ASEN 2003

INTRODUCTION TO DYNAMICS AND SYSTEMS

LAB 3

Locomotive Crankshaft Experiment

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Contents

I. Abstract

The locomotive crankshaft apparatus was designed to demonstrate kinematic relationships for linked mechanisms. A model was derived to show the relationship between the rotational motion of the wheel and the translation of the collar as a function of the geometry of the apparatus. The sensors located on the apparatus measured the wheel's position and speed in addition to the slide's position and speed. Utilizing matlab, the collected experimental data and the simulated model were compared graphically and numerically by error analysis. The mean and standard deviation for the difference between the experiment and model velocities is shown in table [1], and concludes our simulated model can accurately describe the experimental data.

II. Model

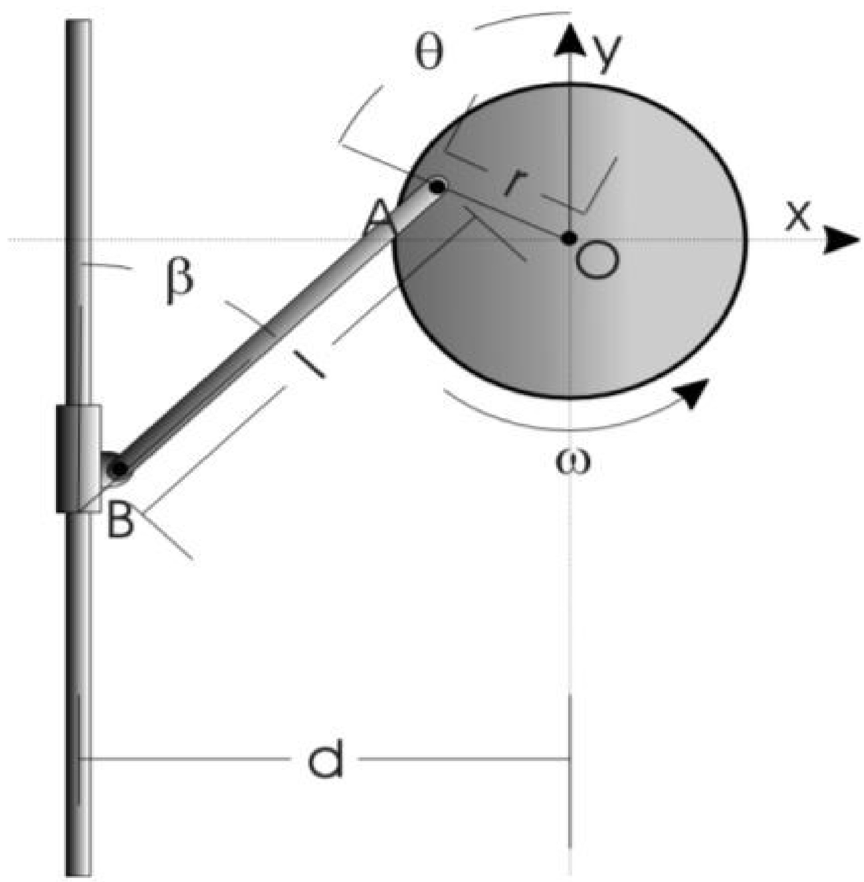

Fig. 1 Model of Locomotive Crankshaft

A few points, angles, and distances were defined before testing. Point A is pinned to a disk that rotates about point O. Point B is pinned to the collar that slides vertically on the shaft. r is defined as the distance between the origin and point A. d is defined as the horizontal distance from the vertical shaft to the center of the disk. l is the length of the bar connecting point A to point B. It is also shown that θ is the angular position of the disk and ω is the angular velocity; both measured counterclockwise. β is the angle from the vertical shaft to the bar connecting points A and B.

A. Derivation of β

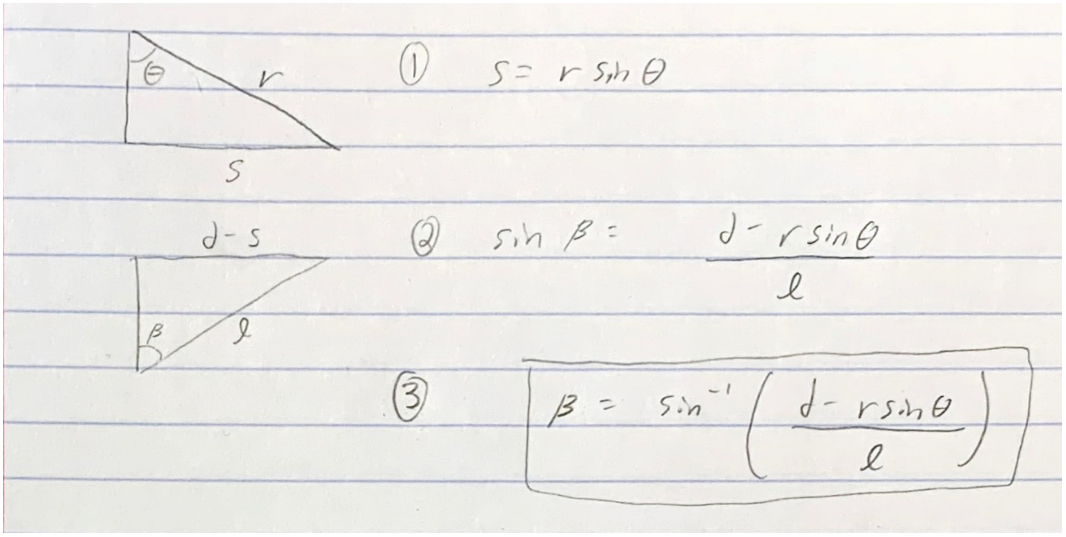

Fig. 2 Derivation of β

The angle β was able to be found utilizing simple trigonometry. Equation 1 in figure 2 finds the horizontal distance from the edge of the disk and the vertical shaft. This solution is used in equation 2, which is then simplified in equation 3 to solve for β.

