CHAPTER 1

Electric Drives

LEARNING OBJECTIVES

After the completion of this unit, students/readers will be able to understand:

1. *What is a drive? Why electric drives are preferred over mechanical drives.*
2. *On the basis of power transfer, why individual drives are preferred.*
3. *What are the basic features of industrial loads?*
4. *What is four quadrant operation of electric machines?*
5. *What factors affect the choice of Electric Motor?*
6. *What is the significance of starting characteristics of a motor?*
7. *What is the significance of running characteristics of a motor?*
8. *How different electric motors behave during starting and running?*
9. *How the speed of different motors can be controlled?*
10. *How different methods of electric braking are applied to stop the train?*
11. *What are the different types of conveyors by which power is transferred?*
12. *Why temperature of a machine rises during operation?*
13. *On the basis of temperature rise how the rating of an electric motor is affected.*
14. *What is meaning of continuous, continuous maximum and short time rating of an electric motor?*
15. *What is the meaning of continuous, short time and intermittent rating of an electric motor?*
16. *On the basis of different electrical and mechanical characteristics, how a motor is chosen for a particular operation in the industry, domestic and commercial places?*

INTRODUCTION

Human dependence on electrical energy is increasing day by day. All domestic, commercial and industrial devices and machines are operated by electrical energy. The major part of the electrical energy is utilized in the industry, where various drives are employed for its conversion into mechanical energy. For all industrial operations, electric drive is almost universal. It is all because of advancement in the development of electric motors and control gears. Both ac and dc supplies are used for electric drives. However, use of dc supply is limited on account of its more cost and larger voltage drop in the feeder, but even then it is still in usem due to the following reasons:

1. In some of the cases dc is more economical than ac *e.g.* variable speed can be obtained very easily and economically with the help of dc drives (dc motors) which need dc supply.
2. In the case of steel rolling mills very fine and accurate controls are required. Almost in every cycle the various operations such as starting, stopping, braking or reversing occur. For such drives dc is only economical.
3. For traction work, dc series motors are ideally suitable on account of their high starting torque. For this dc supply is needed.

1.1. MECHANICAL AND ELECTRIC DRIVE

Drive: A well developed machine consists of three main parts *i.e.* prime-mover (engine, turbine or motor), the transmission system (shaft, pulleys, belt or chain) and the working machine (lathe, shaper, locomotive etc.). The function of first two parts (*i.e.* the prime-mover with its control and transmission system) are to impart motion to operate the working machine. The basic function of the first two parts is to provide the necessary motion to the working machine. The common term used for these two parts is called **drive.**

Hence, the combination of prime-mover with its controls and transmission system is termed as **drive.**

Depending upon the power used in a system, the drives may be divided into two categories *i.e.* mechanical drive and electric drive.

Mechanical drives: The drives in which diesel engine or turbine (water, steam or gas turbines) is used with some suitable transmission system are known as *mechanical drives.* Hydro, thermal and nuclear power stations and all types of automobiles are the live examples where mechanical drives are employed.

Electric drives: The drives in which electric motors (dc or ac) are used with some suitable transmission system are known as *electric drives.* Almost all the industrial operations are the live examples where electric drives are employed.

1.2. CONCEPT OF ELECTRIC DRIVES

An electric drive may be defined as an electromechanical device (electric motor) for converting electrical energy into mechanical energy to impart motion through transmission system to different machines and mechanisms for various types of process control.

Electric drives have numerous applications in diverse areas such as industry, transportation, agriculture and domestic. Electric drives perform various functions such as:

1. imparting motion to conveyors in factories, mines and warehouses.
2. lifting goods by hoists and cranes.
3. running excavators and escalators, electric locomotives, trains, cars, trolley buses and lifts etc.
4. driving fans, ventilators, compressors and pumps, etc.

