A T M E College of Engineering

Industrial Drives and Applications-18EE741

Module-1

Electrical Drives

Dynamics of Electrical Drives

Control of Electrical Drives

Presented By,

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Syllabus

Electrical Drives:

Electrical Drives, Advantages of Electrical Drives. Parts of Electrical Drives, Choice of Electrical Drives, Status of DC and ac Drives.

Dynamics of Electrical Drives:

Fundamental Torque Equations, Speed Torque Conventions and Multi-quadrant Operation. Equivalent Values of Drive Parameters, Components of Load Torques, Nature and Classification of Load Torques, Calculation of Time and Energy Loss in Transient Operations, Steady State Stability, Load Equalization.

Control Electrical Drives:

Modes of Operation, Speed Control and Drive Classifications, Closed loop Control of Drives.

Introduction to Drives

What is Drive

Systems employed for motion control are called drives.

It employs any of the prime movers such as diesel or petrol engines, gas or steam turbines, steam engines, hydraulic motors and electric motors for supplying mechanical energy for motion control.

What is an Electric Drive?

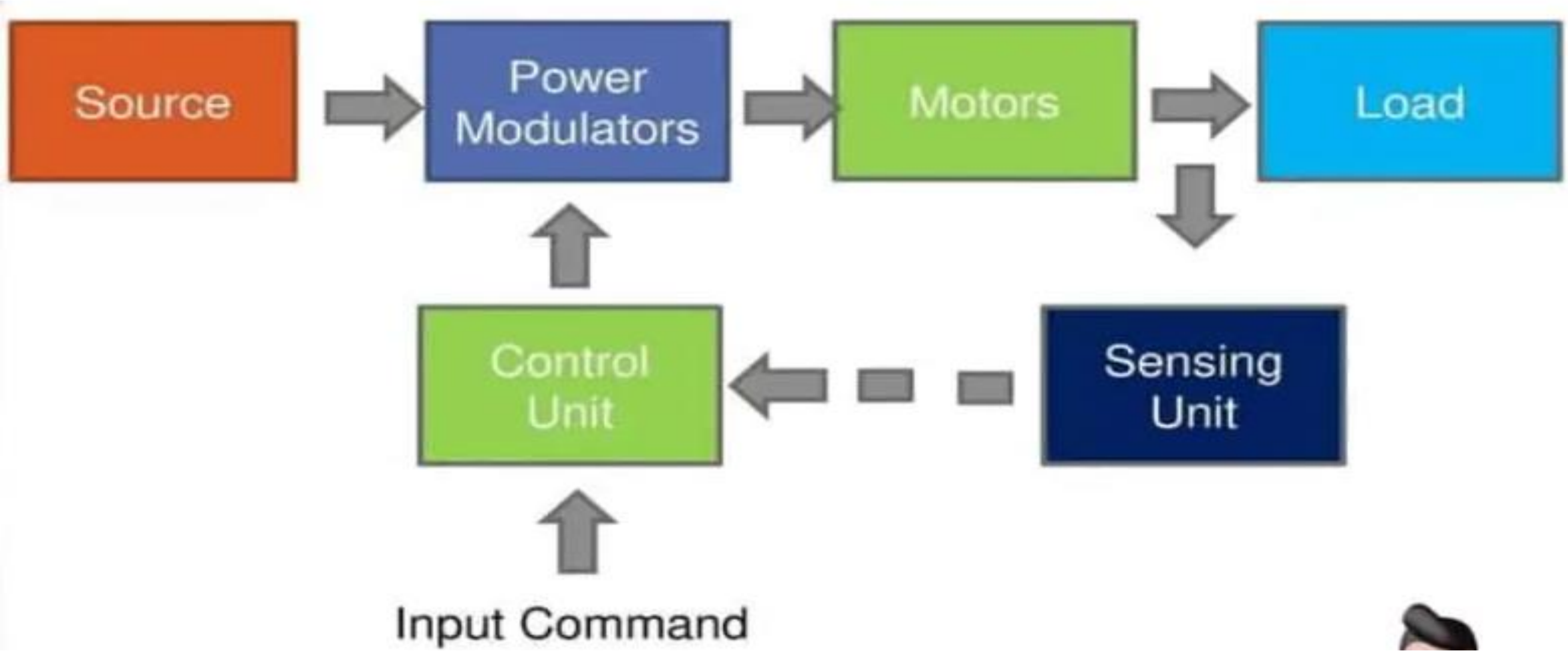
Drives employing electric motors are known as electrical drives.

Electrical Drives

- Motion control is required in large number of industrial and domestic applications

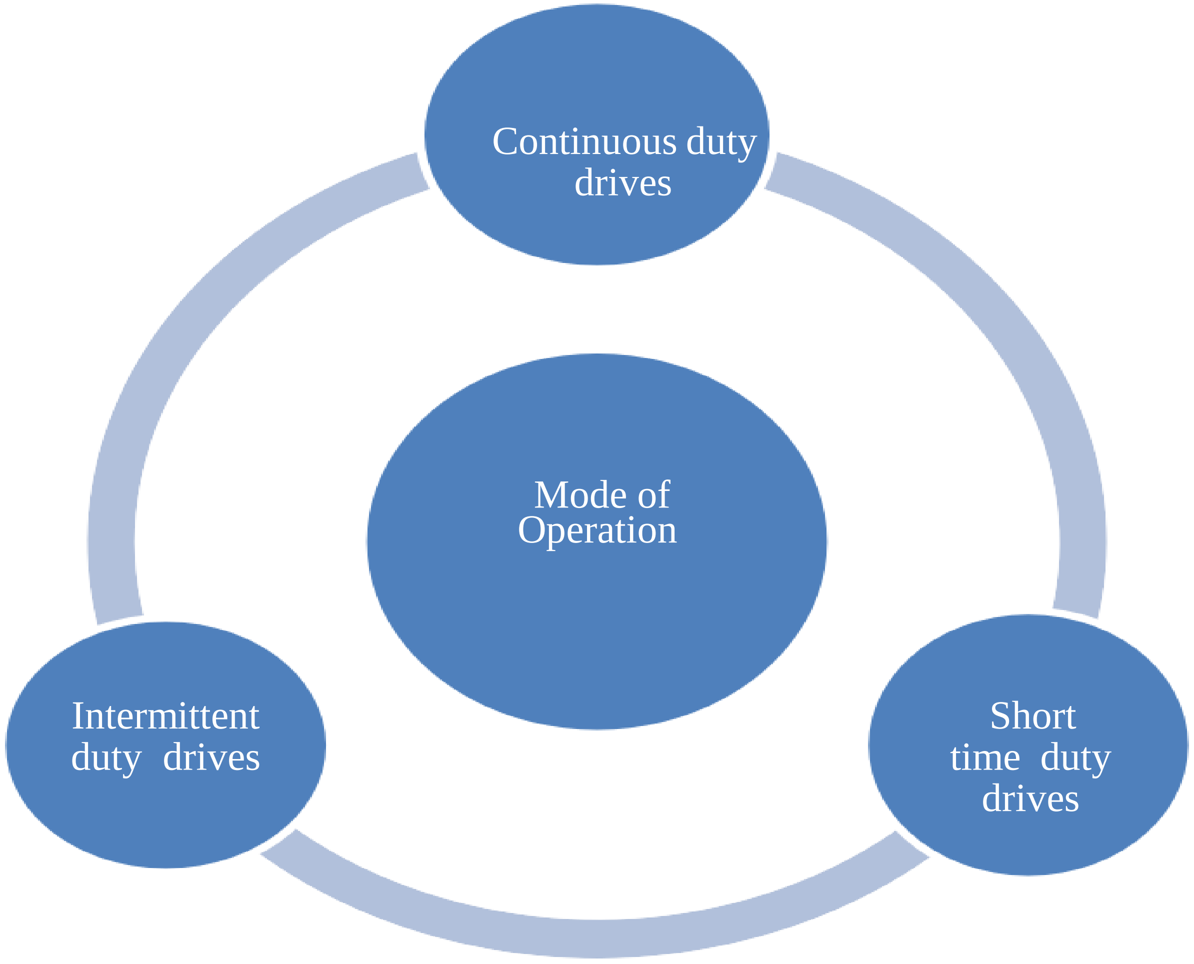
- Systems employed for motion control are called DRIVES, and may employ any of prime movers such as diesel or petrol engines, gas or steam turbines, steam engines, hydraulic motors and electric motors, for supplying mechanical energy for motion control

Block diagram of electric drive

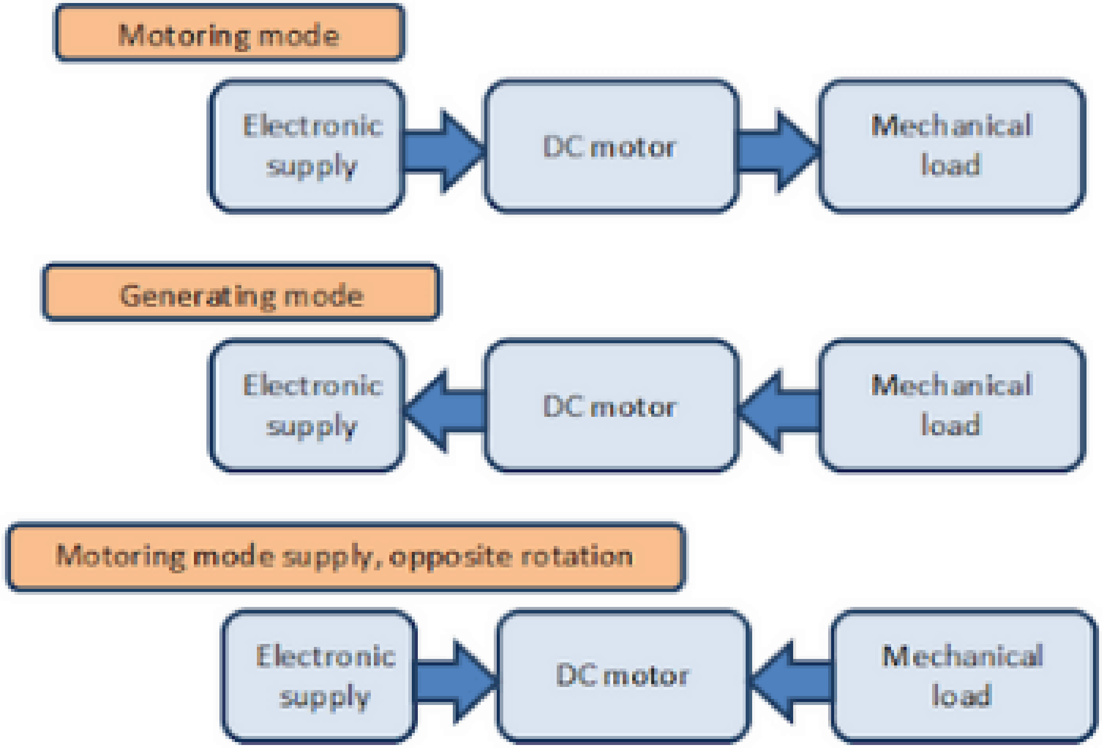


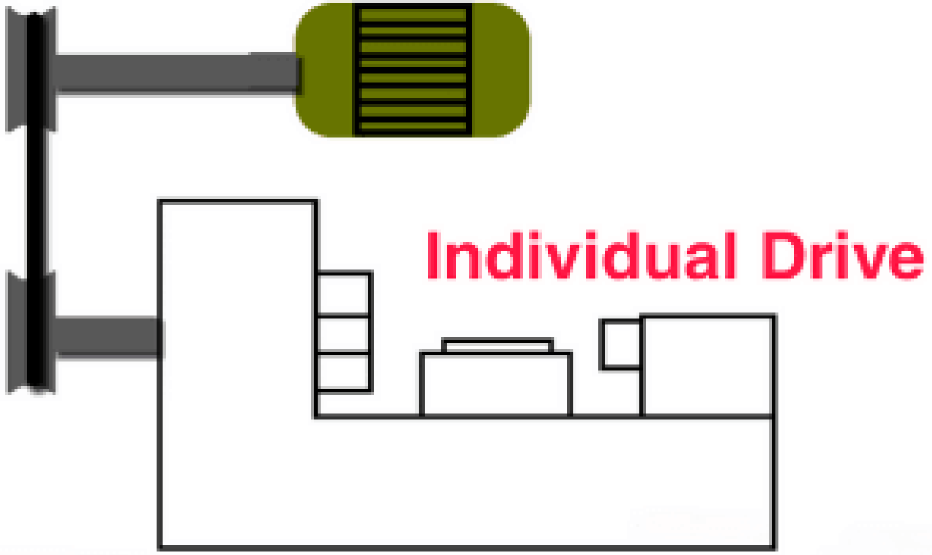
Classification of Electric Drives

- According to Mode of Operation
- According to Means of Control
- According to Number of machines
- According to Dynamics and Transients
- According to Methods of Speed Control



