KOMATSU

Electric Mining Shovel
DC Motors

Peak Performance Practices

This handbook provides basic information about the design, operation, troubleshooting and maintenance of electric motors used on mining shovels. It is not intended nor should it be used as a substitute for electric shovel manufacturers' operating, maintenance or service manuals, but only as a supplement to them.

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Contents

Definitions of Dangers, Warnings and Cautions

DANGERS, WARNINGS and CAUTIONS are used in this manual (see especially Section Five) to emphasize important and critical safety instructions. For the purpose of this manual Dangers, Warnings and Cautions are defined as follows:

⚠ DANGER

DANGER Indicates an imminently hazardous situation which, if not avoided, will result in death or serious injury. This signal word is limited to the most extreme situations.

⚠ WARNING

WARNING Indicates a potentially hazardous situation which, if not avoided, could result in death or serious injury.

⚠ CAUTION

CAUTION Indicates a potentially hazardous situation which, if not avoided, may result in minor or major injury. Caution is used without the signal alert symbol for hazards that result only in property damage.

CAUTION

1. Introduction

Background

A modern electric mining shovel uses a number of electric motors to actuate the various shovel motions required to dig, swing, dump, and propel (Figure 1). The reliable operation of these motors is a key to ensuring high equipment availability and to achieving production goals. Understanding the basics of DC mining motors and their key maintenance requirements will enable mining shovel users to optimize the performance of these motors and maximize motor life.

This handbook provides mining personnel with key information about DC electric mining motors and how to achieve peak performance from them. The information is designed to help in decision making that maximizes the mine's return on investment in mining equipment and ultimately reduce the cost per ton of the commodity mined.

This handbook is intended for mining personnel working in mine management, purchasing, maintenance, and operations.

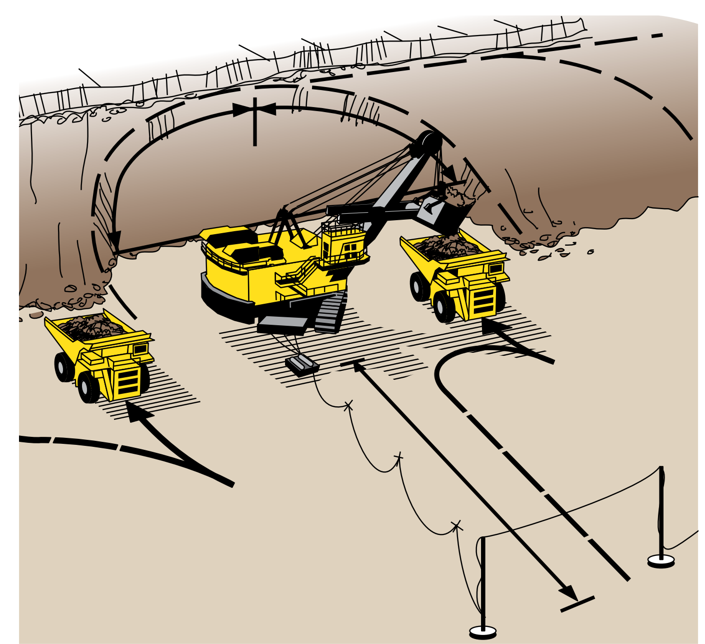


Figure 1 Electric motors control the propel, crowd, hoist and swing motions on an electric mining shovel.

In addition, this book is intended for mining engineering students and faculty and anyone else with a need or desire to learn more about DC mining shovel motors. It is one in a series of documents developed by Komatsu service team members focused on P&H products to help mining personnel and others become more informed about surface mining equipment and practices.

As the only mining equipment manufacturer that builds both the electrical and mechanical components for electric shovels, P&H occupies a unique position in the industry. With known mechanical and electric shovel performance objectives, P&H engineers are fully qualified to specify electric motor performance characteristics for individual work motions. Each characteristic is designed to deliver the performance needed to make a quality contribution to cycle time.

Once the shovel has been designed, engineered and built to its specifications, cycle time performance is largely a matter of the shovel's operation and maintenance. A basic understanding of the motors that drive the shovel's motions can help achieve peak performance and longer service life from the motors and the shovel, with reduced costs for downtime.

Overview

Section 2 of this handbook, "DC Mining Motor Basics", provides a solid foundation of the fundamentals of electricity underlying shovel motor design. The section is divided into basic electric motor principles and advanced principles to provide motor design theory for individuals with various levels of technical background.

The sections that follow focus on DC Motor Control Systems, Brakes, Basic Maintenance Requirements, Troubleshooting, Detrimental Operating Conditions, Motor Removal and Installation, and Repair and Rebuild Options.

Please note that the information presented here is for informational purposes only and not intended to replace the operating maintenance or service manuals supplied with the equipment. Always consult the manufacturers' manuals for recommendations and specific instructions.

2. DC Mining Motor Basics

Description

The DC motors in mining shovel applications use the same basic components found in all DC motors (Figure 2). These components include the armature, commutator, brushes, field coils and the motor frame (Figure 3). DC mining motors are rated up to 2100 peak horsepower at 600 volts.

These motors are designed for a lower than usual base speed and a notably high torque component of the developed horsepower. This is of key importance to shovel work motion performance. The lower base speed and higher torque component optimize the system inertia which, in turn, produces a faster dynamic response characteristic and smooth speed control capability.

For the horsepower developed, these motors contain large amounts of active materials in the steel lamination cores and copper in the coils and commutator. They also feature large diameter commutators and moderate brush current densities, both of which contribute to good commutation performance over a wide range of motor loads.

The unique design of these motors and the rugged construction of the motor components provide mining shovels with a reliable source of power for thousands of hours in the harshest working conditions. The proper operation and maintenance of these motors will assure peak performance is achieved throughout the entire life of the motor.

Basic Motor Theory

The basic motor theory presented here is intended for those with little or no knowledge of DC motor principles and as a refresher for those with previous DC motor experience. Those with a good understanding of DC motor basics should proceed to the advanced motor theory topic on page 6.