Electric drives are incorporated in all steel and plastic rolling mills, textile and paper mills, printing presses and machine tools, etc. Cutting, milling, drilling, grinding, punching, pressing, clipping and other operations of machine tools and industrial installations are all performed by electric drives. Electric drives are also incorporated in flight and landing control systems of aircrafts and in propulsion systems of ships and submarines for cruising underwater. In all, we can say that today the applications of electric drives are as broad and vast as industrialization itself. They provide power outputs from several tenths of watt in recording and controlling instruments to several thousand kilowatt in electric locomotives and rolling mills. The speed of drives ranges from creeping to several thousands of rpm.

The operations of electric drives are selectively regulated and made partly or fully automatic to increase the productivity and efficiency of the industry. The controllers may come in the category of (*a*) Manual, (*b*) Semiautomatic or (*c*) Automatic.

The load and its characteristics are the basic parameters for determining the rating and type of motor *e.g.*, the load may be of continuous or intermittent type. The magnitude of the load can be constant or variable. Environment conditions may be different which are to be taken into account. External temperature, cooling method (natural or forced), humidity, density of dust and dirt, vibrations and shocks are also the important factors that determine the design and construction of transmission system and the type of motor. Electric motors may be dc or ac motors.

1.3. ADVANTAGES AND DISADVANTAGES OF ELECTRIC DRIVE

In the industries, two types of drives (*i.e.* mechanical or electrical drives) can be employed. However, almost in all the industries electric drives are employed due to their following advantages over the mechanical drives:

Advantages

1. Their initial as well as maintenance cost is low as compared to other systems of drive.
2. Their operation is more simple and clean.
3. Their control is very easy and smooth.
4. Their layout is very flexible.
5. They can have remote controls.
6. Transmission of power from one place to the other can be done with the help of cables instead of long shafts etc.

Disadvantages

Although, electric drive is more advantageous but it has some serious disadvantages as mentioned below :

1. Electric drive system can only be employed if the area is electrified.
2. There is every possibility of short circuit, leakage from conductors and breakdown of overhead conductors. This may lead to fatal accidents.
3. Failure of supply for a few minutes may paralyse the whole system.

1.4. CLASSIFICATION OF ELECTRIC DRIVES

Electric drives may be classified on the basis of different criterion as mentioned in the following Table 1.1:

Table 1.1: Classification of electric drive systems

1. Number of machines and inter-relations	(*i*) Group drive	
	(*ii*) Individual drive	
	(*iii*) Multi-motor drive	(*a*) Independent, non-related control
		(*b*) Interdependent, related control
2. Loads and environment	(*i*) Loads	Continuous or intermittent, positive, negative varying sign, constant or variable in magnitude.
	(*ii*) Environment	Temperature, humidity, dust and dirt vibrations and shocks.

(Contd...)

3. Mode of operation	(*i*)	Continuous duty
	(*ii*)	Short time duty
	(*iii*)	Intermittent duty
4. Means of control	(*i*)	Manual
	(*ii*)	Semiautomatic
	(*iii*)	Automatic
5. Dynamic and transients	(*i*)	Uncontrolled transient period
	(*ii*)	Controlled transient period
6. Methods of speed control	(*i*)	Reversible and nonreversible uncontrolled constant speed
	(*ii*)	Reversible and nonreversible step speed control
	(*iii*)	Reversible and nonreversible smooth speed control
	(*iv*)	Constant predetermined position control
	(*v*)	Variable position control (servomechanism)
	(*vi*)	Composite control

Usually, electric drives are classified on the basis of number of machines and their inter-relations as mentioned below:

