NC STATE UNIVERSITY

College of Engineering

Department of Mechanical and Aerospace Engineering

MAE-305, Section 205

Mechanical Engineering Laboratory I – Instrumentation & Solid Mechanics Laboratory

Experiment #7

Velocity and Acceleration Measurement

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Abstract

[Primary Contributor: David Delgado]

The objective of this experiment was to become familiar with three different methods for obtaining angular velocity measurements of a rotating flywheel. In addition to learning how to use different velocity measurement tools (i.e., encoder, tachometer and stroboscope), the accuracy and precision of each tool was investigated. From the three devices, the stroboscope was found to be the most precise due to it having the lowest maximum standard deviation in its speed (12.865 RPM). The standard deviations at all voltages for each individual method can be seen in Table 4.1. Meanwhile, the tachometer was the most accurate tool as it had the lowest average percent error (~0.940%) for all its acquired measurements. Furthermore, contrary to initial speculations, the encoder was found to have the least accurate and second most precise measurement capabilities (see Table 4.1 and 5.1).

1. Introduction

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The purpose of this experiment was to measure the velocity and acceleration of moving objects, and compare the accuracy and precision of different velocity measurement methods. Additionally, the lab promoted experience with LabVIEW software and myRIO hardware for data acquisition purposes while experimentally demonstrating kinematic and kinetic principles of dynamic systems. In summary, the tasks associated with this lab included:

1. Comparing three methods for measuring the speed of a rotating shaft: a) using an encoder, b) using a tachometer, and c) using a stroboscope.
2. Summarizing the experimental methods, results, and comparing the accuracy of velocity measurements in a formal report.

This particular experiment built off the knowledge gained during lab 2 where LabVIEW and myRIO were used to acquire radial measurements of a pipe spool, as well as the knowledge gained in previous dynamics courses regarding velocity and acceleration.

2. Experimental Methods

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In this experiment the speed of the experimental motor was measured using an encoder, a handheld tachometer and a stroboscope. Firstly, the necessary equipment was gathered.

Equipment needed (see Figure 2.1):

- Solderless breadboard (JE25 Jameco)
- Jumper wires
- Power supply
- NI myRIO (30CA637)
- Tachometer (Monarch PT99)
- Stroboscope (Nova-Strobe 2503470)
- Reflective tape
- Phillips head screwdriver
- Allen key
- CPU
- USB

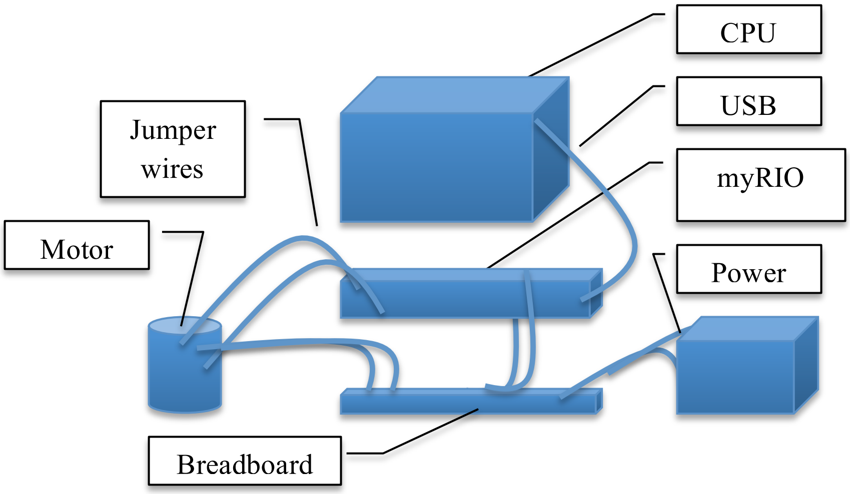

Figure 2.1. Experimental setup for measuring motor speed via encoder per the lab handout. (Credits: NC State Mechanical Engineering Laboratory I Handout).

Then, a piece of reflective tape was placed on the end of the plant flywheel to ensure the tachometer could measure the rotational speed of the motor. The motor was mounted to the base and secured per the lab handout.

Measuring velocity via the encoder relied upon the careful wiring of the motor, breadboard, power supply and myRIO. The wiring directions were indicated in the lab handout. The Encoder VI was opened on the computer and once it was ensured that it was functioning, velocity data was collected at six (6) varying voltages supplied to the motor. The nominal speed of the flywheel was recorded for the same voltages as the encoder using the handheld tachometer and stroboscope. These tools were handled per the lab handout to ensure safe and reliable operation.