The operation of DC motors is based on a key discovery by Hans Christian Oersted in 1820. Oersted discovered that when a current flows through a wire, a magnetic force is developed around the wire. The relevance of this to the operation of an electric motor is that when a wire energized with electric current is placed in close proximity to an electromagnetic field the energized wire will either be attracted or repelled by the force of the magnetic field. The attraction or repulsion of the wire depends on the polarity of the magnetic fields of the wire and field magnets.

This concept is shown relative to the operation of DC mining motors in schematic form in Figure 4. An external voltage source sends current via brushes and a commutator through wire segments AB and CD (armature coils) in the direction shown. The magnetic field F (also called flux or magnetic induction) developed by current flowing through the field coils then creates a force on the wires such that it will rotate the loop (armature) about the axis (motor shaft) MN.

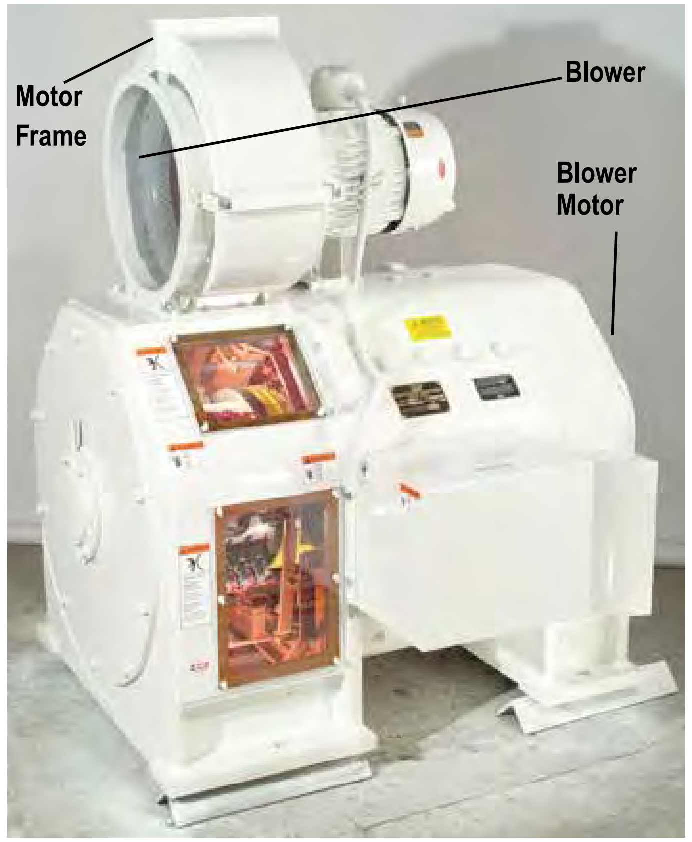


Figure 2 DC electric shovel motor with blower

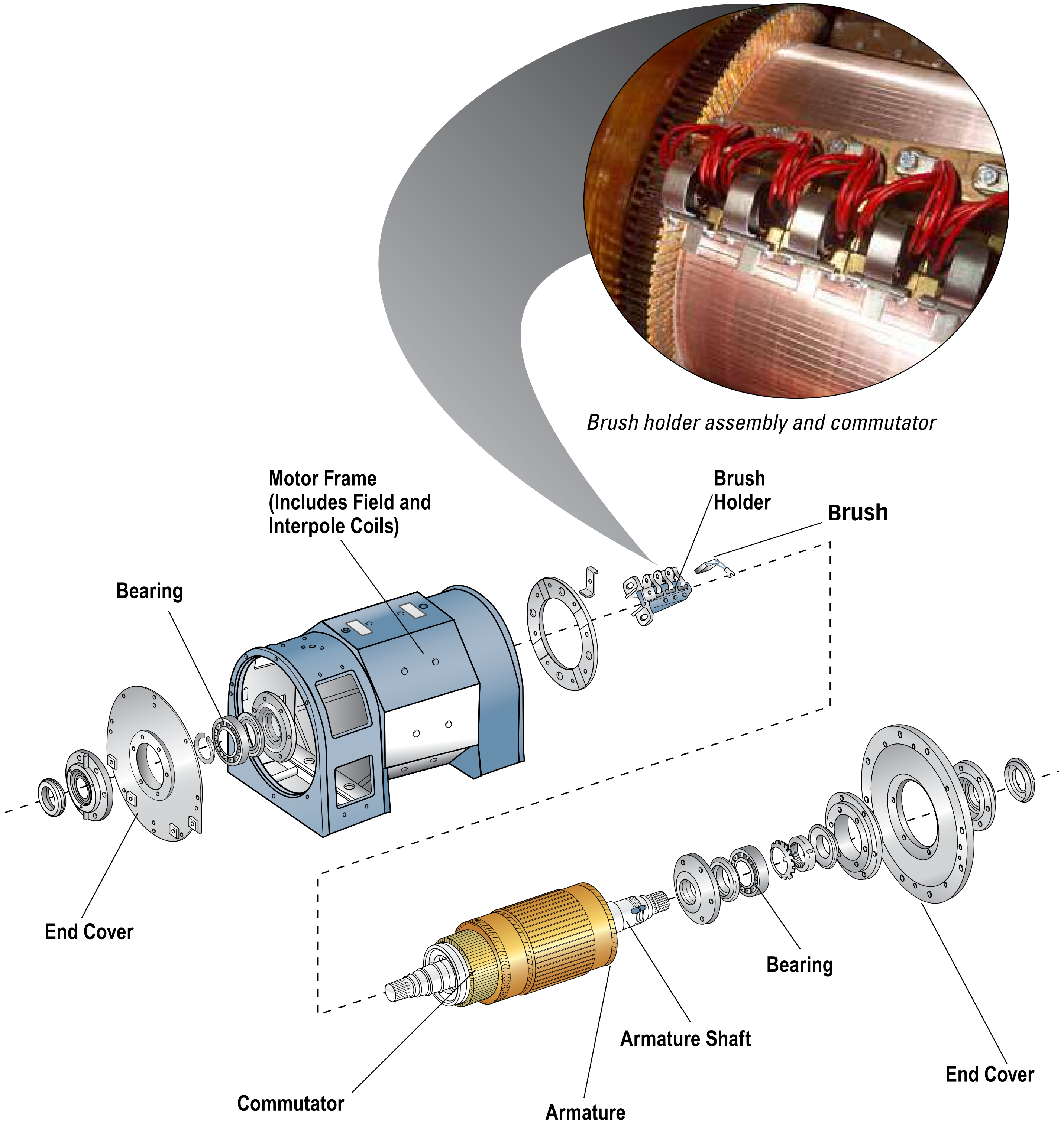


Figure 3 DC mining shovel motor components

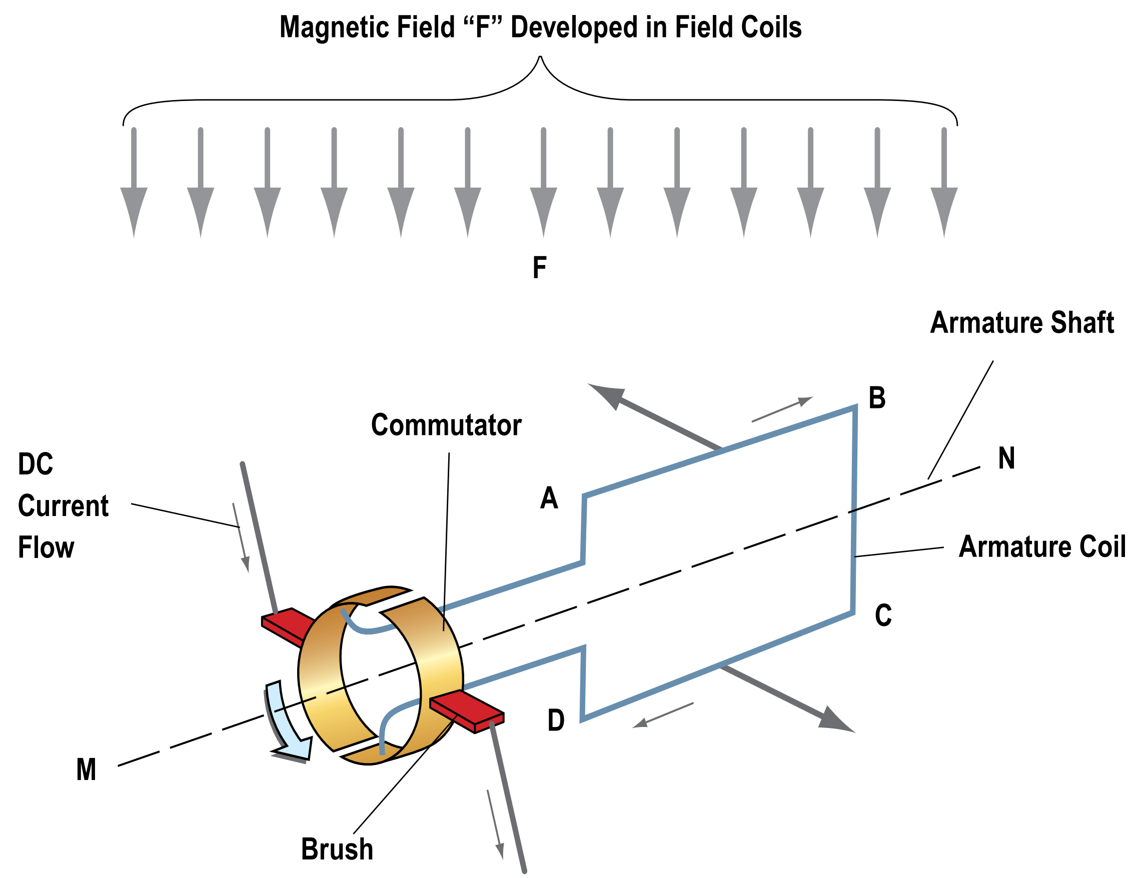


Figure 4 Schematic diagram illustrating basic motor theory

As the wire loop rotates, the forces moving the loop start to diminish and if the current is not reversed after the loop has rotated 180 degrees, the loop will not continue to rotate in the direction shown. For this reason the commutator is split so that the polarity of the leads to the armature coil will reverse as the coil rotates.

In DC mining motors many loops of wire make up each armature. The multiple loops of wire assure a smooth and continuous motion of the armature. The field coils have multiple strands of wire wound around an iron core to provide powerful electromagnets. Brushes provide current to the commutator, which is connected directly to the armature windings.

DC Motor Theory Summary

The information presented in this topic is intended for those with a strong background in DC motor fundamentals. Although this information will help you gain a better grasp of DC mining motors it is not a prerequisite for the balance of the material presented in this handbook.

Description

A DC motor/generator is made up of a magnetic circuit consisting of iron or steel and an air gap, as shown in Figure 5. The air gap provides space for movement between the machine's stationary and rotating parts.

An electrical conductor, also called a winding or coil, is wrapped around the iron parts of the motor a particular number of times. If a DC voltage is applied across the winding, a current flows through the winding. According to Ohm's Law, the amount of current (i) is determined by the voltage (e) and resistance (R) of the winding. The current magnetizes the iron parts and causes a magnetic flux (Ø) to flow through the iron parts and across the air gap. The amount of flux produced is proportional to the number of turns (N) in the winding multiplied by the current (Figure 6).

