**Unit II**

Drive motor characteristics

Dynamics of load system

Fundamental torque equation

A motor generally drives a load through some transmission system, while motor always rotates, the load may rotate and may undergo a translational motion.

![Diagram: Motor and Load](image)

Various notation used are

- \( J \): Polar moment of inertia motor/load
- \( \omega_m \): Angular velocity of motor
- \( T \): Developed motor torque
- \( T_l \): Load torque referred to motor
\[ T - T_L = \frac{d}{dt} (J\omega_m) \]

\[ = J \frac{d\omega_m}{dt} + \omega_m \frac{dJ}{dt} \quad (1) \]

Equation (1) is applicable to variable inertia drives such as mine winders.

For drives, industrial robots.

Constant inertia:

\[ \frac{dJ}{dt} = 0 \]

\[ T - T_L = J \frac{d\omega_m}{dt} \quad (2) \]

Equation (2) shows the torque developed by the motor is counterbalanced by a load torque \( T_L \).
Classification of load torque

1. Active load torque
2. Passive load torque

Load torque which has potential to drive the motor under equilibrium conditions are called active load torque.

Load torque which is always opposed to the motion are called passive load torque.

Component of load torque

Friction torque
Friction will be present at the motor shaft.

Windage torque
When a motor runs the wind generates a torque opposing the motion.
Multi-quadrant operation

For consideration of multi-quadrant operation of drives, it is useful to establish suitable convention about the sign of torque and speed.

Motors operate in two modes: motoring and braking.

**Motoring**: It converts electrical energy to mechanical energy, which supports the motion.

**Braking**: It works as a generator. It converts mechanical energy to electrical energy, opposite to motion.

Motors can provide motoring & braking operation for both forward & reverse directions.

Power developed by a motor is given by $P = \text{torque} \times \text{speed}$. 

[Diagram showing multi-quadrant operation with quadrants labeled.]
In quadrant I

In developed power is positive, machine works as a motor, supply mechanical energy, so called as forward motoring.

Quadrant II

Power is negative, hence machine works under braking opposing the motion, forward braking.

Ⅲ and Ⅳ can be identified reverse motoring & braking respectively.
Forward direction of motor speed will be one which gives upward motion of cage.

10. Load torque like TL in quadrant I & IV deficiency
    Speed-torque characteristics of loaded hoist. The torque is difference
    of torque due to loaded hoist and counter weight.

11. Load torque TL is constant

   Speed-torque characteristics of empty hoist & counter weight. Its sign is negative
   because the counter weight is always higher
   than that of empty cage

   In quadrant I empty
   case ⇒ moment is upwarded
   motor speed is ccw direction
   motor produce + torque is equal to load torque
   developed torque is TN [forward
   motoring]

   In quadrant IV

   weight of loaded cage is higher than that of
   counter weight. It come down due to gravity

   in order to limit the speed, with safe hoist
   +ve torque TL canary to TL in
   anti clockwise direction.
II

**Quadrant II**

When empty case is moved up, the motor must produce a breaking torque.

**Speed** = \( -V_C \) (forward braking)

III

**Quadrant III**

When empty case is lowered, the motor should produce a force in the reverse direction.

**Speed** = \( -V_C \) (reverse motoring)
Characteristics at different types of load

Different types of load exhibit different speed-torque characteristics.

Most industrial loads are classified into the following four sensor categories:

(i) Constant torque type load
(ii) Generator type load
(iii) Fan type load
(iv) Constant power type load

- For most of modern machines & common constant torque integrative of speed.
- For most of modern machines & common constant torque integrative of speed.
Generator type load

(Generally for speed)

Separately excited dc generator connected to a constant resistance load. Tddy current braking
and cycling machines have speed-torque
Given by \( T = k \omega \).

\[ \begin{align*}
\omega^I & \quad TL \\
T & \quad \rightarrow \omega
\end{align*} \]

Speed-torque curve of generator type load.

