CMR
INSTITUTE OF
TECHNOLOGY

USN | | | | | | | | | |

Internal Assesment Test - I

Sub:	**Industrial Drives and Applications**							Code:	17EE82
Date:	07/05/2022	Duration:	90 mins	Max Marks:	50	Sem:	8^{th}	Branch:	EEE

Answer Any FIVE FULL Questions

		Marks	OBE	
			CO	RBT
1.a	Draw the block diagram of an electric drive and mention the functions of Power Modulator.	6	CO1	L2
1.b	Write a short note on classification of load torques.	4	CO2	L1
2.a	A motor drives two loads. One has rotational motion. It is coupled to the motor through a reduction gear with a=0.2 and efficiency of 85%. The load has a moment of inertia of $10kg\text{-}m^{2}$ and a torque of 20N-m. Other load has translational motion and consists of 500 kg weight to be lifted at a m2uniform speed of 1.5 m/s. Coupling between this load and the motor has efficiency of 85%. Motor has an inertia of 0.2 kg-m 2 and runs at a constant speed of 1420rpm. Determine equivalent inertia referred to the motor shaft and power developed by the motor.	6	CO2	L3
2.b	Why is flywheel mounted on the shaft of the motor in non-reversible drive? Deduce the expression for the Moment of Inertia of the flywheel.	4	CO2	L1
3.a	With a neat diagram, explain the four-quadrant operation of a motor driving a hoist load.	6	CO2	L1
3.b	Explain how a current limit control functions in closed loop control of drives.	4	CO2	L1

P.T.O

CMR
INSTITUTE OF
TECHNOLOGY

USN | | | | | | | | | |

Internal Assesment Test - I

Sub:								Code:	18EE35
Date:	25/01/2022	Duration:	90 mins	Max Marks:	50	Sem:	3^{rd}	Branch:	EEE

Answer Any FIVE FULL Questions

		Marks	OBE	
			CO	RBT
1.a	Draw the block diagram of an electric drive and mention the functions of Power Modulator.	6	CO1	L2
1.b	Write a short note on classification of load torques.	4	CO2	L1
2.a	A motor drives two loads. One has rotational motion. It is coupled to the motor through a reduction gear with a=0.2 and efficiency of 85%. The load has a moment of inertia of $10kg\text{-}m^{2}$ and a torque of 20N-m. Other load has translational motion and consist of 500 kg weight to be lifted at a m2uniform speed of 1.5 m/s. Coupling between this load and the motor has efficiency of 85%. Motor has an inertia of 0.2 kg-m 2 and runs at a constant speed of 1420rpm. Determine equivalent inertia referred to the motor shaft and power developed by the motor.	6	CO2	L3
2.b	Why is flywheel mounted on the shaft of the motor in non-reversible drive? Deduce the expression for the Moment of Inertia of the flywheel.	4	CO2	L1
3.a	With a neat diagram, explain the four-quadrant operation of a motor driving a hoist load.	6	CO2	L1
3.b	Explain how a current limit control functions in closed loop control of drives.	4	CO2	L1

P.T.O

4.a	Derive expressions for equivalent values of moment of inertia and torque as referred to motor shaft for loads with rotational motion.	6	CO2	L2
4.b	Explain how a Closed Loop Speed Control functions in closed loop control of drives.	4	CO2	L1
5.a	A motor equipped with a flywheel is to supply a load torque of 1000 N-m for 10 sec followed by a light load period of 200 N-m long enough for the flywheel to regain its steady-state speed. It is desired to limit the motor torque to 700 N-m. What should be the moment of inertia of flywheel? Motor has an inertia of 10 kg-m ^{2}. It's no-load speed is 500 rpm and the slip at a torque of 500 N-m is 5%. Assume speed-torque characteristics of motor to be a straight line in the region of interest	5	CO2	L3
5.b	Explain clearly different components of load torque with its characteristics.	5	CO2	L1
6.a	A drive has following parameters:J-20 kg-m2, T= 200-0.1N, N-m. Passive load torque Tl=0.05N, N-m.Where N is the speed in rpm.Initially the drive is operating in steady state. Now it is to be reversed. For this motor characteristics is changed to T=-200-0.1N, N-m. Calculate the time of reversal.	6	CO2	L3
6.b	Mention the advantages of electrical drives.	4	CO1	L1