The relationship between the product of N times i (ampere-turns) is not linear (Figure 7). At low flux levels, the flux is proportional to the number of ampere-turns and the primary resistance is the air gap in the motor. At higher flux levels, the iron parts become saturated and it becomes harder to force

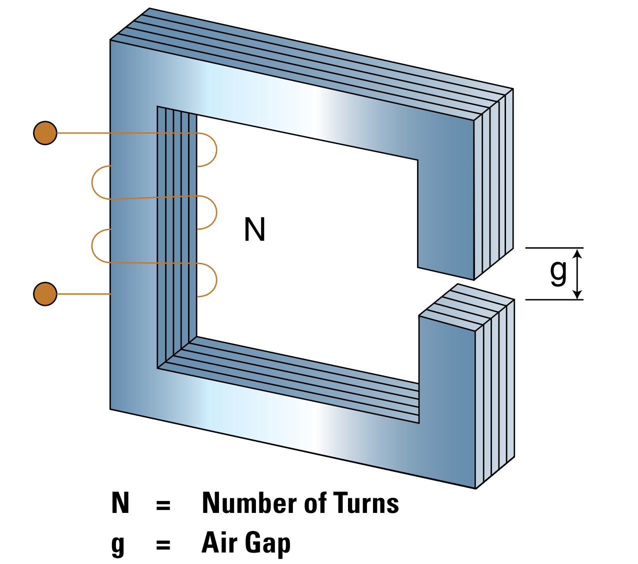


Figure 5 A DC motor consists of a magnetic circuit of iron or steel, a number of windings (N), and an air gap (g) which provides space for the movement of motor's rotating parts.

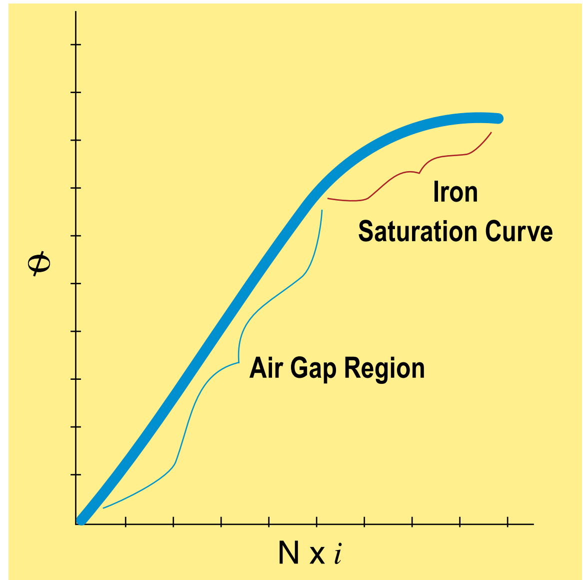


Figure 7 As flux levels increase, the motor's iron parts become saturated, making it harder to force more flux through them.

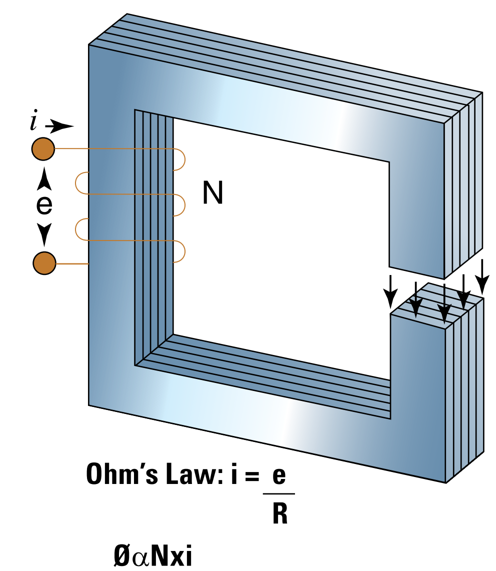


Figure 6 Ohm's law states that the amount of current (*i*) is equal to the voltage (e) divided by the winding's resistance (R). The magnetic flux produced (Ø) is proportional to the number of turns in the winding (N) multiplied by the current (*i*).

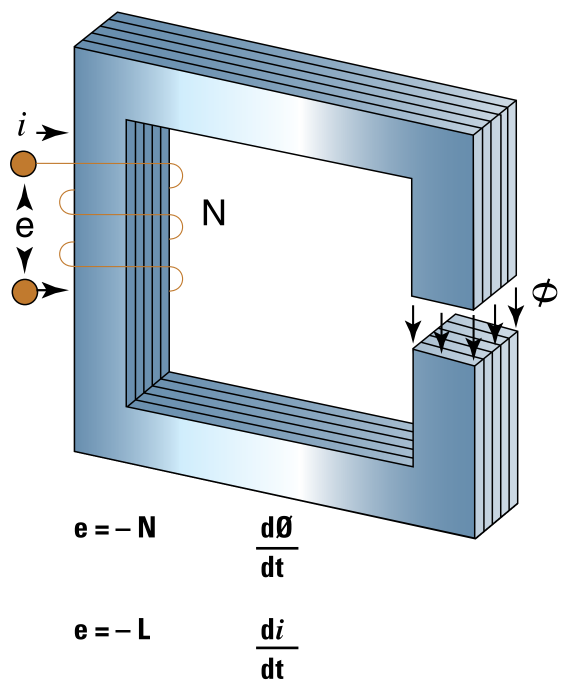
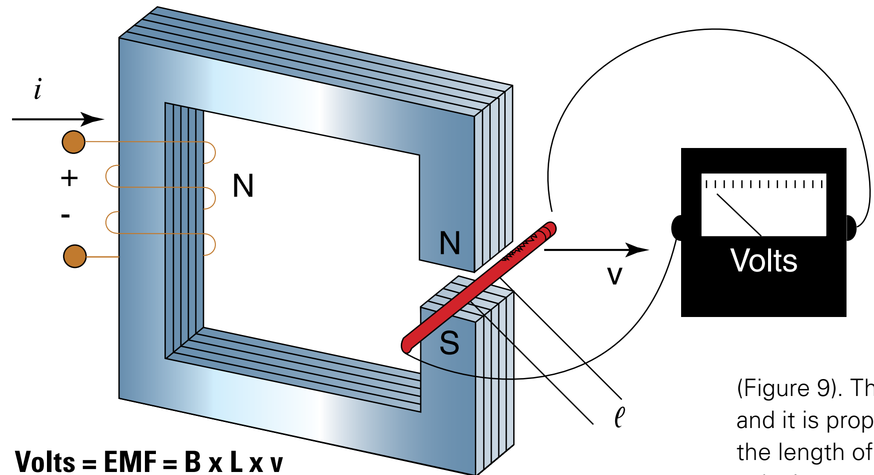


Figure 8 The Property of Inductance (L) - A voltage is produced that is proportional to the inductance times the rate of change of current (di/dt). The negative sign shows that the voltage opposes the change in current.