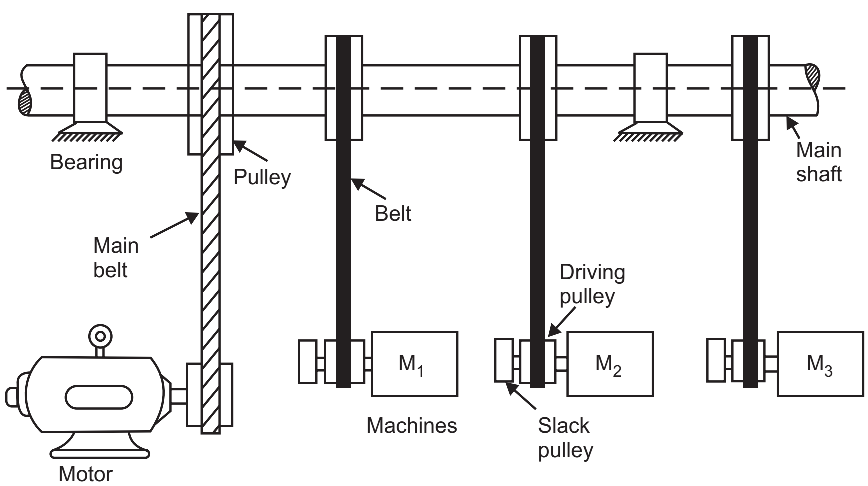
(*i*) Group drive: It is also called a *line shaft drive,* in this case, a single motor of large capacity is used to drive a number of machines and tools in an industry through a long shaft as shown in Fig. 1.1.

A drive in which a single electric motor (*or diesel engine*) *drives a line shaft by which an entire group of working machines are further operated is called a* **group drive.**

This method is economical at the initial stage as cost of motors and control gears is low. A single motor of large capacity costs less than the cost of a number of small motors of the same total horse power. Moreover, a large motor of lesser horse power can be used for group drive as compared to total horse power of small motors required for individual drive because all the machines may not be used on full load at the same time. The efficiency and power factor in case of group drive are very poor if all the machines do not work at the same time because in that case the main motor is partially loaded.

Although, the initial cost of group drive is very low but it suffers from the following drawbacks:

1. The breakdown in single drive stops the whole unit which causes serious loss of production.



Group drive

Fig. 1.1

2. There is huge loss of power in the main shaft while transmitting power to other machines. This reduces efficiency.
3. Usually, the main motor operators at loads which are below its rated capacity, this results in poor efficiency and power factor.
4. The control of machines in the hands of operators is limited. He is not in position to start, stop or change the speed of his machine as per his requirement.
5. In this system, the space cannot be utilised properly.
6. The machines have to be placed along the main shaft, this restricts the layout of machines.
7. The layout of the industry gives a shabby look.

The above discussion clearly shows that group drive does not suit to the modern industry. However, this system is adopted only when some factories previously running on diesel engine drive are changed over to electric drive simply by replacing the engine by electric motor.

(*ii*) Individual drive: In this type of drive, each machine and tool is driven by a separate motor.

A drive in which each working machine is operated by a separate motor is called an **individual drive.**

Although in this system, the initial cost is more than the group drive, but the operator has complete control of his machine; he can start, stop or vary the speed of his motor as and when required. Moreover, the machines can be placed in any desired position. In most of the cases, the motor and its controlling unit are placed on the machine itself which results in good appearance, cleanliness and safety. Individual drive is essential where consistency of speed and flexibility of control is required.

(*iii*) 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 driven mechanism.

In other words, *a multi-motor drive consists of several individual drives each one of which serves to operate one of many working machines or mechanism in a production unit.*

Applications of such a drive are found in complicated metal cutting machine tools, paper making machines, rolling mills, electric trains etc. The drives of a crane can also be considered as an example of a multi-motor drive system. This type of multi-motor drive incorporates three drives: first for vertical movement, second for side movement, and third for forward movement of the load. Each of these drives functions separately and the operator of the crane coordinates their functions. But there are some cases, when an automatic coordinated functioning of several drives is necessary. For instance, a traction drive of an electric locomotive consists of 4–8 motors. It is obvious that functioning of these motors should be coordinated in such a way that none loads the other.