B. Derivation of Collar Velocity

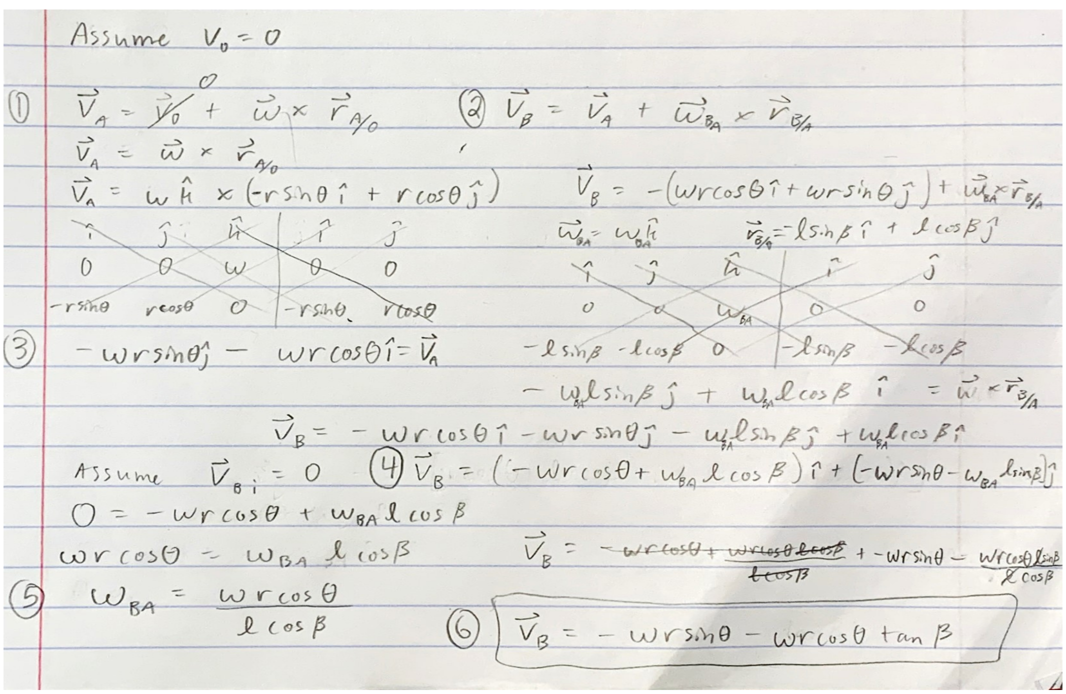

Fig. 3 Derivation of Collar Velocity

Deriving the equation for the collar velocity was a little more complicated than just trigonometry. Starting with equation 1 in figure 3, the velocity of point A from figure 1 is defined. After simplifying the cross product, V_A is redefined in equation 3. This is then substituted into equation 2 where V_B is defined. After simplifying the cross product in equation 2, V_B is redefined in equation 4. Equation 4 is then set to 0 to solve for ω_{BA}, as shown in equation 5, which is then substituted into equation 4 to solve for equation 6.

C. Matlab Model

```
[vMod1] = LCSMODEL(r,d,l,thetaMod,wMod);
```

Fig. 4 Function Call for LCS Model

In figure 4 the function call for LCS Model is shown. The function takes in r, d, l, θ, and ω. Each of these variables are shown in figure 1 and are defined above. The output of this function is the velocity of point B on the collar which slides vertically on the shaft. Point B is also shown above in figure 1.