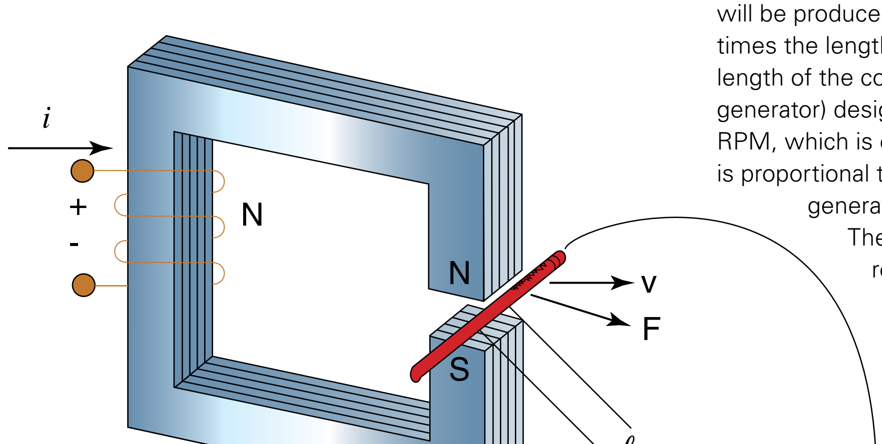
more flux through them. As the iron reaches saturation, it takes a large increase in ampere-turns to produce even a small increase in flux. Figure 7 shows a saturation curve for a DC motor.

If the current and flow of flux are established in a winding, and something occurs that causes a change in either the current or flux, it will produce a voltage at the winding's terminals (Figure 8). The voltage is proportional to the number of ampere-turns multiplied by the rate of change of flux (dØ/dt). As indicated by the negative sign, the voltage is produced in such a manner that it opposes the change in flux.



Volts = EMF = B x L x v
where
B = Flux density (Ø/Area)
L = Length of conductor
V = Velocity of conductor

Figure 9 Voltage or Electromotive Force (EMF) produced is proportional to the flux density (B) multiplied by the length of the conductor multiplied by the velocity at which the flux moves through the air gap.



F = B x I x L
where
B = Flux density (Ø/Area)
I = Current
L = Length of conductor

Figure 10 An increase in flux density (B), current (I), or conductor length (L) increases the force (F) required to pull the conductor through the air gap.

Another way to express this equation is to use the property known as "inductance" (L). A voltage will be produced that is proportional to the inductance times the rate of change of current (di/dt). As before, the negative sign shows that the voltage opposes the change in current. In other words, it attempts to keep the current flowing in the same direction.

If a conductor passes through the magnetic flux in the air gap with a velocity (v), it produces a voltage at the ends of the conductor (Figure 9). This voltage is called an EMF or electromotive force and it is proportional to flux density (flux per unit of area) times the length of the conductor (l) in the air gap multiplied by the velocity at which it is moved through the air gap.

The voltage increases with higher flux densities, longer conductor lengths or higher velocities of movement.

If a circuit is completed so that current can flow through the conductor, it will require a force (F) to pull the conductor through the air gap (Figure 10). The amount of force required is equal to the flux density times the current in the conductor times the length of the conductor in the air gap.

An increase in flux density, current, or conductor length increases the force required to pull the conductor through the air gap. As a result, in a DC generator, an output voltage (V) will be produced that is proportional to the flux density (B) times the length (L) times the velocity of the conductor (v). The length of the conductor is a function of the machine (motor or generator) design, and the velocity is related to the generator's RPM, which is constant. The output voltage of a DC generator is proportional to the flux density, which is related to the generator field current by the saturation curve. Therefore, the output voltage of a DC generator is regulated by adjusting its field current.

Commutation

Commutation is the process of reversing the direction of the flow of current in the windings of a DC motor armature. Commutation is a key consideration in motor design and operation.

All DC machines use brushes that carry the current to produce torque. The current is transferred to and from the armature's rotating copper commutator. When the commutator segments to which the armature coils are connected pass under the brushes, the coils are successively transferred from one armature path, in which the current is flowing in one direction, to an adjoining armature path, with the current flowing in the opposite direction. During the time the coils are in contact with the brush, the coils are short-circuited by the brush and the current must be reduced from its original value to zero and then built up again to an equal value in the opposite direction.

Figure 11 shows an example of a part of the DC motor showing a North and South main pole. As the armature passes under each main pole, the current in individual conductors reverses direction from the north pole to the south pole. This change in current is expressed as DI, and it occurs during a time period expressed as Dt.

Again, if there is a change in current in an armature winding, a voltage (V) is produced that is equal to minus the inductance times the rate of change in current, di/dt. This can be represented as inductance times DI divided by Dt. This voltage is called "reactance voltage," and its polarity is such that it attempts to keep armature current flowing in the same direction, which is undesirable. Ideal, or linear, commutation is represented in Figure 11. The actual current reversal will vary somewhat from the ideal.

