MSE 312 Mechatronics Design II

Electronics Drive Report

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SFU SCHOOL OF MECHATRONIC SYSTEMS ENGINEERING

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Glossary

$\mathbf{A}$ Area of heat sink required.

$\mathbf{CTR}_{min}$ Current Transfer Ratio.

$\mathbf{I}_c$ Collector Current of opto-isolator.

$\mathbf{I}_f$ Forward Current of opto-isolator.

$\mathbf{I}_o$ Output current from device.

$\mathbf{P}_d$ Power dissipated over device.

$\mathbf{R}_{CA}$ Thermal resistance from case to ambient.

$\mathbf{R}_{coil}$ Coil resistance across electromagnet.

$\mathbf{R}_{JC}$ Thermal resistance between junction and case.

$\mathbf{R}_{motor}$ Winding resistance for motor.

$\mathbf{R}_{ON}$ Output ON resistance.

$\mathbf{T}_A$ Ambient Temperature.

$\mathbf{T}_{jmax}$ Max junction temperature.

$\mathbf{V}_{cc}$ Input voltage for opto-isolator.

$\mathbf{V}_{dd}$ Input Voltage for h-bridge and electromagnet.

$\mathbf{V}_{INH}$ Minimum input voltage required for h-bridge.

$\mathbf{V}_{LED_{max}}$ Forward voltage drop across LED.

1 Introduction

In the electronics portion of the project, we are to design, build and test the electronics components which will be used in controlling the mechanical truss bridge we had built in the previous lab. The circuit is required to control the motion of the DC motor in both clockwise(CW) and counter-clockwise(CCW) direction as well as release/pick up of the metal puck. The final design of the circuitry should be tested on the breadboard and approved by the TA to ensure the circuit meets the requirements. The h-bridge and MOSFET require heat sinks due the conduction losses over the devices. Hence we also need to quantify the surface area of the required heat sink. The DC motor used in the lab is equipped with encoder which would be integrated into the system in the next stage of the project. We can control the direction of motor by controlling the input of the PWM signals.

1.1 Analysis and Design

1.1.1 Motor Drive Design

The major components of the motor drive consists the H-bridge and the two opto-isolators. The opto-isolators are used for isolating the control PWM signal from the motor to prevent unwanted electromagnetic interference. Each opto-isolator receives its own PWM signal which corresponds to clockwise and counter-clockwise rotation of the motor.

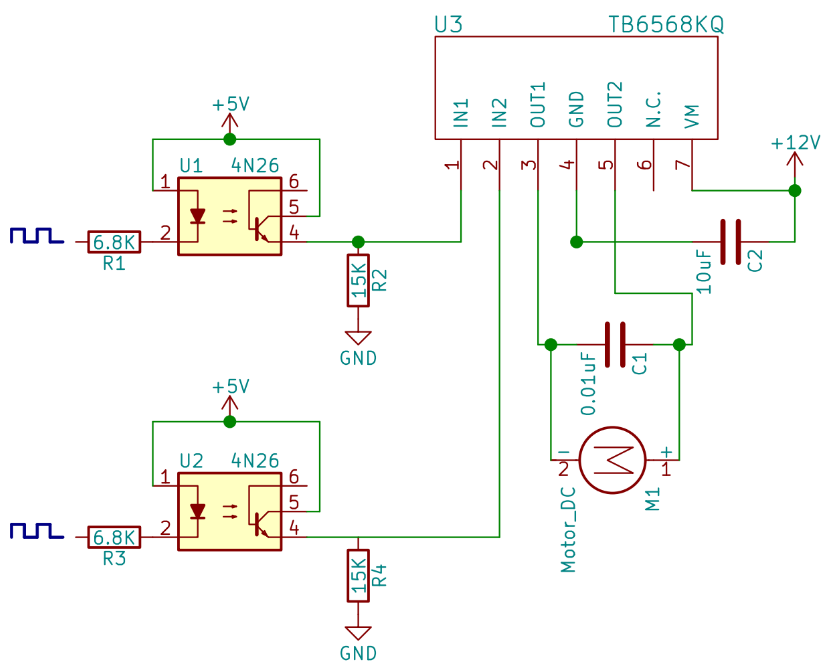

Figure 1: Motor Drive Circuit

As seen in figure 1, the opto-isolator has 6 pins but only 4 of them are used. Pins 1 and 5 are given 5 V, while pins 2 and 4 act as the input and output, respectively. The input has a 6.8kΩ resistor in series with the PWM input and the output has a 15kΩ resistor to properly bias the opto-isolator. Each of the outputs from the isolators is given to pins 1 and 2 on the h-bridge. Pins 3 and 4 are attached to the motor with a 0.01μF capacitor in parallel. The capacitor acts as a filter for any high frequency noise in the system. Pin 7 is connected to 12V with a 10μF capacitor in parallel to reduce electrical noise. Pin 4 is the h-bridge ground and therefore it is connected to the system ground.