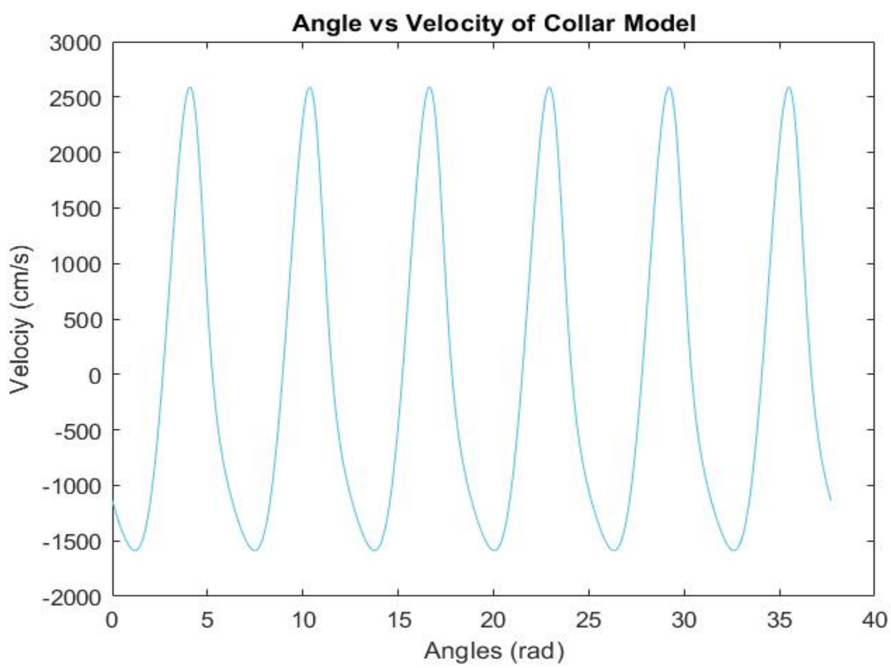

Fig. 5 LCS Model Check

In order to check that the LCS Model function was working, test values were substituted in for the inputs. r was defined as 7.5 cm, d was defined as 15.4 cm, and l was defined as 25.5 cm. These values were chosen after measuring a physical model of figure 1. thetaMod was defined as a vector going through six rotations and wMod was a vector the length of thetaMod but full of the value 200. 200 was chosen for wMod based on the average ω of the provided data files. When the collar moves from the rotating disk it oscillates in the positive and negative direction. Therefore the velocity must also alternate from positive to negative depending on the direction of the collar. This oscillating velocity is shown in figure 5 and therefore the model is working correctly.

III. Results & Analysis

Determining the results for this lab relied on comparing the observed values from the data files to the calculated values from the model. The LCSMODEL.m file found in appendix B determines the velocity of the collar based on input values and the use of Eq. [6]. This was compared to the data retrieved from the given files using ***LCSDATA.m*** also found in appendix B. These experimental values were read in from each test file from the following function call below.

```
[expTheta, expW, expV, time] = LCSDATA(file);
```

Fig. 6 LCS Data Function Call

This data then was modified in LCSDATA.m to start within the range of 0° to 360° and last only for six full revolutions. The experimental values for angle, angular velocity, velocity of the collar, and time were collected in the LCSDATA.m and returned to the main script LCSMAIN.m to compare to our model. Below are all the plots for the velocity of the collar of both the model and experimental values and the error between the two velocities over the time of the test. With increasing the voltage of each experiment, both the velocity of the collar and the error increase.

