

**ME 104**  
**Sensors and Actuators**

**Laboratory #7**  
**Stepper Motors**

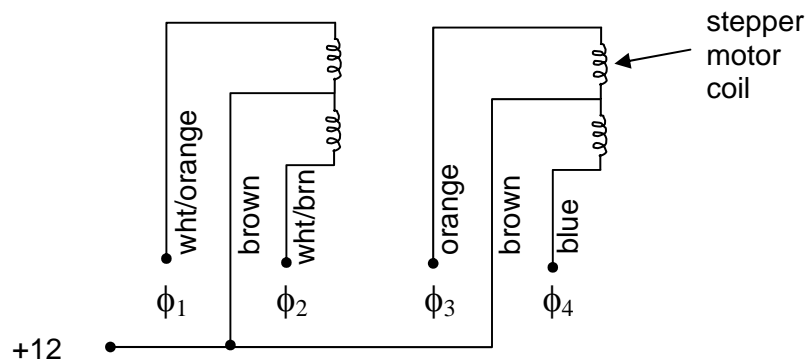
Department of Mechanical Engineering  
University of California, Santa Barbara

(Rev. 2006)

## Introduction

In this Laboratory, a *LabVIEW* VI for generating digital TTL signals is used to provide the stepping sequence for a four-phase unipolar stepper motor. You will then use a function generator and an analog drive circuit to control the rate of rotation of a unipolar stepper motor in full-step mode.

The stepper motor you will use in this Laboratory is a four-phase unipolar stepper motor produced by *Jameco Electronics* (Part #166705). The motor requires a DC **Supply Voltage** of 12 V and a **Current** of 140 mA. The motor has a **Step Angle** of  $3.8^\circ$ , **Phase Resistance** of  $84\ \Omega$ , and **Phase Inductance** of 16 mH. The phase and field coil schematic for this stepper motor is shown in Figure 1.



**Figure 1: Jameco stepper motor phase and field coil schematic. Colors refer to lead wires.**

## Background Reading

Please read the following material prior to this lab:

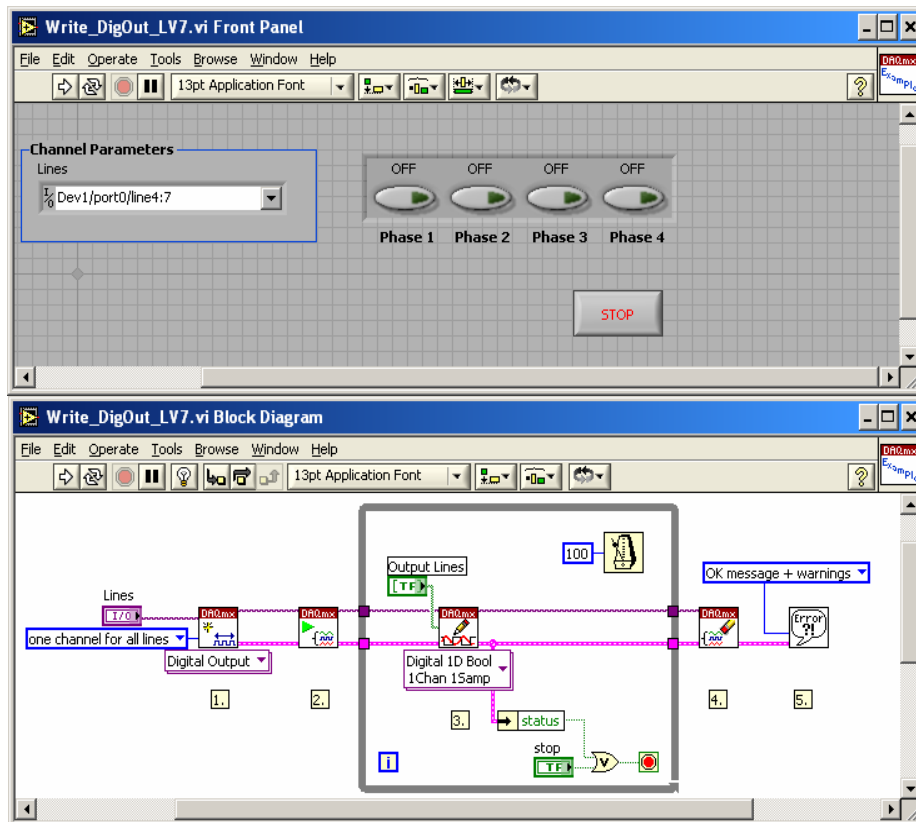
1. Histan and Alciatore, **Introduction to Mechatronics**, Section **6.3** and Sections **10.6**.
2. **Data Sheet**, *IRLIZ34N HEXFET Power MOSFET*, International Rectifier. Available on melab share drive: Z:\ME 104\Lab 7
3. **Data Sheet**, *74LS191 Synchronous 4-Bit Binary Up/Down Counters with Mode Control*. Available on melab share drive: Z:\ME 104\Lab 7
4. **Data Sheet**, *74LS86 Quad 2-Input Exclusive OR Gate*. Available on melab share drive: Z:\ME 104\Lab 7

