

# LEXMARK ROTOARY SHAFT ENCODER [SYSTEM REQUIREMENT SPECIFICATIONS]

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## 1.0 Purpose of the System

Our task is to research the feasibility of implementing an opto-reflective approach to the design of the encoder disk mounted to the shaft of a brush DC motor. If feasible, this will result in cost reductions that will benefit Lexmark. Lowering the cost improves Lexmark's competitive position in the marketplace.

## 2.0 Background Information

Lexmark uses a variety of motors in their design. For the purposes that our project is related to, Lexmark uses brush DC motors. The motors operate with a closed loop feedback to control the speed. In order for Lexmark to continue to be competitive in the marketplace, the cost of the RPM sensor needs to be low.

A rotary encoder, also known as a shaft encoder, is used to convert the position of an axle in to an electronic code. These types of encoders are used in applications which require precise shaft rotation measurement.

The current type of encoder implemented by Lexmark is an Optical Transmissive (opto-transmissive) encoder. This design incorporates an encoder disk which has several cut-out windows for occluding or passing infrared (IR) light. The sensor package consists of a light source and an optical sensor. The light source shines a beam which is repeatedly interrupted as the windows in the disk pass between the emitter and detector. The IR sensor then generates an output signal in the form of a pulse train. The following figures were used by the previous capstone team to help demonstrate this concept.

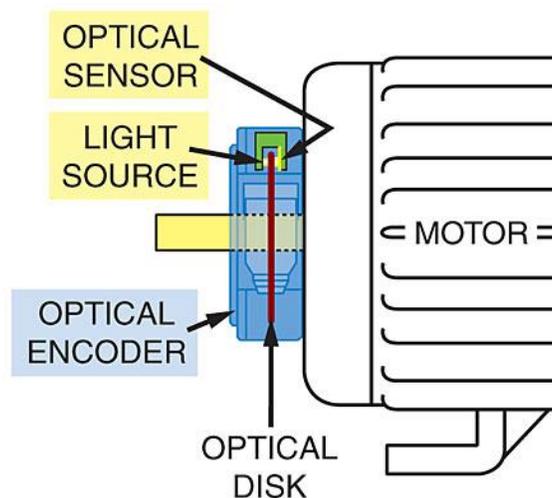
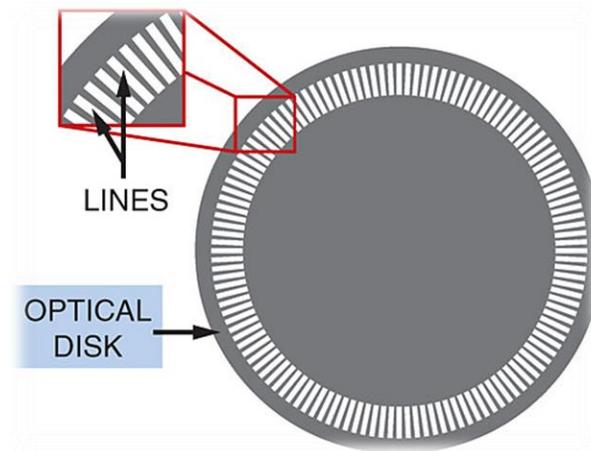


Figure 1: Optical Transmissive array example



**Figure 2: Example of an Optical Transmissive encoding disk**

Previous work was done on this design by another student team from the University of Louisville. The work they conducted looked at the possibility of replacing the opto-transmissive array with either a magnetic (Hall-effect sensor) approach or an opto-reflective approach. They tested both methods and compared their performance to that of the current transmissive method. During the opto-reflective approach, they used a custom made breadboard, an IR sensor, and a hand drawn disk with white and black sections to mark off the disk. Later, they used a plastic disk with windows. As the light beam was interrupted by the encoding disk, the sensor made a transition from high to low or vice versa. During the magnetic approach, the disk had magnetic sections on it with opposing polarities. A transition from a 'north' to a 'south' polarity triggered a rising or falling edge from the output pulse train. However, a Hall Effect sensor was used instead of an IR sensor for this application.

