: constant
T_r: load torque at the rated speed n_r
n: operating speed
k: exponential coefficient

Torque-Speed Characteristics Curves

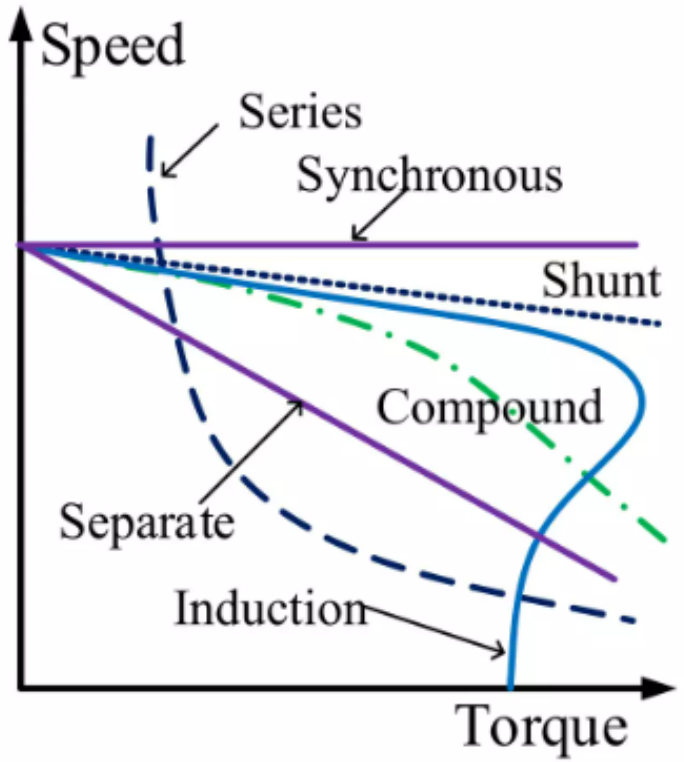
❖ Another way to express the load torque:

$$T_L = T_R + B\omega + C\omega^2$$

- T_R: constant torque
- $B\omega$: Viscous friction torque
- $C\omega^2$: Aerodynamic drag torque

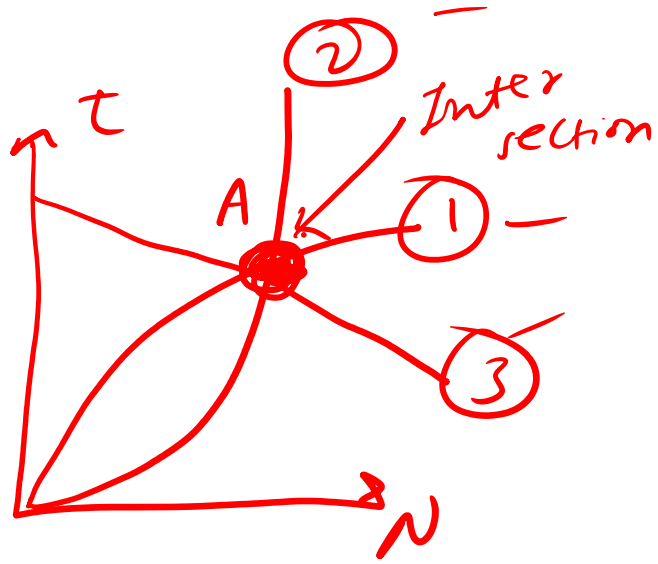
Torque-Speed Characteristics Curves

- Motor TSC
  - Series DC Motor
  - Separate DC Motor
  - Shunt DC Motor
  - Compound DC Motor
  - Induction AC Motor



