1.2 Equations governing motor load dynamics:

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.

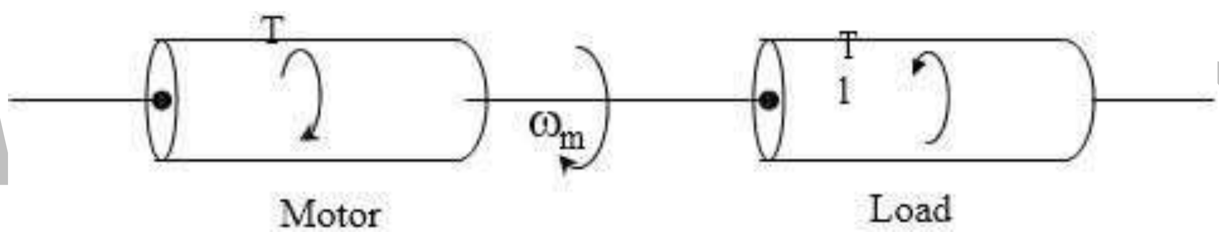


Figure 1.2.1 Motor Load System

(Source: "Fundamentals of Electrical Drives" by G.K.Dubey,page-11)

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.

$$T - T_l = d/dt\,(J\,\omega_m) = J\,d/dt\,(\omega_m) + \omega_m\,dJ/dt \quad \ldots\ldots\ldots\ldots (1)$$

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

For drives with constant inertia

$$\frac{dJ}{dt}=0$$

$$T=T_1+J\ d/dt\ (\omega_m) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Equation (2) shows that torque developed by motor

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 Torques:

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

√ 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.

√ Windage Torque (T_W)

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

√ 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.

Friction at zero speed is called diction or static friction. In order to start the drive the motor should at least exceeds diction.

Friction torque can also be resolved into three components

Component T_v varies linearly with speed is called VISCOUS friction and is given by

$$T_v = B\ m$$

Where B is viscous friction co-efficient.

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.

1.5 Acceleration, deceleration, starting & stopping:

An electrical drive operates in three modes

- ✓ Steady state
- ✓ Acceleration including Starting
- ✓ Deceleration including Stopping

We know that

$$T = T1 + J \frac{d}{dt}(\omega_m)$$

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 ω_m.

Speed is changed to ω_{m} 2 when the motor parameters are adjusted to provide speed torque curve

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.

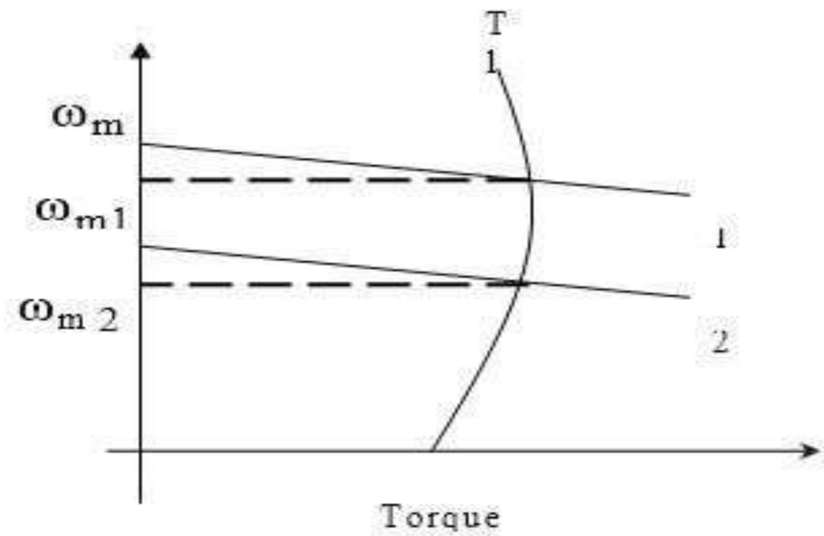


Figure 1.2.1 Speed Torque principle

(Source: "Fundamentals of Electrical Drives" by G.K.Dubey,page-32)

Acceleration and Deceleration modes are transient modes. Drive operates in acceleration mode whenever an increase in its speed is required. For this motor speed torque curve must be changed so that motor torque exceeds the load torque. Time taken for a given change in speed depends on inertia of motor load system and the amount by which motor torque exceeds the load torque.