1.1.2 Motor Drive Analysis

From the data sheets of the opto-isolator and the h-bridge we have:

$$V_{cc} = 5V$$
$$V_{LED_{max}} = 1.5V$$
$$CTR_{min} = 20\%$$
$$V_{INH} = 2V$$

We are using $V_{LED_{max}}$ and CTR_{min} because they are the worst case scenarios for this opto-isolator. Using this data we can find the resistors required to properly bias the opto-isolator. By the definition of CTR we have equation 1.

$$CTR = \frac{I_c}{I_f} \tag{1}$$

$$\left[\frac{V_{cc} - V_{LED}}{R_{IN}}\right] CTR \geq \frac{V_{INH}}{R_{OUT}} \tag{2}$$

solving for R_{out}/R_{in} we get:

$$\frac{R_{out}}{R_{in}} \geq \left[\frac{V_{INH}}{(V_{cc} - V_{LED})CTR}\right] \tag{3}$$

$$\frac{R_{out}}{R_{in}} \geq \left[\frac{2}{(5 - 1.5)0.2}\right]$$

$$\boxed{\frac{\mathbf{R_{out}}}{\mathbf{R_{in}}} \geq \mathbf{2.857}}$$

1.1.3 Electromagnet Drive Design

The major components of the electromagnet drive are the power MOSFET and a diode. The gate of the MOSFET is connected to a PWM signal with a 15kΩ resistor to ground. The purpose of the electromagnet drive is to use PWM signal to vary the voltage source and thus effect the current through the electromagnet to maximize the amount of force generated while maintaining the rated power. The force of the electromagnet is given as $F = u^2N^2I^2A/(2u_oL^2)$ where u, u_o, N, A, L are constant values for material property and physical dimensions for the electromagnet. The adjustable value to change the force is the current. However the maximum on time for the electromagnet is lowered when the applied power is increase and the duty cycle decrease.

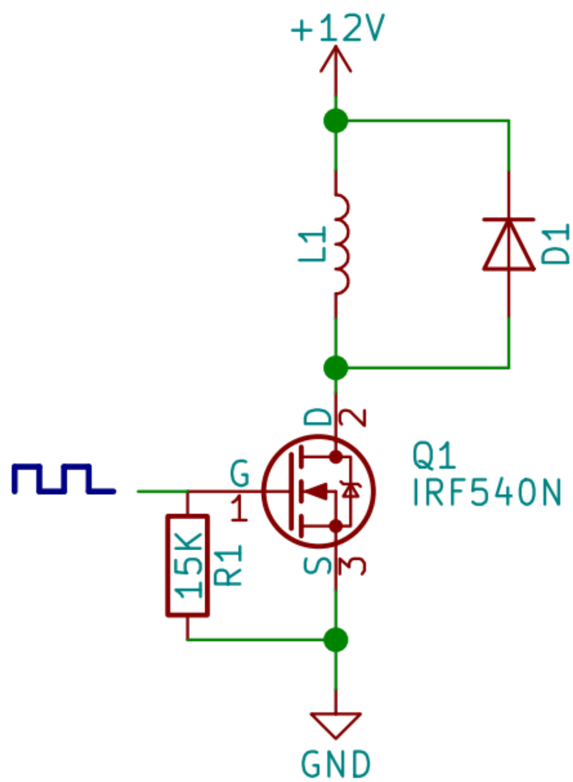

Figure 2: Electromagnet Drive Circuit

1.1.4 Electromagnet Drive Analysis

The only component that we have to specify in this circuit is a pull down resistor. Since we know that, $2V \leq V_{GS_{th}} \leq 4V$, we can just set the peak to peak input PWM to be $V_{pk-pk} = 4V$. The pull-down resistor ensures that the PWM output voltage is grounded when the MOSFET is switched off. The pull-down resistance, R_1, can be calculated by using $I_{DSS} = 250\mu A$ which is the zero gate voltage drain current.

$$R_1 \geq \frac{V_{GS_{th}}}{I_{DSS}}$$
$$R_1 \geq \frac{2}{250 \times 10^{-6}}$$
$$\boxed{\mathbf{R_1 \geq 8k\Omega}}$$

2 Heat Sink Design

The purpose of the heat sink design is to design the required area for the heat sink of the electronic device case to prevent the junction temperature of the electrical component from overheating and causing failures. The larger the power dissipation in the electronic device will require a larger area heat sink to dissipate the heat. The two major sources of power loss is through conduction and switching. Conduction losses occur when there is a voltage drop over the device due to internal resistances. Switching losses occur when the device is transitioning from a blocking state to a conducting state. Switching losses are very difficult to calculate and can vary based on multiple variables. For the purposes of this project we assumed that we only had conduction losses and neglected switching losses.

