Document Intent:

The intent of this document is to provide an example of how a subject matter expert might teach Solenoids - DC Generators and DC Motors. This approach is what Idaho State University College of Technology is using to teach its Energy Systems Instrumentation and Control curriculum for Solenoids - DC Generators and DC Motors. The approach is based on a Systematic Approach to Training where training is developed and delivered in a two step process. This document depicts the two step approach with knowledge objectives being presented first followed by skill objectives. Step one teaches essential knowledge objectives to prepare students for the application of that knowledge. Step two is to let students apply what they have learned with actual hands on experiences in a controlled laboratory setting.

Examples used are equivalent to equipment and resources available to instructional staff members at Idaho State University.

Fundamentals of Solenoids - DC Generators and DC Motors Introduction:

This module covers fundamental aspects of Solenoids - DC Generators and DC Motors as essential knowledge necessary to perform work safely according to national and local standards on or around electrical power sources that are associated with motors and controls. Students will be taught the fundamentals of Solenoids - DC Generators and DC Motors using classroom instruction, demonstration, and laboratory exercises to demonstrate knowledge and skill mastery of Solenoids - DC Generators and DC Motors. Completion of this module will allow students to demonstrate mastery of knowledge and skill objectives by completing a series of tasks demonstrating safe work practices on or around electrical power sources.
References

This document includes knowledge and skill sections with objectives, information, and examples of how Motors and Control could be taught in a vocational or industry setting. This document has been developed by Idaho State University’s College of Technology. Reference material used includes information from:


STEP ONE

Solenoids - DC Generators and DC Motors Course Knowledge Objectives

Knowledge Terminal Objective (KTO)

KTO 2.1. ANALYZE SOLENOIDS, DC GENERATORS, and DC MOTORS to compare advantages and disadvantages to ensure they are correctly selected for applications according to manufacturing specifications and electrical requirements.

Knowledge Enabling Objectives (KEO)

KEO 2.1. DESCRIBE the differences between a MAGNET and an ELECTROMAGNET.

KEO 2.2. DESCRIBE what a SOLENOID is to include: Configurations, Construction, and Characteristics.

KEO 2.3. DESCRIBE SOLENOID Application Rules, Selection Methods, and Voltage Variation Effects.

KEO 2.4. DESCRIBE how SOLENOIDS are used to include applications for: Hydraulics/Pneumatics, Refrigeration, Combustion, and General Purpose uses.

KEO 2.5. DESCRIBE SOLENOID Troubleshooting Techniques to include the effects of: Incorrect Voltage, Incorrect Frequency, Transients, Rapid Cycling, and Environmental Conditions.

KEO 2.6. EXPLAIN how to use a DMM to perform a Troubleshooting Procedure on Solenoids.
KEO 2.7. **DESCRIBE** what a **DC GENERATOR** consists of and its principle of operation.

KEO 2.8. **DESCRIBE** the **Components** of a **DC GENERATOR** to include: **Field Windings, Armature, Commutator,** and **Brushes.**

KEO 2.9. **DESCRIBE** the **LEFT-HAND GENERATOR RULE.**

KEO 2.10. **EXPLAIN** three **TYPES** of **DC GENERATORS** to include operational uses, advantages, and disadvantages.

KEO 2.11. **DESCRIBE** what a **DC MOTOR** consists of and its principle of operation.

KEO 2.12. **DESCRIBE** how a **DC MOTOR** is **CONSTRUCTED.**

KEO 2.13. **DESCRIBE** four basic **TYPES** of **DC MOTORS** to include operational uses, advantages and disadvantages.

KEO 2.14. **DESCRIBE DC MOTOR TROUBLESHOOTING TECHNIQUES** to include: **Troubleshooting Brushes, Troubleshooting Commutators,** and **Troubleshooting Grounded, Open, or Short Circuits.**
KEO 2.1. DESCRIBE the differences between a MAGNET and an ELECTROMAGNET.

A MAGNET is a substance that produces a magnetic field and attracts iron. Magnets are either Permanent or Temporary.

- A Permanent Magnet is a magnetic that can retain its magnetism after a magnetizing force has been removed and includes naturally occurring or manufactured magnets.

Figure 6-1 page 109
- A *Temporary Magnetic* is a magnetic that retains trace amounts of magnetism after the magnetizing force has been removed.

![Temporary Magnets Diagram](image)

**Figure 6-2 page 110**

An *ELECTROMAGNET* is a magnet whose magnetic energy is produced by the flow of electrical current. Some are large enough and powerful enough to lift tons of scrap metal at one time. Other *Electromagnets* used in some electrical and electronic circuits are very small, such as those found in solenoids and relays.

**SUMMARY:**

- A *MAGNET* is a substance that produces a magnetic field and attracts iron. *Magnets* are either *Permanent* or *Temporary*.
- A *Permanent Magnet* is a magnetic that can retain its magnetism after a magnetizing force has been removed and includes naturally occurring or manufactured magnets.
- A *Temporary Magnetic* is a magnetic that retains trace amounts of magnetism after the magnetizing force has been removed.
- An *ELECTROMAGNET* is a magnet whose magnetic energy is produced by the flow of electrical current.
KEO 2. 2. DESCRIBE what a SOLENOID is to include: Configurations, Construction, and Characteristics.

SOLENOIDS are used to control devices such as valves, relays, and other industrial machinery. A Solenoid is an electrical output device that converts electrical energy into a linear mechanical force. The magnetic attraction of a Solenoid may be used to transmit force. Solenoids may be combined with an Armature (the movable part of a solenoid), which transmits the force created by the Solenoid into useful work.

- Configurations: Solenoids are configured several ways for different applications and operating characteristics. The following picture shows five-solenoid configurations (Clapper, Bell-Crank, Horizontal-Action, Vertical-Action, and Plunger):

![Solenoid Configurations Diagram](image-url)
- **Construction**: Solenoids are constructed of many turns of wire wrapped around a magnetic laminate assembly. When electricity passes current through the coil, it causes the armature (the movable part of a solenoid) to be pulled toward the coil. Devices may be attracted to the solenoid to accomplish tasks such as opening and closing contacts. Solenoid Construction takes into account: *Eddy Current*, *Armature Air Gap*, and *Auxiliary Magnetic Field*.