Increase in motor torque is accompanied by an increase in motor current. Care must be taken to restrict the motor current with in a value which is safe for both motor and power modulator. In applications involving acceleration periods of long duration, current must not be allowed to exceed the rated value.

When acceleration periods are of short duration a current higher than the rated value is allowed during acceleration.

In closed loop drives requiring fast response, motor current may be intentionally forced to the maximum value in order to achieve high acceleration. Figure shown below shows the transition from operating point A at speed.

Point B at a higher speed ω_{m2}, when the motor torque is held constant during acceleration. The path consists of AD1E1B. In the figure below, 1 to 5 are motor speed torque curves. Starting is a special case of acceleration where a speed change from 0 to a desired speed takes place. All points mentioned in relation to acceleration are applicable to starting.

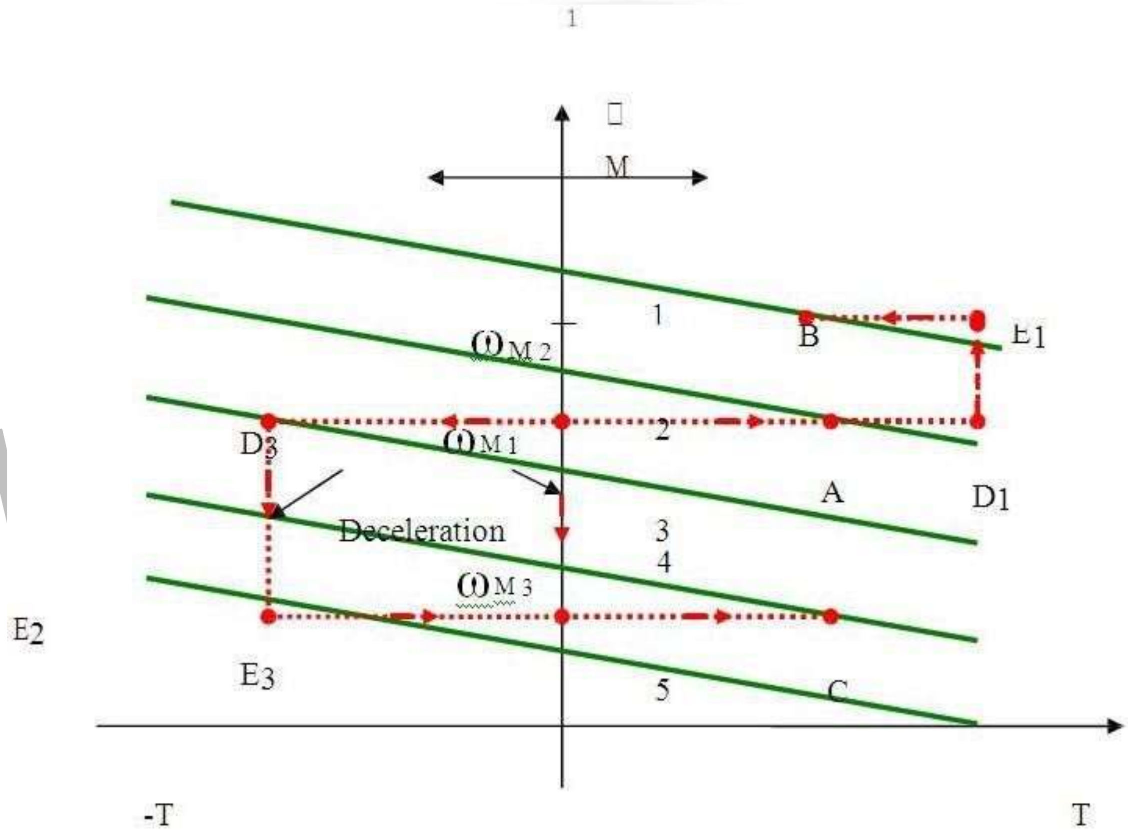


Figure 1.5.2Acceleration and Deceleration of motor

(Source:"Fundamentals of Electrical Drives" by G.K.Dubey,page-33)

The maximum current allowed should not only be safe for motor and power modulator but drop in source voltage caused due to it should also be in acceptable limits. In some applications the motor should accelerate smoothly, without any jerk. This is achieved when the starting torque can be increased stepless from its zero value. Such a start is known as soft start.

