H-BRIDGE MOTOR CONTROL CIRCUIT

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ABSTRACT: The abstract is a summary of your research project and includes motivation, aims, methods used, (preliminary) findings and (preliminary) conclusions. The abstract should be a stand-alone document that someone could read to get a general overview of your research project.

Write the abstract the font shown but make sure it is no longer than about 500 words (and it must fit on a single page which includes the title, authors and keywords). The words of ‘Abstract’ and ‘Keywords’ are set in bold and full caps. Make sure you put your correct project code in the footer. If you have two supervisors you can list both of them. If one of them is from industry you should give their company name etc. Please note the following rules regarding the final paper:

- First page (starts with - Title, Authors, Abstract(s) and Keywords) [MANDATORY] and then follows
- Body of the paper (text and tables and or figures in the format shown) [MANDATORY]
- Notation [OPTIONAL]
- Appendices [OPTIONAL]
- References [MANDATORY]

The total length of the paper is to be no more than **14pp for 3rdyr and 19pp for 4thyr**. A cover sheet is also required in addition to the research paper. Note that the cover sheet is not included in the page limit.

KEYWORDS: Keyword 1, Keyword 2 and Keyword 3. You can include a maximum of 6 keywords for indexing purposes (spaced by commas). Keywords are single words or short phrases describing the main concepts/topics covered in the paper. Sometimes only 2 or 3 keywords will suffice, but definitely no more than six.

STATEMENT OF ORIGINALITY: Using no more than 8 lines of text (including this one) please give your statement of what is original in this paper. E.g., ‘In this paper a new spreadsheet model is developed to calculate the settlement of foundations making use of previously published methods given by Meyerhof’.

Contents

1 INTRODUCTION

The purpose of this project is to develop a basic motor control board specifically designed to drive small, low-cost DC brushed motors using industrial signals. This innovative board is capable of accepting 0-10V inputs from a Programmable Logic Controller (PLC), allowing precise control over the commanded motor power. Additionally, it supports 24V Pulse Width Modulation (PWM) control signals directly for both forward and reverse motor operations, enhancing its versatility and applicability for various learning applications.

The motor control board is equipped with feedback capabilities, providing 0-10V outputs to the PLC for motor speed and position and a digital signal for motor direction. This allows a diverse range of process control learning opportunities. Furthermore, the board includes a position zeroing input from the PLC, enabling the control board to reset the motor position feedback to zero when desired to allow a homing routine to be used to establish absolute position control.

Overall, this project will provide a versatile motor controller that will facilitate a diverse range of learning opportunities.

2 Motor Manufacturer Specifications

2.1 RS-775126000E7 Motor

PG27 RS775-125 Motor with Encoder
The test motor was purchased here: www.andymark.com (PG27 RS775-125 Motor with Encoder)

Product Overview

This motor is the same motor included in our PG27 Gearmotor, and is being sold with the intention of replacing the motor without having to purchase the gearbox as well. This motor comes with the pinion gear and encoder attached and also includes the 2 mounting screws.

The back shaft of this motor features our Hall Effect Encoder, which can be removed if your application needs the long back shaft.

This motor, without the encoder, is am-2766, and is similar to am-2194, (same motor slightly shorter shaft). Both of these base motors are called out in the *FIRST* Robotics Competition manual as being legal for use in 2022.

Encoder Pinout:

- Pin 1: 5V DC
- Pin 2: Ground
- Pin 3: Channel A Output
- Pin 4: Channel B Output

Specifications

- Back Shaft Diameter: 0.2 in.
- Back Shaft Length: 0.45 in.
- No Load RPM: 5700 RPM
- Pulses Per Revolution: 7
- Shaft Diameter: 0.125 in.
- Stall Current: 15-20 AMPs
- Stall Torque: 35 oz-in
- Teeth: 11
- Voltage: 12 Volts DC
- Wattage: 44
- Weight: 0.86 lbs.

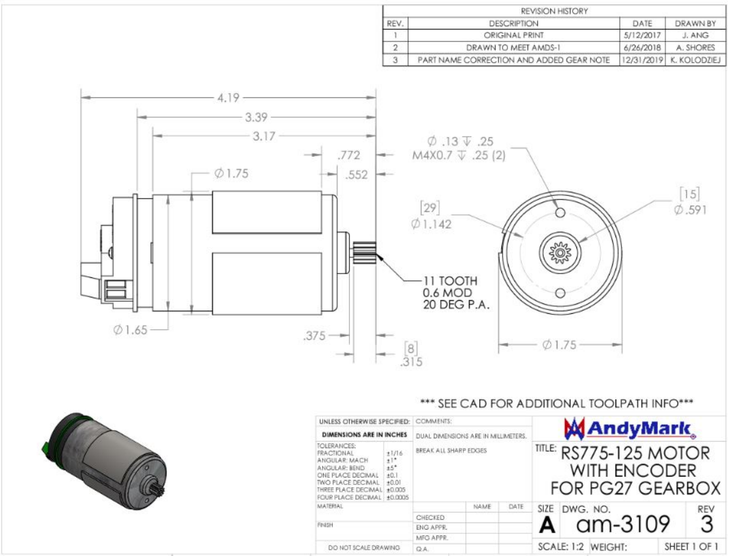

Figure 1: RS-775126000E7 Dimensions

Motor dimensions pdf can be downloaded here: andymark.com (layout prints PG27 RS775-125 Motor with Encoder)

2.2 TS-25GA370H-20 Motor

Encoder Metal Gearmotor 12V DC High Speed 300RPM Gear Motor with Encoder for Arduino and 3D Printers

The test motor was purchased here: www.amazon.com (Encoder Metal Gearmotor 12V DC High Speed 300RPM Gear Motor with Encoder for Arduino and 3D Printers)

Product type: DC Gear motor with two-channel Hall effect encoder

- Rated Voltage: 12V
- No-Load Speed: 300RPM
- No-Load Current: $\leq$ 0.15A
- Rated Torque: 0.5kg.cm
- Single Output 240 Pulses Per Revolution
- Gear Reduction Ratio: 1/20
- Each Loop Output Pulses: 12PPR 20$\times$12=240PPR

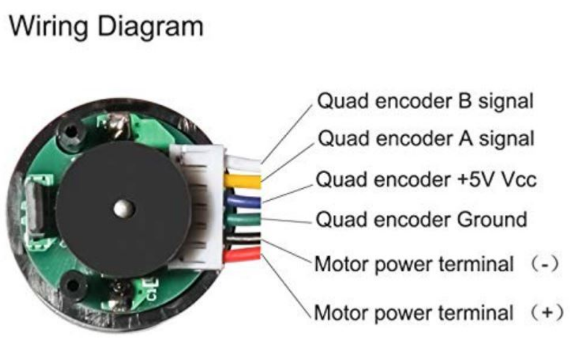

Figure 2: TS-25GA370H-20 Wiring

Motor Dimensions:

- Main Body: 66 x 25mm / 2.6in x 0.99in (L*D)
- Out Shaft: 11 x 4mm / 0.433 x 0.1575in (L*D) with 10 x 0.5mm / 0.39 * 0.017inches flat cut off

Figure 3: TS-25GA370H-20 Dimensions

3 RS-775126000E7

3.1 RS-775126000E7 Initial Test Data

Table 1: RS-775126000E7 Initial Test Data

DC Voltage	DC Current	Power	RPM	Encod Freq	Resolution
12V	680mA	8.16W	5,500 RPM	641.0hz	51.48°
11V	660mA	7.26W	5,037 RPM	602.4hz	50.17°
10V	630mA	6.30W	4,545 RPM	537.6hz	50.73°
9V	620mA	5.58W	4,064 RPM	480.8hz	50.72°
8V	600mA	4.80W	3,600 RPM	434.8hz	49.68°
7V	580mA	4.06W	3,155 RPM	370.4hz	51.107°
6V	510mA	3.06W	2,728 RPM	310.6hz	52.70°
5V	496mA	2.48W	2,200 RPM	252.5hz	52.28°
4V	470mA	1.88W	1,700 RPM	201.6hz	50.60°
3V	460mA	1.38W	1,196 RPM	139.7hz	51.37 °
2V	434mA	868mW	701.0 RPM	82.64hz	50.90°
1V	430mA	430mW	222.0 RPM	23.58hz	56.68°
				Average Measured Resolution	51.53°

3.2 Step Resolution Using Measured Values

3.2.1 Resolution at 12VDC

Measured Frequency = 641.0hz or cycles per second

Measured RPM = 5,500RPM or revolutions per minute

Convert RPM to revolutions per second

$RPS = \frac{RPM}{60} = \frac{5{,}500}{60} = 91.667 RPS$

Set cycles per second equal to revolutions per second and solve for the resolution per clock cycle.

$\frac{641 cycles}{Second} = \frac{91.667 revolutions}{Second}$

$641 cycles = 91.667 revolutions$

$1 cycle = \frac{91.667 revolutions}{641} = 0.143 revolutions$

Convert revolutions to degrees

$1 rev = 360°$

$1 cycle = \frac{91.667 revolutions}{641} = 0.143 \times 360° = 51.48°$

Final Formula for converting measured RPM and Frequency to Step Resolution:

$$Step\ Resolution = \left(\frac{RPM}{Frequency} \times 6\right)^{\circ} \tag{1}$$

3.3 Step Resolution Using Manufacturers Data

The manufacturer specification states ”Pulses Per Revolution: 7”.

$7\ counts = 1rev$

Convert revolutions to degrees

$7\ counts = 360°$

Solve for resolution per count or step

$1\ count = \frac{360°}{7} = 51.43°$

$$Manufacturer\ Step\ Resolution = 51.43°\ per\ step \tag{2}$$

The manufacturer step resolution of $51.43°$ per step is consistent with the average measured step resolution of $51.53°$.

3.4 RS-775126000E7 Encoder Waveforms

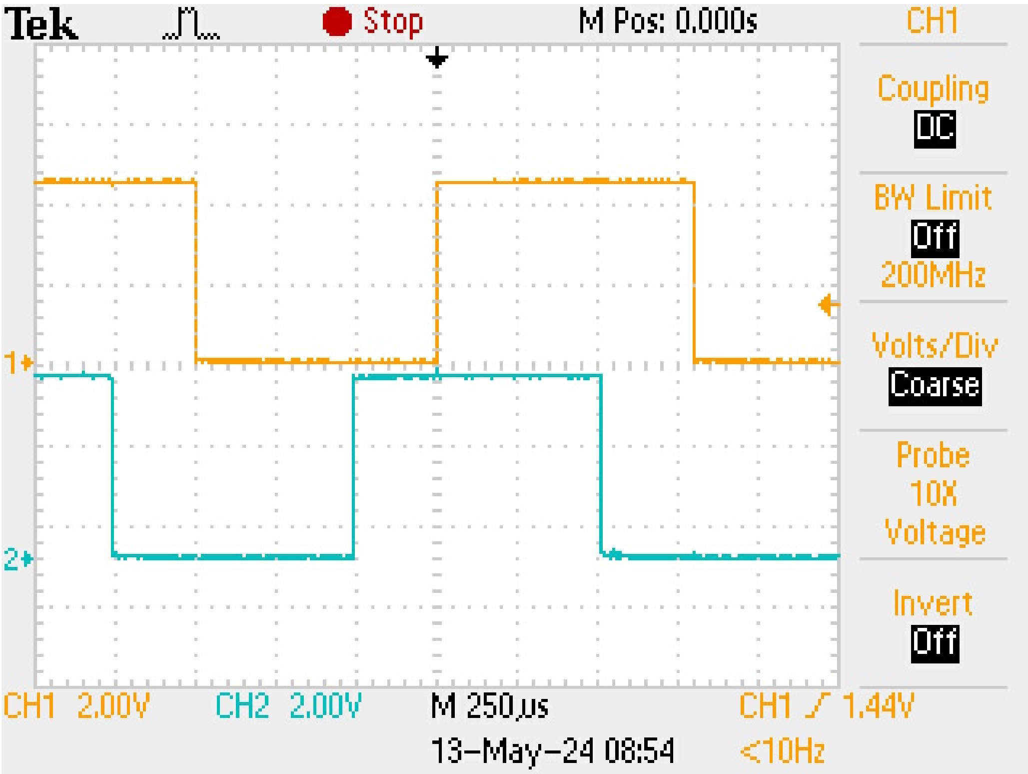

Figure 4: RS-775126000E7 Encoder Waveforms

4 TS-25GA370H-20

4.1 TS-25GA370H-20 Initial Test Data

Table 2: TS-25GA370H-20 Initial Test Data

DC Voltage	DC Current	Power	RPM	Encod Freq	Resolution
12V	78.2mA	938mW	276.5 RPM	1.111Khz	1.493°
11V	66.6mA	733mW	254.7 RPM	1.064Khz	1.436°
10V	61.5mA	615mW	231.1 RPM	980.4hz	1.414°
9V	56.4mA	508mW	210.1 RPM	862.1hz	1.462°
8V	51.0mA	408mW	185.3 RPM	757.6hz	1.468°
7V	47.3mA	331mW	161.4 RPM	657.9hz	1.472°
6V	43.6mA	262mW	138 RPM	574.7hz	1.441°
5V	40.1mA	201mW	114 RPM	480.0hz	1.425°
4V	36.4mA	145.6mW	90.1 RPM	373.1hz	1.449°
3V	32.2mA	96.6mW	67.5 RPM	285.7hz	1.418°
2V	28.8mA	57.6mW	44.3 RPM	177.3hz	1.499°
1V	22.0mA	22.0mW	19.3 RPM	79.37hz	1.459°
Average Measured Resolution					1.435°

4.1.1 Resolution at 12VDC

Measured Frequency = 1.111Khz or cycles per second

Measured RPM = 276.5RPM or revolutions per minute

Convert RPM to revolutions per second

$RPS = \frac{RPM}{60} = \frac{276.5}{60} = 4.608RPS$

Set cycles per second equal to revolutions per second and solve for the resolution per clock cycle.

