STUDENT WORKBOOK

QNET Mechatronic Actuators Board for NI ELVIS

Developed by Quanser

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SOLENOID

Topics Covered

- Magnetic fields of coiled conductors.
- Implementation of electromagnetic field theory for use in a solenoid.

Prerequisites

- The QNET Mechatronic Actuators has been setup and tested. See the QNET Mechatronic Actuators Quick Start Guide for details.
- You have access to the QNET Mechatronic Actuators User Manual.
- You are familiar with the basics of LabVIEW™.
- You are familiar with the basics of electromagnetism.

1 Background

A solenoid is a type of electromagnet that produces a uniform magnetic field in a volume of space when an electric current flows through a conductor that is tightly wound into a helix shape. In electromechanical applications, the coil is wound around a movable steel or iron rod called the armature. Typically, solenoids are only used for fast, but very limited, linear movements of the armature, such as on/off position switches, dot matrix printers or fuel injectors. Its function is based on the principle that current flowing through a conductor will induce a magnetic field that is perpendicular to the conductor.

1.1 Right Hand Rule

Electrons moving through a conductor generate a magnetic field that is centered at the conductor. In particular, the *right hand rule* can be used to determine the direction of the resulting magnetic field. For a straight conductor, imagine your right thumb pointing in the direction of the current flow through the conductor. The curl of the remaining fingers of your hand indicate the direction of the magnetic field. Vice versa, if the direction of magnetic field is known, it is possible to determine the direction in which the current is flowing.

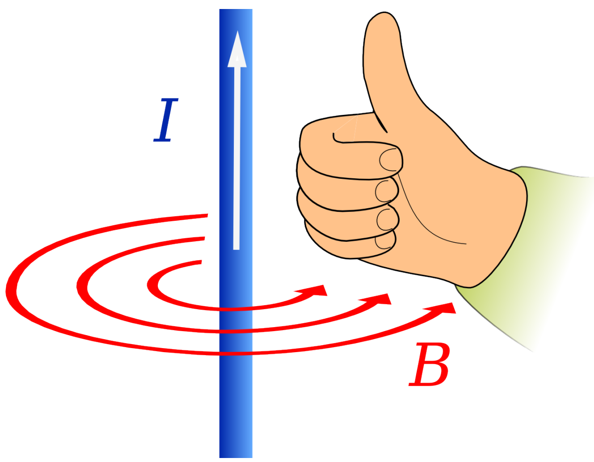


Figure 1.1: Conductor right hand rule [1]

This idea can be extended to coiled conductors such as helices or solenoids. Imagine your right hand curls in the direction of the electron flow of the coil. Your right thumb then indicates the direction of the magnetic field by pointing to the north pole of the coil. Vice versa, if the direction of the magnetic field is known, it is possible to determine the direction of the current flow in the coil.

1.2 Choosing a Solenoid

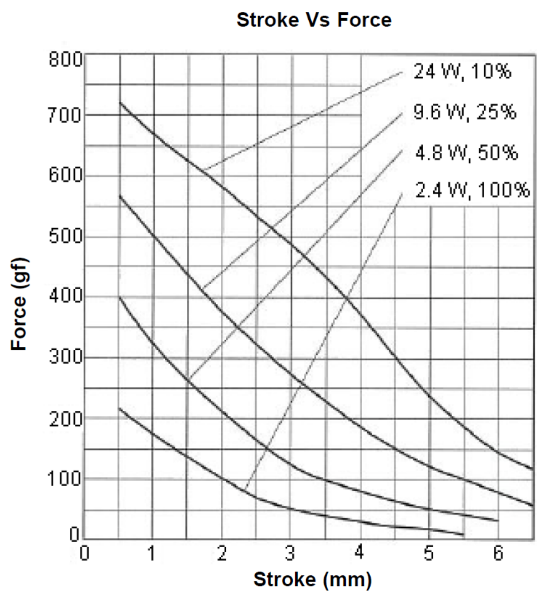
To choose the right solenoid for your project, you first need to specify your requirements, notably the holding force, desired stroke and duty cycle. The holding force of a solenoid is dependent on the length of the solenoid and the number of coil turns, the material of the armature, and the applied current.

Depending on the application, solenoids may be used for short pulses or continuous use. The relationship between active (*ON*) and inactive (*OFF*) times of the solenoid is captured in the duty cycle

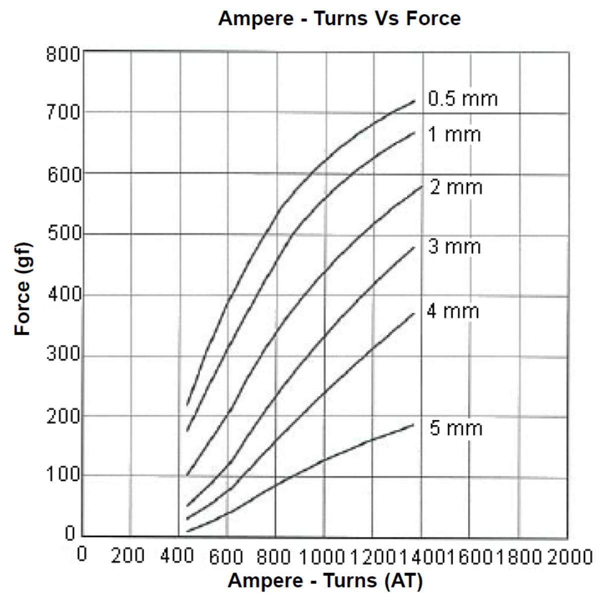
$$\text{Duty Cycle} = \frac{ON}{ON + OFF} \times 100\ \%. \tag{1.1}$$

[1] José Fernando - Universidad de Granada

2 In-Lab Exercise



(a) Stroke vs. Force



(b) amp-vs-force

Coil Data

Duty Cycle (%) = $\frac{\text{“ON” Time}}{\text{“ON” Time + “OFF” Time}} \times 100\%$	Continuous (100%)	Or Less (50%)	Or Less (25%)	Or Less (10%)
Maximum “on” time seconds	∞	55	19	3
Watts at 20°C	2.4	4.8	9.6	24
Ampere - turns at 20°C	432	615	864	1,368

Specification Table

Description	Resistance (20°C) Ω ±10%	Number Turns	Volts DC				Part Number
Solenoid, Open Frame, Push, 6 V	15	1,080	6	8.5	12	19	MCSMO-0630S06STD
Solenoid, Open Frame, Push, 12 V	60	2,160	12	17	24	38	MCSMO-0630S12STD
Solenoid, Open Frame, Push, 24 V	240	4,320	24	34	48	76	MCSMO-0630S24STD

(c) Coil Data and Specifications

Figure 2.1: Parts of the data sheet of a solenoid

1. Open `QNET Actuators - DC Motors and Solendoid.vi` . **Make sure the correct Device is chosen.**
2. Run the VI.
3. You can activate the solenoid by pressing and depressing the Power Solenoid button. Activate the solenoid and touch it with your fingers. Characterize the temperature of the solenoid qualitatively.
4. Leave the VI running in the background with the solenoid activated.
5. Figure 2.1 shows parts of a typical datasheet of a solenoid. In particular, we are interested in the solenoid with the part number MCSMO – 0630S12STD in Figure 2.1c. This solenoid is designed such that it can run continuously at 12 V, but may be run at higher voltages for shorter duty cycles. With the data given in Figure 2.1c, determine the current that runs through the solenoid for the specified voltages that relate to a 100 %, 50 %, 25 % and 10 % duty cycle using Ohm's Law.