Lastly, using the data from all three velocity-measurement methods a table was made to compare results.

3. Experimental Data

[Primary Contributor: David Delgado]

The tachometer and stroboscope provided speeds that were directly inputted into Table 3.1. On the other hand, the speed recorded for the encoder represents an average of the values outputted by the VI:

$$x = \frac{x_1 + x_2 + \cdots + x_n}{n} \tag{1}$$

In this equation, ‘x’ represents the average speed of the flywheel that is recorded in Table 3.1 for different voltages, ‘n’ represents the total number of pulses read from the encoder, and ‘x_i’ represents the speed read by the encoder at different positions. This average value of speed is valid for the encoder due to the fact that the flywheel is not accelerating tangentially (only centripetal acceleration is present). Thus, the average of the derivate of the displacement function at different positions along the flywheel produces a relatively consistent and precise velocity measurement.

Table 3.1. Speeds of Flywheel by Measurement Method

Voltage (V)	Tachometer (RPM)	Stroboscope (RPM)	myRIO (RPM)
2.5	320	323	321
3.5	503	500	499
4.5	668	660	658
5.5	840	839	837
6.5	1031	1031	1029
7	1131	1130	1130

It is important to note that the initial voltage value at which the speed was recorded for all three methods was 2.5 volts. The reason for this is that the myRIO encoder would not read the speed of the flywheel at a voltage below 2.5. Furthermore, the voltage increase was halted at 7 volts due to the concern that the flywheel might become detached from its base. From initial examination of the data, there appears to exist a positive linear trend for speed measurements and voltage provided. This trend and the rest of the data will be analyzed in the next section.

4. Theory and Analysis

[Primary Contributor: David Delgado]

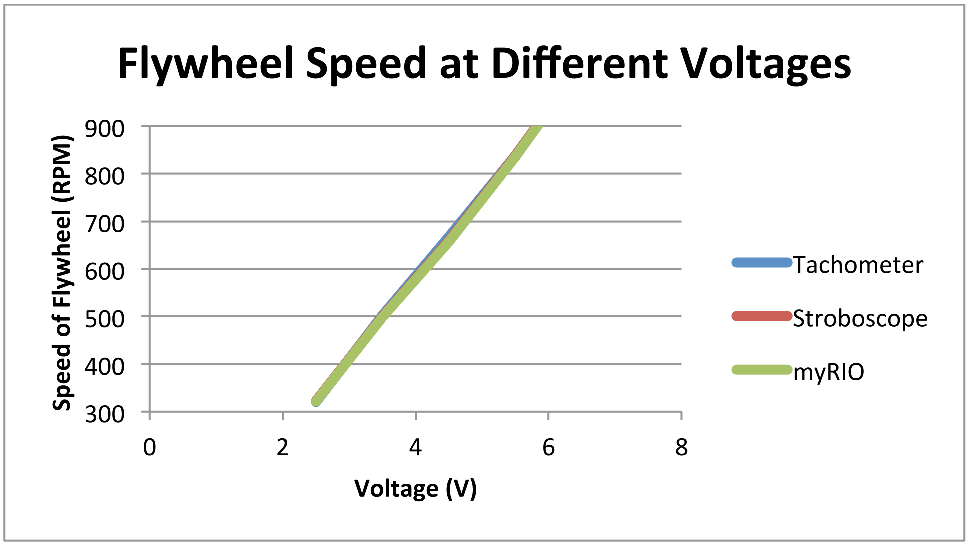

Figure 4.1. Flywheel speed at varying supplied voltages for all three measurement methods.

To analyze the data further, a trendline was added to each method's graphed line. All three measurement methods were fitted with a linear trendline, indicating some level of precision existed among the methods. The following equations represent the best-fit lines for each method:

$$y_{stroboscope} = 178.33x - 129.62 \tag{1}$$

$$y_{tachometer} = 178.48x - 128.7 \tag{2}$$

$$y_{encoder} = 178.51x - 132.01 \tag{3}$$

To evaluate the accuracy of the body of the data, a simple statistical analysis was performed by finding the maximum standard deviation of each method using the following equation:

$$d_i = y_i - y_m \tag{4}$$

Where 'y_i' is the value for that particular method that is furthest from the mean value of speed and 'y_m' is the mean speed for that method at the specific voltage. Table 4.1 shows these deviation values.