The objective of this project is to implement an opto-reflective method instead of the current approach. The difference here is that the sensor will read from the encoder disk, which will have a reflective material imprinted on it, instead of a plastic encoder disk with cut out windows. The opto-reflective array consists of an IR LED and a photo transistor in the same package. The package is planar and surface mountable. This will help since the spacing from the encoding disk to the opto-reflective array will be crucial.

Collector Current  $\frac{I_C}{I_{Cmax}} = f(d)$

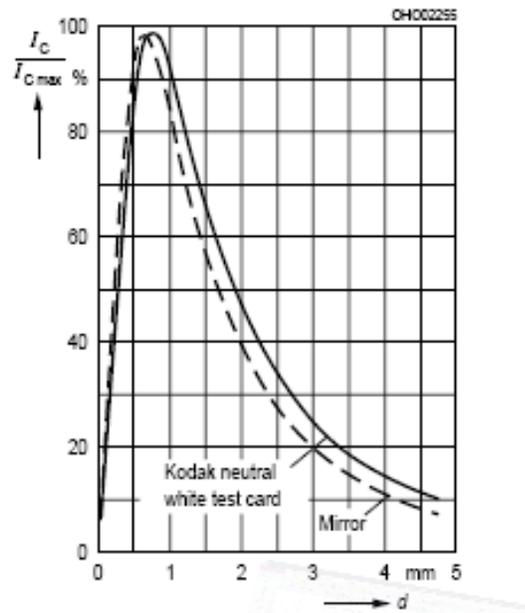


Figure 3: Collector current vs. spacing graph for OSRAM SFH 9201

The above graph came from the data sheet for the OSRAM sensor that we will be using. As shown, the peak of the curve is around 0.7mm-0.8mm. All of the data sheets for the sensors we will be testing state that the optimal distance is approximately one millimeter. However, there is also a noticeable difference in collector current based on the reflective material used. Here the solid black line indicates the results when a standard neutral white test card was used, while the dashed line indicates a highly polished aluminum mirror. Each datasheet for each of the other sensors we will use in testing has a very similar graph indicative of the same spacing requirement. Therefore, as a derived requirement we need to carefully control the encoding disk to opto-reflective array spacing.

### 3.0 System Overview and Operational Concept

Since our project is focusing solely on replacing the current approach with a reflective one, we only need to worry about characterizing one approach. The following diagram is an example of an opto-reflective array.