A. 5.5 Volts

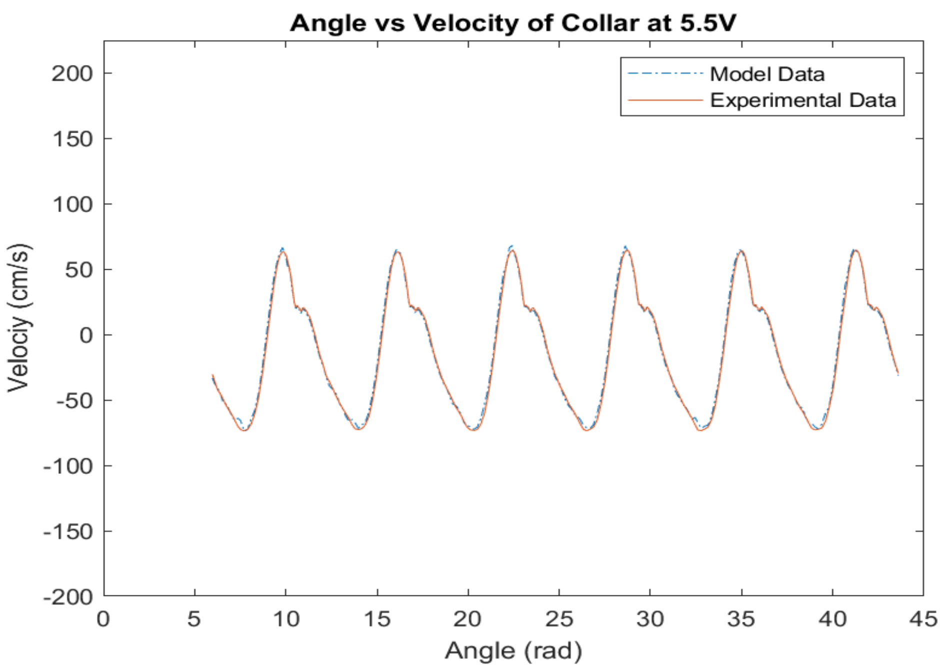

Fig. 7 Angle vs Collar Velocity at 5.5 Volts

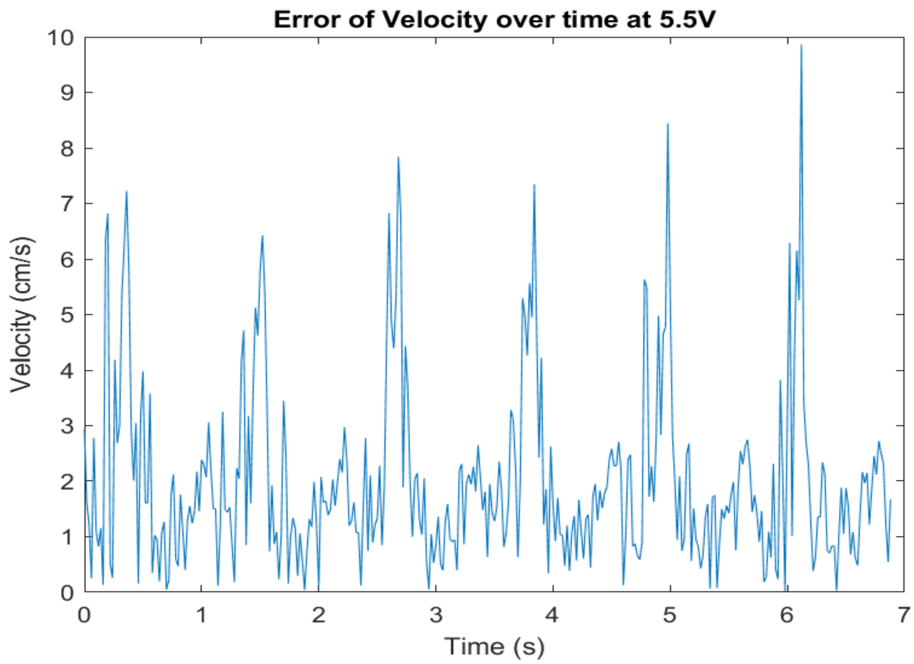

Fig. 8 Error of Collar Velocity at 5.5 Volts

B. 6.5 Volts

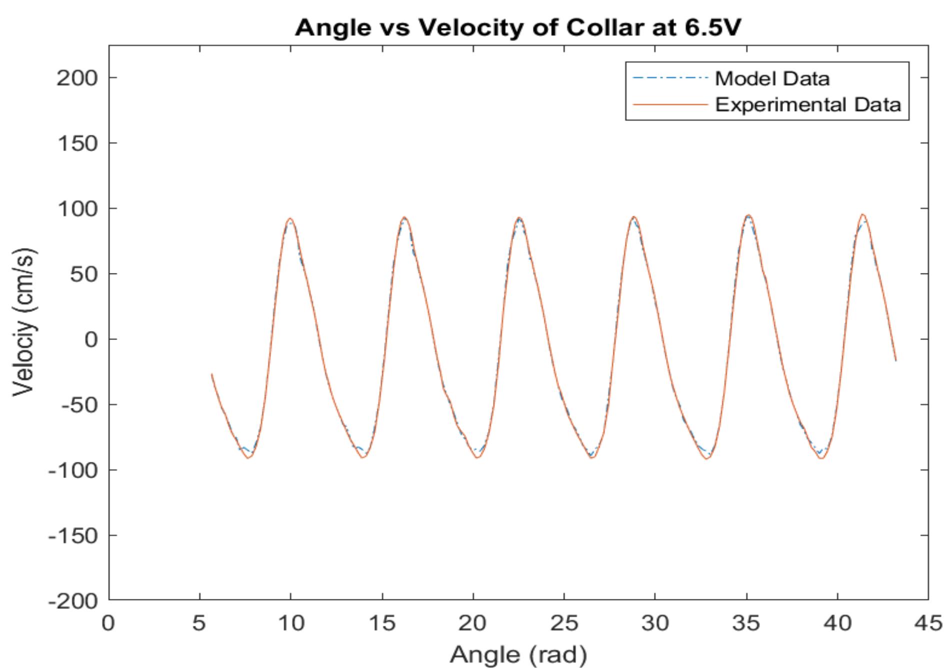

Fig. 9 Angle vs Collar Velocity at 6.5 Volts

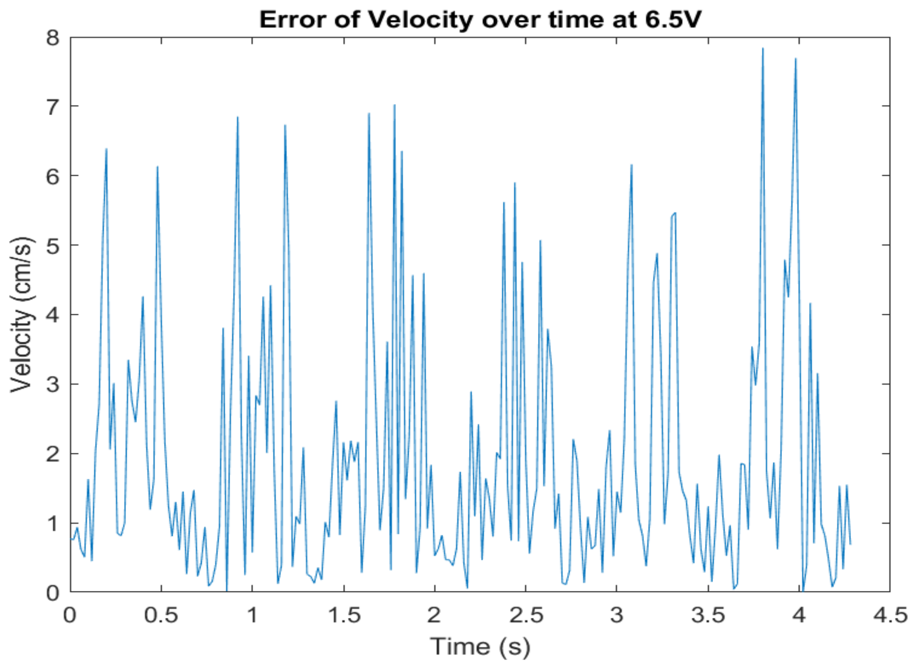

Fig. 10 Error of Collar Velocity at 6.5 Volts

C. 7.5 Volts

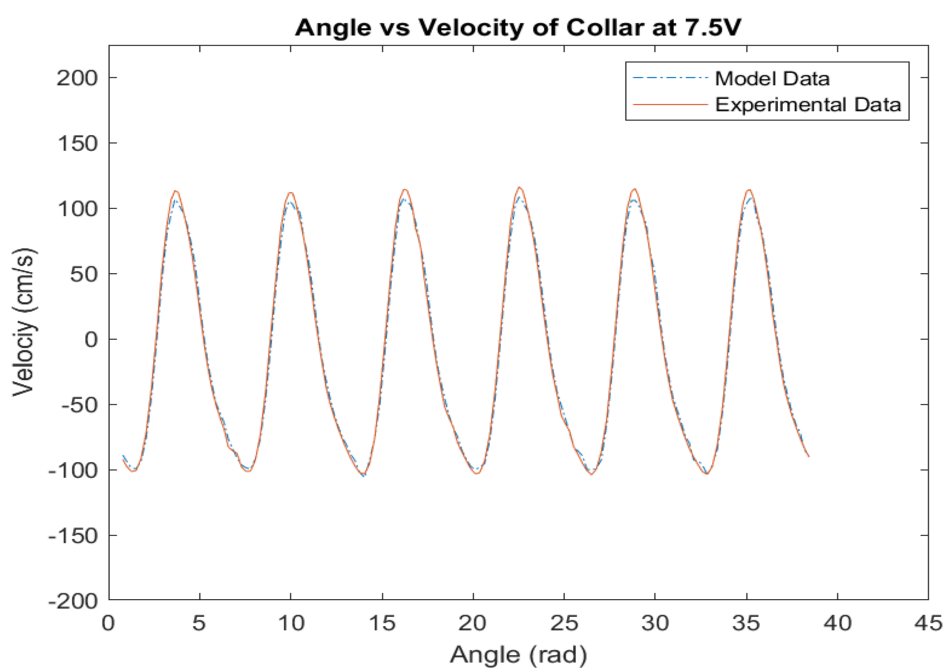

Fig. 11 Angle vs Collar Velocity at 7.5 Volts

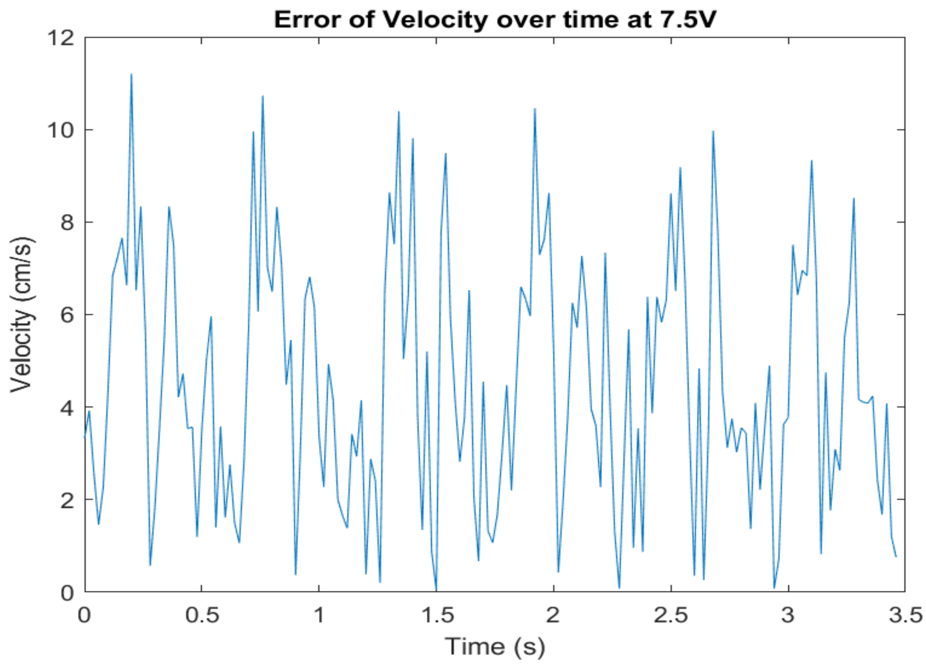

Fig. 12 Error of Collar Velocity at 7.5 Volts

D. 8.5 Volts

