Tribhuvan University
Institute of Engineering
Pulchowk Campus
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Unit: I- Introduction to Electric Drives

Class-05:
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Presented by
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Subject Name
EE: Modelling and Control of Electric Drives

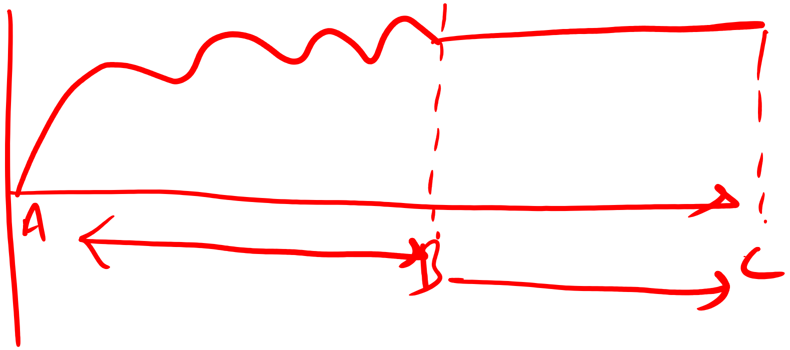
Discussed in the Previous Class

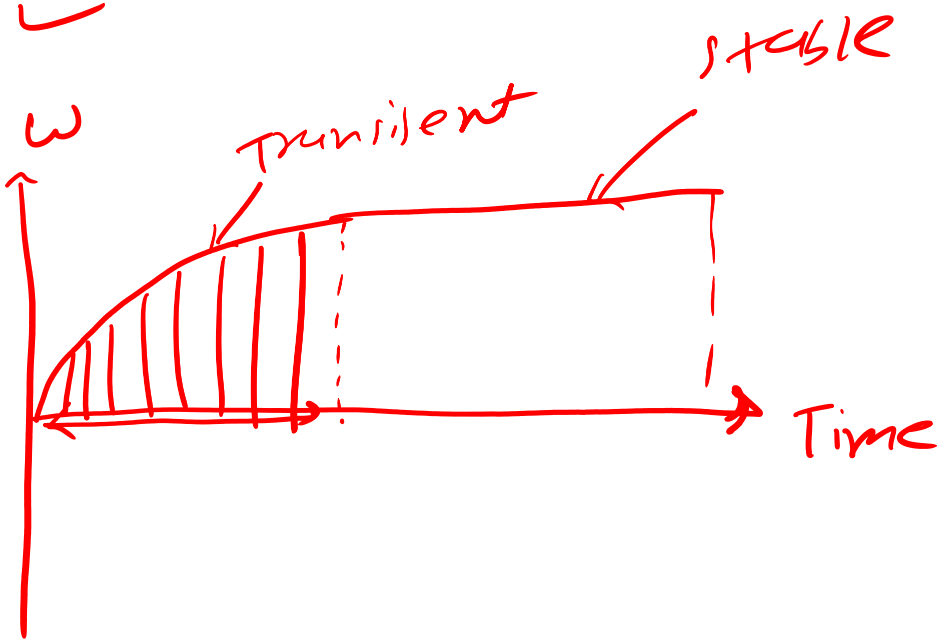
In the previous class discussed the following topics:

- Components of Load Torque
- Classifications of Load Torque

Lecture Outcomes

- ❖ Time and Energy Loss in Transient Operations
- ❖ Steady State Stability of an Electric Drive System
- ❖ Lecture remarks: Key points of today's class





Time and Energy Loss in Transient Operations

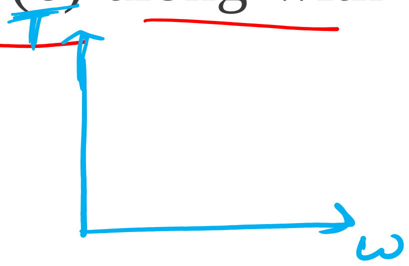
- Starting, braking, speed change and speed reversal are transient operations. Time and Energy Loss in Transient Operations can be evaluated by solving Eq. (6) along with motor circuit equations.

$\frac{d\omega_m^{(1)}}{dt}$ $\frac{d\omega_m^{2}}{dt}$

$$T = J\frac{d\omega_m}{dt} + T_L + B\omega_m \qquad (6)$$

T_f, T_s, T_w

T, T_L B



- When T and T_L are constants or proportional to speed, Eq. (6) will be a first-order linear differential equation. Then it can be solved analytically.