  - *Eddy Currents* are unwanted currents induced in the metal structure of a device due to the rate of change in the magnetic field. Strong *Eddy Currents* are generated in solid metal when using Alternating Current (AC). In AC Solenoids, the magnetic assembly and armature consist of a number of thin pieces of metal laminated together. These thin pieces of metal reduce the *Eddy Currents* produced in the metal. *Eddy Currents* are confined to each lamination, thus reducing the intensity of the magnetic effect and subsequent heat buildup. The following picture depicts the differences between a solid metal and a metal made up of laminations to reduce *Eddy Currents*:

![Figure 6-13 page 114](image_url)
With *Direct Current (DC)*, solenoids constructed of a solid core are acceptable because the current is continuous in one direction which do not generate Eddy Currents.

*Armature Air Gaps* prevent chattering. A small gap is left in the magnetic laminate assembly to break the magnetic field and allows the armature to drop away freely after being de-energized. The following picture depicts how this Air Gap prevents chattering:

![Figure 6-14 page 114](image)

**Figure 6-14 page 114**

*Auxiliary Magnetic Field*: Is generated with a *Shaded Coil* assembly. This is a single turn of conducting material (usually copper or aluminum) mounted on the face of the magnetic laminate assembly or armature which helps hold in the armature as the main coil magnetic field drops to zero in an AC circuit.

The following picture depicts how a shading coil sets up an *Auxiliary Magnetic Field*, which is out of phase with the main coil magnetic field:
Solenoid Characteristics: There are two primary characteristics associated with Solenoids, they are the amount of voltage applied to the coil and the amount of current allowed to pass through the coil. **Solenoid Voltage Characteristics** include pickup voltage, seal-in voltage, and drop-out voltage. **Solenoid Current Characteristics** include coil inrush current and sealed current.

**SUMMARY:**
- **Solenoids** are used to control devices such as valves, relays, and other industrial machinery.
- A **Solenoid** is an electrical output device that converts electrical energy into a linear mechanical force.
- **Solenoids are constructed** of many turns of wire wrapped around a magnetic laminate assembly.
- **Eddy Currents** are unwanted currents induced in the metal structure of a device due to the rate of change in the magnetic field.
- In **AC Solenoids**, the magnetic assembly and armature consist of a number of thin pieces of metal laminated together. These thin pieces of metal reduce the **Eddy Currents** produced in the metal.
- With **Direct Current (DC)**, **solenoids** constructed of a solid core are acceptable because the current is continuous in one direction which do not generate Eddy Currents.
- **Armature Air Gaps** prevent chattering.
- There are two primary characteristics associated with **Solenoids**, they are the amount of voltage applied to the coil and the amount of current allowed to pass through the coil.

**KEO 2.3.** DESCRIBE SOLENOID Application Rules, Selection Methods, and Voltage Variation Effects.
• **Solenoid Application Rules** deal with how solenoids are selected for an application based on the loading conditions that give the optimum performance. Rules to determine appropriate solenoid applications include:

  o Obtain complete data on load requirements to ensure ultimate life of the solenoid and the life of its linkage.
  o Allow for possible low-voltage conditions of the power supply because the pull of the solenoid varies as the square of the voltage (4 lbs at 10 volts, 16 lbs at 20 volts, etc.).
  o Use the shortest possible stroke, produces faster operating rates, require less power, produces greater force, and decreases coil heating.
  o Never use an oversized solenoid as it is inefficient, results in higher initial cost and greater power consumption, and requires a physically larger unit than is necessary.

• **Solenoid Selection Methods** include:

  o *Push or Pull* depends on the application. For example, in the case of a door latch, the unit must pull and in a clamping device, the unit must push.
  o *Length of Stroke* is calculated after determining whether the solenoid must push or pull.
  o *Required Force* is a specification provided on manufactures specification sheets used to determine the correct solenoid based on the force required.
  o *Duty Cycle* characteristics are provided in tables to check the duty cycle requirements of the application against the duty cycle information for a given solenoid.
  o *Mounting* information is provided by manufacture specifications to indicate a code letter to show if it is an end mount (A), a right side mount (B), a throat mount (C), thru-bolt mount (D), left side mount (E), or both side mounts (F).
  o *Voltage Rating* information is also provided by manufactures to indicate a code letter for 115 Volts (2X), 230 Volts (3X), 460 Volts (4X), or 575 Volts (5X).

• **Solenoid Voltage Variation Effects** are one of the most common causes of solenoid failure. Precautions must be taken to select the correct proper coil for a solenoid. Excessive or low voltage must not be applied to a solenoid coil.

**SUMMARY:**

• **Solenoid Application Rules** deal with how solenoids are selected for an application based on the loading conditions that give the optimum performance.
KEO 2.4. **DESCRIPT how SOLENOIDS are used to include applications for:**

*Hydraulics/Pneumatics, Refrigeration, Combustion,* and *General Purpose* uses.

- **Hydraulics/Pneumatics** use a solenoid to control equipment that is operates with Hydraulic or Pneumatic devices to control the fluid or air flow in via a directional control flow valve. The following picture shows an application where electrically operated hydraulic control valves act as the actuator:

![Solenoid Diagram](image)

**Figure 6-25 page 120**

- **Refrigeration** system’s uses two-way solenoid valves to shutoff or open flow of a refrigeration coolant.
The following two picture shows an application where direct-acting two-way solenoid valves open and close lines in a refrigeration system to direct the flow of refrigerant:

![Solenoid Diagram](image1)

**Figure 6-26 page 121**

![Refrigeration System Diagram](image2)

**Figure 6-27 page 121**

- **Combustion** solenoids are used in oil-fired singer burner systems and are crucial in the startup and normal operating functions of these systems.
The following picture shows how different solenoids are used for the safe operation of an oil-fired single-burner system:

Figure 6-28 page 122

- **General Purpose** uses include applications such as printing, calculators, cameras, and airplanes.

