Tutorial 1 - Drive fundamentals and DC motor characteristics

1. In the hoist drive system of figure 1, all frictions and the moments of inertia of the gear wheels compared to the motor or the load are negligible.

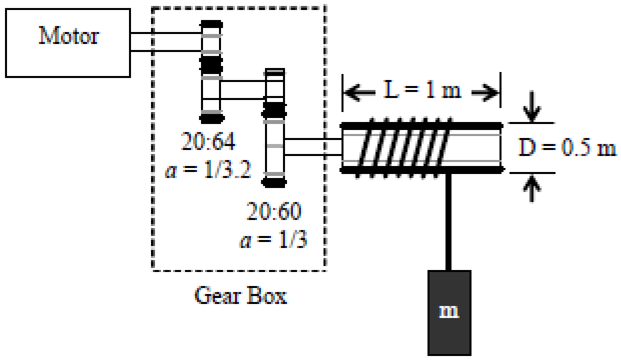

Figure 1

The following are given:

The moment of inertia of the motor, $J_m = 0.5$ kgm^2

The mass of the load, $m = 500$ kg.

The diameter of the drum, $D = 0.5$ m.

The length of the drum, $L = 1$ m.

The mass of the cable is negligible.

A. Determine the moment of inertia of the drum referred to the motor, assuming that the density of the material, $\delta = 7{,}900$ kg/m^3.

[0.52 kg-m^2]

B. Determine the moment of inertia of the load referred to the motor shaft.

[0.339kg-m^2]

C. Determine the total moment of inertia of the moving system. [1.359 kg-m^2]

2. The drive of question 1 lifts and moves the load from point to point with a peak velocity profile as indicated in figure 2.

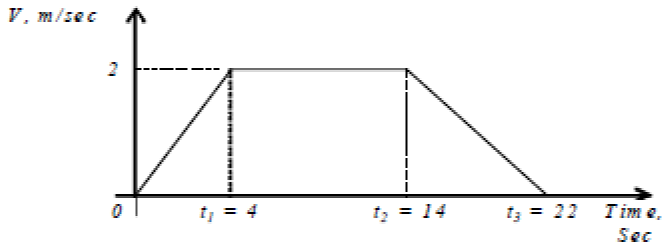

Figure 2

(a) Calculate and plot the torque that the motor must develop in each of the three intervals 0 - t_1, t_1 - t_2 and t_2 - t_3.

[153.8, 127.7, 118.1 Nm]

(b) Discuss suitable drive system structures for this application. Assume that a separately excited DC motor is to be used.

3. Consider the lift drive indicated in figure 3. The motor operating speed is 1465 rev/min. The linear speed of the cage and the counterweight is $v = 1$ m/sec.

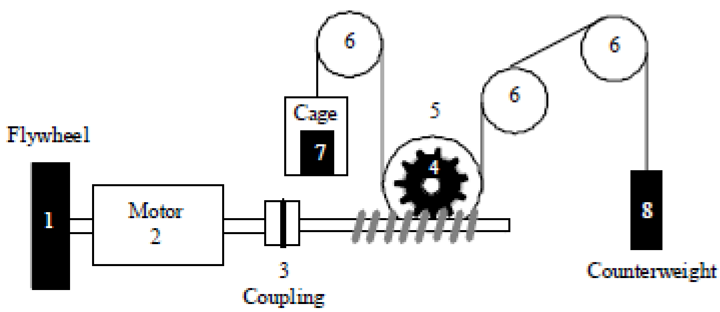

Figure 3

The angular speed of the hoist wheels (4 and 5) is 2.2 rad/sec and those of the upper deflecting wheels 6 are each 6.66 rad/sec. The moments of inertia are known:

J_1 (flywheel) = 25 kgm^2

J_2 (motor) = 9.3 kgm^2

J_3 (coupling) = 2.1 kgm^2

$J_4 = 0.6$ kgm^2

$J_5 = 260$ kgm^2

$J_6 = 9$ kgm^2

The mass of the payload = 1,300 kg

The mass of the counterweight = 800 kg.

A. Calculate the total inertia referred to the motor shaft. [36.539 kg-m^2]

B. Assuming that the transmission efficiency is 0.8, calculate the torque that the motor must develop and its power requirement. [40.17 Nm]

C. Calculate the required torque and power as in B but in the absence of the counterweight.

4. A transmission has a reduction ratio of n. The load has a torque-speed characteristic given by $T_L = D\omega$, where ω is the angular velocity of the load. Find the value of D referred to the motor shaft.

5. Consider the drive of figure 4, where the electromagnetic coupling develops a torque which is proportional to the relative speed between the driving part (armature) and the driven part (hub) of the coupling.

Thus, $T_c = k(\omega_m - \omega')$

where ω_m = the motor angular speed, and ω' = the angular speed of the hub.