$\frac{1.111Kcycles}{Second} = \frac{4.608revolutions}{Second}$

$1.111Kcycles = 4.608revolutions$

$1cycle = \frac{4.608revolutions}{1.111K} = 4.148 \times 10^{-3}revolutions$

Convert revolutions to degrees

$1rev = 360° \ \& \ 1cycle = 4.148 \times 10^{-3}revolutions$

$1cycle = 4.148 \times 10^{-3} \times 360° = 1.493°$

Final Formula for converting measured RPM and Frequency to Step Resolution:

$$Step\ Resolution = \left(\frac{RPM}{Frequency} \times 6\right)^{\circ} \tag{3}$$

4.2 Step Resolution Using Manufacturers Data

The manufacturer specification states ”Single Output 240 Pulses Per Revolution”.

$240\ counts = 1rev$

Convert revolutions to degrees

$240\ counts = 360°$

Solve for resolution per count or step

$1\ count = \frac{360°}{240} = 1.5°$

$$TS25GA370H20\ Manufacturer\ Step\ Resolution = 1.5°\ per\ step \tag{4}$$

The manufacturer step resolution of $1.5°$ per step is consistent with the average measured step resolution of $1.435°$.

4.3 TS-25GA370H-20 Encoder Waveforms

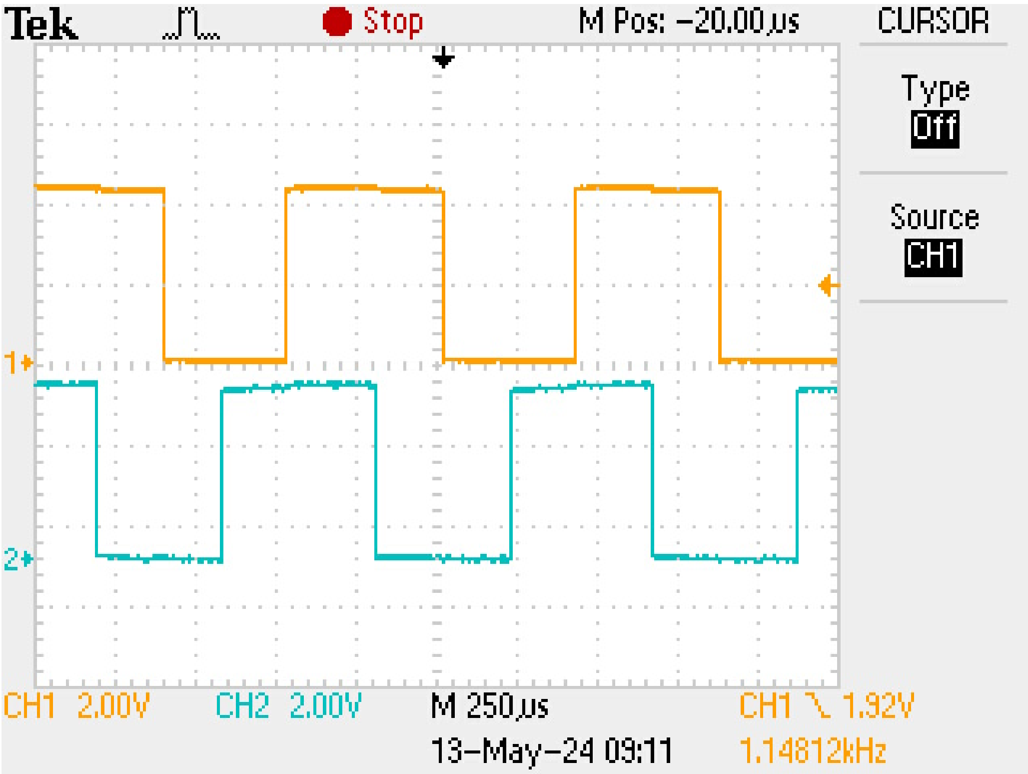

Figure 5: TS-25GA370H-20 Encoder Waveforms

5 Discrete H-Bridge Development

5.1 Switching Ground (N-Channel MosFET)

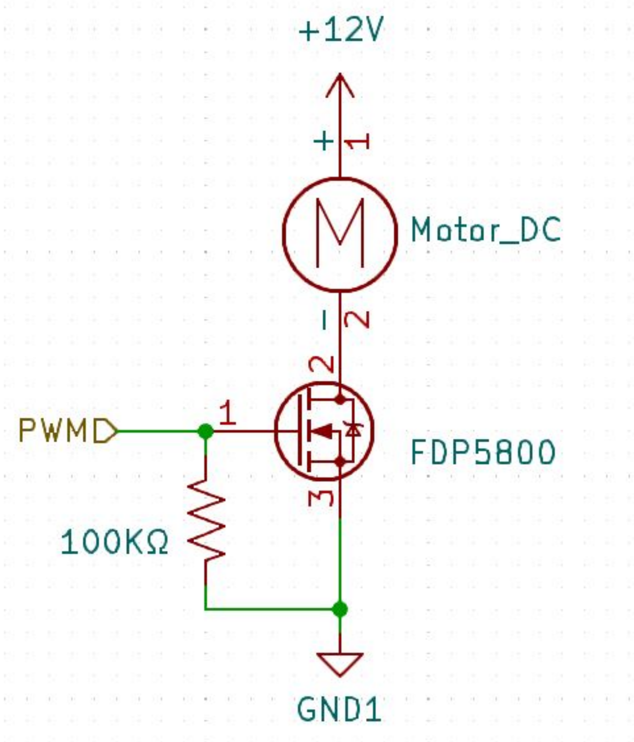

Figure 6: PWM Test Circuit (N-Channel MosFET)

Table 3: N-Channel PWM Test Data

PWM Frequency	PWM ON Voltage	PWM OFF Voltage	PWM Duty-Cycle	RS-775126000E7 RPM	TS-25GA370H-20 RPM
5Khz	4V	0V	99%	5454 RPM	284 RPM
5Khz	4V	0V	90%	4792 RPM	270 RPM
5Khz	4V	0V	80%	4365 RPM	234 RPM
5Khz	4V	0V	70%	3887 RPM	178 RPM
5Khz	4V	0V	60%	3220 RPM	113 RPM
5Khz	4V	0V	50%	2420 RPM	55 RPM
5Khz	4V	0V	40%	1400 RPM	22 RPM