1.1 Introduction Electrical Drives:

Nowadays, modern power electronics and drives are used in electrical as well as mechanical industry. The power converter or power modulator circuits are used with electrical motor drives, providing either DC or AC outputs, and working from either a DC (battery) supply or from the conventional AC supply. Here we will highlight the most important aspects which are common to all types of drive converters. Although there are many different types of converters, all except very low-power ones are based on some form of electronic switching. The need to adopt a switching strategy is emphasized in the Wrist example, where the consequences are explored in some depth. We will see that switching is essential in order to achieve high-efficiency power conversion, but that the resulting waveforms are inevitably less than ideal from the point of view of the motor.

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.

An Electric Drive can be defined as an electromechanical device for converting electrical energy into mechanical energy to impart motion to different machines and mechanisms for various kinds of process control.

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.

They have flexible control characteristics. The steady state and dynamic characteristics of electric drives can be shaped to satisfy the load requirements.

1. 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.
2. They are available in wide range of torque, speed and power.
3. They are adaptable to almost any operating conditions such as explosive and radioactive environments
4. It can operate in all the four quadrants of speed-torque plane
5. They can be started instantly and can immediately be fully loaded.

1.4 Multi quadrant Dynamics:

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.

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, which will move the operating point away from point B

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.

The figure below represents a DC motor attached to an inertial load. 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.

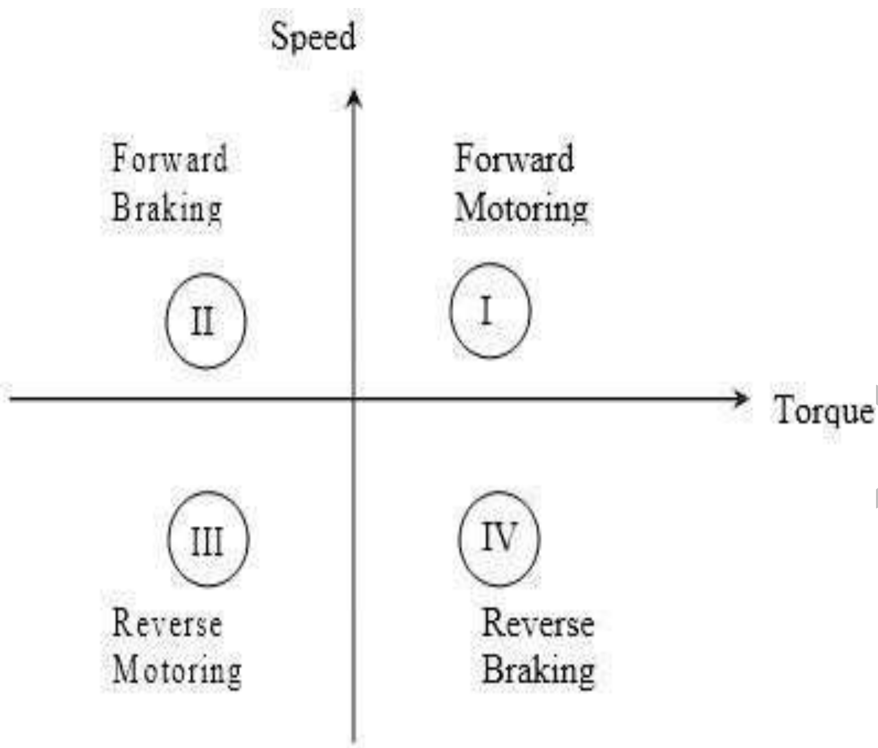


Figure 1.4.1 Four quadrant operation of drives

(Source:"Fundamentals of Electrical Drives" by G.K.Dubey,page-12)

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.

