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ME 747 - Senior Lab

Semester and Year:

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Name of Lab Instructor:

Prof. Barry Fussell

Lab Section and Meeting Time:

Mike deLeon's Section

Report Type:

External Group

Title of Experiment:

Shift Force Profile of a YFZ-450R Engine

Date Experiment Performed:

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Date Report Submitted:

December 14, 2012

Name of Group Members:

Drummond Biles
Ryan Carlson
George Hotton
Benjamin Gardell

Grader's Comments:

Grade:

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1 Objectives

Primary Contributer: Ryan Carlson ;
Secondary Contributors: Drummond Biles, Ben Gardell, George Hutton

A SM-100 Force Transducer and Beckman Industries 10-turn rotational potentiometer were utilized to determine the shift force profile for a YFZ-405R engine. Shift force profile details the torque and angular displacement for a gear change within the motor. The purpose of investigating the shift force profile was to calculate the torque and linkage geometry required of the Lo-Cog DC Servo Gearmotor to electrically shift the motor. Shifting profiles were created for the engine transmission gear shifts of: first to neutral, neutral to first, first to second, second to first, second to third and third to second gears. Speed of response for the shift between respected gear pairs was also theoretical determined for the DC Servo Gearmotor through Matlab Simulink. Subsequent data conclusions from the experiment are to be applied to the current University of New Hampshire Formula SAE race car.

2 Summary of Results

Primary Contributer: George Hutton;
Secondary Contributors: Drummond Biles, Ben Gardell

The force required to shift a Yamaha YFZ-450r engine and the resulting angular displacement were measured and analyzed. Shift force profiles relating the necessary torque to shift between gears and the respective angular displacement were generated.

Table 1: Comparison between simulation load torques and geometric analysis load torques.

Shift	Torque (lbf/ft	Ang Disp (Degrees)
Up-Shift	6	14.5
Down-Shift	5	14.5

Table **??** displays the maximum torque value for up and down shifts. The maximum angular displacement was averaged for all shifts, resulting in an average angular displacement of 14.5 degrees.

A four bar linkage system was designed to translate the torque from the shifting motor to the transmission. The resulting torque required to change gears was 17.85 $\frac{lb}{in}$ for the down-shift, and 15 $\frac{lb}{in}$ for the up-shift. A simulation of the shifter motor determined that the motor can shift gears in 0.023 seconds. The required torque values were simulated to be 18.01 $\frac{lb}{in}$ and 15.05 $\frac{lb}{in}$

2.1 Experimental Methods

Primary Contributer: Ben Gardell ;
Secondary Contributors: George Hotton , Ryan Carlson

To determine the shift force profile of a Yamaha YFZ-450r engine, an experimental setup was designed to accurately measure an force applied and the angular displacement. The experimental setup, Fig. **??**fig:setup, was designed to measure the force required to rotate the sequential gearbox causing a shift from one gear to the subsequent gear.

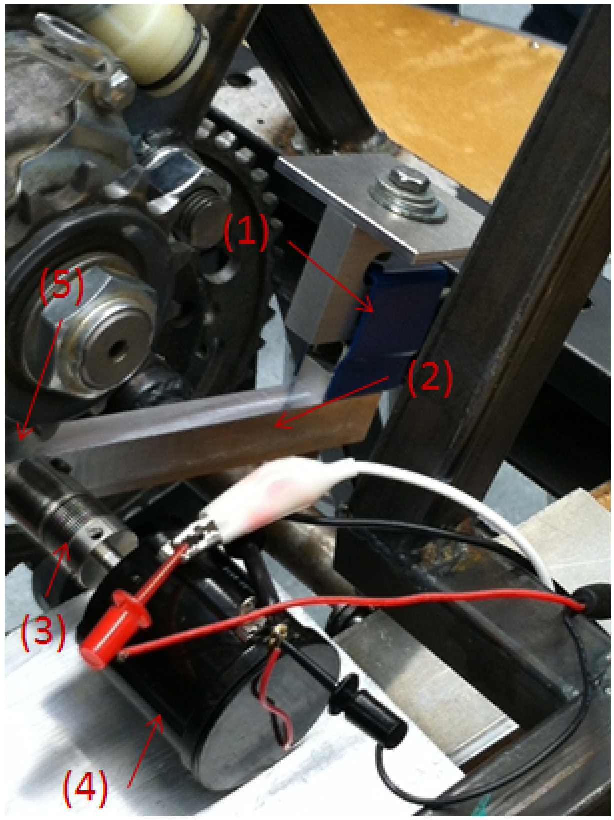

Figure 1: The Shift Force Profile Experimental Setup. 1) Force Transducer. 2) Rotating Arm. 3) Coupling. 4) Rotational Potentiometer. 5) Shifter knob.

The (1) is referring to the force transducer. The force transducer utilized was an Interface SM-100 Force Transducer, Fig. 2. This force transducer is able to measure up to 100 lbf, After 100 lbf the transducer will continue recording 100 lbf. The transmission was not expected to require that much force, therefore the SM-100 was sufficient. The force for each shift was applied rotationally, and in line with the bolt, to accurately measure the force.

Figure 2: SM-100 Force Transducer

The rotating arm, (2) on Fig. **??**, translated the applied force at the force transducer to the shifter knob,(3) on Fig. **??**. The rotating arm was designed to fit the shifter knob, then was machined at UNH machine shop out of Aluminum 6160 T6. The arm is 5 inches from end to end. The output signal from the force transducer was on the scale of microvolts, too small for the Oscilloscope to measure. Therefore the signal was run through a differential amplifying circuit, Fig. 3, to amplify the output voltage to a measurable magnitude.

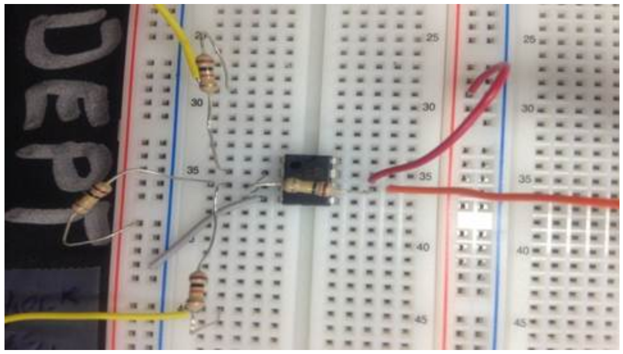

Figure 3: Differential Amplifying Circuit

In addition to applied force, the angular displacement was also necessary to produce the shift force profile. The angular displacement was measured using a 10-turn rotational potentiometer, Fig. 4. The potentiometer, (4) on Fig. **??**, was calibrated to determine the linear range. Ideally the potentiometer should operate in the linear range to accurately convert the output voltage to angular displacement. The potentiometer was calibrated to be linear for the first 5 turns. The experiment occurred at 2.5 turns, well within the linear range.

Figure 4: Beckman 10-turn Rotational Potentiometer

The magnitude of the potentiometer output voltage was large enough where an amplifier was not necessary. The potentiometer was attached to the shifter knob using a 0.25 inch to 0.5 inch coupling, (3) on Fig. **??**.

2.2 Theory

Primary Contributer: Ryan Carlson ;
Secondary Contributors: Drummond Biles, George Hotton

2.2.1 Shift Force Parameters

Calibration of the SM-100 force transducer and 10-turn rotational potentiometer was achieved through experimental data. Operational parameters for the devices were chosen within the linear sensitivity regions to minimize error. The formulation of the force transducer sensitivity, (mV/lbf), was stated as

$$k_{force} = \left(\frac{V}{W}\right), \tag{1}$$

where W corresponded to the weight (lbf) applied to transducer in compression, and V related to the voltage (mV) produced by the deflection of the transducer.

Resulting torque experienced by the motor's shifter mechanism from the applied force was determined

$$T = \frac{V_{force}}{K_{force}} \times \frac{5}{12}, \tag{2}$$

where V_{force} was the measured change in voltage from the differential amplifier in mV, K_{force} was the sensitivity of the force transducer, and the fraction 5/12 was the inch length of the machined shifter lever to the point of loading.