6. Explain why the maximum time the solenoid is active is decreasing with a lower duty cycle.
7. Explain why you would want to run a solenoid at a higher voltage.
8. Using Figure 2.1b, explain why the holding force is lower if the armature is travelling further.
9. Recall the temperature test from the beginning of the laboratory experiment. Note the hot surface warning symbol on the board, shown in Figure 2.2. Repeat the test by briefly and ***cautiously*** touching the solenoid with your fingers. Characterize the temperature of the solenoid qualitatively. Explain your observations.

Figure 2.2: Hot Surface Warning Symbol

10. Click on the Stop button to stop the VI.

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DC MOTOR AMPLIFIERS

Topics Covered

- Actuator dead-band measurement and compensation.
- Linearity of an amplifier.

Prerequisites

- The QNET Mechatronic Actuators has been setup and tested. See the QNET Mechatronic Actuators Quick Start Guide for details.
- You have access to the QNET Mechatronic Actuators User Manual.
- You are familiar with the basics of LabVIEW™.
- You are familiar with basic circuit theory.

1 Background

Amplifiers are essentially an electrical network that have a single input and a single output. The voltage gain of the amplifier is defined as the ratio of the output and input voltages when each is measured relative to earth ground. The *operational amplifier* (op-amp) forms the basis of many approaches to signal conditioning. An op-amp is a high-gain DC amplifier that has two inputs known as the inverting input (-), and the non-inverting input (+).

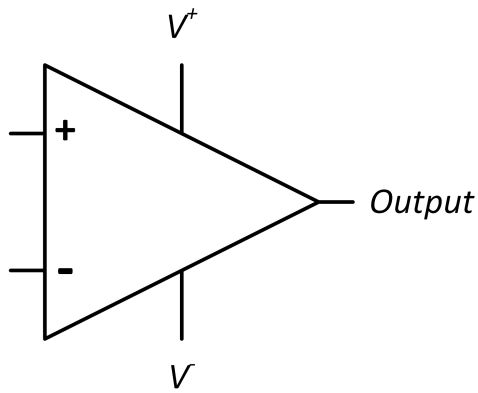


Figure 1.1: Operational amplifier (op-amp) symbol

The output from the amplifier depends on the way in which the inputs and outputs are interconnected. Typically, op-amps are supplied on a silicon chip and have the four inputs shown in Figure 1.1, and a voltage offset.

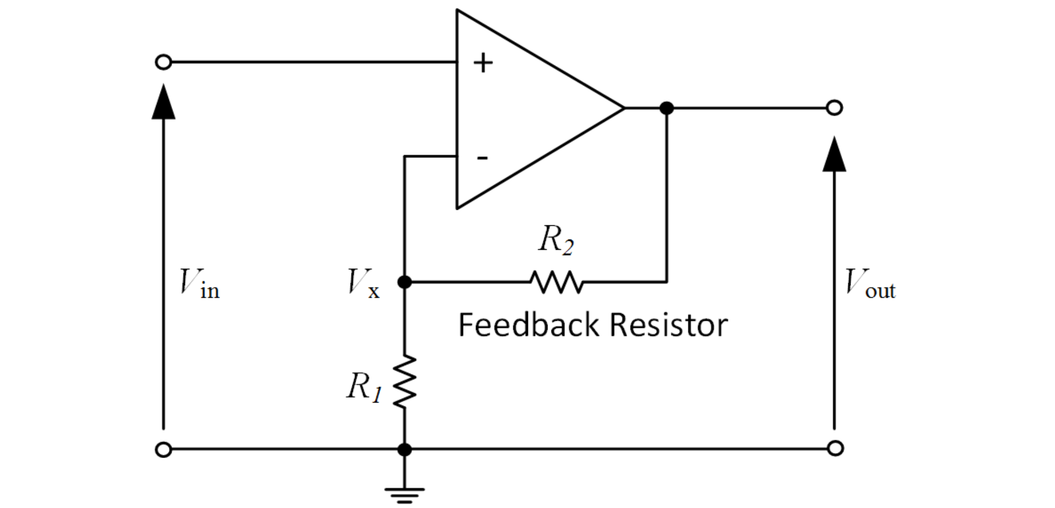
1.1 Linear Amplifier

The first of the two brushed DC motors on the QNET Mechatronic Actuators uses a *linear* amplifier circuit to scale the voltage and current supplied by the NI ELVIS II. The linear amplifier circuit uses two op-amps configured as non-inverting amplifiers, shown in Figure 1.2a. In the case of an op-amp connected as a non-inverting amplifier, the output can be interpreted as being taken across a potential divider circuit consisting of R_1 in series with R_2. Therefore, the voltage, V_x, can be expressed as

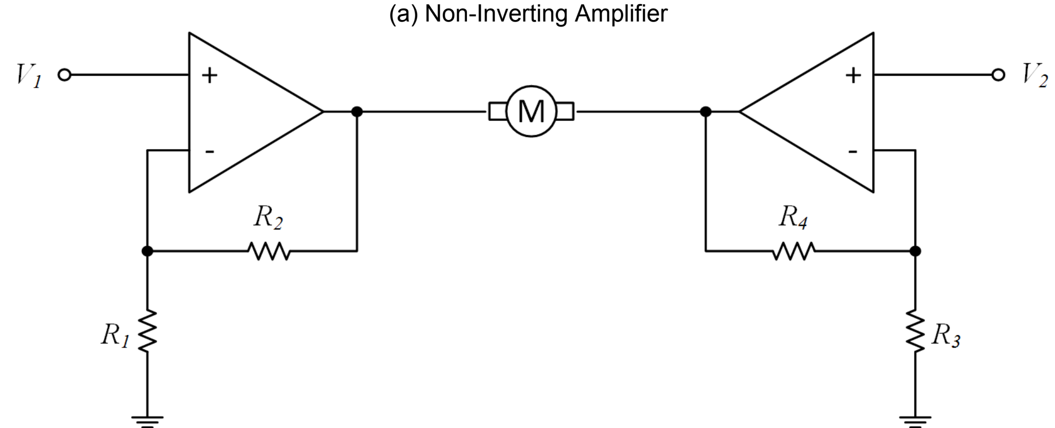
$$V_x = \frac{R_1}{R_1 + R_2} V_{\text{out}} \tag{1.1}$$

Given that there is virtually no current through the op-amp between the two inputs, there is virtually no potential difference between them. Viewing the op-amp as ideal, we can let $V_x = V_{\text{in}}$ which yields

$$\text{Voltage Gain} = \frac{V_{\text{out}}}{V_{\text{in}}} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1} \tag{1.2}$$