**SUMMARY:**

- **Hydraulics/Pneumatics** use a solenoid to control equipment that is operated with Hydraulic or Pneumatic devices to control the fluid or air flow in via a directional control flow valve.
- **Refrigeration** system’s uses two-way solenoid valves to shutoff or open flow of a
refrigeration coolant.

- **Combustion** solenoids are used in oil-fired singer burner systems and are crucial in the startup and normal operating functions of these systems.
- **General Purpose** uses include applications such as printing, calculators, cameras, and airplanes.
KEO 2.5. **DESCRIBE SOLENOID Troubleshooting Techniques** to include the effects of: *Incorrect Voltage, Incorrect Frequency, Transients, Rapid Cycling, and Environmental Conditions.*

Solenoids fail due to coil burnout or mechanical damage. The below picture illustrates a typical manufacture chart used to help determine the cause of a solenoid failure:

![Figure 6-30 page 123]

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**Solenoid Failure Characteristics**

<table>
<thead>
<tr>
<th>Problem</th>
<th>Possible Causes</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure to operate when energized</td>
<td>Complete loss of power to solenoid</td>
<td>Normally caused by blown fuse or control circuit problem</td>
</tr>
<tr>
<td></td>
<td>Low voltage applied to solenoid</td>
<td>Voltage should be at least 85% of solenoid rated value</td>
</tr>
<tr>
<td></td>
<td>Burned out solenoid coil</td>
<td>Normally evident by pungent odor caused by burnt insulation</td>
</tr>
<tr>
<td></td>
<td>Shorted coil</td>
<td>Normally a fuse is blown and continues to blow when changed</td>
</tr>
<tr>
<td></td>
<td>Obstruction of plunger movement</td>
<td>Normally caused by a broken part, misalignment, or the presence of a foreign object</td>
</tr>
<tr>
<td></td>
<td>Excessive pressure on solenoid plunger</td>
<td>Normally caused by excessive system pressure in solenoid-operated valves</td>
</tr>
<tr>
<td>Failure of spring-return solenoids to operate when de-energized</td>
<td>Faulty control circuit</td>
<td>Normally a problem of the control circuit not disengaging the solenoid's hold or memory circuit</td>
</tr>
<tr>
<td></td>
<td>Obstruction of plunger movement</td>
<td>Normally caused by a broken part, misalignment, or the presence of a foreign object</td>
</tr>
<tr>
<td></td>
<td>Excessive pressure on solenoid plunger</td>
<td>Normally caused by excessive system pressure in solenoid-operated valves</td>
</tr>
<tr>
<td>Failure of electrically-operated return solenoids to operate when de-energized</td>
<td>Complete loss of power to solenoid</td>
<td>Normally caused by a blown fuse or control circuit problem</td>
</tr>
<tr>
<td></td>
<td>Low voltage applied to solenoid</td>
<td>Voltage should be at least 85% of solenoid rated value</td>
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<td></td>
<td>Obstruction of plunger movement</td>
<td>Normally caused by broken part, misalignment, or presence of a foreign object</td>
</tr>
<tr>
<td></td>
<td>Excessive pressure on solenoid plunger</td>
<td>Normally caused by excessive system pressure in solenoid-operated valves</td>
</tr>
<tr>
<td>Noisy operation</td>
<td>Solenoid housing vibrates</td>
<td>Normally caused by loose mounting screws</td>
</tr>
<tr>
<td></td>
<td>Plunger pole pieces do not make brush contact</td>
<td>An air gap may be present, causing the plunger to vibrate. These symptoms are normally caused by foreign matter</td>
</tr>
<tr>
<td>Erratic operation</td>
<td>Low voltage applied to solenoid</td>
<td>Voltage should be at least 85% of the solenoid rated voltage</td>
</tr>
<tr>
<td></td>
<td>System pressure may be low or excessive</td>
<td>Solenoid size is inadequate for the application</td>
</tr>
<tr>
<td></td>
<td>Control circuit is not operating properly</td>
<td>Conditions on the solenoid have increased to the point where the solenoid cannot deliver the required force</td>
</tr>
</tbody>
</table>

**Figure 6-30 page 123**
- **Incorrect Voltage** can cause coil damage. The voltage applied to a solenoid should be at plus or minus 10% of the solenoid rated value. This voltage can be measured with a DMM directly at the valve when the valve is energized for both AC and DC solenoids. A solenoid will overheat when the voltage applied is excessive and will cause heat damage to the insulation of the coil and will burn out the solenoid. When the voltage is low, the coil will have difficulty moving the spool and this slow operation causes the solenoid to draw its high inrush current longer and will also create heat damaging the solenoid. The following picture illustrates how to check voltage:

![Solenoid Voltage Measurement](image)

**Figure 6-31 page 124**

- **Incorrect Frequency** may operate the solenoid but will also increase the failure rate and my produce a noisy condition. A standard 60 Hz is used in the United States, Canada, Mexico, and most of the Caribbean. 50 Hz is used in Europe, Asia, and much of South America.

- **Transients** Voltages may damage the insulation of the coil, nearby contacts, and other loads. Transient Voltages may be suppressed by using a **Snubber Circuit** (a circuit that suppresses noise and high voltage on the power lines).
• **Rapid Cycling** of a solenoid can cause the solenoid to overheat. This can be prevented if a high temperature solenoid is selected for applications requiring a solenoid to be cycled more than 10 times per minute.

• **Environmental Conditions** need to be taken into consideration for the solenoid to operate at its environmental rating. A solenoid must not become damaged mechanically by its surrounding atmosphere. A solenoid is subject to heat during its normal operation and this heat comes from the combination of the product flowing through the solenoid, the temperature rise from the coil when energized, and the ambient temperature of the solenoids environment.

