PART II : ELECTRICAL DRIVES
CHAPTER TEN

INTRODUCTION TO ELECTRICAL DRIVES

10.1 INTRODUCTION

An **ELECTRIC DRIVE** is defined as an electromechanical device designed to convert electrical energy into mechanical energy to impart motion to different machines and provides electrical control for various kinds of processes by means of "controller".
The aim of the controller is to adjust or stabilize the speed of the motor to suit a given industrial task.

In the past, horse power replaces the hand power drive by using animals. These animals were replaced by mechanical drive powered by wind mills, water wheels and turbines, steam engine, internal combustion engine and electrical machines (Electric Drives).

Development of Electrical Drives

The development of different kinds of electric drives used in industry may be divided into three stages:

(1) 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 halted.

(2) Individual Electric Drive

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

(3) Multi-Motor Electric Drive

In this drive system, there are several individual drives, each of which serves to operate of many working machines or mechanism in some production unit, such as complicated metal cutting machine tools, paper making industries, rolling machines, building cranes, aircrafts, etc.

10.2 GENERAL ELECTRIC DRIVE SYSTEM

Fig.10.1 shows the basic structural diagram of a variable speed electrical drive system which generally has the following components:

- A device that transforms electrical power into mechanical power (An electric motor or electromagnet).
- A device that control the electrically driven assembly to obtain motion of specific form (linear or rotary motion) and response to a master controller.
- A device that converts mechanical energy and impart it to the actuating mechanism (reducers and other intermediate gearing).

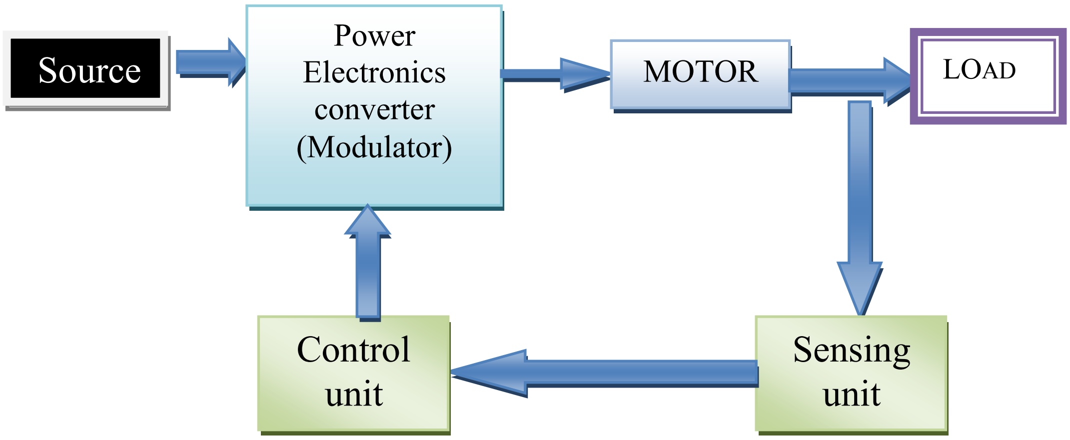


Fig.10.1 Block diagram of drive system.

10.2.1 Drive System Components

1-Electrical Motors

Most commonly used electrical motor for speed control applications are the following:

❖ DC Machines

Separately-excited and permanent magnet, shunt, series, compound motors and switched reluctance machines.

- AC Machines
  Induction, wound rotor, synchronous, PM synchronous and synchronous reluctance machines.
- Special Machines
  Brush less d.c. motors, stepper motors, switched reluctance motors are used.

2- Power Modulators

The functions of the power modulator are

- 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.
- It converts electrical energy of the source in the form suitable to the motor.
- Selects the mode of operation of the motor, i.e. Motoring or 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)
- Frequency changers (Cycloconverters or PWM Inverters)

3- Electrical Sources (Input Power)

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

4- Sensing Unit

- Speed Sensing (From Motor)
- Torque Sensing
- Position Sensing
- Current sensing and voltage sensing from lines or from motor terminals or from Load
- Temperature Sensing

5- Controller

Controller for a power modulator matches the motor and power converter to meet the load requirements.

10.2.2 Classification of Electric Drives

Electric drives may be classified as follows:

1. According to Mode of Operation
    - Continuous duty drives
    - Short time duty drives
    - Intermittent duty drives
2. According to Means of Control
    - Manual
    - Semi automatic
    - Automatic
3. According to Number of machines
    - Individual drive
    - Group drive
    - Multi-motor drive
4. Another main classification of electric drive is
    - DC drive
    - AC drive

Table 10.1 gives comparison between DC and AC drives.

Table 10.1 Comparison between DC and AC drives.

DC DRIVES	AC DRIVES
• Well established technology • Requires frequent maintenance • The commutator makes the motor bulky, costly and heavy • Fast response and wide speed range • Speed and design ratings are limited due to commutations • Poor power factor • Environmentally sensitive	• The power circuit and control circuit are complex • Less Maintenance • No commutator problems exist in these motors and they are inexpensive, particularly squirrel-cage induction motors • Good line power factor • Environmentally insensitive

10.2.3 Advantages of the drive system

A modern variable speed electrical drive system are static system using power semiconductor devices such as thyristors (SCRs) and power transistors. These systems have replaced the old pneumatic or hydraulic drives as well as electromechanical and other forms of control to electronic control using SCR’s drive which has the following advantages:

1. Basic operation is simple and reliable.
2. Saving in space and capital cost.
3. Higher efficiency.

4. Better speed response.
5. Low maintenance cost and long life.
6. Braking power can be transformed into electrical power and feedback to the main supply.

Applications of Electrical Drives

Electric drives are used in several indusrial applications such as:

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

10.3 REVIEW OF ROTATIONAL MECHANICS

Rotational mechanics is very important in electric drives studies. The following Table 10.2 gives comparison between rotational and linear mechanics formulae.

Table 10.2 : Rotational mechanics VS linear mechanics.

Rotational Mechanics	Linear Mechanics
θ =Angular displacement (rad)	S = Displacement (m)
ω = Angular velocity (rad/s) $= \frac{d\theta}{dt}$	v = velocity (m/s) $= \frac{dS}{dt}$
α = Angular acceleration (rad/s^2) $= \frac{d\omega}{dt} = \frac{d2\theta}{dt^2}$	a = Acceleration (m / s^2) $= \frac{dv}{dt} = \frac{d2S}{dt^2}$
J = Moment of inertia (kg.m^2)	m = Mass (kg)
T = Torque (Nm) = $J\ \alpha$	F = Force (N) = $m\ a$
M = Angular momentum (kg.m^2.rad/s) = $J\ \omega$	M = Momentum (kg.m /s) = $m\ v$
Kinetic energy = $\frac{1}{2}\ J\ \omega^2$ (Jouls)	Kinetic energy = $\frac{1}{2}\ m\ v^2$ (Jouls)
Power = P = $T\ \omega$ (Watts)	Power = $F\ v$ (Watts)
Work = $T\ \theta$	Work = $F\ S$

10.4 DYNAMICS OF MOTOR- LOAD SYSTEM: FUNDAMENTALS OF TORQUE EQUATIONS

A motor generally drives a load (Machines) through some mechanical transmission systems. The equivalent rotational system of motor and load is shown in the Fig.10.2.

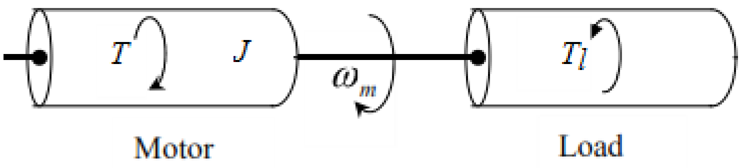


Fig.10.2 Typical motor-load system.

where :

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 /s.

T = Instantaneous value of developed motor torque, Nm.

T_l = Instantaneous value of load torque, referred to the motor shaft, Nm.

Load torque T_l includes *friction* and *windage* torque of motor.

Motor-load system shown in Fig.10.2 can be described by the following fundamental torque equation.

$$T - T_l = \frac{d}{dt}(J\omega_m) = \frac{d\omega_m}{dt} + \omega_m \frac{dJ}{dt} \qquad (10.1)$$

Equation (10.1) is applicable to variable inertia drives such as mine winders, reel drives, Industrial robots.

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

$$T = T_l + \frac{d\omega_m}{dt} \qquad (10.2)$$

$J\frac{d\omega_m}{dt}$ = Torque component called dynamic torque because it is present only during the transient operations.

At steady state operation $J\frac{d\omega_m}{dt} = 0$.

Note: The energy associated with dynamic torque $J\frac{d\omega_m}{dt}$ is stored in the form of kinetic energy given by

$$KE = \frac{1}{2} J\,\omega^2 \qquad (10.3)$$

10.4.1 Types of Loads

Various load torques can be classified into broad categories, however, the loads are of two types according to the applied torque:

- 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) , for example :

- ❖ Torque due to gravitational force.
- ❖ Torque due to deformation in elastic bodies and due to 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, for example :

- ❖ Torque due to friction.
- ❖ Torque due to shear (cutting).
- ❖ Torque due to deformation in inelastic bodies etc.

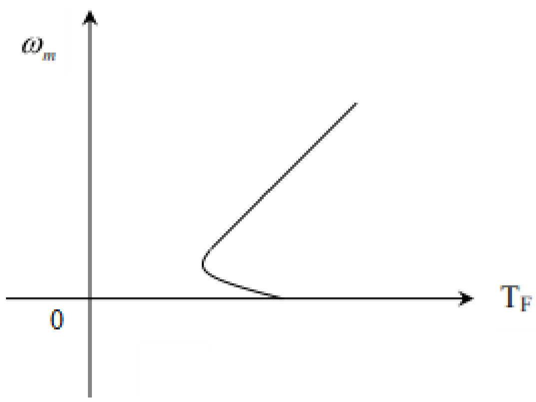
Components of Load Torque (T_l)

The load torque T_l can be further divided into 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. Variation of friction torque with speed is shown in Fig10.3.

Fig.10.3Variation of friction torque with speed.



Friction torque (T_F) can also be resolved into three components :

(1) VISCOUS friction T_v : Component varies linearly with speed and is given by

$$T_v = B\omega_m \qquad (10.4)$$

where B is viscous friction coefficient.