The rotational potentiometer sensitivity was determined though mechanically turning the potentiometer through the 10-turn range of measurement. The resulting sensitivity equated to,

$$K_{angle} = \frac{V_{angle}}{\beta}, \tag{3}$$

where V_{angle} was the voltage output of the potentiometer, and θ equated angle of the potentiometer. To find the angle of the force profile for the respective shifts, the output of the potentiometer was multiplied by the sensitivity of Eq. (3);

$$\alpha = V_{angle} * K_{angle}, \tag{4}$$

with V_{angle} equaling the output voltage of the potentiometer for given angle.

2.2.2 Linkage Geometry

Primary Contributer: Drummond Biles ;

Secondary Contributors: George Hotton , Ryan Carlson, Ben Gardell

Next the linkage geometry is analyzed to find a description of the dynamic movement of the shifter linkage. From this it will then becomes possible to relate the torque required to shift the engine to the load torque seen by the electric motor.

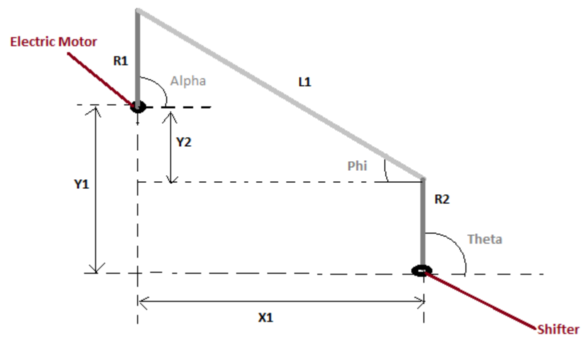

Figure 5: 4 Bar linkage system which describes the linkage sued to shift the motor.

In Fig. 5 a model is displayed which describes the 4 bar linkage system that will shift the motor. The electric shifter motor is labeled in the top left and through R1, L1, and then R2 it is connected to the shifter on the engine. Next by using geometry based on the engine R1=.25" and X1 equals 2.5". Then L1 can be said to be;

$$L1 = \sqrt[2]{R1^2 + X1^2} \tag{5}$$

from this L1 equals 2.51". Next when R1 rotates 90 degrees such that α is zero, it can be seen that R2 will be at its maximum displacement. By knowing the maximum over which R2 must rotate dictated by the maximum shift angle, the length R2 can be found from;

$$R2 = \frac{R1}{cos(\theta_{max}} \tag{6}$$

Next basic geometric equations can be created from the 4 bar linkage model in Fig. 5, the goal of which is to describe the relationship between theta and alpha. Where ϕ can be described as;

$$\phi = sin^-1(\frac{R1sin(\alpha) + Y2}{L1} \tag{7}$$

Next Y2 must be described in terms of Y1, and R2 and the angles θ, and α. This can then be put back into Eqn. 7 such that ϕ is then fully described.

$$Y2 = R2 - Y1 \tag{8}$$

$$Y2 = R2 - R2sin(\theta) \tag{9}$$

$$Y2 = R2(1 - sin(\theta)) \tag{10}$$

Next the x components of the linkage members can be compared such that the following governing equation can be created;

$$R2cos(\theta) + X1 = R1cos(\alpha) + L1cos(\phi) \tag{11}$$

Then by defining all of the angles used in Eqn. 11 both θ, and α can be defined with respect to time during the shift. With these angles defined a force analysis can now be preformed on the 4 bar linkage system to find the load torque seen by the electric motor. If the maximum torque to shift the motor is T1, then;

$$F1 = \frac{T1}{R2} \tag{12}$$

F1 can be described as the torque T1 divided by the length R2. Next by assuming that L1 is a two force member the force seen at the joint between R1 and L1 is;

$$F2 = F1cos(90 - (\theta + \phi)) \tag{13}$$

Finally F2 can be related to the force seen by the electric motor from;

$$F_{motor} = F2cos(90 - (\alpha + \phi)) \tag{14}$$

Then by combining Eqn. 12 through Eqn. 14 a final equation is found which describes the load torque seen by the electric motor.

$$T_{motor} = \frac{T1R1}{R2}cos(90 - (\theta + \phi))cos(90 - (\alpha + \phi)) \tag{15}$$

2.3 Speed of Response

Primary Contributer: Drummond Biles ;

Secondary Contributors: George Hotton , Ryan Carlson, Ben Gardell

Now by having an accurate description of the load torque seen by the electric motor a block diagram can be created that can simulate the response of the electric motor and therefore calculate the required shift time. A basic motor block diagram was created by using the characteristics of the DC servo Gear-motor used. Then the output of the motor diagram was put through a gear reduction gain due to based on the 19.7 reduction ratio of the motor. This signal was then integrated to obtain a position. From this a look-up block was utilized to compare the motor's angular position, described in the previous section to the load torque seen. This was then fed back into the motor diagram and compared to the ideal value as feedback. The motor block diagram can be seen in the appendix Sec. C. From this model all characteristic of the motors response to the shift could be seen.

3 Results and Discussion

Primary Contributer: Ryan Carlson ;
Secondary Contributors: George Hotton , Drummond Biles, Ben Gardell

3.1 Shift Force Profiles

To obtain the shift force profiles, first the calibration data from the force tranducer calibration was plotted such that the sensitivity of the force transducer could be found.

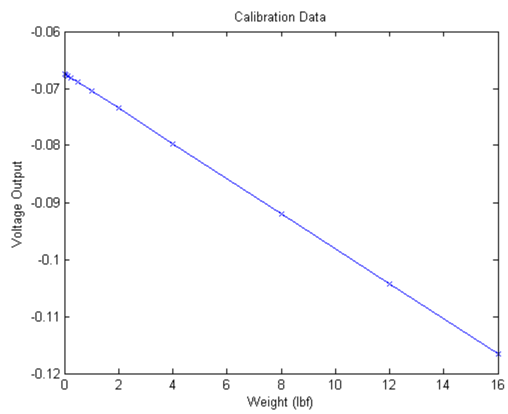

Figure 6: Plot of calibration data for force transducer.

In Fig. 6 the calibration data is plotted and s fit line is set to the data. The data points are shown as x's and the raw data for the plot is displayed in Sec. B. Then a fit line is plotted to the data and the sensitivity of the data is found to be $.003\frac{Volts}{lb}$. This data can then be used to convert the output data from the force transducer into the required force data. This force data is then multiplied by the length of lever arm used which was 5 inches. In the following plots the data from the three tested shifts of neutral to first, first to second, and second to third is shown.

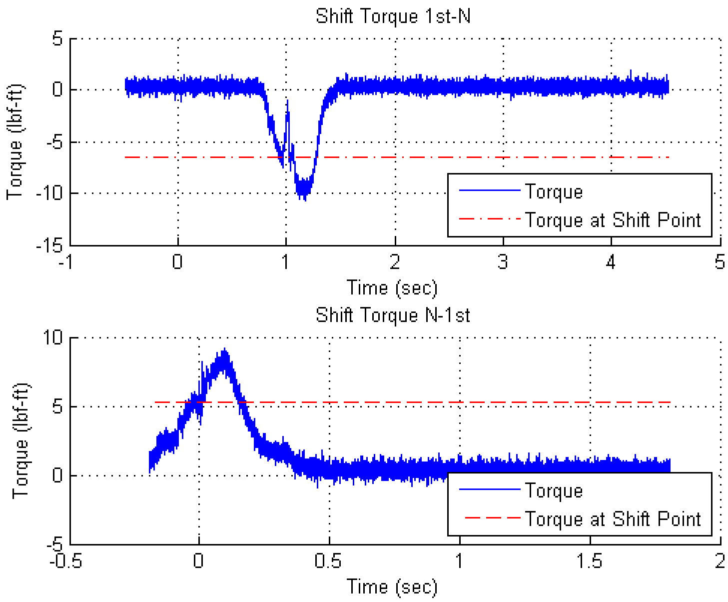

Figure 7: Plot of torque data as seen in up-shift, neutral to first, and down-shift, first to neutral.