**SUMMARY:**

• **Solenoids** fail due to coil burnout or mechanical damage.
• **Incorrect Voltage** can cause coil damage. The voltage applied to a solenoid should be at plus or minus 10% of the solenoid rated value.
• A **solenoid will overheat** when the voltage applied is excessive and will cause heat damage to the insulation of the coil and will burn out the solenoid.
• When **the voltage is low**, the coil will have difficulty moving the spool and this slow operation causes the solenoid to draw its high inrush current longer and will also create heat damaging the solenoid.
• **Incorrect Frequency** may operate the solenoid but will also increase the failure rate and my produce a noisy condition.
• **Transients** Voltages may damage the insulation of the coil, nearby contacts, and other loads. Transient Voltages may be suppressed by using a **Snubber Circuit** (a circuit that suppresses noise and high voltage on the power lines).
• **Rapid Cycling** of a solenoid can cause the solenoid to overheat. This can be prevented if a high temperature solenoid is selected for applications requiring a solenoid to be cycled more than 10 times per minute.
• **Environmental Conditions** need to be taken into consideration for the solenoid to operate at its environmental rating.

**KEO 2. 6.** **EXPLAIN how to use a DMM to perform a Troubleshooting Procedure on Solenoids.**
Troubleshooting solenoids using a DMM is illustrated in the below picture:

**Figure 6-32 page 124**

**Troubleshooting Procedure Steps:**

1. Turn off (Lock-out/Tag-out) power to solenoid per local procedures.

2. With a DMM, ensure power is not present to the solenoid.

3. Remove the solenoid coil cover and visually inspect for:

   - Signs of a burnt coil
   - Broken parts
   - Any other problems that should not be present
   - Replace the valve, contactor, starter, or solenoid-operated device when the parts are available
   - Note: Ensure the cause of failure is known and corrected before replacing components when a solenoid has failed due to a burnt or shorted coil
Physically observe solenoid operation after parts have been replaced or a new solenoid has been installed

4. If no obvious problem is observed, disconnect the solenoid wires from the electrical circuit.

5. Connect a DMM to the coil to verify continuity of the coil reads the resistance of a plus or minus 15% of the manufactures coil reading recommendations (measuring the coil resistance of a new coil can also provide a resistance reading) and replace coil if found to be shorted or open.

SUMMARY:

- To troubleshoot a solenoid:
  - (Lock-out/Tag-out) power
  - Inspect for physical damage or overheating of the coil
  - Replace if any damage is visible
  - If no damage is present disconnect coil and verify the coils has continuity
  - If continuity is not present replace coil
  - Verify solenoid operation after restoring power

KEO 2.7. **DESCRIBE** what a DC GENERATOR consists of and its principle of operation.

A **DC GENERATOR** is a mechanical device designed to convert mechanical energy into *Direct Current Electrical Energy*. This is accomplished through the principle of *Electromagnetic Induction*. The **principle of operation for a DC Generator** involves a coil of wire rotated in a magnetic field. This principle induces a voltage in the coil and the amount of voltage induced is determined by the rate at which the coil is rotated in the magnetic field.

When a coil is rotated in a magnetic field at a constant rate, the voltage induced in the coil depends on the number of magnetic lines of force in the magnetic field at each given instant of time. **DC Generators** consist of **Field Windings**, an **Armature**, a **Commutator**, and **Brushes**. As depicted in the below picture:
SUMMARY:

- A **DC GENERATOR** is a mechanical device designed to convert mechanical energy into *Direct Current Electrical Energy*.
- DC Generators consist of **Field Windings**, an **Armature** (moveable coil), a **Commutator**, and **Brushes**.
- The principle of operation includes a coil (armature) of wire rotating in a magnetic field which induces a voltage in the coil (armature).
- The DC Voltage is then provided to a load via the **Commutator** and the **Brushes**.

**KEO 2.8.** DESCRIBE the Components of a **DC GENERATOR** to include: *Field Windings*, **Armature**, **Commutator**, and **Brushes**.

*Field Windings* are magnets used to produce a magnetic field in a generator. This magnetic field can be produced by **Permanent Magnets** or by **Electromagnets**. **Permanent Magnets** are used in very small generators and are referred to as magnetos. The disadvantage of *permanent magnets*...
are that their magnetic lines of force decrease as the age of the magnet increases, and the strength of a permanent magnet cannot be varied for control purposes of the output voltage. Most DC Generators use Electromagnets, which must be supplied with a controlled current to maintain the magnetic field. If the current for the field is supplied by an outside source (a battery or another generator), the generator is separately excited. If the generator itself supplies the current to the field windings, the generator is referred to as being self-excited. DC Generators are usually self-excited.

The Armature is the movable coil of wire in the generator that rotates through the magnetic field. A DC Generator always has a rotating armature and a stationary field (field windings. The rotating armature may consist of numerous coils which reduce the ripples (pulsations) in the output voltage being generated. There are other methods to remove the ripples completely with the use of Filter Circuits. Filter Circuits (Smoothing Circuits) are used to reduce ripple. Because a DC Generator generates a DC voltage, its sine wave will be pulsed.

NOTE: As a comparison, the DC sine wave from a DC Battery will not have a ripple (as it is not mechanically generated) as depicted below:

![Diagram of Battery Output](image)

The Commutator is a ring consisting of segments that are insulated from one another. Each end of a coil wire is connected to a segment. A voltage is induced in the coil whenever the coil cuts the magnetic lines of force of a magnetic field. The Commutator segments reverse the connections to the brushes every half cycle and this maintains a constant polarity of output voltage produced by the generator.

The following picture depicts how the voltage is induced in the armature of a generator when the coil cuts the lines of force of the magnetic field:
Figure 6-34 page 126

The Generator’s *Brushes* are the sliding contact that rides against the *Commutator Segments* and are used to connect the *Armature* to the external circuit. *Brushes* are made of a soft carbon (natural graphite) and are softer than the *Commutator* bars, yet strong enough so that the *Brushes* do not chip or break from vibration. One brush makes contact with each segment of the...
Commutator. DC Generators are designed so that the **Brushes** ride on the different segments of the Commutator each time the current is zero.

Therefore, the current in the external circuit (load circuit) always flows in one direction; however, its magnitude varies continuously. The action of reversing the connections to the coil (armature) to obtain a direct current is referred to as commutation. The resulting output voltage of a DC Generator is a pulsating DC Voltage, and these pulsations of the output voltage are known as **Ripples**.