(a) Non-Inverting Amplifier



(b) Bi-Directional Motor Control

Figure 1.2: QNET Mechatronic Actuators Linear amplifier configuration

The two non-inverting amplifiers are combined in a bi-directional configuration, shown in Figure 1.2b, to allow the motor to turn in either direction. This configuration was used because the brushed DC motors on the NI ELVIS II are rated for 24V. Using the ideal non-inverting configuration shown in Figure 1.2a, we would ideally connect one side of the motor to the amplifier, and the other to ground. We would then be able to drive the motor using ±24V. However, as is often the case when working with specific system configurations in mechatronics, the QNET Mechatronic Actuators does not have a -24V supply. To overcome this limitation, the system was configured as shown in Figure 1.2b in order to provide a complete 48V operating range. In the configuration shown, the two amplifiers work together to supply the commanded voltage across the motor. For example, when a command of +6V is sent to the motor, one amplifier supplies 12 - (6/2) = +9V, while the other supplies 12 + (6/2) = +15V. For a command in the opposite direction, such as -10V, the first amplifier supplies 12 + (10/2) = +17V, and the second 12 - (10/2) = +7V.

1.2 PWM Amplifier

In mechatronic systems, brushed DC motors are often controlled using the output from a microprocessor. The most common technique to allow a microprocessor to drive and control a DC motor is using a technique known as pulse width modulation (PWM). This technique generally involves rapidly chopping a DC supply voltage such that the commanded voltage is represented by the average value of the signal. The commanded voltage can thus be varied by modulating the width of the pulse supplied.

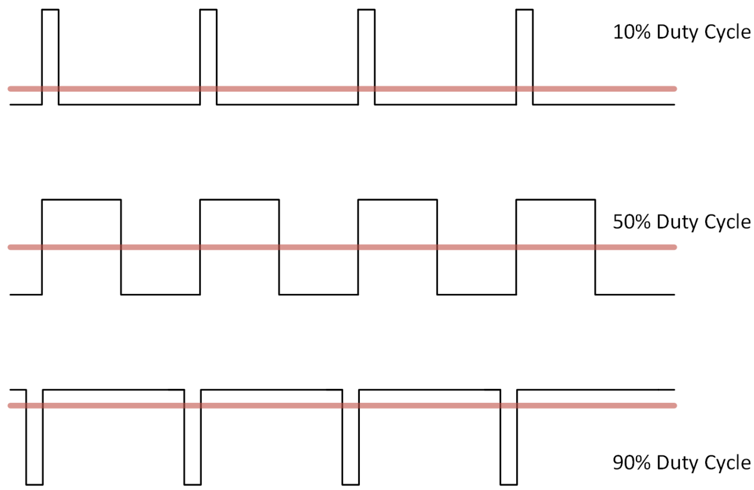


Figure 1.3: PWM Signal

To create a PWM signal that is appropriate for driving a DC motor, a basic transistor circuit known as an H-circuit or H-bridge is used. Figure 1.4 shows a typical full H-bridge configuration for bi-directional DC motor control as it is most commonly configured using transistors. Using the PWM signal to turn the transistors on and off at different rates, we can control the average voltage that the motor sees as a function of the duty cycle and source voltage. For example, with a 24V source, a duty cycle of 25% is equivalent to an applied voltage of $0.25 \times 24 = 6$V, whereas a duty cycle of 50% results in a voltage of $0.5 \times 24 = 12$V.

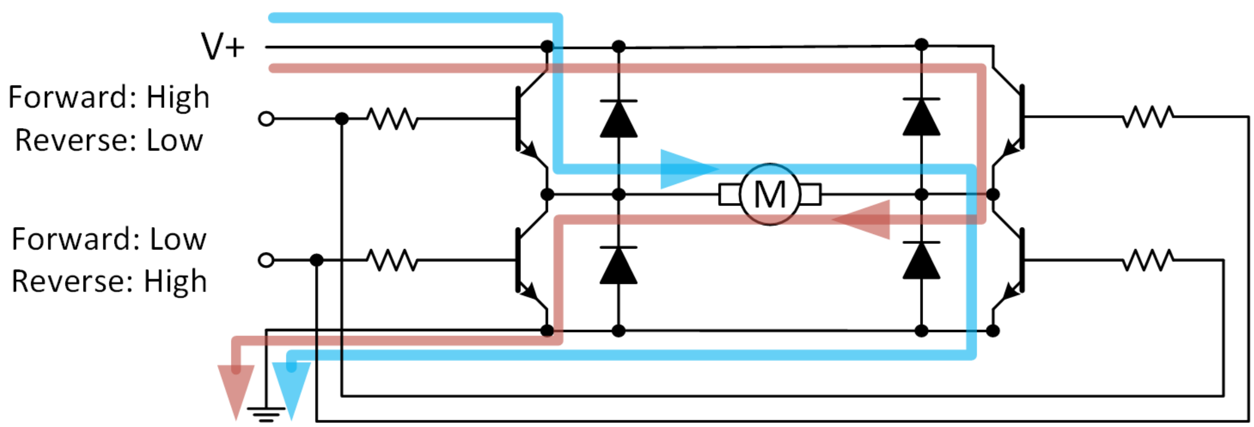


Figure 1.4: H-bridge

The QNET Mechatronic Actuators uses a full H-bridge driver in an integrated circuit. This reduces the required components and provides additional protection, including over-current protection, thermal protection, and shoot-through protection. *Shoot-through* occurs when two of the adjacent transistor switches are open at the same time, shorting the voltage supply to ground. The H-bridge driver used in the QNET Mechatronic Actuators contains MOSFET transistors, as shown in Figure 1.5, which is taken from the block diagram in the data sheet.

