INDUSTRIAL DRIVES & APPLICATIONS

MODULE – 1:

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.

AN INTRODUCTION TO ELECTRICAL DRIVES & ITS DYNAMICS

- 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 equation
- Speed torque conventions and multiquadrant operation.
- Equivalent values of drive parameters, components of low torques
- Nature and classification of load torques
- Calculation of time and energy loss in transient operations
- Steady state stability, load equalization.

Electrical Drives:

Motion control is required in large number of industrial and domestic applications like transportation systems, rolling mills, paper machines, textile mills, machine tools, fans, pumps, robots, washing machines etc.

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. Drives employing electric motors are known as ELECTRICAL DRIVES.

Classification of Electric Drives

According to Mode of Operation

- Continuous duty drives
- Short time duty drives
- Intermittent duty drives

According to Means of Control

- Manual
- Semi automatic
- Automatic

According to Number of machines

- Individual drive
- Group drive
- Multi-motor drive

According to Dynamics and Transients

- Uncontrolled transient period
- Controlled transient period

According to 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.

Advantages of Electrical Drive

1. They have flexible control characteristics. The steady state and dynamic characteristics of electric drives can be shaped to satisfy the load requirements.
2. Drives can be provided with automatic fault detection systems. Programmable logic controller and computers can be employed to automatically control the drive operations in a desired sequence.
3. They are available in wide range of torque, speed and power.
4. They are adaptable to almost any operating conditions such as explosive and radioactive environments
5. It can operate in all the four quadrants of speed-torque plane
6. They can be started instantly and can immediately be fully loaded
7. Control gear requirement for speed control, starting and braking is usually simple and easy to operate.

Choice (or) Selection of Electrical Drives

Choice of an electric drive depends on a number of factors. Some of the important factors are.

1. Steady State Operating conditions requirements

   Nature of speed torque characteristics, speed regulation, speed range, efficiency, duty cycle, quadrants of operation, speed fluctuations if any, ratings etc
2. Transient operation requirements

   Values of acceleration and deceleration, starting, braking and reversing performance.
3. Requirements related to the source

   Types of source and its capacity, magnitude of voltage, voltage fluctuations, power factor, harmonics and their effect on other loads, ability to accept regenerative power.

4. Capital and running cost, maintenance needs life.
5. Space and weight restriction if any.
6. Environment and location.
7. Reliability.

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.

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.
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.

A modern variable speed electrical drive system has the following components

Electrical machines and loads

Power Modulator
Sources

Control unit

Sensing unit

Electrical Machines

Most commonly used electrical machines for speed control applications are the following

DC Machines

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

AC Machines

Induction, wound rotor, synchronous, PM synchronous and synchronous reluctance machines.

Special Machines

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

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)

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.

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

Control unit for a power modulator are provided in the control unit. It matches the motor and power converter to meet the load requirements.

Classification of Electrical Drives

Another main classification of electric drive is

DC drive, AC drive

Comparison between DC and AC drives

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

Applications

Paper mills

Cement Mills

Textile mills

Sugar Mills

Steel Mills

Electric Traction

Petrochemical Industries

Electrical Vehicles

Dynamics of Electrical drives:

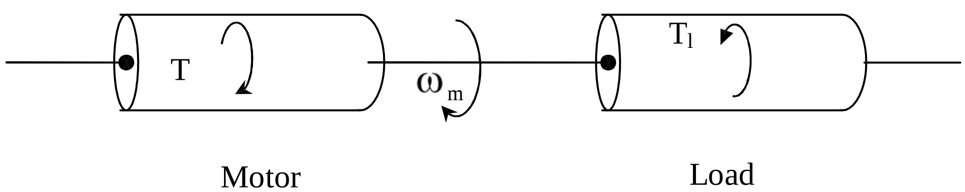
Fundamental torque equations

Dynamics of Motor Load System

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.



Notations Used:

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_l = Instantaneous value of load torque, referred to the motor shaft N-m

Load torque includes friction and wind age 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 $\frac{dJ}{dt} = 0$

$$\therefore T = T_l + J\frac{d\omega_m}{dt} \text{------------------}(2)$$

Speed torque conventions

Classification of Load Torques:

Various load torques can be classified into broad categories.

Active load torques

Passive load torques

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)

Eg: Torque due to force of gravity

Torque due tension

Torque due to compression and torsion etc.

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

Eg: Torque due to friction, cutting etc.

Components of load torque

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

(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 the motor shaft.

(ii) Windage Torque (T_W)

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

(iii) Torque required to do useful mechanical work.