(2) COULOMB friction T_C : Component which is independent of speed.

(3) STATIC friction T_s : Component T_s accounts for additional torque present at stand still. Since T_s is present only at stand still it is not taken into account in the dynamic analysis. 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.

The variation of these three torques are shown in Fig.10.4. Hence, the total friction torque is given by

$$T_F = T_v + T_C + T_S \tag{10.5}$$

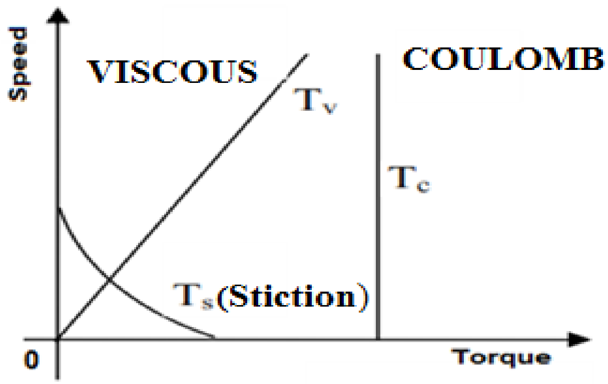


Fig.10.4 Types of friction torques in drive system.

(ii) Windage Torque (T_W)

When motor runs, wind generates a torque opposing the motion. This is known as windage torque. Windage torque, T_w which is proportional to the square of the speed is given by

$$T_W = C\,\omega_m^2 \qquad C \text{ is a constant} \tag{10.6}$$

(iii) Torque required doing useful mechanical work (T_L).

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.

From the above discussions, and for finite speed,the load torque T_l *is*

$$T_l = T_L + B\omega_m + C\,\omega_m^2 + T_C \tag{10.7}$$

10.4.2 Classifications of Various Types of Loads

Most of the industrial loads can be classified into the following two categories :

(i) Load torques varying with time :

- Constant continuous type loads: Loads oprating continuously for the same loading (same torque) conditions for a long time.
- Continuous variable loads : Loads varying and having duty cycle.
- Pulsating loads : Loads of machines with crank shafts.
- Impact loads : Regular repetitive load peaks such as in rolling mills, forging hammer, etc.
- Short time loads (e.g. hoists).

(ii) Load torques varying with with speed :

- Load torques which are independent of speed (e.g.cranes).
- Load torques proportional to speed (Generator type load) .
- Load torques proportional to square of the speed (Fan type load).
- Torque inversely proportional to speed (Constant power type load).

Load Torque-Speed Charachteristics

Speed-torque characteristics of the load must be known to calculate the acceleration time and to select the proper type of motor to suit the load. The load speed-torque characteristics of industrial loads are generally non-analytical function $T_L = f(\omega)$. However, some of them may be approximated to an analytic form such as :

1- Constant Torque characteristics: $T_L = k$

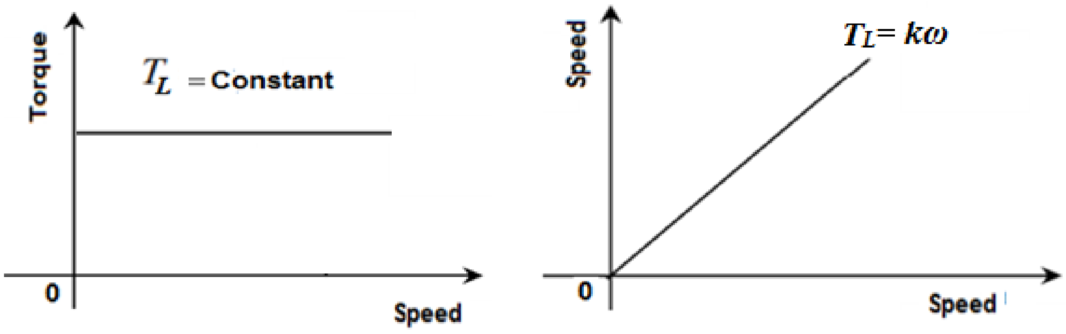
Most of the working machines that have mechanical nature of work like shaping, cutting, grinding or shearing, require constant torque irrespective of speed, (See Fig.10.5(a)). Similarly cranes during the hoisting and conveyors handling constant weight of material per unit time also exhibit this type of characteristics.

2- Torque Proportional to speed: $T_L = k\omega$

Separately-excited d.c. generators connected to a constant resistance load, eddy current brakes have speed-torque characteristics given by $T_L = k\omega$. (See Fig.10.5(b)).

3- Torque proportional to square of the speed: $T_L = k\omega^2$

Another type of load met in practice is the one in which load torque is proportional to the square of the speed, e.g. : Fans, rotary pumps, compressors and ship propellers. (See Fig.10.6 (a)).

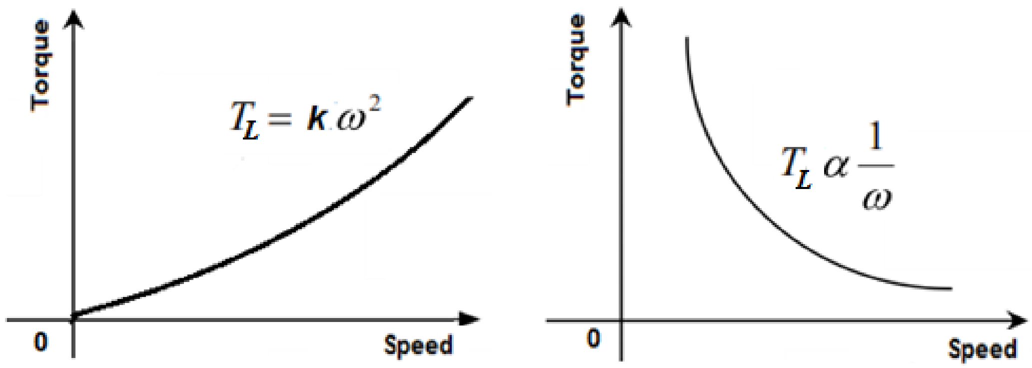


(a) (b)

Fig.10.5 Types of load torque : (a) Constant torque characteristics, (b) Torque proportional to speed.

4. Torque Inversely proportional to speed: $T_L \; \alpha \; \frac{1}{\omega}$

Certain types of lathes, boring machines, milling machines, steel mill coiler and electric traction load exhibit hyperbolic speed-torque characteristics as shown in Fig.10.6(b).



(a) (b)

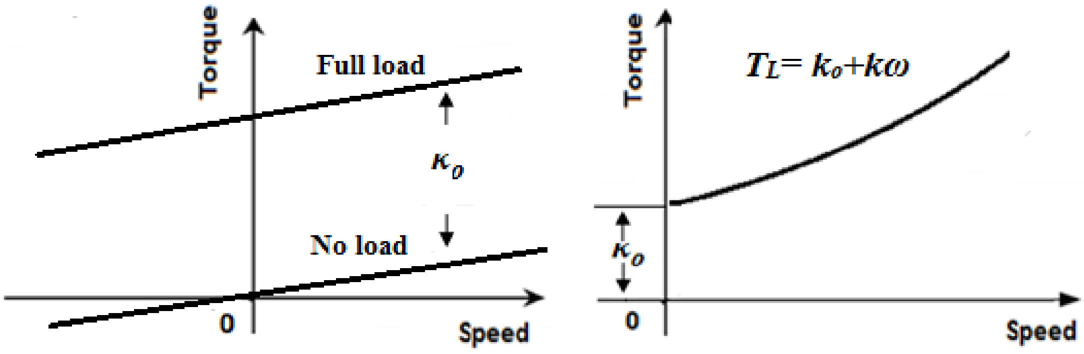
Fig.10.6 Types of load torque : (a) Torque proportional to square of the speed, (b) Torque inversely proportional to speed .

5. Torque polinomialy related to the speed:

For the particular characteristics of Fig.10.7 each example may be approximated to a polynomial form :

$T_L = k_o + k\omega$ for a hoist or elevator (Fig.10.7(a))

$T_L = k_o + k_1\,\omega + k_2\omega^2 + ...$ for a compressor (Fig.10.7(b))



(a) (b)

Fig.10.7 Torque approximated to a polynomial form .

10.4.3 BASIC EQUATION OF MOTION FOR DRIVE SYSTEM

Generally, the basic equation of motion of motor driving a load, Fig.10.8, is given by

$$T_m = T_l + J\frac{d\omega}{dt} = T_L + J\frac{d\omega}{dt} + T_{FW} \qquad (10.8)$$

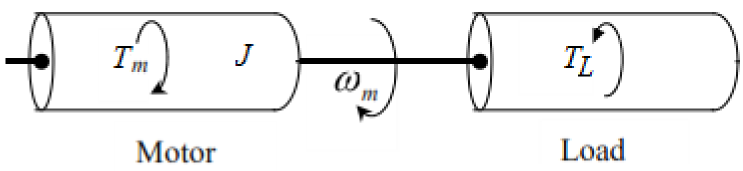


Fig.10.8 Motor-load system.

where

J = Polar moment of inertia of motor-load system referred to the motor shaft, Kg.m^2
ω_m = Instantaneous angular velocity of the motor shaft, rad/sec
T_m = Developed torque of the motor, Nm
T_L = Load (resisting) torque, referred to the motor shaft, Nm
T_{FW} = Friction and windage torque $= T_v + T_c + T_w$

$$= B\omega_m + T_C + C\,\omega_m^2$$

Coulomb friction is generally neglected in drive systems.

If T_{FW} is small then, $T_{FW} = 0$, hence, Eq.(10.7) becomes,

$$T_m = T_L + J\,\frac{d\omega}{dt} \qquad (10.9)$$

- ❖ For motor operation, T_m and ω_m have same directions
- ❖ Always T_m and T_L have opposite directions

In the drive systems, depending on the mechanical load, the motor may be subjected to variable operating conditions in its duty cycles. The motor in an electric car can operates in various conditions such as starting, accelerating, steady-state, decelerating and stopping. Fig.10.9 illustrates motor-load torque characteristics, the available starting torque is T_{st}. At this condition, the motor is accelerated and subjected to most severe service. The equation of motion govern the motor in this case is Eq.(10.8).