A rolling mill is yet another example where several individual drives are incorporated. To eliminate tearing and breakage of the product (rods, wires, plates), the speeds of individual drives are to be coordinated to maintain continuous uninterrupted flow of material at uniform speed and constant tension. Similarly, paper mill drives and cloth printing machines are other examples of multi-motor drives with coordinated functioning.

1.4.1 Comparison between Individual and Group Drive

The following Table 1.2 gives a comparison of the two drives:

S.No.	*Particulars*	*Individual drive*	*Group drive*
1.	Initial cost	Initial cost is high.	Initial cost is low.
2.	Operating cost	Operating cost is low because different machines are operated only when there is necessity.	Operating cost is high because the main motor has to be operated even when only one machine is required to be operated.
3.	Power factor	Individual motor works at good power factor.	Group drive motor works at poor power factor.
4.	Efficiency	High, usually motor works at rated capacity.	Low, usually motor works at less than rated capacity loads.
5.	Reliability	System is more reliable as each machine has individual drive.	Reliability is poor, if main motor fails, whole industry will come to stand still.
6.	Flexibility	Machines may be fitted whereever convenient.	Machines have to be fitted near the main shaft.
7.	Speed	Speed can be controlled as per the need.	Speed control is not easy.
8.	Type of machines	Only individual drive can be employed for driving heavy machines such as cranes, lifts and hoists etc.	This system cannot be employed in such cases.
9.	Space utility	Space can be fully and conveniently utilised.	Space cannot be used fully and conveniently.

SOLVED EXAMPLES

EXAMPLE 1.1: *A group drive with a motor costing ₹ 80000 with that of 8 individual motors each costing ₹ 30000. With group drive annual consumption is 60000 kWh whereas with individual drive the annual consumption is 45000 kWh. The electrical energy costs ₹ 4.00 per kWh. Annual interest, depreciation and maintenance charges may be taken as 20% in either case. Compare the total annual cost for the group and individual drive. Mention the learning outcome of this example.*

SOLUTION. Here, for group drive: Capital investment = ₹ 80000

Annual energy consumption = 60000 kWh

For individual drive: Capital investment = ₹ 8 × 30000 = ₹ 240000

Annual energy consumption = 45000 kWh

Annual interest, depreciation and maintenance charges = 20%

Cost of energy = ₹ 4.00/kWh

$$\text{Annual cost for group drive} = ₹ \left(80000 \times \frac{20}{100} + 60000 \times 4.00\right)$$

$$= ₹\ 256000$$

$$\text{Annual cost for individual drive} = ₹\left(8 \times 30000 \times \frac{20}{100} + 45000 \times 4.00\right)$$
$$= ₹\ 228000$$

Learning outcome:

1. In case of individual drive, although the investment is more but the annual cost comes out to be less, it ensures that in the long run individual drive is better than the group drive.
2. For the same production, the energy consumption in case of individual drive is quite less (45000 kWh) than the group drive (60000 kWh). It shows that there is huge wastage of energy (15000 kWh) in group drive because the drive motor rarely operates at its full-load causing a national wastage.
3. In case of an individual drive, each machine can be operated as and when required, controls are better, maintenance can be done without disturbing the other operations, reliability of the system is more.

Conclusion: *Individual drive is better than group drive.*

TEST YOUR LEARNING–1.1

Type-I: Short Answer Questions (*Section–A: 2 marks each*) **Refer Art. No.**

1. Explain drive. What are its basic types? **(PTU May 2008)** **[Art. 1.1]**
2. What do you mean by mechanical drive? **[Art. 1.1]**
3. What is an electric drive? **[Art. 1.1]**
4. What is group drive? **[Art. 1.4(i)]**
5. What do you understand by individual drive? **[Art. 1.4(ii)]**
6. What are individual and group drives? **(PTU May 2010)** **[Art. 1.1]**
7. What is multi-motor drive? **[Art. 1.4(iii)]**
8. Why individual drive is preferred over group drive? **[Art. 1.4.1]**

