EE4323 Industrial Control Systems
Homework Assignment 2

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June 13, 2017

1 Raw model

$$e_{in}(t) = R_A\ i_A + L_A\ \dot{i_A} + \alpha\ \omega_1 \tag{1}$$
$$J_1\ \dot{\omega_1} + B_1\ \omega_1 = \alpha\ i_A + R_1\ f_c \tag{2}$$
$$J_2\ \dot{\omega_2} + B_2\ \omega_2 + B_{2C}\ sign(\omega_2) = -\tau_{LE} - R_2\ f_c \tag{3}$$
$$C_{TM}\ \dot{\theta_M} + (\theta_M - \theta_A)/R_{TM} = i_A^2\ R_A \tag{4}$$

Which delivers in sate-vector differential equations $x = [i_A\ \omega_2\ \theta_M]^T$ and input $u = [e_{in}\ \tau_{LE}\ \theta_A]^T$.

$$\dot{i_A} = -a\ i_A - b\ \omega_2 + e_{in}/L_A \tag{5}$$
$$\dot{\omega}_2 = c\ i_A - d\ \omega_2 - e\ sign(\omega_2) - \tau_{LE}/J_{eq} \tag{6}$$
$$\dot{\theta}_M = f\ i_A^2 - g\ \theta_M + g\ \theta_A \tag{7}$$

Where,

$$J_{eq} = J_2 + N^2\ J_1; \quad B_{eq} = B_2 + N^2\ B_1$$
$$a = R_A/L_A; \quad b = \alpha\ N/L_A$$
$$c = N\ \alpha/J_{eq}; \quad d = B_{eq}/J_{eq}; \quad e = B_{2C}/J_{eq}$$
$$f = R_A/C_{TM}; \quad g = 1/(C_{TM}R_{TM})$$

2 Code and simulation

In `asst02.m` it can be seen the input and the state-vector differential equations, and `run asst02.m` is the code for the simulation of Fig.1.

Listing 1 : asst02.m

```
function xdot = asst02_2017(t,x)
global E_0 Tau_0 T_Amb B_2C %%% make these settable from a script
% motor parameters, Nachtigal, Table 16.5 p. 663
J_1 = 0.0035; % in*oz*s^2/rad
B_1 = 0.064; % in*oz*s/rad
% electrical/mechanical relations
K_E = 0.1785; % back emf coefficient, e_m = K_E*omega_m (K_E=alpha for omega)
K_T = 141.6*K_E; % torque coeffic.; in English units K_T is not = K_E! (K_T=alpha for iA)
R_A = 8.4; % Ohms
L_A = 0.0084; % H
% gear-train and load parameters
J_2 = 0.035; % in*oz*s^2/rad % 10x motor J
B_2 = 2.64; % in*oz*s/rad (viscous)
```

```
N = 8; % motor/load gear ratio; omega_1 = N omega_2
% Thermal model parameters
R_TM = 2.2; % Kelvin/Watt
C_TM = 9/R_TM; % Watt-sec/Kelvin (-> 9 sec time constant - fast!)

Jeq=J_2+N*2*J_1;
Beq=B_2+N^2*B_1;
a=R_A/L_A;
b=K_E*N/L_A;
c=N*K_T/Jeq;
d=Beq/Jeq;
e=B_2C/Jeq;
f=R_A/C_TM;
g=1/(C_TM*R_TM);

if t < 0.05,
  e_i = 0;
else
  e_i = E_0;
  %e_i = E_0*sin(2*pi*5*(t - 0.05));
end
if t < 0.5
  Tau_L = 0;
else
  Tau_L = Tau_0;
end

xdot(1) = -a*x(1)-b*x(2)+e_i/L_A;
xdot(2) = c*x(1)-d*x(2)-e*sign(x(2))-Tau_L/Jeq;
xdot(3) = f*x(1)^2-g*x(3)+g*T_Amb;
```