Nature of this torque 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.

Another component T_C, which is independent of speed, is known as COULOMB friction. Third component T_S accounts for additional torque present at stand still. Since Ts is present only at stand still it is not taken into account in the dynamic analysis. Windage torque, T_W which is proportional to speed
squared is given by

From the above discussions, for finite speed

$$T_l = T_L + B\omega_m + T_C + C\omega_m^2$$

Characteristics of Different types of Loads

One of the essential requirements in the section 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.

Constant torque type load

Torque proportional to speed (Generator Type load)

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

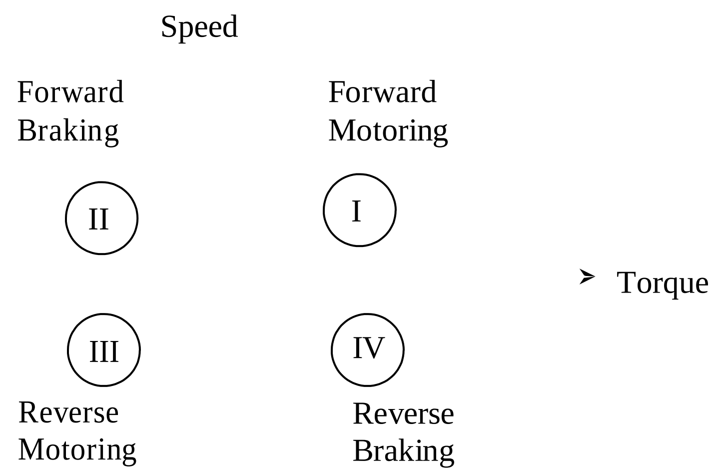
Torque inversely proportional to speed (Constant power type load)

Constant Torque characteristics:

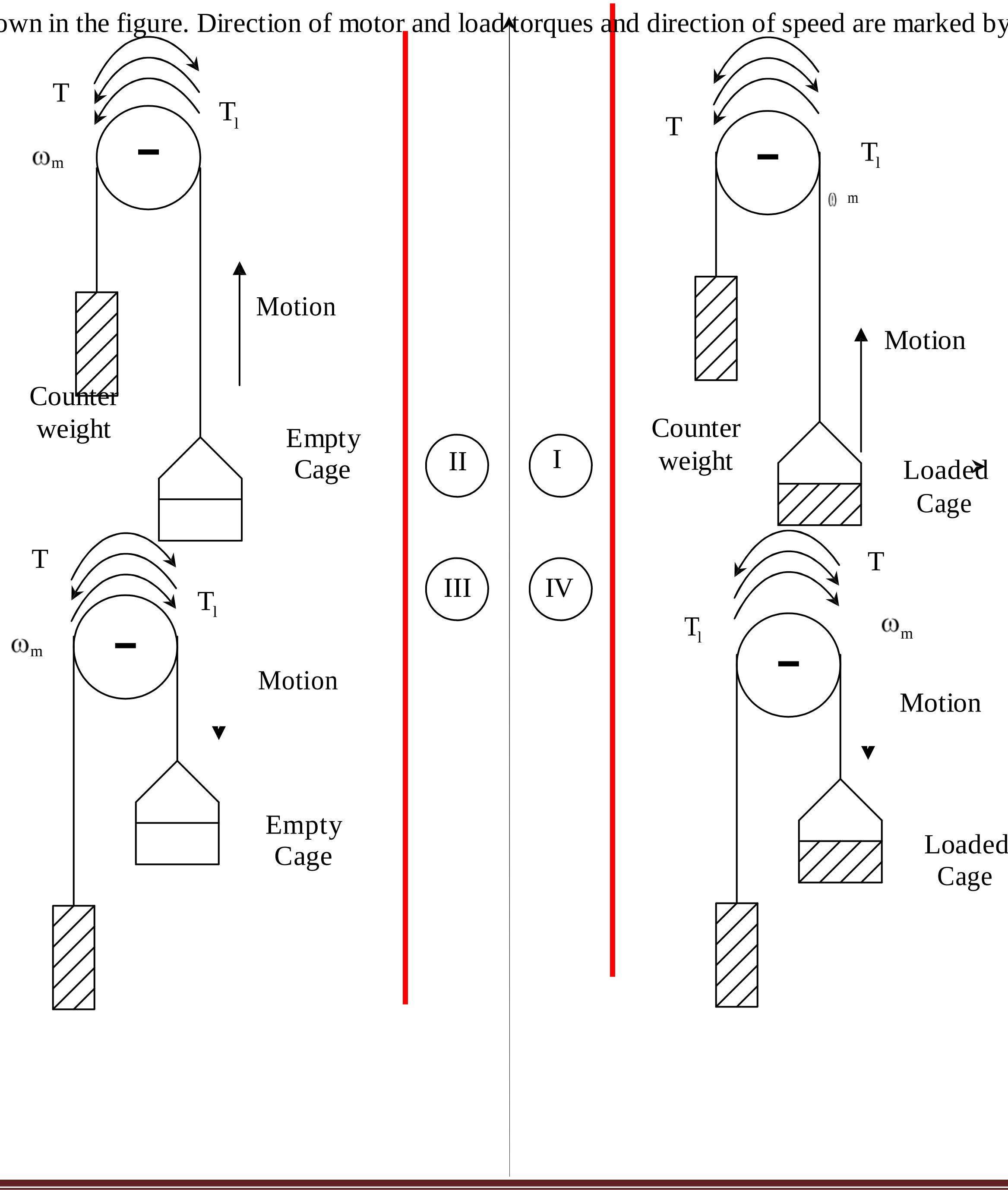
Most of the working machines that have mechanical nature of work like shaping, cutting, grinding or shearing, require constant torque irrespective of speed. Similarly cranes during the hoisting and conveyors handling constant weight of material per unit time also exhibit this type of characteristics.