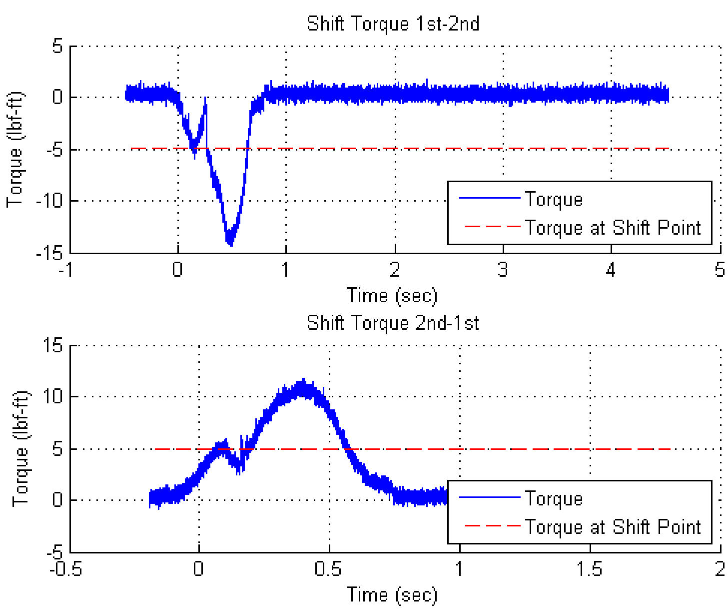

Figure 8: Plot of torque data as seen in up-shift, first to second, and down-shift, second to first.

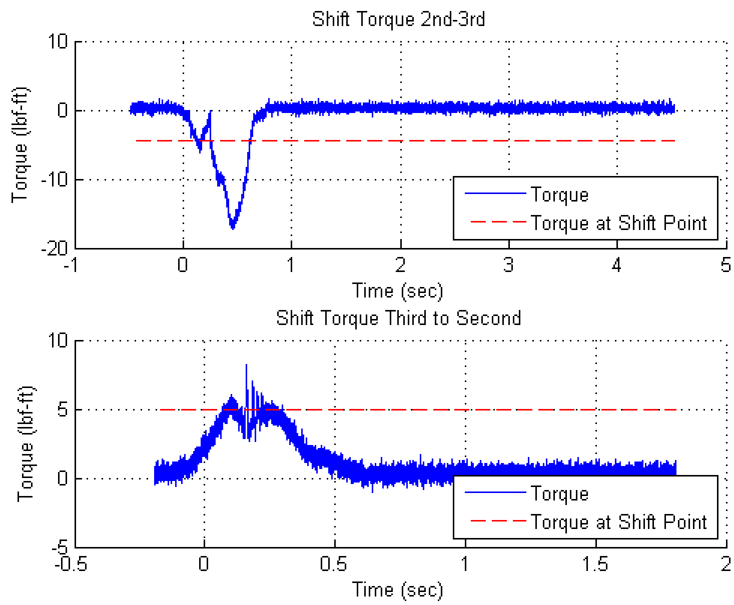

Figure 9: Plot of torque data as seen in up-shift, second to third, and down-shift, third to second.

In Fig. 7-Fig. 9 the torque seen for the given up and down shifts is displayed. Then for each graph a red dotted line indicates the moment of shift, which is shown on the graph as the first peak. This peak represents when the next gear is engaged then the torque peaks again from when shifter hits the maximum displacement for the given shift. From these plots the torque value needed to shift the motor can be recorded as the red line. When the up and down shifts are averaged, the required torque value for an up-shift is $6\frac{lb}{ft}$, and the required torque value for a down-shift is $5\frac{lb}{ft}$. Next the angular displacement data was put on top of the torque data in order to compare the data sets and also to see the angle at which the maximum torque occurs. From this the maximum angular displacement can then be quantified.

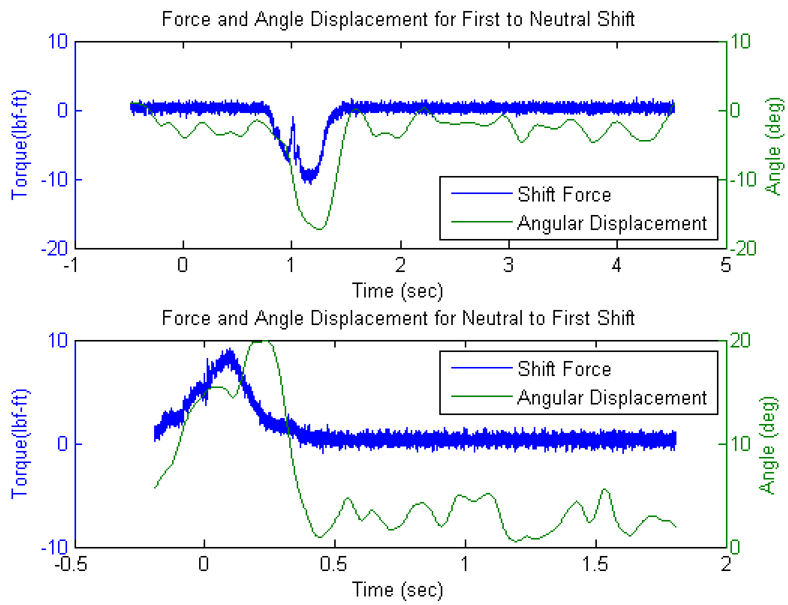

Figure 10: Plot of torque and angular displacement data as seen in up-shift, neutral to first, and down-shift, first to neutral.

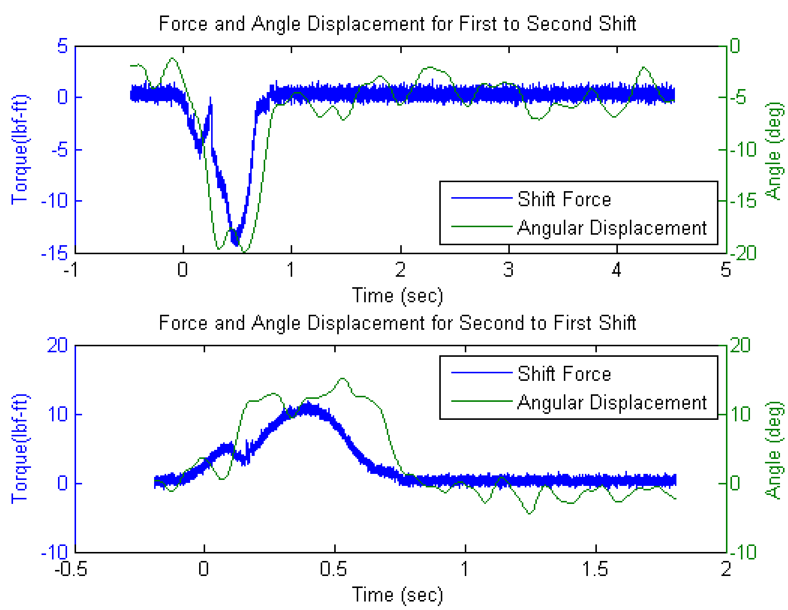

Figure 11: Plot of torque and angular displacement data as seen in up-shift, first to second, and down-shift, second to first.

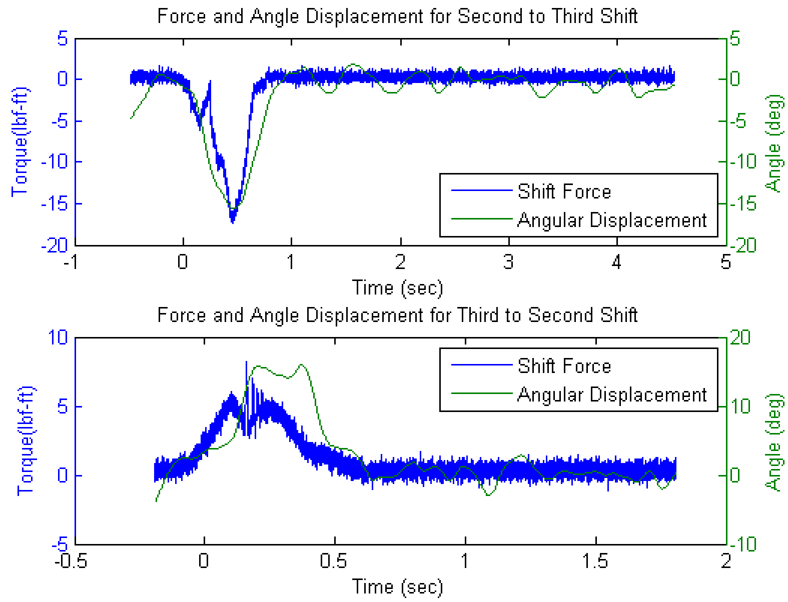

Figure 12: Plot of torque and angular displacement data as seen in up-shift, second to third, and down-shift, third to second.