Listing 2 : run asst02.m

```
clear; close all; clc;
global E_0 Tau_0 T_Amb B_2C ;

E_0 = 120; Tau_0 = 80; T_Amb = 18; B_2C = 80;
t0 = 0; tfinal = 1.2; stp = 0.0001;
x0 = [ 0;0;0 ]; %initial conditions

timer = clock;
[t1,x1] = ode45m('asst02_2017',t0,tfinal,x0,stp);
Tsim1 = etime(clock,timer), % integration time
Len1 = length(t1), % number of time-steps

figure

subplot(3,1,1)
plot(t1,x1(:,1));
title('Motor+Load+thermal model simulation, B_{2C}=80')
xlabel('Time, t (sec)')
ylabel('i_A (amperes)')
text(0.2,1,['E_0 =',num2str(E_0,3)]);

subplot(3,1,2)
plot(t1,x1(:,2));
title('Motor+Load+thermal model simulation, B_{2C}=80')
xlabel('Time, t (sec)')
ylabel('\omega_2 , Motor angular velocity (rad/sec)')
text(0.2,24,['B_{2C} =',num2str(B_2C,3),'\tau_0 =',num2str(Tau_0,3)]);

subplot(3,1,3)
plot(t1,x1(:,3));
title('Motor+Load+thermal model simulation, B_{2C}=80')
xlabel('Time, t (sec)')
ylabel('\theta_M (deg)')
text(0.2,5,['\Theta_A=',num2str(T_Amb,3) ' deg']);
```

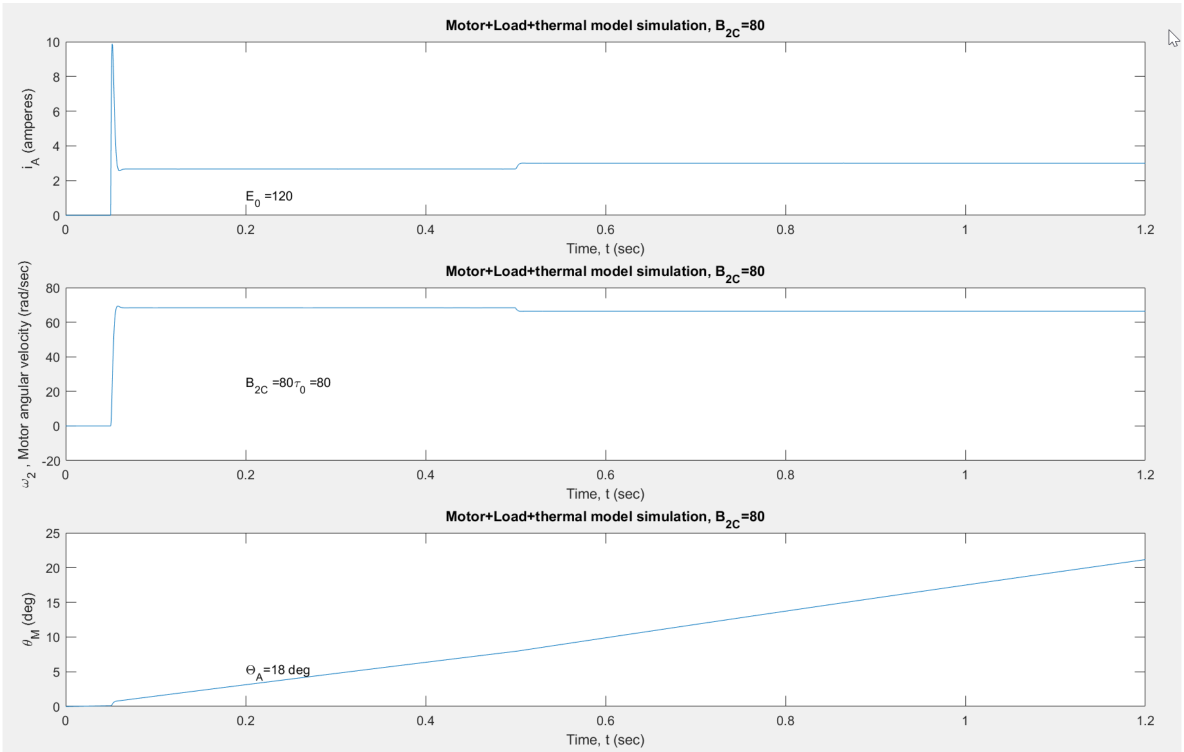


Figure 1: Simulation for Q. 2

The high current peak in before 0.1 sec is because of the inertia that the motor has to overcome, after it breaks the inertia the amount of current drops down to a constant value. In 0.5 sec the τ_{LE} is applied and we can see an increment of the current and a decrease of the angular velocity.

3 Ode45 vs eufix1

In Fig.2 can be seen that the **maximum peak current** for ode45 and eufix1 at two different integration steps, **1e-4** and **1e-3**.

There is little difference between ode45 and eufix at step=1e-4 but when we change to step=1e-3 there a big difference, about 70% more.