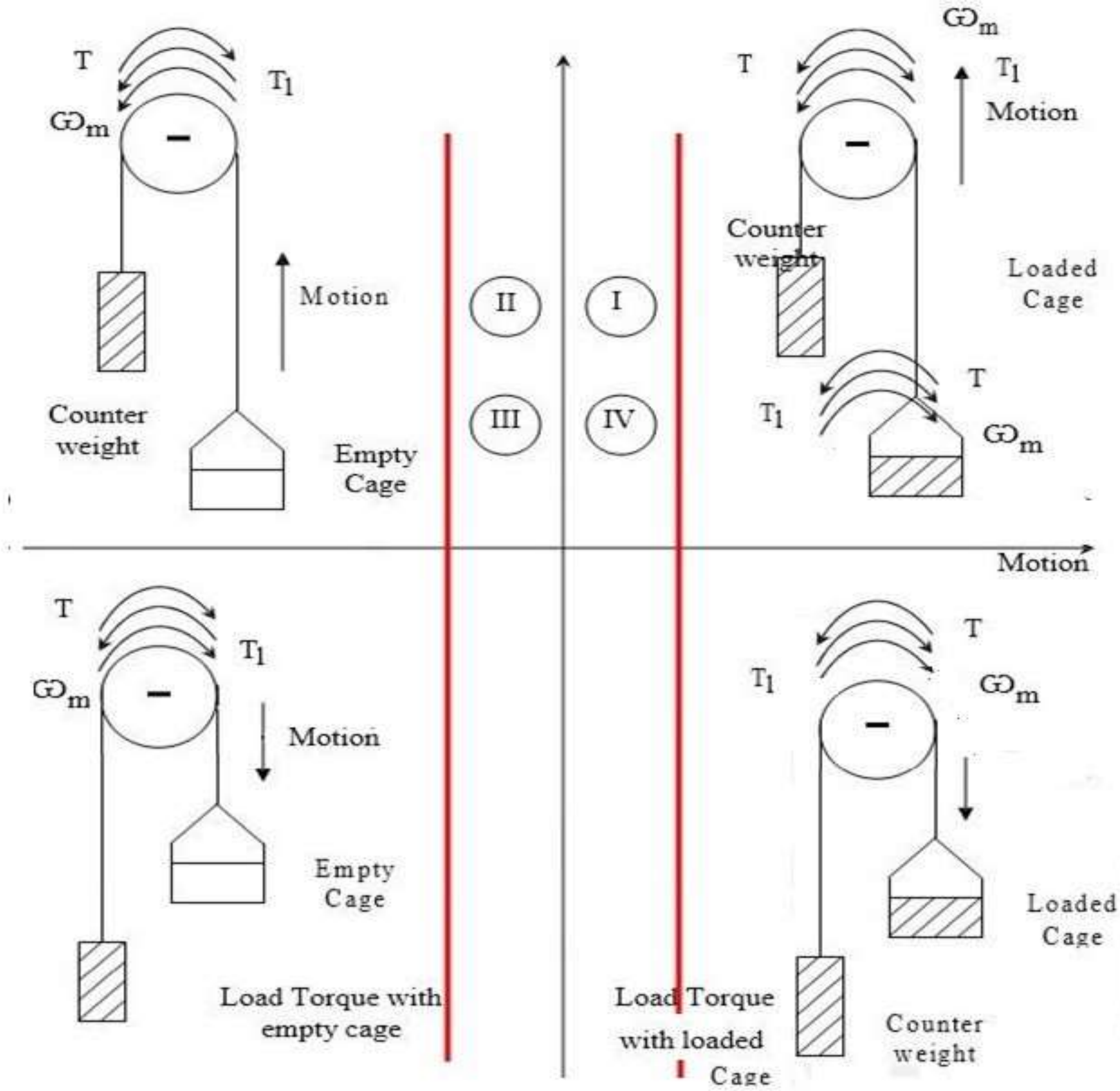


Figure 1.4.2 Operation of hoist in four quadrants

(Source:"Fundamentals of Electrical Drives" by G.K.Dubey,page-13)

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. 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.

1.7 Selection of Motor for Electrical Drives

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

- √ 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

- √ Transient operation requirements:

  Values of acceleration and deceleration, starting, braking and reversing performance.

