```matlab
clc; clear; close all
% Benjamin Eldreth
% ME 3610
% 3 - 22 - 2023
% Engineering Analysis
% -- Description -- %
% This script takes the derived equations from parts 1a, 1b, and 2 of the
% engineering analysis and provides plots for the Motor torque, forces on
% the actuator, and force on the spring catch
%
% -- CODE -- %
% - Constants - %
% Forces (lbf)
Fa = 0.3  ;   % Weight of the actuator
Ff = 0.125;   % Weight of the food
% Spring constant (lbf/in)
k = 0.6;
% Angles (deg)
alpha_1 = -40; % Angle between food holder and parallel
alpha_2 = -21; % Angle between top of the curve and top of back wall
alpha_3 = -5 ; % Angle between top of wall and parallel
alpha_4 = 0  ; % Angle between top of wall and end position
% Lengths (in)
La  = 17.6 ; % Distance from the servo to the food curve
Ma  = 9.205; % Distance from the servo to the actuators center of mass (estimate)
% - Variables - %
% Change in angle (deg)
theta = [alpha_1:abs((alpha_1-alpha_2))/100:alpha_2,...
         alpha_2:abs((alpha_2-alpha_3))/100:alpha_3,...
         alpha_3:abs((alpha_3-alpha_4))/100:alpha_4];
% Linear velocity at the end of the actuator (in/s)
Va = 1;
% Time (sec)
time_tot = (alpha_4 - alpha_1)/((Va/La)*(180/pi));
time = [0:time_tot/302:time_tot];
% - Torque equations - %
T_12 = (Fa.*Ma + Ff.*La).*cosd(theta(1:101));
T_23 = (Fa.*Ma + Ff.*La).*cosd(theta(102:202)) - k.*(La^2).*...
       (cosd(theta(102:202)) - cosd(alpha_2)).*sind(theta(102:202));
T_34 = (Fa.*Ma + Ff.*La).*cosd(theta(203:303));

% Motor Torque
motor_torque = [T_12, T_23, T_34];
% Minimum and maximum torques
[max_torque, max_torque_angle_loc] = max(motor_torque);
[min_torque, min_torque_angle_loc] = min(motor_torque);
max_torque_angle = theta(max_torque_angle_loc);
min_torque_angle = theta(min_torque_angle_loc);

% Power (W)
motor_power = (Va/La) .* motor_torque .* 12 .* 1.3558;
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% Minimum and maximum power
[max_power, max_power_angle_loc] = max(motor_power);
[min_power, min_power_angle_loc] = min(motor_power);
max_power_angle = theta(max_power_angle_loc);
min_power_angle = theta(min_power_angle_loc);
% Current Draw (mA), Assuming the stepper motor runs off of 5 V DC
motor_current = (motor_power./5) * 10^3;
max_current = max(motor_current);
min_current = min(motor_current);

% - Actuator Equations - %
% Axial Forces (lbf)
Ax_12 = (Fa + Ff)*sind(theta(1:101));
Ax_23 = (Fa + Ff).*sind(theta(102:202)) + k.*La.*...
    (cosd(theta(102:202)) - cosd(alpha_2)).*cosd(theta(102:202));
Ax_34 = (Fa + Ff)*sind(theta(203:303));
actuator_axial = [Ax_12, Ax_23, Ax_34];
% Transverse Forces (lbf)
Trans_12 = -(Fa + Ff)*cosd(theta(1:101));
Trans_23 = -(Fa + Ff).*cosd(theta(102:202)) + k.*La.*...
    (cosd(theta(102:202)) - cosd(alpha_2)).*sind(theta(102:202));
Trans_34 = - (Fa + Ff)*cosd(theta(203:303));
actuator_trans = [Trans_12, Trans_23, Trans_34];
% Minimum and maximum loads
% Axial
[max_axial, max_axial_angle_loc] = max(actuator_axial);
[min_axial, min_axial_angle_loc] = min(actuator_axial);
max_axial_angle = theta(max_axial_angle_loc);
min_axial_angle = theta(min_axial_angle_loc);
% Transverse
[max_trans, max_trans_angle_loc] = max(actuator_trans);
[min_trans, min_trans_angle_loc] = min(actuator_trans);
max_trans_angle = theta(max_trans_angle_loc);
min_trans_angle = theta(min_trans_angle_loc);

% - Spring Catch (lbf)- %
spring_catch = [zeros(1,101),...
                k*La*(cosd(theta(102:202)) - cosd(alpha_2)),...
                zeros(1,101)];
[max_spring, max_spring_angle_loc] = max(spring_catch);
max_spring_angle = theta(max_spring_angle_loc);
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% - Plotting - %
% Motor Torque Plot
ylim_torque = [min_torque, 1.05*max_torque];
xlim_torque = [1.05*alpha_1, 1.05*alpha_4];
figure('Name',"Motor Torque")
hold on
plot(theta,motor_torque,'k-')
plot([alpha_2, alpha_2], [motor_torque(1), motor_torque(102)],'k--',...