CCI **HOD**

4.a	Derive expressions for equivalent values of moment of inertia and torque as referred to motor shaft for loads with rotational motion.	6	CO2	L2
4.b	Explain how a Closed Loop Speed Control functions in closed loop control of drives.	4	CO2	L1
5.a	A motor equipped with a flywheel is to supply a load torque of 1000 N-m for 10 sec followed by a light load period of 200 N-m long enough for the flywheel to regain its steady-state speed. It is desired to limit the motor torque to 700 N-m. What should be the moment of inertia of flywheel? Motor has an inertia of 10 kg-m ^{2}. It's no-load speed is 500 rpm and the slip at a torque of 500 N-m is 5%. Assume speed-torque characteristics of motor to be a straight line in the region of interest	5	CO2	L3
5.b	Explain clearly different components of load torque with its characteristics.	5	CO2	L1
6.a	A drive has following parameters:J-20 kg-m2, T= 200-0.1N, N-m. Passive load torque Tl=0.05N, N-m.Where N is the speed in rpm.Initially the drive is operating in steady state. Now it is to be reversed. For this motor characteristics is changed to T=-200-0.1N, N-m. Calculate the time of reversal.	6	CO2	L3
6.b	Mention the advantages of electrical drives.	4	CO1	L1

CCI **HOD**

Solution

Q.1 a Draw the block diagram of an electric drive and mention the functions of Power Modulator.

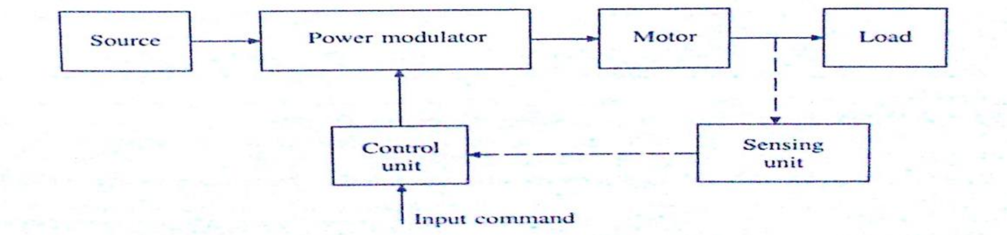


Fig. 1.1 Block diagram of an electrical drive

Functions of Power Modulator:

- Modulates the power flow from source to the motor in such a way that the motor is imparted speed-torque characteristics required by the load.
- During transient operations, such as staring, braking and speed reversal, it restricts source and motor currents within permissible values; excessive current drawn from source may overload it or may cause a voltage dip.
- Converts electrical energy of the source in the form suitable to the motor, e.g. if the source is D.C and the Induction motor is to be driven, then the power modulator is required to convert the DC into a variable frequency AC.
- Selects the mode of operation of the motor i.e. motoringnor braking.

Q.1 b Write a short note on classification of load torques.

- Active load
- Passive load

Q.2 a A motor drives two loads. One has rotational motion. It is coupled to the motor through a reduction gear with a=0.2 and efficiency of 85%. The load has a moment of inertia of 10kg-m ^{2} and a torque of 20N-m. Other load has translational motion and consists of 500 kg weight to be lifted at a m2uniform speed of 1.5 m/s. Coupling between this load and the motor has efficiency of 85%. Motor has an inertia of 0.2 kg-m 2 and runs at a constant speed of 1420rpm. Determine equivalent inertia referred to the motor shaft and power developed by the motor.

$$J = J_0 + a_1^2 J_1 + m_1 \left(\frac{v_1}{\omega_m}\right)^2$$

$$J = 0.2 + (0.2)^2 \times 10 + 500 \left(\frac{1.5}{148.7}\right)^2$$

$$= 0.2 + 0.4 + 0.0508$$

$$J = 0.6508 \text{ kg-m}^2$$

$$T_1 = \frac{a_1 T_{l1}}{\eta_1} + \frac{F_1}{\eta_1} \left(\frac{v_1}{\omega_m}\right)$$

$$T_e = \frac{0.2 \times 10}{0.85} + \frac{500 \times 9.81}{0.85} \left(\frac{1.5}{148.7}\right)$$

$$= 2.35 + 58.21$$

$$= 60.56 \text{ N-m}$$

Q. 2 b Why is flywheel mounted on the shaft of the motor in non-reversible drive? Deduce the expression for the Moment of Inertia of the flywheel.