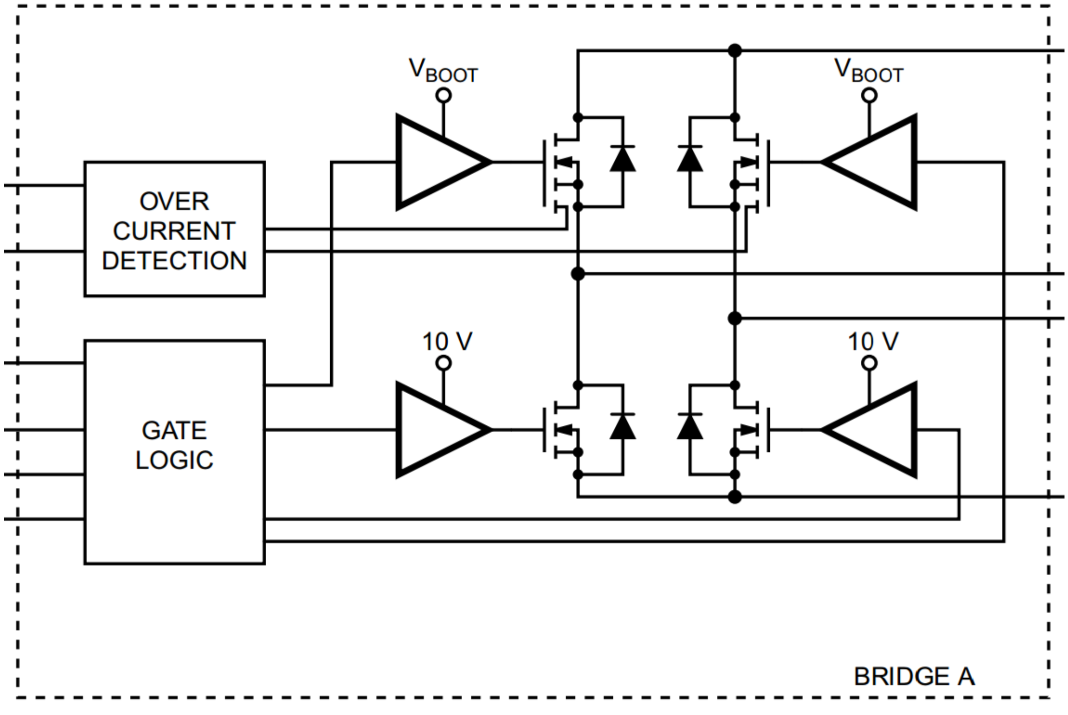


Figure 1.5: MOSFET-based full H-bridge configuration

1.3 Deadband

Deadband is a common non-linear phenomenon that is characterized by a momentary delay in the response of a system. In the case of a DC motor, this behaviour is usually observed as the system transitions from one direction to another, or is close to stationary. Deadband is undesirable because it introduces non-linearity into the response of the motor which can cause the actuator to respond poorly to control signals. The deadband performance of DC motor amplifiers varies significantly depending on the approach taken. Linear amplifiers often exhibit smaller deadbands because their response to commands is immediate, and directly proportional to the input command. PWM amplifiers on the other hand can introduce significant deadband into an actuator system because at lower duty cycles the delay between pulses can cause the motor to lose momentum and stall due to static friction, or stiction. PWM amplifiers can also introduce further delays when transitioning from one direction to another as the shoot-through protection prevents the two switch sets from being simultaneously powered. Custom logic can be introduced into PWM amplifier circuits to compensate for their deadband, and to make the response of an actuator more linear.

2 In-Lab Exercise

1. Open `QNET Actuators - DC Motors and Solendoid.vi`. **Make sure the correct Device is chosen.**
2. Ensure that the Power Solenoid button is off.
3. Run the VI, and gradually increase the voltage applied by the linear amplifier until the DC motor starts to move. Record the voltage. Repeat the process to find the negative dead-band by gradually decreasing the voltage. Record the voltage.
4. What do the two voltages recorded represent? Comment on their values, and how they might effect the performance of the DC motor.
5. Reset the voltage applied to 0V, then increase the voltage once again to the value found in Question 3 that causes the motor to begin to turn.
6. Slowly decrease the applied voltage until the motor stops moving. Comment on this phenomenon, and what might be the cause.
7. Design and implement a procedure to test the linearity of the amplifier. Record your results, and discuss the performance of the amplifier.

   Note: If the motor is stalled for more than a couple seconds, the current applied to the motor will be halted to protect the motor and amplifier from overheating. If you would like to reset the status of the stall detection monitor, press the Linear PWM Stall Ack button.

8. Using the theoretical torque constant of the DC motor, k_t = 0.0253, what is the torque that corresponds to the static friction of the motor?
9. Repeat the tests performed in Question 3 and Question 7 using the PWM amplifier driven DC motor to analyze the dead-band and linearity of the PWM-driven system. Record and discuss your results.
10. Compare your results from the linear amplifier testing to the PWM amplifier tests. What do the results indicate about the mutual performance of the two types of amplifiers?
11. How might a compensation algorithm be added to the PWM amplifier logic in order to reduce the effects of the dead-band on the response of the system?
12. Given that PWM amplifiers generally have a smaller form factor, generate less heat, and are cheaper than linear amplifiers, give some examples of when you would use one technology over the other.

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BRUSHLESS DC MOTOR

Topics Covered

- Brushed DC Motors.
- Brushless DC Motors.

Prerequisites

- The QNET Mechatronic Actuators has been setup and tested. See the QNET Mechatronic Actuators Quick Start Guide for details.
- You have access to the QNET Mechatronic Actuators User Manual.
- You are familiar with the basics of LabVIEW™.

1 Background

Direct Current motors, or DC motors, are synchronous motors that convert electrical energy into mechanical energy using electromagnetism by leveraging the fact that identical and opposing magnetic poles repel and attract each other, respectively. In general, a DC motor consists of a stationary component called stator, or housing, that encloses a rotating part called rotor, or armature. The two most common types of DC motors are brushed and brushless DC motors.

1.1 Flemming's Left Hand Rule

In general, a current flowing through a wire induces an magnetic field that is perpendicular to the wire, while also experiencing a force that is perpendicular to both the wire and the magnet field. This relationship can be visualized using Flemming's left hand rule: Using your left thumb, index and middle fingers as mutually perpendicular axis, the direction of the resulting force (thumb), magnetic field (index finger) and direction of current flow (middle finger) can be obtained. Here, it is assumed that the direction of the mechanical force is literal, the direction of the magnetic field is from the north to the south pole, and the direction of the electric current is in line with that of conventional current (positive to negative). There are several mnemonics to memorize what quantity is related to which finger, one of which is the *FBI* rule that associates the SI units for force (F), magnetic flux density (B) and current (I) with the fingers starting from the thumb to the middle finger, as in Figure 1.1.

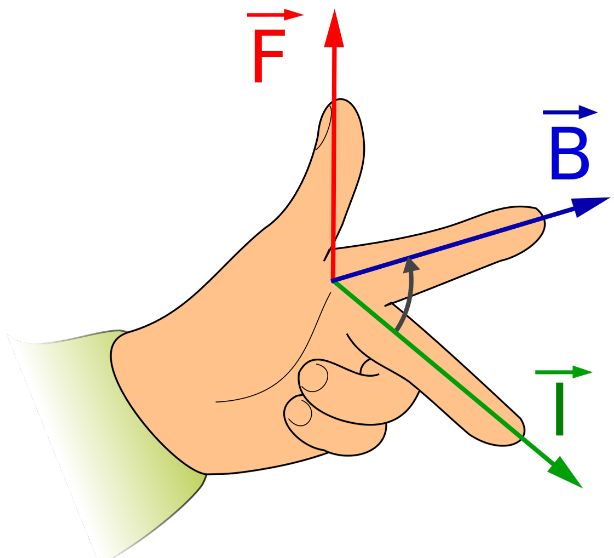


Figure 1.1: Flemming's left hand rule [1]

Note that this rule can be extended to Flemming's right hand rule when it used to determine the direction of an induced current in generators.