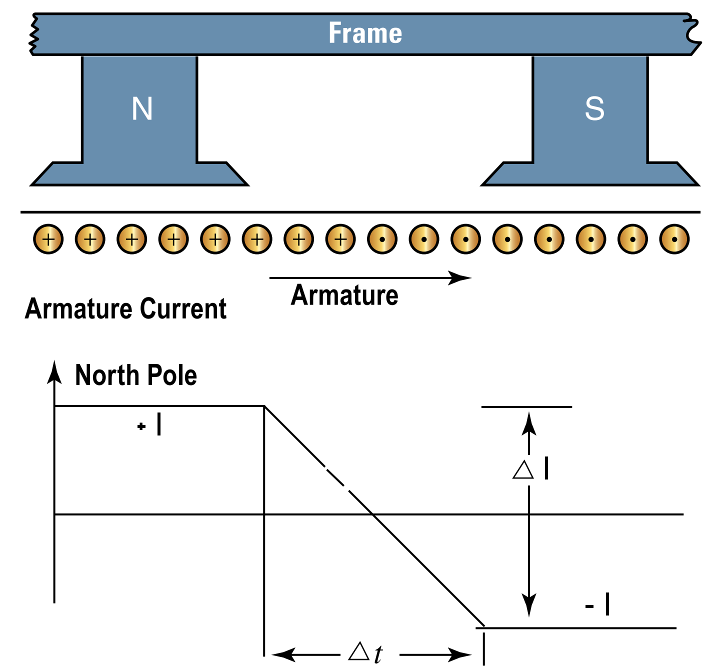


Figure 11 As the armature passes under each of the main poles, the current in individual conductors reverses direction. The reversal of the current through the brushes is called commutation.

To assist the current reversal process, DC motors incorporate a "commutating pole" or "interpole" which fits in between the main poles and produces a flux that cuts the armature conductors (Figure 12). The flux from the interpole will produce a voltage, which approximately compensates for the reactance voltage, allowing for the coil to reverse current.

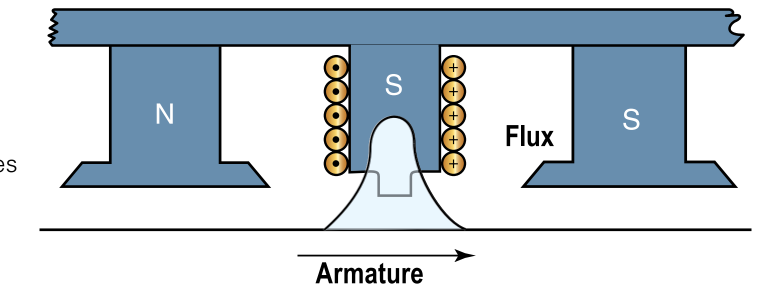


Figure 12 DC machines incorporate a commutating pole or "interpole" in between the main poles to assist the current reversal process. The interpole flux cuts the armature conductors.

With the current in the armature coil varying load, similar change in flux or voltage is needed from the interpole coil in order to compensate for the change in reactance voltage. With these considerations in mind, a flux density produced by the commutating pole that is proportional to armature current is desirable. This is accomplished by connecting the windings on the commutating pole in series with the armature. The commutating pole magnetic circuit should not be saturated so that flux is always proportional to ampere-turns.

Flux Distribution and Armature Reaction

As shown in Figure 13, there is a uniform distribution of flux underneath the main poles when the main field is excited. If there is current in the armature but no excitation of the main fields, the flux distribution is as shown in Figure 14. And if there is both current in the armature and main field excitation, the fluxes combine, as Figure 15 illustrates.

The flow of current in the armature distorts the main pole flux, causing the flux density to be high at one tip of each pole. It also distorts the flux so that it may not be zero near the centerline between the main poles. This tends to sustain armature current in the same direction, which is undesirable. This distortion on the flux in the air gap is referred to as "armature reaction."

To overcome the effect of armature reaction, one additional winding, called the "poleface winding" (Figure 16), is placed in larger DC motors. This winding is comprised of large conductors that are placed through the face of the main pole pieces, and connected such that they oppose the flux from current in the armature conductors.

The poleface winding cancels out the effect of armature reaction, reduces the bar-to-bar voltage at the commutator bars and improves some output characteristics of the machine, notably DC motor speed stability. The poleface winding is connected in series with the armature.

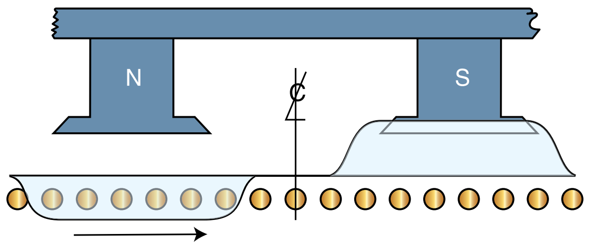


Figure 13 Flux due to main field i.

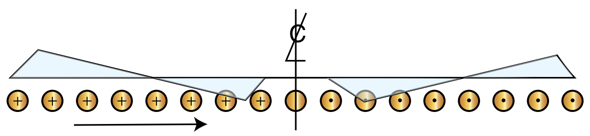


Figure 14 Flux due to armature conductor circuit.

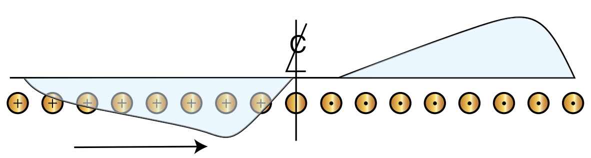


Figure 15 Net flux due to main field and armature current.

To provide proper commutation, the amount of flux from the commutating fields must be adjusted or fine tuned. Since the amount of flux is proportional to the number of ampere-turns times the current, and the number of turns and current are determined by the machine design and load, some other method must be provided to adjust the amount of flux. This can be done by changing the air gap.

There are two air gaps in the magnetic circuit for the commutating fields (Figure 17), a "front" gap and a "back" gap. The front gap is between the commutating pole and the armature. Increasing the front gap's size reduces the amount of flux for given ampere-turns in the commutating field winding, and it changes the distribution of flux over the armature surface. Since a certain amount of flux distribution is desirable, it is best to avoid large changes in the front gap.

The back gap, consisting of magnetic and non-magnetic shims (aluminum or brass), is provided between the back of the commutating pole and the motor frame. The amount of flux can be adjusted by changing the number of magnetic and non-magnetic shims. The order of the shims is important as well as the quantity of magnetic and non-magnetic shims.