Fluctuating loads are overcome by mounting a flywheel on the motor shaft in non-reversible drives.

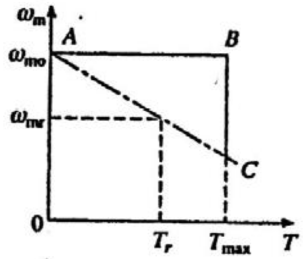


Fig. 2.10 Shapes of motor speed torque curves for fluctuating roads

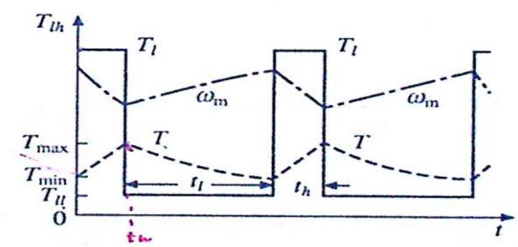


Fig. 2.11

$$\omega_m = \omega_{m0} - \frac{\omega_{m0} - \omega_{mr}}{T_r} \cdot T$$

J gives

$$J\frac{d\omega_m}{dt} = -\frac{J(\omega_{m0} - \omega_{mr})}{T_r}\frac{dT}{dt} \quad (2.32)$$

$$= -\tau_m \frac{dT}{dt} \quad (2.33)$$

where

$$\tau_m = \frac{J(\omega_{m0} - \omega_{mr})}{T_r} \quad (2.34)$$

Term τ_m is defined as the mechanical time constant of the motor. It is the time required for the motor speed to change by $(\omega_{m0} - \omega_{mr})$ when motor torque is maintained constant at rated value T_r.

From Eqs. (2.2) and (2.33)

$$\tau_m \frac{dT}{dt} + T = T_l \quad (2.35)$$

Consider now a periodic load torque, a cycle of which consists of one high load period with torque T_{lh} and duration t_h, and one light load period with torque T_{ll} and duration t_l (Fig. 2.11). For high load period $(0 \le t \le t_h)$ solution of Eq. (2.35) is

$$T = T_{lh}(1 - e^{-t/\tau_m}) + T_{min} e^{-t/\tau_m}$$

for

$$0 \le t \le t_h \quad (2.36)$$

where T_{min} is the motor torque at $t = 0$, which is also the instant when heavy load T_{lh} is applied.

If motor torque at the end of heavy load period is T_{max}, then from Eq. (2.36)

$$T_{max} = T_{lh}(1 - e^{-t_h/\tau_m}) + T_{min} e^{-t_h/\tau_m} \quad (2.37)$$

Solution of Eq. (2.35) for the light load period $(t_h \le t \le t_h + t_l)$ with the initial motor torque equal to T_{max} is

$$T = T_{ll}(1 - e^{-t'/\tau_m}) + T_{max} e^{-t'/\tau_m}$$

$$0 \le t' \le t_l \quad (2.38)$$

where

$$t' = t - t_h \quad (2.39)$$

When operating in steady-state, motor torque at the end of a cycle will be the same as at the beginning of cycle. Hence at $t' = t_l$, $T = T_{min}$. Substituting in Eq. (2.38) gives

$$T_{min} = T_{ll}(1 - e^{-t_l/\tau_m}) + T_{max} e^{-t_l/\tau_m} \quad (2.40)$$

From Eq. (2.37)

$$\tau_m = \frac{t_h}{\log_e\left(\dfrac{T_{lh} - T_{min}}{T_{lh} - T_{max}}\right)} \quad (2.41)$$

From (2.34) and (2.41)

$$J = \frac{T_r}{(\omega_{m0} - \omega_{mr})} \left[\frac{t_h}{\log_e \left(\frac{T_{lh} - T_{min}}{T_{lh} - T_{max}} \right)} \right] \tag{2.42}$$

Also from Eq. (2.40)

$$\tau_m = \frac{t_l}{\log_e \left(\frac{T_{max} - T_{ll}}{T_{min} - T_{ll}} \right)} \tag{2.43}$$

From Eqs. (2.34) and (2.43)

$$J = \frac{T_r}{(\omega_{m0} - \omega_{mr})} \left[\frac{t_l}{\log_e \left(\frac{T_{max} - T_{ll}}{T_{min} - T_{ll}} \right)} \right] \tag{2.44}$$

Moment of inertia of the flywheel required can be calculated either from Eq. (2.42) or (2.44). Further

$$J = WR^2, \text{ kg-m}^2 \tag{2.45}$$

where W is the weight of the flywheel (kg) and R is the radius (m).