### SUMMARY:
- **Field Windings** are magnets used to produce a magnetic field in a generator
- The **Armature** is the movable coil of wire in the generator that rotates through the magnetic field.
- The **Commutator** is a ring consisting of segments that are insulated from one another
- The Generator’s **Brushes** are the sliding contact that rides against the **Commutator Segments** and are used to connect the **Armature** to the external circuit.
- The output of a DC Generator is a pulsed DC voltage.

### KEO 2.9.
**DESCRIBE the LEFT-HAND GENERATOR RULE.**

The **LEFT-HAND GENERATOR RULE** is the relationship between the current in a conductor and the magnetic field existing around that conductor. The **Left Hand Rule** states that with the thumb, index finger, and middle finger of the left hand set at right angles to each other, the index finger points in the direction of the magnetic field, the thumb points in the direction of the motion of the conductor, and the middle finger points in the direction of the induced current.

When using the **Left Hand Rule**, it is assumed that the magnetic field is stationary and that the conductor is moving through the field as depicted below:
SUMMARY:

- The **LEFT-HAND GENERATOR RULE** is the relationship between the current in a conductor and the magnetic field existing around that conductor.
- The **Left Hand Rule** states that with the thumb, index finger, and middle finger of the left hand set at right angles to each other, the index finger points in the direction of the magnetic field, the thumb points in the direction of the motion of the conductor, and the middle finger points in the direction of the induced current.
- When using the **Left Hand Rule**, it is assumed that the magnetic field is stationary and that the conductor is moving through the field.
KEO 2.10. **EXPLAIN** three **TYPES** of **DC GENERATORS** to include operational uses, advantages, and disadvantages.

The three **TYPES** of **DC GENERATORS** are: **Series-Wound**, **Shunt-Wound**, and **Compound-Wound**. The difference between the types of generators is based on the relationship of the field windings to the external circuit.

- **Series-Wound** generators have its field windings connected in series with the armature and the external circuit (load). The following picture depicts a **Series-Wound Generator** illustrating a Pictorial Drawing, a Wiring Diagram, and a Schematic Diagram:

![Series-Wound Generator Diagram](image)

**Figure 6-36 page 127**
In a **Series-Wound Generator**, the field windings consist of a few turns of low-resistance wiring because the load current flows through them.

The ability of a generator to have a constant voltage under varying load conditions is referred to as the generator voltage regulation. **Series-Wound Generators** have poor voltage regulation. Because of their poor voltage regulation, **Series-Wound Generators** are not frequently used. The output voltage of a **Series-Wound Generator** may be controlled by a rheostat (variable resistor) connected in parallel with the field windings.

- **Shunt-Wound Generator** is a generator that has its field windings connected in parallel (shunt) with the armature and the external circuit (load). The following picture depicts a **Shunt-Wound Generator** illustrating a Pictorial Drawing, a Wiring Diagram, and a Schematic Diagram:

![Shunt-Wound Generator Diagram](image)

**Figure 6-37 page 128**
Because the field windings are connected in parallel with the load, the current through them is wasted as far as output is concerned. The field windings consist of many turns of high-resistance wire to keep the current flow through them low.

A Shunt-Wound Generator is suitable for use if the load is constant. However, if the load fluctuates, the voltage also varies and so it is only used for an application where the load current is constant. The output voltage of a Shunt-Wound Generator may be controlled by a rheostat (variable resistor) connected in series with the shunt field.

A Compound-Wound Generator is a generator that includes series and shunt field windings. In a Compound-Wound Generator, the series field windings and shunt field windings are combined in a manner to take advantage the characteristics of each. The shunt field is used only to compensate for effects that tend to decrease the output voltage. Because a Compound-Wound Generator has the series and shunt field windings, they are more suitable in controlling the output voltage as the load changes. The following picture depicts a Compound-Wound Generator illustrating a Pictorial Drawing, a Wiring Diagram, and a Schematic Diagram:

Figure 6-38 page 129
SUMMARY:

- **Series-Wound** generators have its field windings connected in series with the armature and the external circuit (load).
- In a **Series-Wound Generator**, the field windings consist of a few turns of low-resistance wiring because the load current flows through them.
- **Series-Wound Generators** have poor voltage regulation. Because of their poor voltage regulation, **Series-Wound Generators** are not frequently used.
- A **Shunt-Wound Generator** is a generator that has its field windings connected in parallel (shunt) with the armature and the external circuit (load).
- A **Shunt-Wound Generator** is suitable for use if the load is constant.
- A **Compound-Wound Generator** is a generator that includes series and shunt field windings.
- In a **Compound-Wound Generator**, the series field windings and shunt field windings are combined in a manner to take advantage the characteristics of each.
- Because a **Compound-Wound Generator** has the series and shunt field windings, they are more suitable in controlling the output voltage as the load changes.

**KEO 2.11.** Describe what a **DC MOTOR** consists of and its principle of operation.

A **DC MOTOR** is a machine that converts electrical energy into mechanical energy by means of **Electromagnetic Induction**. **DC Motors** operate on the principle that when a current-carrying conductor is placed in a magnetic field, a force that tends to move the conductor out of the field is exerted on the conductor. The conductor tends to move at right angles to the field as depicted in the below picture:

![Figure 6-39 page 129](image-url)
DC Motors operate on the Electron Flow Motor Rule to determine the direction of motion of a current-carrying conductor in a magnetic field as depicted in the below picture:

Figure 6-40 page 129

- The amount of force on the conductor depends on: The intensity of the magnetic field, the Current through the conductor, and the Length of the conductor. The intensity of the magnetic field and the amount of current in the conductor are normally changed to increase the force on the conductor. However, the amount of force (speed of the motor) can be increased by increasing Field Intensity, Conductor Current, and Conductor Length.

**SUMMARY:**

- A DC MOTOR is a machine that converts electrical energy into mechanical energy by means of Electromagnetic Induction.
- DC Motors operate on the Electron Flow Motor Rule to determine the direction of motion of a current-carrying conductor in a magnetic field.
- The amount of force on the conductor depends on: The intensity of the magnetic field, the Current through the conductor, and the Length of the conductor.
- The amount of force (speed of the motor) can be increased by increasing Field Intensity, Conductor Current, and Conductor Length.