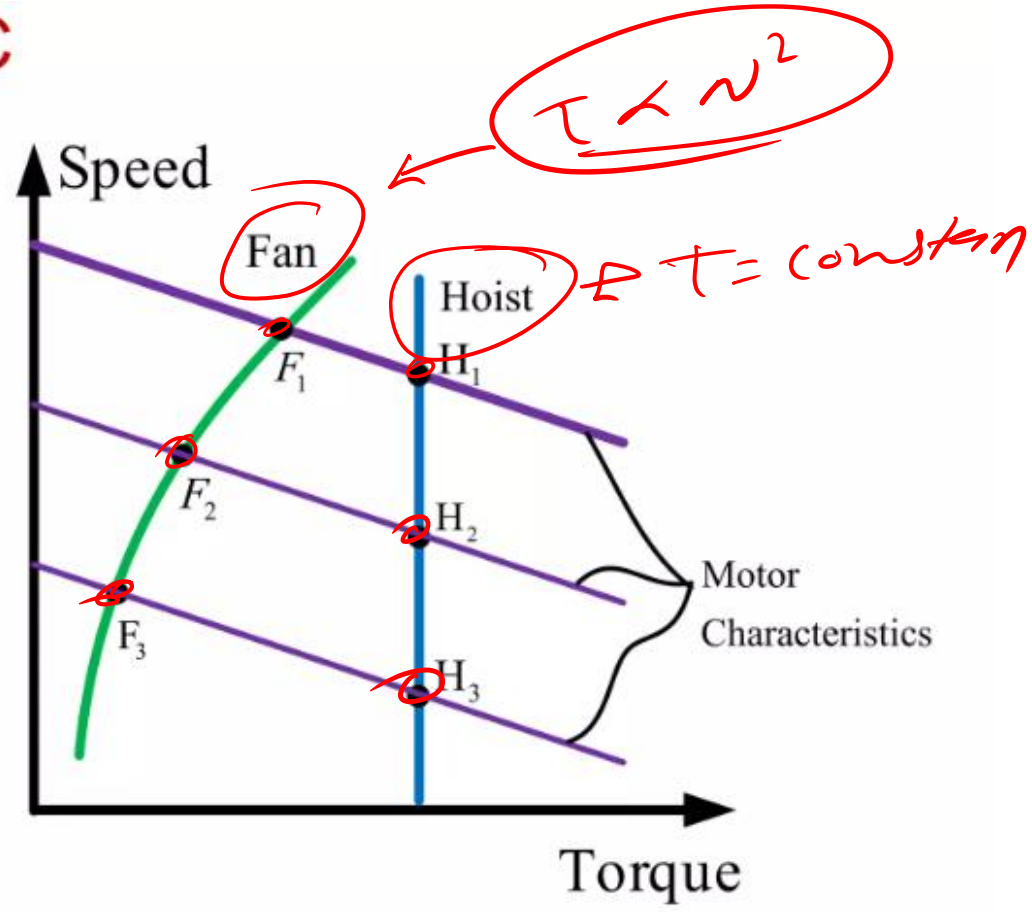
Torque-Speed Characteristics Curves

- Joint TSC Characteristic
  - Loads have a wide range of speed-torque characteristics
  - Electric motors exhibit variety of speed-torque characteristic curves
  - Equilibrium point: the intersection of the two curves
  - The speed of the system is not determined by the motor only, but is also heavily depended on the mechanical load characteristics.