Q.3 a. With a neat diagram, explain the four-quadrant operation of a motor driving a hoist load.

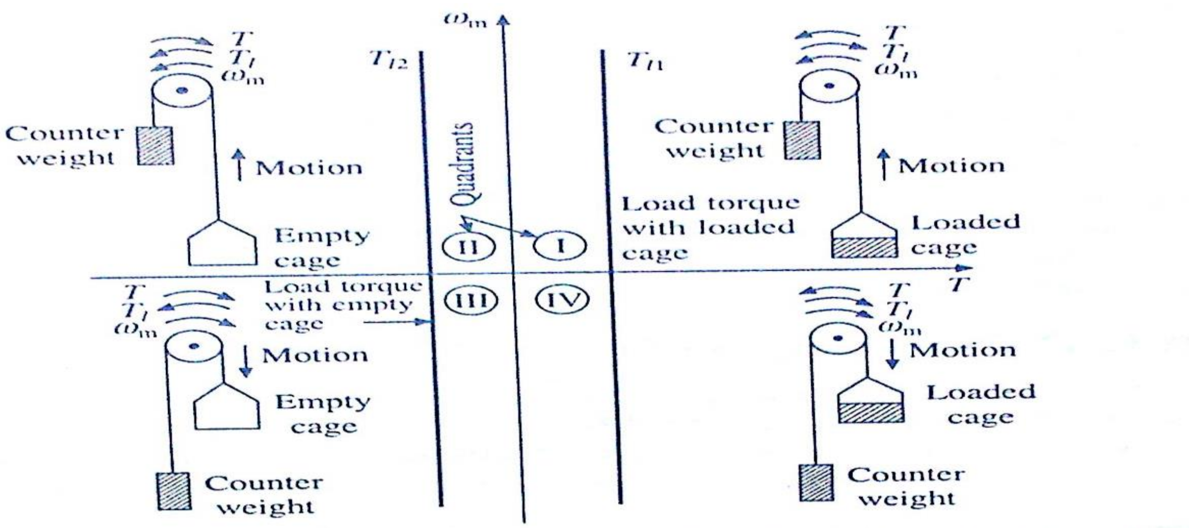


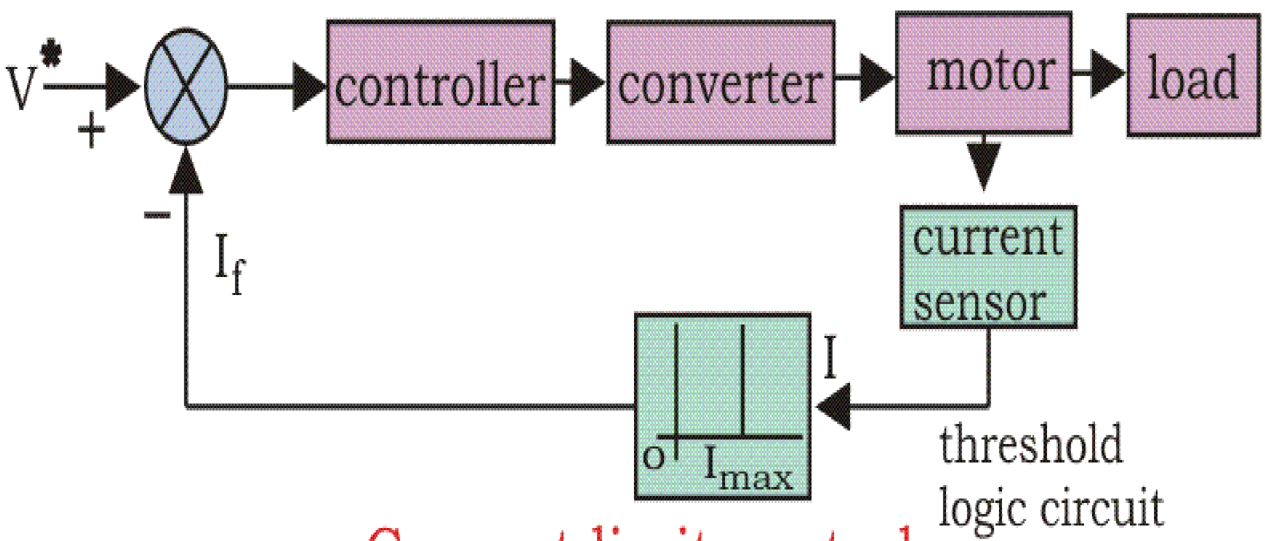
Fig. 2.3 Four quadrant operation of a motor driving a hoist load