- When T or T_L is neither constant nor proportional to speed, (6) will be a non-linear differential equation.

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

- It could then be solved numerically by the **Runga-Kutta method**.

$T(\omega_m) - T_L(\omega_m)$

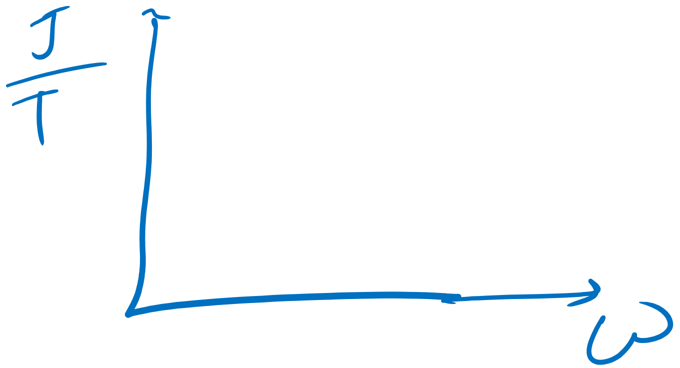
$$T = J\frac{d\omega_m}{dt} + T_L + B\omega_m.$$

$$T >> T_L >> B\omega_m$$

T & $T_L >> B\omega_m$ very less.

Transient

$$T = J\frac{d\omega_m}{dt} + T_L \quad \text{—} \quad (1)$$



$$T - T_L = J\frac{d\omega_m}{dt} \quad (A)$$

$$(T - T_L)\omega_m = J\frac{d}{dt}$$

$$\boxed{\frac{J}{\omega_m(T - T_L)} = dt}$$

Time and Energy Loss in Transient Operations

- For any of the above mentioned transients, the final speed is an equilibrium speed.

- Theoretically, transients are over in infinite time, which is not so in practice.

- To resolve this anomaly, Time and Energy Loss in Transient Operations is considered to be over when 95% change in speed has taken place.

- For example, when speed changes from ω_{m1} to equilibrium speed ω_{me}, the time taken for the speed to change from ω_{m1} to $[\omega_{m1} + 0.95(\omega_{me} - \omega_{m1})]$ is considered to be equal to the transient time.

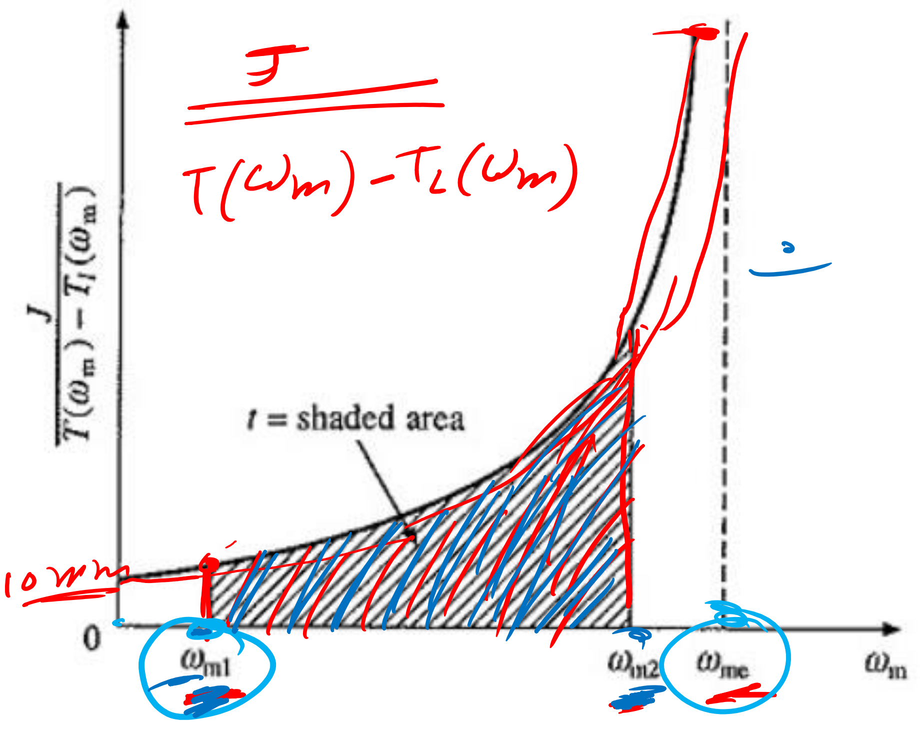


Fig. 6. Calculation of time during a transient operation.