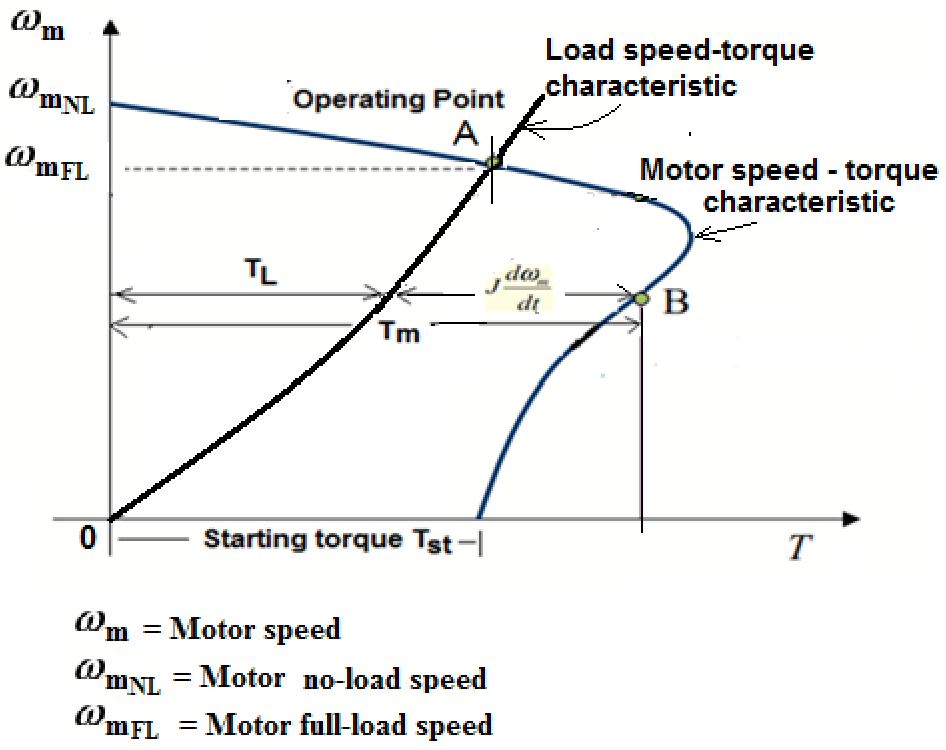


Fig.10.9 Motor and load speed-torque characteristics.

- When the motor operates at steady-state: $\frac{d\omega}{dt} = 0 \Longrightarrow T_m = T_L$
- When $T_m > T_L$, i.e. the dynamic torque $J\,\frac{d\omega}{dt} > 0$, the drive accelerating.
- When $T_m < T_L$, i.e. the dynamic torque $J\,\frac{d\omega}{dt} < 0$, the drive decelerating and coming to rest.

- When $T_m = T_L$, i.e. $\frac{d\omega}{dt} = 0$, the drive continues to run at same speed if it was running.
- The steady-state operation of the motor occurs when its speed-torque characteristic intersects with the load speed-torque characteristic at the operating point A as shown in Fig.10.9.

Example 10.1

A variable speed d.c. drive has rated power of 10 kW,rated speed of 1500 rpm drives a load that comprises a constant load of $T_L = 30$ Nm. The inertia of the drive system is 0.10 kg.m^2. Calculate the time taken to accelerate the load from zero to 800 rpm , assuming the drive develops rated torque during the acceleration phase.

Solution

$$\text{Rated speed} = 1500\text{ rpm}, \quad \text{in rad/s} = \frac{1500}{60} \times 2\pi = 157 = \omega$$

$$\text{Rated torque} = \frac{P_{\text{rated}}}{\omega} = \frac{10000}{157} = 63.6\text{ Nm}$$

$$T_a = T_m - T_L = J\,\frac{d\omega_r}{dt}$$

$$T_a = 63.6 - 30 = 33.6\text{ Nm}$$

$$T_a = J\frac{\Delta\omega}{\Delta t}$$

$$\Delta t = J\frac{\Delta\omega}{T_a}$$

$$\Delta\omega = (800\,rpm - 0\,rpm) \times \frac{2\pi}{60} = 800 \times \frac{2\pi}{60} = 83.73\ \text{rad/s}$$

$$\Delta t = \frac{0.10 \times 83.73}{33.6} = 250\text{ ms}$$

Example 10.2

An induction motor directly connected to a 400V, 50Hz supply utility has a rated torque of 30Nm that occurs at a speed of 2940 rpm. The motor drives a fan load that can be approximated by: $T_L = B\ .\ \omega_m$

where B = 0.05 Nm/rad/s, and the rated speed of the motor is 3000 rpm. Stating any assumption made, calculate the speed, in equilibrium position at which the torque developed by the motor is equal to the load torque.

Solution

The torque speed characteristic of an induction motor is shown in Fig.10.9, part of which can be approximated as straight line.

Let ω_{mFl} = speed of the motor at full load.
ω_{mNl} = speed of the motor at no load.

At full load $T_m = T_{rated}$ = 30 Nm

$$\omega_{mFl} = \frac{2940}{60} \times 2\pi = 307.72 \text{ rad/s}$$

At no-load T_m at ω_{mNl} = 0 Nm

$$\omega_{mNl} = \frac{3000}{60} \times 2\pi = 314.15 \text{ rad/s}$$

For the linear region (only)

$$T_m = K\,(\omega_{mNl} - \omega_m)$$

$$\therefore \qquad K = \frac{30}{(314.15 - 307.72)} = 4.66$$

For the load

$$T_L = B\omega_m = 0.05\,\omega_m$$

For the equilibrium position

$$4.66 \times (\omega_{mNl} - \omega_m) = 0.05\,\omega_m$$

$$4.66\,\omega_{mNl} = 4.71\,\omega_m$$

$$\omega_m = \frac{4.66 \times 314.15}{4.71} = 310.8 \text{ rad/s} \qquad \rightarrow \; 2967\text{rpm}$$

Load Torque and Load Power

At steady state $T_m = T_L$.
The output power from a motor running at speed ω_m is

$$P_m = T_m \omega_m$$

The power required by the load is

$$P_L = T_L \omega_L$$

If the motor is connected directly to the load as shown in Fig.10.8, then

$$\omega_m = \omega_L$$

Hence $\quad P_m = P_L \quad$ (10.10)

If η is the efficiency of the motor on full load, then

$$T_m = T_L = \frac{\text{Watts output}}{\eta \omega_m} \quad \text{Nm} \qquad (10.11)$$

In some applications, the motor is connected to the load through a set of gears. The gears have a teeth ratio and can be treated as speed or torque transformers. The motor-gear-load connection is shown in Fig.10.10.

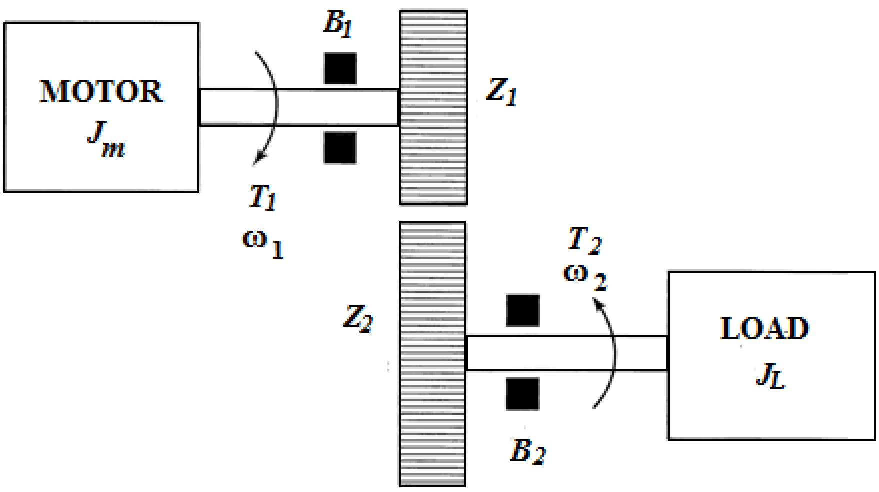


Fig.10.10 Motor connected to the load through a gear.

In Fig.10.10,

Z_1 , Z_2 = Teeth number in the gear
B_1 ,B_2 = Bearings and their coefficients

J_m ,J_L = Moment of inertia of the motor and load
The gears can be modelled from the following facts:
(i) The power handled by the gear is the same on both sides.
(ii) Speed on each side is inversely proportional to its tooth number.
Hence

$$T_1\omega_1 = T_2\omega_2 \tag{10.12}$$

$$T_2 = \frac{\omega_1}{\omega_2}T_1 \tag{10.13}$$

and

$$\frac{\omega_1}{\omega_2} = \frac{Z_2}{Z_1} = g_r \quad = \text{gears ratio} \tag{10.14}$$

Substituting Eq.(10.14) into Eq.(10.13) yields

$$T_2 = \frac{Z_2}{Z_1}T_1 \;= g_r\; T_1 \tag{10.15}$$

At steady-state $T_m = T_L$.

If η is the efficiency of the motor on full load, then

$$T_m = T_L = \frac{\text{Watts input}}{\omega} \times \eta \qquad \text{Nm} \tag{10.16}$$

and

$$\text{kW required by the load} = \frac{\text{Watts input}}{1000}\cdot\eta \tag{10.17}$$

Now if the motor is geared to the load, then the torque seen by the load is increased or decreased by the ratio: $\frac{\omega(motor)}{\omega(load)} = \frac{\omega_1}{\omega_2}$.