In Fig. 10-Fig. 12 the torque data is compared to the angular displacement data. At the point at which the gear engage the angle of displacement is averaged to be 10 degrees, yet the maximum displacement is required for a full shift. Therefore the maximum displacement is averaged at all the maximum torque values and an angle of 14.5 degrees is seen.

3.2 Linkage Geometry

Primary Contributer: George Hutton ;
Secondary Contributors: Drummond Biles, Ryan Carlson, Ben Gardell

The following lengths were found for the model shown in Fig. 5.

Table 2: Final values used to describe 4 bar linkage.

Member	Length (inches)
R1	.25
R2	.9985
L1	2.512
X1	2.5
θ_{max}	14.5

Using the values in the above table and Eqn. 11, the relationship between α and θ can be found.

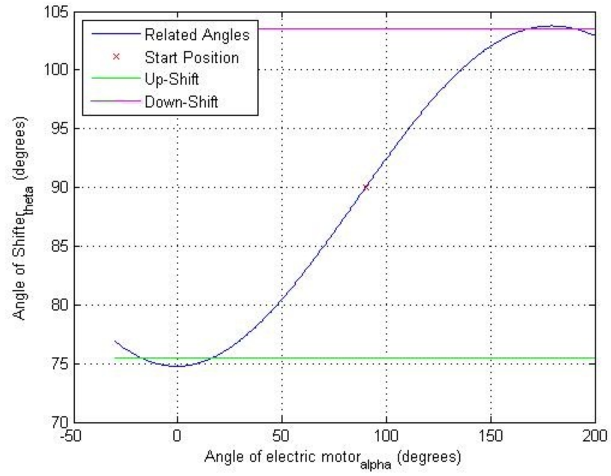

Figure 13: Graph representing the response of θ and α during an up or down shift

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In Fig. 13 α is plotted with respect to θ for an up and down shift. Both angles start at 90 degrees seen by the red x. Then for an up shift the electric motor arm is rotated backwards decreasing α until θ reaches the necessary shift angle of 14.5 degrees shown by the green line. Then the motor returns to the start position. Next for a down shift the electric motor angle, α increases until it reaches the required down shift angle shown in magenta. Now by having a representation of the receptive linkage angles using Eqn. 15 the electric motor load torque can be calculated with respect to the shift angle α.

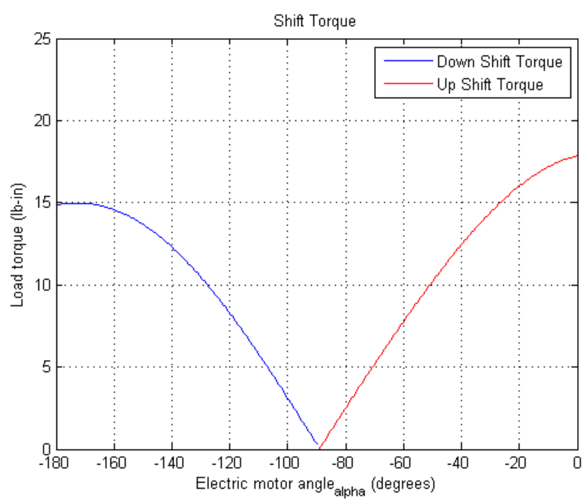

Figure 14: Graph representing the two torque load curves for an up-shift and down-shift.

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In Fig. 14 the load torque seen the electric motor is plotted. These torques are based off the average values found from Sec. 3.1, which indicated and average up-shift torque of 6 $\frac{lb}{ft}$ required. Then an average value of 5 $\frac{lb}{ft}$ was required for a down-shift. From these values the load torque on the electric motor for an up-shift is shown in red, and for a down-shift shown in blue. The down-shift requires a higher maximum torque output of 17.85 $\frac{lb}{in}$, where as the up-shift has a maximum torque output from the motor of 15 $\frac{lb}{in}$. From the motor spec sheet it is seen that the motor has a maximum torque output of 183.7 $\frac{lb}{in}$. Therefore both of the required load torques are well within the motors performance range.

3.3 Speed of Response

Primary Contributer: Drummond Biles ;
Secondary Contributors: George Hutton , Ryan Carlson, Ben Gardell

By using the characteristics of the DC servo Gear-motor shown in the appendix Sec. A. The following data was then achieved by running the Simulink simulation of both an up and down shift.

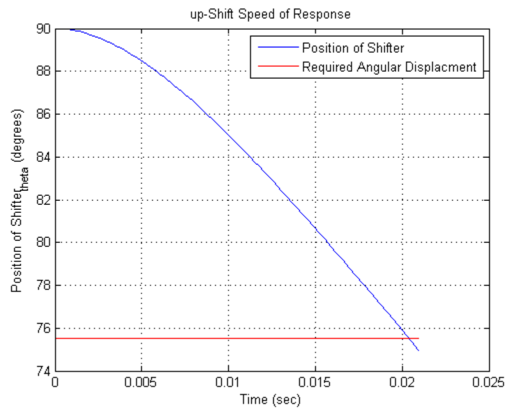

Figure 15: Graph representing the response of θ during a simulated up-shift.

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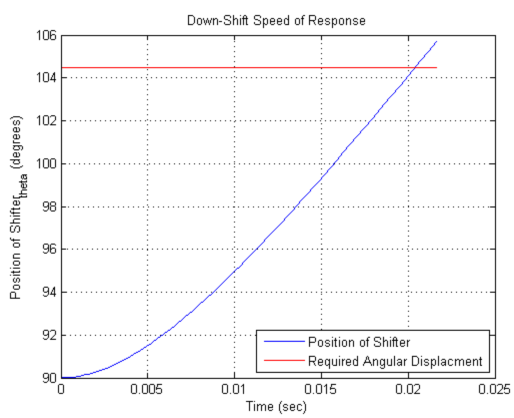

Figure 16: Graph representing the response of θ during a simulated down-shift.

In Fig. 15 θ is shown with respect to time for an up-shift. From Fig. 15 it can be seen that the shift is preformed in approximately .023 seconds, which is well within the desired time for a shift. Then in Fig. 16 θ is plotted with respect to time for a down shift. It is seen that during this simulation the shift is also completed within about .023 seconds. Next the corresponding loads on the electric motor where plotted as seen during the simulation.

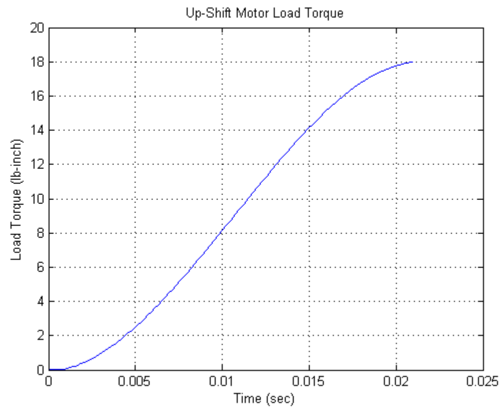

Figure 17: Graph representing the load torque seen by the electric motor during a simulated up-shift.

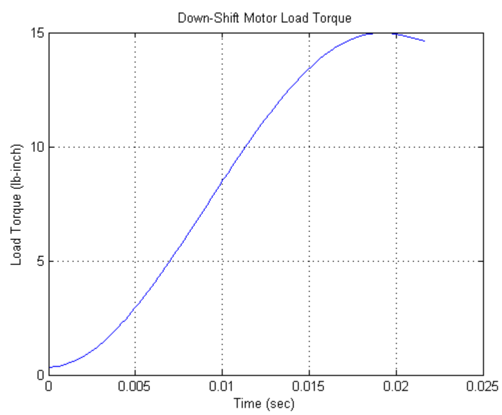

Figure 18: Graph representing the load torque seen by the electric motor during a simulated down-shift.