1. Power developed by a motor is given by the product of speed and torque.
2. In quadrant I, power Developed is positive; machine works as a motor supplying Mechanical energy.
3. In quadrant II, power is negative. Hence the machine works under Braking opposing the motion

4. A motor operates in two modes – Motoring and braking.
5. In motoring, it converts electrical energy into mechanical energy, which supports its motion
6. In braking it works as a generator converting mechanical energy into electrical energy and thus opposes the motion.
7. A motor can provide motoring and braking operations for both forward and reverse directions
8. The inertia or dynamic torque appears when the speed changes from one value to another.
9. If the drive is undergoing acceleration, this torque opposes drive motion.
10. If the drive is being braked, supports motion.
11. The inertia torque both in magnitude and in sign, is determined as the algebraic difference between the motor torque and the load torque. In general the torque equation is written as

$$\pm T \mp T_L = J\frac{d\omega}{dt}$$

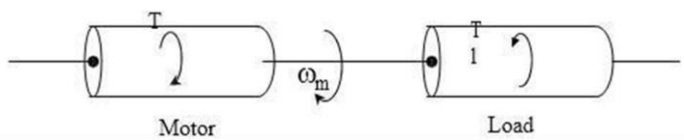
Q. 3.b Explain how a current limit control functions in closed loop control of drives.



Current limit control

- During the starting, we know if precautionary measures are not taken there is a chance of huge current flow through the motor circuit.
- Current Limit Control scheme is employed to limit the converter and motor current below a safe limit during transient operations.
- It has a current feedback loop with a threshold logic circuit.
- To limit the current and sense the current fed to the motor, current limit controller is installed.
- The feedback loop does not effect the normal operation of the drive but if the current exceeds the predetermined safe limit, the feedback loop activates and the current is brought down below the safe limit.
- Once the current is brought down below the safe limit the feedback loop again deactivates and in this way the control of current takes place.

Q.4.a Derive expressions for equivalent values of moment of inertia and torque as referred to motor shaft for loads with rotational motion.



J = Moment of inertia of motor load system referred to the motor shaft kg / m²

ω_m = Instantaneous angular velocity of motor shaft, rad/sec.

T = Instantaneous value of developed motor torque, N-m

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

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

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

$$T = T_l + J\,d/dt\,(\omega_m) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Loads with Rotational Motion

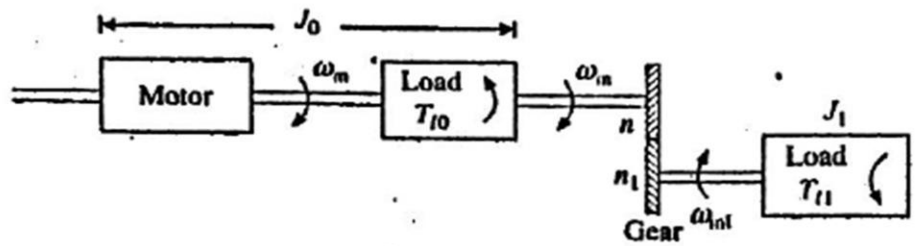
$$\frac{1}{2} J\omega_m^2 = \frac{1}{2} J_0\omega_m^2 + \frac{1}{2} J_1\omega_{m1}^2$$