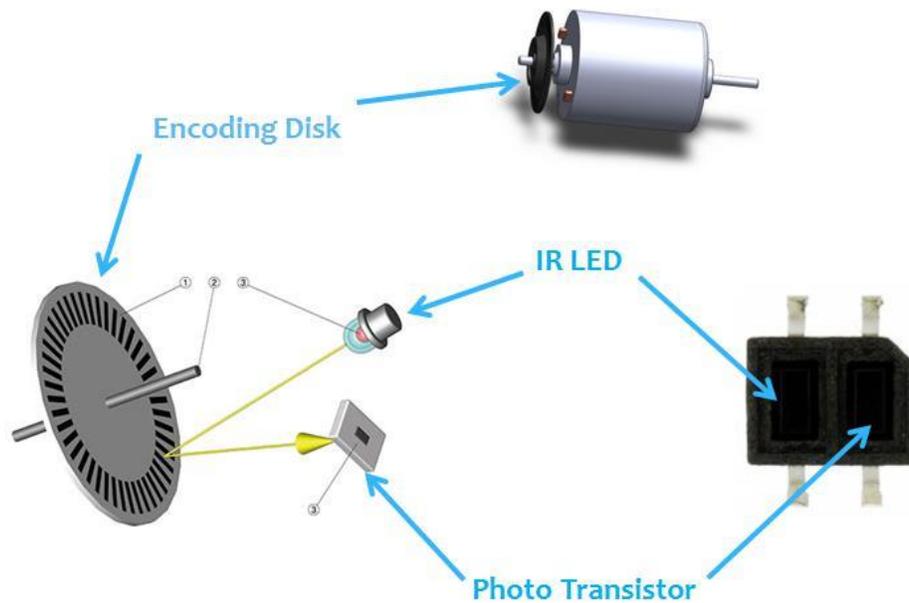


Figure 4: Opto-reflective array

Power will be provided to the PCB via a 5-pin connector. The power will then be fed to the motor and the opto-reflective array. The encoder disk is attached to a shaft running through the length of the motor. In the current design and in the previous group's work, the sensor detects when either a window or a piece of the disk is passing over it. Our design will be different only in that the sensor will detect whether a reflective or non-reflective portion of the disk is over it. The signal from the sensor is fed through the 5-pin connector and then to a Schmitt trigger, which is not located on the PCB. The Schmitt trigger helps clean up the signal into a pulse train. Since the Schmitt trigger is not located on the PCB of the shaft encoder, it is not required that we implement this in our design. We do have one available for observation purposes. The pulse train frequency is then used to determine how fast the motor is running. The following equation is how we determine rotations per minute (RPM) from the frequency of the pulse train:

$$(\text{speed in kHz}) \times \left( \frac{60 \frac{\text{sec}}{\text{min}}}{\frac{(\# \text{ of windows})}{\text{revolution}}} \right) = (\text{speed in RPM})$$

#### 4.0 System Description

Since our team is going for a reflective approach and not a magnetic or opto-transmissive approach as with previous efforts, the system is based around the opto-reflective array and disk. The disk will be pressure mounted to the motor shaft. The opto-reflective array will read the disk as it rotates, which

will be caused by supplying DC power input to the motor. The sensor array package will be mounted to the PCB along with the supporting circuitry. External power is supplied, and the output signal is also sent off the PCB.