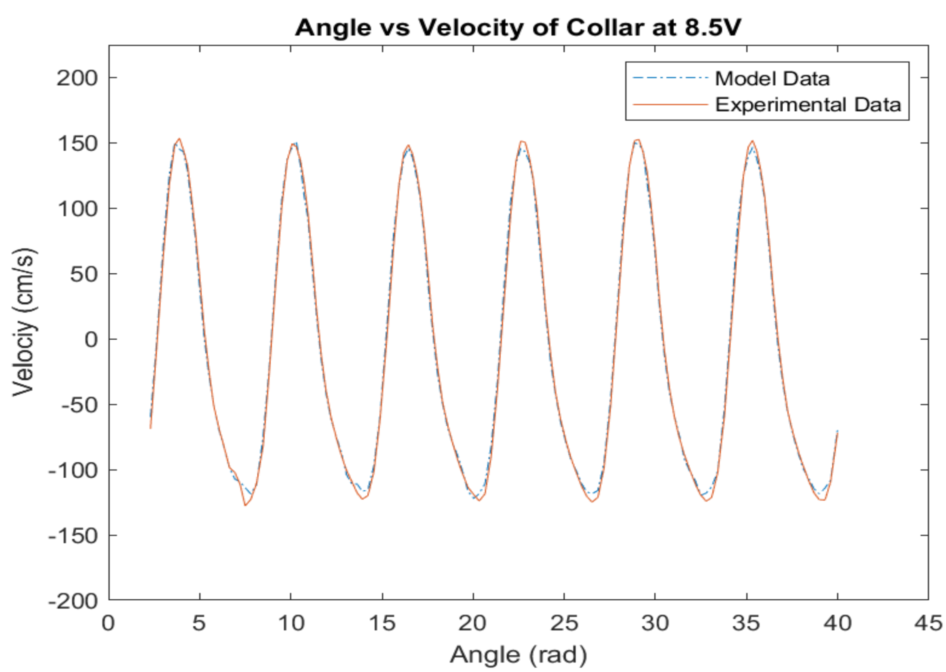

Fig. 13 Angle vs Collar Velocity at 8.5 Volts

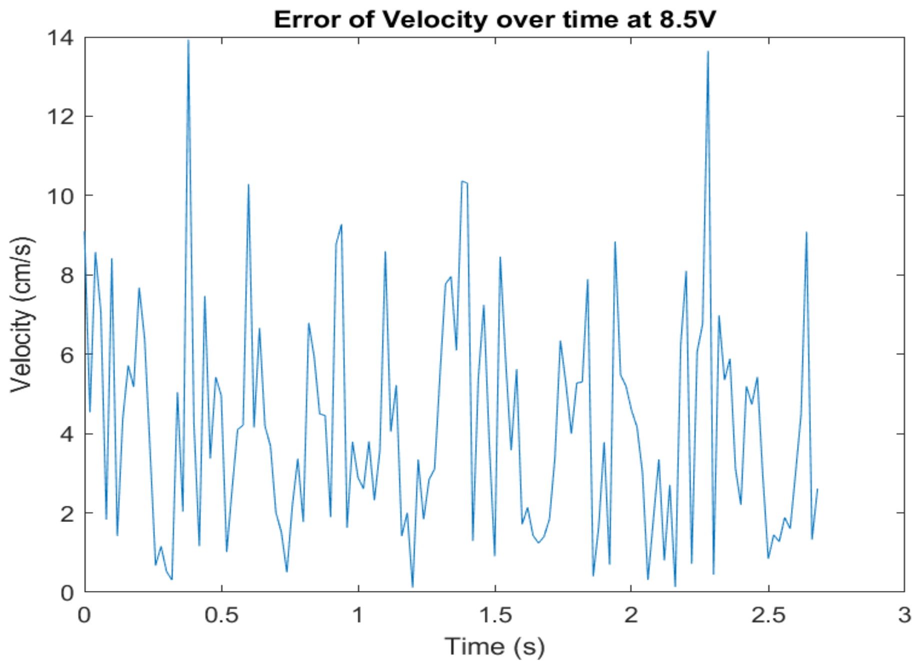

Fig. 14 Error of Collar Velocity at 8.5 Volts

E. 9.5 Volts

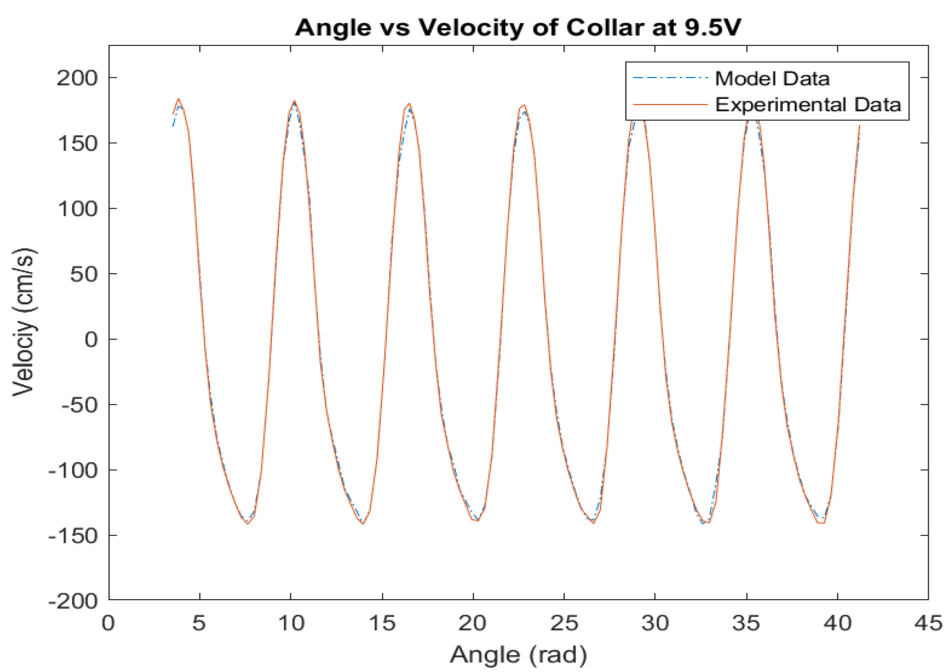

Fig. 15 Angle vs Collar Velocity at 9.5 Volts

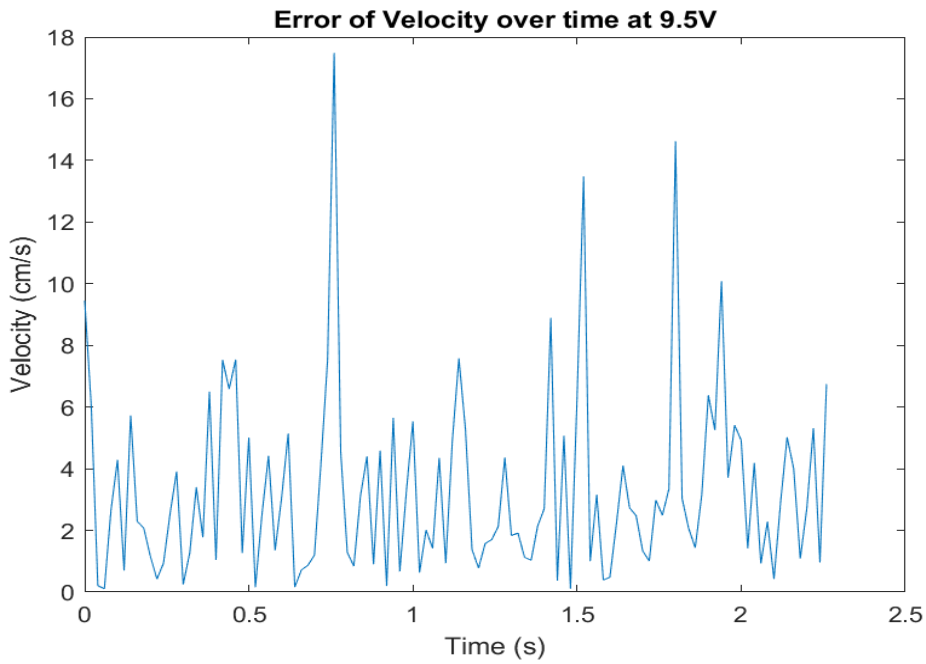

Fig. 16 Error of Collar Velocity at 9.5 Volts

F. 10.5 Volts

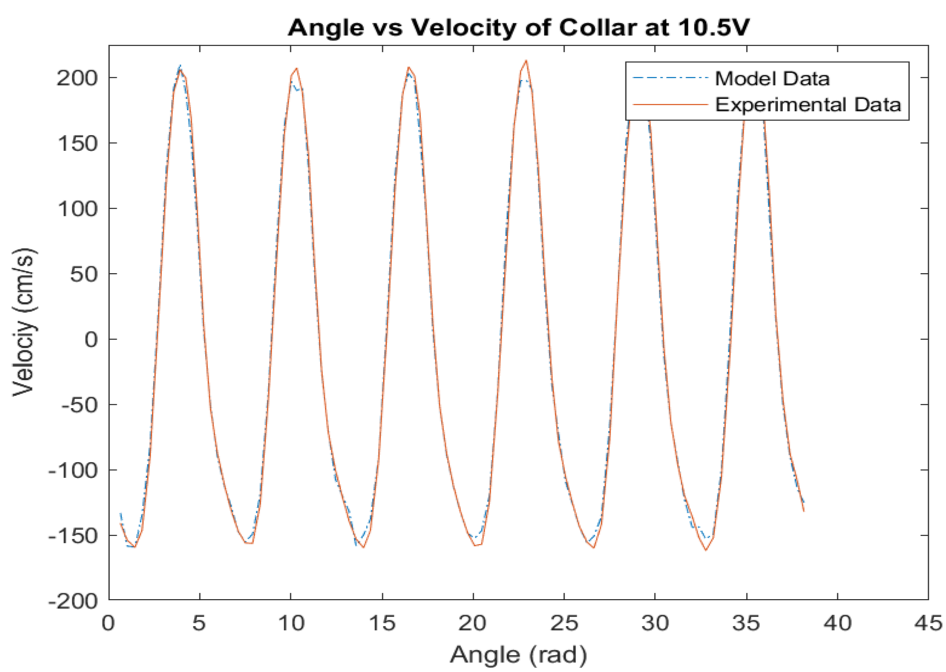

Fig. 17 Angle vs Collar Velocity at 10.5 Volts

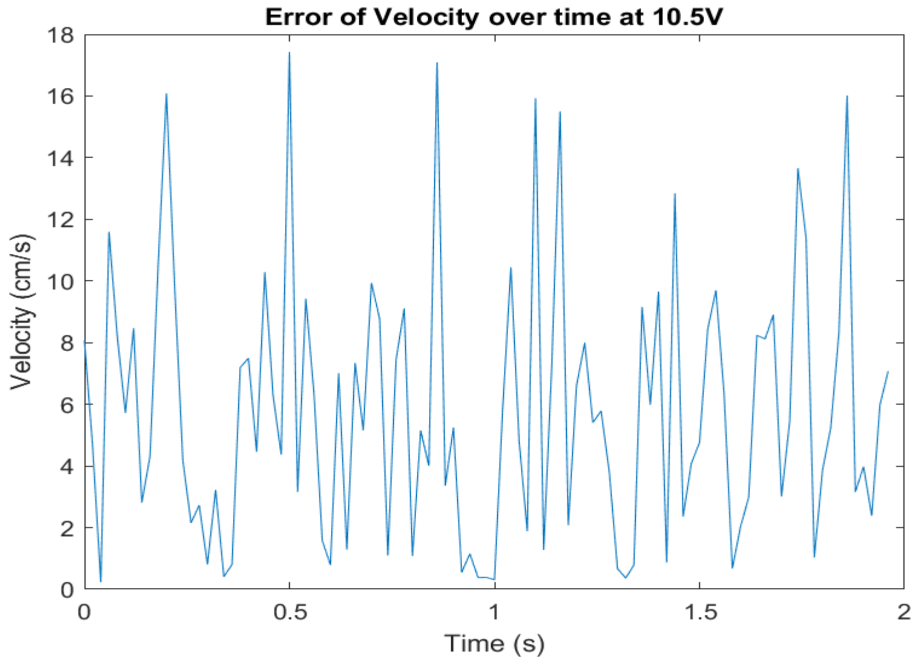

Fig. 18 Error of Collar Velocity at 10.5 Volts

Volts	Mean (cm/s)	Standard Deviation (cm/s)
5.5 V	2.06	1.71
6.5 V	1.86	1.73
7.5 V	4.54	2.71
8.5 V	4.32	2.96
9.5 V	3.84	3.01
10.5 V	5.68	1.71

Table 1 Mean and Standard Deviations of Test Error

G. Error

The model matched the experimental results well but there is some deviation between the two lines at peaks and valleys. To quantify this difference, the error between the experimental data and model was calculated in the ***LCSMAIN.m*** matlab script. This was completed by first taking the absolute difference between the experimental and modeled velocities. The absolute difference in velocities is shown against the angular position of the disk in figures [8,10,12,14,16,18]. The mean and standard deviation for each voltage were also calculated for the difference in velocities using the built in matlab functions ***std*** and ***mean***. The main sources of this error could be either from misalignment and calibration of the machine or more prominently from the variable angular velocity readings. The motor in the crank-shaft may not have been able to account quick enough for the torque loading on the bar throughout the experiment. As the most error is found at the peaks of the velocity graphs, this would probably have to do with the motor in the LCS.