In Fig. 17 the load torque as seen by the electric motor is plotted for a down-shift. Then in Fig. 18 the load torque seen by the electric motor for a up-shift is seen. Then the maximum values found during simulation will be compared to the values found using a geometric analysis.

Table 3: Comparison between simulation load torques and geometric analysis load torques.

Shift	Simulation (lb/inches)	Geometric (lb/inches)	Error
Up-Shift	18.01	17.85	.8%
R2	15.05	15	.3%

From Table. 3 it can be seen that the maximum load torque seen by the motor closely matches between the simulation and analysis.

4 Conclusions

4.1 Drummond Biles

In this report an analysis of the torque and displacement required to shift the YFZ-450R engine. A Sm-100 force transducer and rotational potentiometer were used to measured the dynamics of the shift. This data was then analyzed such that maximum angular displacement and shift torque could be determined for both up and down shifts. Then using the physical constraints on the placement of the electric shift motor, a 4 bar linkage system was designed such that the required shift torque could be placed upon the engine. From this a description of the load torque seen by the electric motor could then be produced. This load torque was then compared to the maximum output torque of the electric motor in order to insure that the electric motor was capable of shifting the engine. The load torque was well under the peak torque value of the electric motor. Then based on the known motor characteristics a simulated speed of response was done by creating a block diagram of the motor in Simulink. Then the load torque seen by the eclectic motor at different angular positions was simulated and the speed of response for the shifter mechanism was quantified to be .023 seconds. Based on this ideal time the shifter mechanism is sufficiently fast and will greatly improve the time for shift from a manual shift preformed by a bump shifter.

The data in this analysis represents the ideal condition with a shift preformed ”cold”. Each of the shifts were preformed with the engine off and therefore when a true shift is preformed the load torque will have a slight deviation from the required torque specified by this report. In an ideal shift in which the rpm's of the engine match the wheel speed the shift force will be lower than the value seen during the experiment. If this ideal shift is not preformed than the torque to shift the motor could increase. This will increase the load torque on the electric motor. The next factor that may change due to the cold shift is the inertial forces involved in the gear change. The cold shift represented high inertial forces, although due to the small time seen in the simulated response these forces will increase. Therefore it is hard to predict the exact forces and torques that will be seen by the shifting mechanism. This design will be sufficient for the initial design due to the motor has a safety factor of 10 for the load torque that it will experience. This analysis gives ground work for the design of the shifting mechanism, such that basic components can be built. Further testing will be preformed using the linkage and motor outlined in this report. Then dynamic testing can be preformed with the car running, and modification can be made to the design based on the outcome of subsequent testing.

4.2 Ryan Carlson

4.3 George Hotton

4.4 Benjamin Gardell

References

[1] Palm, William J. *System Dynamics*. Boston, MA, McGraw-Hill, 2010. Print.

Appendices

A Equipment List

- 741 Power Operational Amplifier
- Potentiometer
- rotational coupling
- NI Function Generator
- 100lb Force Trasnducer
- NI Oscilloscope

INCLUDE MOTOR SPEC SHEET!

B Raw Data Sheets

INCLUDE RAW DATA FROM FORCE CALIBRATION!

C Sample Calculations

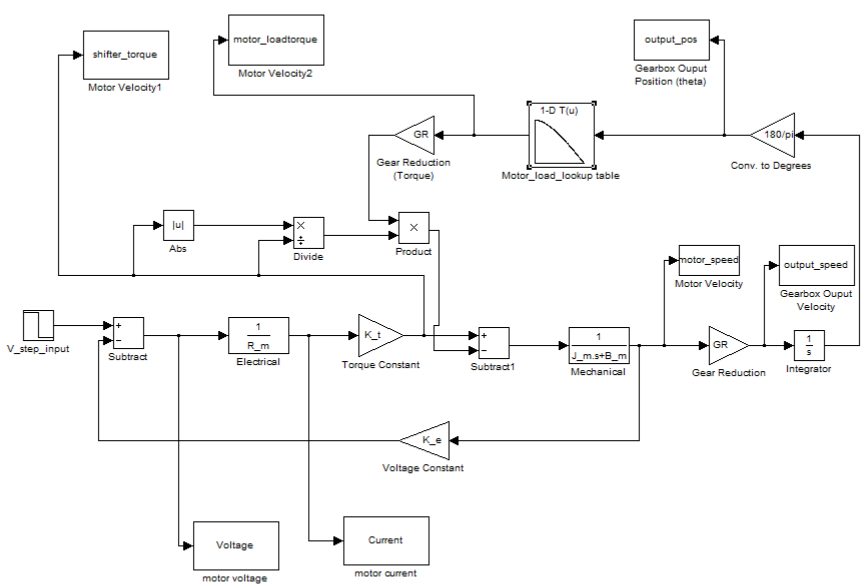

Figure 19: Image representing the block diagram used to model the up and down shifts with the given electric motor.

MATLAB code utilized during the analysis of the data.