Type-II: Test Questions (*Section: B & C – 5 to 8 marks each*) **Refer Art. No.**

1. Why electric drives are preferred over mechanical drives? What can be the demerits of electric drives? **[Art. 1.3]**
2. Classify electric drives on the basis of different criterian. **[Art. 1.4]**
3. Compare a group drive and an individual drive. **(PTU Dec. 2011)** **[Art. 1.4.1]**

Type-III: Numerical for Practice

1. A group drive with a motor costing ₹ 70000 with that of 6 individual motors each costing ₹ 25000. With group drive annual consumption is 60000 kWh whereas with individual drive the annual consumption is 45000 kWh. The electrical energy costs ₹ 4.00 per kWh. Annual interest, depreciation and maintenance charges may be taken as 20% in either case. Compare the total annual cost for the group and individual drive. Mention the learning outcome of this example.

(**Ans.** ₹ 254000; ₹ 216000)

1.5. BASIC FEATURES OF INDUSTRIAL LOADS

In general, all the mechanical loads may be subdivided as:

1. Lifting load: This involves lifting of some weight by a crane or hoist etc. In lifting of loads the torque required is independent of speed as shown in Fig. 1.2. Load torque remains constant *w.r.t.* speed.

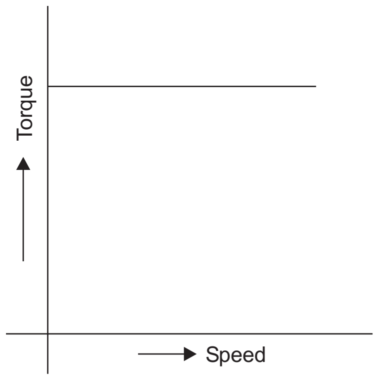


Fig. 1.2

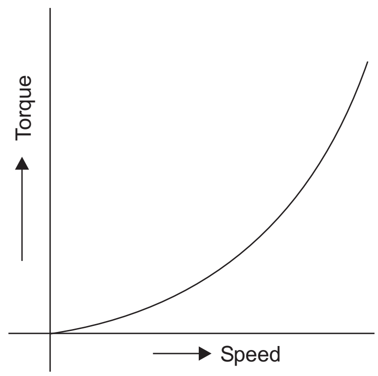


Fig. 1.3

2. Air and fluid friction: In this type of loads the torque changes with the square of the speed *i.e.* $T \alpha N^2$ as shown in Fig. 1.3. The loads which come under this category are blowers, fans, water wheels etc.

3. Load due to friction: Whenever two surfaces move one over the other or a shaft rotates in a bush or bearing, an opposite force always acts at the surface. This force is called the frictional force. However, this force can be decreased by using a lubricant. When no lubricant is used, the friction is called dry friction. In such cases, torque remains constant with respect to speed. On the other hand ,when lubricant is used, the frictions is called fluid friction and in such cases, torque is directly proportional to the speed as shown in Fig. 1.4.

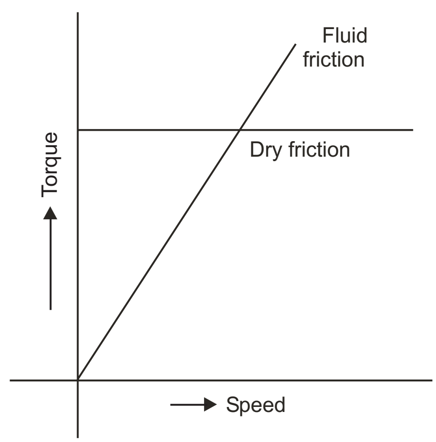


Fig. 1.4

4. Deformation loads: Such type of loads occur in crushing, grinding and metal drawing etc. In such cases the torque is inversely proportional to the speed as shown in Fig. 1.5. The loads which come in this category are barring machines, crushing machines, cutting machines, grinders, milling machines etc.