- √ 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

- √ Capital and running cost, maintenance needs life.

- √ Space and weight restriction if any.

- √ Environment and location.

- √ 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 sometimes 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.

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.

Classification of Electrical Drives

Another main classification of electric drive is

- √ DC drive
- √ AC drive

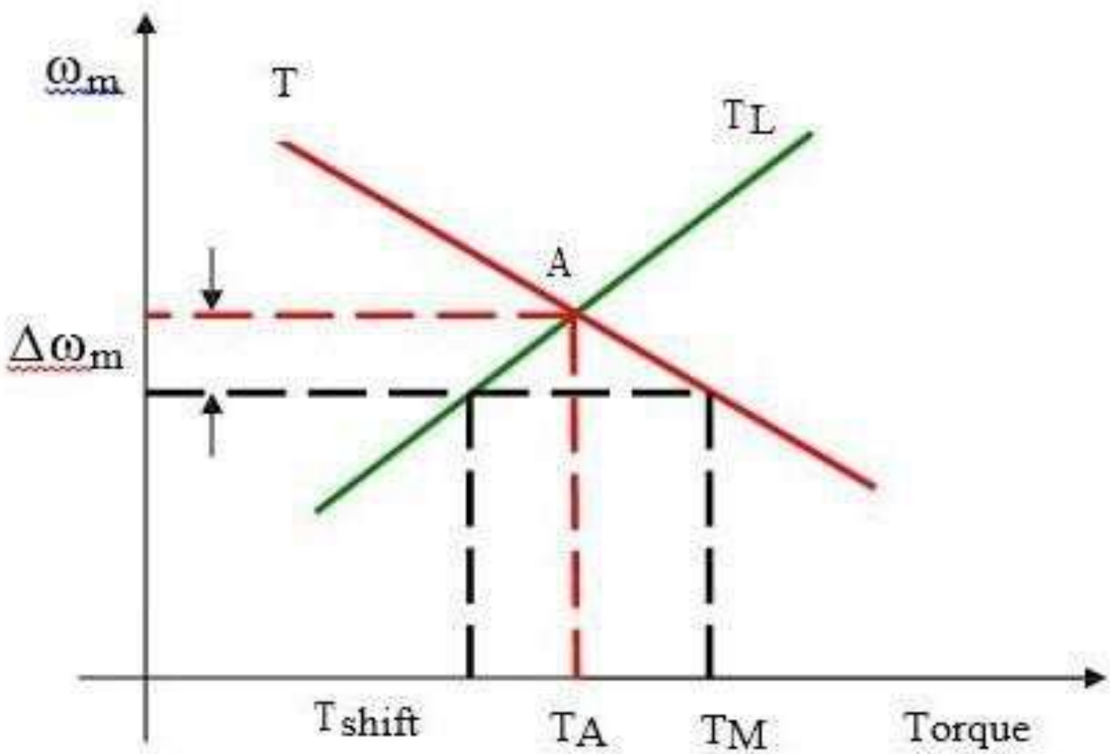
Applications

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

1.3 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



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, which will move the operating point away from point B