Code for Pot and Force Transducer Manipulation

```
lose all
clear all
clc

%S-Lab Final Project
%Drummond Biles, Ryan Carlson, George Hotton, Ben Gardell
%Data Reduction Code for Angle Displacement for shift profile.
%NOTE: Sensitivity for POT calucalted in Rot_Pot_Code

%% POT sensitiviy Data
%sensitivity data for the rot pot from code Rot_Pot_Code
pot_sensitivity = -1.6875*10^-4; %v/deg
pot_sensitivity = pot_sensitivity ^-1; %deg/v



%% 1st to Neutral

%1st to neutral gear shift Data
first_n_data = csvread('1st_n_trial2.csv');
first_n_time = first_n_data(:,1); %time for 1st to neutral data
first_n_pot = first_n_data(:,2); %angular displacement of the pot Volts

%application of the whitticar smoother to decerase noise of the signal
first_n_pot = wsmooth(first_n_pot, first_n_time, 8); %smooth pot data

offset_1st_n = 7205;

first_n_angle = first_n_pot * pot_sensitivity + offset_1st_n; %output in deg

% Plotting 1st to 2nd data (angular displacement to time)
% figure
% plot(first_n_time, first_n_angle)
% xlabel('Time(sec)')
% ylabel('Angle (deg)')
% title('Angluar Displacement for 1st-Neutral Gear Shift')

%% Neutral to 1st

%N to 1st gear shift data
n_first_data = csvread('n_1st_trial2.csv');
n_first_time = n_first_data(:,1); %time for 1st to neutral data
```

```
n_first_force = n_first_data(:,4); %force transducer data
n_first_pot = n_first_data(:,2); %angular displacement of the pot Volts

%application of the whitticar smoother to decerase noise of the signal
n_first_pot = wsmooth(n_first_pot, n_first_time, 8); %smooth pot data

offset_n_first = 7215;

n_first_angle = n_first_pot * pot_sensitivity + offset_n_first; %output in deg

%Plotting 1st to 2nd data (angular displacement to time)
% figure
% plot(n_first_time, n_first_angle)
% xlabel('Time(sec)')
% ylabel('Angle (deg)')
% title('Angluar Displacement for Neutral-1st Gear Shift')

%% 1st to 2nd gear shift

%1st to 2nd gear shift Data
first_2nd_data = csvread('1st_2nd_trial2.csv');
first_2nd_time = first_2nd_data(:,1); %time for 1st to neutral data
first_2nd_force = first_2nd_data(:,4); %force transducer data
first_2nd_pot = first_2nd_data(:,2); %angular displacement of the pot Volts

%application of the whitticar smoother to decerase noise of the signal
first_2nd_pot = wsmooth(first_2nd_pot, first_2nd_time, 8); %smooth pot data

%adjusting for sensitivity to have output in degrees and offset of gain
offset_1st_2nd = 7205; %degrees from graph for adjustment
first_2nd_angle = first_2nd_pot * pot_sensitivity + offset_1st_2nd; %output in deg

%Plotting 1st to 2nd data (angular displacement to time)
% figure
% plot(first_2nd_time, first_2nd_angle)
% xlabel('Time(sec)')
% ylabel('Angle (deg)')
% title('Angluar Displacement for 1st-2nd Gear Shift')

%% 2nd to 1st gear shift

%2nd to 1st gear shift Data
second_first_data = csvread('2nd_1st_trial2.csv');
second_first_time = second_first_data(:,1); %time for 1st to neutral data
second_first_force = second_first_data(:,4); %force transducer data
```

```
second_first_pot = second_first_data(:,2); %angular displacement of the pot Volts

%application of the whitticar smoother to decerase noise of the signal
second_first_pot = wsmooth(second_first_pot, first_2nd_time, 8);


%adjusting for sensitivity to have output in degrees and offset of gain
offset_2nd_1st = 7210;
second_first_angle = second_first_pot * pot_sensitivity + offset_2nd_1st;

%Plotting 2nd_first data (angular displacement to time)
% figure
% plot(second_first_time, second_first_angle)
% xlabel('Time(sec)')
% ylabel('Angle (deg)')
% title('Angluar Displacement for 2nd_1st Gear Shift')

%% 2nd to 3rd gear shift

%2nd to 3rd gear shift Data
second_third_data = csvread('2nd_3rd_trial2.csv');
second_third_time = second_third_data(:,1); %time for 1st to neutral data
second_third_force = second_third_data(:,4); %force transducer data
second_third_pot = second_third_data(:,2); %angular displacement of the pot Volts

%application of the whitticar smoother to decerase noise of the signal
second_third_pot = wsmooth(second_third_pot, second_third_time, 8);

%adjusting for sensitivity to have output in degrees and offset of gain
offset_second_third = 7210;
second_third_angle = second_third_pot * pot_sensitivity + offset_second_third;

%Plotting 2nd-3rd data (angular displacement to time)
% figure
% plot(second_third_time, second_third_pot)
% xlabel('Time(sec)')
% ylabel('Angle (deg)')
% title('Angluar Displacement for 2nd-3rd Gear Shift')

%% 3rd to 2nd gear shift

%2nd to 3rd gear shift Data
third_second_data = csvread('3rd_2nd_trial2.csv');
third_second_time = third_second_data(:,1); %time for 1st to neutral data
third_second_force = third_second_data(:,4); %force transducer data
```

```
third_second_pot = third_second_data(:,2); %angular displacement of the pot Volts

%application of the whitticar smoother to decerase noise of the signal
third_second_pot = wsmooth(third_second_pot, third_second_time, 8);

%adjusting for sensitivity to have output in degrees and offset of gain
offset_third_second = 7210;
third_second_angle = third_second_pot * pot_sensitivity + offset_third_second;

%Plotting 2nd-3rd data (angular displacement to time)
% figure
% plot(third_second_time, third_second_pot)
% xlabel('Time(sec)')
% ylabel('Angle (deg)')
% title('Angluar Displacement for 3rd-2nd Gear Shift')


%% Creation of subplots for all of the data

figure
subplot(3,2,1)
plot(first_n_time, first_n_angle)
xlabel('Time(sec)')
ylabel('Angle (deg)')
title('Angluar Displacement for 1st-Neutral Gear Shift')

first_n_start_angle = -3.0;
first_n_end_angle = -17;
first_n_diff = abs(first_n_start_angle - first_n_end_angle)

subplot(3,2,2)
plot(n_first_time, n_first_angle)
xlabel('Time(sec)')
ylabel('Angle (deg)')
title('Angluar Displacement for Neutral-1st Gear Shift')

n_1st_start_angle = 2.6;
n_1st_end_angle = 19.72;
n_1st_diff = abs(n_1st_start_angle - n_1st_end_angle)

subplot(3,2,3)
plot(first_2nd_time, first_2nd_angle)
xlabel('Time(sec)')
ylabel('Angle (deg)')
title('Angluar Displacement for 1st-2nd Gear Shift')
```

```
first_2nd_start_angle = -4.7;
first_2nd_end_angle = -19.18;
first_2nd_diff = abs(first_2nd_start_angle - first_2nd_end_angle)

subplot(3,2,4)
plot(second_first_time, second_first_angle)
xlabel('Time(sec)')
ylabel('Angle (deg)')
title('Angluar Displacement for 2nd-1st Gear Shift')

second_first_start_angle = 0.0;
second_first_end_angle = 12.86;
second_first_diff = abs(second_first_start_angle - second_first_end_angle)


subplot(3,2,5)
plot(second_third_time, second_third_angle)
xlabel('Time(sec)')
ylabel('Angle (deg)')
title('Angluar Displacement for 2nd-3rd Gear Shift')

second_third_start_angle = -.27;
second_third_end_angle = -15.47;
second_third_diff = abs(second_third_start_angle - second_third_end_angle)

subplot(3,2,6)
plot(third_second_time, third_second_angle)
xlabel('Time(sec)')
ylabel('Angle (deg)')
title('Angluar Displacement for 3rd-2nd Gear Shift')

third_second_start_angle = 0.0;
third_second_end_angle = 14.29;
third_second_diff = abs(third_second_start_angle - third_second_end_angle)

avg_shift_angle = (first_n_diff + n_1st_diff + first_2nd_diff...
    + second_first_diff + second_third_diff + third_second_diff)/6
```

```
%% Force Transducer Data

% Calibration Force Transducer
weight2=[0 1 2 4 8 16 32 64 128 192 256];
weight2=weight2.*0.0625;

Vout2=[-67.39 -67.6 -67.74 -68.1 -68.9 -70.5 -73.5 -79.72 -92.0 -104.3 -116.5];
Vout2=Vout2./1000;


sens2=diff(Vout2)./diff(weight2);
sensitivity2=sum(sens2)/10;
sensitivity=sensitivity2*-1;

figure
plot(weight2,Vout2,'-x')
title('Calibration Data')
xlabel('Weight (lbf)')
ylabel('Voltage Output')

%% Force Transducer: shift data

%1st to neutral
first_n_force = first_n_data(:,4); %force transducer data
first_n_force = first_n_force +.07;

%neutral to 1st
n_first_force = n_first_data(:,4); %force transducer data
n_first_force = n_first_force + 0.07;

%1st to 2nd
first_2nd_force = first_2nd_data(:,4); %force transducer data
first_2nd_force = first_2nd_force + 0.07;

%2nd to 1st
second_first_force = second_first_data(:,4); %force transducer data
second_first_force = second_first_force + 0.07;

%2nd to third
second_third_force = second_third_data(:,4); %force transducer data
second_third_force = second_third_force + 0.07;

%third to 2nd
third_second_force = third_second_data(:,4); %force transducer data
third_second_force = third_second_force + 0.07;
```

```
%% Plotting Force Profiles: 1st to N - N to 1st

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% 1st to N %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% %volts
