Homework 5 – DC Machines

This homework is to be solved using computational tools (such as MATLAB). You should show your work (how the resultant plot is obtained analytically, and required explanations).
*The provided template must be used and the homework should be submitted by converting the .m file solution to pdf by using **publish** command. Required explanations and several tips are given in the template.*

Consider a fully electric train traction system, which is composed of two DC machines (Figure 1). Spesifications of the train and the traction motors are given in Table 1 and the motor drive system is shown in Figure 2.
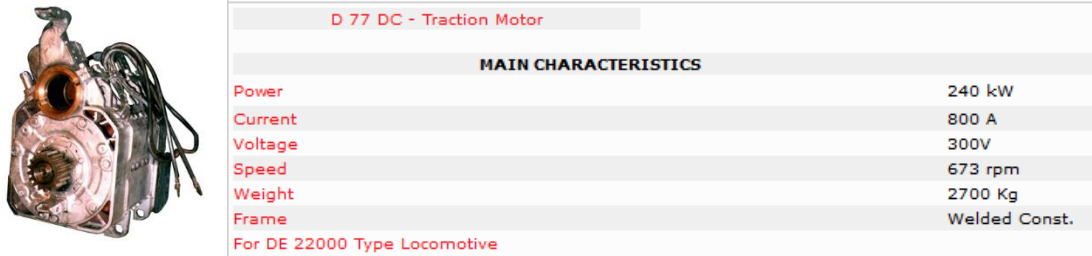

D 77 DC - Traction Motor	
MAIN CHARACTERISTICS	
Power	240 kW
Current	800 A
Voltage	300V
Speed	673 rpm
Weight	2700 Kg
Frame	Welded Const.
For DE 22000 Type Locomotive	

Figure 1: DC Traction Motor (*http://www.tulomsas.com.tr/en/main.php?kid=198&rid=104*)

Table 1: Specifications of the Fully Electric Train and Selected DC Traction Motor

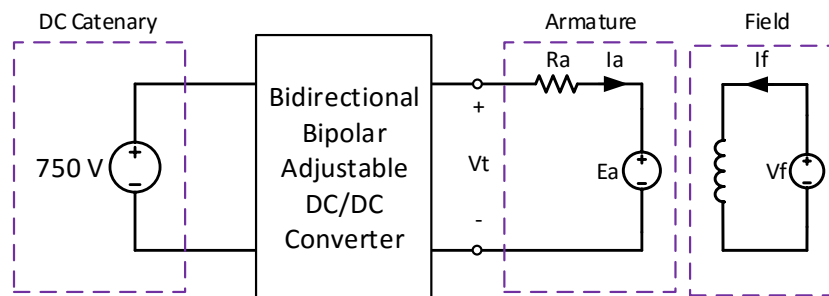| Total Weight	70 tons	Rated Power	2x240 kW = 480 kW
Motor type	Sperately Excited DC	Gearbox Ratio	1 : 0.72
Number of Motors	2	Wheel Diameter	80 cm
Rated Speed	140 km/h	Armature Resistance	27 mΩ

Figure 2: Motor Drive System of the Fully Electric Train

- The drag force acting on the train has the following characteristics:

$$F_d = \frac{1}{2}\rho A C_d v^2$$

where C_d is the dimensionless drag coefficient (0.8), A is the front surface area of the train (10 m^2), ρ is the density of air (1.225 kg/m^3) and v is the velocity of the train (m/s).

- The force corresponding to the mechanical losses (rail friction, rotational losses etc) has the following characteristics:

$$F_f = Kv$$

where K is a coefficient (10 kg/s).

- The gearbox ratio of 1:0.72 means that the rotational speed is increased from the motor to the wheels.
- The field current is kept constant in all operating conditions at its rated value. The armature constant: **$K = K_a \times \phi_f = 4$ V/(rad/s).**
- You can control the terminal voltage for the drive system. It is adjusted by the power electronics DC/DC converter which is fed from the 750V catenary line which can be considered as an *adjustable, bidirectional and bipolar DC power supply*.

PART I: In this part, the train is tested on a flat railroad.

   a) Acceleration: The train will be accelerated from stationary to its rated speed with constant force which corresponds to the rated torque of the two motors.

   i) What is the rated torque of one DC motor?

   ii) Obtain and plot the net force (in Newtons), *as a function of time.*

   iii) Obtain the acceleration (in m/s^2), velocity (in km/h) and position (in m) of the train, *as a function of time,* and plot them on the same axis using subplot.

   iv) Obtain the armature current, I_a (in Amps), the back emf current, E_a (in Volts) and the terminal voltage, V_t (in Volts) *as a function of time,* and plot them on the same axis using subplot.

   v) Obtain and plot the electrical efficiency of one DC motor, *as a function of time.*

   vi) How much time (in seconds) does it take for the train to reach its rated speed?

   vii) How long (in meters) does it take for the train to reach its rated speed?

   viii) What is the operating condition? Comment on the direction of I_a and polarity of E_a and V_t.

   b) Deceleration: The train will be decelerated from its rated speed to stationary with constant force which corresponds to the rated torque of the two motors.

   i) Obtain and plot the net force (in Newtons), *as a function of time.*

   ii) Obtain the deceleration (in m/s^2), velocity (in km/h) and position (in m) of the train, *as a function of time,* and plot them on the same axis using subplot.

   iii) Obtain the armature current, I_a (in Amps), the back emf current, E_a (in Volts) and the terminal voltage, V_t (in Volts) *as a function of time,* and plot them on the same axis using subplot.

   iv) Obtain and plot the electrical efficiency of one DC motor, *as a function of time.*

   v) How much time (in seconds) does it take for the train to fully stop?

   vi) How long (in meters) does it take for the train to fully stop?

   vii) What is the operating condition? Comment on the direction of I_a and polarity of E_a and V_t.

PART II: In this part, the train is tested on an uphill railroad with a slope of 0.5 degrees and distance of 40 km. The train starts climbing uphill at the rated speed. Along its journey, motors produce constant rated torque, as in Part I.

i) Obtain and plot the net force (in Newtons), *as a function of time.*

ii) Obtain the acceleration (in m/s^2), velocity (in km/h) and position (in m) of the train, *as a function of time,* and plot them on the same axis using subplot.

iii) Obtain the armature current, I_a (in Amps), the back emf current, E_a (in Volts) and the terminal voltage, V_t (in Volts) *as a function of time,* and plot them on the same axis using subplot.

iv) Obtain and plot the electrical efficiency of one DC motor, *as a function of time.*

v) How much time (in seconds) does it take for the train to climb up the slope?

vi) What is the operating condition? Comment on the direction of I_a and polarity of E_a and V_t.

PART III: In this part, the train is tested on a downhill railroad with a slope of 0.5 degrees and distance of 40 km. The train enters the slope with the speed of 50 km/h and along its journey, 1/5 times the rated torque is applied by the motors in the opposite direction to the speed.

i) Obtain and plot the net force (in Newtons), *as a function of time.*

ii) Obtain the acceleration (in m/s^2), velocity (in km/h) and position (in m) of the train, *as a function of time,* and plot them on the same axis using subplot.

iii) Obtain the armature current, I_a (in Amps), the back emf current, E_a (in Volts) and the terminal voltage, V_t (in Volts) *as a function of time,* and plot them on the same axis using subplot.

iv) Obtain and plot the electrical efficiency of one DC motor, *as a function of time.*

v) How much time (in seconds) does it take for the train to climb down the slope?

vi) What is the operating condition? Comment on the direction of I_a and polarity of E_a and V_t.