ASEN 2003 Lab 3 - Locomotive Crankshaft Report

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Contents

The objectives of the locomotive crankshaft lab were to analyze the system's general planar motion, and from the system's kinematic description create a model of the crankshaft. Once modeled, the discrepancies between the physical system and the modeled system were investigated, and the experimental results were assessed. The locomotive crankshaft model created for this lab demonstrated kinematic relationships for linked mechanisms, which show that at 5.5 volts the maximum magnitude of the linear velocity of the collar was 71 cm/s. At that speed the standard deviation for the misfit was 3.30 cm/s. At 10.5 volts the magnitude of the linear velocity of the collar was 220 cm/s with a standard deviation for the misfit of 9.67 cm/s. This trend over time showed that our model was more accurate at lower voltages due to additional forces on the collar which our model did not account for.

I. Nomenclature

β	=	angle between
θ	=	angular position of the disk
l	=	length of the connecting bar
d	=	distance between shaft and origin of the disk
ω	=	angular velocity of the disk
r	=	distance between the origin of the disk and the bar attachment point

II. Model

Derivation of angle β

Given the set up as shown in fig 1 we can say the distance from the bar to point A on the disk is

$$a = d - r\sin(\theta) \tag{1}$$

Then from looking at how the angle relates to the two lengths we can determine the following

$$\beta = \arcsin(\frac{a}{l}) \tag{2}$$

Which when rewritten in terms of our givens we get

$$\beta = \arcsin(\frac{d - r\sin(\theta)}{l}) \tag{3}$$

Derivation of velocity vector

Given that we know the following equation

$$V_B = V_A + \omega \times r_{B/A} \tag{4}$$

$$V_B = \omega_{wheel} \times r + \omega_{bar} \times l \tag{5}$$

$$V_B = -\omega_{wheel} r\cos(\theta)\hat{\imath} - \omega_{wheel} r\sin(\theta)\hat{\jmath} + \omega_{bar} \times l \tag{6}$$

$$V_{bar} = \omega_{bar} l\cos(\beta)\hat{\imath} - \omega_{bar} l\sin(\beta)\hat{\jmath} \tag{7}$$

[H] Then setting these two equations equal we can go through and see that the terms will have to cancel thus setting the two terms equal we can solve for ω_{bar}.

$$[H]\omega_{bar} = \frac{\omega_{wheel} r\cos(\theta)}{l\cos(\beta)} \tag{8}$$

Then plugging that back into the equation for V$_{B} weget$

$$[H]V_B = -\omega_{wheel} r \sin(\theta) - \omega_{wheel} r \tan(\beta) \tag{9}$$

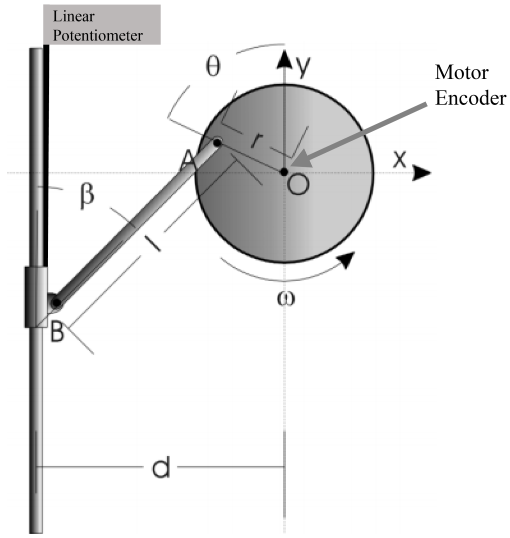

Fig. 1 Lab setup indicating the different terms

The MATLAB function call that use these equations can be seen in Appendix A on page 10. We decided to use the 5.5 volt and 10.5 volt experiments to confirm the correct operation of our function. The following plots were used to visually inspect the accuracy of the our of model. As seen in these figures and as mentioned the lower voltage model was more accurate than the higher voltage.