5.2 Opto-Isolation, Switching 12V (P-Channel MosFET)

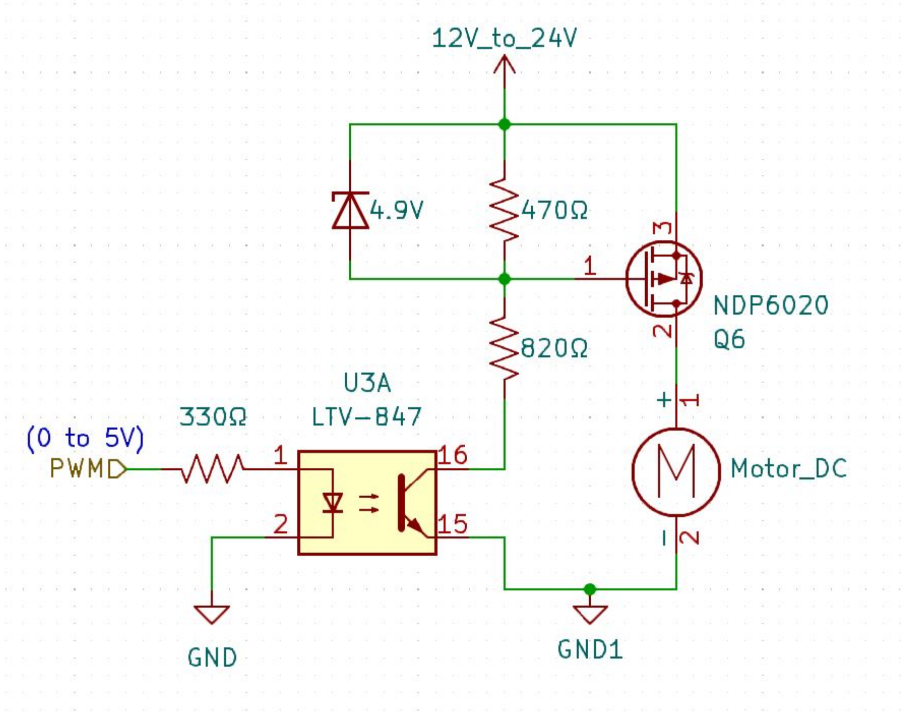

Figure 7: PWM Test Circuit (Opto-Isolated P-Channel MosFET)

Table 4: Opto-Isolated, P-Channel PWM Test Data

PWM Frequency	PWM ON Voltage	PWM OFF Voltage	PWM Duty-Cycle	RS-775126000E7 RPM	TS-25GA370H-20 RPM
5Khz	5V	0V	99%	5547 RPM	283 RPM
5Khz	5V	0V	90%	5471 RPM	283 RPM
5Khz	5V	0V	80%	4921 RPM	276RPM
5Khz	5V	0V	70%	4615 RPM	249 RPM
5Khz	5V	0V	60%	4226 RPM	203 RPM
5Khz	5V	0V	50%	3728 RPM	142 RPM
5Khz	5V	0V	40%	3072 RPM	82 RPM
5Khz	5V	0V	30%	2177 RPM	32 RPM
5Khz	5V	0V	20%	1010 RPM	0 RPM

5.3 Opto-Isolation, Switching 12V (N-Channel MosFET)

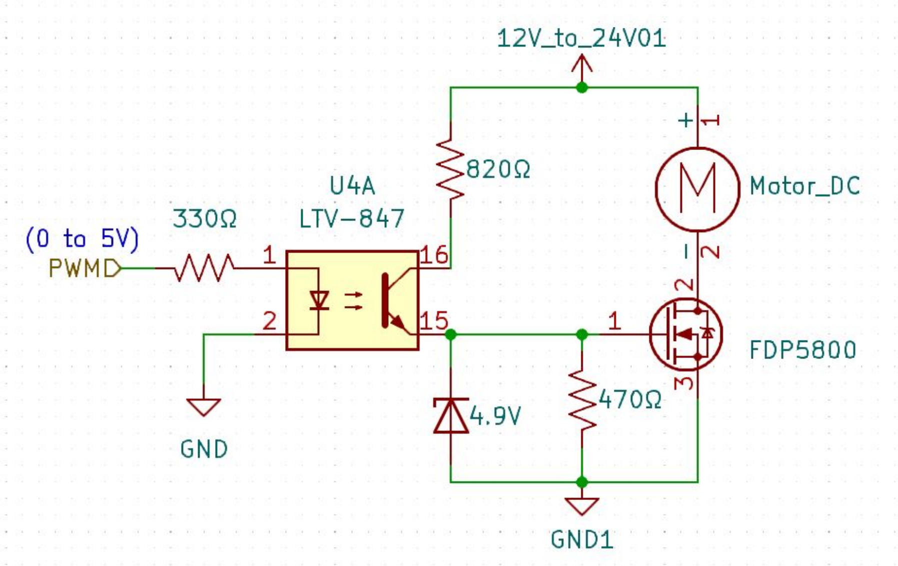

Figure 8: PWM Test Circuit (Opto-Isolated N-Channel MosFET)

Table 5: Opto-Isolated N-Channel PWM Test Data

PWM Frequency	PWM ON Voltage	PWM OFF Voltage	PWM Duty-Cycle	RS-775126000E7 RPM	TS-25GA370H-20 RPM
5Khz	5V	0V	99%	5525 RPM	280 RPM
5Khz	5V	0V	90%	5520 RPM	280 RPM
5Khz	5V	0V	80%	4720 RPM	268 RPM
5Khz	5V	0V	70%	4335 RPM	233 RPM
5Khz	5V	0V	60%	3909 RPM	179 RPM
5Khz	5V	0V	50%	3395 RPM	113 RPM
5Khz	5V	0V	40%	2669 RPM	55 RPM
5Khz	5V	0V	30%	1688 RPM	18 RPM
5Khz	5V	0V	20%	380 RPM	0 RPM

5.4 Opto-Isolation, Switching 12V (N-Channel and P-Channel MosFETs)

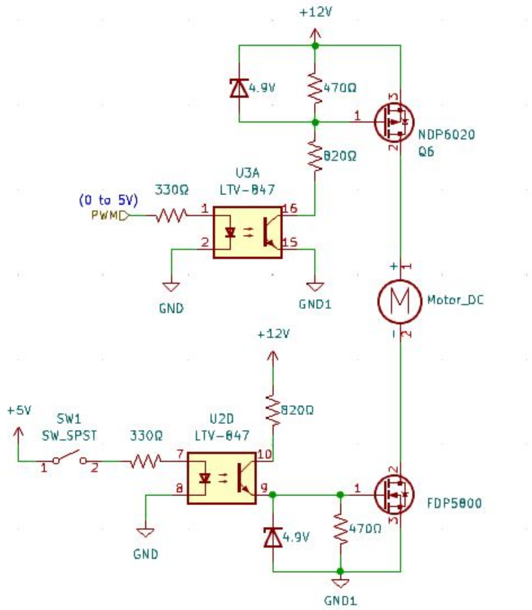

Figure 9: PWM Test Circuit (Opto-Isolated N-Channel and P-Channel MosFETs)