Determination of Referred Load Torque

In the system of Fig. 10.10, If the speed of the motor shaft ω_1 and that of the motor is ω_2 , T_2 is the load torque , T_2' is the load torque referred to motor shaft , g_r = gear ratio = $\frac{Z_2}{Z_1} = \frac{\omega_1}{\omega_2}$, and η_t = efficiency of transmission, then equating power :

$$T_2\omega_2\frac{1}{\eta_t} = T_2'\,\omega_1$$

$$T_2' = T_2\,\frac{\omega_2}{\omega_1}\times\frac{1}{\eta_t} = \frac{T_2}{g_r\eta_t} \tag{10.18}$$

If the losses in transmission are neglected, then the kinetic energy due to equivalent inertia is

$$\frac{1}{2}J\omega_1^2 = \frac{1}{2}J_2\omega_2^2 = \frac{1}{2}J_2\,\frac{\omega_2^2}{g_r^2}$$

$$\therefore \quad J = J_2 \times \frac{1}{g_r^2} \qquad (10.19)$$

When there are number (k) of stages of transmission between the driving motor and the drive load, as shown in Fig.10.11, Eq.(10.18) becomes:

$$T_L' = T_L\,\frac{1}{g_{r1}g_{r2}g_{r3}\cdots\cdots g_{rk}} \times \frac{1}{\eta_{t1}\eta_{t2}\eta_{t3}\cdots\cdots\eta_{tk}} \qquad (10.20)$$

where : $g_{r1}g_{r2}g_{r3}\cdots\cdots g_{rk}$, and $\eta_{t1}\eta_{t2}\eta_{t3}\cdots\cdots\eta_{tk}$ are the gear ratios and the efficiencies of the respective transmission.

Similarly the equivalent inertia will be :

$$\frac{1}{2}J'\omega_m^2 = \frac{1}{2}J_m\omega_m^2 + \frac{1}{2}J_1\omega_1^2 + \frac{1}{2}J_2\omega_2^2 + \frac{1}{2}J_3\omega_3^2 + \cdots + \frac{1}{2}J_k\omega_k^2$$

$$J' = J_m + J_1\frac{\omega_1^2}{\omega_m^2} + J_2\frac{\omega_2^2}{\omega_m^2} + J_3\,\frac{\omega_3^2}{\omega_m^2} + \cdots\cdots\cdots\cdots\cdots + J_k\frac{\omega_k^2}{\omega_m^2} \qquad (10.21)$$

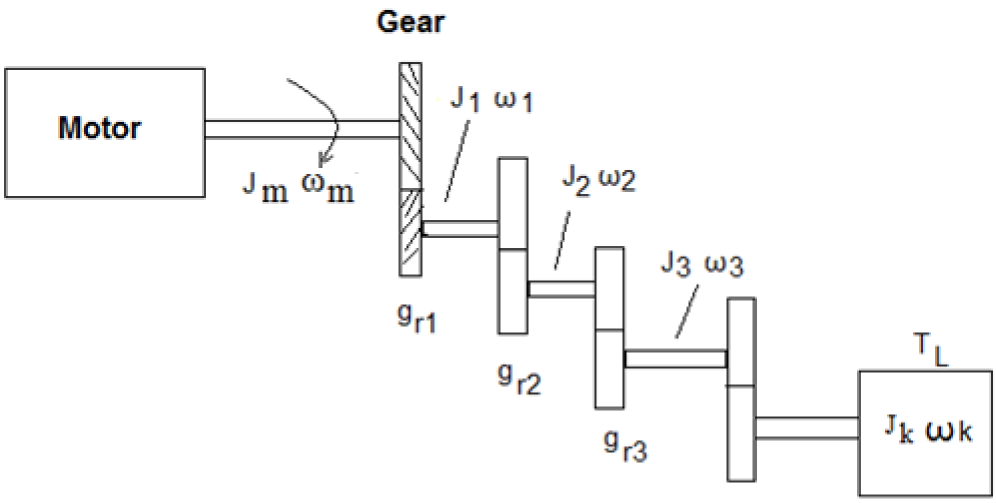


Fig.10.11 Motor-load system with multi gears.

Referring Forces and Masses Having Translation Motion to a Rotating One

In some machines or systems, some moving parts rotate while others undergo translation motion, e.g. cranes, hoists, etc. It is necessary to refer the translational motion in terms of referred load torque and moment of inertia referred to motor shaft.

Fig.10.12 shows a hoist load lift, wound on drum driven through gears by a motor. If F is the force required due to gravitational pull to lift the moving weight W, η is the efficiency of transmission , v (m/s) is the velocity of the moving mass , and ω_m (rad/s) is the angular velocity of the motor shaft, the referred load torque is obtained by equating the power.

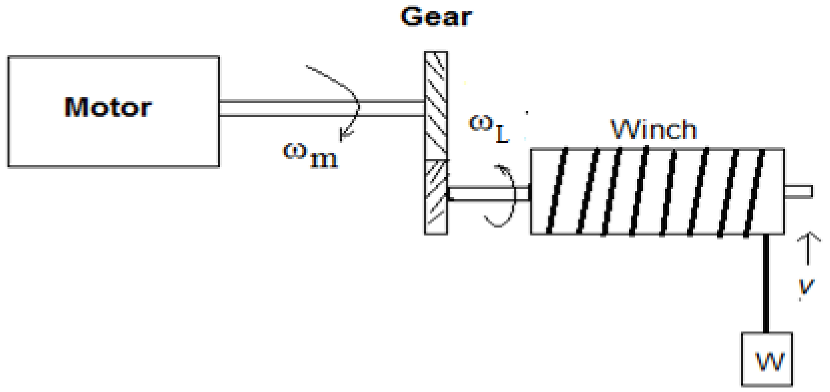


Fig.10.12 Motor-hoist load system.

The referred load torque T_L':

$$T_L' = \frac{F \cdot v}{\eta \cdot \omega_m} \tag{10.22}$$

The moment of inertia referred to the motor shaft is obtained by equating kinetic energy:

$$\frac{1}{2} m\, v^2 = \frac{1}{2} J' \omega_m^2$$

$$\text{or} \quad J' = m\left(\frac{v^2}{\omega_m^2}\right) = \frac{W}{g}\left(\frac{v^2}{\omega_m^2}\right) \tag{10.23}$$

where $m = \frac{W}{g}$ kg weight , g = gravitational accelaration = 9.81 .

Example 10.3

A weight W of (1500 kg) is to be lifted up with a velocity of (1.5 m/s) by means of a motor-hoist system shown in Fig.10.12. The winch has a diameter of (0.35 m) and driven by motor running at (1000 rpm). The inertia of the motor and the winch drum are (1.8 kg.m^2) and (4.2 kg.m^2) respectively. Calculate the total load torque of the system referred to the motor shaft .

Solution

Winch drum diameter = o.5 m
Circumference of the winch drum = 0.5π = 1.57 m
Velocity of the weight = 1.5 m /s
Speed of the winch =1.5/1.57 = 0.955 rev/s
ω of the winch, ω_{winch} = 2π × 0.955 = 5.997 rad / s
speed of the motor = 1000/60 = 16.6 rev / s
ω_m of the motor = 2π ×16.6 = 104.6 rad / s
constant load torque = weight × radius of the winch drum
= 1500 × (0.5/2) = 375 kgf . m = 375 Nm at ω_{winch}.
Hence

$$\frac{\omega_L}{\omega_m} = \frac{2\pi \times 0.955}{2\pi \times 16.6} = 0.0575$$

If J' is the moment of inertia of the translation movement of the weight referred to the motor shaft of the motor , then

$$\frac{1}{2}\ mv^2 = \frac{1}{2} J'\,\omega_m^2$$

$$\therefore \quad J' = \frac{1500}{9.81} \times \frac{1.5^2}{104.6^2} = 0.03144 \ \text{kg.m}^2$$

Total torque referred to the motor shaft :

$$T_m = J_m \frac{d\omega}{dt} + W \cdot r \left(\frac{\omega_L}{\omega_m}\right) + J_{winch} \times \left(\frac{\omega_L}{\omega_m}\right)^2 \times \frac{d\omega}{dt} + J' \frac{d\omega}{dt}$$

$$T_m = 1.8 \frac{d\omega}{dt} + 375 \times \left(\frac{\omega_L}{\omega_m}\right) + 4.2 \times (0.0575)^2 \frac{d\omega}{dt} + 0.0144 \frac{d\omega}{dt}$$

If the system operates at steady-state (running continuously without acceleration) ,then

$$\frac{d\omega}{dt} = 0 \quad \text{and} \quad T_m = 375 \times \left(\frac{\omega_L}{\omega_m}\right) = 375 \times 0.0575 = 21.56 \ \text{Nm}$$

Example 10.4

A motor has two loads. Load-1 has rotational motion which is coupled to the motor through a reduction gear with gear ratio g_{r1} =10 and efficiency of

90%. Load-1 has a moment of inertia of 10 kg.m^2 and torque of 10 Nm. Load-2 has translation motion and consists of 1000 kg weight to be lifted up at uniform speed of 1.5 m / s. The coupling between load-2 and the motor has an efficiency of 85%.The motor has an inertia of 0.2 kg.m^2 and runs at constant speed of 1420 rpm. Determine the equivalent inertia referred to the motor shaft and the power developed by the motor.

Solution

From equations (10.21) :

$$J' = J_m + J_1 \frac{\omega_1^2}{\omega_m^2} + J_2 \frac{\omega_2^2}{\omega_m^2}$$

$$J' = J_m + J_1 \frac{1}{g_{r1}^2} + m \left(\frac{v^2}{\omega_m^2}\right)$$

J_m= 0.2 kg.m^2 , g_{r1} = 10 , v = 1.5 m /s , and

$$\omega_m = \frac{2\pi n}{60} = 2\pi \times \frac{1420}{60} = 148.7 \text{ rad/s}$$

Hence, substituting these values in the above equation we get;

$$J' = 0.2 + 10 \times \frac{1}{10^2} + 1000 \left(\frac{1.5^2}{148.7^2}\right) = 0.4 \text{ kg.m}^2$$

The referred torques are calculated as follows:

The referred torque for load-1 (T'_{L1}), can be found from Eq.(10.18),

$$T'_{L1} = \frac{T_{L1}}{g_{r1}\eta_{t1}}$$

The referred torque for load-2 (T'_{L2}) can be found from Eq.(10.22),

$$T'_{L2} = \frac{F \cdot v}{\eta_{t1} . \omega_m}$$

The total load torque referred o the motor shaft is,

$$T'_L = T'_{L1} + T'_{L2}$$

or
$$T'_L = \frac{T_{L1}}{g_{r1}\eta_{t1}} + \frac{F.v}{\eta_{t1}\omega_m}$$

Here: η_{t1} = 0.9 , g_{r1} = 10 , T_{L1} = 10 Nm , η_{t2} = 0.85 , F = mg =1000 × 9.81 = 9810 N , v = 1.5 m / s , and ω_m =148.7 rad / s.