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. A motor operates in two modes – Motoring and braking. In motoring, it converts electrical energy into mechanical energy, which supports its motion. In braking it works as a generator converting mechanical energy into electrical energy and thus opposes the motion. Motor can provide motoring and braking operations for both forward and reverse directions. Figure shows the torque and speed co-ordinates for both forward and reverse motions. Power developed by a motor is given by the product of speed and torque. For motoring operations power developed is positive and for braking operations power developed is negative.


Speed
Forward Braking
Forward Motoring
II
I
Torque
III
IV
Reverse Motoring
Reverse Braking

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. In quadrant II, power developed is negative. Hence, machine works under braking opposing the motion. Therefore operation in quadrant II is known as forward braking. Similarly operation in quadrant III and IV can be identified as reverse motoring and reverse braking since speed in these quadrants is negative. For better understanding of the above notations, let us consider operation of hoist in four quadrants as shown in the figure. Direction 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 from 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 empty cage but lower than of a fully loaded cage. Forward direction of motor speed will be one which gives upward motion of the cage. Load torque line in quadrants I and IV represents speed-torque characteristics of the loaded hoist. This torque is the difference of torques due to loaded hoist and counter weight.

The load torque in quadrants II and III is the speed torque characteristics for an empty hoist. This torque is the difference of torques due to counter weight and the empty hoist. Its sigh is negative because the counter weight is always higher than that of an empty cage.

The quadrant I operation of a hoist requires movement of cage upward, which corresponds to the positive motor speed which is in counter clockwise direction here. This motion will be obtained if the motor products positive torque in CCW direction equal to the magnitude of load torque T_{L1}. Since developed power is positive, this is forward motoring operation. Quadrant IV is obtained when a loaded cage is lowered. Since the weight of the loaded cage is higher than that of the counter weight .It is able to overcome due to gravity itself.

In order to limit the 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 operation. Operation in quadrant II is obtained when an empty cage is moved up. Since a counter weigh is heavier than an empty cage, its 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 direction. Since speed is positive and developed power is negative, it’s forward braking operation.

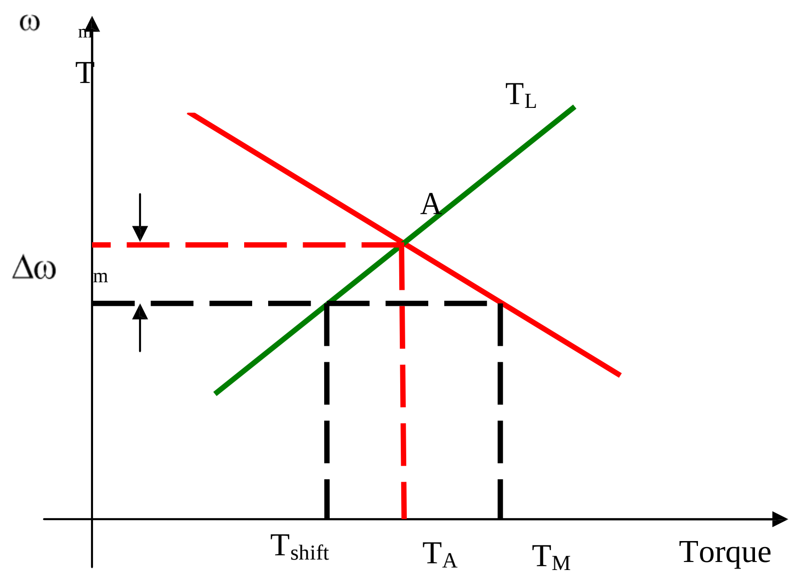
Operation in quadrant III is obtained when an empty cage is lowered. Since an empty cage has a lesser weight than a counter weight, the motor should produce a torque in CW direction. Since speed is negative and developed power is positive, this is reverse motoring operation.