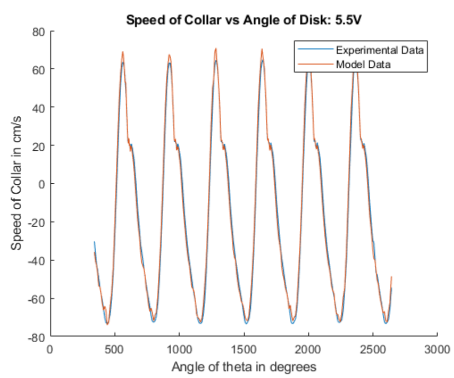

Fig. 2 5.5 Volt experiment vs model

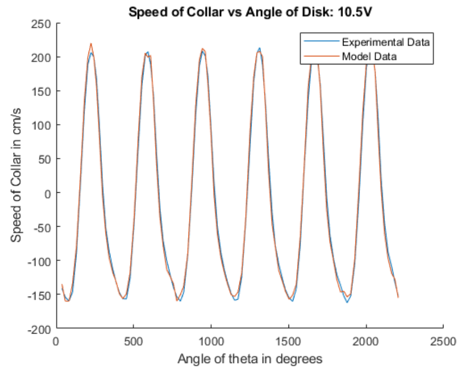

Fig. 3 10.5 Volt experiment vs model

For all of the experiments versus model plots and an analysis of those plots see Appendix B and the Results and Analysis section respectively.

III. Results and Analysis

The model was relativity accurate compared to the experimental results; as the voltage increased, the model became less accurate. One source of error was the accuracy of the measurement, having an uncertainty of 0.0005; this is extremely small when compared to other sources of error. Another would be friction and misalignment; however, a well-designed system would minimize these errors; well-oiled components, tight connection points, and an inspection before each experiment. The most likely source of error would be the weight of the system's components, as the model was done in ideal conditions that did not account for the weight of any components. As the voltage increases, the error also increases, resulting in a larger error for faster velocities. The bar's weight would cause the wheel to begin to accelerate during the downwards portion of the cycle when the force due to gravity would be acting in line with the bar's direction of movement. This would decelerate the wheel during the upwards portion of the cycle when gravity acted against the direction of movement. This trend can be seen in the lab videos where the wheel has an uneven angular velocity following this explanation.

The results for all of the experiments are shown below in Appendix B on separate graphs. These graphs compare the experimental and model data for each voltage input.

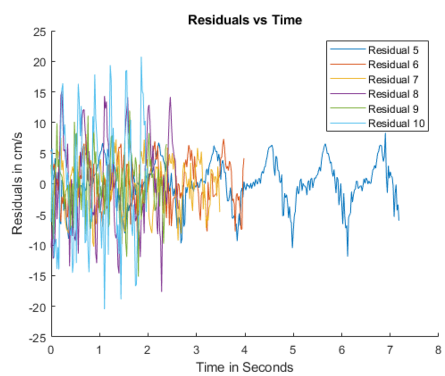

Fig. 4 Residuals vs Time: All Experiments

The MATLAB function call LCSDATA is shown below on page 10 of Appendix A. This function was used to output the measured angle, angular rate, time for the first six disk revolutions, and the vertical velocity.

Voltage	Mean	Standard Deviation
5.5V	-0.01	3.63
6.5V	-0.06	3.56
7.5V	-0.02	4.00
8.5V	0.06	7.50
9.5V	-0.05	4.90
10.5V	-0.02	10.0

Table 1 The mean and standard deviation of each experiment (with outliers)

Voltage	Mean	Standard Deviation
5.5V	0.24	3.30
6.5V	0.10	3.33
7.5V	0.21	3.83
8.5V	0.08	7.28
9.5V	-0.20	4.23
10.5V	-0.03	9.67

Table 2 The mean and standard deviation of each experiment (outliers removed)

IV. Conclusion and Recommendations

From the lab we were able to create a fairly accurate model for how to determine the linear velocity of the collar. Through this we learned how to relate angular velocity of one rigid body to the linear velocity of another rigid body. We did not perform any in person experiments due to COVID restrictions however the model which we created for the experiment was generally the most accurate at a lower voltage. As the voltage increased and subsequently the angular velocity increased the model became considerably less accurate. We also realized both when comparing the plots and when analyzing the video that our model will not account for the weight of the bar which will change the speed of the collar as well. As a result we would suggest that for future models an additional component be added, to take into account weight of the bar and how that affects the linear velocity of the collar.

V. Acknowledgements

Assistance from multiple TAs and instructors was received during lab hours, who helped derive and verified the equation for the velocity of the collar. These included Bobby Hodgkinson and Jeffery Hadley.

VI. References

[1] Hodgkinson, R, "*ASEN 2003: LOCOMOTIVE CRANKSHAFT EXPERIMENT*". 2021.
[2] Hodgkinson, R, "*Locomotive Data 2020*". 2021.
[3] Hodgkinson, R, "*Locomotive Crankshaft*". 2021.
[4] Hodgkinson, R, "*Dimensions*". 2021.
[5] Ann and H.J. Smead AES Laboratory and Shops Videos, "*Locomotive Crank 6.5V*". Feb, 2021.
[6] Ann and H.J. Smead AES Laboratory and Shops Videos, "*Locomotive Crank 7.5V*". Feb, 2021.
[7] Ann and H.J. Smead AES Laboratory and Shops Videos, "*Locomotive Crank 8.5V*". Feb, 2021.
[8] Ann and H.J. Smead AES Laboratory and Shops Videos, "*Locomotive Crank 9.5V*". Feb, 2021.
[9] Ann and H.J. Smead AES Laboratory and Shops Videos, "*Locomotive Crank 10.5V*". Feb, 2021.