$$J = J_0 + a_1^2 J_1$$

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

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

Loads with Rotational Motion

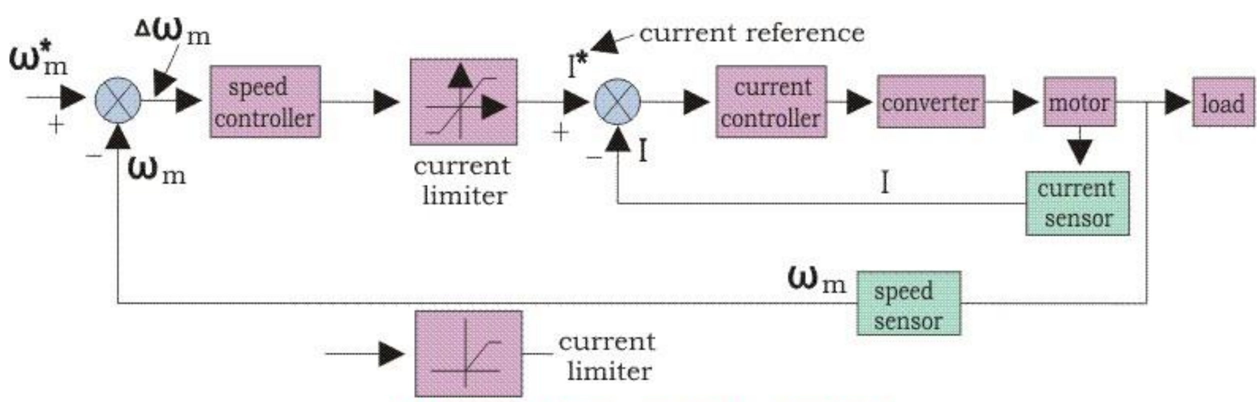


(a) Loads with rotational motion

$$J = J_0 + a_1^2 J_1 + a_2^2 J_2 + \ldots + a_m^2 J_m$$

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

Q.4 b Explain how a Closed Loop Speed Control functions in closed loop control of drives.



Closed-loop speed control

- Speed control loops are perhaps the most widely used feedback loops for drives.
- From the diagram that there are two control loops, which can be said as an inner loop and outer loop.
- The inner current control loop limits the converter and motor current or motor torque below the safe limit.
- Suppose the reference speed W_m^* increases and there is a positive error ΔW_m, which indicates that the speed is needed to be increased.
- Now the inner loop increases the current keeping it under maximum allowable current.
- And then the driver accelerates, when the speed reaches the desired speed then the motor torque is equal to the load torque and there is a decrease in the reference speed W_m^* which indicates that there is no need of any more acceleration but there must be deceleration, and braking is done by the speed controller at maximum allowable current.
- So, that during speed controlling the function transfers from motoring to braking and from braking to motoring continuously for the smooth operation and running of the motor.

Q. 5 a.A motor equipped with a flywheel is to supply a load torque of 1000 N-m for 10 sec followed by a light load period of 200 N-m long enough for the flywheel to regain its steady-state speed. It is desired to limit the motor torque to 700 N-m. What should be the moment of inertia of flywheel? Motor has an inertia of 10 kg-m ^{2}. It's no-load speed is 500 rpm and the slip at a torque of 500 N-m is 5%. Assume speed-torque characteristics of motor to be a straight line in the region of interest

$$J = \frac{T_r}{(\omega_{m0} - \omega_{mr})}\left[\frac{t_h}{\log_e\left(\frac{T_{lh} - T_{min}}{T_{lh} - T_{max}}\right)}\right]$$

$$\text{no load speed} = \frac{500 \times 2\pi}{60} = 52.36 \text{ rad/sec}$$

$$\frac{T_r}{(\omega_{m0} - \omega_{mr})} = \frac{500}{52.36 - 49.74} = 190.84$$

$$T_{lh} = 1000 \text{ N-m},\ T_{max} = 700 \text{ N-m},\ T_{min} = T_{ll} = 200 \text{ N-m},\ t_h = 10 \text{ S}.$$

$$J = 190.84 \left[\frac{10}{\log_e \left(\frac{1000 - 200}{1000 - 700} \right)} \right] = 1871.8 \text{ kg-m}^2$$

Moment of inertia of the flywheel = 1871.8 – 10 = 1861.8 kg-m^2.