IV. Conclusion & Recommendations

For this lab, a model was derived to show the relationship between the rotational motion of the wheel and the translation of the collar in a locomotive crankshaft system. When compared to experimental data collected from a real crankshaft system, the results from the model matched the experimental results decently. Minor differences were noticed and can be attributed to improper measurements, misalignment of machine parts, improper calibration for sensors, and forces including friction or gravity not included in the model. Due to these noticeable differences, the error between the modeled and experimental velocities are numerically shown for each voltage in table [1]. The experiments that were performed best were both the 5.5 and 10.5 voltage tests. This is because they had the lowest values of standard deviation of 1.71 cm/s. The worst test performed was the 8.5 voltage test as it had the highest value of standard deviation of 2.96 cm/s. Some improvements that can be made to this experiment would be to run more trials at different velocities or to set the position of the slide to zero for all trials. Both improvements would help determine the accuracy of the created model.

V. References & Acknowledgements

A. Acknowledgements
We would like to thank Josh Mellin and Bobby Hodgkinson for assistance in this project and for their advice given.

B. References
Hodgkinson, R., "ASEN 2003 Lab 3: Locomotive Crank" Feb. 13, 2020.

Bedford, A., Fowler, W., *Engineering Mechanics Dynamics*, 5th ed., Pearson, 2008.

VI. Appendix

A. Contributions

Name	Plan	Model	Results	Report	Code
Daniel Mathews	1	1	1	1	2
Devin Geegan	2	2	1	1	0
Connor O'Reilly	2	1	1	1	0

B. MATLAB Code
LCSMAIN.m

```
%%%%%%%%%%% Dynamics Lab 3 %%%%%%%%%%%
%
% Authors: Daniel Mathews
%          Devin Geegan
%          Connor O'Reilly
%
% Date: 2/20/2020
%
%% Read in data
close all
clear
clc

files = dir('Test1_*'); % reads in files from directory containing "Test1_"
%% Constants
r = 7.5; % cm
d = 15.4; % cm
l = 25.5; % cm
volts = [10.5 5.5 6.5 7.5 8.5 9.5]; % voltages from data
thetaMod = linspace(0,6*2*pi,1000)'; % creates vector of 6 revolutions for test case

%% Model Testing
wMod = 4*ones(length(thetaMod)); % model omega
[vMod1] = LCSMODEL(r,d,l,thetaMod,wMod); % Function call for model

```

```
%Plots the test case for our model
figure(20)
plot(thetaMod,vMod1)
title('Angle vs Velocity of Collar Model')
xlabel('Angles (rad)')
ylabel('Velociy (cm/s)')

%% This is something
for i = 1:length(files)
    file = readtable(files(i).name); % Reads in a single file from all files

    [expTheta, expW, expV, time] = LCSDATA(file); % calls LCSDATA to retrieve data

    [vMod] = LCSMODEL(r,d,l,expTheta,expW); % Calls model to calculate velocity

    % Error stuff
    error = abs(expV - vMod);
    mean1(i) = mean(error);
    std1(i) = std(error);

    %Plots velocity of collar of both model and experiment
    figure(i)
    plot(expTheta,vMod,'-.',expTheta,expV)
    title(['Angle vs Velocity of Collar at ',num2str(volts(i)),'V'])
    xlabel('Angle (rad)')
    ylabel('Velociy (cm/s)')
    xlim([0 45])
    ylim([-200 225])
    legend('Model Data','Experimental Data')

    % Plots error in velocty over time
    figure(length(files) + i)
    plot(time, error)
    title(['Error of Velocity over time at ',num2str(volts(i)),'V'])
    xlabel('Time (s)')
    ylabel('Velocity (cm/s)')
end
```

LCSMODEL.m

```
%% MODEL
%
% Model for calculating velocity of the collar
%
function [vMod] = LCSMODEL(r,d,l,theta,w)
    beta = asin((d-r*sin(theta))/l);
    vMod = -w.*r.*sin(theta) - w.*r.*cos(theta).*tan(beta);
end
```

LCSDATA.m

```
%% DATA
%
% Reads in data from files
function [expTheta, expW, expV, time] = LCSDATA(file)
    expTheta = file.Var2(:) * pi/180; % gets theta values from file (rad)
    expW = file.Var4(:) * pi/180; % gets omega values from file (rad/s)
    expV = file.Var5(:) * 10^-1; % gets velocity values from file (cm/s)
    time = file.Var1(:); % gets time values from table (s)

    while expTheta(1) > 2*pi % Reduces the angle to within 0-360 degrees
        expTheta = expTheta - 2*pi;
    end

    arr = expTheta <= expTheta(1) + 6*2*pi; % creates logical array for the first 6 revs

    % reduces arrays to only 6 revolutions
    expTheta(arr == 0) = [];
    expW(arr == 0) = [];
```

```
    expV(arr == 0) = [];
    time(arr == 0) = [];
end
```