# Unit: I- Introduction to Electric Drives

Class-04:
4th January 2024

Presented by
**Dr. Rajesh M. Pindoriya**
rajeshpindoriya@ieee.org
Website: rmpindoriya.weebly.com

Subject Name
**EE: Modelling and Control of Electric Drives**

# Discussed in the Previous Class

In the previous class discussed the following topics:

- ❖ Fundamental Torque Equation of Electric Drives
- ❖ Four-quadrant Operation of drive
- ❖ Equivalent Values of Drive Parameters

# Lecture Outcomes

- Components of Load Torque
- Classifications of Load Torque
- Lecture remarks: Key points of today's class

# Components of Load Torque

Components of Load Torques $T_l$ can be further divided into the following components:

**(i) Friction torque ($T_F$)**

**(ii) Windage torque, ($T_w$)**

**(iii) Torque required to do the useful mechanical work ($T_L$)**

# Components of Load Torque

**(i) Friction torque ($T_F$):**

- Friction will be present at the motor shaft and also in various parts of the load.
- $T_F$ is the equivalent value of various friction torques referred to by the motor shaft.

**(ii) Windage torque, ($T_w$):**

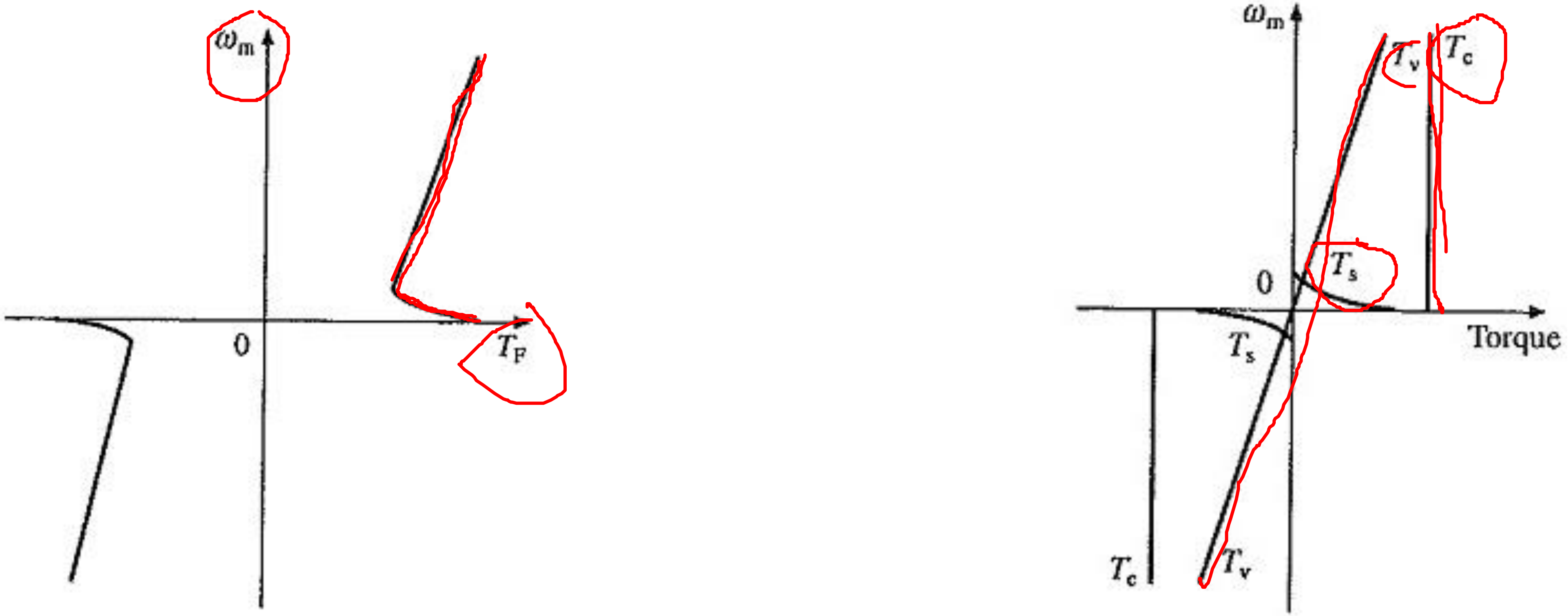
When a motor runs, wind generates a torque opposing the motion. This is known as windage torque.

# Components of Load Torque

## (iii) Torque required to do the useful mechanical work ($T_L$)

- The nature of these Components of Load Torques depends on the particular application.
- It may be constant and independent of speed;
- It may be some function of speed;
- It may depend on the position or path followed by the load;
- It may be time-invariant or time-variant;
- It may vary cyclically and its nature may also change with the load’s mode of operation.