Types of Electrical Drives





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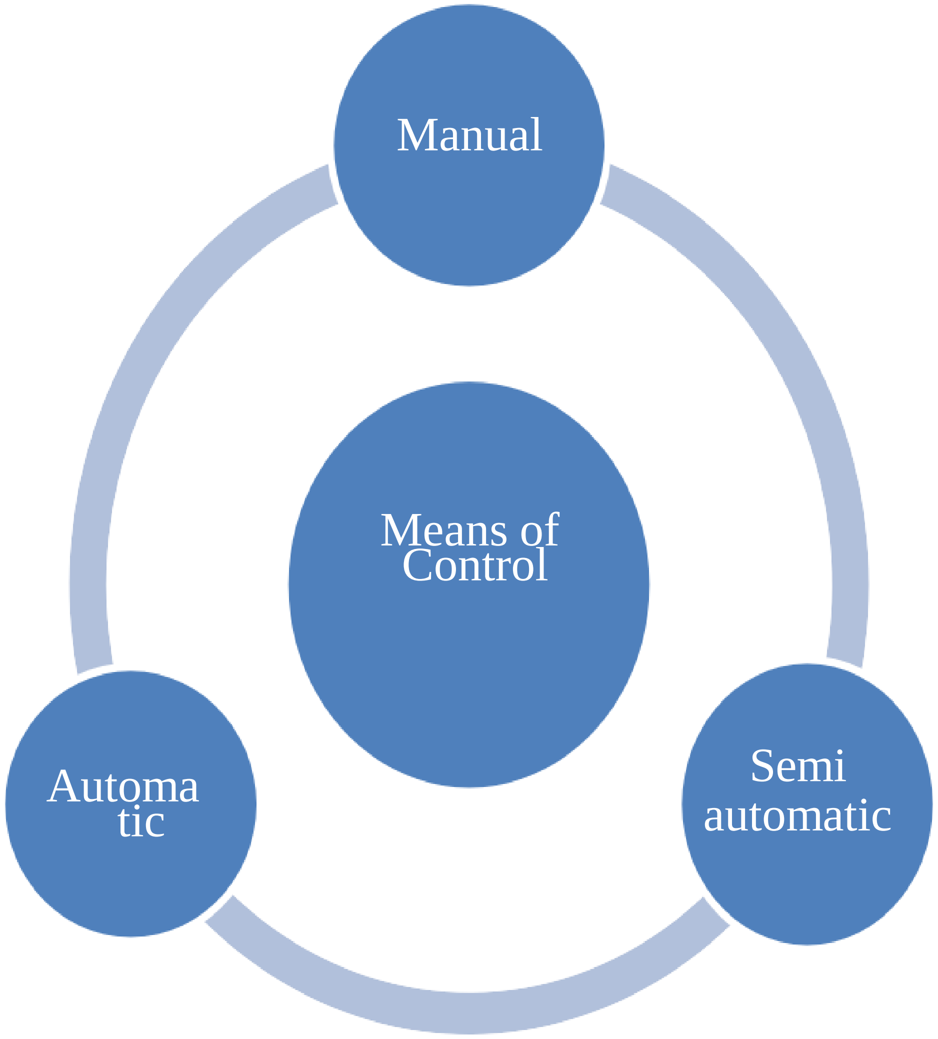
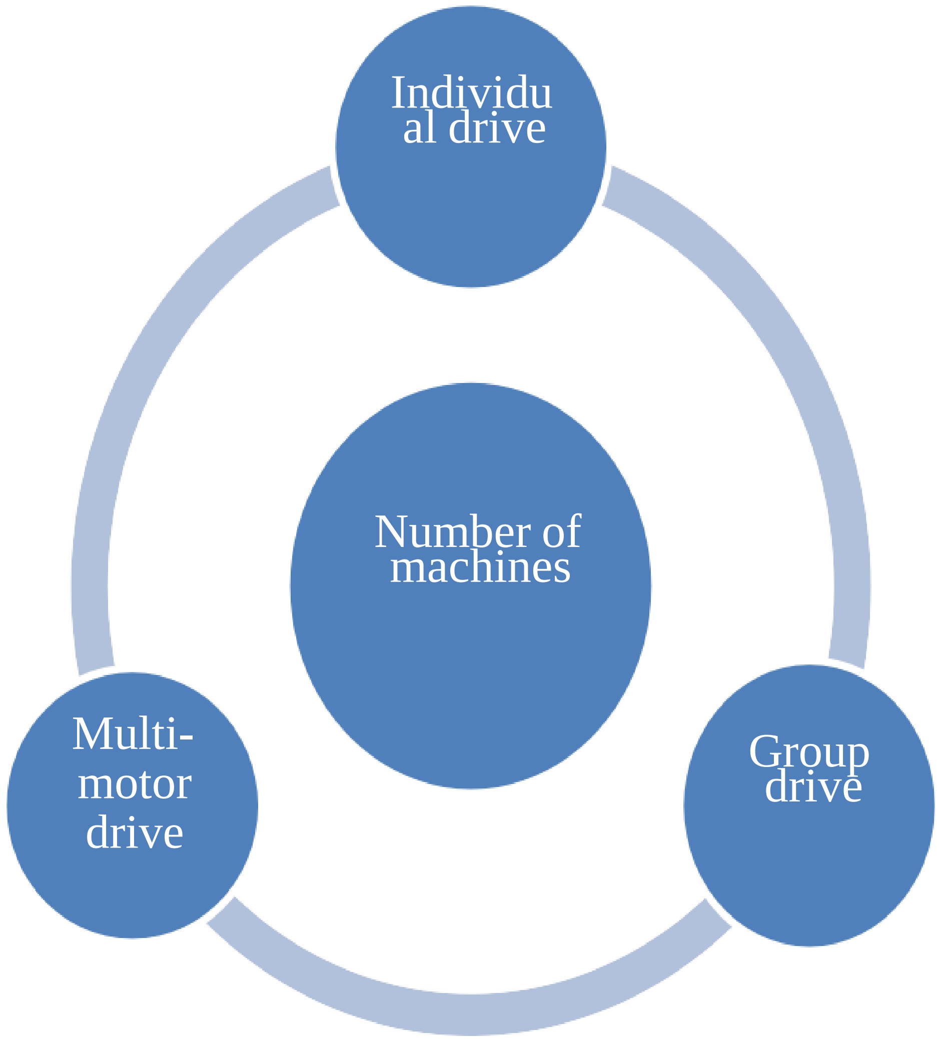
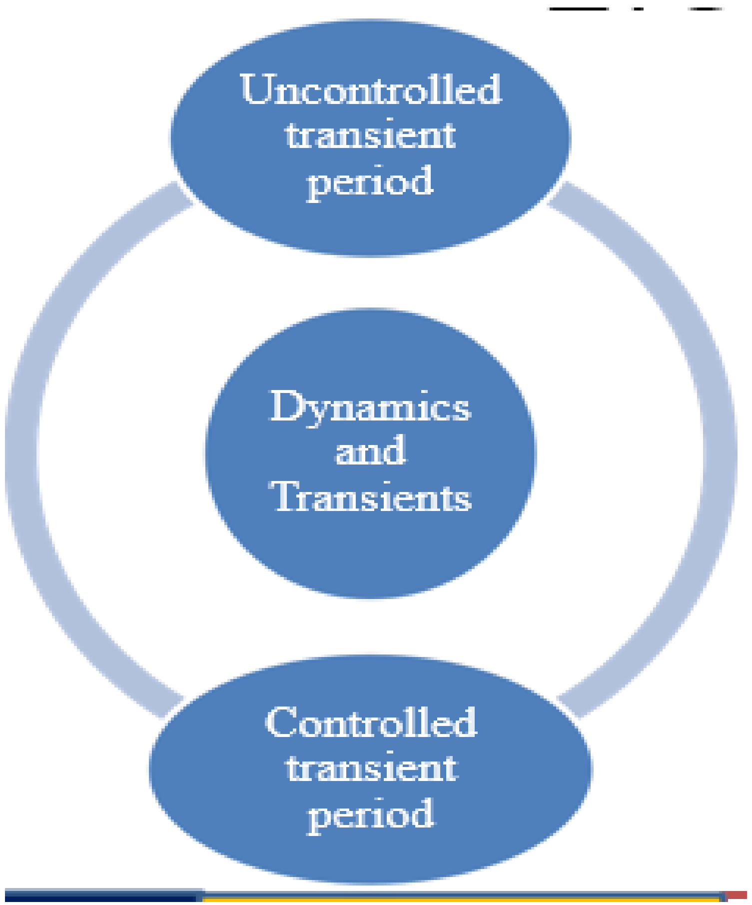
Classification of Electric Drives





Classification of Electric Drives

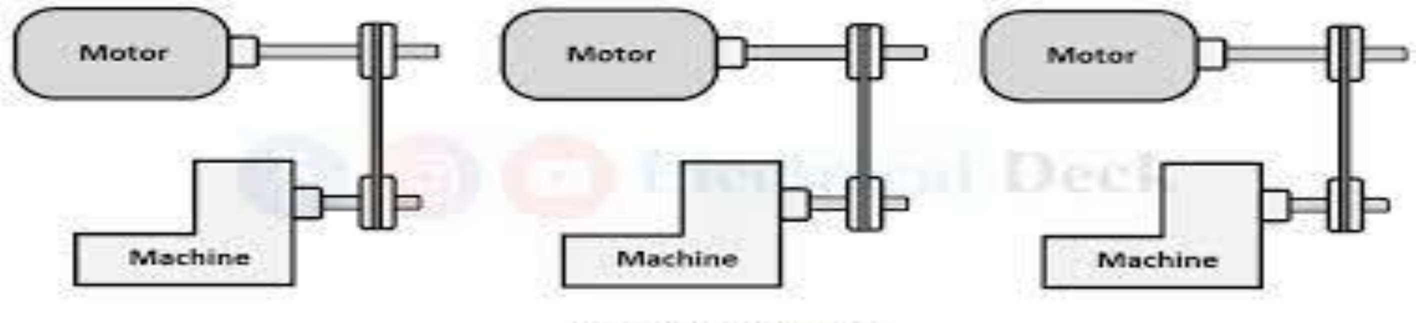


Methods of Speed Control

- Reversible and non-reversible uncontrolled constant speed.
- Reversible and non-reversible step speed control.
- Variable position control.
- Reversible and non-reversible smooth speed control.

Individual Electric Drive

In this drive each individual machine is driven by a separate motor. This motor also imparts motion to various parts of the machine.

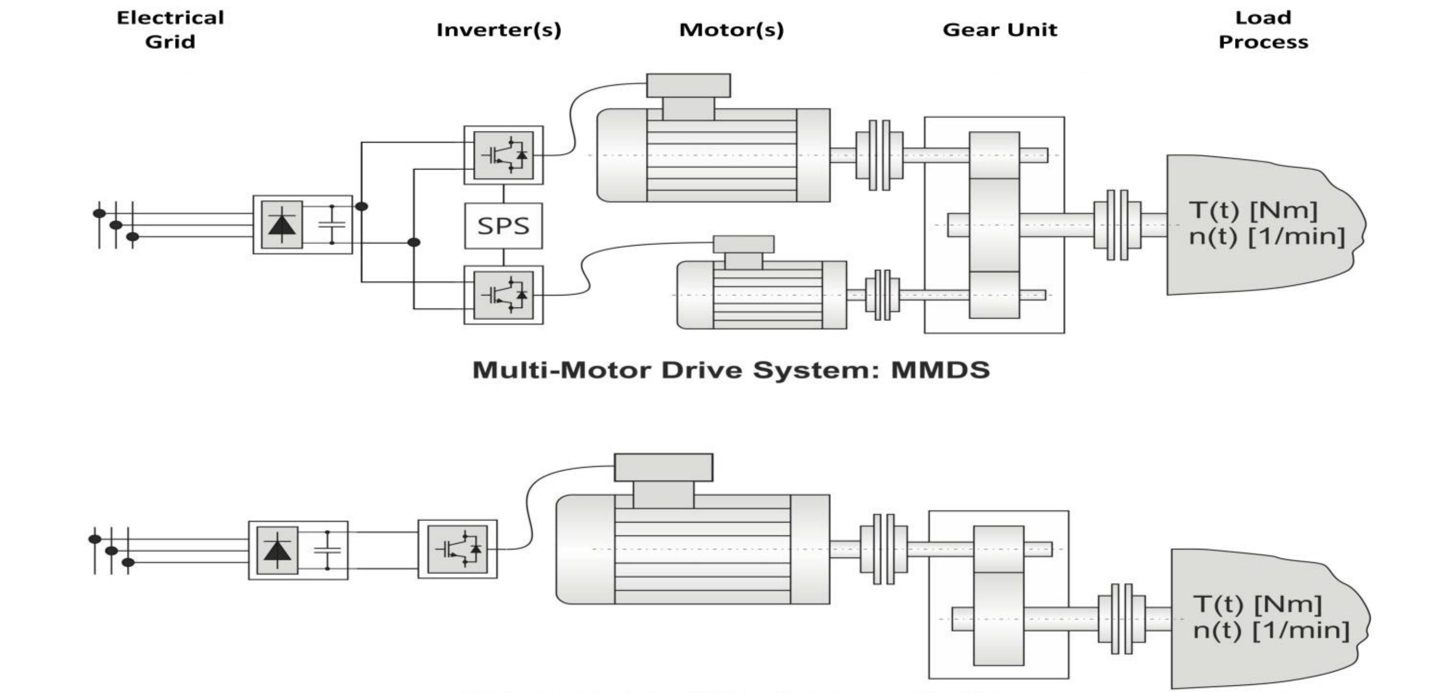


Individual Drive

Multi Motor Electric Drive

In this drive system, there are several drives, each of which serves to actuate one of the working parts of the drive mechanisms.

E.g.: Complicated metal cutting machine tools, Paper making industries, Rolling machines etc.