## Experiment #1: Run VI to Simultaneously Generate Four Digital Signals

In this experiment, you will use a *LabVIEW* VI that simultaneously generates four digital TTL signals that can be used to provide the stepping sequence for a four-phase unipolar stepper motor.

The PCI-6024E DAQ Board has one digital input/output port (P0) with eight channels, all of which are TTL (transistor-to-transistor logic). Of these eight channels, the first four channels (P0.0, P0.1, P0.2, and P0.3) have been configured to **Read** (acquire) TTL signals, while the last four channels (P0.4, P0.5, P0.6, and P0.7) have been configured to **Write** (generate) TTL signals.

1. Open **Write\_DigOut.vi** from the melab share drive. The VI is shown in Figure 2.



**Figure 2.** This VI generates four digital output signals that are used to provide the stepping sequence for a four-phase unipolar stepper motor.

2. Choose an appropriate\* **Digital Ground** (D GND) pin on your CB-68LP connector block and provide (define) ground to that pin using the black (-) terminal of the “5 V FIXED 3 A” output from your Tektronix PS280 DC Power Supply\*. You **do not** need to turn on the power supply.

\* Choose a D GND pin that is reasonably close to the four Digital I/O channels (pins) you are using.

3. For viewing purposes, connect **Digital I/O Channel 4** (P0 . 4) and **Digital I/O Channel 5** (P0.5) to your oscilloscope. (Use the Connector Pinout sheets at each station to determine pin number for each digital output channel.)
4. Run your VI by clicking the **Run** button. Press the different Phase buttons to toggle them between ON (high) and OFF (low) states. Using your oscilloscope display, verify that the outputs from **Digital I/O Channel 4** (P0 . 4) and **Digital I/O Channel 5** (P0 . 5) are what you expect them to be.
5. Now connect **Digital I/O Channel 6** (P0 . 6) and **Digital I/O Channel 7** (P0 . 7) to your oscilloscope and verify that the outputs from those two channels are what you expect them to be (i.e., repeat Step 3 above for those two channels).
6. Stop running the VI by clicking the **Stop** button.
7. Ask your TA to check that you have successfully completed Experiment #1.

## Experiment #2: Increment the Position of a Unipolar Stepper Motor Using an Analog Current Amplification Circuit

In this experiment, you will use the *LabVIEW* VI to produce the stepping sequence for the *Jameco* four-phase unipolar stepper motor. The current from the Digital I/O Channels on the DAQ Board is not sufficient to drive the stepper motor. Therefore, before being sent into the stepper motor, the current from each of those digital channels must be amplified using a **Power MOSFET**. A power MOSFET is used to interface a low output current device such as a data acquisition board or computer port to another device (such as a stepper motor) that requires larger currents. The power MOSFET you will use in this laboratory is an **IRLIZ34N HEXFET Power MOSFET** manufactured by *International Rectifier*. (See Figure 3)