     [alpha_3, alpha_3], [motor_torque(1), motor_torque(202)],'k--',...
     [alpha_1, max_torque_angle], [motor_torque(max_torque_angle_loc),...
      motor_torque(max_torque_angle_loc)], 'r--',...
     [alpha_1, alpha_1], [motor_torque(min_torque_angle_loc),...
      motor_torque(max_torque_angle_loc)], 'r--')
text((alpha_1 - max_torque_angle), 1.01*max_torque,...
     "T_m_a_x = " + string(max_torque) + " lbf-in",'Color','r')
text((alpha_1 - max_torque_angle), 0.99*max_torque,...
     "T_m_i_n = " + string(min_torque) + " lbf-in",'Color','r')
hold off
ylim(ylim_torque)
xlim(xlim_torque)
xlabel("Angle from parallel (Degrees)")
ylabel("Torque (lbf-in)")
title("Torque required from the motor")


% Motor Power Plot
figure('Name', "Motor Power: Va" + string(Va) + " in\s")
hold on
ylim_power = [min_power, 1.05*max_power];
xlim_power = [1.05*alpha_1, 1.05*alpha_4];
plot(theta,motor_power,'b-')
ylim(ylim_power)
xlim(xlim_power)
plot([alpha_2, alpha_2], [motor_power(1), motor_power(102)],'b--',...
     [alpha_3, alpha_3], [motor_power(1), motor_power(202)],'b--',...
     [alpha_1, max_power_angle], [motor_power(max_power_angle_loc),...
     motor_power(max_power_angle_loc)], 'g--',...
     [alpha_1, alpha_1], [motor_power(min_power_angle_loc),...
     motor_power(max_power_angle_loc)], 'g--')

text((alpha_1 - max_power_angle), 1.01*max_power,...
     "P_m_a_x = " + string(max_power) + " W, Current = " +...
     string(max(motor_current)) + " mA",'Color','g')
text((alpha_1 - max_power_angle), 0.99*max_power,...
     "P_m_i_n = " + string(min_power) + " W, Current = " +...
     string(min(motor_current)) + " mA",'Color','g')

xlabel("Angle from parallel (Degrees)")
ylabel("Power (W)")
title("Power needed for the motor")
subtitle("Actuator Velocity: "+ string(Va) + " in/s")
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```
hold off

% Actuator Force plot
figure('Name',"Axial and transverse loads on the actuator")
hold on
% Axial
ylim_loads = [1.15*min([min_axial, min_trans]), 1.15*max([max_axial, max_trans])];
xlim_loads = [1.05*alpha_1, 1.05*alpha_4];
plot(theta,actuator_axial,'r')

plot([alpha_2, alpha_2], [min_axial, actuator_axial(102)],'r--',...
     [alpha_3, alpha_3], [min_axial, actuator_axial(202)],'r--',...
     [alpha_1, alpha_4], [min_axial, min_axial],'r--',...
     [alpha_1, max_axial_angle], [actuator_axial(max_axial_angle_loc),...
     actuator_axial(max_axial_angle_loc)], 'k--',...
     [alpha_1, alpha_1], [actuator_axial(min_axial_angle_loc),...
     actuator_axial(max_axial_angle_loc)], 'k--',...
     [xlim_loads(1) xlim_loads(2)], [0 0], 'k', 'HandleVisibility','off')

 % Transverse
plot(theta,actuator_trans,'g-')
plot([alpha_2, alpha_2], [actuator_trans(1), actuator_trans(102)],'g--',...
     [alpha_3, alpha_3], [actuator_trans(1), actuator_trans(202)],'g--',...
     [alpha_1, alpha_4], [actuator_trans(1), actuator_trans(1)],'g--',...
     [alpha_1, min_trans_angle], [actuator_trans(min_trans_angle_loc),...
     actuator_trans(min_trans_angle_loc)], 'k--',...
     [alpha_1, alpha_1], [actuator_trans(max_trans_angle_loc),...
     actuator_trans(min_trans_angle_loc)], 'k--', 'HandleVisibility','off')

text((alpha_1 - max_axial_angle)/2, 1.05*max_axial,...
     "Fax_m_a_x = " + string(max_axial) + " lbf",'Color','r')
text((alpha_1 - max_axial_angle)/2, 0.95*max_axial,...
     "Fax_m_i_n = " + string(min_axial) + " lbf",'Color','r')
text((alpha_1 - min_trans_angle), 0.95*min_trans,...
     "Ftrans_m_a_x = " + string(min_trans) + " lbf",'Color','g')
text((alpha_1 - min_trans_angle), 1.05*min_trans,...