% figure
% subplot(2,1,1)
% plot(first_n_time, first_n_force);
% grid on
% title('Shift Force Voltage Output 1st-N');
% ylabel('Output Voltage');
% xlabel('Time (sec)');

%Force
first_n_force1 = first_n_force./sensitivity;

%Force-Torque
first_n_force2 = first_n_force1.*(5/12);

%
% subplot(2,1,2)
% plot(first_n_time, first_n_force2);
% grid on
% title('Shift Torque 1st-N');
% ylabel('Torque (lbf-ft)');
% xlabel('Time (sec)');
% hold off

%%%%%%%%%%%%%%%%%%%%%%%%%% N to 1st %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% figure
% subplot(2,1,1)
% plot(n_first_time, n_first_force);
% grid on
% title('Shift force voltage output N-1st');
% ylabel('Output Voltage');
% xlabel('Time (sec)');

%Force
n_first_force1 = n_first_force./sensitivity;

%Force-Torque
n_first_force2 = n_first_force1.*(5/12);
```

```
% subplot(2,1,2)
% hold on
% plot(n_first_time, n_first_force2);
% plot(n_first_time, 6, 'r--') %plot of the shift force required
% grid on
% title('Shift Torque N-1st');
% ylabel('Torque (lbf-ft)');
% xlabel('Time (sec)');


%% Plotting Force Profiles: first to second - second to first

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% first to second %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%volts
% figure
% subplot(2,1,1), plot(first_2nd_time, first_2nd_force);
% grid on
% title('Shift Force Voltage Output First to Second');
% ylabel('Output Voltage');
% xlabel('Time (sec)');

%Force
first_2nd_force1 = first_2nd_force./sensitivity;

%Force-Torque
first_2nd_force2 = first_2nd_force1.*(5/12);
%

% hold on
% subplot(2,1,2), plot(first_2nd_time, first_2nd_force2);
% grid on
% title('Shift Torque 1st-2nd');
% ylabel('Torque (lbf-ft)');
% xlabel('Time (sec)');

%%%%%%%%%%%%%%%%%%%%%%%%%% second to first %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% figure
% subplot(2,1,2), plot(second_first_time, second_first_force);
% grid on
% title('Shift force voltage output 2nd-1st');
% ylabel('Output Voltage');
% xlabel('Time (sec)');
```

```
%Force
second_first_force1 = second_first_force./sensitivity;

%Force-Torque
second_first_force2 = second_first_force1.*(5/12);

% subplot(2,1,2), plot(second_first_time, second_first_force2);
% grid on
% title('Shift Torque 2nd-1st');
% ylabel('Torque (lbf-ft)');
% xlabel('Time (sec)');


%% Plotting Force Profiles: second to third - third to second

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% second to third %%%%%%%%%%%%%%%%%%%%%%%%

%volts
% figure
% subplot(2,1,1), plot(second_third_time, second_third_force);
% grid on
% title('Shift Force Voltage Output Second to Third');
% ylabel('Output Voltage');
% xlabel('Time (sec)');

%Force
second_third_force1 =second_third_force./sensitivity;
%
%Force-Torque
second_third_force2 = second_third_force1.*(5/12);

% figure
% subplot(2,1,1), plot(second_third_time, second_third_force2);
% grid on
% title('Shift Torque 2nd-3rd');
% ylabel('Torque (lbf-ft)');
% xlabel('Time (sec)');

%%%%%%%%%%%%%%%%%%%%%%%%%% third to second %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% figure
% subplot(2,1,2), plot(third_second_time, third_second_force);
% grid on
% title('Shift force voltage output Third to Second');
% ylabel('Output Voltage');
```

```
% xlabel('Time (sec)');

%Force
third_second_force1 = third_second_force./sensitivity;

%Force-Torque
third_second_force2 = third_second_force1.*(5/12);

% subplot(2,1,2), plot(third_second_time, third_second_force2);
% grid on
% title('Shift Torque Third to Second');
% ylabel('Torque (lbf-ft)');
% xlabel('Time (sec)');


%% ALL FORCE SHIFT DATA with shift force position line

%%%%%%%%%%%%%%%%%%%%%%%%%%% first to n and to first %%%%%%%%%%%%%%%%%%%%%%%

% %first to n

a = ones(1,length(first_n_time)) .* -6.5; %vector for shift torque.

figure
subplot(2,1,1)
hold on
plot(first_n_time, first_n_force2);
plot(first_n_time, a, 'r-.') %plot of the shift force required estimated value
grid on
title('Shift Torque 1st-N');
ylabel('Torque (lbf-ft)');
xlabel('Time (sec)');

%
% %n to first
a = ones(1,length(n_first_time)) .* 5.3;%vector for shift torque estimated value

subplot(2,1,2)
hold on
plot(n_first_time, n_first_force2);
plot(n_first_time, a, 'r--') %plot of the shift force required
grid on
title('Shift Torque N-1st');
ylabel('Torque (lbf-ft)');
xlabel('Time (sec)');
```

```
hold off
%
% %%%%%%%%%%%%%%%%%%% first to second and second to first %%%%%%%%%%%%%%%%
%
% %first to second
a = ones(1,length(first_2nd_time)) .* -4.9;%vector for shift torque estimated value

figure
subplot(2,1,1)
hold on
plot(first_2nd_time, first_2nd_force2);
plot(first_2nd_time, a, 'r--');
grid on
title('Shift Torque 1st-2nd');
ylabel('Torque (lbf-ft)');
xlabel('Time (sec)');
%
% %second to first
a =  ones(1, length(second_first_time)) .* 5.0;%vector for shift torque estimated value

subplot(2,1,2)
hold on
plot(second_first_time, second_first_force2);
plot(second_first_time, a, 'r--')
grid on
title('Shift Torque 2nd-1st');
ylabel('Torque (lbf-ft)');
xlabel('Time (sec)');
hold off
%
% %%%%%%%%%%%%%%%%%%%% second to third and third to second %%%%%%%%%%%%%%%%
%
% %second to third
a =  ones(1, length(second_third_time)) .* -4.5;%vector for shift torque estimated value

figure
subplot(2,1,1)
hold on
plot(second_third_time, second_third_force2);
plot(second_third_time, a, 'r--');
grid on
title('Shift Torque 2nd-3rd');
ylabel('Torque (lbf-ft)');
xlabel('Time (sec)');
%
```

```
% %third to second
a =  ones(1, length(third_second_time)) .* 5;%vector for shift torque estimated value

subplot(2,1,2)
hold on
plot(third_second_time, third_second_force2);
plot(third_second_time, a, 'r--')
grid on
title('Shift Torque Third to Second');
ylabel('Torque (lbf-ft)');
xlabel('Time (sec)');


%% LOCATION OF MAXIMUM ANGLE FOR SHIFT



%% Plotting the Force Trans. Data and Angular Displacements for the shift

%%%%%%%%%%%%%%%%%%%%%%%%  1st to N and N to 1st %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%1st to N
figure
subplot(2,1,1)
[AX, H1, H2]=plotyy(first_n_time, first_n_force2 ,...
    first_n_time, first_n_angle);
set(get(AX(1), 'ylabel'), 'String', 'Torque(lbf-ft)');
set(get(AX(2), 'ylabel'), 'String', 'Angle (deg)');
xlabel('Time (sec)')
title('Force and Angle Displacement for First to Neutral Shift')
legend([H1, H2], 'Shift Force', 'Angular Displacement',...
    'location', 'southeast')

%N to 1st
subplot(2,1,2)
[AX, H1, H2]=plotyy(n_first_time, n_first_force2,...
    n_first_time, n_first_angle);
set(get(AX(1), 'ylabel'), 'String', 'Torque(lbf-ft)');
set(get(AX(2), 'ylabel'), 'String', 'Angle (deg)');
xlabel('Time (sec)')
title('Force and Angle Displacement for Neutral to First Shift')
legend([H1, H2], 'Shift Force', 'Angular Displacement',...
    'location', 'northeast')

%%%%%%%%%%%%%%%%%%%%%%%%  1st to 2nd and 2nd to 1st %%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
% %1st to 2nd
figure
subplot(2,1,1)
[AX, H1, H2]=plotyy(first_2nd_time, first_2nd_force2,...
    first_2nd_time, first_2nd_angle);
set(get(AX(1), 'ylabel'), 'String', 'Torque(lbf-ft)');
set(get(AX(2), 'ylabel'), 'String', 'Angle (deg)');
xlabel('Time (sec)')
title('Force and Angle Displacement for First to Second Shift')
legend([H1, H2], 'Shift Force', 'Angular Displacement',...
    'location', 'southeast')

%2nd to 1st
subplot(2,1,2)
[AX, H1, H2]=plotyy(second_first_time, second_first_force2,...
    second_first_time, second_first_angle);
set(get(AX(1), 'ylabel'), 'String', 'Torque(lbf-ft)');
set(get(AX(2), 'ylabel'), 'String', 'Angle (deg)');
xlabel('Time (sec)')
title('Force and Angle Displacement for Second to First Shift')
legend([H1, H2], 'Shift Force', 'Angular Displacement',...
    'location', 'northeast')

% %%%%%%%%%%%%%%%%%%%%  2nd to 3rd and 3rd to 2nd %%%%%%%%%%%%%%%%%%%%%%%%
%
%2nd to 3rd
figure
subplot(2,1,1)
[AX, H1, H2]=plotyy(second_third_time, second_third_force2,...
    second_third_time, second_third_angle);
set(get(AX(1), 'ylabel'), 'String', 'Torque(lbf-ft)');
set(get(AX(2), 'ylabel'), 'String', 'Angle (deg)');
xlabel('Time (sec)')
title('Force and Angle Displacement for Second to Third Shift')
legend([H1, H2], 'Shift Force', 'Angular Displacement',...
    'location', 'southeast')

%3rd to 2nd
subplot(2,1,2)
[AX, H1, H2]=plotyy(third_second_time, third_second_force2,...
    third_second_time, third_second_angle);
set(get(AX(1), 'ylabel'), 'String', 'Torque(lbf-ft)');
set(get(AX(2), 'ylabel'), 'String', 'Angle (deg)');
xlabel('Time (sec)')
```

```
title('Force and Angle Displacement for Third to Second Shift')
legend([H1, H2], 'Shift Force', 'Angular Displacement',...
    'location', 'northeast')
```