Time and Energy Loss in Transient Operations

- Transient time and energy loss can also be computed with satisfactory accuracy using steady-state speed-torque and speed-current curves of the motor and speed-torque curve of load.

V, I T, ω

- This is because the mechanical time constant of a drive is usually very large compared to the electrical time constant of a motor.

- Consequently, electrical transients die down very fast and motor operation can be considered to take place along the steady-state speed-torque and speed-current curves.

  From $(T = T_l + J d\omega_m/dt)$

$$\boxed{dt = \frac{J d\omega_m}{T(\omega_m) - T_l(\omega_m)}} \qquad (7)$$

T·(ωm) T (function of ωm)

- where $T(\omega_m)$ and $T_l(\omega_m)$ indicate that the motor and load torques are functions of drive speed ω_m.

Time and Energy Loss in Transient Operations

Time taken for drive speed to change from ω_{m1} to ω_{m2} is obtained by integrating Eq. (7)

$$t = J\int_{\omega_{m1}}^{\omega_{m2}} \frac{d\omega_m}{T(\omega_m) - T_l(\omega_m)} \qquad (8)$$

- Equation (8) can be integrated only if functions $T(\omega_m)$ and $T_l(\omega_m)$ are known and are of integral form.

$$t = \int_1^2 f(x)\, dt$$

$$\boxed{f(x) = \frac{d\omega_m}{T(\omega_m) - T_L(\omega_m)}}$$

ω_m

$i^2 dt$

$T \propto i$

$T(\omega)$ function of speed

Time and Energy Loss in Transient Operations

- When ω_{m2} is an equilibrium speed ω_{me}, then the reciprocal of acceleration will become infinite at ω_{me}. Consequently, time evaluated this way will be infinite.

- Therefore, in this case transient time is computed by measuring the area between speeds ω_{m1} and $\omega_{m1} + 0.95(\omega_{m2} - \omega_{m1})$.

- Energy dissipated in a motor winding during a transient operation is given by

$E = \int_0^t R i^2 dt$

$$\boxed{E = \int_0^t Ri^2 dt} \qquad (9)$$

$\int_0^t$

$T \propto I$

$N \propto V$

$V = IR$

- where R is the motor winding resistance and *i* is the current flowing through it.

Steady State Stability of Drive

Steady State Stability of Drive

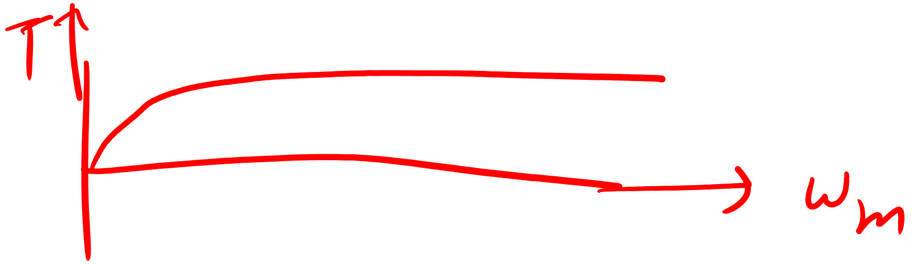
- Equilibrium speed of a motor-load system is obtained when motor torque equals the load torque.

$T_L = T$

- Drive will operate in steady-state at this speed, provided it is the speed of stable equilibrium.

- Concept of Steady State Stability of Drive has been developed to readily evaluate the stability of an equilibrium point from the steady-state speed-torque curves of the motor and load, thus avoiding solution of differential equations valid for the transient operation of the drive.

$T = T_L$

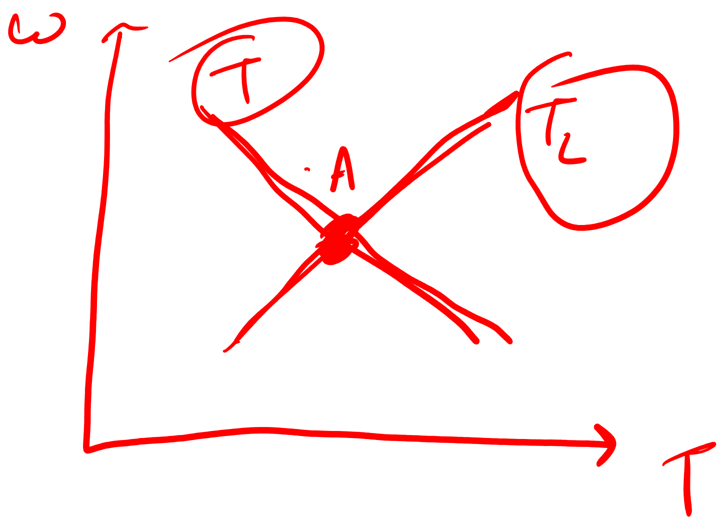


Steady State Stability of Drive

- In most drives, the electrical time constant of the motor is negligible compared to its mechanical time constant.