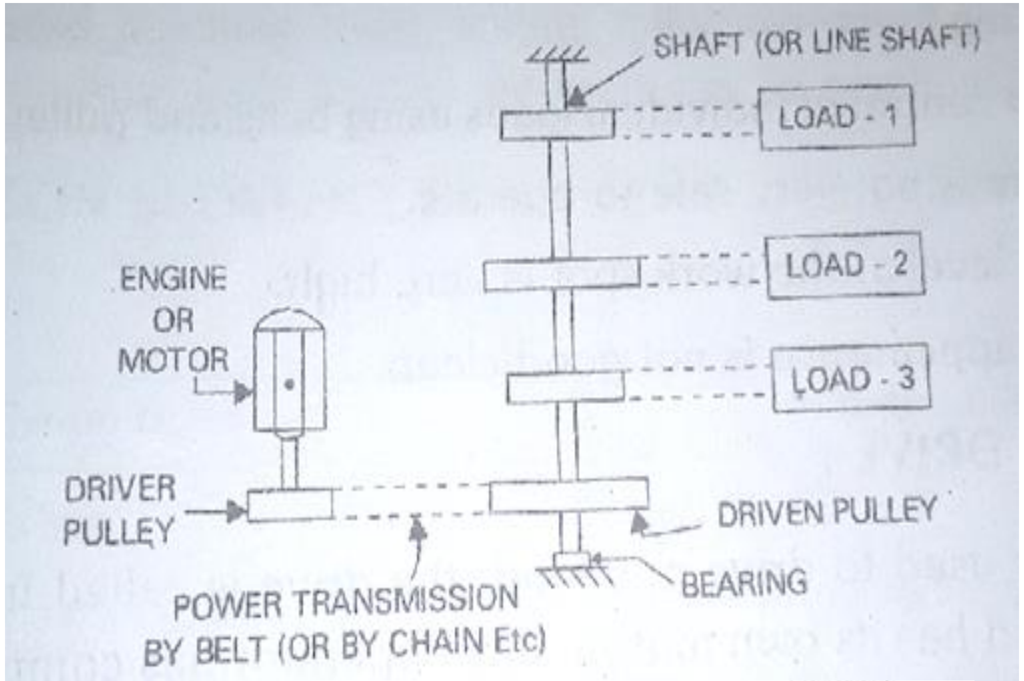
Multi-Motor Drive System: MMDS

Single-Motor Drive System: SMDS

Electrical Drives

Group Electric Drive

This drive consists of a single motor, which drives one or more line shafts supported on bearings. The line shaft may be fitted with either pulleys and belts or gears, by means of which a group of machines or mechanisms may be operated. It is also some times called as SHAFT DRIVES.

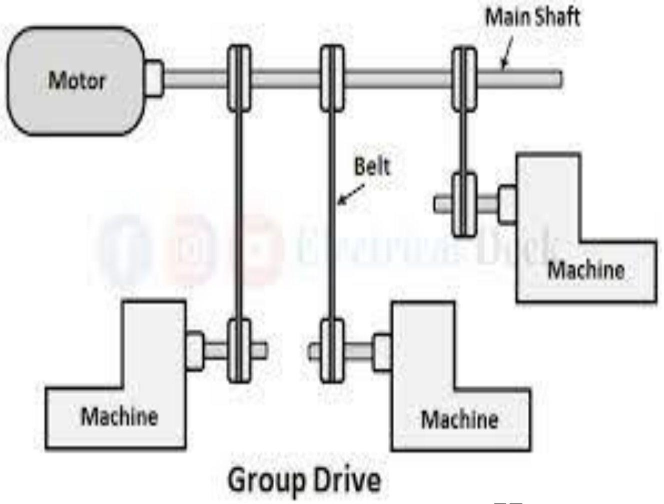


Advantages

A single large motor can be used instead of number of small motors

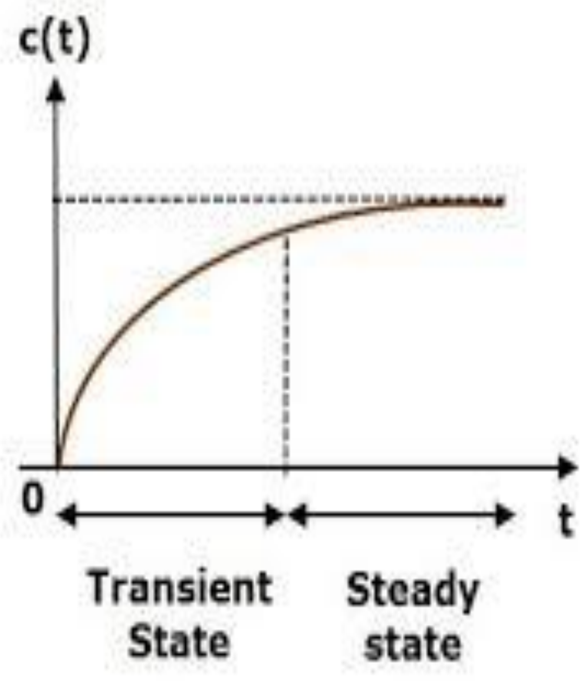
Disadvantages

There is no flexibility. If the single motor used develops fault, the whole process will be Stopped



Choice (or) Selection of Electrical Drives

- Steady State Operating conditions requirements.
- Transient operation requirements.
- Requirements related to the source.
- Capital and running cost, maintenance needs life.
- Space and weight restriction if any.
- Environment and location.
- Reliability.



Advantages of Electrical Drive

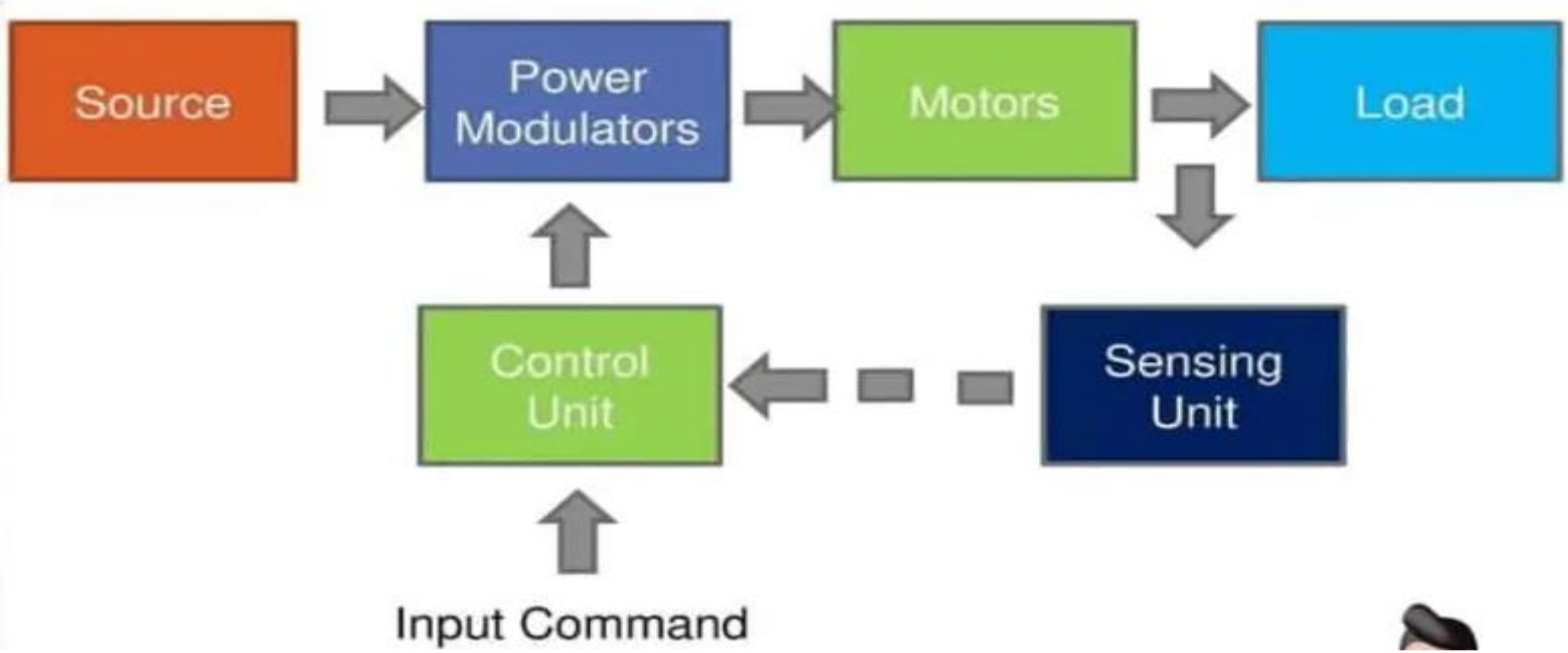
- Flexible Control Characteristics & Steady state & dynamic of drives can be shaped to Load requirements .
- Automatic fault detection systems & automatically control the drive operations in a desired sequence.
- Wide range of torque, speed and power.
- Adaptable to almost any operating conditions.
- Four quadrants of speed-torque plane.
- Started instantly and can immediately be fully loaded.
- Control operations, Braking is simple and easy to operate.

Advantages of Electrical Drives

Electrical drives are readily used these days for controlling purpose but this is not the only the **advantage of Electrical drives**. There are several other advantages which are listed below:

1. These drives are available in wide range torque, speed and power.
2. The control characteristics of these drives are flexible. According to load requirements these can be shaped to steady state and dynamic characteristics. As well as speed control, electric braking, gearing, starting many things can be accomplished.
3. The are adaptable to any type of operating conditions, no matter how much vigorous or rough it is.
4. They can operate in all the four quadrants of speed torque plane, which is not applicable for other prime movers.
5. They do not pollute the environment.
6. They do not need refueling or preheating, they can be started instantly and can be loaded immediately.
7. They are powered by electrical energy which is atmosphere friendly and cheap source of power.

Block diagram of an electric drive



Parts of Electric Drive

1. Electrical Sources

- Very low power drives are generally fed from single phase sources.
- Rest of the drives is powered from a 3 phase source.
- Low and medium power motors are fed from a 400V supply.
- For higher ratings, motors may be rated at 3.3KV, 6.6KV and 11 KV.
- Some drives are powered from battery.

2. Power modulator

It is most commonly used as a converter

Power Modulators Functions:

- Modulates flow of power from the source to the motor in such a manner that motor is imparted speed-torque characteristics required by the load.
- During transient operation, such as starting, braking and speed reversal, it restricts source and motor currents with in permissible limits.
- It converts electrical energy of the source in the form of suitable to the motor.
- Selects the mode of operation of the motor (i.e.) Motoring and Braking.

Types of Power Modulators

In the electric drive system, the power modulators can be any one of the following

- Controlled rectifiers (ac to dc converters)
- Inverters (dc to ac converters)
- AC voltage controllers (AC to AC converters)
- DC choppers (DC to DC converters)
- Cyclo converters (Frequency conversion)

Power Modulators - are the devices which alter the nature or frequency as well as changes the intensity of power to control electrical drives. Roughly, power modulators can be classified into three types,

1. Converters,
2. Variable impedance circuits,
3. Switching circuits.

As the name suggests, converters are used to convert currents from one type to other type. Depending on the type of function, converters can be divided into 5 types -

i. *AC to DC converters*

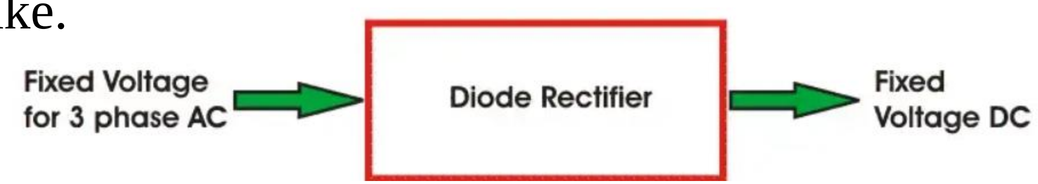
ii. *AC regulators*

iii. *Choppers or DC - DC converters*

iv. *Inverters*

v. *Cycloconverters*

AC to DC converters are used to obtain fixed DC supply from the AC supply of fixed voltage. The very basic diagram of AC to DC converters is like.



Power Modulators cntd.

ii.AC Regulators are used to obtain the regulated AC voltage, mainly auto transformers or tap changer transformers are used in this regulators.

iii. Choppers or DC-DC converters are used to get a variable DC voltage. Power transistors, IGBT's, GPO's, power MOSFET's are mainly used for this purpose.

Power Modulators cntd.

iv. Inverters are used to get AC from DC, the operation is just opposite to that of AC to DC converters. PWM semiconductors are used to invert the current.

v. Cycloconverters are used to convert the fixed frequency and fixed voltage AC into variable frequency and variable voltage AC. Thyristors are used in these converters to control the firing signals.

Power Modulators cntd.

2. Variable Impedance circuits:

- These are used to control speed by varying the resistance or impedance of the circuit. But these controlling methods are used in low cost DC and AC drives.
- There can be two or more steps which can be controlled manually or automatically with the help of contactors.
- To limit the starting current inductors are used in AC motors.

3. Switching circuits:

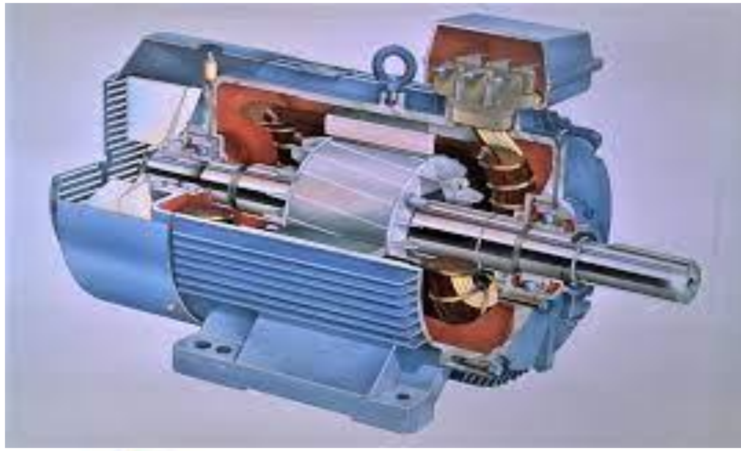
- These are used in motors and electrical drives for running the motor smoothly and they also protects the machine during faults.
- These circuits are used for changing the quadrant of operations during the running condition of a motor.
- These circuits are implemented to operate the motor and drives according to predetermined sequence, to provide interlocking, to disconnect the motor from the main circuit during any abnormal condition or faults.

General Electric Drive System

Electrical Machines

DC Machines

Shunt, series, compound, separately excited DC motors and switched reluctance machines.