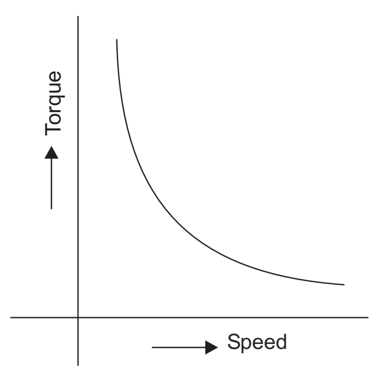


Fig. 1.5

1.6. TYPES OF LOAD TORQUES

There are two types of loads:

- Those which provide active torque and
- Those which provide passive torque

The active torque may be provided due to gravitational force (*e.g.* in case of hoists, lifts elevators or railway locomotives operating on gradients etc.) or due to deformation of elastic bodies. These torques are also developed during compression or release of spring. In all these cases, potential energy plays its important role. The active torque may act opposite to the driving torque or it may act in the same direction.

The passive torque may be provided due to friction, due to shearing or deformation in inelastic bodies. These torques always oppose the motion.

1.7. FOUR QUADRANT OPERATION OF A MOTOR DRIVING A HOIST LOAD

In general, both active and passive load torques are present in a drive system, the motor driving the load may operate in different regimes. Therefore, while sketching the speed-torque characteristics of either the load or motor, it is preferred to make use of all the four quadrants rather than to confine to only first quadrant.

While plotting characteristics in four quadrants some conventions are used for positive and negative values of speed, motor torque and load torque in a diagram of this type which are as follows:

The speed is assumed to have a positive sign, if the direction of rotation is counter-clockwise or it causes an 'upward' or 'forward' motion of the drive. In case of reversible drives the positive sign for speed may have to be assigned arbitrarily either to counter-clockwise or clockwise direction of rotation. The motor torque is taken to be positive when it causes an increase in speed in the positive sense. The load torque is assigned a positive sign when it acts against the motor torque.

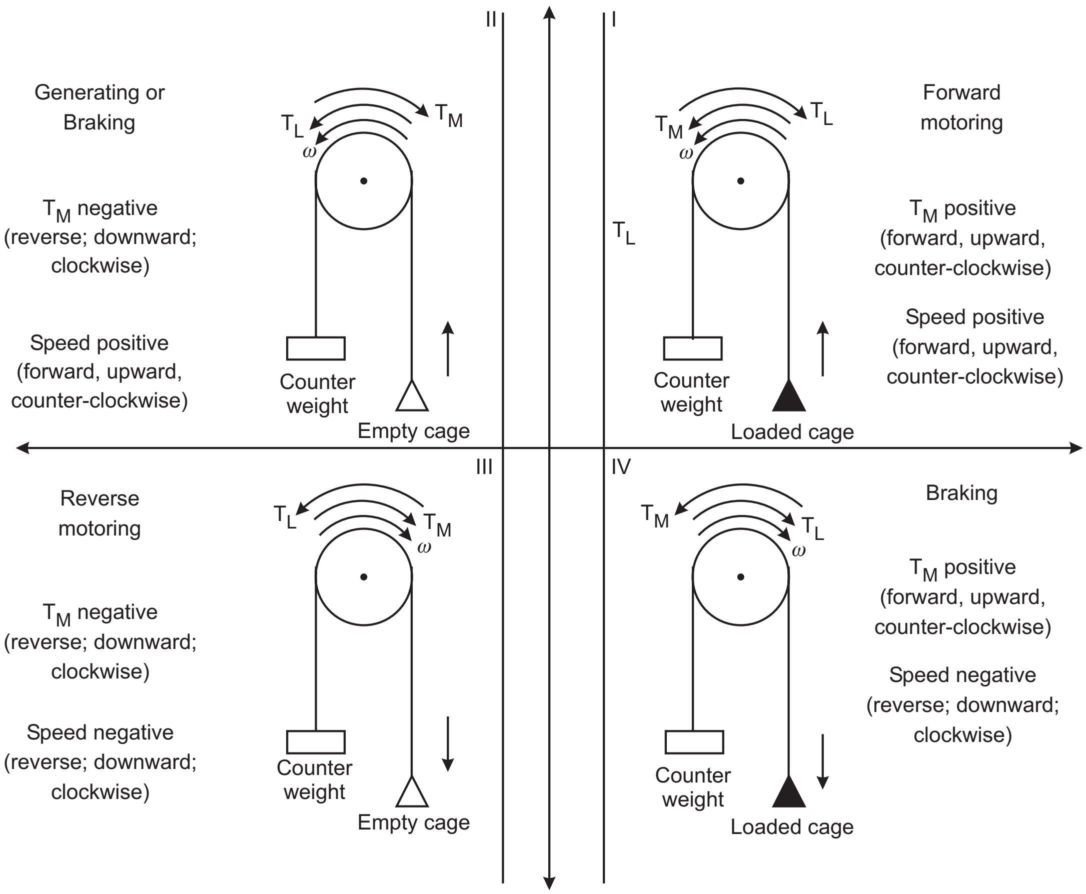
The four quadrant operation of a motor driving a hoist consisting of a cage with or without load, a rope wound onto a drum to hoist the cage and a balance weight magnitude larger than that of the empty cage but smaller than that of the loaded one is shown in Fig. 1.6. The arrows indicate the actual directions of motor (or electro-magnetic) torque, load torque and motion in the four quadrants. It may be observed that they correspond to the sign conventions mentioned above.