On larger machines, DC motors and generators can also be adjusted by moving the large ring to which the brush arms are connected. In the proper position, the brushes will contact commutator segments that are connected to armature coils that pass through the commutating zone where the armature current reverses (Figure 18). Since the relationship between the position of armature conductors and commutator bars varies slightly from one armature to the next, it is important to check the brush position when a new armature is installed.

Unless the brush position and the amount of flux from the commutating poles is correct, the current in the armature windings will not reverse properly, resulting in sparking at the brushes, shortening brush life, and deteriorating the commutator's surface.

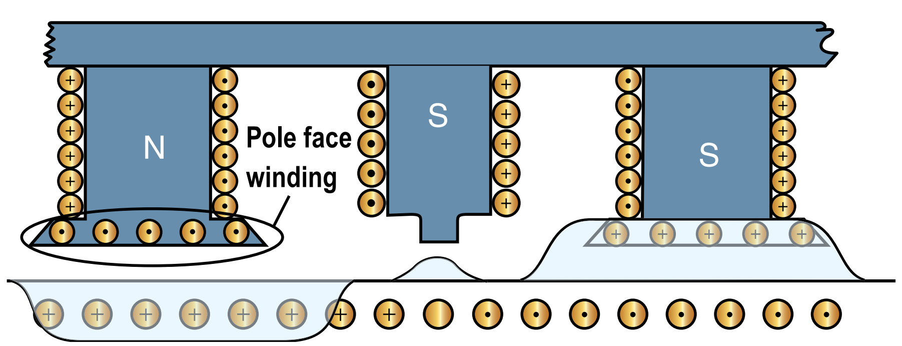


Figure 16 The poleface winding cancels the effect of armature reaction, reduces bar-to-bar voltage at the commutator bars and improves output characteristics of the machine.

2. DC MINING MOTOR BASICS

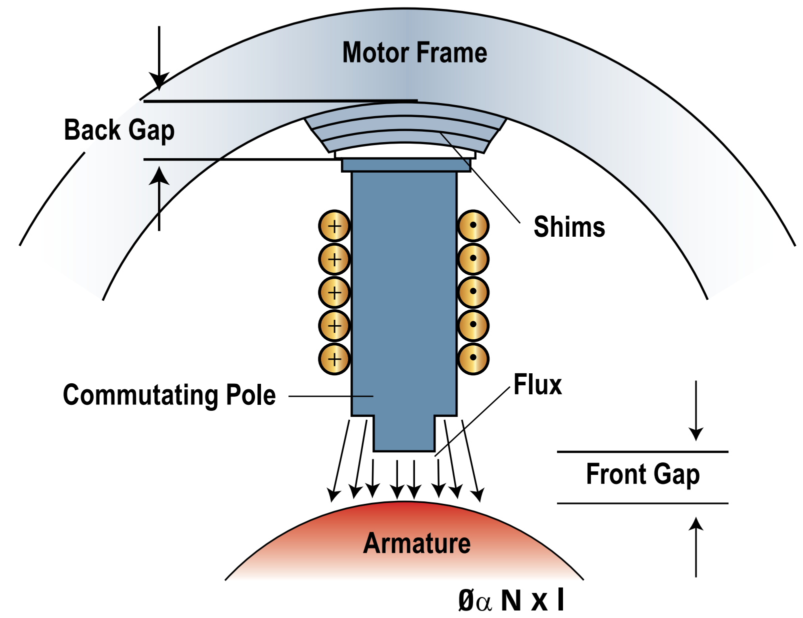


Figure 17 The front gap of the commutating fields is between the commutating pole and the armature. The back gap is between the back of the commutating pole and the motor frame.

Brush position and commutating field strength are adjusted at the factory by a method requiring large and specialized equipment that is not practical for use in the field. Other methods of checking machine adjustment are necessary for use in the field.

Speed and Torque

A DC motor operates by the same principles as a DC generator (Figure 19). A voltage is produced that is proportional to the flux density times length times velocity. Likewise, the voltage is proportional to the flux density (B) times the RPM. Restating this equation to determine the RPM, we see that the RPM is proportional to the voltage applied to the motor divided by the flux. Since the flux density is determined by the field current, the RPM is proportional to the voltage divided by the field current.

Therefore, as the voltage applied to the motor increases, the faster the motor rotates. Also, if the motor field current is high, the motor runs slower, and if the motor field current is low, the motor runs faster. On excavating equipment, the DC motors often incorporate a strong and weak field setting. This allows the motors to run faster for a given voltage in the weak field setting. An example of this is the hoist motion on a shovel.

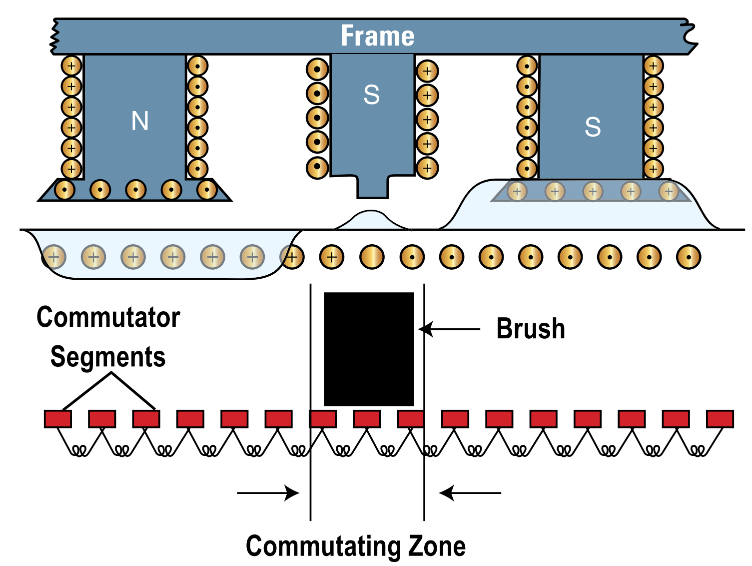
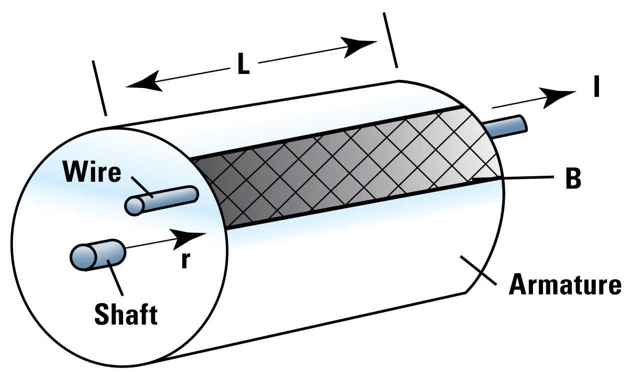


Figure 18 In the proper position, the brushes will contact the commutator segments connected to the armature coils that pass through the commutating zone.