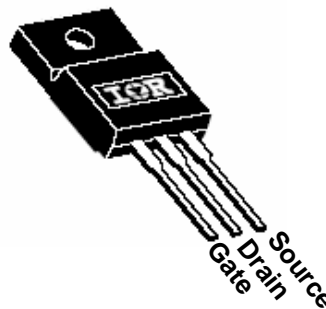
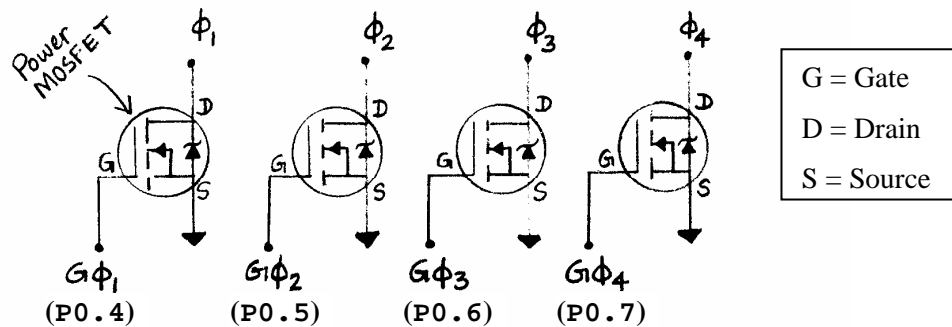


Figure 3. IRLIZ34N Power MOSFET

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\* Since the ground terminal from the DC Power Supply has already been connected to your electronic breadboard, you can use the ground connection from that breadboard to define ground.

1. Build and connect the circuits shown in Figure 1 and Figure 4. Your **gate phase** ( $G\phi$ ) signals will be generated by the **Digital I/O Channels**. Obtain  $G\phi_1$  from P0.4, obtain  $G\phi_2$  from P0.5, obtain  $G\phi_3$  from P0.6, and obtain  $G\phi_4$  from P0.7.



**Figure 4. Current amplification circuit using Power MOSFET**

Your goal is to verify that the phase sequence shown in Table 1\* does, in fact, induce  $3.8^\circ$  full-steps (increments) in shaft angular position.

**Table 1: Unipolar full-step phase sequence**

Step	$\phi_1$	$\phi_2$	$\phi_3$	$\phi_4$
1	ON	OFF	ON	OFF
2	ON	OFF	OFF	ON
3	OFF	ON	OFF	ON
4	OFF	ON	ON	OFF

↑ CCW  
 ↓ CW

2. Open yourname\_lab8\_ex1.vi.
3. Press the Phase buttons so that they specify **Step 1** (from Table 1) and then run your VI (once) by clicking the **Run** button. Your stepper motor shaft may move initially, but it will quickly come to a stop.

\* This is a direct copy of Table 10.1 from the Mechatronics textbook.

4. Now set (specify) **Step 2** (from Table 1) and then run your VI (once) by clicking the **Run** button. The position of your stepper motor shaft should full-step (increment) once by  $3.8^\circ$  in the clockwise (CW) direction\*.
5. Specify **Step 3** (from Table 1) and then run your VI (once) by clicking the **Run** button. Verify that the position of your stepper motor shaft full-steps (increments) once by  $3.8^\circ$  in the clockwise (CW) direction.
6. Specify **Step 4** (from Table 1) and then run your VI (once) by clicking the **Run** button. Verify that the position of your stepper motor shaft full-steps (increments) once by  $3.8^\circ$  in the clockwise (CW) direction.
7. Specify **Step 1** (from Table 1) and then run your VI (once) by clicking the **Run** button. Verify that the position of your stepper motor shaft full-steps (increments) once by  $3.8^\circ$  in the clockwise (CW) direction.
8. Repeat the step sequence as indicated above (in Table 1) and verify that each step results in a CW full-step (increment) of  $3.8^\circ$ .
9. Now reverse the step sequence and verify that each step results in a CCW (counter-clockwise) full-step (increment) of  $3.8^\circ$ .

You can also verify that the phase sequence shown in Table 2<sup>†</sup> does, in fact, induce  $1.9^\circ$  half-steps (increments) in shaft angular position. Notice that, to jump between any two adjacent steps shown in Table 2, you would need to change the state of only one phase at a time. Therefore, you can conveniently verify the half-step sequence by running the VI continuously.

**Table 2: Unipolar half-step phase sequence**

Step	$\phi_1$	$\phi_2$	$\phi_3$	$\phi_4$
1	ON	OFF	ON	OFF
1.5	ON	OFF	OFF	OFF
2	ON	OFF	OFF	ON
2.5	OFF	OFF	OFF	ON
3	OFF	ON	OFF	ON

▲ CCW

▼ CW

\* Although it is not practical for the human eye to exactly verify a small angle such as  $3.8^\circ$ , you should make sure that the step (increment) you observe is within the ballpark.

<sup>†</sup> This is a direct copy of Table 10.2 from the Mechatronics textbook.