Fan type load

Another type of load met in practice
is the one in which load torque is
proportional to square of speed.

Ex: fan, rotary pumps

\[ \begin{align*}
\omega^I & \quad TL \\
\frac{T \omega^2}{T = k \omega^2} & \quad \rightarrow
\end{align*} \]
Torsion inversely proportional to speed

Certain types of lathes, boring machines exhibit hyperbolic speed-torque characteristics.

In such case, torque is inversely proportional to speed: \( T = \frac{K}{\omega} \)

\[ \uparrow \quad \omega \]

\[ T \propto \frac{1}{\omega} \]

\[ T = \frac{K}{\omega} \]

Constant power is drawn.
characteristics

Basic relation.

The following fundamental equations are used to determine the various quantities of a dc machine in terms of an armature circuit.

\[ V = E + I_a R_a \]

\[ E = \frac{1}{2\pi} P \Phi \omega \]

\[ T = \frac{1}{2\pi} P \Phi \omega I_a \]

- **V** - Voltage at the terminals of the machine
- **E** - Induced emf
- **I_a** - Armature current
- **R_a** - Armature resistance
- **P** - Number of poles
- **Φ** - Flux per pole
- **ω** - Angular speed
There are two types of characteristics available:

i) Speed vs. Armature Current

ii) Torque vs. Armature Current

iii) Speed vs. Torque → Mechanical Characteristic

Before drawing the characteristic, we know the solution:

\[ E_b = V - I_a R_a = \frac{\phi 2 \pi}{60} \frac{V}{A} \]

\[ N = \frac{V - I_a R_a}{60 \frac{A}{p}} \]

\[ N = \frac{k (V - I_a R_a)}{\phi} \]

\[ \frac{N}{V - I_a R_a} = \frac{N}{E_b} = \frac{\phi}{2} \]

Hence the speed of the motor is directly proportional to the voltage, i.e., \( E_b \) and inversely proportional to the flux, \( \phi \).
\[ N = \frac{V - I_F a}{\Phi} \]

Torsional equation of DC motors is

\[ T = \Phi I_a \]

**Speed & Torsional Characteristics of DC Motors**

**Series Motor**

- Field winding is connected in parallel to armature winding.

\[ I_L = I_a + I_F \]

**Shunt Motor**

**Speed - Torsional Characteristics**

- Mechanical Characteristics

\[ N = \frac{E_b}{\Phi} \]  
\[ N = \frac{V - I_F a}{\Phi} \]

\[ T = \Phi I_a \]
In DC shunt motor from (3)

\[ T = I_a \times e, \quad I_a = kT \]

\[ I_a \uparrow, I_{aR} \uparrow \]

\[ (V - I_{aR}) \Delta V \]

and \( N \Delta I_a \)

\[ N \propto \frac{1}{I_a} \]

If load torque increases, the speed of motor is slightly decreases.

Series motor

The connection for a series motor, the field winding and armature are in series.

\[ I_L = I_a = I_S, \quad S.E. \]

\[ \frac{W = V - I_{aR}}{12\Omega} \]

The motor torque may be expressed as \( T = 12\Phi I_a \) in a Series motor, the flux \( \Phi \) depends on armature current \( I_a \).

\[ \Phi = k_1 \times I_a \]

\[ T = k_1 \Phi I_a \Rightarrow k_1(I_{aR})^2 \]

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Compound motor

A compound motor has both series field and shunt field.

- Shunt field always stronger than the series field.

Cumulative Compound

Series field aids the shunt field.
It has higher starting torque than a shunt motor but lower than a series motor.
Differentiated Compound

In this motor, shunt mmf and series mmf subtract from each other. This means that as load on motor increases (Ia) increases and flux in motor decreases.

Flux decreases → Speed increases

So this motor is unsuitable for any application.
Braking of motors

Definition — when ever an electric drive is disconnected from the supply, the speed of driving motor gradually decreases and becomes zero.

Why (s) what is the need for braking

It include maintaining the speed to a desired value.