**KEO 2.12.** DESCRIBE how a DC MOTOR is CONSTRUCTED.
A DC Motor is a motor that uses direct current connected to the field and armature to produce shaft rotation. A **DC MOTOR’S CONSTRUCTION** consists of: **Field Windings**, **Armature**, a **Commutator**, and **Brushes** (like a DC Generator).

**NOTE:** The difference between a DC Motor and a DC Generator is that a Generator is driven by a mechanical force to generate DC electricity, and a DC Motor is driven by a DC Power Source to provide a mechanical force to do work. As a DC Generator is rotated, the rotation induces a voltage to the Commutator and out through the brushes. As a DC power source is applied to the brushes of a DC Motor, the motor rotates to do work.

- **Field Windings** are the stationary windings or magnets of a DC motor.

- The **Armature** is the rotating part of a DC Motor.
  - A magnetic field is produced in the armature by current flowing through the armature coils.
  - The armature magnetic field interacts with the direct current produced by the field windings.
  - The interaction of the magnetic fields causes the armature to rotate.

- The **Commutator** is a ring made of segments that are insulated from one another.
  - The Commutator is part of the armature that connects each armature coil to the brushes using copper bars (segments) that are insulated from each other with pieces of mica.
  - The Commutator is mounted on the same shaft as the armature and rotates with the motors shaft.

- **A Brush** is the sliding contact that rides against the Commutator segments and is used to connect the armature to the external DC circuit.
  - **Brushes** are made of carbon or graphite material and are held in place by brush holders.
A pigtail connects a brush to the external DC circuit (power supply). The pigtail is an extended, flexible connection or a braided copper conductor.

Brushes are free to move up and down in the brush holders. The freedom allows the brush to follow irregularities in the surface of the Commutator. A spring is placed behind the brushes to force the brushes to make contact with the Commutator. The spring pressure is normally adjustable, as is the entire brush holder assembly.

Brushes make contact with successive copper bars of the Commutator as the shaft, armature, and Commutator rotate. A DC Motor is depicted in the picture below showing the internal components of a typical DC Motor:

**Figure 6-43 page 131**

**SUMMARY:**

- A DC Motor is a motor that uses direct current connected to the field and armature to
produce shaft rotation.

- A **DC Motor’s Construction** consists of: **Field Windings**, **Armature**, a **Commutator**, and **Brushes** (like a DC Generator).
- The difference between a DC Motor and a DC Generator is that a Generator is driven by a mechanical force to generate DC electricity, and a DC Motor is driven by a DC Power Source to provide a mechanical force to do work.
- **Field Windings** are the stationary windings or magnets of a DC motor.
- The **Armature** is the rotating part of a DC Motor.
- The **Commutator** is a ring made of segments that are insulated from one another.
- A **Brush** is the sliding contact that rides against the Commutator segments and is used to connect the armature to the external DC circuit.
  - **Brushes** are made of carbon or graphite material and are held in place by brush holders.
- A **pigtail** connects a brush to the external DC circuit (power supply).
KEO 2.13. DESCRIBE four basic TYPES of DC MOTORS to include operational uses, advantages and disadvantages.

The four basic TYPES of DC MOTORS are: Series, Shunt, Compound, and Permanent-Magnetic. These DC Motors have similar external appearances, but are different in their internal construction and output performance. The following picture describes and illustrates each of these types of motors with symbols and motor lead identification connectivity:

![DC Motors Diagram](image)

**Figure 6-45 page 133**
• A **DC Series Motor** is a motor that has the series field coils connected in series with the **Armature**. The field must carry the load current passing through the armature. The field coil has relatively few turn of heavy-gauge wire. The wires extending from the series coil are marked as S1 and S2, and the wires from the armature are marked as A1 and A2. The following picture shows the **Pictorial Drawing** and **Wiring Diagram** for a DC Series Motor:

![DC Series Motors Diagram](image)

**Figure 6-46 page 134**

- DC Series Motors are used as traction motors because they produce the highest torque of all DC Motors. They can develop 500% of full-load torque upon starting.

- **Typical applications** of DC Series Motors include: **Traction Bridges, Hoists, Gates, and Automobile Starters**.

- The **speed regulation of DC Series Motors is poor**. As the mechanical load on the motor is reduced, a simultaneous reduction of current occurs in the field and
the armature. **If the mechanical load is entirely removed, the speed of the motor increases without limit and may destroy the motor.** For this reason, DC Series Motors are always permanently connected to the load and the motor controls.

- A **DC Shunt Motor** is a motor that has the field connected in shunt (parallel) with the armature. The wires extending from the shunt field are marked F1 and F2, and the armature windings are marked A1 and A2. The following picture shows the *Pictorial Drawing* and *Wiring Diagram* for a DC Shunt Motor:

![Pictorial Drawing and Wiring Diagram for a DC Shunt Motor](image)

**Figure 6-47 page 134**
o The field has numerous turns of wire, and the current in the field is independent of the armature, providing the **DC Shunt Motor** with excellent speed control.

o The shunt field may be connected to the same power supply as the armature or may be connected to another power supply.

o A **Self-Excited Shunt Field** is a shunt field connected to the same power supply as the armature.

o A **Separately Excited Shunt Field** is a shunt field connected to a different power supply than the armature.

o **DC Shunt Motors** are used where constant or adjustable speed is required and starting conditions are moderate.

o **Typical applications** of **DC Shunt Motors** include: **Fans, Blowers, Centrifugal Pumps, Conveyers, Elevators, Woodworking Machinery, and Metalworking Machinery**.

- **A DC Compound Motor** is a motor with the field connected in both series and shunt (parallel) with the armature. The field coil is a combination of the series field (S1 and S2) and the shunt field (F1 and F2). The following picture shows the **Pictorial Drawing** and **Wiring Diagram** for a DC Compound Motor:
The series field is connected in series with the armature.