3.5	OFF	ON	OFF	OFF
4	OFF	ON	ON	OFF
4.5	OFF	OFF	ON	OFF

10. Press the Phase buttons so that they specify **Step 1** (from Table 2).
11. Continuously run your VI by clicking the **Run Continuously** button. Your stepper motor shaft may move initially, but it will quickly come to a stop.
12. Now set (specify) **Step 1.5** (from Table 2). Verify that the position of your stepper motor shaft half-steps (increments) once by  $1.9^\circ$  in the clockwise (CW) direction.
13. Now set (specify) **Step 2** (from Table 2). Verify that the position of your stepper motor shaft half-steps (increments) once by  $1.9^\circ$  in the clockwise (CW) direction.
14. Continue this process by specifying the half-step sequence shown in Table 2. Verify that each half-step results in a CW half-step (increment) of  $1.9^\circ$ .
15. Now reverse the half-step sequence shown in Table 2 and verify that each half-step results in a CCW (counter-clockwise) half-step (increment) of  $1.9^\circ$ .
16. Stop running the VI by clicking the **Abort Execution** (stop) button.
17. **Ask your TA to check that you have successfully completed Experiment #2.**

### Experiment #3: Observe the Output of a Binary Counter Chip

In this experiment, you will use a function generator and an oscilloscope to verify the behavior of the four output bits of a binary counter chip. The binary counter chip you will use in this Laboratory is the **74LS191 Synchronous 4-Bit Binary Up/Down Counter**. The pin diagram for this counter chip is shown in Figure 5.

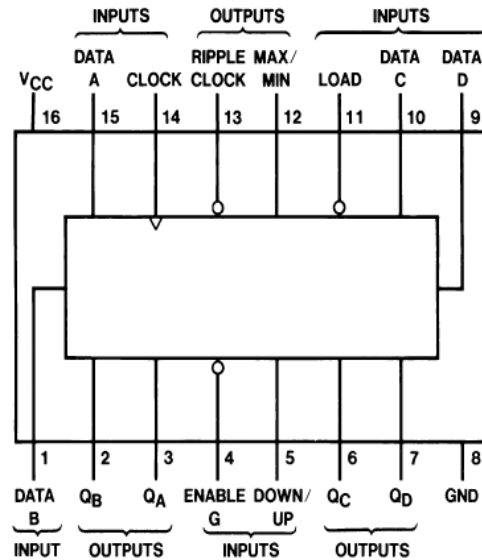
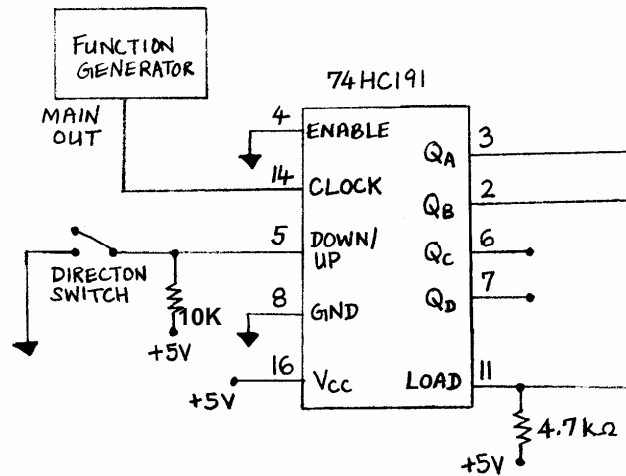


Figure 5. Pinout for 74LS191 binary counter chip

1. Make sure that your CB-68LP connector block is no longer connected to your power MOSFETs. In particular, **disconnect the CB-68LP connector block from Pin 1 of each of the four power MOSFETs.** (Recall that you made these connections during Experiment #2). Retain the connection from the stepper motor to the power MOSFETs.
2. Connect the **MAIN OUT** terminal on the function generator to **Channel 1** on your oscilloscope. Set the vertical scale on your oscilloscope to 5.00 volts/division.
3. Find the **FUNCTION** selection buttons on your function generator. Select (press down) the square wave function ( $\square$ ) button. Make sure that none of the other buttons on that row are pressed down.
4. On your function generator, select the “**0-20Vp-p OPEN CIRCUIT**” setting by pressing up that button. This will extend your voltage output range to 0-20 volts, peak-to-peak.
5. Generate a **square wave** with the following characteristics:
  - Amplitude = **5 V** peak-to-peak
  - **DC offset = 2.5 V** (all parts of the square wave should be above 0 V)
  - Frequency = **100 Hz**.
6. Verify the properties of your square wave using the oscilloscope display. The period of your square wave should be  $T = 10$  milliseconds. For best viewing, set the horizontal scale on your oscilloscope to 10 ms/division.