Q. 5 b. Explain clearly different components of load torque with its characteristics.

Components of Load Torque

- Friction Torque, TF
- Windage Torque,TW
- Torque required to do the useful mechanical work,TL
- Tl can be divided into the following components;
- i) Friction torque TF – Friction will be present at the motor shaft and also in various parts of the load. TF is equivalent value of various friction torques referred to the motor shaft.
- ii) Windage Torque Tw – It is a torque generated when a motor runs, which opposes the motion.
- iii) Torque required to do the useful mechanical work TL Nature of this torque depends on particular application.
- It may be constant and independent of the speed;
- It may be some function of speed;
- It may depend on the position or path followed by the load;
- It may be time invariant or time variant;
- It may vary cyclically and its nature may also change with the load's mode of operation

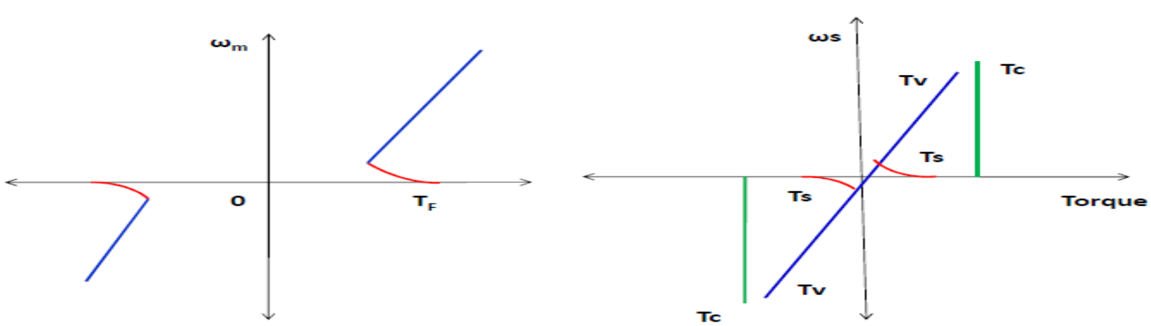


Fig. 3.5. Variation of Friction torque and its components

As can be seen from the figure, the Friction torque 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 for a drive to start, the motor torque should at least exceed Stiction.

• Friction torque can be resolved into three components (see the fig.)

- Viscous friction torque (Tv) : - component which varies linearly with speed.
- Tv = Bωm; where B is viscous friction coefficient.
- Coulomb friction (Tc) which is independent of speed. Additional friction torque at standstill (Ts):
- Ts is present only at stand still and is not taken into account in the dynamic analysis.
- Windage friction torque (Tw): - which is proportional to the speed squared.
- Tw = Cω2 m; where C is a constant
- - From the above discussion, for finite speeds;
- Tl = TL + Bωm + Tc + Cω2 m
- where,
- Tl – instantaneous value of load torque referred to motor shaft.
- TL – torque required to do the useful mechanical work. . In many applications,
- (Tc + Cω2 m) is very small and can be neglected. Then the fundamental torque equation becomes;

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

Q.6.a A drive has following parameters:J-20 kg-m2, T= 200-0.1N, N-m. Passive load torque Tl=0.05N, N-m.Where N is the speed in rpm.Initially the drive is operating in steady state. Now it is to be reversed. For this motor characteristics is changed to T=-200-0.1N, N-m. Calculate the time of reversal.

For steady-state speed $T - T_l = 0$

$$200 - 0.1N - 0.05 = 0$$

$$0.15N = 200$$

$$N = 1334 \text{ rpm.}$$

After reversal, for steady-state speed, nothing that the load is passive

$$-200 - 0.1N - 0.05N = 0$$

$$N = -1334 \text{ rpm.}$$

when reversing

$$J\frac{d\omega}{dt} = -200 - 0.1N - 0.05N$$

$$\frac{dN}{dt} = \frac{30}{J\pi}(-200 - 0.15N) = \frac{30}{20\times\pi}(-200 - 0.15N)$$

$$= -95.59 - 0.143N$$

$$t = \int dt = \int_{N_1}^{N_2} \frac{dN}{-95.49 - 0.0716}$$

$N_1 = 1334$ rpm and $N_2 = 0.95 \times -1334$ rpm

$$= -1267.3$$

$t = \cong 2$ sec

Q.6.b Mention the advantages of electrical drives.

- They have flexible control characteristics.
- The electric drive has very large range of torque, speed and power.
- Their working is independent of the environmental condition.
- The electric drives are free from pollution.
- The electric drives operate on all the quadrants of speed torque plane.
- The drive can easily be started and it does not require any refuelling.
- The efficiency of the drives is high because fewer losses occur on it.
- They are powered by electrical energy which has a number of advantages over other forms of energy.