Preventing the motor from over speeding

Little maintenance is required (no need for mechanical brake);

- Efforts to mechanical brake reduced
- Lining need reduced
- Dust Produced
- Heat Produced

In electric braking is smooth without snatching.
- Electric braking use for braking for economic consideration.

Based on purpose:

Two forms of braking:

(i) While bringing the drive to rest.
(ii) While lowering loads.

In first type braking - absorbs the kinetic energy of moving parts.

In second absorb - additional kinetic energy, potential energy.

Braking, while stopping, may be employed for any one following purpose:

(i) Reducing the time taken to stop.

(ii) Stopping exactly at specified points (eg. lifts).

(iii) Feeding back at least any portion of power to supply network.
Breaking lowering loads enables one to achieve any one of the following:

(i) controlling the speed at which the load comes down & limiting it to a safe value.

(ii) feeding power back to supply

Types

There are three types of braking, all of which are applicable to the regular type of electric motor.

(i) Regenerative braking

(ii) Rheostatic or dynamic

(iii) Plugging or reverse current
For Shunt motor

Regenerative braking

In the regenerative braking operation, the motor operates as a generator, while it is still connected to the supply.

Regenerative braking

Regenerative braking involves returning energy to the supply circuit. It is obtained when under certain conditions, the motor is forced to run at a speed higher than its no-load speed; due to its back emf $E_b$ in the armature exceeding the supply voltage $V$.

$$\sum \alpha = \frac{V - E_b}{R_a} = \frac{+E_b - V}{R_a} = -2\alpha.$$
with reversal of direction of armature current the motor rotates also reverse (ii) braking torque is developed.

**Plugging**

The dc machines, the shaft of the machine rotate in the same direction as the magnetic field by interchanging any two supply terminals, the braking torque is produced. It is called plugging.

For plugging of motor reversal may be accomplished by reversing the polarity of the applied voltage either to armature (or) field winding.

$V$ is reversed
\(-v_2E_b + I_a R_a \quad I_a = - \left( \frac{v + E_b}{R_a} \right)\)

\(T_p = I_a + \Phi I_a\)
\(\Rightarrow -I_a - \Phi \frac{v + E_b}{R_a}\)

Total braking torque is
\(T_{br} = T_p + T_L\).

When the necessary of rotation is not required, the supply must be switched off when the motor speed becomes very nearly equal to zero.

Dynamic Braking

Dynamic braking can be obtained by disconnecting the armature from supply and connecting an external resistance across the armature terminals. It is called Resistor Braking.
Due to becoming the operating point shifts to B on the characteristics II from point A, the DC motor then decelerates along Bo to stand still. It is called braking applied to DC series motor.

**Braking of DC Series Motor**

**Plugging**

Current braking is accomplished by connecting the supply to the armature of the motor so that the motor draws a current to develop a torque to oppose its already existing rotation.

Plugging occurs when the motor windings are connected for reverse direction of rotation at anytime when the armature is still rotating in the forward direction either under the action of any external electromechanical braking.
During plugging

\[ V = E_b + I_a R_a \]

\[ I_a = \frac{V + E_b}{R_a} \]

Plugging torque \( T_p = K_f \phi I_a \)
Dynamic braking

In both armature and field winding are disconnected from the supply and shorted across a braking resistor so that it should be noted that when dynamic braking executed.

\[ T_d = \frac{1}{b} = -k_f k_c \frac{R_N}{\text{out of rel}} \]

[Diagram of electrical circuit]
Torsam - Slip characteristics

The curve drawn between torsam and slip from $s=1$ to $s=0$ is called torsam-slip characteristics of induction motor.

The torsam equation for 3φ induction motor is given by

\[ T \propto \frac{S E^2 R_2}{R_2^2 + (S X_2)^2} \]

Here the input voltage is constant.