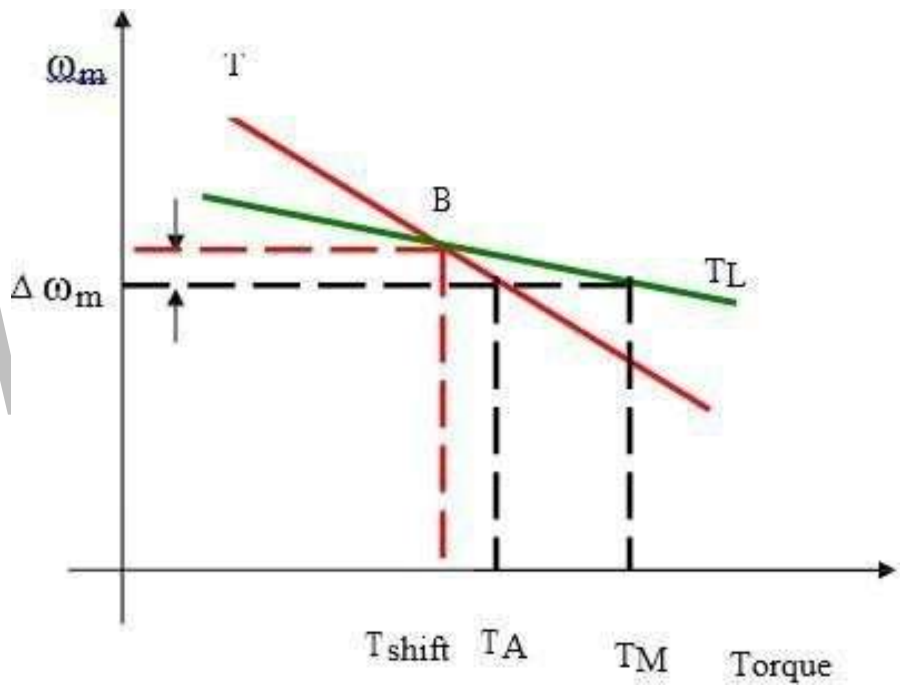


Figure 1.3.1 Steady state equilibrium point

(Source: "Fundamentals of Electrical Drives" by G.K.Dubey,page-23)

1.6 Typical load torque characteristics:

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 co n stant 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.

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

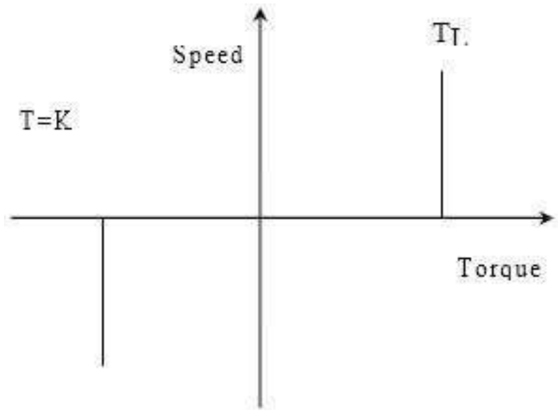


Figure 1.6.1 Torque Proportional to speed

(Source: "Fundamentals of Electrical Drives" by G.K.Dubey,page-19)

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.

Examples:

- ✓ Fans rotary pumps,
- ✓ Compressors
- ✓ Ship propellers

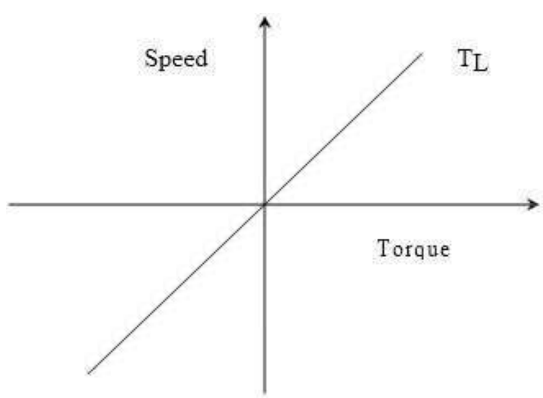


Figure 1.6.2 Torque Proportional to square of the speed

(Source: "Fundamentals of Electrical Drives" by G.K.Dubey,page-20)

Torque Inversely proportional to speed:

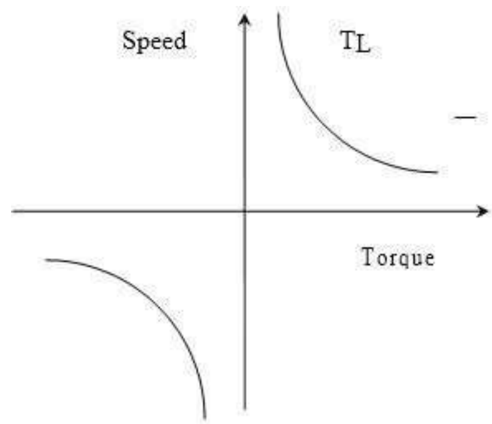


Figure 1.6.3 Torque Inversely proportional to speed

(Source: "Fundamentals of Electrical Drives" by G.K.Dubey,page-20)

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