AC Machines

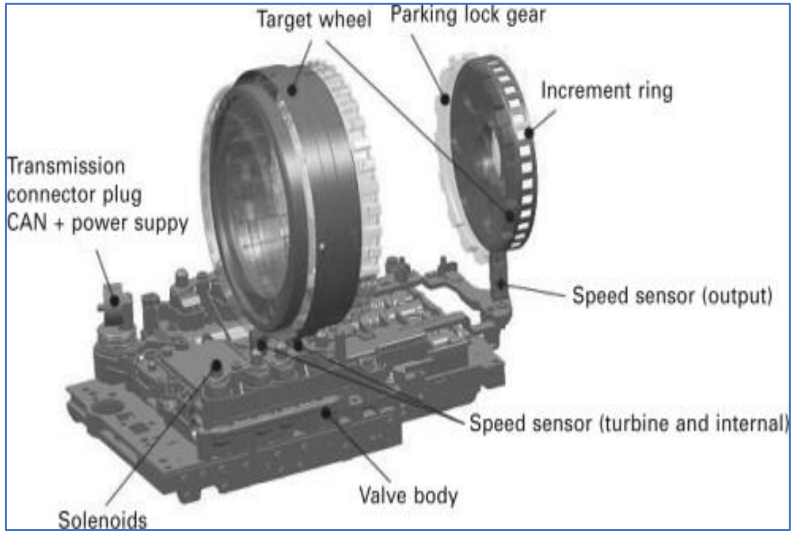
Induction, wound rotor, synchronous, PM (Permanent Magnet) synchronous and synchronous reluctance machines

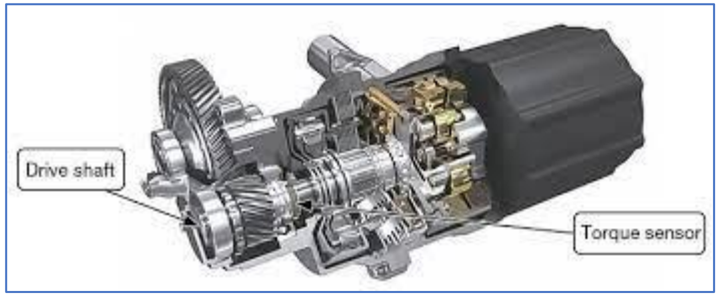
Special Machines

Brush less DC motors, stepper motors, switched reluctance motors are used.

Sensing Unit

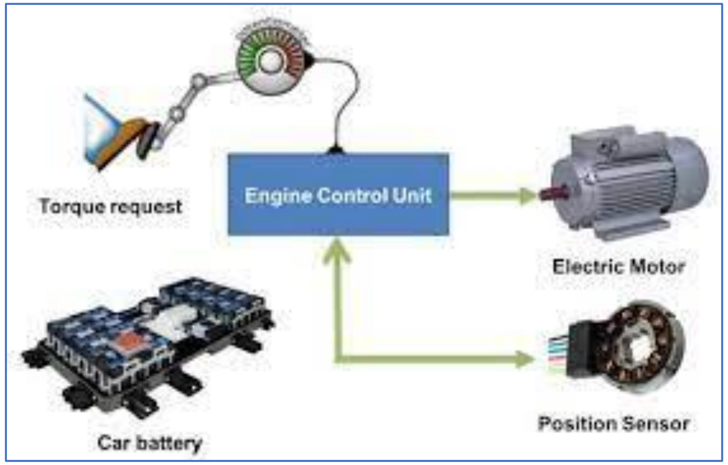
- Speed Sensing (From Motor)
- Torque Sensing
- Position Sensing
- Current sensing and Voltage Sensing from Lines or from motor terminals





From Load

- ➢ Torque sensing
- ➢ Temperature Sensing



Control unit: Choice of control unit depends upon the type of power modulator that is used. These are of many types, like when semiconductor converters are used, then the control unit consists of firing circuits, which employ linear devices and which employ linear and digital integrated circuits and transistors, and a microprocessor when sophisticated control is required.

Classification of Electrical Drives

Comparison between DC and AC drives

DC Drive	AC Drive
The power circuit and control circuit is simple and inexpensive	The power circuit and control circuit are complex
It requires frequent maintenance	Less Maintenance
The commutator makes the motor bulky, costly and heavy	These problems are not there in these motors and are inexpensive, particularly squirrel cage induction motors

DC Drive	AC Drive
Fast response and wide speed range of control, can be achieved smoothly by conventional and solid state control	In solid state control the speed range is wide and conventional method is stepped and limited
Speed and design ratings are limited due to commutations	Speed and design ratings have upper limits

Note:

- A power circuit supplies the main power (e.g. 3 phase AC) whereas the control circuit is lower in current & voltage which may consist of PLCs & small relays,low voltage DC power supply,etc.
- Solid state power controllers (SSPC) are semiconductor devices that control power (voltage and/or current) supplied to a load. They identify overload conditions and prevent short circuits.

Applications

- Paper mills
- Cement Mills
- Textile mills
- Sugar Mills
- Steel Mills
- Electric Traction
- Petrochemical Industries
- Electrical Vehicles

Paper mills

Cement Mills

Textile mills

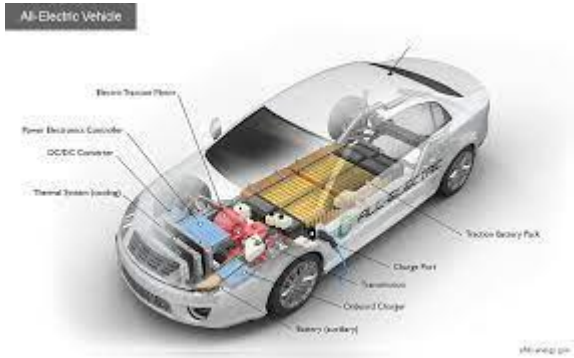
Sugar Mills

Steel Mills

Electric Traction

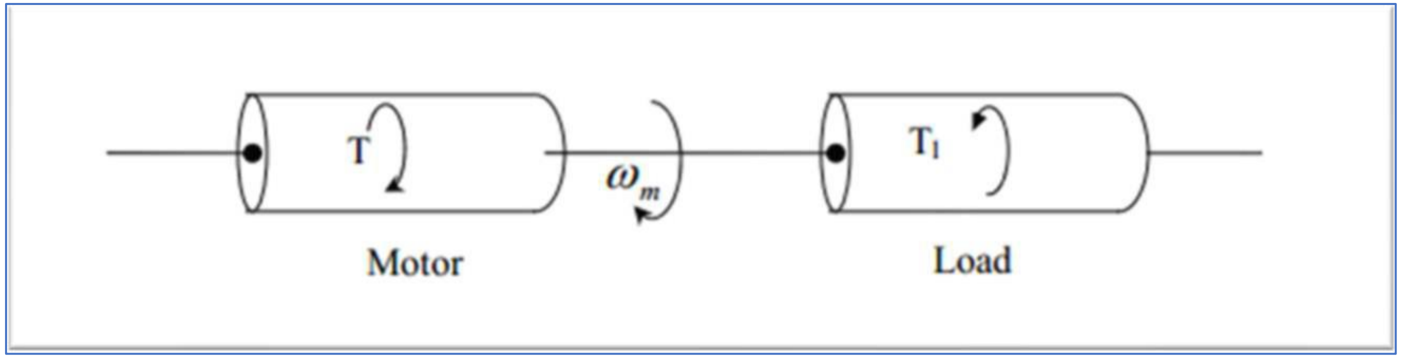
Petrochemical Industries

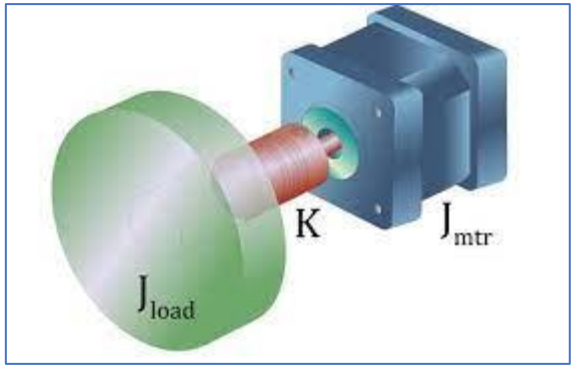
Electrical Vehicles



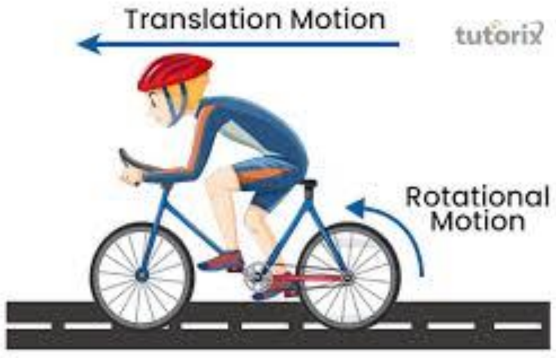
Fundamentals of Torque Equations

- A motor generally drives a load (Machines) through some transmission system.
- While motor always rotates, the load may rotate or undergo a translational motion.
- Load speed may be different from that of motor, and if the load has many parts, their speed may be different and while some parts rotate others may go through a translational motion.
- Equivalent rotational system of motor and load is shown in the figure.

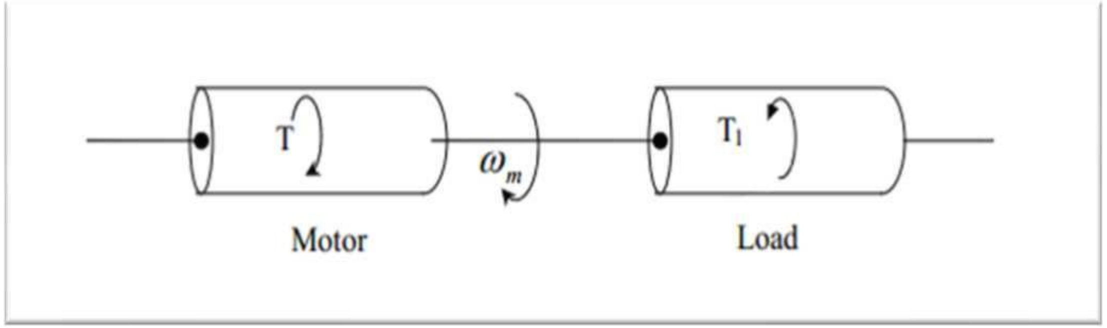




J = Moment of inertia of motor load system referred to the motor shaft $kg-m^2$
ω_m= Instantaneous angular velocity of motor shaft, rad/sec.
T = Instantaneous value of developed motor torque, N-m
T^1=Instantaneous value of load torque, referred to the motor shaft N-m



Fundamentals of Torque Equations



Load torque includes friction and windage torque of motor. Motor-load system shown in figure can be described by the following fundamental torque equation

$$T - T_l = \frac{d}{dt}(J\omega_m) = J\frac{d\omega_m}{dt} + \omega_m\frac{dJ}{dt} \text{-----------} (1)$$

Equation (1) is applicable to variable inertia drives such as mine winders, reel drives, Industrial robots.

For drives with constant inertia $\frac{dJ}{dt} = 0$

For drives with constant inertia $\frac{dJ}{dt} = 0$

$$T = T_l + J\frac{d\omega_m}{dt}$$

1

Equation (2) shows that torque developed by motor is counter balanced by load torque T_l and a dynamic torque $\left(J\frac{d\omega_m}{dt}\right)$. Torque component $\left(J\frac{d\omega_m}{dt}\right)$ is called dynamic torque because it is present only during the transient operations.

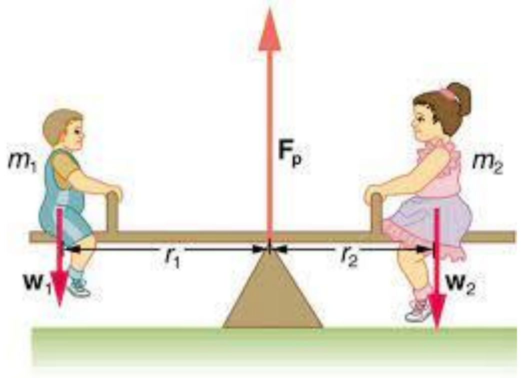
Classification of Load Torques

1. Active load torques
2. Passive load torques

1. Load torques which has the potential to drive the motor under equilibrium conditions are called active load torques. Such load torques usually retain their sign when the drive rotation is changed (reversed)

Examples

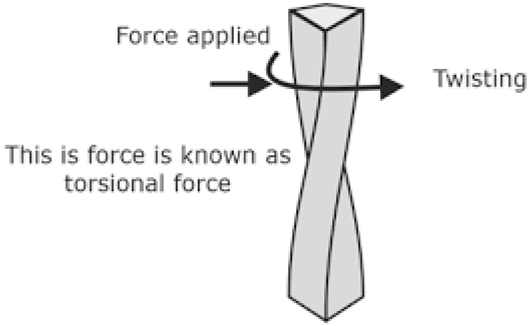
- Torque due to force of gravity
- Torque due to tension
- Torque due to compression and torsion etc



2. Load torques which always oppose the motion and change their sign on the reversal of motion are called passive load torques

Examples

- Torque due to friction, cutting etc.