Now substitute these values in the above equation yields;

$$T_L^{'} = \frac{10}{10 \times 0.9} + \frac{9810 \times 1.5}{0.85 \times 148.7} = 117.53 \text{ Nm}$$

Example 10.5

A drive used in a hoist to raise and lower weights up to 400 kg at velocities up to ± 2 m/s. The weight hangs from a cable that is wound on a drum of radius of 0.4 m . The drum is driven by the drive motor through a gearbox that has an efficiency of 85% . The maximum speed of the motor is ± 1300 rpm. It is required to:

(a) Sketch the system and find the nearest integer gearbox ratio that will match the maximum speed of the motor to the maximum velocity of the hoist.
(b) Determine the torque and power provided by the motor when lifting the maximum weight at the maximum velocity.
(c) Calculate the torque and power provided by the motor when lowering the maximum weight at the maximum velocity.

Solution

(a) The system is shown in Fig. 10.13.

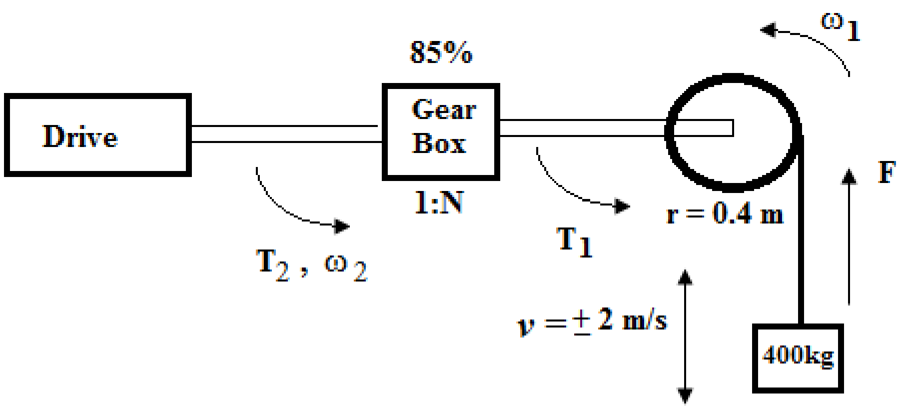


Fig.10.13 System diagram of Example 10.5.

The speed of the weight is given as: $v = 2$ m /s

$$\omega_1 = \frac{v}{r} = \frac{2}{0.4} = 5 \text{ rad/s}$$

The motor speed in rad /s is given by

$$\omega_2 = 1300 \times \frac{2\pi}{60} = 136.06 \text{ rad/s}$$

$$N = \frac{\omega_2}{\omega_1} = \frac{136.06}{5} = 27.21 \quad \rightarrow \quad \text{use } 27$$

$$\frac{\omega_2}{27} = 5$$

$$\therefore \quad \omega_2 = 135 \ \text{rad/s} = \frac{135 \times 60}{2\pi} = 1290 \text{ rpm}$$

(b) Now, when lifting and lowering F is upwards, T_l is in the direction shown (here anticlockwise)

$$T_1 = \text{Force } \times \text{radius} = 400 \times 9.81 \times 0.4 = 1569.6 \text{ Nm}$$

(Since Force = mass × gravity)

When lifting, motor drive supplies the losses in the gearbox :

$$T_2 = \frac{T_1}{N.\eta} = \frac{1569.6}{27 \times 0.85} = 68.4 \text{ Nm}$$

$$T_2 \times \omega_2 \times \eta = T_1 \times \omega_1$$

$$P_{drive} = T_2 \times \omega_2 = 68.4 \times 135 = 9.234 \text{ kW}$$

When lowering , moving mass now supplies gearbox losses, hence

$$T_2 \times \omega_2 = T_1 \times \omega_1 \times \eta$$

$$T_2 = \frac{1569.6 \times 0.85}{27} = 49.41 \text{ Nm}$$

$$P_{drive} = 49.41\,(-135\,) = -\,6.67 \text{ kW}$$

The minus sign indicates that the drive is regenerating.

10.5 MECHANICAL TRANSMISSIONS EMPLOYED IN ELECTRICAL DRIVE SYSTEMS

Motion from the electric motor to the actuating or drive system is imparted through a system drives. The electric drive widely employs the mechanical transmission designed to convey and convert the rotational motion of the motor shaft to the desired kind of motion of the actuating mechanism, the speed and torque being changed accordingly.

10.5.1 Reducers

The electric motor generally produces relatively high rpm (speed). Since most of loads in drive systems require low speed operation, therefore it is required to install a reducer, i.e. an encased transmission mechanism, between the motor and the actuating mechanism or load. In order obtain drastic reduction in the speed of motion, the reducers may be fitted with several series-connected mechanical transmissions. The reducers are mainly provided by gears, planetary, worm, and screw-gear transmissions. These types will be discussed briefly hereinafter.

(A) Gear Transmission

(1) Simple reducers with ordinary gear wheels employ external and internal gearing (Fig.10.14) with efficiency of 98% or more in one pair of wheels. Such reducers are simple in construction. One pair of gear wheels is capable of providing small gear ratios ($g_t \approx 6$) which imply the ratio of the input speed ω_1 to the output speed ω_2 , i.e.:

$$g_t = \frac{\omega_1}{\omega_2} = \frac{z_1}{z_2} \qquad (10.24)$$

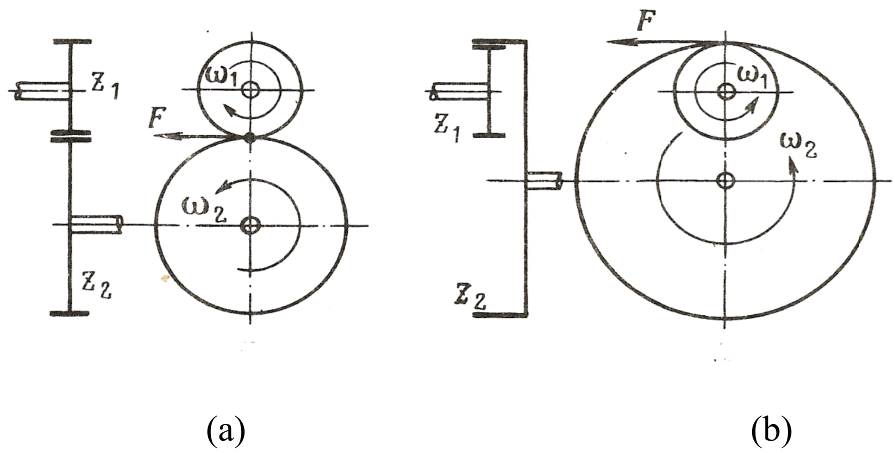


Fig.1.14 Single- stage gear transmission with : (a) External transmission, and (b) Internal transmission.

where Z_2 and Z_1 are, respectively, the number of teeth on the output and input gear wheels.

(2) Multi-stage gearing: To obtain greater ratios, multi stage transmission as shown in Fig.10.15, is used. This type is mainly used in low-power drive systems.The gear ratio of the multi-stage gearing canbe obtained by the following formula

$$g_t = \frac{Z_2}{Z_1} \times \frac{Z_4}{Z_3} \times \frac{Z_6}{Z_5} \dots\dots\dots \frac{Z_{2n}}{Z_{2n-1}} = g_1 \times g_2 \times g_3 \dots\dots\dots\dots \times g_n \quad (10.25)$$

where n = number of transmission stages ,
g_n = gear ratio of transmission stage.

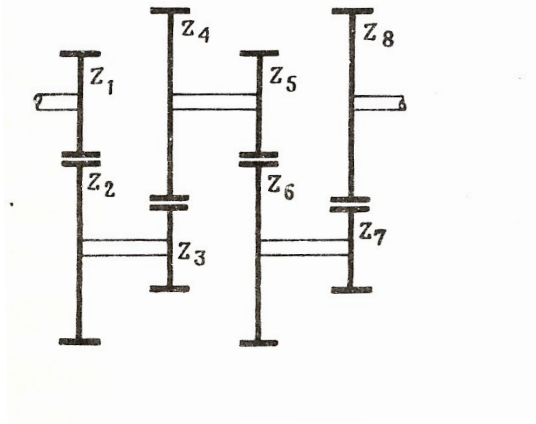


Fig.10.15 Multi-stage gear transmission with pairwise meshing.

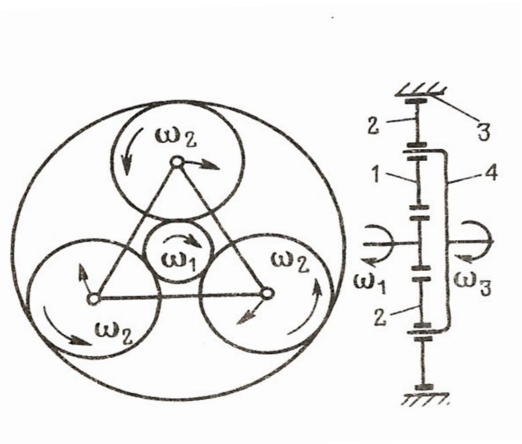


Fig.10.16 Coaxial planetary tray transmission.

(B)The planetary gear transmission

Fig.10.16 shows a simple diagram of a planetary reducer. As compared to simple reducers, the planetary reducers have a relatively small size. The rotary motion is imparted sun gear 1 which is fixed firmly to the driving shaft, to satellite gear 2 (minimum two gears) which ride over a fixed rim gear 3 and rotate carrier 4 linked to the output shaft. The gear ratio of such transmission is determined from

$$g_t = \frac{\omega_1}{\omega_2} = \frac{Z_1 + Z_2}{Z_2} \quad (10.26)$$

It is clear from Eq.(10.26) that the gear ratio in planetary system of transmission does not depends on the number of satellite gears and their teeth number.

(C)The worm gear transmission

These are designed to transmit rotation between two shafts that are located at angle of 90^{o} to each other and in different planes, Fig.10.17. As the worm rotates, its threads apply pressure to the teeth and drive the gear wheel. The worm gear transmission consists of worm 1 and worm wheel 2, meshed with each other.