### 4.1 Major Components

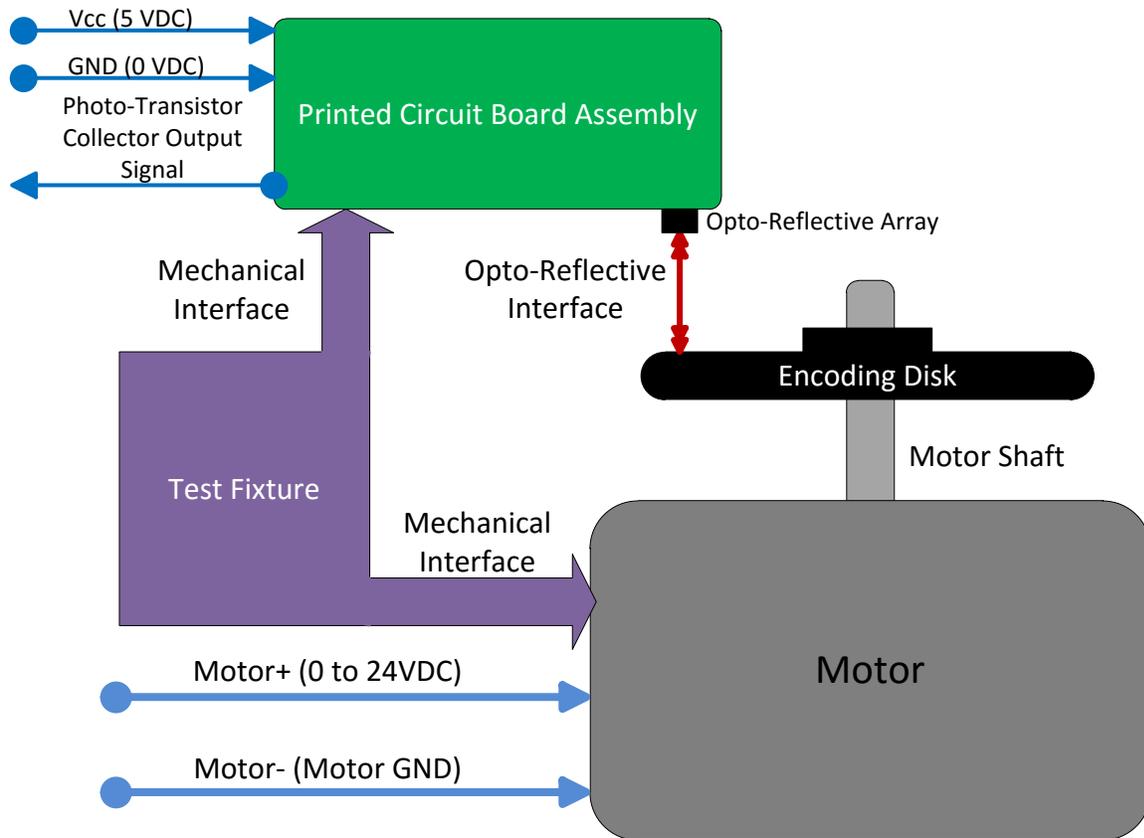


Figure 5: Major Component Diagram

#### 4.1.1 Printed Circuit Board (PCB) Assembly

The PCB is solder mounted on the motor assembly. It consists of printed circuit traces, supporting circuit components, the Opto-reflective array, and a 5-pin connector assembly soldered to the PCB.

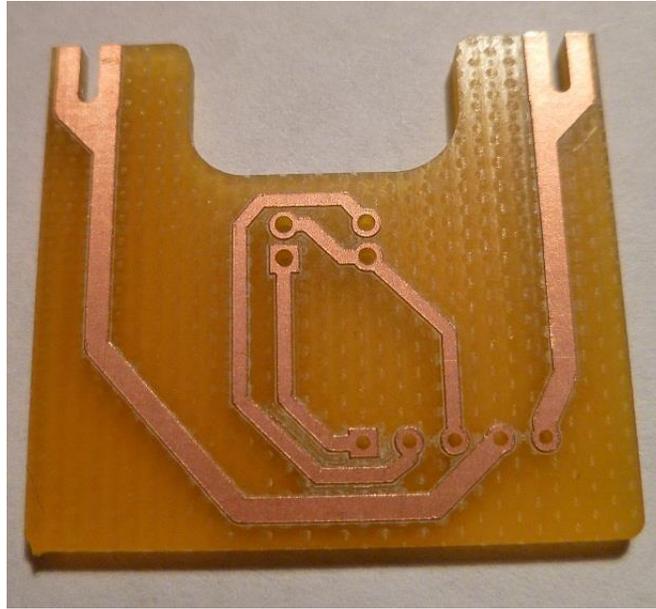


Figure 6: Version 1 of PCB

#### 4.1.1.A Opto-reflective Sensor

The sensor itself is an infrared LED emitter and photo transistor detector assembly. The sensor package is planar and is surface mountable. This helps us keep the size of the assembly within specifications. The LED emits an IR beam at a slight angle from the vertical which will then reflect off of the encoding disk. The reflected beam will then be sensed by the photo transistor. As each window passes over the sensor a transition from high to low or vice versa will be seen on the pulse train output. The required life time or “On-time” of the sensor needs to be around six months. During this time, the output signal must meet the on/off times detailed in the Functional Requirements section.

#### 4.1.1.B 5-pin Connector

The 5-pin connector that we will use in our project is the same one used in previous attempts on this project. The part number can be found on the appropriate data sheet. The pin-out can be found under the Electrical Interface section.

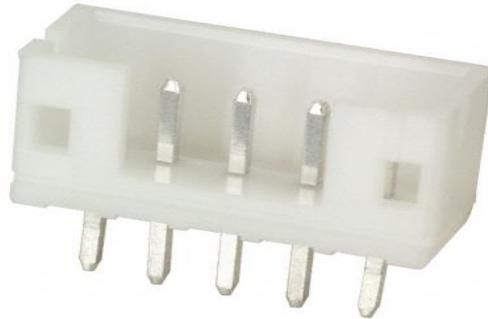


Figure 7: 5-pin connector B5B-PH-K-S

#### 4.1.2 Encoding disk

In previous work, the disk was plastic with windows, or was a disk with several magnetic sections of opposing polarities. The change from window-to-disk or from north-to-south is how the sensor determined its output signal.

The goal our group has set is to obtain a reflective solution. This means we are taking a simple material to make the disc out of, most likely plastic, and altering the surface characteristics so that half of the sections are reflective while the other half are not. We will implement encoders with 8, 48, and 64 windows per disk. A window designates the transition from a reflective area to a non-reflective area on the disk.