Components of Load Torques

The load torque T_l can be further divided in to following components

1. **Friction Torque (T_F)**
2. **Windage Torque (T_W)**
3. **Torque required to do useful mechanical work.**

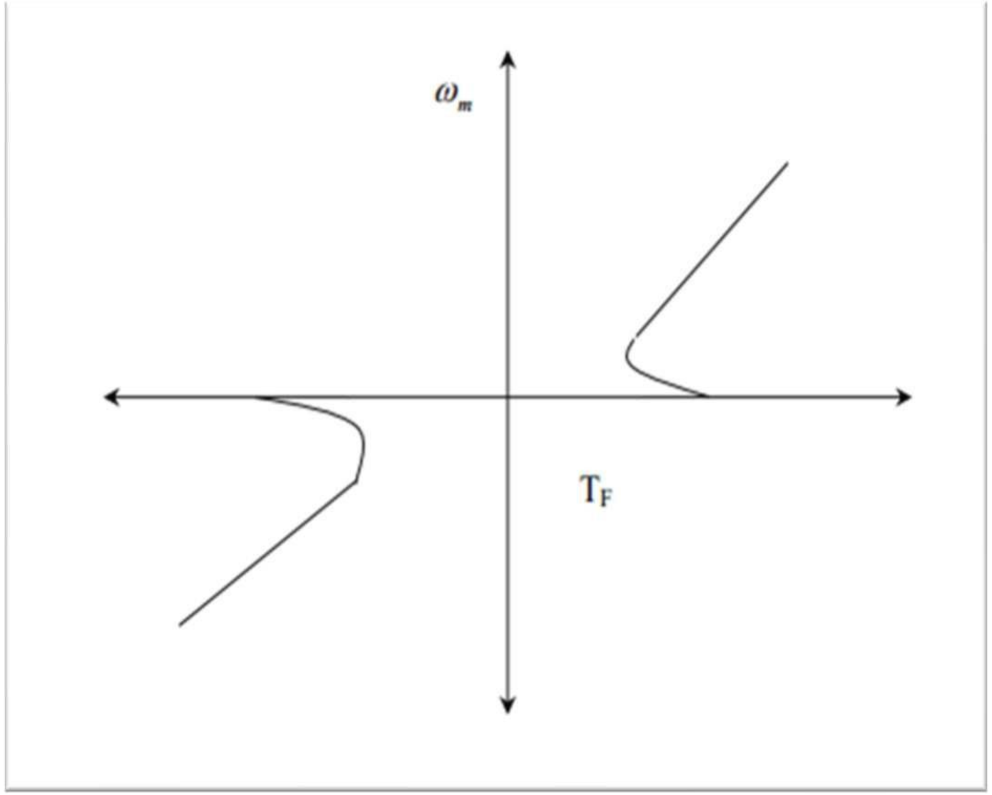
1. Friction will be present at the motor shaft and also in various parts of the load. T_F is the equivalent value of various friction torques referred to the motor shaft.
2. When motor runs, wind generates a torque opposing the motion. This is known as windage torque.
3. Nature of this torque(Torque required to do useful mechanical work) depends upon particular application. It may be constant and independent of speed. It may be some function of speed, it may be time invariant or time variant, its nature may also change with the load's mode of operation.

Friction Torque

- Value of friction torque with speed is shown in figure below

➢ Its value at stand still is much higher than its value slightly above zero speed. Friction at zero speed is called stiction or static friction.

➢ In order to start the drive the motor should at least exceed stiction.



Characteristics of Different types of Loads

- One of the essential requirements in the selection of a particular type of motor for driving a machine is the matching of speed-torque characteristics of the given drive unit and that of the motor.
- Therefore the knowledge of how the load torque varies with speed of the driven machine is necessary.
- Different types of loads exhibit different speed torque characteristics.
- However, most of the industrial loads can be classified into the following four categories:

i. *Constant torque type load*

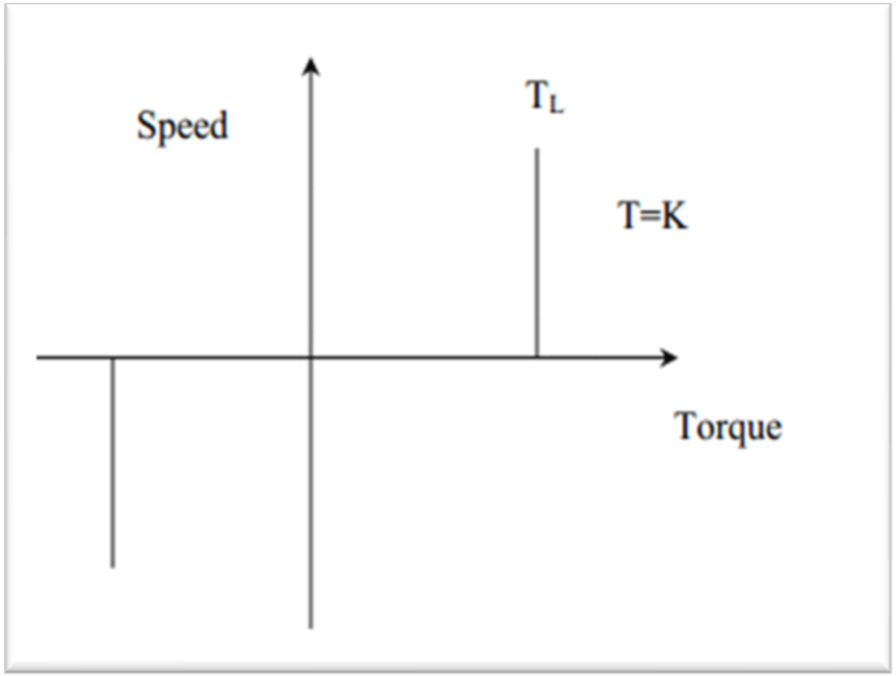
ii. *Torque proportional to speed (Generator Type load)*

iii. *Torque proportional to square of the speed (Fan type load)*

iv. *Torque inversely proportional to speed (Constant power type load)*

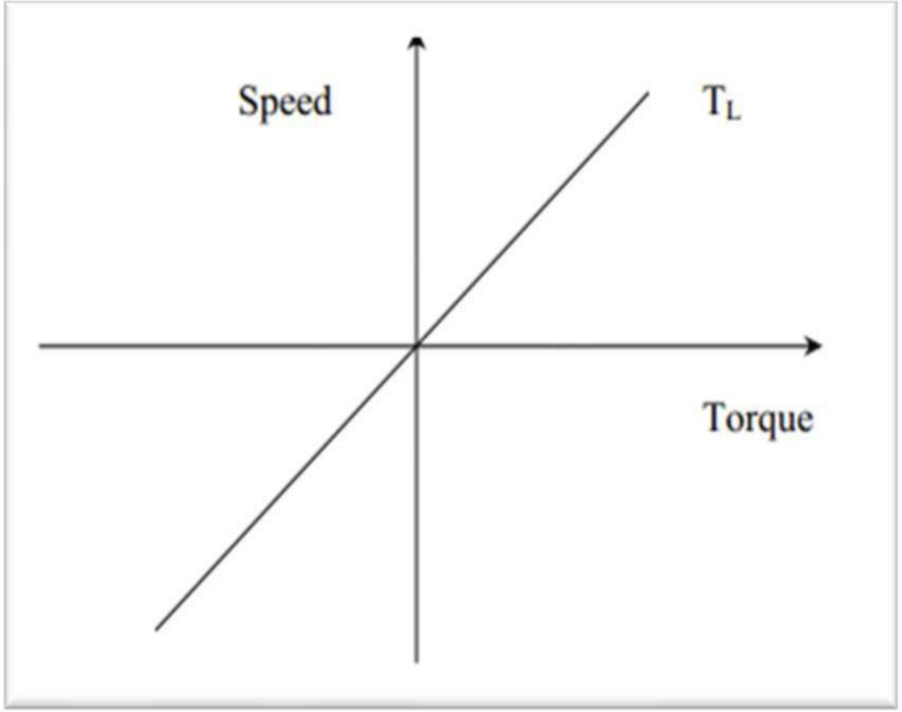
i. Constant Torque characteristics

- Most of the working machines that have mechanical nature of work like shaping, cutting, grinding or shearing, require constant torque irrespective of speed.
- Similarly cranes during the hoisting and conveyors handling constant weight of material per unit time also exhibit this type of characteristics.



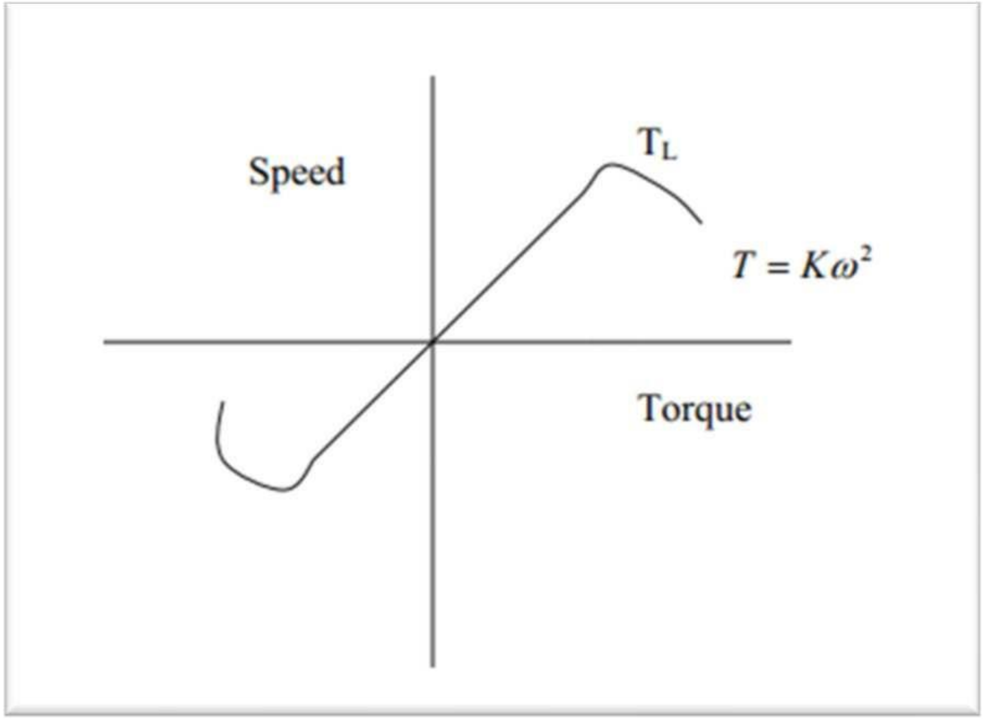
ii. Torque Proportional to speed

Separately excited dc generators connected to a constant resistance load, eddy current brakes have speed torque characteristics given by $T=k\omega$



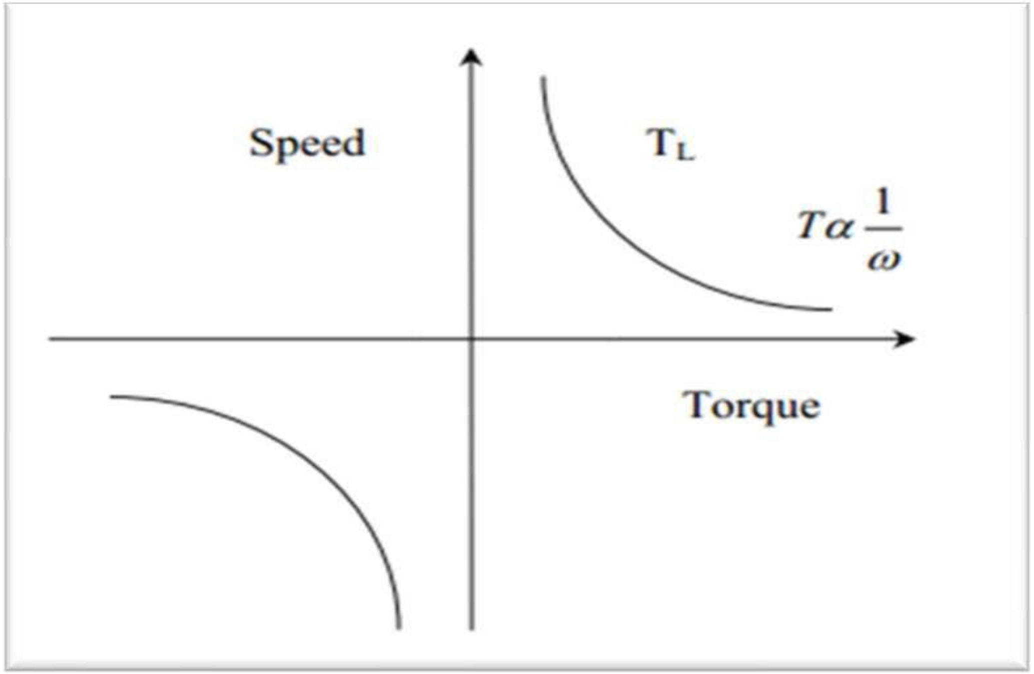
iii. Torque proportional to square of the speed

- Another type of load met in practice is the one in which load torque is proportional to the square of the speed.
- Ex: Fans rotary pumps, compressors and ship propellers.



iv. Torque Inversely proportional to speed

- Certain types of lathes, boring machines, milling machines, steel mill coiler and electric traction load exhibit hyperbolic speed-torque characteristics



Speed Torque Conventions and Multi-quadrant Operation

- For consideration of multi-quadrant operation of drives, it is useful to establish suitable conventions about the signs of torque and speed.
- Motor is considered positive when rotating in the forward direction.
- For drives which operate only in one direction, forward speed will be their normal speed.
- In loads involving up-and-down motions, the speed of motor which causes upward motion is considered forward motion.
- For reversible drives, forward speed is chosen arbitrarily. Then the rotation in opposite direction gives reverse speed which is assigned the negative sign.
- Positive motor torque is defined as the torque which produces acceleration or the positive rate of change of speed in forward direction.
- According to Eq. (1) positive load torque is opposite in direction to the positive motor torque. Motor torque is considered negative if it produces deceleration.

$$\boxed{T = T_l + J\frac{d\omega_m}{dt}} \quad (1)$$

Speed Torque Conventions and Multi-quadrant Operation cntd.

- A motor operates in two modes—motoring and braking.
- In motoring, it converts electrical energy to mechanical energy, which supports its motion.
- In braking, it works as a generator converting mechanical energy to electrical energy, and thus, opposes the motion.
- Motor can provide motoring and braking for both forward and reverse directions.
- Figure 2.2 shows the torque and speed coordinates for both forward (positive) and reverse (negative) motions.
- Power developed by a motor is given by the product of speed and torque.
- In quadrant I, developed power is positive. Hence, machine works as a motor supplying mechanical energy. Operation in quadrant I is, therefore, called forward motoring.