7. Using an electronic breadboard, build and connect the circuits shown in Figure 6. For the purposes of this Laboratory, the “**direction switch**” shown in Figure 6 will consist of a black wire. You can use this direction switch to make the counter count up or count down.



**Figure 6. Binary up/down counter circuit**

8. Turn on (engage) the direction switch. When you do this, Pin 5 on your counter chip has been connected to 0 V (low), so your counter should count up (increment).\*
9. Connect the least significant bit  $Q_A$  (pin 3) of the counter chip output to **Channel 2** of your oscilloscope. Verify that the output  $Q_A$  is a digital pulse train with period  $2T$ , where  $T$  is the period of your clock input (from the function generator). Make a sketch.
10. Now connect the second least significant bit  $Q_B$  (pin 2) of the counter chip output to **Channel 2** of your oscilloscope. (Remove the connection to  $Q_A$ ). Verify that the output  $Q_B$  is a digital pulse train with period  $4T$ . Make a sketch.
11. Connect the third least significant bit  $Q_C$  (pin 6) of the counter chip output to **Channel 2** of your oscilloscope. (Remove the connection to  $Q_B$ ). Verify that the output  $Q_C$  is a digital pulse train with period  $8T$ . Make a sketch.
12. Connect the most significant bit  $Q_D$  (pin 7) of the counter chip output to **Channel 2** of your oscilloscope. (Remove the connection to  $Q_C$ ). Verify that the output  $Q_D$  is a digital pulse train with period  $16T$ . Make a sketch.
13. **Ask your TA to check that you have successfully completed Experiment #3.**

\* See counter data sheet for explanation.

## Experiment #4: Control the Angular Velocity of a Unipolar Stepper Motor Using an Analog Drive Circuit

In this experiment, you will use a function generator and an analog drive circuit to control the rate of rotation of a unipolar stepper motor in full-step mode. Your analog drive circuit will consist of a binary counter chip and an exclusive OR (XOR) gate chip. For this laboratory, the XOR gate chip we will use is the **74LS86 Quad 2-Input Exclusive OR Gate**. This XOR gate chip has four XOR gates (Figure 7), but you will only need to use three of them for this Laboratory.

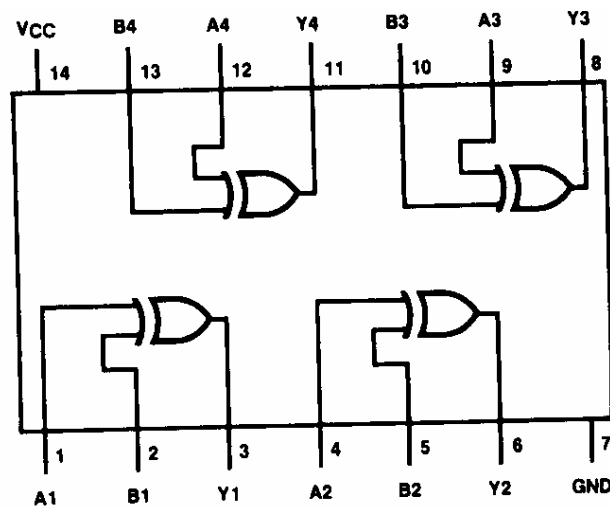


Figure 7: Pinout for 74LS86 Exclusive OR chip

1. Set your function generator to output a square wave with amplitude 5V and frequency 1 Hz.
2. Build\* and connect the circuits shown in Figure 8. Don't forget to provide power ( $V_{CC} = +5V$ ) and ground (GND) to your XOR gate chip.

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\* Hint: before building the circuit, refer to Figure 7 and select appropriate pins on your XOR chip to implement the logic circuit shown in Figure 8. Write down those pin numbers on Figure 8.