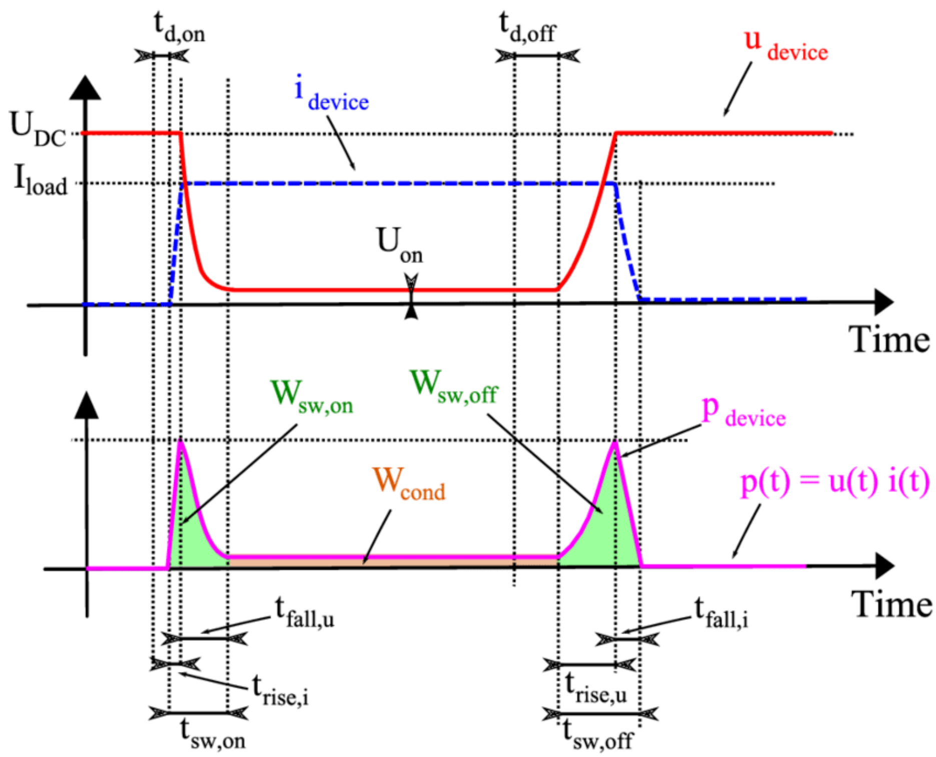

Figure 3: Power Loss over Swtiching Devices

2.1 H-Bridge (TB6568KQ)

By measuring the motor winding resistance we can get the current draw across the h-bridge and from the data sheet of the h-bridge we have:

$$T_{j_{max}} = 150°C$$

$$T_A = 25°C$$

$$R_{JC} = 6°C/W$$

$$R_{ON} = 0.55\Omega$$

$$R_{motor} = 6\Omega$$

$$I_o = \frac{V_{dd}}{R_{motor} + R_{ON}} = \frac{12V}{6\Omega + 0.55\Omega} = 1.832A$$

Using the equation for conduction loss and the current draw we can find the power loss across the h-bridge.

$$P_d = I_o^2 R \tag{4}$$
$$P_d = (1.832)^2(0.55) = 1.846W$$

To find the area of the heat sink, formula 7 is given. The thermal resistance from junction to ambient is equal to the thermal resistance of junction to the case plus the thermal resistance from junction to ambient as can be seen from formula 6.

$$T_{jmax} - T_A = R_{JA}P_d \tag{5}$$
$$R_{JA} = R_{JC} + R_{CA} \tag{6}$$
$$A = \left[\frac{50}{R_{CA}}\right]^2 \tag{7}$$

Substituting equation 6 into 5, the case to ambient thermal resistance is:

$$R_{CA} = \frac{T_{max} - T_A}{P_d} - R_{JC} \tag{8}$$
$$R_{CA} = \frac{150 - 25}{1.846} - 6$$
$$R_{CA} = 61.712°C/W$$

Plugging the thermal resistance into formula 7 we get:

$$\boxed{\mathbf{A} = \left[\frac{\mathbf{50}}{\mathbf{61.712}}\right]^{\mathbf{2}} = \mathbf{0.656cm^2}}$$

2.2 MOSFET (IRF540)

From the data sheet of the power MOSFET and the electromagnet we have:

$$T_{j_{max}} = 175°C$$
$$T_A = 25°C$$
$$R_{JC} = 10°C/W$$
$$R_{ON} = 0.077\Omega$$