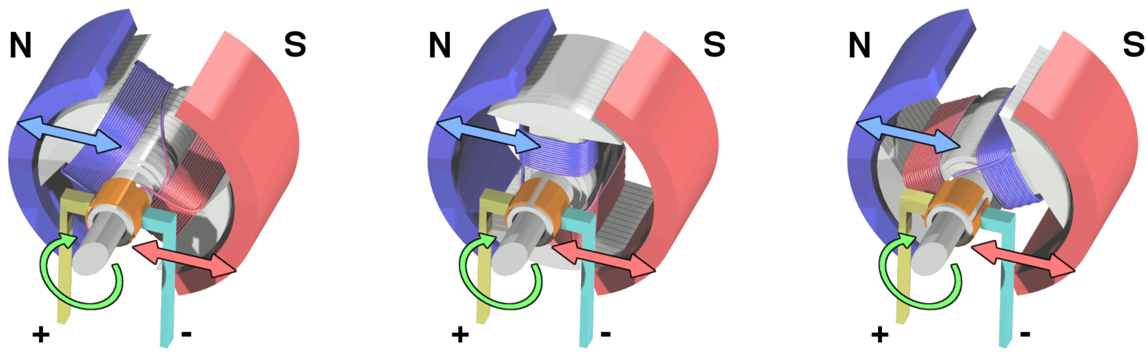
1.2 Brushed DC Motors

A brushed DC motor generates torque by housing a permanent magnet in the stator and commutating an electromagnet in the rotor as it rotates. Carbon brush assemblies are used to pass an electrical current through a commutator to the rotor as it rotates, hence the name brushed DC motor. Changes in the magnitude of the applied voltage lead to changes in the rotor's magnetic field, thus the rotational speed can be varied by changing the applied voltage.

The functionality of a simple two-pole brushed DC motor can be explained with Figure 1.2 where the commutator is shown in orange, and the brushes are located at the ends of the yellow and blue power connections. Here,

[1] José Fernando - Universidad de Granada

Figure 1.2a depicts a (random) starting position. The rotor coil is powered through the commutator ring and the carbon brushes to induce a magnetic field that is opposite to the external field from the stator, hence both north and south poles repel each other. The direction of the rotation of the rotor can be obtained using Flemming's left hand rule. The armature continues to rotate through the position where the magnetic field of the rotor is perpendicular to that of the stator as in Figure 1.2b. Once the rotor is almost horizontally aligned again as in Figure 1.2c, the resulting torque drops to zero and the commutator reverses the direction of the current through the coil, hence reversing the magnetic field.



(a) (b) (c)

Figure 1.2: Brushed DC Motor [2]

The torque achieved is highest in a holding position and decreases with an increase in speed.

1.3 Brushless DC Motors

A brushless DC motor generates torque by housing a permanent magnet in the rotor and commutating several electromagnets in the stator. There is no need for brushes to pass an electrical current to the rotor, thus the name brushless DC motor. The design of a brushless DC motor is more complicated than that of a brushed motor, as additional sensors are needed to detect the angular position of the armature and more complex circuitry and feedback control is necessary to ensure proper commutation of the electromagnetic fields in the stator. This often results in a high initial cost than a comparable brushed DC motor. That being said, the lack of brushes inherently leads to a longer life span and little or no maintainable costs since the mechanical elements are not in direct contact and are therefore less likely to wear over time.

Typically, rotary encoders, back EMF measurements, or Hall effect sensors are used to determine the angular position of the rotor. With this information, a motor controller generates AC signals that drive the electromagnets in the stator. This makes brushless DC motors more efficient than brushed DC motors since the applied voltage is pulsed as opposed to direct. Alternating current in this context does not imply a sinusoidal waveform but rather bi-directional current that can follow an arbitrary waveform. The brushless DC motor on the QNET Mechatronic Actuators has built in Hall effect sensors, which are transducers that vary their output voltage in response to a magnetic field. These kind of sensors are most frequently used for proximity switching and current sensing, as well as position and speed control of brushless DC motors.

In a typical configuration, there are three Hall effect sensors separated by 120° placed around the stator that can detect the position of the armature similar to Figure 1.3. There are a total of six possible combinations of active/inactive Hall effect sensor states before the sensing pattern is repeated. This implies that a 2-pole rotor completes a full revolution for one pattern cycle, whereas only half or a quarter of a rotation are completed for a 4-pole and 8-pole rotor, respectively. Note that the other two theoretical combinations of sensors - all high or all low - can never be reached and represent a faulty state.

[2] Eric Pierce

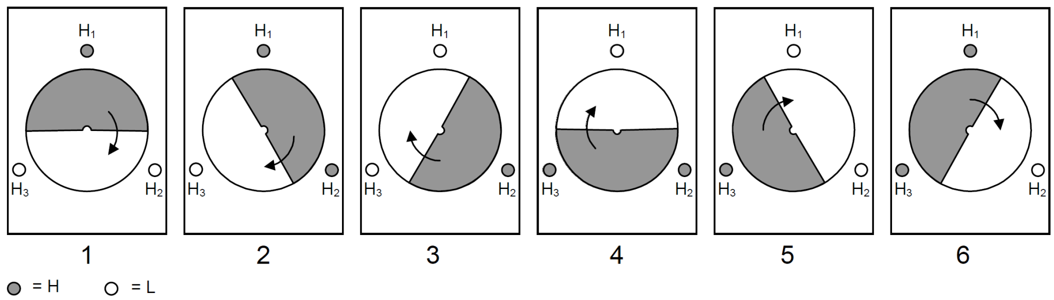
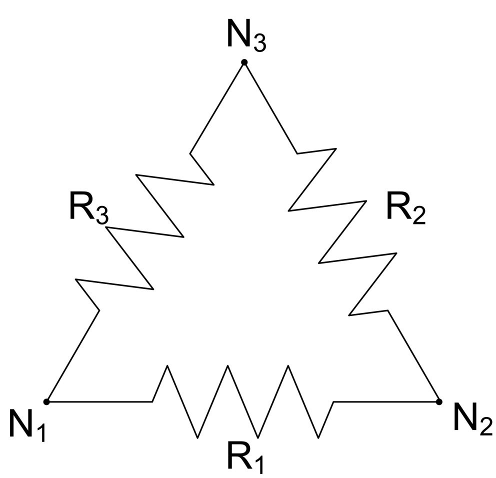
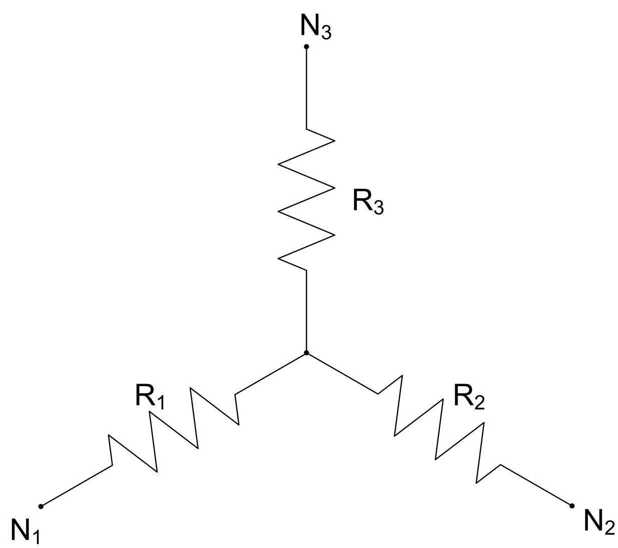


Figure 1.3: Hall effect sensors

To achieve maximum torque, the angle between the magnetic field of the stator and the rotor should be $\pm 90°$, depending on the desired directionality. The winding configuration in the stator is either a *Delta* or *Wye* configuration, see Figure 1.4. A Delta configuration connects the windings in a triangular shape, where two windings are connected to a common node at all times as in Figure 1.4a. This configuration provides low torque at low speeds, but also allows for a high top speed. Conversely, the Wye configuration in Figure 1.4b provides a high torque at low speeds and a lower top speed.