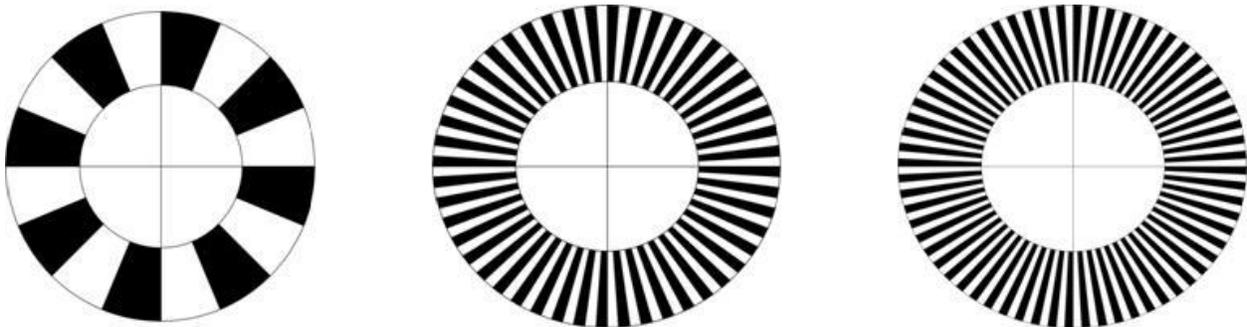
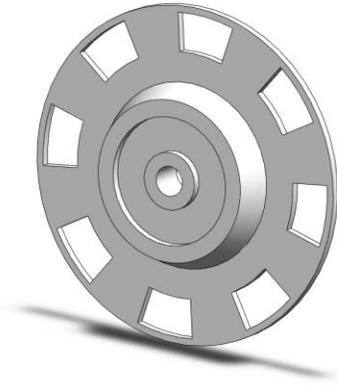


Figure 8: Encoding disk patterns - 8, 48, 64

We will be using several different methods of disk fabrication to use in our testing. We will first be using the very same disk that is currently used in the opto-transmissive shaft encoder design, which can be seen in Figure 10. We are testing this not only as a control for the rest of our disks but also to see if the sensor will work without having to replace any other component. If it works, it would be less expensive, and would achieve the goals of this project.



**Figure 9: 3-D representation of 8-window Encoding Disk**



**Figure 10: 3-D representation of 64-window Encoding Disk**

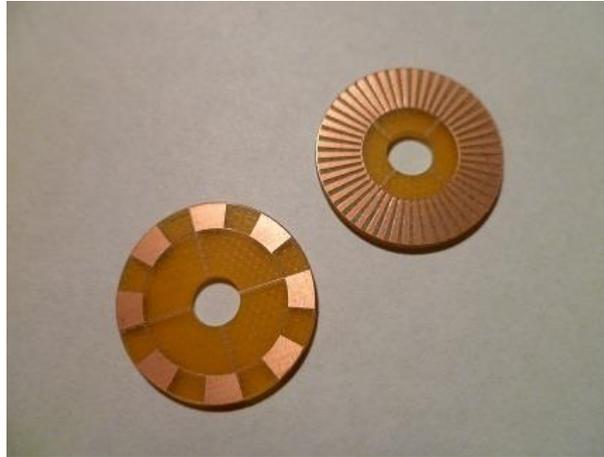


Figure 11: PCB version of 8-window and 48-window encoding disk

### 4.1.3 Motor

We will use the same motor currently used by Lexmark for testing our design. It is a Brushed DC motor which is controlled by a closed feedback loop involving the shaft encoder. By varying the voltage difference between the positive and negative leads one can control how fast the motor is spinning, and the direction (either clockwise or counter-clockwise). The negative lead pin can be set to ground for ease of control during testing (since our requirements focus on motor rotation speed and not direction).

Lexmark has been kind enough to provide us with several of these motors; therefore we have not had to go through any difficult procurement procedure to acquire them.

## 4.2 External Interfaces

### 4.2.1 Electrical Interface

DC power will be applied to the PCB via the 5-pin connector assembly. The output signal will also be sent out via that same assembly. The electrical requirements for the Input and Output are listed in the Functional Requirements section.