- Therefore, during transient operation, motor can be assumed to be in electrical equilibrium implying that steady-state speed-torque curves are also applicable to the transient operation.

$T = T_L$



point A is stable or unstable

Steady State Stability of Drive

- As an example let us examine the Steady State Stability of Drive of equilibrium point A in Fig. 2.9(a).

- The equilibrium point will be termed as stable when the operation will be restored to it after a small departure from it due to a disturbance in the motor or load.

$\Delta\omega_m = \omega_{m_2} - \omega_{m_1}$

- Let the disturbance cause a reduction of $\Delta\omega_m$ in speed.

$T_m > T_L$

- At new speed, the motor torque is greater than the load torque, consequently, the motor will accelerate and operation will be restored to A. Similarly, an increase of $\Delta\omega_m$ in speed caused by a disturbance will make load torque greater than the motor torque, resulting into deceleration and restoration of operation to point A. Hence the drive is steady-state stable at point A.

$T = T_L$

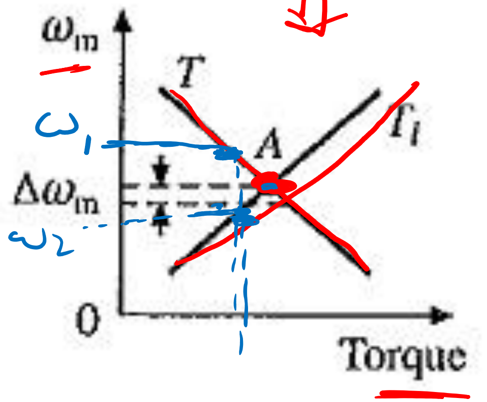


Fig. 7. Point A is stable.

Steady State Stability of Drive

- Let us now examine equilibrium point B which is obtained when the same motor drives another load.
- A decrease in speed causes the load torque to become greater than the motor torque, the drive decelerates and the operating point moves away from B.

- Similarly, when working at B an increase in speed will make motor torque greater than the load torque, which will move the operating point away from B.

- Thus, B is an unstable point of equilibrium. Readers may similarly examine the Steady State Stability of Drive of points C and D given in Figs. (9) and (10).

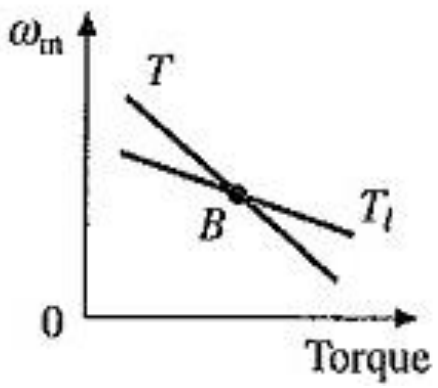


Fig. 8. Point B is unstable.

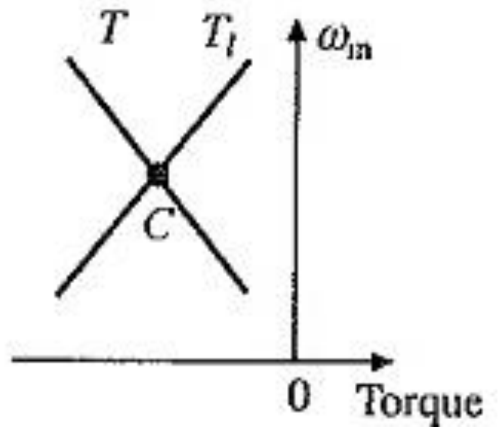


Fig. 9. Point C is stable.