The shunt field is connected in parallel with the series field and armature combination. This arrangement gives the DC Compound Motor the advantages of the DC Series Motor (High Torque) and the DC Shunt Motor (Constant Speed).

DC Compound Motors are used when high starting and constant torque speed are required.

Typical applications include: Punch Presses, Shears, Bending Machines and Hoists.
• **A DC Permanent-Magnet Motor** is a motor that uses magnets, not a coil or wire for the field windings. **DC Permanent-Magnet Motors** have molded magnets mounted into a steel shell. The permanent magnets are the field coils. **DC power** is supplied only to the armature of the motor. The following picture shows the **Pictorial Drawing** and **Wiring Diagram** for a DC Permanent-Magnet Motor:

![DC Permanent-Magnet Motors Diagram](image)

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**Figure 6-49 page 135**

- **DC Permanent-Magnetic motors are used in automobiles to control power seats, power windows, and windshield wipers.**

- **DC Permanent-Magnetic motors produce relatively high torque at low speeds and provides some self-breaking when power is removed.**
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- Not all DC Permanent-Magnet motors are designed to run continuously because they can overheat rapidly. This overheating can destroy the permanent magnets.

SUMMARY:

- A DC MOTOR is a machine that converts electrical energy into mechanical energy by means of Electromagnetic Induction.
- The four basic TYPES of DC MOTORS are: Series, Shunt, Compound, and Permanent-Magnetic. These DC Motors have similar external appearances, but are different in their internal construction and output performance.
- A DC Series Motor is a motor that has the series field coils connected in series with the Armature.
  - DC Series Motors are used as traction motors because they produce the highest torque of all DC Motors. They can develop 500% of full-load torque upon starting.
  - Typical applications of DC Series Motors include: Traction Bridges, Hoists, Gates, and Automobile Starters.
  - The speed regulation of DC Series Motors is poor. As the mechanical load on the motor is reduced, a simultaneous reduction of current occurs in the field and the armature.
  - If the mechanical load is entirely removed, the speed of the motor increases without limit and may destroy the motor. For this reason, DC Series Motors are always permanently connected to the load and the motor controls.
- A DC Shunt Motor is a motor that has the field connected in shunt (parallel) with the armature.
  - The DC Shunt Motor has the ability to provide excellent speed control.
  - DC Shunt Motors are used where constant or adjustable speed is required and starting conditions are moderate.
  - Typical applications of DC Shunt Motors include: Fans, Blowers, Centrifugal Pumps, Conveyers, Elevators, Woodworking Machinery, and Metalworking Machinery.
- A DC Compound Motor is a motor with the field connected in both series and shunt (parallel) with the armature.
  - The shunt field is connected in parallel with the series field and armature combination. This arrangement gives the DC Compound Motor the advantages of the DC Series Motor (High Torque) and the DC Shunt Motor (Constant Speed).
  - DC Compound Motors are used when high starting and constant torque speed are required.
  - Typical applications include: Punch Presses, Shears, Bending Machines and Hoists.
- A DC Permanent-Magnet Motor is a motor that uses magnets, not a coil or wire for the field windings.
  - DC Permanent-Magnetic motors are used in automobiles to control power seats, power windows, and windshield wipers.
  - DC Permanent-Magnetic motors produce relatively high torque at low speeds and provides some self-breaking when power is removed.
  - Not all DC Permanent-Magnet motors are designed to run continuously because they can overheat rapidly. This overheating can destroy the permanent magnets.
KEO 2.14. DESCRIBE DC MOTOR TROUBLESHOOTING TECHNIQUES to include: Troubleshooting Brushes, Troubleshooting Commutators, and Troubleshooting Grounded, Open, or Short Circuits.

DC MOTORS require considerable troubleshooting. This is because the Brushes and Commutator of DC MOTORS are subject to wear. Brushes are designed to wear as the motor ages. Most DC Motors are designed so that the Brushes and Commutator can be inspected without disassembling the motor. Some motors may require disassembly for inspection of the brushes and commutator due to operational and environmental applications and sparking from the brushes or commutator needs to be contained. Troubleshooting DC motors also includes: troubleshooting for grounded, open, or short circuits.

- Troubleshooting Brushes is one of the most common problems associated with DC Motors as they wear faster than any other component. This is because they ride on the fast-moving commutator. Lubrication is not used between the brushes and the commutator because the brushes carry current from the armature. Sparking occurs as the current passes from the commutator to the brushes. Sparking causes heat, burning, and wear of electrical parts.

  o Replacing worn brushes is easier and less expensive than servicing or replacing a worn commutator, so when troubleshooting the brushes, a technician needs to observe the brushes as the motor operates.

  o The following picture illustrates what to look for to determine if brushes are positioned correctly to maintain proper contact with the commutator (brushes must be positioned correctly for proper contact with the commutator):
The brushes should ride smoothly on the commutator with little or no sparking.

There should be not brush noise, such as chattering.

Brush sparking, chattering, or a worn commutator indicates service is required.

 Troubleshooting Brushes Procedure:
1. **Lockout and Tagout** the starting mechanism per internal policy and procedures. The following picture depicts how this procedure can be accomplished:

![Troubleshooting Bruschees Diagram](image)

**Figure 6-51 page 137**

2. **Measure the voltage** at the armature to verify voltage is turned OFF.

3. **Check brush movement and tension.** The brushes should move freely in the holder. The spring tension should be approximately the same on each brush.

4. **Check the length of the brushes.**
   - Brushes should be replaced when they have worn down to about half of their original size.
   - Replace all brushes if any brush is less than half its original length.
   - Never replace only one brush.
   - Always replace brushes with the same composition.
   - Check manufactures recommendations for proper brush position and brush pressure.
- **Troubleshooting Commutators** – Brushes wear faster than the commutator and after the brushes have been replaced once or twice, the commutator may need to be serviced. Any markings on the commutator, such as grooves or discolorations other than a polished, brown color where the brushes ride, indicate a problem. The following picture address a two step process for inspecting a commutator:

![Diagram of Commutator](image)

**Figure 6-52 page 137**

- **Troubleshooting Commutator Procedure:**
  1. **Make a visual check of the commutator.**
     - The commutator should be smooth and concentric.
     - A uniform, dark, copper oxide-carbon film should be present on the surface of the commutator. This naturally occurring film acts like a lubricant by prolonging the life of the brushes and reduces wear on the commutator surface.
  2. **Check the mica insulation between the commutator segments.**
     - The mica insulation should separate and insulate each segment.
• The mica insulation should be undercut (lowered below the surface) approximately 1/32” to 1/16”, depending on the size of the motor.
• The larger the motor, the deeper the undercut.
• Replace or service the commutator if the mica is raised.