(a) Delta configuration



(b) Wye configuration

Figure 1.4: Delta and Wye configuration

The brushless DC motor on the QNET Mechatronic Actuators has stator coils wired in a Wye configuration. To control the brushless DC motor, one can use the phase/Hall effect sensor diagram in Figure 1.5. Here, the Hall effect sensor states are overlaid with the phase directions of the motor. For the first state in Figure 1.5 where only H_3 is active, one locates the matching orientation of the rotor in Figure 1.5. For a clockwise rotation, locate the phase vector that is 90° clockwise from its position to find the active phase and directionality of current. For example, in the first state A_{off}, B_+, and C_-, the A branch of the Wye configuration is inactive and the current flows from B to C, see state 1 in Figure 1.6. This process is then repeated for the other sensing states and the overall speed is determined by the frequency with which the commutation is driven.

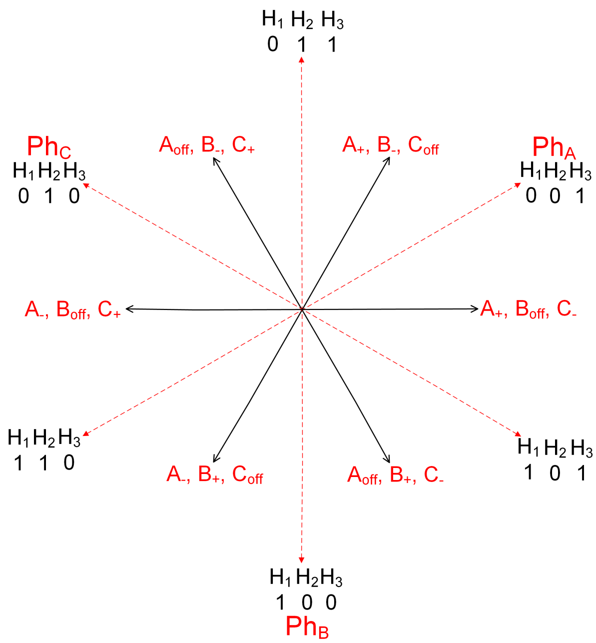


Figure 1.5: Brushless DC motor phase diagram

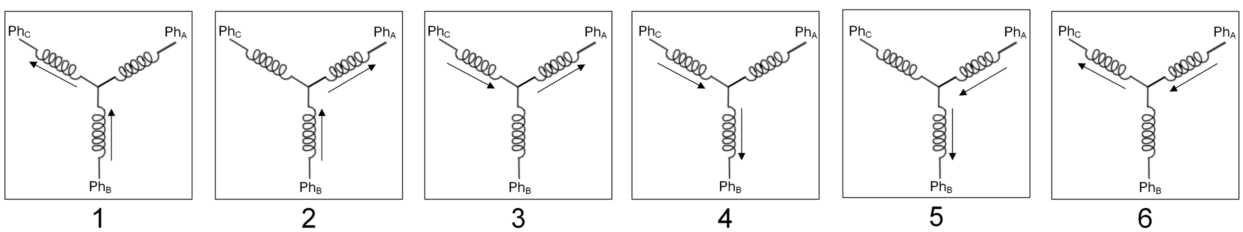


Figure 1.6: Six step commutation

The desired states can be achieved using three half H-bridges similar to Figure 1.7.

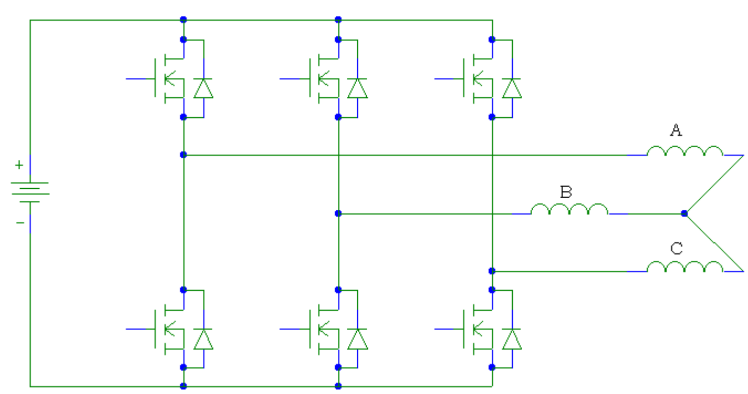


Figure 1.7: Three half H-bridges required to drive the brushless DC motor

2 In-Lab Exercise

1. Open the `QNET Actuators - Brushless Motor.vi`. **Make sure the correct Device is chosen.**
2. Based on the configuration of the brushless DC motor on the QNET Mechatronic Actuators, determine the appropriate control sequence to rotate the motor clockwise into the table, and enter the table into the VI.

   Note: The states in the table on the VI are **Z** for an off or neutral state, **H** for a positive voltage, and **L** for a negative voltage.

Sensor	A	B	C
001			
101			
100			
110			
010			
001			

Table 2.1: Brushless DC motor control sequence

3. Run the VI, change the mode switch to User Table, and push the Write Table button to send the table to the motor controller. If there are any errors in the table that might harm the motor, they will be indicated by a → symbol next to that row and the Write Table button will be disabled.
4. Increase the commanded PWM duty cycle and ensure that the motor is rotates as expected. Stop the VI.
5. Change the control mode of the motor back to the Internal Table setting and run the VI.
6. Starting with the commanded duty cycle of 0%, gradually increase the applied voltage until the motor begins to rotate. Record this value, and comment on what might be the cause of a lack of continuous movement at low voltage.
7. Next, starting again from a commanded duty cycle of 0%, stall the motor at gradually increasing commanded duty cycles. To avoid any harm from the spinning motor, stall the cog wheel with your finger at a low speed and *then* increase the applied voltage to the desired level *with the motor already stalled*. Record the resultant applied current at 5% increments, and comment on your observations.

   Note: If the motor is stalled for an extended period of time, a stall detection system will engage and cut power to the motor. Press the Stall Error Ack button to reset the stall status and restart the motor controller.

8. How might any discontinuous non-linear behaviour exhibited by the motor affect its performance, and how could it be compensated for?
9. Click on the Stop button to stop the VI.

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STEPPER MOTOR

Topics Covered

- Stepper motors.
- Stepper motor control and excitation modes.