The gear ratio of the worm gear transmission is given may reach comparatively that can be expressed as

$$g_t = \frac{Z}{m} \qquad (10.27)$$

where Z = number of teeth on worm wheel.
m= number of threads turns.

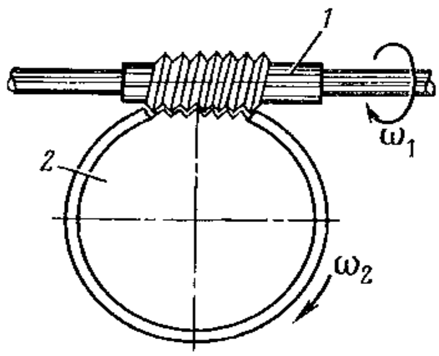


Fig.10.17 Worm transmission.

Disadvantages:
Usually this type of transmission has low transmission efficiency (50% - 85%), rapid wear and relative low power transmission.

(D)The screw transmission

These devices are served to convert rotary, motion to progressive (linear) motion, Fig.10.18 , and usually used in output devices.

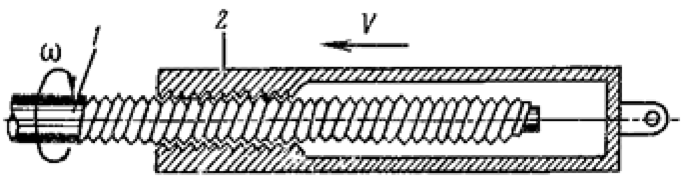


Fig.10.18 Screw transmission.

The gear ratio of such drive is given by:

$$g_t = \frac{\omega}{v} \qquad (10.28)$$

where ω = angular speed of the input shaft.
v = linear speed of the output shaft.

The efficiency of such transmission is about 50%. This type of transmission can be made self braking.

10.5.2 Cluches

A clutch is an electromagnetic device designed to join together two shafts of a transmission system, as well as to break either one of them. In general, there are three main types of clutches used in main industrial tasks:

- Friction clutches

- Braking clutches
- Safety clutches

The application of the friction and braking clutches is to preclude malfunction of a controlled mechanism which may occurs due to rundown of the electric motor, after it turned off, and to shorten the transient process when the mechanism responds to a control signal or when it is being reversed. The torque-limiting clutches protect transmission systems from excessive mechanical stress which may developed by overloading. The safety clutches safeguard the electric motors in the event of inadvertent damage ,seizing or any other unexpected failures.

(A) Friction clutches

The electrical mechanisms widely use clutch of mechanical coupling with electromagnetic control; such mechanism is called electromagnetic friction clutch and depicted in Fig.10.19. As winding 2 of the clutch is energized, the electromagnetic force overcomes the tension of the leaf spring 5 and this draws the armature 3 of the clutch toward core 4, and the torque is transmitted from the electric motor to the actuating mechanism.

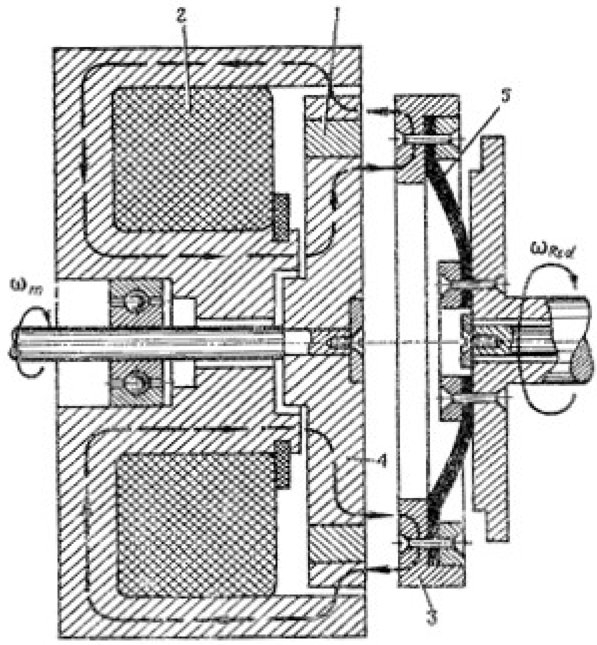


Fig.10.19 Electromagnetic clutch.

The turning off of the power supply of the motor de-energizes the winding of the clutch. Leaf springs 5 force off armature 3 to the initial position, and the armature of the electric motor disengaged from the actuating mechanism.

(B)The braking clutches

These types of clutches are used in electric drives of low and medium power. A typical breaking clutch is presented in Fig.10.20. The end shield 8 of the electric motor carries electromagnet frame 7. When winding 6 is de-energized, electromagnet armature 4 is pressed by spring 5 to brake ring 3 on disc 2 secured to the motor shaft 1.The frictional forces acting between armature 4 and the brake ring rapidly bring the motor armature to stop. When the electromagnet winding is activated, armature 4 is attracted to core 7 and the electric motor is disengaged.

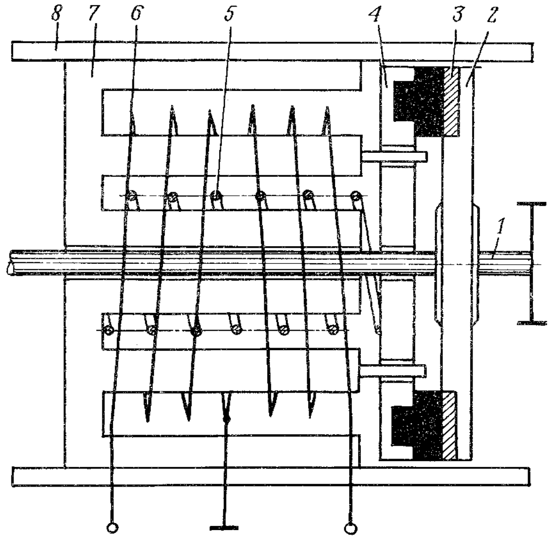


Fig.10.20 Electromagnetic breaking clutch.

(C) The safety clutches

These are installed between the electric motor and the actuating mechanism. In Fig.10.21, the safety friction clutch is presented in the form of two discs 5, 6 and springs 10. The friction torque between the discs depends on the tension of spring 10 and the friction coefficient of the discs. When the resisting (counter) torque on the shaft of the actuating mechanism exceeds the permissible value determined by the slipping torque of the discs, they start slipping with respect to each other, thus limiting the resisting torque transmitted via gear 1 to the shaft of the electric motor.

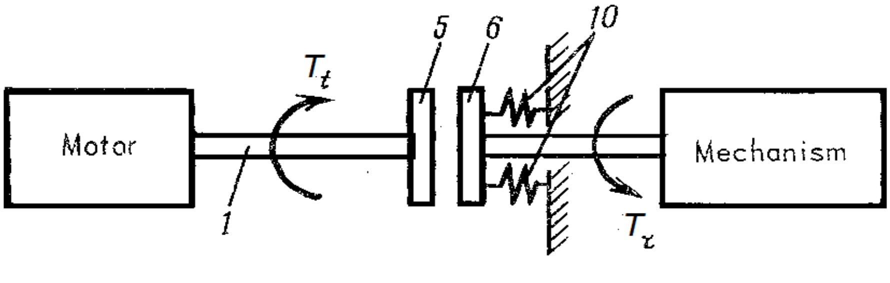


Fig.10.21 Safety clutches.

10.6 RATING OF MOTORS

Rating or size of motor can be selected in accordance to specific industrial applications. Beside the rated voltage and rated frequency, the size of the motor depends also upon:

(1) Temperature rise , which also depend on the duty cycle of the load
- Continuous load
- Intermittent load
- Variable load

(2) Maximum torque required of the motor

Temperature rise :

An electric machine can be considered as a homogeneous body in which heat is internally developed at uniform rate and heat dissipation is not a rate proportional to its temperature rise. The relation between the temperature rise and time is an exponential function which is given by:

$$\theta = \theta_m \left(1 - e^{-\frac{t}{\tau}}\right) \qquad (10.29)$$

where: θ = temperature rise C°
θ_m = Maximum temperature rise C°
τ = heating time constant
t = time in seconds

The temperature rise characteristics is depicted in Fig.10.22.

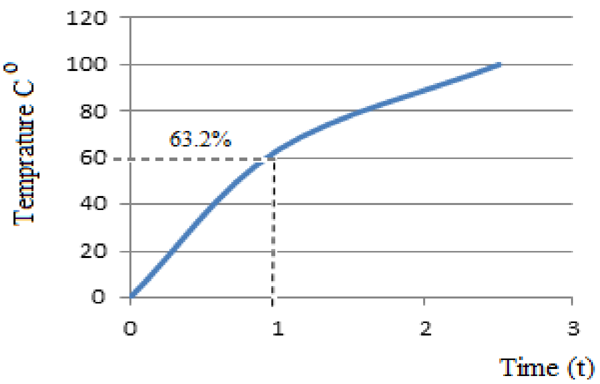


Fig.10.22 Temperature rise in electrical machine.

Cooling:

During cooling period (motor speed reduce or stopped) the temperature equation will be

$$\theta = \theta_m\, e^{-\frac{t}{\tau}} \qquad (10.30)$$

Example10.6

A motor has a thermal heating time constant of 45 min. When the motor runs continuously on full rating; its final temperature rise is 75 C°. (a) What is the temperature rise after two hour if the motor runs continuously on full load? (b) If the temperature on one hour rating is 70 C°, find the maximum steady temperature at this rating.

Solution

(a) Heating time constant τ = 45 min.

$$\Theta = \Theta_\infty\left(1 - e^{-\frac{t}{\tau}}\right) = 80(1 - e^{-\frac{120}{45.0}}) = 69.43\ \text{C}°$$

(b)

$$70 = \Theta_\infty\left(1 - e^{-\frac{120}{45.0}}\right)$$

$$\therefore\ \Theta_\infty = \frac{70}{0.925} = 75.6\ C°$$

10.6.1 Rating of the Motor for Continuous Load

If the motor has load torque T in Nm and it is running at ω rad /sec , the power rating of the motor:

$$p = \frac{T \cdot \omega}{1000} kW \qquad \rightarrow \qquad p = \frac{T \cdot \omega}{746}\ hp \qquad (10.31)$$

Such loads are pumps, fan, etc.