• **Troubleshooting for Grounded, Open, or Short Circuits** – A DC motor can be tested for these conditions with the use of a continuity meter or a continuity test light.

**NOTE**

The following discussion is geared toward using a continuity tester or ohm meter. If problems are found, service is required. If problems are not found, it does not mean there are no problems. For example, grounded circuits or short circuits may exist when higher voltages are applied to the motors. A test will need to be performed using a MEGGER. A MEGGER is an instrument that supplies a high voltage to be pushed through conductors to verify that a grounded or short circuit condition does not exist when actual operating voltages are applied. A continuity (ohm) meter or a continuity test light uses a small DC voltage to detect if a circuit exists and cannot effectively detect problems when a higher voltage source is applied to the actual circuit.

- A **grounded circuit** is a circuit in which current leaves its normal path and travels to the frame of the motor. A grounded circuit is caused when insulation breaks down or is damaged, allowing circuit wiring to come in contact with the metal frame of the motor.

- An **open circuit** is a circuit that has an incomplete path that prevents current flow. An open circuit can be caused when a conductor or connection has physically moved apart from another conductor or connection.

- A **short circuit** is a circuit in which current takes a shortcut around the normal path of current flow and may trip a breaker or fuse to that circuit. A short circuit is caused when the insulation of two conductors fails, allowing different parts of a circuit to contact with one another. They are usually a result of insulation breakdown. Insulation can break down after extended periods of vibration, friction or abrasion.
A **Continuity Tester** is a preferred quick check of a motor and can give results quickly when there is a problem that needs to be identified. The following picture illustrates how to use a **Continuity Tester** to look for Grounded, Open, or Short Circuits:

![Figure 6-53 page 138](image)

**Figure 6-53 page 138**

- **Testing for Grounded, Open, or Short Circuits with a Continuity Tester Procedure:**
  1. **Lockout and Tagout the Motor Control Circuit.**
  2. **Check for a Grounded Circuit.**
     - Connect one lead of the continuity tester or ohm meter to the frame of the motor.
     - Touch the other end of the continuity tester or ohm meter to one motor lead and the other motor lead. If there is continuity, a grounded condition exists and the motor needs serviced, repaired, or replaced.
3. **Check for an Open Circuit.**
   - Connect the two test leads of the continuity tester or ohm meter to the motor field and armature circuits as follows:
     a. **Series Motor** – A1 to A2 and S1 to S2 to verify continuity of both circuits.
     b. **Shunt Motor** – A1 to A2 and F1 to F2 to verify continuity of both circuits.
     c. **Compound Motor** – A1 to A2, F1 to F2, and S1 to S2 to verify continuity of the three circuits.
     d. If there is no continuity in any of the above, an open circuit condition exists and the motor needs serviced, repaired, or replaced.

4. **Check for a Short Circuit:**
   - Connect the two test leads of the continuity tester or ohm meter to the motor field and armature circuits as follows:
     a. **Series Motor** – A1 to S1, A1 to S2, and A2 to S1 to verify no continuity of circuits.
     b. **Shunt Motor** – A1 to F1, A1 to F2, A2 to F1, and A2 to F2 to verify no continuity of circuits.
     c. **Compound Motor** – A1 to F1, A2 to F2; A1 to F2, A2 to S1; A1 to S1, A2 to S2; A1 to S2, F1 to S1; and A2 to F1, F1 to S2 to verify no continuity of circuits.
     d. If there is continuity in any of the above, a short circuit condition exists and the motor needs serviced, repaired, or replaced.

**SUMMARY:**
- **DC MOTORS** require considerable troubleshooting. This is because the *Brushes and Commutator of DC MOTORS* are subject to wear.
- Most **DC Motors** are designed so that the *Brushes and Commutator* can be inspected without disassembling the motor.
- **Troubleshooting Brushes** is one of the most common problems associated with DC Motors as they wear faster than any other component.
  - Sparking occurs as the current passes from the commutator to the brushes. Sparking causes heat, burning, and wear of electrical parts.

- **Troubleshooting Commutators** – Brushes wear faster than the commutator and after the brushes have been replaced once or twice, the commutator may need to be serviced.

- **Troubleshooting for Grounded, Open, or Short Circuits** – A DC motor can be tested for these conditions with the use of a continuity meter or a continuity test light.

- Testing a DC Motor for continuity is mostly a quick test for obvious continuity checks. The fact that a motor checks out good via a continuity test does not guarantee it is functional when full voltage is applied to the motor. The use of a MEGGER is required.

- A MEGGER is an instrument that supplies a high voltage to be pushed through conductors to verify that a grounded or short circuit condition does not exist when actual operating voltages are applied.
STEP TWO

Solenoids - DC Generators and DC Motors

Skill/Performance Objectives

Skill Knowledge Introduction:

Below are the skill knowledge objectives. How these objectives are performed depend on equipment and laboratory resources available. With each skill objective it is assumed that a set of standard test equipment and tools be provided and safety procedures be implemented during each task being performed.

- Disassemble various DC motor types identifying service needs
- Assemble various DC motor types replacing parts as required per the technical manual
- Bench and service test DC motors verifying proper operation
- Inspect the brushes of a DC motor, determine the need for dressing or replacement
- Dress DC motor brushes
- Trouble shoot DC motors, isolate and identify the fault and take the appropriate corrective action
- Given an application, select the appropriate replacement motor from vendor data
- Identify faults in solenoid operators and repair or replace to return the system to service
- Given an application, select the appropriate replacement solenoid from vendor data