Table 6: Opto-Isolated N-Channel and P-Channel PWM Test Data

PWM Frequency	PWM ON Voltage	PWM OFF Voltage	PWM Duty-Cycle	RS-775126000E7 RPM	TS-25GA370H-20 RPM
2Khz	5V	0V	99%	5563 RPM	275 RPM
2Khz	5V	0V	90%	5264 RPM	272 RPM
2Khz	5V	0V	80%	4939 RPM	260 RPM
2Khz	5V	0V	70%	4800 RPM	232 RPM
2Khz	5V	0V	60%	4508 RPM	186 RPM
2Khz	5V	0V	50%	4033 RPM	128 RPM
2Khz	5V	0V	40%	3396 RPM	73 RPM
2Khz	5V	0V	30%	2467 RPM	31 RPM
2Khz	5V	0V	20%	980 RPM	0 RPM

5.5 H-Bridge

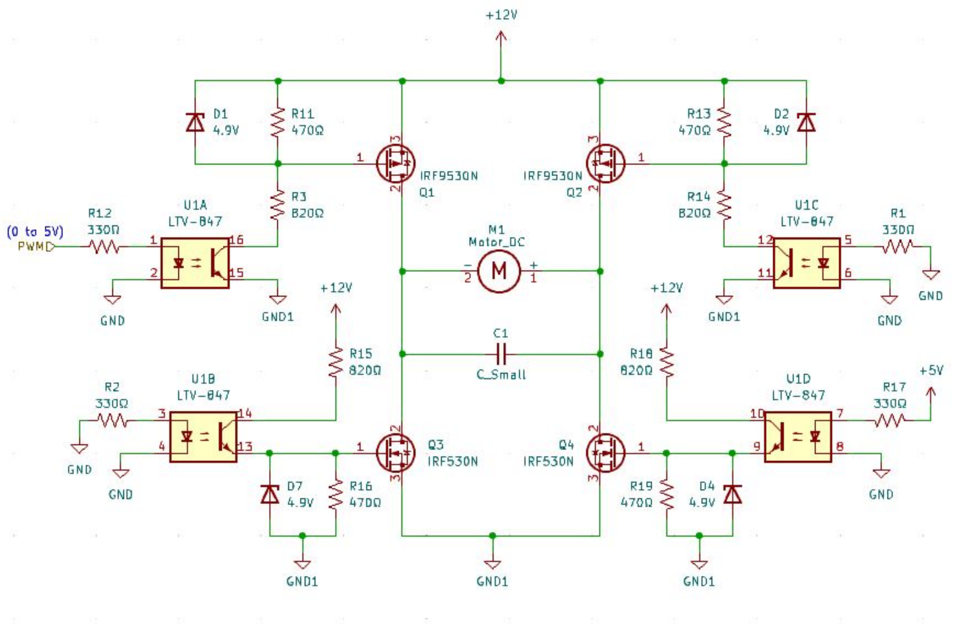

Figure 10: Clockwise Test Circuit

5.5.1 Clockwise Test

See Figure 10 verified. With U1B and U1C inputs tied to ground (GND), Q2 and Q3 will be off. With U1D's input tied high, Q4 is on. Applying PWM to U1A provides speed control to the motor via Q1. This configuration will provide speed and direction control "clockwise" or forward.

5.5.2 Counter-Clockwise Test

Re-configuring or swapping inputs U1A with U1C and U1B with U1D. The motor turns in the opposite orientation "Counter-Clockwise" or reverse.

Table 7: RS-775126000E7 Discrete H-Bridge PWM Test Data

PWM Frequency	PWM ON Voltage	PWM OFF Voltage	PWM Duty-Cycle	CW Forward	CCW Reverse
2Khz	5V	0V	99%	5645 RPM	5525 RPM
2Khz	5V	0V	90%	4941 RPM	4891 RPM
2Khz	5V	0V	80%	4965 RPM	4799 RPM
2Khz	5V	0V	70%	4630 RPM	4530 RPM
2Khz	5V	0V	60%	4310 RPM	4155 RPM
2Khz	5V	0V	50%	3760 RPM	3643 RPM
2Khz	5V	0V	40%	3000 RPM	2795 RPM
2Khz	5V	0V	30%	1922 RPM	1535 RPM
2Khz	5V	0V	20%	480 RPM	0 RPM

Table 8: TS-25GA370H-20 Discrete H-Bridge PWM Test Data

PWM Frequency	PWM ON Voltage	PWM OFF Voltage	PWM Duty-Cycle	CW Forward	CCW Reverse
2Khz	5V	0V	99%	288 RPM	290 RPM
2Khz	5V	0V	90%	284 RPM	282 RPM
2Khz	5V	0V	80%	268 RPM	262 RPM
2Khz	5V	0V	70%	238 RPM	226 RPM
2Khz	5V	0V	60%	191 RPM	174 RPM
2Khz	5V	0V	50%	132 RPM	113 RPM
2Khz	5V	0V	40%	70 RPM	57 RPM
2Khz	5V	0V	30%	32 RPM	23 RPM
2Khz	5V	0V	20%	0 RPM	0 RPM