Prerequisites

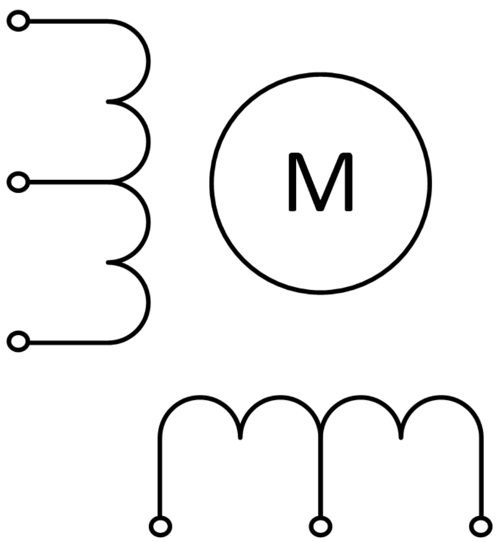
- The QNET Mechatronic Actuators has been setup and tested. See the QNET Mechatronic Actuators Quick Start Guide for details.
- You have access to the QNET Mechatronic Actuators User Manual.
- You are familiar with the basics of LabVIEW™.

1 Background

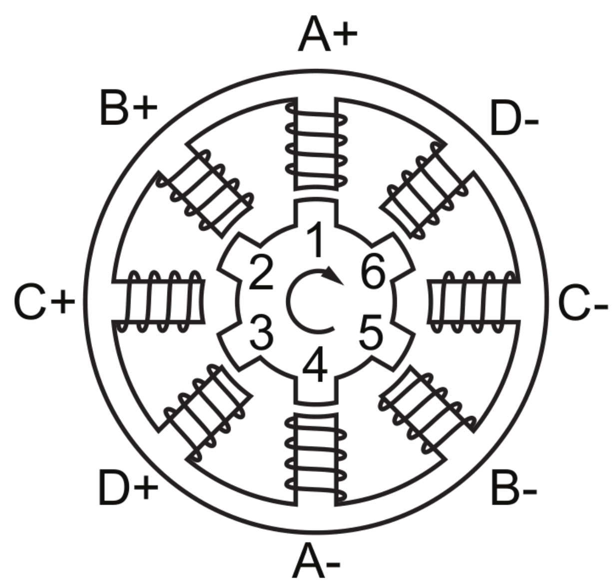
In contrast to the continuous rotation of a brushed or brushless DC motor, a stepper motor rotates the armature in discrete steps. The amount of steps it takes to complete a full revolution determines the stepper motor's step size. As the motor is only stepping between known distinct positions, it is possible to command it to hold a certain position without requiring any feedback sensors. This kind of control is called open-loop control and is easily implemented. To perform the same position control task with brushed or brushless DC motors requires sensor data feedback and is called closed-loop control.

The two basic winding configurations for stepper motors are unipolar and bipolar windings. A unipolar configuration has one winding with a center tap per face. Therefore, changing the polarity only requires choosing the other section of the winding, see Figure 1.1a. This commutation can be achieved by a single transistor for each winding, and a typical configuration is shown in Figure 1.1b.

In a bipolar configuration, there is a single winding per phase. Therefore, the current has to be reversed to change the polarity of the magnetic pole. This configuration requires a driving circuit that is more complex than that required for a unipolar configuration.



(a) Unipolar stepper motor coils



(b) Typical unipolar stepper configuration

Figure 1.1: Unipolar stepper motor

For the unipolar configuration used by the QNET Mechatronic Actuators and shown in Figure 1.1b, the armature has six teeth that are driven in four phases, resulting in a total of 6×4 steps per revolution, or a step size of 15°. There are several excitation modes for stepper motors of this configuration that are explained below, and summarized in Figure 1.2.

The most basic excitation mode is called *wave drive*. In this mode, one phase is on and three phases are off at any given time. At each step, the teeth of the rotor are aligned with the active phase pair, for example A+ and A- in Figure 1.1b. Once the next step is commanded, the currently active phase pair, A, deactivates and the next phase pair, B, activates, resulting in a 15° step and a total of 24 steps per revolution. This excitation mode is easy to implement, but the holding torque is significantly less than the rated torque of the motor.

To achieve the rated torque, a *full step* drive is used. In this excitation mode, two neighboring phases are active at any given time, resulting in the maximum rated torque. Starting, for example, from phase A and B being active, a step command deactivates phase A and activates phase C. This approach results in a 15° step and a total of 24 steps per revolution.

Another excitation mode is the *half-step drive*. Here, the motor alternates between one and two active phases, resulting in double the angular resolution of wave or full step drives. Starting from phase A being active, the next step would activate phase A and B, rotating the armature by 7.5°. The next step would deactivate phase A and phase B remains active, moving the armature another 7.5°, resulting in a total of 48 steps for a complete revolution. This also implies that the maximum holding torque is only present when two phases are active, or only for every other step command.

Lastly, a stepper motor can be excited using *micro-stepping*. In this excitation mode, the current in each of the phases approximate sinusoids, allowing for very smooth motor operation. It is often referred to as *sine cosine micro-stepping* and is depicted in Figure 1.2. In contrast to the other excitation modes described above, micro-stepping requires a more complex amplifier circuitry. Furthermore, as the micro-stepping divisor grows, the step size repeatability degrades.

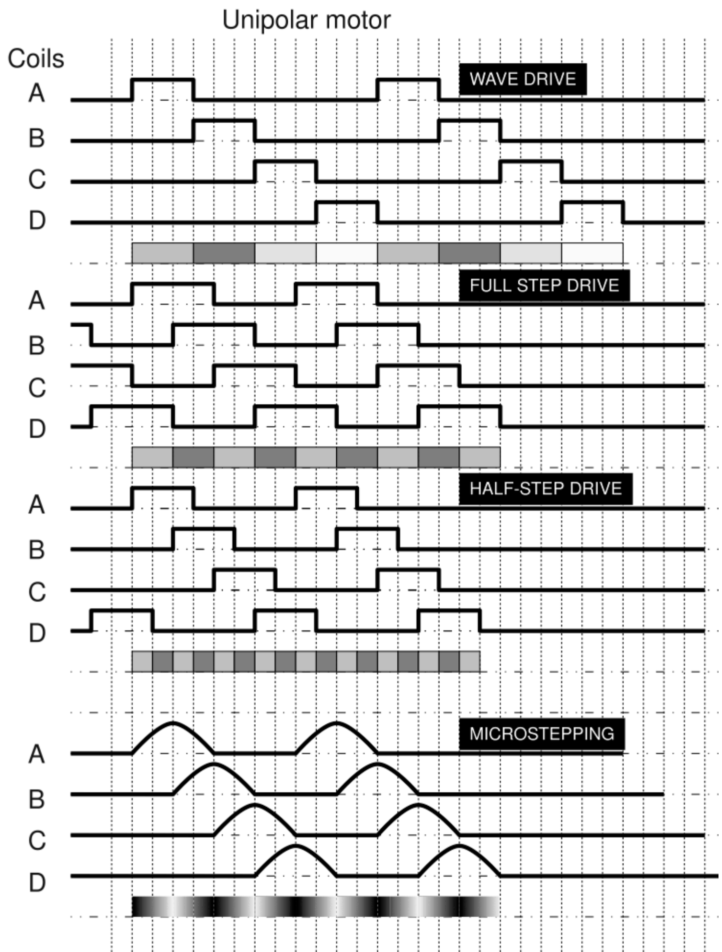


Figure 1.2: Drive modes of a 4 phase unipolar stepper motor [1]