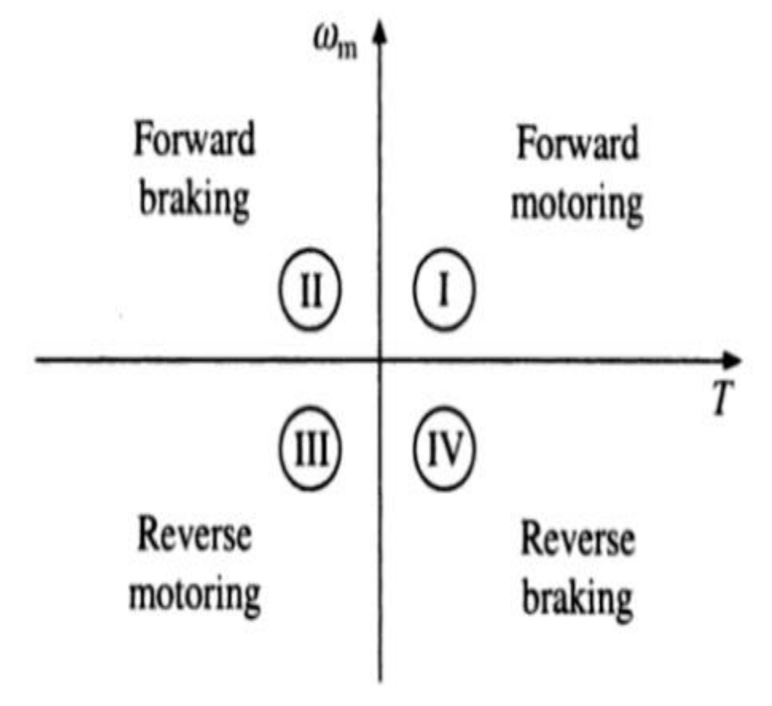


Fig. 2.2 Multiquadrant-operation of drives

- In quadrant II, power is negative. Hence, machine works under braking opposing the motion. Therefore, operation in Quadrant II is known as forward braking.
- Similarly, in quadrant Ill and IV can identified as reverse motoring and braking respectively.

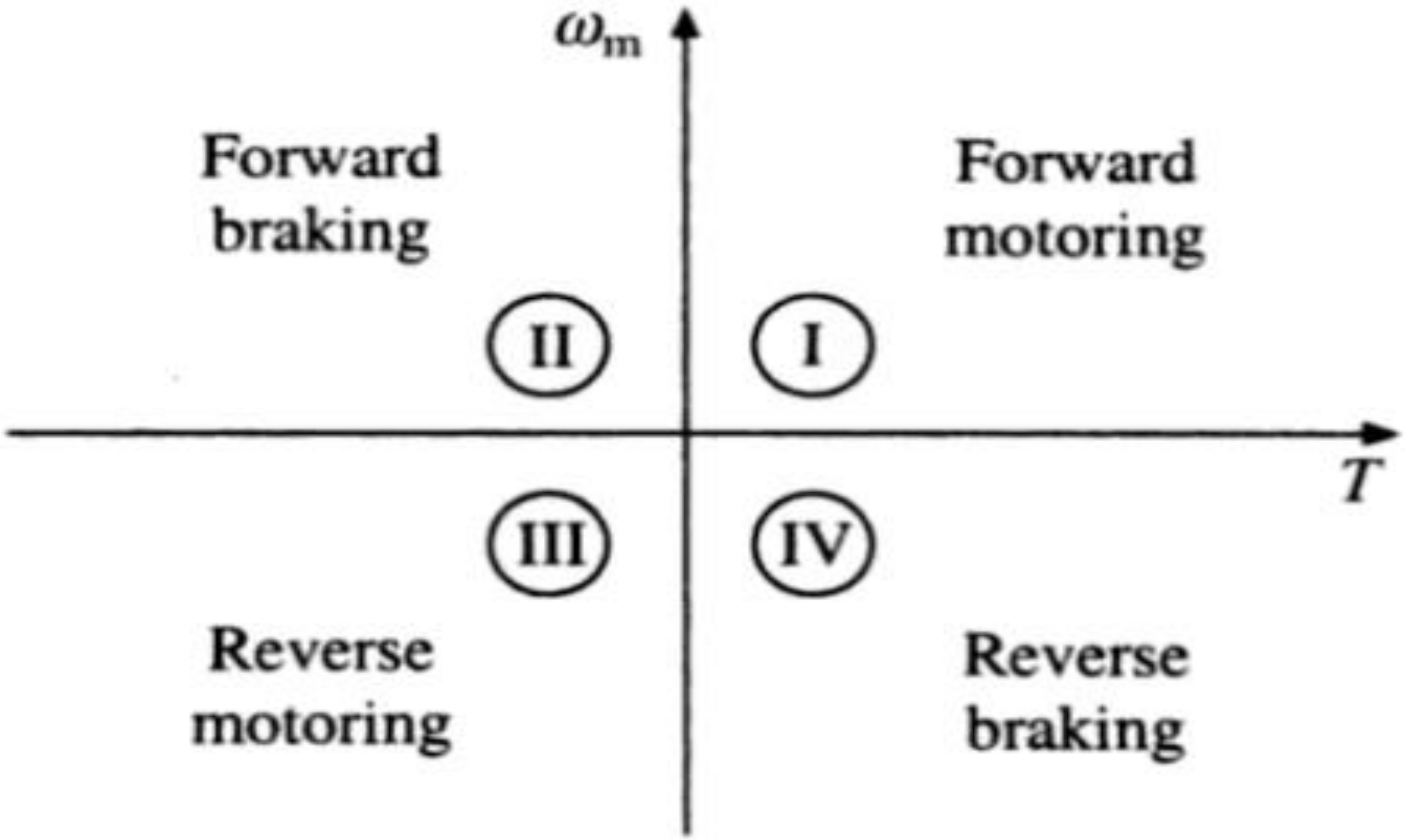


Fig. 2.2 Multiquadrant-operation of drives

Orientation of a hoist in four quadrants

- For better understanding of the above notations, **let us consider orientation of a hoist in four quadrants** as shown in Fig. 2.3. Directions of motor and load torques, and direction of speed are marked by arrows.
- A hoist consists of a rope wound on a drum coupled to the motor shaft.
- One end of the rope is tied to a cage which is used to transport man or material form one level to another level.
- Other end of the rope has a counter weight. Weight of the counter weight is chosen to be higher than the weight of an empty cage but lower than of a fully loaded cage.

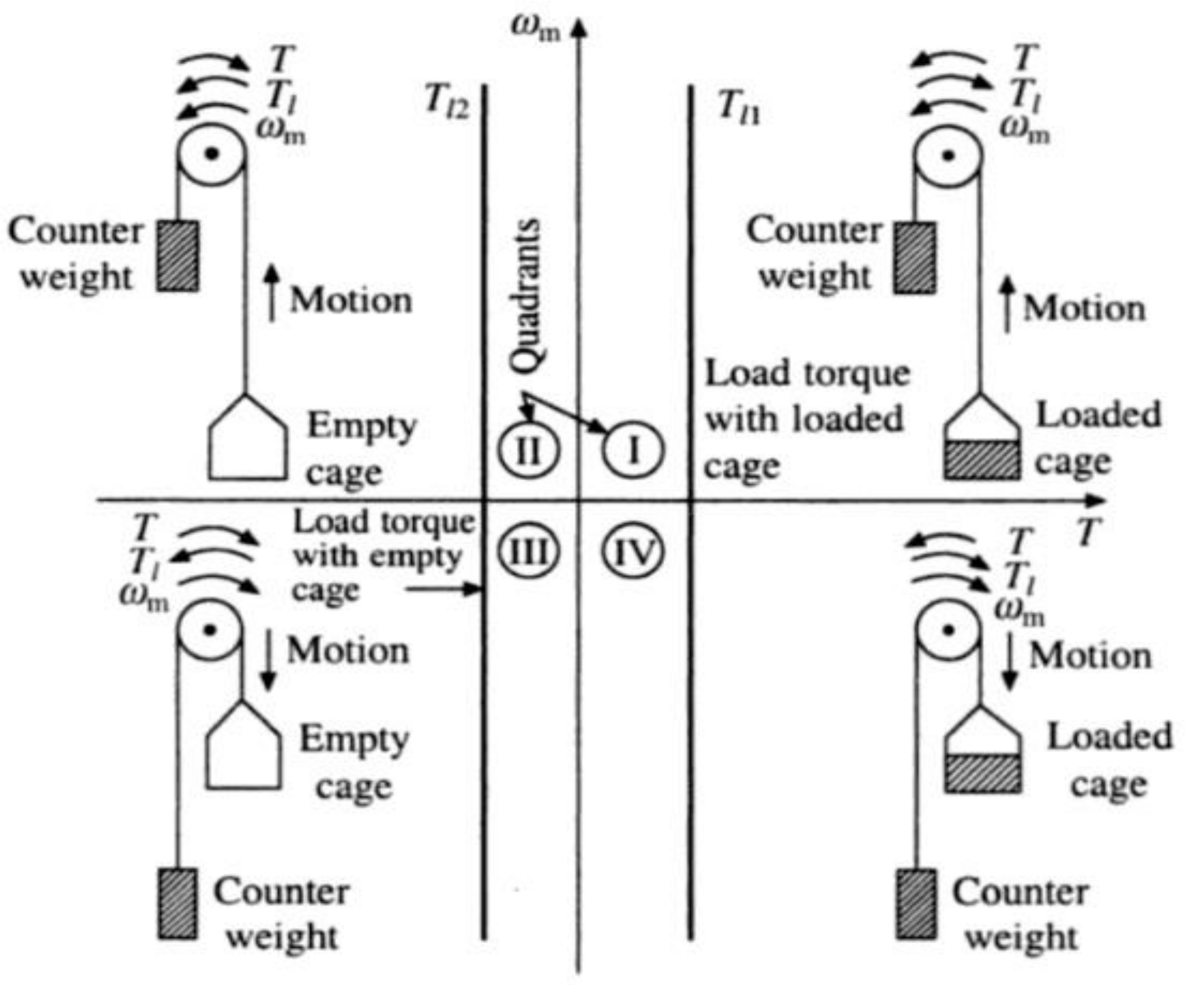


Fig. 2.3 Four quadrant operation of a motor driving a hoist load

Orientation of a hoist in four quadrants cntd.

- Forward direction of motor speed will be one which gives upward motion of the cage. Speed- torque characteristics of the hoist load are also shown in Fig. 2.3.
- Though the positive load torque is opposite in sign to the positive motor torque, according to Eq. (2.2), it is convenient to plot it on the same axes.
- Load-torque curve drawn in this manner is, in fact, negative of the actual.

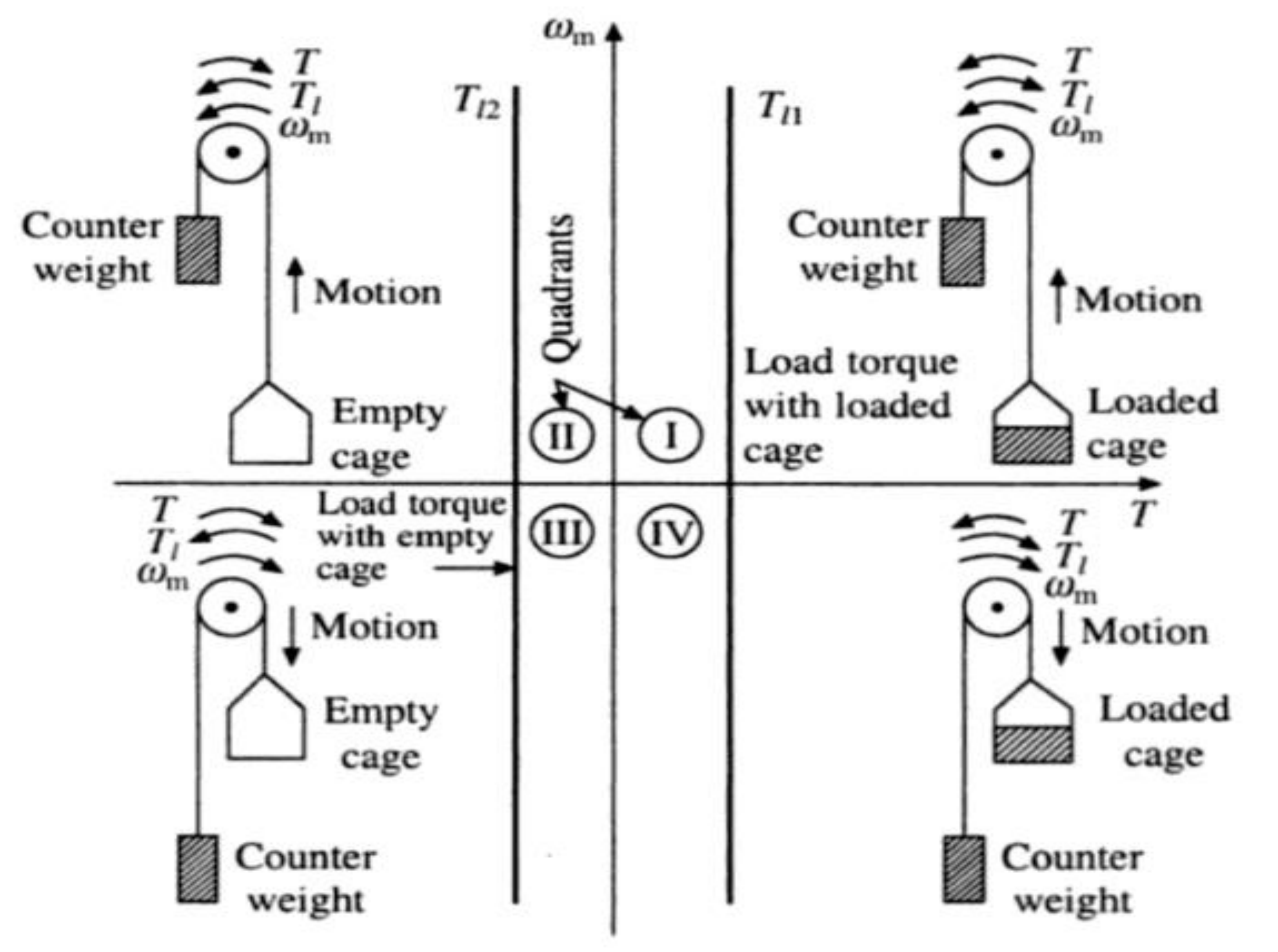


Fig. 2.3 Four quadrant operation of a motor driving a hoist load

- Load torque line T_{L1} in quadrants I and IV represents speed-torque characteristic for the loaded hoist. -This torque is the difference of torques due to loaded hoist and counter weight.
- The load torque line T_{L2} in quadrants II and III is the speed- torque characteristic for an empty hoist.- This torque is the difference of torques due to counter weight and the empty hoist. Its sign is negative because the weight of a counter weight is always higher than that of an empty cage.