VII. Appendix A

Matlab Code

```
%% LAB 3 LOCOMOTIVE CRANK SHAFT
% Flynn HIll
% Linus Schmitz
% Andrew Logue
% Benjamin Bauman

%% House Keeping

clear all;
clear;
clc;

%% Variables

r = 7.5; %distance between the origin (rotation axis)and the attachment point
    A
d = 15.5; %horizontal distance between the vertical shaft and the center of
    the disk
l = 25; %length of the connecting bar from A to B

uncertanty = 0.0005; % +/- '

%% Loading in Data

Test_5 = 'Test1_5pt5V';
Test_6 = 'Test1_6pt5V';
Test_7 = 'Test1_7pt5V';
Test_8 = 'Test1_8pt5V';
Test_9 = 'Test1_9pt5V';
Test_10 = 'Test1_10pt5V';

%% Functions Calls

[theta_exp_5, w_exp_5, v_exp_5, time_5] = LCSDATA(Test_5);
[theta_exp_6, w_exp_6, v_exp_6, time_6] = LCSDATA(Test_6);
[theta_exp_7, w_exp_7, v_exp_7, time_7] = LCSDATA(Test_7);
[theta_exp_8, w_exp_8, v_exp_8, time_8] = LCSDATA(Test_8);
[theta_exp_9, w_exp_9, v_exp_9, time_9] = LCSDATA(Test_9);
[theta_exp_10, w_exp_10, v_exp_10, time_10] = LCSDATA(Test_10);

v_model_5 = LCSMODEL(r, d, l, theta_exp_5, w_exp_5);
v_model_6 = LCSMODEL(r, d, l, theta_exp_6, w_exp_6);
v_model_7 = LCSMODEL(r, d, l, theta_exp_7, w_exp_7);
v_model_8 = LCSMODEL(r, d, l, theta_exp_8, w_exp_8);
v_model_9 = LCSMODEL(r, d, l, theta_exp_9, w_exp_9);
v_model_10 = LCSMODEL(r, d, l, theta_exp_10, w_exp_10);

%% Calculations

misfit_5 = v_exp_5(1:360) - v_model_5(1:360);
```

```
misfit_6 = v_exp_6(1:200) - v_model_6(1:200);
misfit_7 = v_exp_7(1:175) - v_model_7(1:175);
misfit_8 = v_exp_8(1:132) - v_model_8(1:132);
misfit_9 = v_exp_9(1:120) - v_model_9(1:120);
misfit_10 = v_exp_10(1:100) - v_model_10(1:100);

mean_5 = mean(misfit_5);
mean_6 = mean(misfit_6);
mean_7 = mean(misfit_7);
mean_8 = mean(misfit_8);
mean_9 = mean(misfit_9);
mean_10 = mean(misfit_10);

std_5 = std(misfit_5);
std_6 = std(misfit_6);
std_7 = std(misfit_7);
std_8 = std(misfit_8);
std_9 = std(misfit_9);
std_10 = std(misfit_10);

track = 1;
nMisfit_5 = 0;
for i=1:360
    if (misfit_5(i) <= (mean_5 + 2*std_5) && misfit_5(i) >= (mean_5 - 2*std_5))
        nMisfit_5(track) = misfit_5(i);
        track = track + 1;
    end
end

track = 1;
nMisfit_6 = 0;
for i=1:200
    if (misfit_6(i) <= (mean_6 + 2*std_6) && misfit_6(i) >= (mean_6 - 2*std_6))
        nMisfit_6(track) = misfit_6(i);
        track = track + 1;
    end
end

track = 1;
nMisfit_7 = 0;
for i=1:175
    if (misfit_7(i) <= (mean_7 + 2*std_7) && misfit_7(i) >= (mean_7 - 2*std_7))
        nMisfit_7(track) = misfit_7(i);
        track = track + 1;
    end
end

track = 1;
nMisfit_8 = 0;
for i=1:132
    if (misfit_8(i) <= (mean_8 + 2*std_8) && misfit_8(i) >= (mean_8 - 2*std_8)
```

```
        )
        nMisfit_8(track) = misfit_8(i);
        track = track + 1;
    end
end

track = 1;
nMisfit_9 = 0;
for i=1:120
    if (misfit_9(i) <= (mean_9 + 2*std_9) && misfit_9(i) >= (mean_9 - 2*std_9)
        )
        nMisfit_9(track) = misfit_9(i);
        track = track + 1;
    end
end

track = 1;
nMisfit_10 = 0;
for i=1:100
    if (misfit_10(i) <= (mean_10 + 2*std_10) && misfit_10(i) >= (mean_10 - 2*
        std_10))
        nMisfit_10(track) = misfit_10(i);
        track = track + 1;