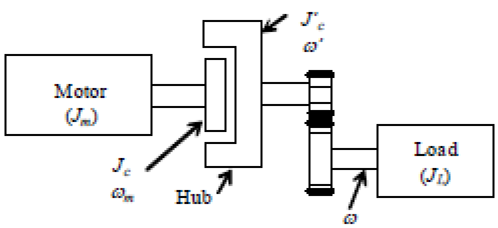

Figure 4

The gear transmission reduces the speed by a factor of n. The efficiency of the transmission is unity. The moments of inertia of the system are

The motor inertia = J_m

Inertia of the driving part = J_c

Inertia of the driven part = J'_c

Inertia of the load = J_L

Inertia of the gear wheels are negligible. The load torque T_L is assumed to be constant.

Write equations of motion referred to the motor shaft.

6. An electric motor has a linear *T*-ω characteristic given by

   $T = T_0 - D_{mL}\omega$, referred to the load.

   The load torque is proportional to speed, $T_L = D_L\omega$.
   The total system inertia is J_T is also referred to the load. Dynamics of the electrical circuits are neglected.

   A. Develop an expression for the speed ω as a function of time with the initial condition that at $t = 0,\ \omega = 0$.

   B. Develop an expression for the steady-state operating speed.

   C. Find expressions for the mechanical time-constant and the time taken by the drive to reach 98% of the final speed.

7. A motor is required to drive the take-up roll (coiler) on a plastic strip line. The mandrel on which the strip is wound is 60 cm in diameter and the roll builds up to a maximum diameter of 200 cm. The strip emerges from the line at 20 m/sec and the tension required during rolling is 1000 N. The motor is coupled to the mandrel trough a 5:1 reduction gearing of 0.85 efficiency. Determine the power rating and the required speed range of the motor for this application.

8. Figure 5 shows the torque-speed characteristics of the motor and the load in the four quadrants. Comment on the stability of the equilibrium points A, B, C and D.

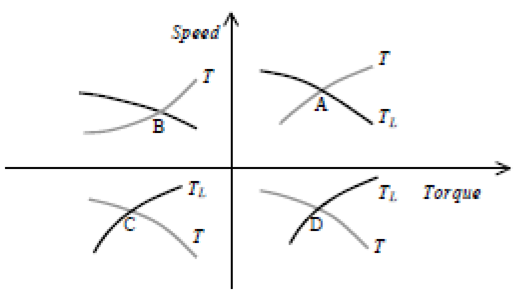

Figure 5

9. A motor operating with a suitable control scheme develops a torque given by $T = a\omega - b$. The motor drives a load for which the torque is given by $T = c\omega^2$. The constants *a*, *b* and *c* have positive real values. Here ω is the angular speed of the load in rad/sec.

A. Find the equilibrium speeds.

B. What relation must exist between the constants for the drive to have two positive speeds?

C. Determine the stability of the equilibrium points.

10. A motor operating with a suitable control scheme develops a torque given by $T = a\omega + b$. The motor drives a load which has a torque speed characteristic given by $T = c\omega^2 + d$. The constants a, b, c and d are all positive real constants.

A. Find and expression for the equilibrium speeds in terms of the constants.

B. What relation must exist between the constants so that the drive has two positive real speeds?

C. Will the operating points in A be stable?

11. The mass of an electric car is 900 kg including the passengers. A single motor mounted on the front wheels drives the car, and the radius of the wheel is 0.3m. The car is going downhill at a speed of 50 km/hr, and the slope of the hill is 30°. The friction coefficient of the road surface is assumed to be 0.3.

A. Calculate the power developed by the motor. Ignore the motor losses.

B. Assume that car takes 1 minute to reach the bottom of the hill, while running at a constant speed of 50 km/hr. Calculate the energy generated by the motor of the car.

C. If the overhauling energy is to be returned to the 42V battery which drives the car, calculate the rate at which this energy must be returned to the battery and the charging current.

12. A separately exited DC motor has the following ratings:

230V, 460 rev/min, 100 A.

The motor armature resistance $R_a = 0.11\Omega$. The motor drives its rated torque load which is independent of speed. Operation below the base speed (460 rev/min) is obtained with armature voltage control at full field and above the base speed with field control at rated armature voltage.

A. Calculate the required armature voltage when the speed is 380 rev/min.

B. Calculate the % change in field flux if the motor is to be operated at 800 rev/min.

C. Find the required armature current for condition B and comment on whether weakening of the field is suitable for such a load. Also comment on which type of load is suitable for operation above base speed when the field is weakened, if the armature current is to remain limited to its rated value.

13. The motor of problem 12 is used to brake an overhauling load regeneratively. The overhauling load has a constant torque of 700 Nm. [A hoist or a lift is a good example]. The available dc supply voltage is at 230V. Neglecting any other rotational losses, calculate the speed at which the motor will hold the overhauling load.

14. A separately excited DC motor runs at 500 rev/min when operated from the rated supply voltage of 230V. The load torque is proportional to the square of the speed and the armature current drawn at this speed is 32 A. The armature circuit resistance is 0.7Ω. Calculate the required armature voltage if the speed is to be reduced by half.

15. A DC series motor drives a load whose torque is proportional to the square of the speed. When supplied with a voltage of 200V, it draws 100 A and runs the load at 1000 rev/min. The total resistance of the armature and the field is 0.1Ω. Calculate the required supply voltage to the motor if the load speed is to be reduced to 500 rev/min. Assume that the magnetic circuit is linear and that all frictional losses are negligible.