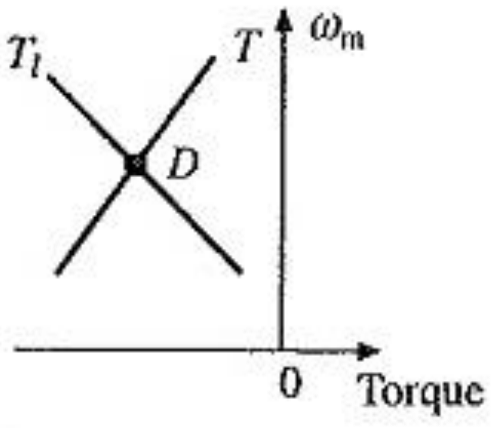
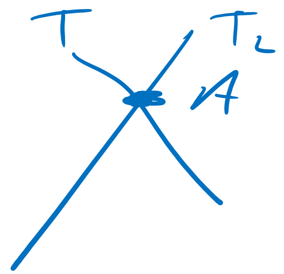


Fig. 10. Point D is unstable.

Steady State Stability of Drive

Above discussion suggests that an equilibrium point will be stable when an increase in speed causes load-torque to exceed the motor torque, i.e. when at equilibrium point following condition is satisfied:

$$\frac{dT_l}{d\omega_m} > \frac{dT}{d\omega_m} \qquad \frac{dT_L}{d\omega_m} > \frac{dT}{d\omega_m} \qquad (10)$$



Inequality (~~2.24~~ 10) can be derived by an alternative approach. Let a small perturbation in speed, $\Delta\omega_{m,}$ results in ΔT and ΔT_l perturbations in T and T_l respectively. Then from Fr~~o~~m ($T = T_l + J d\omega_m/dt$)

$T = \Delta T$

$T_L = \Delta T_L$

$\omega_m = \Delta\omega_m$

$\omega_m \Rightarrow \Delta\omega_m$

$T \Rightarrow \Delta T$

$T_L \Rightarrow \Delta T_L$

$$(T + \Delta T) = (T_l + \Delta T_l) + J\frac{d(\omega_m + \Delta\omega_m)}{dt} \qquad (11)$$

$$T + \Delta T = T_l + \Delta T_l + J\frac{d\omega_m}{dt} + J\frac{d\Delta\omega_m}{dt}$$

Steady State Stability of Drive

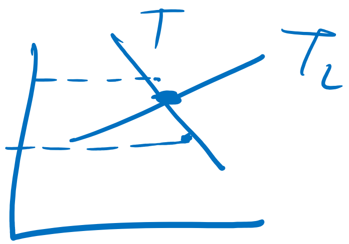
Subtracting (fundamental torque equation: ($T = T_l + J d\omega_m/dt$)) from (11) and rearranging terms gives

$$J\frac{d\Delta\omega_m}{dt} = \Delta T - \Delta T_l \qquad (12)$$

For small perturbations, the speed torque curves of the motor and load can be assumed to be straight lines. Thus

$$\left(\frac{dT}{d\omega_m}\right) \delta\omega_m \qquad \Delta\omega_m$$

$$\Delta T = \left(\frac{dT}{d\omega_m}\right)\Delta\omega_m \qquad (13)$$



$$\Delta T_l = \left(\frac{dT_l}{d\omega_m}\right)\Delta\omega_m \qquad (14)$$

where ($dT/d\omega_m$) and ($dT_l/d\omega_m$) are respectively slopes of the steady-state speed-torque curves of motor and load at operating point under consideration. Substituting Eqs. (13) and (14) into (12) and rearranging the terms yields

Steady State Stability of Drive

$T = T_L$

$\Delta\omega_m$

$$J \frac{d\Delta\omega_m}{dt} + \left(\frac{dT_l}{d\omega_m} - \frac{dT}{d\omega_m} \right) \Delta\omega_m = 0 \qquad (15)$$

This is a first order linear differential equation. If initial deviation in speed at t = 0 be $(\Delta\omega_m)0$ then the solution of Eq. (15) will be

$$\Delta\omega_m = (\Delta\omega_m)_0 \exp\left\{ -\frac{1}{J} \left(\frac{dT_l}{d\omega_m} - \frac{dT}{d\omega_m} \right) t \right\} \qquad (16)$$

An operating point will be stable when $\Delta\omega_m$ approaches zero as t approaches infinity. For this to happen the exponent in Eq. (16) must be negative.

Key Points from Today's Class

- ❖ Time and Energy Loss in Transient Operations
- ❖ Steady State Stability of an Electric Drive System

Key Points from Next Class

In the next class, we will be discussing on:

Power Electronics Converters

- ❖ Introduction of Control of Electric Drives
- ❖ Modes of Operation of Electric Drives
- ❖ Speed Control and Drive Classifications
- ❖ Closed Loop Control of Drives

Thank you so much for your attentions
Q & A