In the first quadrant the load torque acts in opposite direction to that of rotation. Hence, to drive the loaded hoist up, the developed torque in the motor *M* must act in the same direction as the speed of rotation *i.e.* T_M should be of positive sign. Since the speed is also positive being an upward motion, the power will also have a positive sign, *i.e.* the drive is said to be motoring. This quadrant is designated as 'forward motoring quadrant'.

In the second quadrant, the unloaded cage is hoisted-up. Since the counter-weight is heavier than the empty cage, the speed at which the hoist is moved upwards may attain a dangerously high value. In order to avoid this, the motor torque must act in a direction opposite to that of rotation, *i.e.*, the motor should switch-over to a braking or generator regime. It may be noted that T_M will have a negative sign but the speed has a positive sign, being forwards, upwards and counter-clockwise.

In the third quadrant, empty cage moves downward, as shown in Fig. 1.6. The downward journey of the cage is opposed by the torque due to the counter-weight and friction at the transmitting parts. So for moving the cage downwards, the motor torque must act in the same direction as the motion of the cage. The electrical machine acts as a motor as in the first quadrant, but in the reverse direction. Thus, in this quadrant 'reverse motoring' action took place. The motor torque has a negative sign as it causes an increase in speed in the negative sense and the speed also has a negative sign being a downward motion.

Fourth quadrant shows the downward motion of loaded cage. The motion can take place under the action of load itself, without the use of any motor. But in order to limit the speed of the downward motion of the hoist, the electrical machine must act as a brake. The motor torque has a positive sign as it causes a decrease in speed in the downward motion. The speed, of course, has a negative sign, being a downward journey.



Four quadrant operation of a motor driving a hoist load

Fig. 1.6

1.8. CHOICE OF MOTOR (or DRIVE)

To meet with the requirements of a particular type of mechanical load, one is to select a drive, which must contain a peculiar motor to perform the given job.

While selecting a motor, we are to consider the conditions under which it has to work and the load which it has to handle. The selection of motor, for a particular service depends upon various factors as given below:

1. **Electrical Characteristics**

   This includes (*i*) Starting characteristics
   (*ii*) Running characteristics
   (*iii*) Speed control
   (*iv*) Braking characteristics

2. **Mechanical Characteristics**

   This includes (*i*) Types of enclosure
   (*ii*) Types of bearings