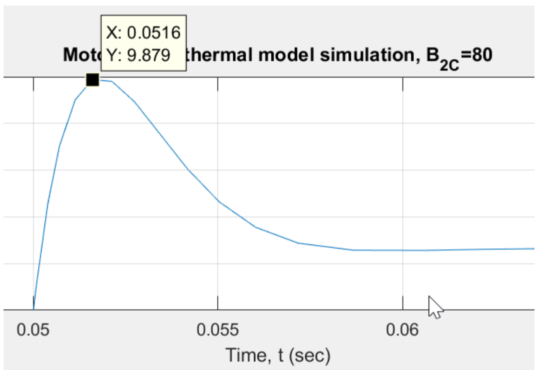
The number of time steps is given by the instruction `Len1 = length(t1),` which delivers two results, `Len1 = 663` for `ode45` and `Len1 = 1202` for `eufix1`.

4 Will the motor melt?

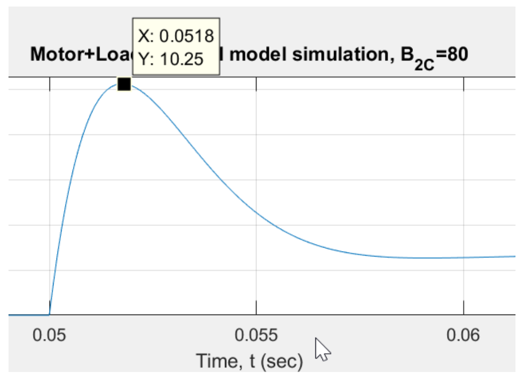
Fig.3 shows that the maximum temperature is 182.4°C at time 40 sec, which means that the heating it's not enough to melt the metal of the motor that could be around 700°C if it's made of Aluminum or 419°C if it has Zinc.

5 Motor is continually reversing at 5Hz

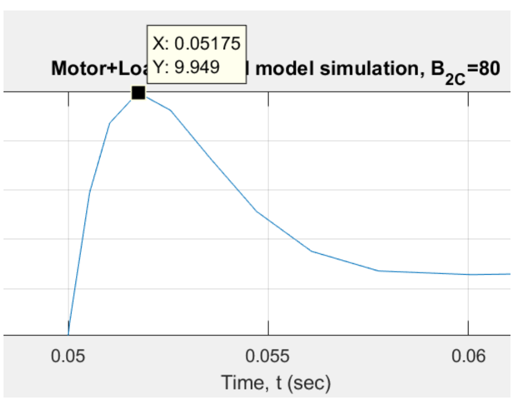
Fig.4 shows the result of 5 cycles with an 5Hz of input; `e_i = E_0*sin(2*pi*5*(t - 0.05))`, and with a 6315 time steps for `ode45` and 10002 time steps for `eufix1`.