To find the current from drain to source we first need to find coil resistance across the electromagnet. By measuring the resistance across the terminal of the electromagnet we found, $R_{coil} = 13\Omega$, therefore:

$$I_o = \frac{V_{dd}}{R_{coil} + R_{ON}} = \frac{12V}{13\Omega + 0.077\Omega} = 0.917A$$

Hence power dissipation will be:

$$P_d = I_o^2 R_{ON} = (0.917)^2(0.077) = 0.0706W$$

Using formula 8, we can find the thermal resistance from case to ambient.

$$R_{CA} = \frac{175 - 25}{0.0706} - 10$$
$$R_{CA} = 2112.89°C/W$$

Then using formula 7 we can find the required heat sink surface area

$$\boxed{\mathbf{A} = \left[\frac{\mathbf{50}}{\mathbf{2221.89}}\right]^{\mathbf{2}} = \mathbf{5.599 \times 10^{-4} cm^2}}$$

3 Experimental Results

From figure 4, we can see that as the duty cycle of the PWM input increases, the speed and terminal voltage of the motor increases. As we are limited by the function generator, we can only apply a minimum duty cycle of 20% and a maximum of 80%, thus this is our operating region. To determine the angular velocity we took a slow motion video of the rotor at no-load condition and counted the number of rotations in a second. Then by extrapolation we determined the approximate rpm.Peak angular velocity was around 660 rpm while the peak terminal voltage was around 11.15V for clockwise and counter-clockwise rotation. This shows that variable power and speed control can be achieved by using PWM signals. This data will be useful in the next section of the project when we have to control the speed and position of the motor shaft.

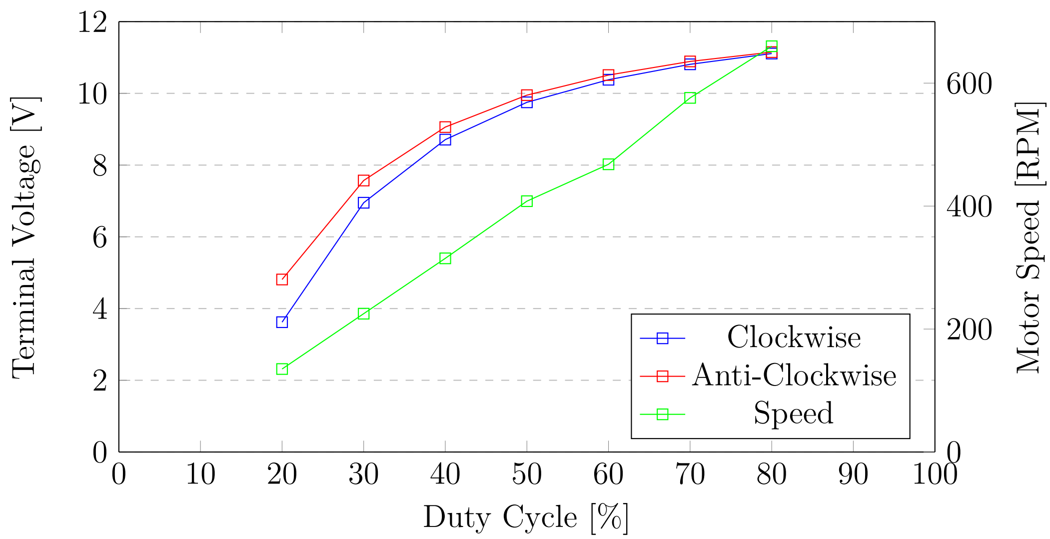

Figure 4: DC Motor Experimental Data

4 Conclusion

In this project we have learned about the theory of many electronic devices and their application, such as MOSFET, optical isolators, and the h-bridge integrated circuit. Some of the theoretical application includes MOSFET biasing, optical isolator biasing and heat sink design. In addition to learning theories, we were able to get hands on experience with using the electrical components along with the opportunity to design electronic circuit systems such as the motor and electromagnetic drive. The electromagnet drive design with the PWM allowed us to generate a larger magnitude force than with a constant DC voltage supply. While the motor drive design allowed us to control the magnitude and direction of the motor with a constant DC supply voltage. One key finding from the motor drive experiment was that an increase of PWM increases the terminal voltage and speed of the motor. The finding makes sense as increasing the PWM increase the average voltage, thus creating a higher DC source when the switching frequency is high enough. Overall, for future reference to improve the lab experience we recommend the lab or lecture to give more example questions and solutions to help us understanding how to choose the different type of electrical components and biasing. Otherwise, the electrical part of the project was nicely coordinated with the lecture and the learning experience from the class and the lab was pleasant to be part of.