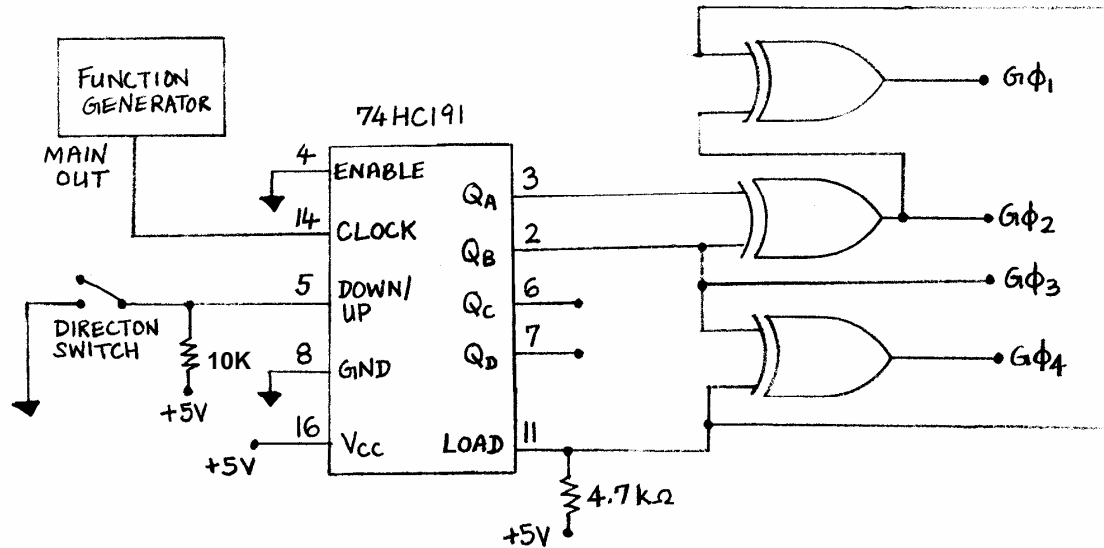


Figure 8: Unipolar stepper motor full-step drive circuit

3. Turn on (engage) the direction switch.
4. Vary the frequency of your clock signal (square wave from the function generator) between the range 0-400 Hz and observe the direction and rate of rotation of the shaft of the stepper motor. The rate of rotation should increase with frequency.
5. Verify that the direction of rotation changes depending on whether the **direction switch** is on (engaged) or off (disengaged).
6. Ask your TA to check that you have successfully completed Experiment #4.

## Saving Files

Before you leave, remember to save all of your files to your ECI account (for later use and backup purposes).

## Laboratory Report

1. For the VI you wrote in this laboratory (listed in the preceding section), provide a printout that shows the front panel and block diagram.

2. In instruction 4 during Experiment #2, you were told that “Your stepper motor shaft *may* move initially, but it will quickly come to a stop.” In which scenario will the stepper motor not move at all? In which scenarios will the stepper motor initially move, but quickly come to a stop? Explain.
3. In Experiment #2, you ran your VI using the **Run** button to verify the full-step sequence, but you used the **Run Continuously** button to verify the half-step sequence. Explain why using the **Run Continuously** button to verify the full-step sequence would have been problematic.
4. Figure 10.28 in the Mechatronics textbook shows the timing diagram for the two least significant output bits of a binary counter. Draw a timing diagram that shows the clock input bit and the output bits for the binary counter you observed in Experiment #3. That is, provide a timing diagram that clearly shows **CLOCK**, **Q<sub>A</sub>**, **Q<sub>B</sub>**, **Q<sub>C</sub>**, and **Q<sub>D</sub>**. Make sure that your signals are in phase.
5. In Experiment #3, the clock input to your counter chip had a voltage in the range [-5V, +5V], but the output from the counter chip was in the range [0, +5V]. From a physical point of view, explain why the output from your counter chip could not take negative values.
6. Redraw the analog drive circuit shown in Figure 8, but include the pin numbers you used for the XOR gate chip.
7. In this Laboratory, you controlled the angular position and/or the angular velocity of the stepper motor shaft. Would you describe your control methods as **open loop** or **closed loop**? Explain.
8. What is the (listed) detent torque and holding torque of the stepper motor used in this Laboratory?\*

## Additional Reading

Feel free to read the following material to learn more about *Jameco* stepper motor specifications.

1. **Jameco Electronics Catalog**, , Page 41 (**Stepper Motors**), Jameco Electronics. Available online at [www.jameco.com/Jameco/Products/ProdCT/motor.pdf](http://www.jameco.com/Jameco/Products/ProdCT/motor.pdf).

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\* Refer to **Additional Reading** section.