    end
end

mean_5 = mean(nMisfit_5);
mean_6 = mean(nMisfit_6);
mean_7 = mean(nMisfit_7);
mean_8 = mean(nMisfit_8);
mean_9 = mean(nMisfit_9);
mean_10 = mean(nMisfit_10);

std_5 = std(nMisfit_5);
std_6 = std(nMisfit_6);
std_7 = std(nMisfit_7);
std_8 = std(nMisfit_8);
std_9 = std(nMisfit_9);
std_10 = std(nMisfit_10);

m = max(v_model_5)
m_10 = max(v_model_10)
%% Plots

figure(1)
hold on
plot(theta_exp_5(1:360), v_exp_5(1:360))
plot(theta_exp_5(1:360), v_model_5(1:360))

xlabel('Angle of theta in degrees')
ylabel('Speed of Collar in cm/s')
title('Speed of Collar vs Angle of Disk: 5.5V')

legend('Experimental Data','Model Data')
```

```
hold off

figure(2)
hold on
plot(theta_exp_6(1:200), v_exp_6(1:200))
plot(theta_exp_6(1:200), v_model_6(1:200))

xlabel('Angle of theta in degrees')
ylabel('Speed of Collar in cm/s')
title('Speed of Collar vs Angle of Disk: 6.5V')
legend('Experimental Data', 'Model Data')
hold off

figure(3)
hold on
plot(theta_exp_7(1:175), v_exp_7(1:175))
plot(theta_exp_7(1:175), v_model_7(1:175))

xlabel('Angle of theta in degrees')
ylabel('Speed of Collar in cm/s')
title('Speed of Collar vs Angle of Disk: 7.5V')
legend('Experimental Data', 'Model Data')
hold off

figure(4)
hold on
plot(theta_exp_8(1:132), v_exp_8(1:132))
plot(theta_exp_8(1:132), v_model_8(1:132))

xlabel('Angle of theta in degrees')
ylabel('Speed of Collar in cm/s')
title('Speed of Collar vs Angle of Disk: 8.5V')
legend('Experimental Data', 'Model Data')
hold off


figure(5)
hold on
plot(theta_exp_9(1:120), v_exp_9(1:120))
plot(theta_exp_9(1:120), v_model_9(1:120))

xlabel('Angle of theta in degrees')
ylabel('Speed of Collar in cm/s')
title('Speed of Collar vs Angle of Disk: 9.5V')
legend('Experimental Data', 'Model Data')
hold off


figure(6)
hold on
plot(theta_exp_10(1:100), v_exp_10(1:100))
plot(theta_exp_10(1:100), v_model_10(1:100))

xlabel('Angle of theta in degrees')
```

```
ylabel('Speed of Collar in cm/s')
title('Speed of Collar vs Angle of Disk: 10.5V')
legend('Experimental Data', 'Model Data')
hold off

figure(7)
hold on
plot(time_5(1:360),misfit_5)
plot(time_6(1:200),misfit_6)
plot(time_7(1:175),misfit_7)
plot(time_8(1:132),misfit_8)
plot(time_9(1:120),misfit_9)
plot(time_10(1:100),misfit_10)

xlabel('Time in Seconds');
ylabel('Residuals in cm/s');

title('Residuals vs Time');

legend('Residual 5','Residual 6','Residual 7','Residual 8','Residual 9','
    Residual 10')

hold off

figure(8)
hold on
voltage = [5.5,6.5,7.5,8.5,9.5,10.5];
std = [3.6370,3.5625,4.0661,7.5018,4.9038,10.0126];
plot(voltage,std,'o');
lsline

hold off
%% Functions

function [theta_exp, w_exp, v_exp, time] = LCSDATA(filename)

    data = load(filename);

    time = data(:,1);

    v_exp = data(:,5);
    v_exp = v_exp/10;

    w_exp = data(:,4);

    theta_exp = data(:,2);
    theta_exp = theta_exp/360;

    theta_exp = theta_exp - fix(theta_exp(1));

    theta_exp = theta_exp*360;
end

function Vb = LCSMODEL(r, d, l, theta, w)
```

```
    beta = asind((d - r.* sind(theta))./l);

    Vb = -r .* w.*(pi/180) .* sind(theta) - r .* w.*(pi/180) .* cosd(theta) .*
        tand (beta);

end
```