Torque-Speed Characteristics Curves

❖ Joint TSC



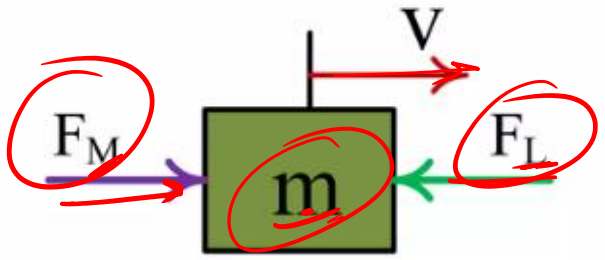
Motion Dynamics

Linear Motion		Rotational Motion	
Position	x	θ	Angular position
Velocity	v	ω	Angular velocity
Acceleration	a	α	Angular acceleration
Motion equations	$x = \bar{v}t$	$\theta = \bar{\omega}t$	Motion equations
	$v = v_0 + at$	$\omega = \omega_0 + \alpha t$	
	$x = v_0 t + \frac{1}{2}at^2$	$\theta = \omega_0 t + \frac{1}{2}\alpha t^2$	
	$v^2 = v_0^2 + 2ax$	$\omega^2 = \omega_0^2 + 2\alpha\theta$	
Mass (linear inertia)	m	I or J	Moment of inertia
Newton's second law	$F = ma$	$\tau = I\alpha$	Newton's second law
Momentum	$p = mv$	$L = I\omega$	Angular momentum
Work	Fd	$\tau\theta$	Work
Kinetic energy	$\frac{1}{2}mv^2$	$\frac{1}{2}I\omega^2$	Kinetic energy
Power	Fv	$\tau\omega$	Power