# Components of Load Torque




(a) (b)

Fig. 1. Friction torque and its components.

# Components of Load Torque

- Variation of friction torque with speed is shown in Fig. 1 (a).
- Its value at a standstill is much higher than its value slightly above zero speed.
- Friction at zero speed is called stiction or static friction. The motor torque should at least exceed stiction for a drive to start. Friction torque can be resolved into three components (see Fig. 1 (b)).
- Component $T_v$ which varies linearly with speed is called viscous friction and is given by (1):

$$T_v = B\omega_m \tag{1}$$

where $B$ is the viscous friction coefficient.

# Components of Load Torque

- Another component $T_c$, which is independent of speed, is known as Coulomb friction.
- Third component $T_s$ accounts for additional torque present at a standstill.
- Since $T_s$ is present only at standstill it is not taken into account in the dynamic analysis.
- Windage torque $T_w$, which is proportional to speed squared, is given by

$$T_w = C\omega_m^2 \qquad (2)$$

where $C$ is a constant.

# Components of Load Torque

From the above discussion, for finite speeds,

$$T_l = T_L + B\omega_m + T_c + C\omega_m^2 \qquad (3)$$

- In many applications $(T_c + C\omega^2{}_m)$ is very small compared to $B\omega_m$ and negligible compared to $T_L$.
- In order to simplify the analysis, term $(T_c + C\omega^2{}_m)$ is approximately accounted for by updating the value of viscous friction coefficient, B. With this approximation, from fundamental torque equation

$$T = J\frac{d\omega_m}{dt} + T_L + B\omega_m \qquad (4)$$

# Components of Load Torque

- If there is a torsional elasticity in shaft coupling the load to the motor, an additional Components of Load Torques, known as **Coupling Torque**, will be present.

- Coupling torque ($T_e$) is given by

$$T_e = K_e \Theta_e \qquad (5)$$

where $\theta_e$ is the torsion angle of coupling (radians) and $K_e$ the rotational stiffness of the shaft (N-m/rad).

# Components of Load Torque

- In most applications, shaft can be assumed to be perfectly stiff and coupling torque $T_e$ can be neglected. Its presence in appreciable magnitude has adverse effects on motor.

- There is potential energy associated with coupling torque and kinetic energy with the dynamic torque.

- Exchange of energy between these two energy storages tends to produce oscillations which are damped by viscous friction torque $B\omega_m$.

- When B is small, oscillations occur producing noise. Further, shaft may also break when the drive is started.

# Classification of Load Torques

# Classification of Load Torques

Classification of Load Torques can be broadly classified into two categories-

**1.Active**

**2.Passive**

- Load torques that have the potential to drive the motor under equilibrium conditions are called **Active Load Torques**. Such load torques usually retain their sign when the direction of the drive rotation is changed. Torque(s) due to gravitational force, tension, compression, and torsion, undergone by an elastic body, come under this category.
- Load torques that always oppose the motion and change their sign on the reversal of motion are called **Passive Load Torques**. Such torques are due to friction, windage, cutting etc.

# Classification of Load Torques

- As we know already, the nature of Classification of Load Torques depends on particular application.

- A low-speed hoist is an example of a load where the torque is constant and independent of the speed.

- At low speeds, windage torque is negligible.

- Therefore, net torque is mainly due to gravity which is constant and independent of speed. There are drives where coulomb friction dominates over other torque components. Consequently, torque is independent of speed, e.g. paper mill drive.

# Classification of Load Torques

- Fans, compressors, airplanes, centrifugal pumps, ship-propellors, coilers, high-speed hoists, traction, etc. are examples of cases where load torque is a function of speed.

- In fans, compressors, and airplanes, windage dominates, consequently, load torque is proportional to speed squared

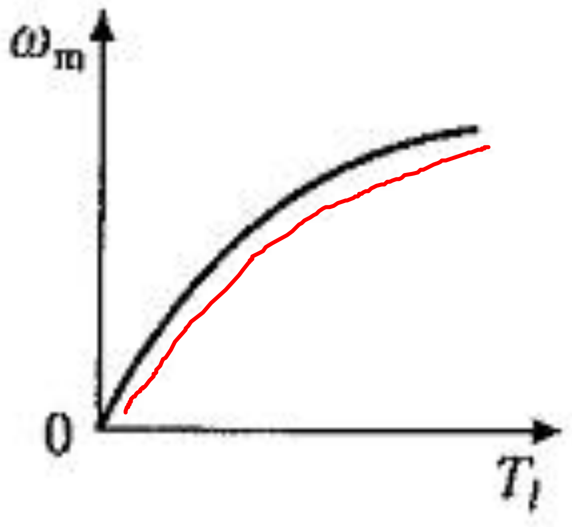



Fig. 2. $T_l \propto \omega_m^2$

# Classification of Load Torques

- Windage is the opposition offered by air to the motion. A similar nature of the Classification of Load Torques can be expected when the motion is opposed by any other fluid, e.g. by water in centrifugal pumps and ship-propellors, giving the same characteristic as shown in Fig. 3.