VIII. Appendix B

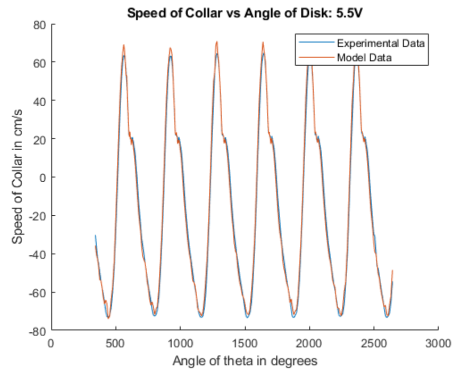

Fig. 5 Speed of Collar vs Angle of Disk for the first six cycles: 5.5V Experiment

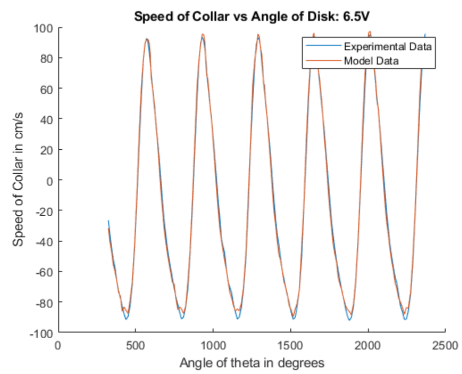

Fig. 6 Speed of Collar vs Angle of Disk for the first six cycles: 6.5V Experiment

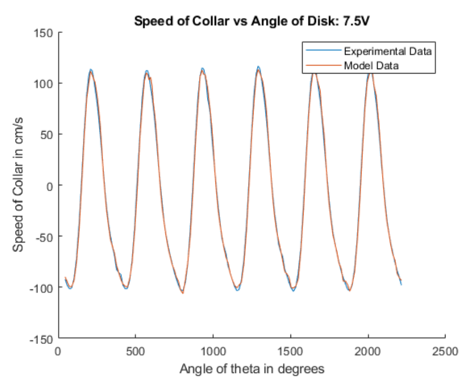

Fig. 7 Speed of Collar vs Angle of Disk for the first six cycles: 7.5V Experiment

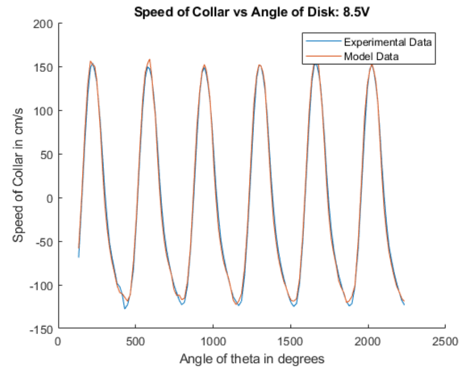

Fig. 8 Speed of Collar vs Angle of Disk for the first six cycles: 8.5V Experiment

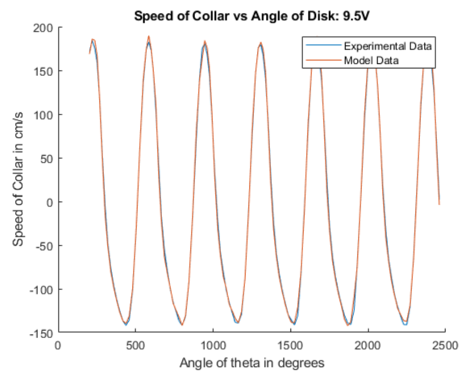

Fig. 9 Speed of Collar vs Angle of Disk for the first six cycles: 9.5V Experiment

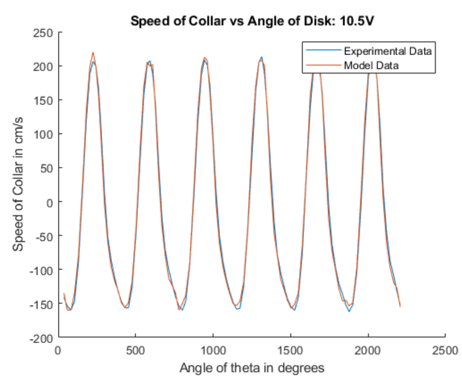

Fig. 10 Speed of Collar vs Angle of Disk for the first six cycles: 10.5V Experiment