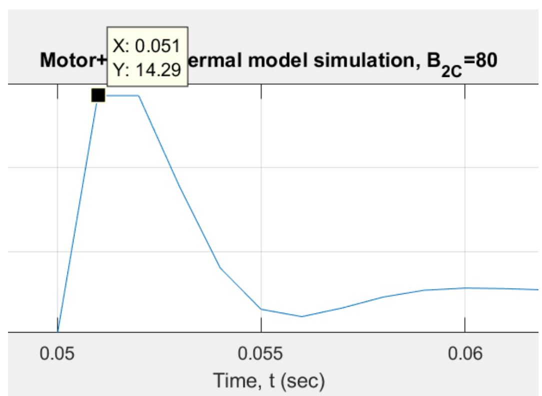
(a) ode45 with step=1e-4



(b) eufix1 with step=1e-4



(c) ode45 with step=1e-3



(d) eufix1 with step=1e-3

Figure 2: Maximum peak current with **ode45 vs eufix1**

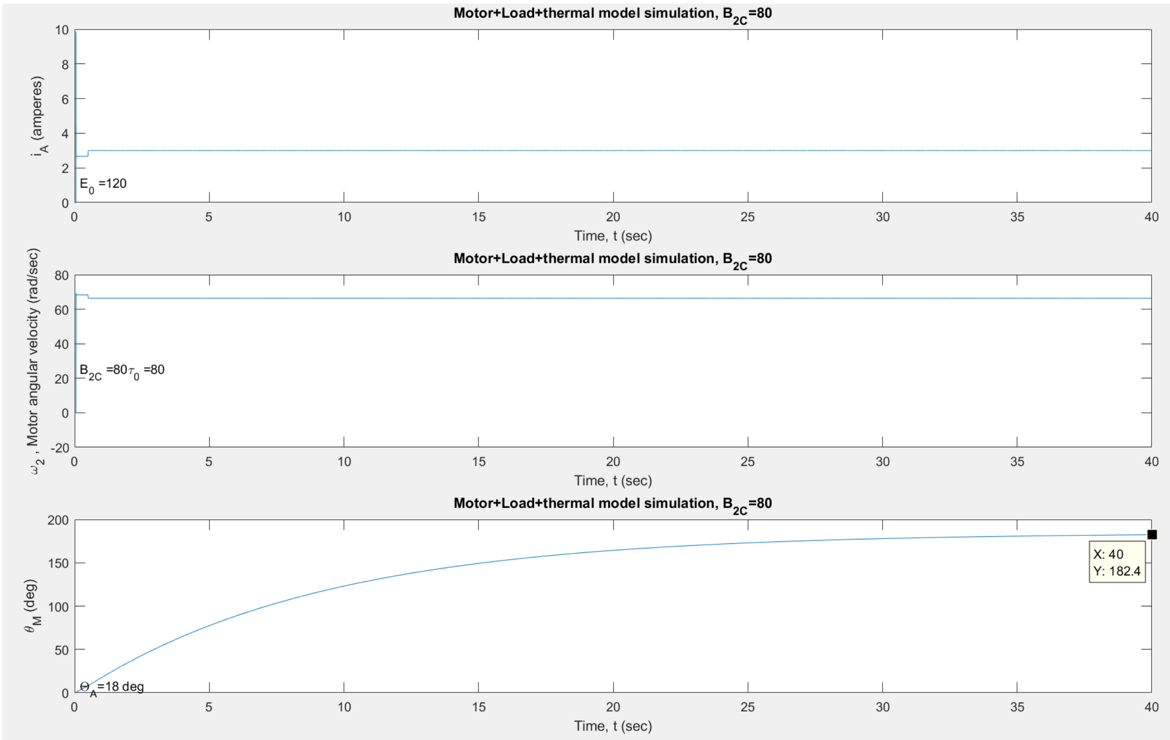


Figure 3: Ode45 simulation with t = 40sec

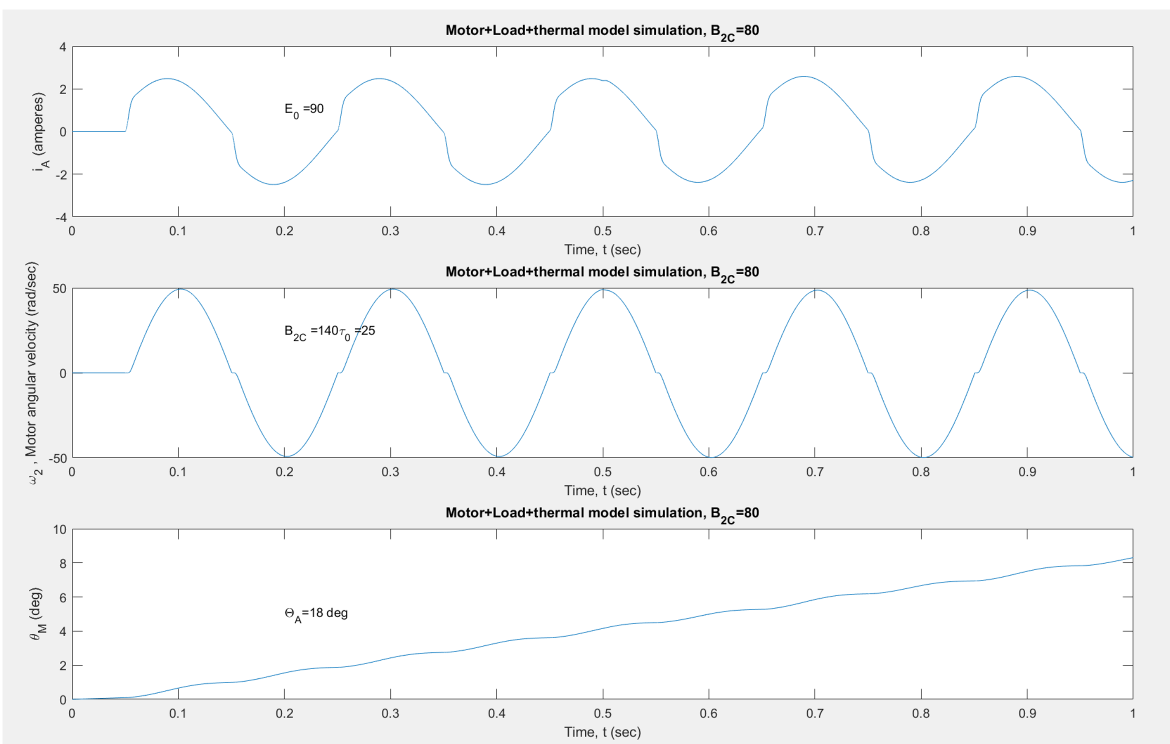


Figure 4: Motor at 5Hz