Important Formulas

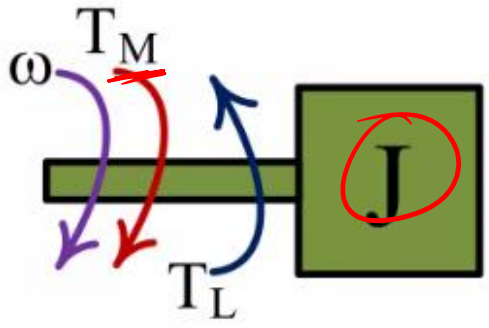
Motion Dynamics

❖Rotational and Linear Motion Relationship



$$\sum F = \frac{d(mv)}{dt}$$

$$F_M - F_L = \frac{d(mv)}{dt}$$

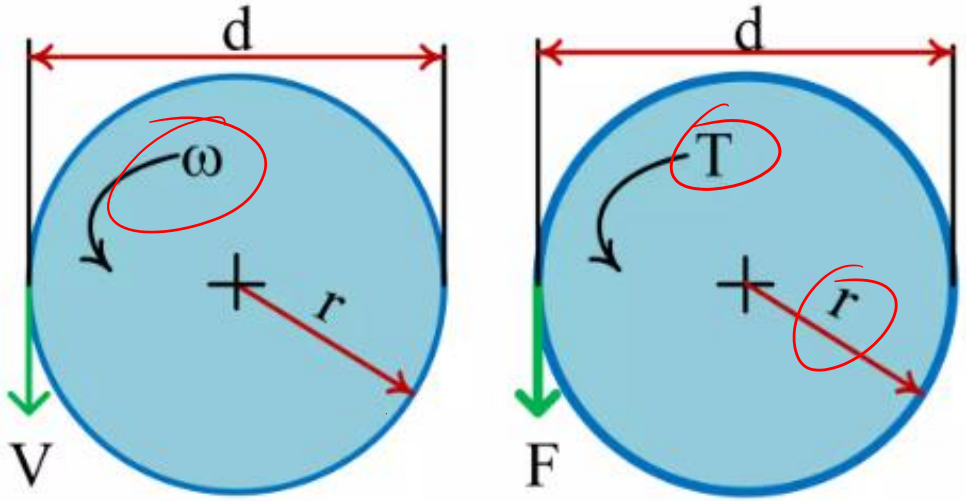


$$\sum T = \frac{d(J\omega)}{dt}$$

$$T_M - T_L = \frac{d(J\omega)}{dt}$$

Motion Dynamics

❖Rotational and Linear Motion Relationship



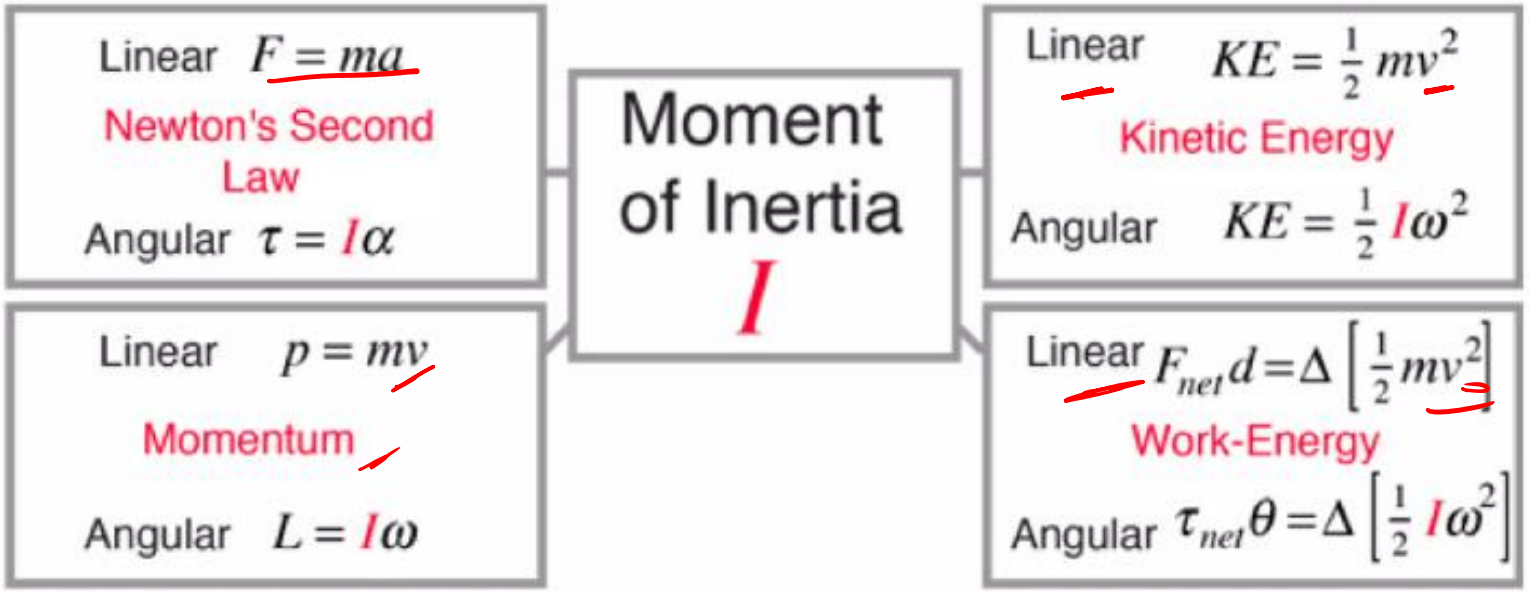
$$V = r \bullet \omega \qquad T = r \bullet F$$

Motion Dynamics

❖Moment of Inertia

- Inertia is the resistance of an object to be accelerated, or decelerated
- Moment of inertia is the name given to rotational inertia, the rotational analog of mass for linear motion

$J = kg \cdot m^2$



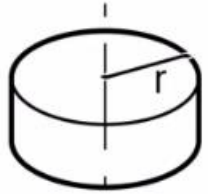
Motion Dynamics

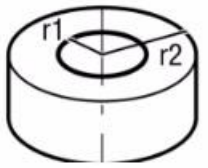
❖Moment of Inertia

– Centre of gravity: $J = m * r^2$

– Solid cylinder: $J = \frac{1}{2} m * r^2$

– Hollow cylinder: $J = \frac{1}{2} m(r_2^2 + r_1^2)$





❖A mass in linear motion

– Transformed to a rotating motion

$$J = m\left(\frac{v}{\omega}\right)^2$$

J in kg.m^2; m in kg; r in m; v in m/s; ω in rad/s

Key Points from Today's Class

- Block Diagram of Electric Drives
- Classifications of Electric Drives
- Concepts and Elements of Electric Drives
- Torque-Speed Characteristics Curves

Thank you so much for your attentions

Q & A