10.6.2 Rating of the Motor for Intermittent Loads

Here the motor operating for short time and switch off for long time (motor is loaded for sometime). The motor is switched on before cooling completely to the ambient temperature such loads also referred as fluctuating loads, see Fig.10.23. An approximate and simple method of determined the rating of a motor subjected to fluctuating load is by assuming that the heating is proportional to the square of the current drawn by the motor and hence square of the load. The suitable continuous rating of the motor is the *rms* value of the load curve.

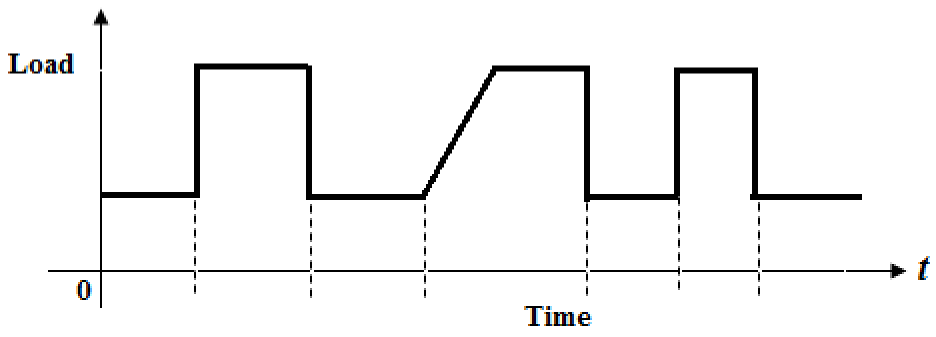


Fig.10.23 Fluctuating loads. e.g. (elevators).

Example10.7

The load cycle of a motor operating an elevator (lift) for 11 minutes is as follows:

Load period at the bottom	5 minutes	2 hp
Load going up	1 minute	25 hp
Load period at the top	4 minutes	2 hp
Load period going down	1 minute	-20 hp

Regenerative braking takes place when the load is disconnected. The cycle is repeated continuously. Estimate suitable *hp* for the motor.

Solution

Load variation is plotted in Fig.10.24.

The total area under the $(\text{hp})^2$ curve:

$$A = (2)^2 \times 5 + 25^2 \times 1 + 2^2 \times 4 + -20^2 \times 1 = 1061\ (\text{hp})^2.\ \text{min.}$$

$$\therefore \quad \text{hp}^2 = \frac{1061}{11} = 96.45 \qquad \text{or} \qquad \text{hp} = 9.82$$

The nearest standard rating = 10 hp.

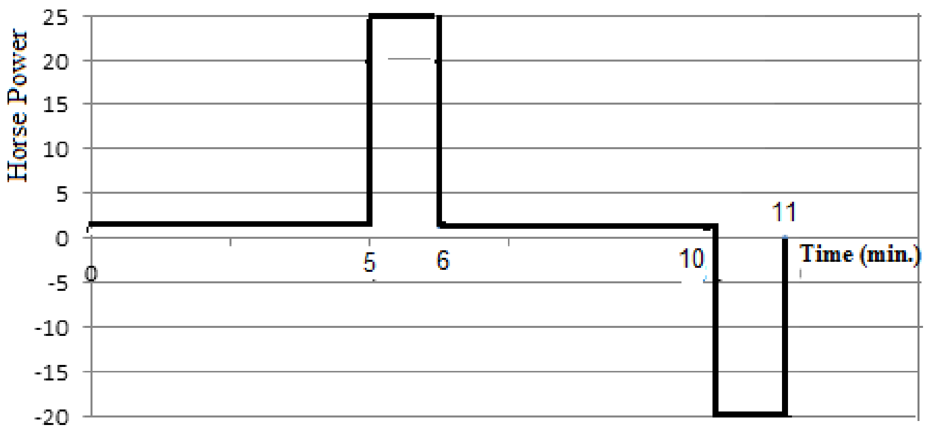


Fig.10.24 Power variation with time.

10.6.3 Rating of the Motor for Variable Load

The rating of the motor under such load conditions can be determined from the load torque vs time carve as depicted in Fig.10.25. This is called the method equivalent torque. In case of machines, whose flux remains constant irrespective of load variation, the equivalent torque rating is given by:

$$T_{eq} = \sqrt{\frac{\sum_{i=0}^{n} T_i^2 . t_i}{\sum_{i=0}^{n} t_i}} \quad (10.32)$$

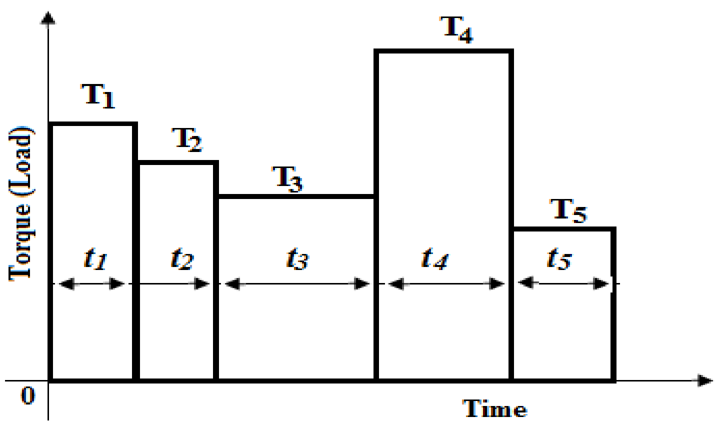


Fig.10.25 Load torque variation with time.

If the speed at which the load operates is approximately constant, the power P is proportional to the torque T and,

$$P_{eq} = \sqrt{\frac{\sum_{i=0}^{n} P_i^2 . t_i}{\sum_{i=0}^{n} t_i}} \quad (10.33)$$

Example 10.8

An electric motor has load variation as:

Torque	250 Nm	for 25 minutes
	150 Nm	for 10 minutes
	320 Nm	for 12 minutes
	180 Nm	for 20 minutes

Find the equivalent torque rating of the motor. If the speed of the motor is 1000 *rpm* find the power rating of the motor?

Solution

$$T_{eq}^2 = \frac{(250)^2 \times 25 + (150)^2 \times 10 + (320)^2 \times 12 + (180)^2 \times 20}{25 + 10 + 12 + 20}$$

$$= 47588.3$$

$$\therefore T_{eq} = \sqrt{47588.3} = 218.14 \text{ Nm}$$

Power rating of the motor

$$P = T_{eq}\,\omega = \frac{218.14 \times 2\pi \times 1000}{60} = 22.8 \text{ kW}$$

Example 10.9

A motor driving an industrial load which follows the following cycles:

Power	50 kW	for 15 minutes
	No load	for 5 minutes
	30 kW	for 10 minutes
	No load	for 8 minutes

The cycle repeated indefinitely. Find the suitable size of the continuously rated motor for the purpose.

Solution

$$P_{eq}^2 = \frac{(50)^2 \times 15 + (30)^2 \times 10}{15 + 5 + 10 + 8} = \frac{46500}{38} = 1223.68$$

$$\therefore \ \mathrm{P_{eq}} = 34.98 \text{ kW}$$

The nearest standard motor size is 37 kW or 50 hp.

PROBLEMS

10.1 A motor drive system produces 150 kW at the motor shaft when the motor runs at 1200 rpm.The motor is coupled to a gearbox with a ratio 4:1. The gearbox efficiency is 85%. Calculate the speed, power and torque delivered at the output of the gearbox.

[Ans: 300 rpm, 127.5 kW, 4060.5 Nm]

10.2 An a.c. motor is used to lift a mass of 750 kg through hight of 50 meter as shown in Fig.10.26. It is required that the mass must be lifted in time of 22 s. Calculate the power developed by the motor and the power rating of the motor needed.

[Ans: 16.72 kW → 18.5 kW]

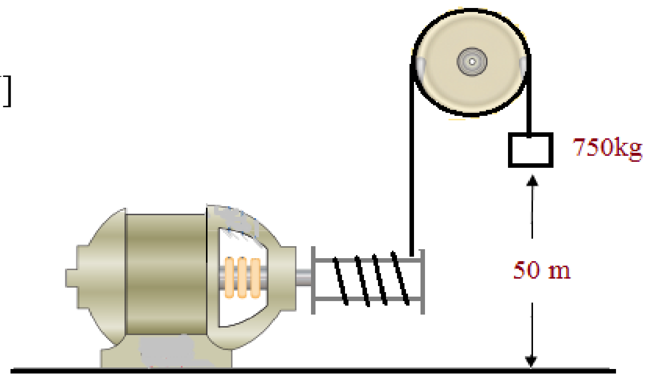


Fig.10.26.

10.3 Figure 10.27 shows a motor lifting a load by means of a winch. The weight lifted is1500 kg at a velocity of 0.5 m/s. The motor runs at a speed of 1250 rpm. The inertia of the winch drum and motor are 1.8 kg.m^2 and 3.6 kg.m^2

respectively. Calculate (i) the total load torque of the system referred to motor shaft, (ii) the inertia referred to the motor shaft.

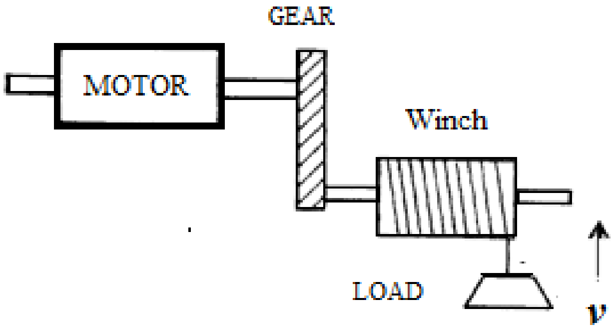


Fig.10.27.

[Ans: (i) 56.23 Nm, (ii) 0.0146 kg.m^2]

10.4 In a textile factory a motor is required to drive the take-up roll on a fabric strip line; the mandrel on which the strip is wound is 0.05 m in diameter and the strip rolls up to a roll 0.25 m in diameter. The strip emerges from the line at a speed of 15 m /s; the strip tension required is 20 kgf. The motor is coupled to the mandrel by a 1:2 reduction gearing. The gears may be considered to be 90% efficient at all speeds. Determine the speed and power rating of the motor needed for this service.