- In a high-speed hoist, viscous friction, and windage also have appreciable magnitude, in addition to gravity, thus giving the speed-torque curve of Fig. 3.

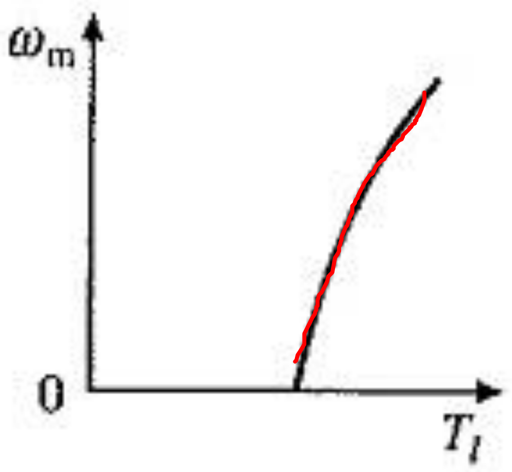



Fig. 3. High speed hoist.

# Classification of Load Torques

- The nature of the speed-torque characteristic of a traction load when moving on a leveled ground is shown in Fig. 4.

- Because of its heavy mass, the stiction is large.

- Near zero speed, net torque is mainly due to stiction.

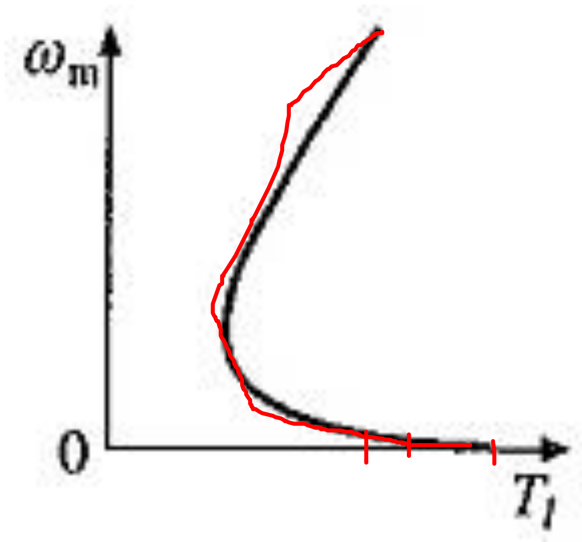



Fig. 4. Traction load.

# Classification of Load Torques

- The stiction however disappears at a finite speed and then windage and viscous friction dominate.

- Because of the large stiction and need for accelerating a heavy mass, the motor torque required for starting a train is much larger than what is required to run it at full speed.

- Torque in a coiler drive is also a function of speed. It is approximately hyperbolic in nature as shown in Fig. 5. The developed power is nearly constant at all speeds.

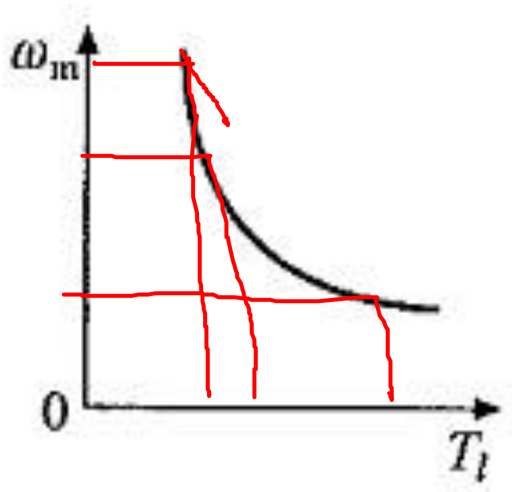



Fig. 5. Constant power load.

# Key Points from Today's Class

- Components of Load Torque
- Classifications of Load Torque

# Key Points from Next Class

In the next class, we will be discussing on the

❖ Time and Energy Loss in Transient Operations

❖ Steady State Stability of an Electric Drive System

Thank you so much for your attentions

Q & A