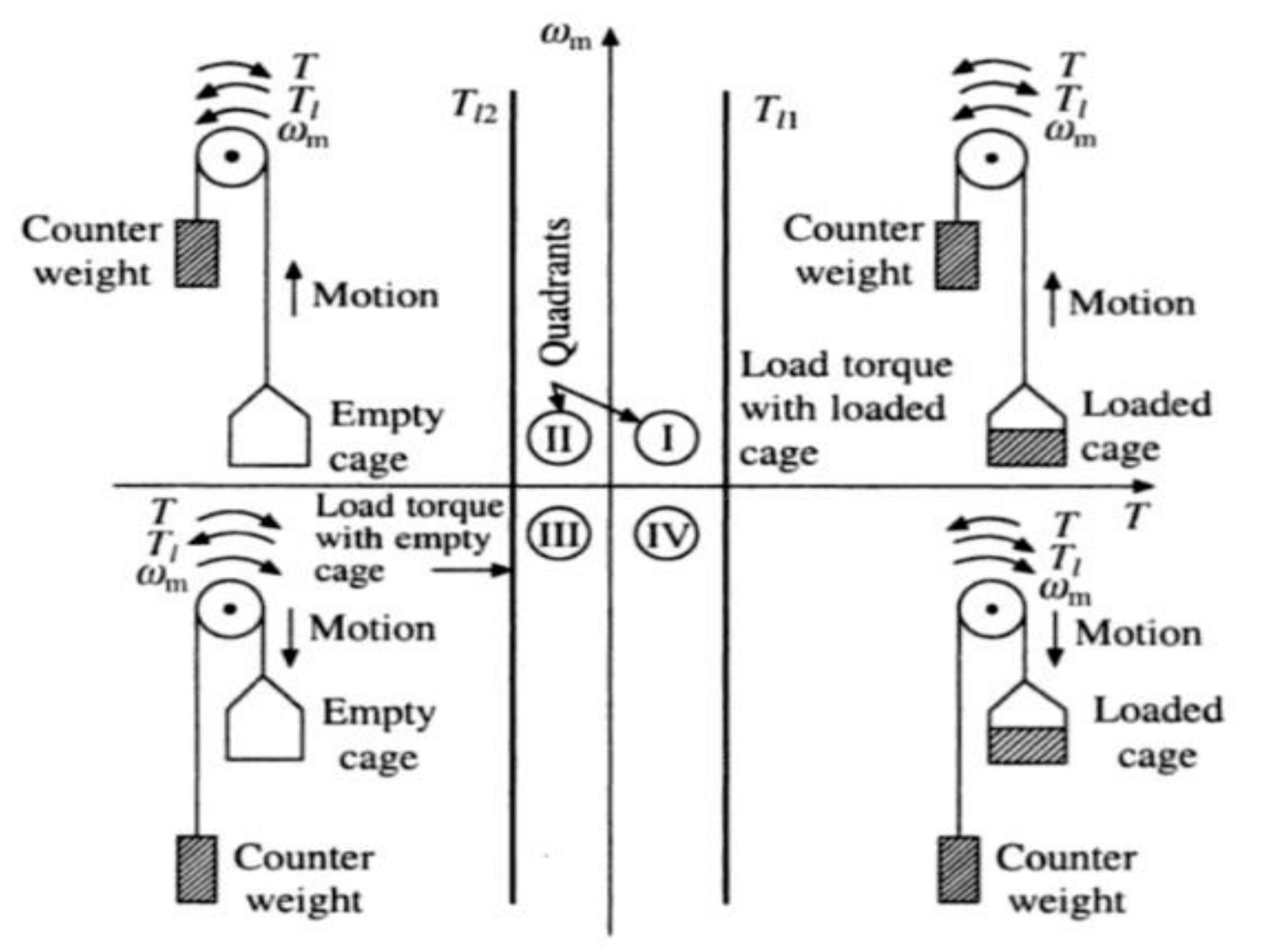


Fig. 2.3 Four quadrant operation of a motor driving a hoist load

The quadrant I operation of a hoist requires the movement of the cage upward, which corresponds to the positive motor speed which is in anticlockwise direction here. This motion will be obtained if the motor produces positive torque in anticlockwise direction equal to the magnitude of load torque T_{L1}. Since developed motor power is positive, this is forward motoring operation.

Quadrant IV operation is obtained when a loaded cage is lowered. Since the weight of a loaded cage is higher than that of a counter weight, it is able to come down due to the gravity itself. In order to limit the speed of cage within a safe value, motor must produce a positive torque T equal to T_{L2} in anticlockwise direction. As both power and speed are negative, drive is operating in reverse braking.

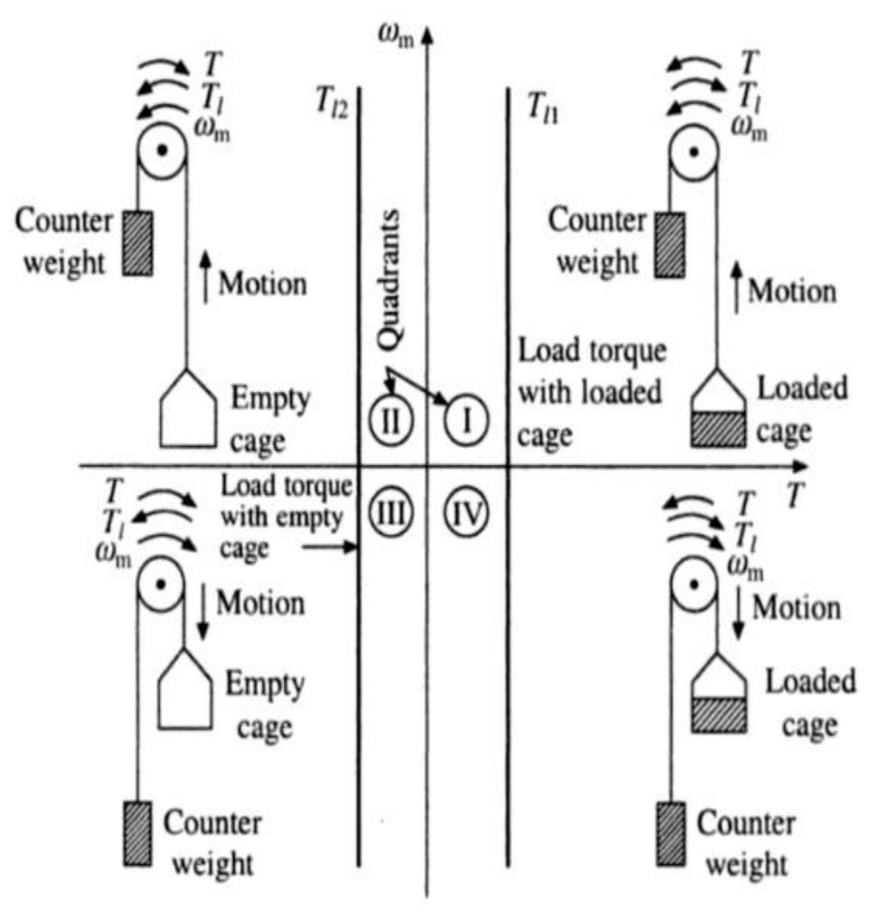


Fig. 2.3 Four quadrant operation of a motor driving a hoist load

Operation in quadrant II is obtained when an empty cage is moved up. Since a counter weight is heavier than an empty cage, it is able to pull it up. In order to limit the speed within a safe value, motor must produce a braking torque equal to T_{L2} in clockwise (negative) direction. Since speed is positive and power negative, it is forward braking.

Operation in quadrant III is obtained when an empty cage is lowered. Since an empty cage has a lesser weight than a counter weight, the motor should produce a torque in clockwise direction. Since speed is negative and developed power positive, this is reverse motoring operation.

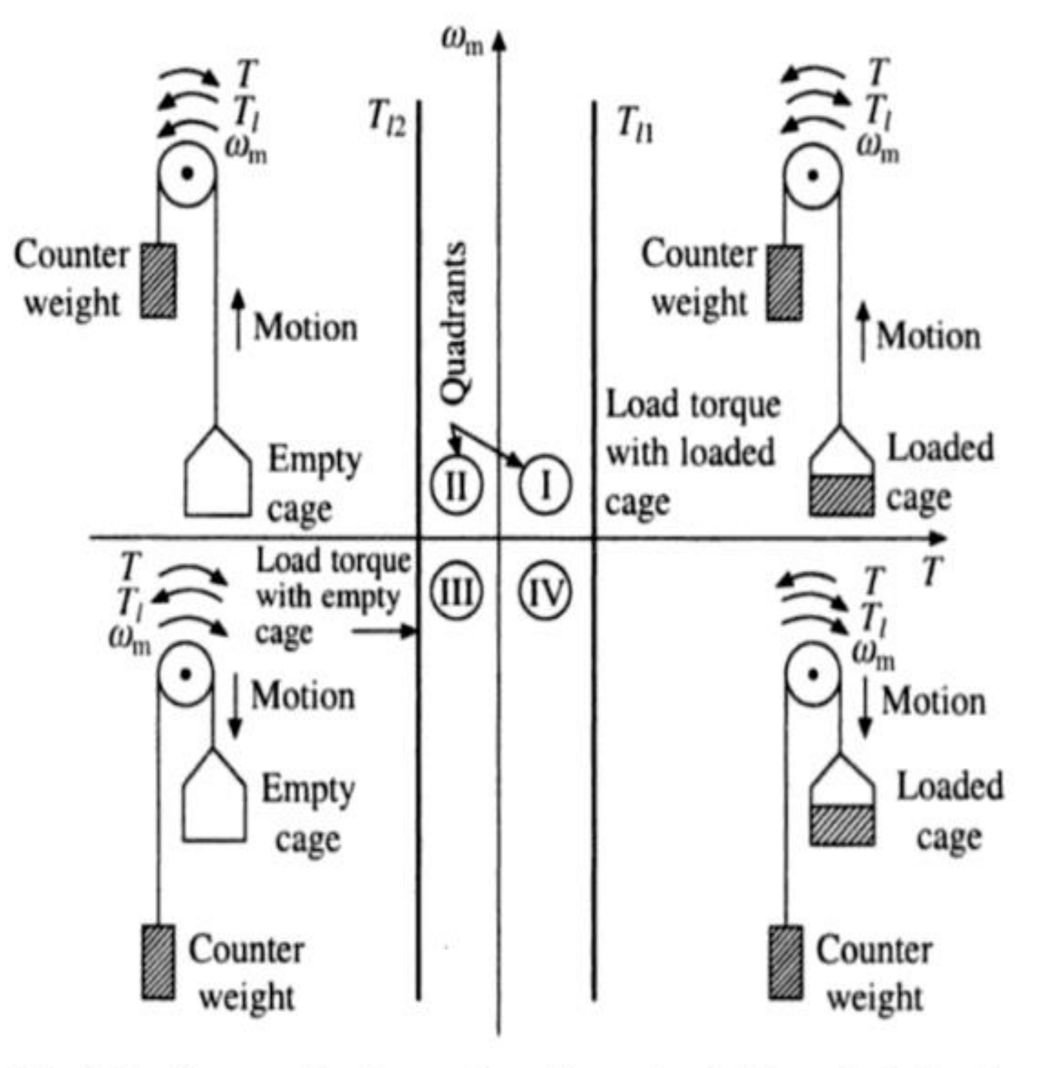
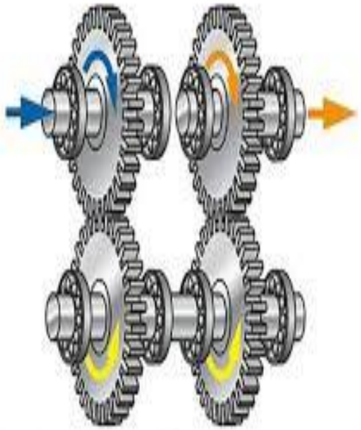


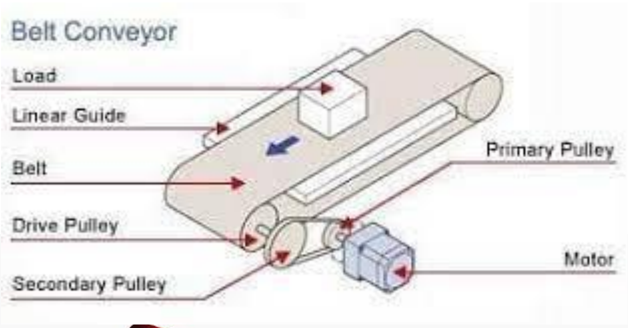
Fig. 2.3 Four quadrant operation of a motor driving a hoist load