Table 4.1. Maximum Standard Deviation of Speed Value for Each Measurement Method

Voltage (V)	Tachometer Deviation (RPM)	Stroboscope Deviation (RPM)	myRIO Deviation (RPM)
2.5	2.5	6.795	6.735
3.5	7.02	5.465	6.225
4.5	6.46	12.865	13.285
5.5	12.94	12.195	12.795
6.5	0.42	1.475	0.695
7	10.34	11.31	12.44

From the standard deviation values above, the myRIO encoder presented the greatest difficulty in terms of accurately predicting the velocity of the flywheel. On the other hand, the tachometer had the best accuracy when measured relative to the expected linear relationship between voltage and flywheel velocity.

5. Discussion

[Primary Contributor: David Delgado]

To discuss the accuracy of each method, the percent error was calculated using the following equation:

$$\% \, Error = \frac{d_i}{y_m} \times 100\% \tag{1}$$

Table 5.1. Percent Error for Each Measuring Method

Voltage (V)	Tachometer % Error	Stroboscope % Error	myRIO % Error
2.5	0.78125	2.1037	2.0981
3.5	1.3956	1.0930	1.2475
4.5	0.96707	1.9492	2.0190
5.5	1.5405	1.4535	1.5287
6.5	0.040737	0.14306	0.067541
7	0.91424	1.0009	1.1009

From the table above, it is clear that the tachometer produced the most accurate readings of the flywheel's speed. The encoder and the stroboscope both have equally less accurate readings, but myRIO is the least accurate method. The tables also show that while the tachometer has the smallest percent errors on average in when compared to the other tools, it also has the largest slope and standard deviation from the three graphs. This indicates that while the tachometer is the most accurate method, it is also the least precise. The encoder had the largest percent error on average and the second largest standard deviation from its graph. According to these results, the encoder is the least accurate and second most precise measuring tool.

Given this analysis, it becomes more obvious why tachometers are more commonly used in automobiles to monitor engine speed during operation. Furthermore, the Tachometer would be useful to measure these larger devices that have a direct line of sight as it uses a sensor or laser to measure the frequency that a certain reflective surface passes by over a period of time. On the other hand, while the stroboscope was the second most accurate method, its uses seem very limited in industry as it must be used in low light areas and handled by personnel that are not sensitive to flashing lights. Encoders are commonly used in servo-control applications (robotics, industrial manufacturing processes, imaging systems, etc.) to provide rotational or linear position feedback because of the fact that this method is very hands-off. Although it is the least accurate method, it is still valuable in the sense that it produces precise measurements and eliminates the human error associated with the stroboscope.

6. Conclusions

[Primary Contributor: David Delgado]

From the results of the analysis it was found that the tachometer was the most accurate tool, while the encoder was the least accurate. Even though the encoder had the largest percent error on average and the second largest standard deviation in its measurements, it was able to measure angular velocity to three decimal places, which the other tools were unable to provide. Before analyzing the data, it was expected that the encoder had the best accuracy since it measures speed directly from the shaft of the motor assembly. Hence, it would be worthwhile to attain additional information about the flywheel (radius, mass, etc.) and the velocity of the motor's shaft to calculate the true angular velocity to compare against the experimental results. Re-calculating the percent differences in error measurements from the actual angular velocity should be investigated in a future lab experiment.

7. References

[Primary Contributor: David Delgado]

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8. Sample Calculations

[Primary Contributor: David Delgado]

Several equations were used to properly conduct the lab.

Let the linear best-fit lined use to describe each method of measurement be described by:

$$y_i = 178.33x - 129.62 \tag{1}$$

Where y_i is the speed in RPM at each voltage for each method, and x is the supplied voltage (V). The experimental values of the flywheel were calculated as such:

$$y_{tachometer} = 178.48(2.5\ volts) - 128.7 = \ 317.5\ RPM \tag{2}$$

The maximum standard deviation of each method using the following equation:

$$d_i = \ |y_i - y_m| \tag{3}$$

Where ‘y_i’ is the value for that particular method that is furthest from the mean value of speed and ‘y_m’ is the mean speed for that method at the specific voltage. A sample calculation for the previous tachometer example follows:

$$d_i = \ y_i - y_m = |\ 317.5\ RPM - 320\ RPM\ | = \ 2.5\ RPM \tag{4}$$

Lastly, the percent error for each method of velocity measurement was calculated using the following equation:

$$\%\ Error = \frac{d_i}{y_m} \times 100\% \tag{5}$$

Where “d_i’ is the deviation calculated for each method and each given voltage using Equation 3 and ‘y_m’ is the mean speed for that method at the specific voltage. As an example, the percent error found for the tachometer reading at 2.5 volts was calculated as such:

$$\%\ Error = \frac{d_i}{y_m} \times 100\% = \frac{2.5}{320} \times 100\% = 0.71825\%. \tag{6}$$