[Ans: 2866 rpm, 16.42 kW – typical ratings would be 3000 rpm, 18.5 kW]

10.5 A crane hoist is required to raise 300 kg weight at a speed of 0.40 m/s. The hook is mounted on a block which carries a single pulley sheave. One end of the hoisting cable is anchored on the crane trolley and the other is wound up on a winch drum 0.30 m in diameter. The drum is driven by a speed reducing gear of 45:1 ratio. The whole mechanism may be considered to be 65% efficient. Determine the power and speed rating of the motor and the braking torque exerted by the motor when it lowers the load at a rate of 0.5 m /s.

[Ans: 1813.3 W, 2296 rpm, – 3.18 Nm]

10.6 A paper manufacturing machine driving a large reel of paper installed at the end of the machine. The reel has a radius of 1 m , length of 4.5 m ,and a moment of inertia of 3750 kg.m^2. The machine employes driving motor a variable-speed driving motor running at 100 rpm. The paper is kept under constant tension of 5500 N.

(a) What is the power of the motor when it runs at 100 rpm.
(b) Calculate the torque and power produced by the motor when the motor speed raised to 150 rpm in 10 s.

[Ans: (a) $T = 5500$ Nm, $P = 57.52$ kW, (b) $T = 7463.35$ Nm, $P = 86.38$ kW]

10.7 A horizontal conveyer is to be used to move feedstock boxes, with an average of 6 boxes per metre run of conveyer belt. The weight of each box is 2kg. The belt is to move at a speed of 2.5 m /s. Determine the power rating of the motor required, noting that the mechanical power transmission has an efficiency of 60 % , and the motor has an efficiency of 90 % . Length of conveyer = 30 m and the mass of the part of the conveyer belt supporting the load = 1 kg per meter. The system is shown in Fig.10.28.

[Ans: 12.26 kW – typical rating would be 15 kW]

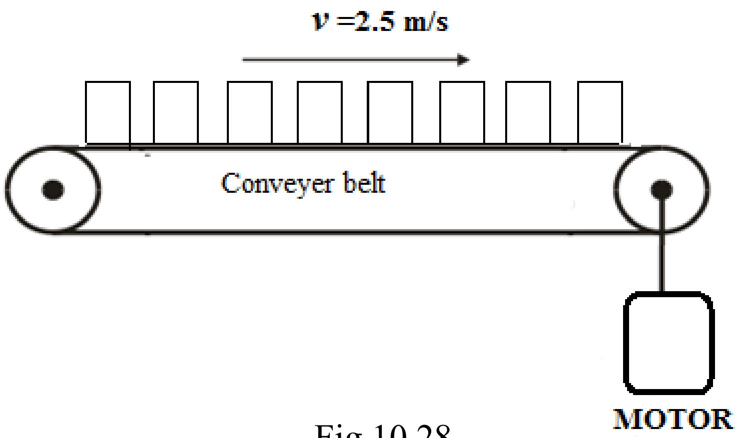


Fig.10.28.

10.8 A motor drive is supplied from a three-phase power converter has conversion efficiency of 90 % when operating at rated load. On the other hand,when the motor operates at rated load, it delivered net output power of 45 kW. The motor electrical and mechanical losses are 1125 W and 1200W respectively. Calculate the efficiency of the system from supply utility to motor shaft.

[Ans : 85.5%]

10.9 A variable speed d.c. drive has a rated power of 15 kW, and a rated speed of 1500 rpm drives a load that comprises a constant load T_L = 45 Nm. The inertia of the drive system is 0.10 kg.m^2. Calculate the time taken to accelerate the load from zero to 1000 rpm assuming the drive develops rated torque during the acceleration phase.

[Ans: 207 ms]

10.10 A drive system is used in the takeup roll in a paper making process. The paper is wound on a drum such that the radius from empty to full varies from 0.3 m to 1.25 m. The drum is driven through a 4:1 lossless reduction gearbox by the drive motor. The process requires that the tension in the paper is maintained at 75 N and the paper velocity is 15 m /s .

(a) Sketch the torque-speed characteristics of the load as seen by the motor.

(b) Determine the required motor power rating.

[Ans: 4686 W– typical rating would be 5 kW]

10.11 A weight of (1000 kg) is to be lifted up with a velocity of (1 m /s) by means of winch having a diameter of (0.30 m). The winch is driven by motor running at (960 rpm) and inertia of the motor and the winch drum are (1.6 kg.m^2) and (3.2 kg.m^2) respectively. Calculate the total load torque of the system referred to the motor shaft. The system is shown in Fig.10.29.

[Ans :9.9 Nm]

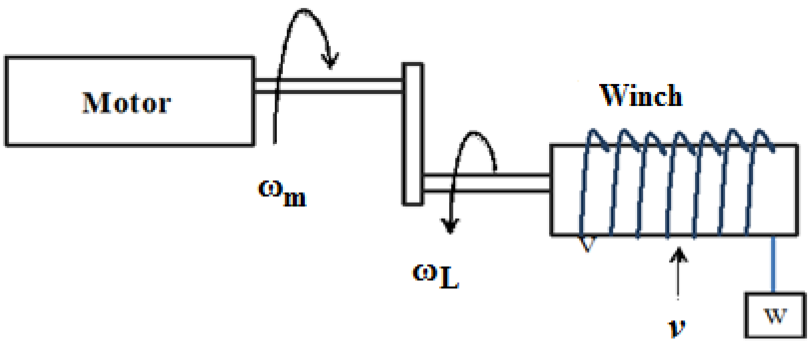


Fig . 10.29.

10.12 A horizontal conveyor belt is moving at a velocity of (1.5 m /s) and moves load at the rate of (60,000 kg/hour). The belt is (90 m) long is driven by a motor with speed of (960 rpm). Determine equivalent rotational inertia at the shaft of the motor. Fig.10.30 shows the system.

[Ans: 0.0227 kg.m^2]

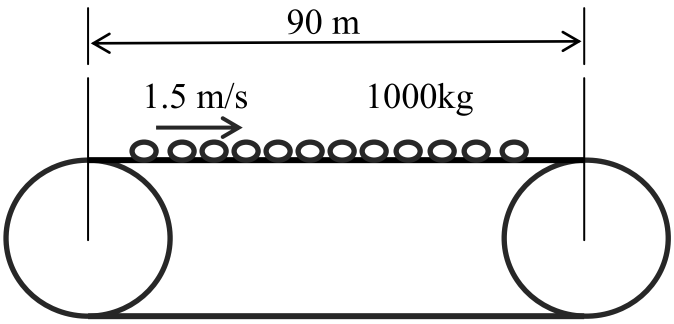


Fig.10.30.

10.13 A load torque of (6000 Nm) is supplied by motor through gears of ratios (1:2:4:8:16). The speed of motor is (960 rpm). Find the load torque referred to the motor shaft if the efficiency of each gear is (85%). Find power required by the load. Also find the power input to the motor if the motor efficiency is (88 %). The system is shown in Fig.10.31.

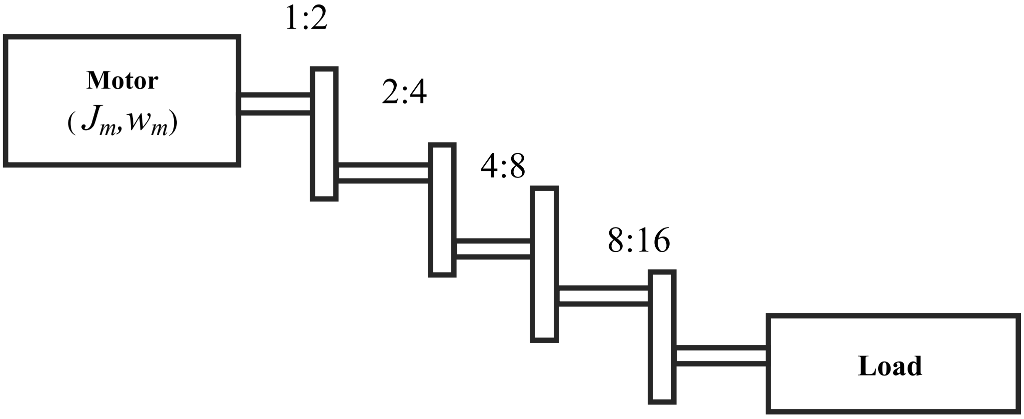


Fig .10.31.

[Ans: 11.22 Nm , 1128 Watts , 1282 Watts]

10.14 In the hoist drive system shown in Fig.10.32 , the mass M is considered being moved upwards with negligible frictional torque. Show that the load torque and the equivalent moment of inertia are given by

$$T_m = J_e \frac{d\omega_m}{dt} + \frac{\omega_2}{\omega_m} M.r$$

$$J_e = J_m + (\frac{\omega_1}{\omega_m})^2 J_1 + (\frac{\omega_2}{\omega_m})^2 [J_2 + M.r^2]$$

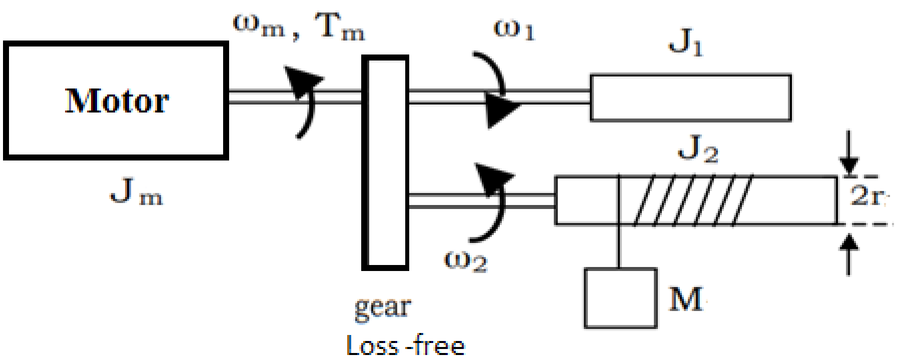


Fig.10.32.