#### 1) 5-Pin Connector

The five pin connector that we will be using will be attached directly to the PCB, which is attached to the motor assembly. A picture of the actual connector can be seen in Figure 7. As seen in Figure 12, the pin-out is as follows:

- 1) Pin 1: Input to IR array (power supply for LED and phototransistor)
- 2) Pin 2: Feedback/output of IR sensor
- 3) Pin 3: Ground connection
- 4) Pin 4: Negative motor lead (ground for testing)

## 5) Pin 5: Positive motor lead

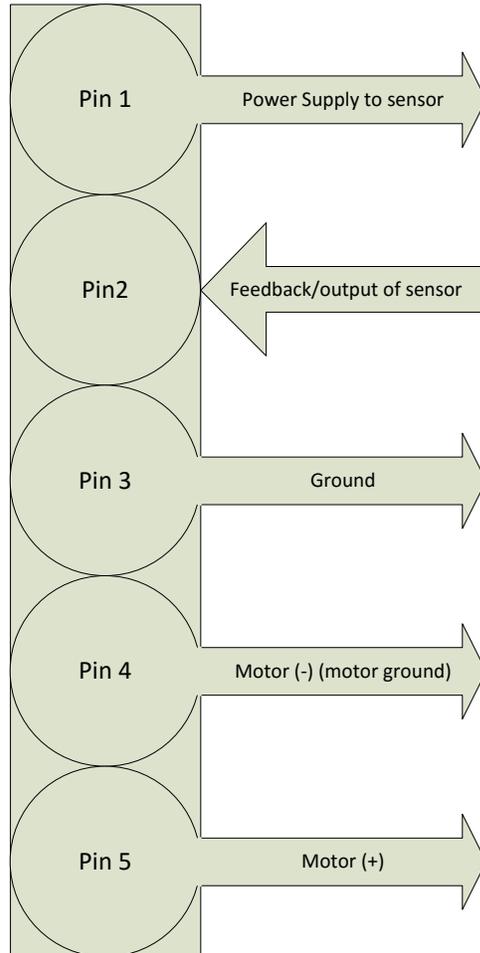


Figure 12: 5-Pin Connector Pin-out

## 4.2.2 Mechanical Interface

### 1) 5-Pin Connector

The five pin connector will be used to physically connect the motor to the external circuitry used by the printer. Note once again that Schmidt trigger is not on the PCB we are designing and is kept off board somewhere else in the printer.

### 2) Test Mount Assembly

The mechanical engineer majors in our group have been kind enough to provide us with a test mount assembly to anchor the motor to during our testing procedures. This will ensure that the signal we read from the sensor and is later sent through the Schmitt trigger is as clean as it can be. The previous group to work on this project used only their own hands to steady the motor during testing. We feel this will not only help with the accuracy and precision of our testing, but will also enable us to test the spacing requirement precisely.