5.6 Control Logic and H-Bridge

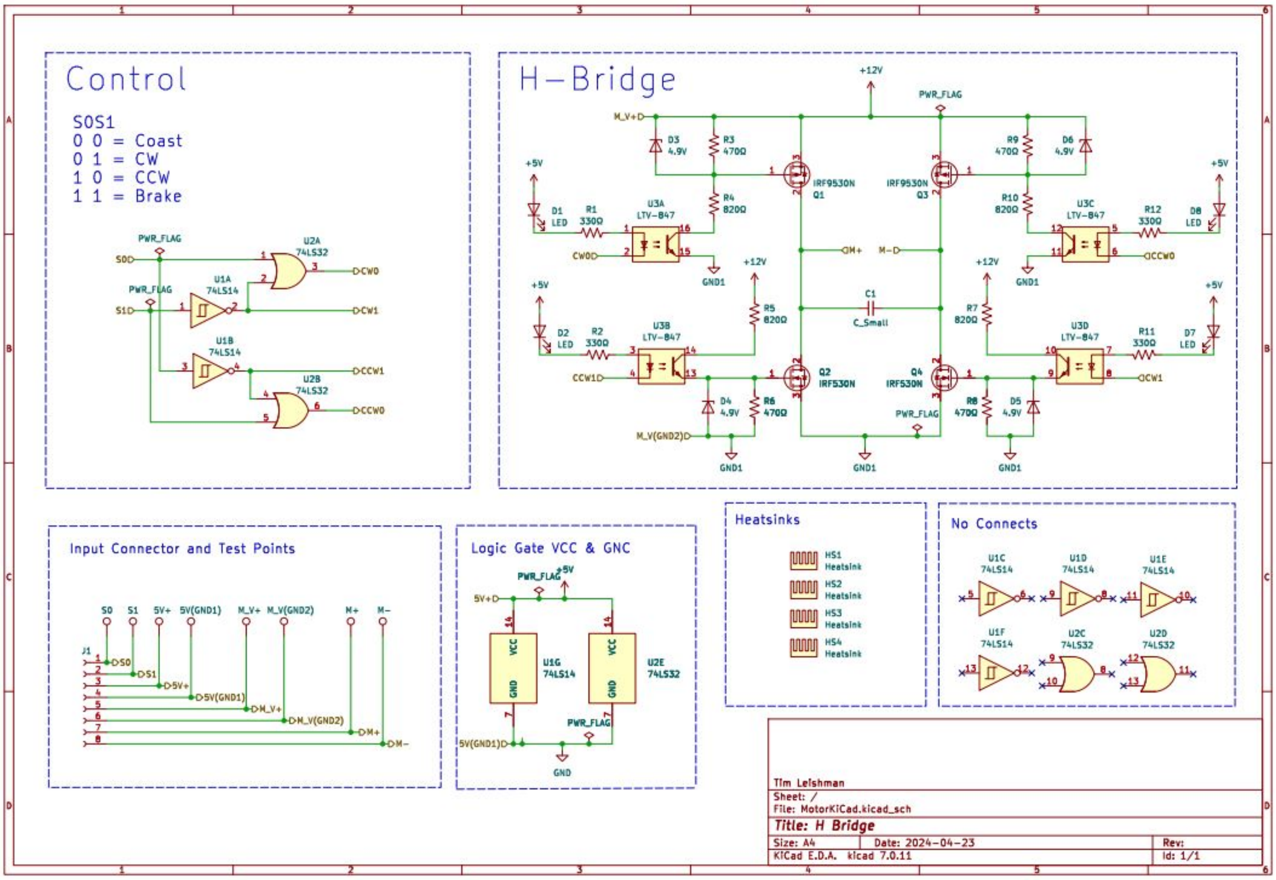

Figure 11: H-Bridge and Control Logic Schematic

The control inputs S0 and S1 will provide TTL voltage level inputs to control the H-Bridge.

SO & S1 = 0

When both SO and S1 are both equal to 0V, the H-Bridge will be disabled and the motor will be in Coast mode.

SO = 0 & S1 = 1

When SO is equal to 0V and S1 is equal to a TTL High ($\approx 5V$) the H-Bridge turn on Q1 and Q4 and the motor will move full speed in a ”Clockwise” direction.

SO = 1 & S1 = 0

When SO is equal to a TTL High ($\approx 5V$) and S1 is equal to 0V the H-Bridge turn on Q2 and Q3 and the motor will move full speed in a ”Counter Clockwise” direction.

SO = 1 & S1 = 1

When SO and S1 are both equal to a TTL High ($\approx 5V$) the H-Bridge turn on Q2 and Q4 and the motor will be in Brake mode.

5.7 H-Bridge PCB

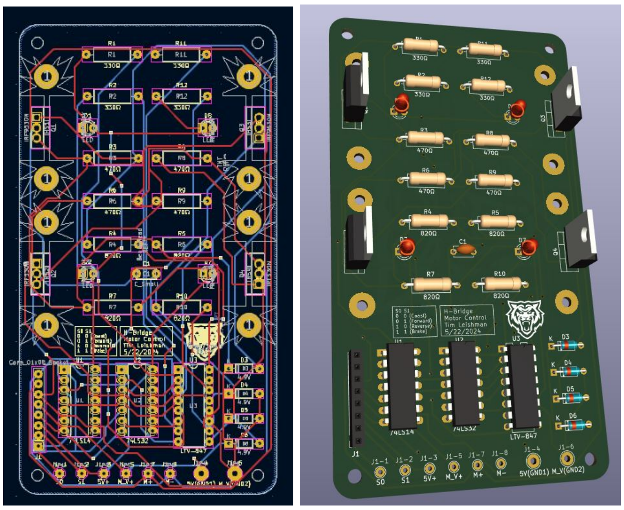

Figure 12: H-Bridge PCB KiCAD

5.8 H-Bridge PCB Build and Test

There were no issues with the assembly of the PCB. The H-Bridge PCB operated as expected. The rotational speed was measured at approximately 5,500 RPM in both directions using the RS-775126000E7 motor.

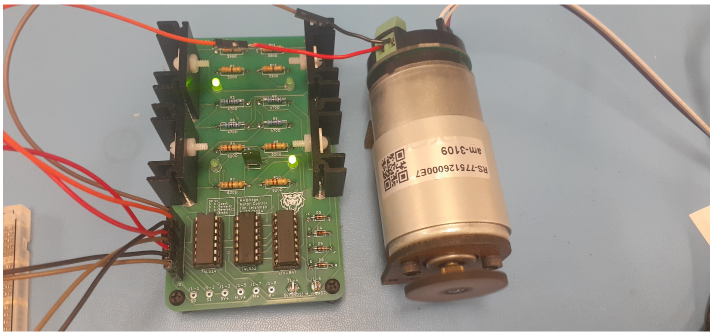

Figure 13: H-Bridge PCB Clockwise test

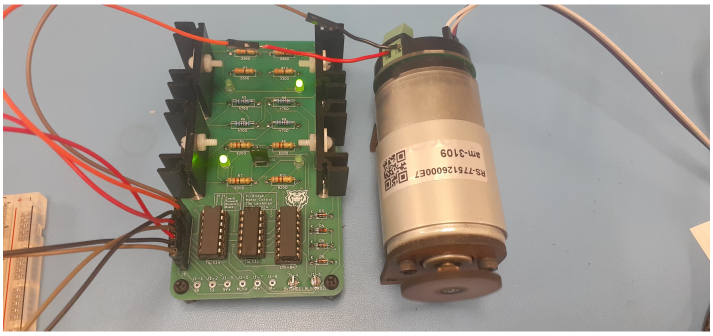

Figure 14: H-Bridge PCB Counter Clockwise test

5.9 Problems with the H-Bridge PCB

The H-Bridge PCB can operate in both clockwise and counterclockwise modes along with coast and brake. However, the circuit cannot control speed. An external circuit was used to provide PWM for the motor speed control. Additionally, the

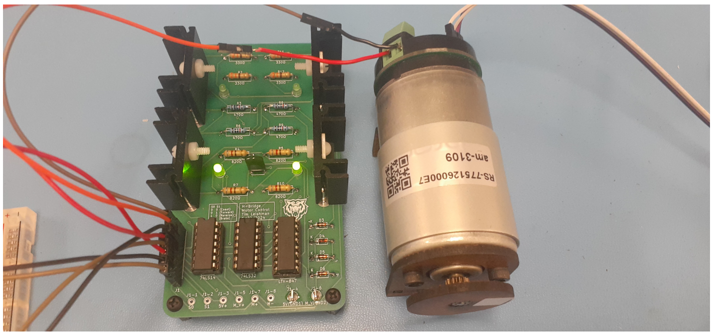

Figure 15: H-Bridge PCB Brake test

H-Bridge circuit requires both motor voltage and TTL voltage inputs. A 5V regulator could be implemented to minimize the number of voltage inputs required to operate the PCB.