     "Ftrans_m_i_n = " + string(max_trans) + " lbf",'Color','g')

ylim(ylim_loads)
xlim(xlim_loads)
legend(["Axial Load into Actuator", "Transverse Force on↙
Actuator"],'Location','northeastoutside')
xlabel("Angle from Parallel (Degrees)")
ylabel("Force (lbf)")
title("Loads on the Actuator")
subtitle("Axial and Transverse")

% Spring Catch Force Plot
figure('Name',"Spring Catch Force")
ylim_spring = [0, 1.15*max_spring];
xlim_spring = [1.05*alpha_1, 1.05*alpha_4];
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```
hold on
plot(theta,spring_catch,'k')
plot([max_spring_angle, max_spring_angle], [0, max_spring],'k--',...
     [alpha_1, max_spring_angle],[max_spring, max_spring],'k--',...
     [alpha_1, alpha_1],[0, max_spring],'k--')
text((alpha_1 - max_spring_angle), 1.05*max_spring,...
     "Fs_m_a_x = " + string(max_spring) + " lbf",'Color','k')
hold off
ylim(ylim_spring)
xlim(xlim_spring)
xlabel("Angle from Parallel (Degrees)")
ylabel("Force (lbf)")
title("Force on the Spring Catch")


% - Command Window Report - %
% Torque equations
T_equations = [
"T_12 = (Fa*La - Ff*Ma)*cos(thta)                                              ",...
"T_23 = (Fa*La - Ff*Ma)*cos(thta) - k*(La^2)*(cos(thta) - cos(alp_2))*sin(thta)",...
"T_34 = (Fa*La - Ff*Ma)*cos(thta)                                              "
];

% Actuator force equations
Actuator_equations = [
"Ax_12    = (Fa - Ff)*sin(thta)                                         ",...
"Ax_23    = (Fa - Ff)*sin(thta) - k*La*(cos(thta) - cos(alp_2))*cos(thta)",...
"Ax_34    = (Fa - Ff)*sin(thta)                                         ",...
"Trans_12 = (Fa - Ff)*cos(thta)                                         ",...
"Trans_23 = (Fa - Ff)*cos(thta) - k*La*(cos(thta) - cos(alp_2))*sin(thta)",...
"Trans_34 = (Fa - Ff)*cos(thta)                                         "
];
% Spring catch equation
Spring_catch_equation = "Fs = k*La*(cos(thta) - cos(alp_2))*sin(thta)";
% Constants
fprintf("--------------------------------------------------------------------------------↙
\n"+...
        "GIVEN\n"+...
        "-----\n\n"+...
        "Actuator Weight:                  %2.4f lbf\n"+...
        "Food Weight:                      %2.4f lbf\n"+...
        "Spring Constant:                  %2.4f lbf / in\n\n"+...
        "Distance to end of actuator:      %2.4f in\n"+...
        "Distance to center of actuator:   %2.4f in\n\n"+...
        "Velocity at end of actuator:      %2.4f in/s\n\n"+...
        "Rest Angle:                       %2.4f deg\n"+...
        "Angle to end of curve:            %2.4f deg\n"+...
        "Angle to top of wall:             %2.4f deg\n"+...
        "End Angle:                        %2.4f deg\n",...
        Fa, Ff, k, La, Ma, Va, alpha_1, alpha_2, alpha_3, alpha_4)
% Equations
```

```
fprintf("----------------------------------------------------------------------------------↙
\n"+...
        "EQUATIONS\n"+...
        "---------\n\n"+...
        "Motor Torque\n"+...
        "------------\n"+...
        "%s\n%s\n%s\n\n"+...
        "Actuator Loading\n"+...
        "----------------\n"+...
        "AXIAL\n"+...
        "%s\n%s\n%s\n\n"+...
        "TRANSVERSE\n"+...
        "%s\n%s\n%s\n\n"+...
        "Spring Catch Loading\n"+...
        "--------------------\n"+...
        "%s\n",...
        T_equations, Actuator_equations, Spring_catch_equation)
% Results
fprintf("----------------------------------------------------------------------------------↙
\n"+...
        "RESULTS\n"+...
        "-------\n\n"+...
        "Torque\n"+...
        "------\n"+...
        "T_max = % 2.3f in-lbf\n"+...
        "T_min = % 2.3f in-lbf\n\n"+...
        "Power\n"+...
        "------\n\n"+...
        "P_max = % 2.3f W\n"+...
        "P_min = % 2.3f W\n\n"+...
        "Current\n"+...
        "-------\n"+...
        "I_max = % 2.3f mA\n"+...
        "I_min = % 2.3f mA\n\n"+...
        "Actuator Loading\n"+...
        "----------------\n"+...
        "AXIAL\n"+...
        "Fax_max = % 2.3f lbf\n"+...
        "Fax_min = % 2.3f lbf\n\n"+...
        "TRANSVERSE\n"+...
        "Ftrans_max = % 2.3f lbf\n"+...
        "Ftrans_min = % 2.3f lbf\n\n"+...
        "Spring Catch Loading\n"+...
        "--------------------\n"+...
        "Fs_max = % 2.3f lbf\n"+...
        "--------------------------------------------------------------------------------↙
\n",...
        max_torque,min_torque,max_power,min_power,max_current,...
        min_current,max_axial,min_axial,max_trans,min_trans,max_spring)
```