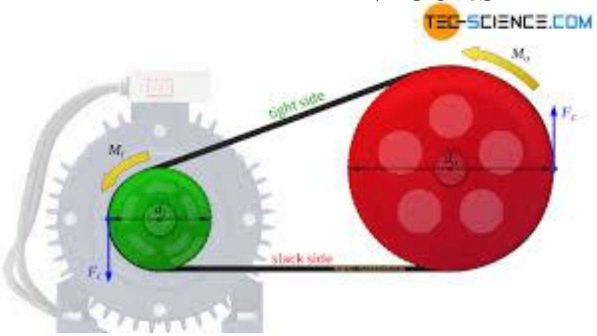
Equivalent Values of Drive Parameters

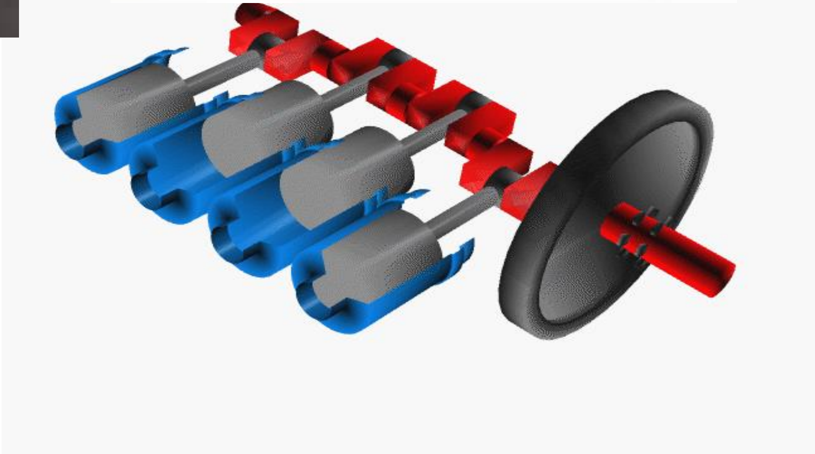
- Different parts of a load may be coupled through different mechanisms, such as gears, V-belts and crankshaft. These parts may have different speeds and different types of motions such as rotational and translational.
- The following presents the methods of finding the equivalent moment of inertia (J) of motor-load system and equivalent torque components, all referred to motor shaft.

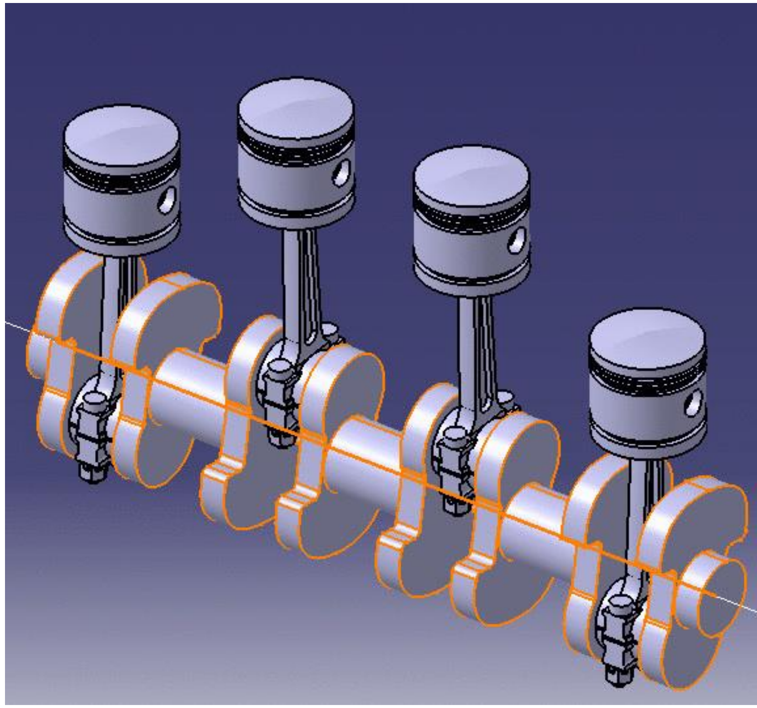

gears


V-belts



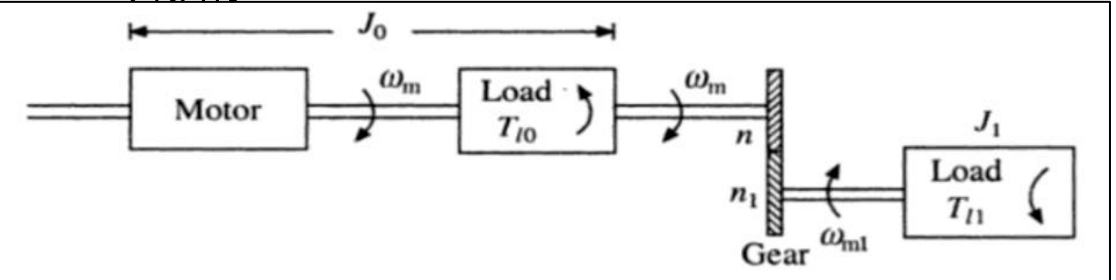





crankshaft

1. Loads with Rotational Motion

- Let us consider a motor driving two loads, one coupled directly to its shaft and other through a gear with n and n_1 and teeth as shown in Fig. (a).
- Let the moment of inertia of motor and load directly coupled to its shaft be Jo, motor speed and torque of the directly coupled load be ω_m and T_{LO} respectively.
- Let the moment of inertia, and torque of the load coupled through a gear be J_l, ω_{m1} and T_{L1} respectively. Now,



(a) Loads with rotational motion

$$\frac{\omega_{m1}}{\omega_m} = \frac{n}{n_1} = a_1 \quad (1)$$

where a_1 is the gear tooth ratio.

If the losses in transmission are neglected, then the **kinetic energy due to equivalent inertia** must be the same as kinetic energy of various moving parts. Thus

$$\boxed{\frac{1}{2}J\omega_m^2 = \frac{1}{2}J_0\omega_m^2 + \frac{1}{2}J_1\omega_{m1}^2} \quad (2)$$

$\omega_{m1} = a_1 . \omega_m$

From equations 1 and 2

$$\boxed{J = J_0 + a_1^2 J_1}$$

Power at the loads and motor must be the same. If transmission efficiency of the gears be m, then

$$\boxed{T_l\omega_m = T_{l0}\omega_m + \frac{T_{l1}\omega_{m1}}{\eta_1}}$$

$\omega_{m1} = a_1 . \omega_m$

where T_l is the total equivalent torque referred to motor shaft.

From Eqs. (2.3) and (2.6)

$$\boxed{T_l = T_{l0} + \frac{a_1 T_{l1}}{\eta_1}} \tag{2.7}$$

If in addition to load directly coupled to the motor with inertia J_0 there are m other loads with moment of inertias $J_1, J_2, \ldots, J_m$ and gear teeth ratios of $a_1, a_2, \ldots a_m$ then

$$\boxed{J = J_0 + a_1^2 J_1 + a_2^2 J_2 + \ldots + a_m^2 J_m} \tag{2.8}$$

If m loads with torques $T_{l1}, T_{l2}, \ldots, T_{lm}$ are coupled through gears with teeth ratios $a_1, a_2, \ldots a_m$ and transmission efficiencies $\eta_1, \eta_2, \ldots, \eta_m$, in addition to one directly coupled, then

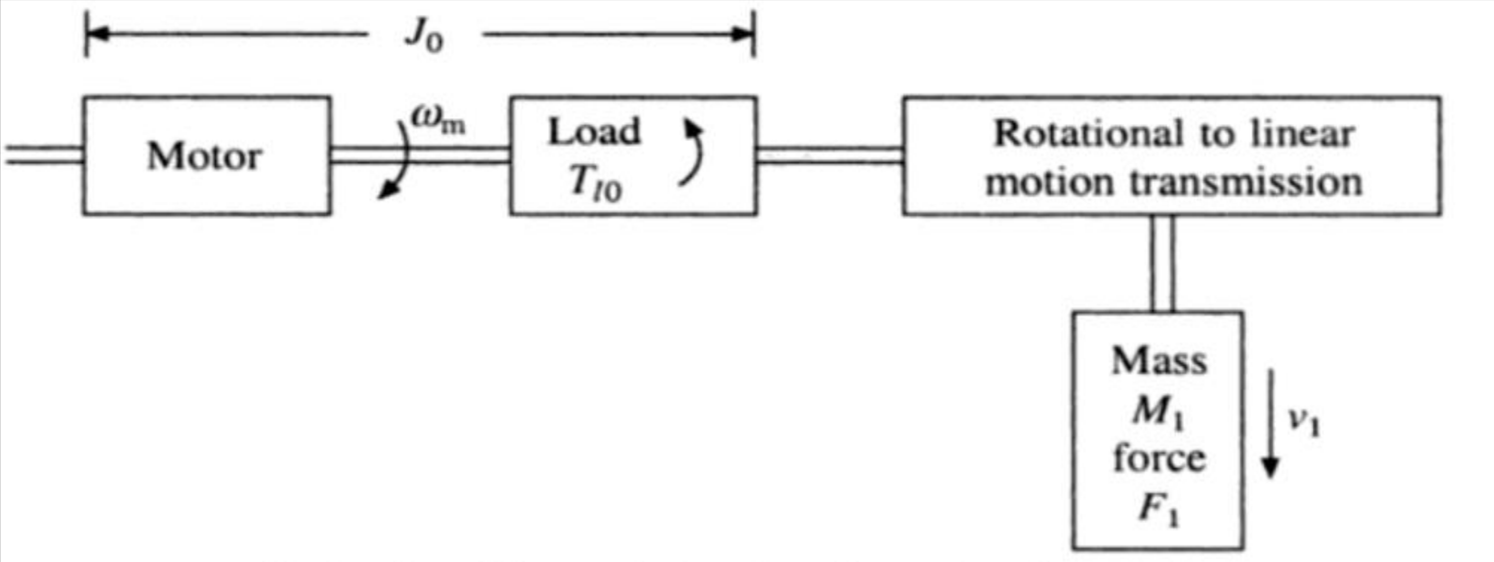
$$T_l = T_{l0} + \frac{a_1 T_{l1}}{\eta_1} + \frac{a_2 T_{l2}}{\eta_2} + \ldots + \frac{a_m T_{lm}}{\eta_m} \tag{2.9}$$

If loads are driven through a belt drive instead of gears, then, neglecting slippage, the equivalent inertia and torque can be obtained from Eqs. (2.8) and (2.9) by considering $a_1, a_2, \ldots, a_m$ each to be the ratios of diameters of wheels driven by motor to the diameters of wheels mounted on the load shaft.

2. Loads with Translational Motion

- Let us consider a motor driving two loads, one coupled directly to its shaft and other through a transmission system converting rotational motion to linear motion Fig (b).

- Let moment of inertia of the motor and load directly coupled to it be Jo, load torque directly coupled to motor be T_{LO}), and the mass, velocity and force of load with translational motion be M_1 (kg), V_1 (m/sec) and F_1 (Newtons), respectively.



(b) Loads with translational and rotational motion

If the transmission losses are neglected, then kinetic energy due to equivalent inertia J must be the same as kinetic energy of various moving parts. Thus

$$\frac{1}{2} J\omega_m^2 = \frac{1}{2} J_0\omega_m^2 + \frac{1}{2} M_1 v_1^2$$

or

$$J = J_0 + M_1\left(\frac{v_1}{\omega_m}\right)^2 \qquad (2.10)$$

Similarly, power at the motor and load should be the same, thus if efficiency of transmission be η_1

$$T_l \omega_m = T_{l0} \cdot \omega_m + \frac{F_1 v_1}{\eta_1}$$

or
$$T_l = T_{l0} + \frac{F_1}{\eta_1}\left(\frac{v_1}{\omega_m}\right) \tag{2.11}$$

If, in addition to one load directly coupled to the motor shaft, there are m other loads with translational motion with velocities $v_1, v_2, \ldots v_m$ and masses $M_1, M_2, \ldots, M_m$, respectively, then

$$J = J_0 + M_1\left(\frac{v_1}{\omega_m}\right)^2 + M_2\left(\frac{v_2}{\omega_m}\right)^2 + \ldots + M_m\left(\frac{v_m}{\omega_m}\right)^2 \tag{2.12}$$

and
$$T_l = T_{l0} + \frac{F_1}{\eta_1}\left(\frac{v_1}{\omega_m}\right) + \frac{F_2}{\eta_2}\left(\frac{v_2}{\omega_m}\right) + \ldots + \frac{F_m}{\eta_m}\left(\frac{v_m}{\omega_m}\right) \tag{2.13}$$

Measurement of Moment of Inertia

- Moment of inertia can be calculated if dimensions and weights of various parts of the load and motor are known. It can also be measured experimentally by **retardation test**.
- In **retardation test**, the drive is run at a speed slightly higher than rated speed and then the supply to it is cut off. Drive continues to run due to kinetic energy stored in it and decelerates due to rotational mechanical losses. Variation of speed with time is recorded.
- At any speed ω_m, power P consumed in supplying rotational losses is given by

$$P = \text{Rate of change of kinetic energy}$$

$$= \frac{d}{dt}\left(\frac{1}{2} J\omega_m^2\right) = J\omega_m \frac{d\omega_m}{dt} \qquad \text{Eq. (1).}$$

- From retardation test $d\omega_m/dt$ at rated speed is obtained.
- Now drive is reconnected to the supply and run at rated speed and rotational mechanical power input to the drive is measured. This is approximately equal to P. Now J can be calculated from Eq. (1).
- Main problem in this method is that rotational mechanical losses cannot be measured accurately because core losses and rotational mechanical losses cannot be separated.
- In view of this, retardation test on a dc separately excited motor or a synchronous motor is carried out with field on. Now core loss is included in the rotational loss, which is now obtained as a difference of armature power input armature copper loss.
- In case of a wound rotor induction motor, retardation test can be carried out by keeping the stator supply and opening the rotor winding connection.