6 TL494 with H-Bridge Development

6.1 TL494 Data Sheet Description

The TL494 device incorporates all the functions required in the construction of a pulse-width modulation (PWM) control circuit on a single chip. - TL494 Data Sheet

The supply voltage for the TL494 is a minimum of 7V to a maximum of 40V.

6.2 Voltage Level Adj. and PWM Circuit

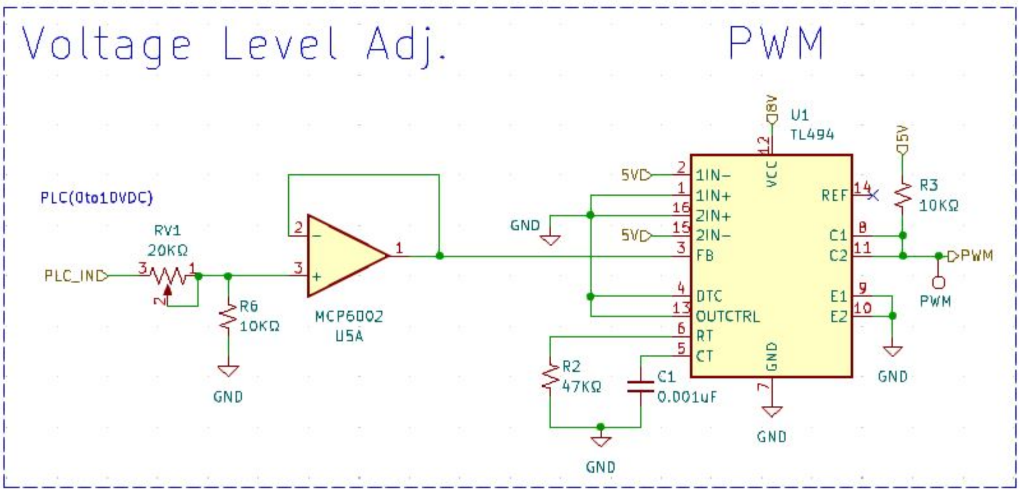

Figure 16: Voltage Level Adjust and PWM Circuit

The MCP6002 U5A is a rail-to-rail operational amplifier - MCP6002 Data Sheet. U5A is configured as a buffer between the analog voltage in "PLC_IN" and the FB (Feedback) input of the TL494. The FB input pin of the TL494 will have a maximum threshold voltage of 4.5VDC and the PLC analog input will have a maximum voltage of 10VDC. The MCP6002 U5A having a rail voltage of 5VDC will prevent the FB input from ever going above 5VDC. RV1 and R6 will provide a voltage divider allowing for calibration of the TL494 PWM and can be adjusted for either a PLC (0 to 10V) input or a 0 to 5V input depending on the application.

R2 and C1 determine the frequency of the PWM waveform.

$$F_{OSC} = \frac{1}{R_T \times C_T}$$

$$F_{OSC} = \frac{1}{47K\Omega \times 0.001\mu F}$$

$F_{OSC} = \frac{1}{47K\Omega \times 0.001\mu F}$

$F_{OSC} = 21.28Khz$

6.2.1 RV1 Calibration Proceedure

1. For PLC input, set the input voltage to 5V. For a 5V input, set the input voltage to 2.5V.
2. Adjust RV1 until the PWM waveform is at 50% duty cycle.

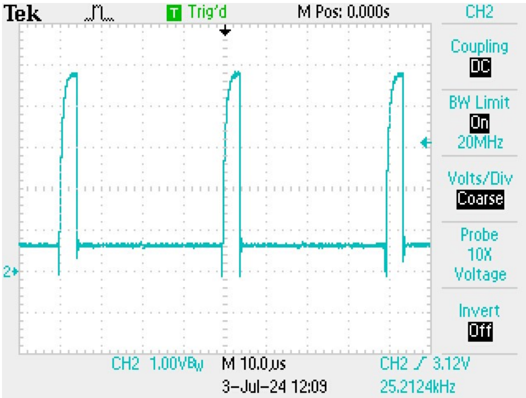

Figure 17: PWM with TL494 Feedback Voltage set to 0V

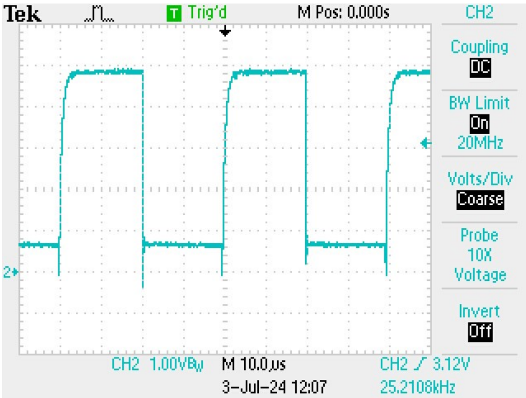

Figure 18: PWM with TL494 Feedback Voltage set to mid-voltage

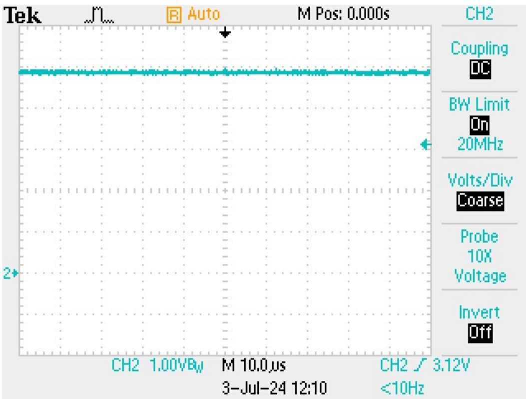

Figure 19: PWM with TL494 Feedback Voltage set to max-voltage

7 Pico Encoder Documentation

7.1 Using a Quadrature Encoder for Motor Direction, Speed, and Position

A quadrature encoder is a type of incremental encoder used to measure the direction, speed, and position of a rotating shaft. It provides two output signals, typically labeled A and B, which are 90 degrees out of phase. By analyzing these signals, the system can determine the shaft's state changes, allowing for precise measurement of its movement. Here's a detailed explanation of how state changes are used to determine direction, speed, and position with a quadrature encoder:

7.1.1 Direction

The direction of rotation is determined by the phase relationship between the A and B signals. There are four possible state transitions that occur when the encoder rotates:

1. **A leads B**: If the signal on channel A transitions before the signal on channel B, the encoder is rotating in one direction (e.g., clockwise).
2. **B leads A**: If the signal on channel B transitions before the signal on channel A, the encoder is rotating in the opposite direction (e.g., counterclockwise).

By continuously monitoring which channel leads the other, the system can accurately determine the direction of rotation.

7.1.2 Speed

The speed of rotation is calculated by measuring the frequency of the state changes (transitions) in the A and B signals. Since each transition represents a specific amount of shaft movement, a higher frequency of transitions indicates a higher speed of rotation. There are two primary methods to measure speed:

1. **Counting Transitions**: By counting the number of transitions in a given time period, the system can determine the speed. More transitions in a shorter time indicate higher speed.
2. **Time Between Transitions**: By measuring the time interval between consecutive transitions, the system can calculate speed. Shorter intervals between transitions indicate higher speed.