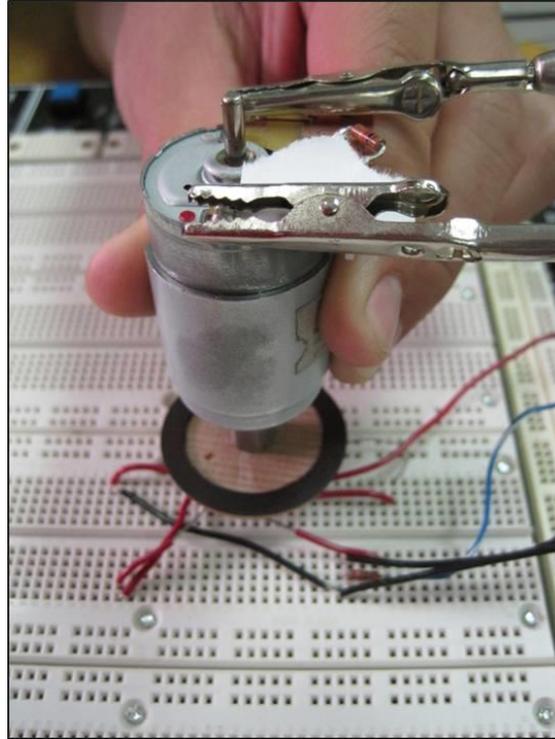


Figure 13: Previous group's test fixture

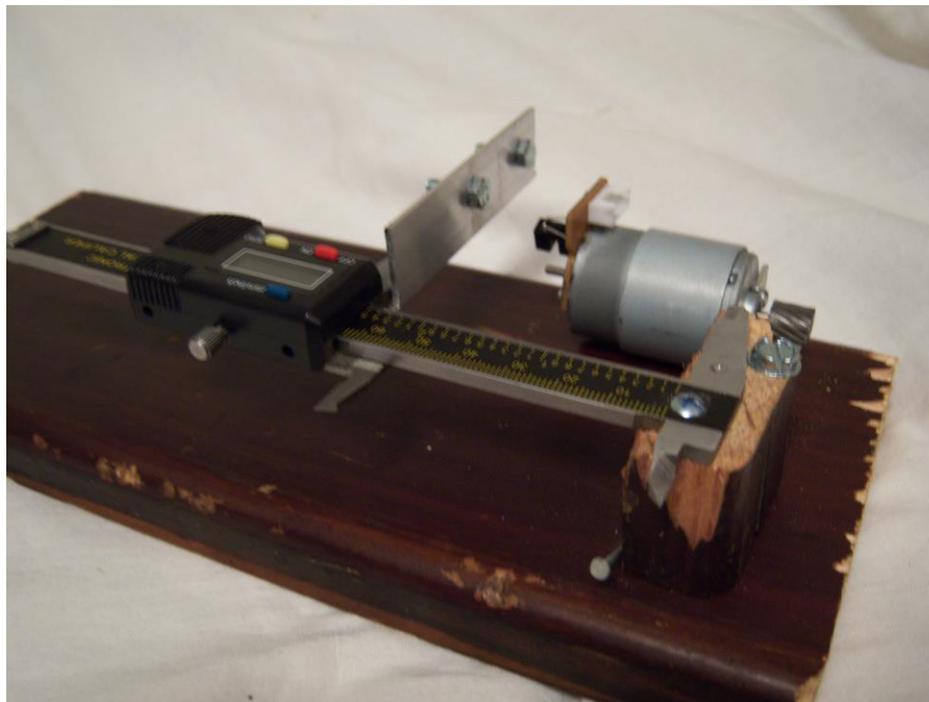


Figure 14: Our test fixture version 1

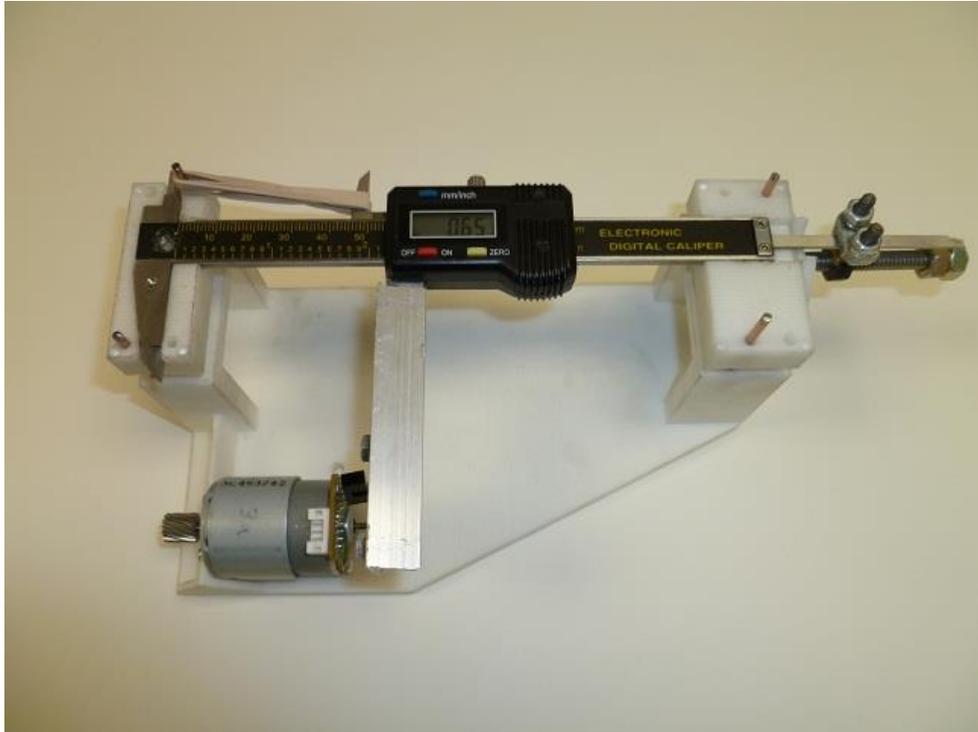


Figure 15: Our test fixture version 2

### 4.3 Internal Interfaces

The encoder disk will be pressure mounted on to the shaft of the motor. The distance from the disk to the sensor will be measured and controlled to be within a given tolerance listed in the Functional Requirements section. The IR sensor, supporting electronic devices and the 5-pin connector will be soldered to the PCB, which is directly mounted on to the motor.

### 4.4 Functional Requirements

#### 4.4.1 Input

The following are to be used as inputs to the design:

1. 24.0 Volts motor power, 5.0 Volts or 3.3 Volts, and Ground.

#### 4.4.2 Output

1. The encoder output should be a single channel 3.3 Volt level signal which will be passed through a Schmidt trigger. After which, the resulting pulse train should have the following specifications:
  - a. Input High must be  $\geq 2.2$  Volts.
  - b. Input Low must be  $\leq 0.6$  Volts.
  - c. Minimum On-Time of 17 microseconds and Minimum Off-Time of 17 microseconds
    - i. Pulse width is greater than 17 microseconds.
  - d. Encoder Counts per Revolution (CPR) should fall into a range of 1-8 and/or 48 or higher.

- e. Maximum Motor RPM = 6000 +/- 150 [RPM]
- f. Minimum Motor RPM  $\approx$  200 [RPM]

## 4.5 Design Constraints

1. Must have little to no environmental impact.
2. The following safety requirements are to be ensured:
  - a. Circuit to be RoHS compliant. Any plastics used to be UL Material Flame Class 94V0 minimum
3. The system must operate successfully between 0° and 50° C.
4. EMC testing to be performed once solution is established.