Steady State Stability:

Equilibrium speed of motor-load system can be obtained when motor torque equals the load torque. Electric drive system will operate in steady state at this speed, provided it is the speed of stable state equilibrium. Concept of steady state stability has been developed to readily evaluate the stability of an equilibrium point from the steady state speed torque curves of the motor and load system.

In most of the electrical drives, the electrical time constant of the motor is negligible compared with the mechanical time constant. During transient condition, electrical motor can be assumed to be in electrical equilibrium implying that steady state speed torque curves are also applicable to the transient state operation.

Now, consider the steady state equilibrium point A shown in figure below



The equilibrium point will be termed as stable state when the operation will be restored to it

after a small departure from it due to disturbance in the motor or load. Due to disturbance a reduction of $\Delta\omega_m$ in speed at new speed, electrical motor torque is greater than the load torque, consequently motor will accelerate and operation will be restores to point A, similarly an increase in $\Delta\omega_m$ speed caused by a disturbance will make load torque greater than the motor torque, resulting into deceleration and restoring of operation to point A.

Now consider equilibrium point B which is obtained when the same motor drives another load as shown in the figure. A decrease in speed causes the load torque to become greater than the motor torque, electric drive decelerates and operating point moves away from point B. Similarly when working at point B and increase in speed will make motor torque greater than the load torque.

Load equalization

In the regenerative braking operation, the motor operates as generator, while it is still connected to the supply. Here, the motor speed is greater than the synchronous speed. Mechanical energy is converted into electrical energy, part of which is returned to the supply and rest of the energy is last as heat in the winding and bearings of electrical machines pass smoothly from motoring region.

An example of regenerative braking is shown in the figure below. Here an electric motor is driving a trolley bus in the uphill and downhill direction. The gravity force can be resolved into two components in the uphill direction. One is perpendicular to the load surface (F) and another one is parallel to the road surface Fl. The parallel force pulls the motor towards bottom of the hill.

Now we consider that the same bus is traveling in down hill, the gravitational force doesn't change its direction but the load torque pushes the motor towards the bottom of the hill. The motor produces a torque in the reverse direction because the direction of the motor torque is always opposite to the direction of the load torque. Here the motor is still in the same direction on both sides of the hill. This is known as regenerative braking. The energy is exchange under regenerative braking operation is power flows from mechanical load to source. Hence, the load is driving the machine and the machine is generating electric power that is returned to the supply.

Regenerative braking of Induction motor:

An induction motor is subjected to regenerative braking, if the motor rotates in the same direction as that of the stator magnetic field, but with a speed greater than the synchronous speed. Such a state occurs during any one of the following process.

Downward motion of a loaded hoisting mechanism

During flux weakening mode of operation of IM.

Calculation of time and energy loss in transient operations

Modes of Operation

An electrical drive operates in

three modes:

Steady state

Acceleration including Starting

Deceleration including Stopping.

Regenerative Braking for DC motor:

In regenerative braking of dc motor, generated energy is supplied to the source. For this the following condition is to be satisfied.

$E > V$ and I_a should be negative

According to the above expression the steady state operation takes place when motor torque equals the load torque. The steady state operation for a given speed is realized by adjustment of steady state motor speed torque curve such that the motor and load torques are equal at this speed. Change in speed is achieved by varying the steady state motor speed torque curve so that motor torque equals the load torque at the new desired speed. In the figure shown below when the motor parameters are adjusted to provide speed torque curve 1, drive runs at the desired speed.Speed is changed to when the motor parameters are adjusted to provide speed torque curve 2. When load torque opposes motion, the motor works as a motor operating in quadrant I or III depending on the direction of rotation. When the load is active it can reverse its sign and act to assist the motion. Steady state operation for such a case can be obtained by adding a mechanical brake which will produce a torque in a direction to oppose the motion. The steady state operation is obtained at a speed for which braking torque equal the load torque. Drive operates in quadrant II or IV depending upon the rotation.