7.1.3 Position

The position is determined by counting the number of state changes or pulses from the encoder. Each full cycle of the A and B signals represents a fixed increment of rotation (usually a fraction of a degree or a millimeter, depending on the encoder's resolution). The position can be tracked by incrementing or decrementing a counter based on the direction of rotation.

1. **Incremental Counting**: Every transition (rising or falling edge) of both A and B signals is counted. Since there are four transitions per cycle (A rising, A falling, B rising, B falling), the system can achieve high resolution by counting each transition.
2. **Quadrature Decoding**: This method considers all four possible states (00, 01, 11, 10) in each cycle. By tracking the sequence of these states, the system can detect and count each increment of rotation.

7.1.4 Example of State Transitions and Counting:

Assume the initial state is 00 (A low, B low):

1. **00 to 01** (A low, B rising): One transition.
2. **01 to 11** (A rising, B high): Another transition.
3. **11 to 10** (A high, B falling): Another transition.
4. **10 to 00** (A falling, B low): Another transition.

This sequence repeats, and by tracking these transitions, the system determines the position by incrementing or decrementing a counter based on the direction of rotation.

In summary, by monitoring the state changes between the A and B signals, a quadrature encoder can accurately determine the direction, speed, and position of a rotating shaft. This information is crucial for precise control in various applications such as robotics, industrial automation, and motor control.

7.2 Encoder Implementation

A Raspberry Pi Pico microcontroller was used in this project to read and process the encoder signal. The Pico uses Raspberry Pi's RP2040 chip which has some unique capabilities, specifically, programmable I/O (PIO). PIO is a new piece of hardware developed for RP2040. It allows you to create new types of (or additional) hardware interfaces on your RP2040-based device. The PIO subsystem on RP2040 allows you to write small, simple programs for what are called PIO state machines, of which RP2040 has eight split across two PIO instances. A state machine is responsible for setting and reading one or more GPIOs, buffering data to or from the processor, and notifying the processor, via IRQ or polling, when data or attention is needed. These programs operate with cycle accuracy at up to system clock speed.

The pico C/C++ SDK (Software Development Kit) includes a PIO program example for reading a quadrature encoder. The example PIO tracks the A and B phase inputs and increments, decrements, or holds a count value depending on the state changes. The count value is accessible from a 32 bit register by the user program. The code in the CPU works with this PIO program to calculate speed, direction, and position.

The C code calculates the required motor values by reading the count register on a fixed period and calculating the difference from the previous read. Direction is determined based on whether the difference is positive or negative. Speed is calculated by dividing the difference by the time period of the loop. Position is maintained by adding the difference to a variable which is limited between zero and a maximum number of counts. The maximum number of counts represents the number of counts in a full revolution of the motor output shaft. This number can be adjusted in code based on motor gearing or for a specific application.

7.3 Encoder Feedback Configuration

The values from the encoder have to be converted into a form that can be easily transmitted to the PLC. Specifically for this project, the goal is to provide feedback using 0-10v signals. It was determined that the easiest way to accomplish that was to output PWM signals from the Pico microcontroller that could then be integrated into a voltage signal.

The speed feedback was the most straight forward. The PWM duty cycle was set to match the speed as a percentage from 0% to 100%. The maximum expected speed has to be programmed into the controller.

Add Calibration pot for adjusting max speed setting??

The position feedback system uses PWM duty cycle to represent the percentage of a revolution. For example, a 180° rotation corresponds to a 50% duty cycle. This method provides high-resolution position feedback within a single revolution for the gear motor. However, for the non-geared motor, the resolution within a single revolution is poor.

To enhance the position feedback capability, the position is scaled by a factor of ten, providing feedback across ten revolutions of the motor. This approach allows for a broader indication of motor position with lower resolution over a larger rotation range, while still maintaining fine resolution within a single rotation, based on the PLC's analog input resolution.

7.4 Encoder Testing Results

7.4.1 TS-25GA370H-20 (Small Gear Motor)

This small motor's gearbox results in excellent position feedback making it ideal for any precision application. The motor vendor stated a pulse resolution of 240 pulses per revolution and the the initial motor testing demonstrated a similar value (values from section 4):

$$\frac{1.111\ Kcyles}{second} = \frac{4.608\ revolutions}{second}$$

Solving for cycles per second yields:

$$\frac{1,111\ cycles}{4.608\ revolutions} = \frac{241.1 cycles}{revolutions}$$

Our initial testing is mostly consistent with the vendor-provided spec, but when utilizing the encoder as described above, a state change per revolution number is needed. The cycles per second recorded during initial testing are for a single encoder signal. When reading the encoder using state changes, a resolution of four times the signal frequency is achieved. The result is that the motor should have $(240 \times 4) = 960$ state changes per revolution. The motor position accuracy was tested over ten rotations and it was found that the zero position drifted by almost 90° indicating that our 960 state changes per revolution value was inaccurate. Through trial and error, a value of 980 state changes per revolution was determined to be accurate across 10 turns. This means there is likely 245 pulses per revolution for each encoder signal. This error could be attributed to the vendor reporting a round value for the 20:1 gear reduction which may be actually closer to 20.4:1.

A maximum speed of 4700 state changes per second was recorded for this motor. This number is an approximation and could vary between motors. For this reason, a speed adustment will be provided to allow maximizing the resolution of the speed feedback to the PLC.

7.4.2 RS775-125 (Bare Motor)

This larger motor has significantly less encoder resolution because it does not have a gear reduction and because it it has almost half the resolution with the encoder itself. The motor vendor stated a pulse resolution of 240 pulses per revolution and the the initial motor testing demonstrated a similar value (values from section 1.2.1):

$$\frac{641\ cyles}{second} = \frac{91.667\ revolutions}{second}$$

Solving for cycles per second yields:

$$\frac{641\ cycles}{91.667\ revolutions} = 6.99 \frac{cycles}{revolutions}$$

This tested value is much more consistent with the vendor's specification than the gear motor. As described with the gear motor, the Pico counts the state changes per revolution which is four times the signal frequency. The result is 28 state changes per revolution. The resolution per state change is calculated as follows:

$$\frac{360°}{7\ pulses} \times \frac{pulses}{4\ state\ changes} = \frac{12.9°}{state\ change}$$

With this low resolution, it was simple to verify at the bench by checking that the feedback PWM signal returns to 0% duty cycle at the same point on each revolution. Because the resolution is so poor for this motor it will be better used for speed control applications instead of position control.

A maximum speed of less than 2700 state changes per second was recorded for this motor. As described previously, an adjustment potentiometer on the controller board will allow the speed signal to be set appropriately for each individual motor.

Use this section to thank your data sources including citations to the data, weblinks, etc.