1. \( R_2 \) is constant

\[ T \propto \frac{S E^2}{R_2 + (S X_2)^2} \]

It consists of 3 regions

(i) Stable region
(ii) Unstable region
(iii) Normal region
Stable region

The slip is very small, \( T \propto \frac{(S_x^2)^2}{R_2^2} \) is small compared to \( R_2 \)

\[ T \propto \frac{S_x^2}{R_2} \]

\( R_2 = \text{constant} \)

Unstable region

Slip is further increased from \( S_m \), the region is unstable region, \( S_{ip} \)
value is high, \( r_2 \) is may be neglected.

\[ T = \frac{S}{(S \times 2)} \times \frac{1}{S} \]

\[ \frac{T}{S} \]

\[ S \uparrow \& T \downarrow \]

curve is similar to rectangular hyperbola. motor speed decreases, slip increases.

speed-torque characteristic

\[ \begin{align*}
\text{(i) motoring region } (0 \leq S \leq 1) \\
\text{(ii) generation region } (S > 0) \\
\text{(iii) motoring region } (S < 0)
\end{align*} \]
**Motoring Region**

The induction motor rotate in the same direction as that of field here. The speed is decreases and torque increase till breakdown torque is reached. Airgap Flux is constant. After breakdown $T_{max}$, decrease of slip increases.

\[ \text{(i) Generating region (} s \leq 0 \text{)} \]

The machine operates as a generator. The rotor rotates at a speed greater than synchronous speed in same direction as that of rotor. Magnetic field due to super synchronous speed slip becomes negative. (i.e. regeneration)

\[ \text{(ii) Pulling region (} 1 \leq s \leq 2 \text{)} \]

In this region, the slip becomes greater than unity so that the motor rotates in the opposite direction to the supply.
magnetic field. This region occurs only when the stator field is reversed by changing the phase sequence or input supply. The direction of the rotating magnetic field also changes.

under this condition the machine is quickly come to stop, and if the supply is not disconnected, the motor starts to rotate in reverse direction.

so plugging the power is appears to be網頁 no power.
SINGLE PHASE INDUCTION MOTOR

1-phase induction motors are identical to 3-phase I'm motors. They are mainly used in home applications.

Synchronous speed is given by:

\[ n_s = \frac{120f}{p} \]

If an AC supply is applied to stator, the current is applied to stator & corresponding 1-phase flux produced. Flux induces an AC voltage in stationary rotor, it acts as a transformer. Currents in opposite rotor are developed and cancelled each other. Thus single phase I'm does not operate.

**Starting method**

The winding case displaced by 90° electrically (starting & auxiliary winding)

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Types

(ii) Split Phase I'M

They are two windings (starting & auxiliary winding).
They are displaced by 90° electrical degrees.
Auxiliary winding has high resistance & low reactance when supply is given the motor starts running
to reach 75% of speed the auxiliary winding is disconnected from circuit.

Characteristics

Starting torque
is 100-250% of rated value.
Efficiency is 55 to 65%.

Application

Fan
Blowers
Centrifugal Pumps

Capacitor Start motors

In supply is applied to two winding, starting
capacitor leads the line voltage because capacitor
is present in auxiliary windings.

To start speed characteristic is up to
75% & auxiliary winding is disconnected
from circuit

Capacitor is used only for starting purpose

Application

Pump's
Conveyors
Two capacitors are used: one for starting and the other one is used for running. If \( \text{R} \) is large, \( \text{Vs} \rightarrow \text{low value} \). It is connected permanently about 75% speed. The speed is disconnected from the circuit.

**Application**

Compressors
Pumps
Conveyor

**Shaded Pole Motors**

- It has salient pole construction on one side or pole small opening is provided. Fix flux shift from unshaded pole to shaded pole so rotor rotates from unshaded to shaded region.

**Characteristics**

Starting torque: 200 to 300% breakdown torque: 250%.

**Characteristics**

Starting torque: 40 to 60% rated value.

**Breakdown** is \( \text{Vs} \rightarrow \text{140V} \).

**Unit 2 - 28-10-07**