  - a. We will not have the capability to perform this test.
5. The encoder plus circuitry to fit in a pcb area with the following dimensions:
  - a. Length = 37.0 mm, Width = 30.5mm, Height = 14.0mm.

### 4.5.1 Cost

In volumes of 500K or greater:

1. For 1-8 CPR Solution
  - a. Bill of Material cost per unit should not exceed: \$0.20
2. For  $\geq$  48 CPR Solution
  - a. Bill of Material cost per unit should not exceed: \$0.35

## 4.6 Development Requirements

### 4.6.1 Flame Class 94V-0

Classification Requirements:

1. Not have any specimen that burns with flaming combustion for more than 10 seconds after either application of the test flame.
2. Not have a total flaming combustion time exceeding 50 seconds for the 10 flame applications for each set of 5 specimens.
3. Not have any specimens that burn with flaming or glowing combustion up to the holding clamp.
4. Not have any specimens that drip flaming particles that ignite the dry absorbent surgical cotton located 12" below the test specimen.
5. Not have any specimens glowing combustion that persists for more than 30 seconds after the second removal of the test flame.

## 5.0 References

### Flame Class 94V-0

"UL Test Procedures." *Specifications*. Web. 14 Feb. 2011.

<<http://www.portplastics.com/download/pdf/plastics/techspecs/techspecs24.pdf>>.

"UL94 Flammability Test Method Overview." *Boedeker Plastics*. 2011. Web. 14 Feb. 2011.

<<http://www.boedeker.com/bpi-ul94.htm>>.

### Sensors

#### OSRAM SFH 9201

See Appendix A

#### Fairchild QRE1113

See Appendix B

#### Sharp GP2S24J000F

See Appendix C

### 5-Pin Connector

#### JST B5B-PH-K-S

See Appendix D

### Motor

#### Grape2 3056582-004

See Appendix E

### Calipers

#### Cen-tech model 47256

See Appendix F

### Encoding Disk

#### 18B1192

See Appendix G