Code for Shift Linkage Analysis, Load Torque Analysis, and Simulink Response

```
close all; clear all; clc;
%FSAE
%Shift Linkage Analaysis and Torque and Speed of Response
%S-Lab Final Project
%Drummond Biles, Ryan Carlson, George Hotton, Ben Gardell


%%%%%Initial Guesses

%alpha=angle of motor
%theta=angle of shifter {on engine}


%Distances  [inches]
R1=.25;
X1=2.5;
L1=(R1^2+X1^2)^(1/2);

%Angles [degrees]
alpha_shift=14.5;
alpha_max=90-alpha_shift;

%%%%%Analysis

R2=R1/cosd(alpha_max); %[inches]

%create all alpha angles
alpha=200:-.5:-30; %[deg]
% alpha=90:-.5:-270; %[deg]
alpha=reshape(alpha,461,1);

alpha=(pi/180)*alpha; %[rads]

%Find theta

for i=1:length(alpha)
    f=@(theta) R1*cos(alpha(i))+L1*cos(asin((R2*(1-sin(theta))+R1*sin(alpha(i)))/L1))-X1
    theta(i,1)=fzero(f, pi/2); %[rad]
end
```

```
theta=theta*(180/pi);   %[degrees]
alpha=alpha*(180/pi);   %[degrees]

a_low=90-alpha_shift;
a_high=90+alpha_shift-1;

figure
plot(alpha, theta,'b', 90,90,'xr',alpha, a_low, 'g-', alpha, a_high,'m-');
hold on
ylabel('Angle of Shifter_{theta} (degrees)');
xlabel('Angle of electric motor_{alpha} (degrees)');
grid on

legend('Related Angles','Start Position','Up-Shift','Down-Shift','Location','NorthWest')

phi=asin((R1*sind(alpha)+R2*(1-sind(theta)))/L1)*(180/pi);
% figure
% plot(alpha, phi)
% grid on
% ylabel('Angle of Shift Linkage_{phi} (degrees)');
% xlabel('Angle of electric motor_{theta} (degrees)');
% hold on
% plot(90,5.71,'xr')
%% Torque

T_up=6; %[lb-ft]
T_down=5; %[lb-ft]


T_up=T_up*12; %[lb-inch]
T_down=T_down*12; %[lb-inch]

c=find(alpha== 90);
% Tload_down=T_down*R1/R2*cosd(90-(theta(1:c)+phi(1:c))).*...
%    cosd(90-(phi(1:c)+alpha(1:c))); %[in-lb]

Tload_down=T_down*R1/R2*cosd(90-(theta(c:length(alpha))+...
    phi(c:length(alpha)))).*cosd(90-(phi(c:length(alpha))+alpha(c:length(alpha)))); %[in


[w,x]=min(theta(1:c));

% Tload_down(x:length(Tload_down))=0;
```

```
for i=1:length(Tload_down)

    if Tload_down(i,1)<0
        Tload_down(i,1)=0;
        c1=i;
    end
end

% Tload_up=T_up*R1/R2*cosd(90-(theta(c:length(alpha))+...
%     phi(c:length(alpha)))).*cosd(90-(phi(c:length(alpha))+alpha(c:length(alpha)))); %[

Tload_up=T_up*R1/R2*cosd(90-(theta(1:c)+phi(1:c))).*...
   cosd(90-(phi(1:c)+alpha(1:c)));

[w,x]=max(theta(c:length(alpha)));

% Tload_up(x:length(Tload_up))=0;

for i=1:length(Tload_up)

    if Tload_up(i,1)<0
        Tload_up(i,1)=0;
        c2=i;
    end
end
c3=find(alpha==0);

alpha_up=alpha(c+1:c3);
alpha_up=-1*(alpha_up);
alpha_down=alpha_up-90;

figure
plot(alpha_down,Tload_down(1:180));
axis([-180 0 0 25])
grid on
title('Shift Torque');
ylabel('Load torque (lb-in)');
xlabel('Electric motor angle_{alpha} (degrees)');
hold on


plot(alpha_up, Tload_up(42:221),'r')
grid on
title('Shift Torque');
ylabel('Load torque (lb-in)');
```

```
xlabel('Electric motor angle_{alpha} (degrees)');
legend('Down Shift Torque','Up Shift Torque');

%% SIMULINK

%Constants
L_m=.4*10^-3; %[H]
R_m=.27; %[Ohm]
J_m=3.7*10^-3; %[oz-inch-sec^2]
B_m=.18/(60/(2*pi));  %[V-sec/rad]
K_e=3.21/1000*60/(2*pi);  %[v-sec/rad]
K_t=4.33; % [oz-inch/Amp]
GR=1/19.7; %gear reduction

%%%%%%%%%%%%%%%%%%%%%%%    Up-shift %%%%%%%%%%
%Torque manipulation
Tload_up1=Tload_up(42:221);   %[lb-inch]
Tload_up1=flipud(Tload_up1);    %[lb-inch]
Tload_up1=Tload_up1*16;     %[oz-inch]

alpha_initial=pi/2;
V_step=-12;

sim('simulated_speed_up.mdl');

figure
plot(output_pos.time(1:87),output_pos.signals.values(1:87));
grid on
hold on
title('up-Shift Speed of Response');
ylabel('Position of Shifter_{theta} (degrees)');
xlabel('Time (sec)');
max_up(1:180)=90-14.5;
plot(output_pos.time(1:87),max_up(1:87),'r');
legend('Position of Shifter','Required Angular Displacment');

motor_loadtorque.signals.values=motor_loadtorque.signals.values./16;

figure
plot(motor_loadtorque.time(1:87),motor_loadtorque.signals.values(1:87))
grid on
title('Up-Shift Motor Load Torque');
ylabel('Load Torque (lb-inch)');
xlabel('Time (sec)');
```

```
%%%%%%%%%%%%%% Down-Shift %%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Torque manipulation
Tload_down1=Tload_down(1:180);   %[lb-inch]
Tload_down1=flipud(Tload_down1);    %[lb-inch]
Tload_down1=Tload_down1*16;     %[oz-inch]

alpha_initial=pi/2;
V_step=12;


sim('simulated_speed_down.mdl');

figure
plot(output_pos_down.time(1:87),output_pos_down.signals.values(1:87));
grid on
hold on
title('Down-Shift Speed of Response');
ylabel('Position of Shifter_{theta} (degrees)');
xlabel('Time (sec)');
max_down(1:180)=90+14.5;
plot(output_pos_down.time(1:87),max_down(1:87),'r');
legend('Position of Shifter','Required Angular Displacment','Location','SouthEast');

motor_loadtorque_down.signals.values=motor_loadtorque_down.signals.values./16;

figure
plot(motor_loadtorque_down.time(1:87),motor_loadtorque_down.signals.values(1:87))
grid on
title('Down-Shift Motor Load Torque');
ylabel('Load Torque (lb-inch)');
xlabel('Time (sec)');
```