Stepper motors are designed to run at high temperatures. The stepper motor on the QNET Mechatronic Actuators is rated at 130 °C, or 266 °F. To protect users from potential burns, the stepper motor on the QNET Mechatronic Actuators is not energized continuously, and instead uses a pulsed voltage. The coils are energized enough to move the motor one step position, and then de-energized until it's time to move to the next step position. Although this method isn't standard, it keeps the stepper motor cool while the VI is running. This method of excitation does, however, limit the stepper motor to full-stepping as outlined above. The stepper motor performs half-stepping with a pulsed half-step, but is not capable of micro-stepping.

[1] Misan2010

2 In-Lab Exercise

1. With power to the QNET Mechatronic Actuators turned off, rotate the cog wheel of the stepper motor and count the number of steps in one revolution.
2. What is the step angle for wave, full, and half-stepping drives of the QNET Mechatronic Actuators stepper motor?
3. Complete the logic table for full stepping below where phase B follows phase A.

A	B	C	D
1			
0			
0			
1			

Table 2.1: Full stepping

4. Open `QNET Actuators - Stepper Motor.vi`. Enter your result from the previous question in the first four lines of the table. Repeat the sequence for the last four lines of the table, and make sure that the toggle switch is set to User Table. Run the VI, and enable the stepper motor. Verify that the stepper motor rotates as expected, noting the direction of rotation.
5. Disable the stepper motor.
6. Complete the logic table below to configure full stepping in the opposite direction.

A	B	C	D
1			
0			
0			
1			

Table 2.2: Full stepping - change of direction

7. Update the table in your VI, and enable the stepper motor. Verify that you have indeed changed the direction of operation of the stepper motor. Note the time required to complete a full rotation.
8. Disable the stepper motor.
9. Complete the logic table for a half-stepping drive below where phase B follows phase A.

A	B	C	D
1			
1			
0			
0			
0			
0			
0			
1			

Table 2.3: Half-stepping

10. Update the table in your VI, and enable the stepper motor. Describe the motion of the stepper motor. Why is it not performing half-stepping as outlined in the background section?
11. How long does it take to complete one revolution compared to the full stepping drive used previously?
12. Record the Motor Current plot, and comment on the current commands observed when half-stepping is implemented.
13. Based on your observations of the performance and characteristics of the stepper motor, brainstorm potential applications for a stepper motor.
14. Click on the Stop button to stop the VI.

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SERVO MOTOR

Topics Covered

- Hobby Servos for position control.

Prerequisites

- The QNET Mechatronic Actuators has been setup and tested. See the QNET Mechatronic Actuators Quick Start Guide for details.
- You have access to the QNET Mechatronic Actuators User Manual.
- You are familiar with the basics of LabVIEW™.

1 Background

A servomechanism is a device that uses a feedback sensor to automatically adjust the behaviour of a system using feedback control. A DC servo motor, or servo, is a rotary actuator that transforms electrical energy into mechanical energy incorporating a feedback mechanism for position control. It holds the commanded position, even under load, until it is instructed to do otherwise.

A typical servo includes a motor, a gearbox, a potentiometer to sense angular position, and a control circuit. The gearbox is used to generate a high holding torque compared to standalone motors of a similar size. The travel range of servos is typically restricted to be $\pm 180^{\circ}$, with the position command provided as a pulse width modulation (PWM) signal. Whenever the servo is pulsed with a low pulse width, also called *Minimum Pulse*, the motor will remain in the low position. A neutral pulse will result in a rotation of half the range, and a large pulse, also referred to as *Maximum Pulse*, will result in a rotation to the full range of the servo, see Figure 1.1. Note that the pulse length that is required to command a certain position varies between servos. In the case of the servo used on the QNET Mechatronic Actuators, the servo is provided with a 3-5V pulse, at 50Hz. The width of the pulse is varied between 0.9ms and 2.1ms, with a pulse width of 1.5ms corresponding to the neutral (centre) position.

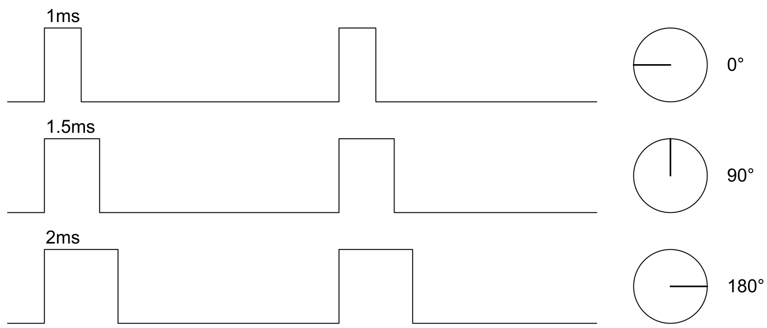

Figure 1.1: Commanding the servo position

2 In-Lab Exercise

1. Open the `QNET Actuators - Servo Motor.vi`. **Make sure the correct Device is chosen.**
2. Run the VI, and enable the servo using the Servo Enable, button.
3. Vary the Servo Pulse Width between 0.9 and 2.1 ms. Measure the resultant servo angles on the cog wheel using a protractor, or other angle measurement device.
4. Based on your measurements, determine a calibration gain to allow you to command the servo using a desired angle command in degrees.
5. Enter your calculated calibration gain into the field on the front panel, and ensure that the Command Type is set to *Position*. Vary the commanded position, and verify that your gain is correct.
6. Using either the position or pulse width command fields, command the servo motor to traverse its full range and record the resultant speed and current profile.
7. Analyze the response and comment on the current control profile. Try moving the servo through a series of positions by sweeping the command dial back and forth. How does the measured current relate to the position of the servo?

   Note: Think about the elements of the servo motor and how it achieves the desired position.

8. Click on the Stop button to stop the VI.

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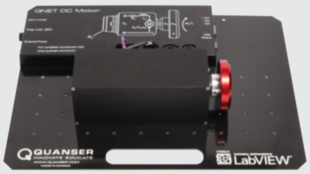

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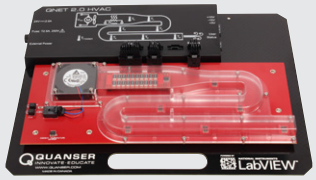
teaches temperature (process) control



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QNET Mechatronic Sensors Board
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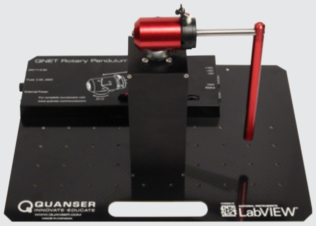

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