Figure 19 illustrates an armature with a core length (l), and a conductor passing through the armature at radius (r) from the centerline of the shaft. Flux density (B) enters the armature in the cross-hatched area. If current flows through the conductor in the armature, and the armature rotates such that it passes the conductor through the magnetic flux, a force will be produced on the conductor proportional to the flux density times the current times the length of the armature iron.

Torque is determined by multiplying force times radius. Since the length of a motor armature is established during the machine's design, for any given machine, the torque is proportional to the flux density times the current in the armature. As the current in the DC motor increases, its output torque increases. If the flux density is high, such as in the strong field setting, the torque will be high. And if the flux density is low, such as when the field is weakened, the torque will be low.



Speed

$V = BLV$

$V \propto B \times RPM$

$RPM \propto \frac{Volts}{B} \propto \frac{Volts}{Field}$

Torque

$Force \propto B \times I \times L$

$Torque = Force \times Radius$

$Torque \propto B \times I$

Figure 19 - Flux density (B) enters an armature with a core length (L) and a conductor passing through the armature at radius (r) from the centerline. Flux density enters in the cross-hatched area.

Looking at the equations for speed and torque, high field flux produces high torque and low speed, while low field flux produces low torque and high speed.

To vary the speed and torque of the DC shunt type motors used on shovels, a control system will change either the voltage or flux (field current) depending on the application requirements. Proper control of the voltage and flux will insure smooth, dynamic performance from the motors, which results in a highly productive shovel. The ability to control speed and torque in this manner has made DC motor drives the leading choice for powering mining shovel equipment.

Types of DC Motors

There are three types of DC motors, classified by the types of windings they incorporate: series-wound; shunt-wound; and compound-wound. A compound wound motor is one designed with both a series and shunt field winding. Each type of motor has its advantages in different applications in terms of handling variations in torque, speed and load. For the purposes of electric mining shovels, shunt-wound motors are used.

3. Mining Shovel Motor Applications

Electric mining shovel motors are applied primarily to meet the needs of the shovel's work cycle (Figure 20). The work cycle is divided into four basic phases. The work cycle phases include: digging, swinging, dumping and returning. Three machine motions, crowd, hoist and swing are used in every work cycle. In addition, the propel motion is used to reposition the shovel relative to the bank, and for traveling to different locations within the mine.

Figure 20 A shovel's work cycle consists of digging, swinging, dumping, and returning to the bank.

The Work Cycle

The digging phase involves crowding the dipper into the bank, hoisting to fill the dipper, and retracting the dipper from the bank. A proper balance of crowd and hoist forces is essential for efficient and productive digging (Figure 21).

The swinging phase begins when the dipper clears the bank vertically and horizontally. During this phase, the operator controls the position of the dipper on a planned swing path and dump height, as well as the swing motion, until the dipper is positioned over the haul unit.

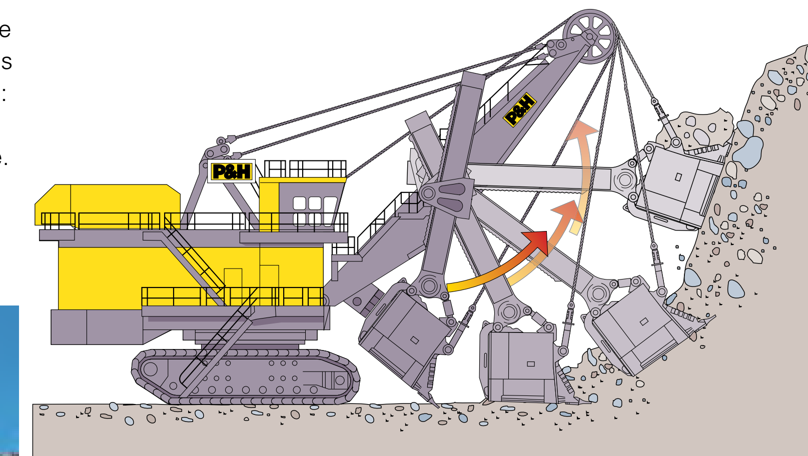


Figure 21 The digging phase

The dumping phase begins before the loaded dipper passes over the end of the haul unit and finishes when the swing motion stops and reverses direction to return the dipper to the bank. During the dumping phase, the operator trips open the door to dump the load while controlling the dump height to avoid damage to the truck bed, especially during the first load (Figure 20).

The returning phase includes swinging the upper frame back to the bank and lowering the dipper to close the dipper door, and engage the door latch.

Throughout the digging cycle, the shovel's motors supply the power for the three motions required to extract material from the bank, deliver it to the haul unit and return to dig. Regulating the speed of each motion is largely up to the operator, although shovels are often equipped with various motor control devices to improve performance.

Shovel Motions

The crowd motion provides the thrust needed to force the dipper into the bank under enough material to make effective use of the available bail pull (hoist power) to fill the dipper. Good fill factors depend on adequate bank penetration but excessive penetration will cause the hoist speed to slow or stall. The crowd motion is activated by the boom mounted crowd motor (Figure 22).

The hoist motion is the tensioning of the hoist ropes to pull the dipper through the bank. The shovel operator must maintain a proper balance of crowd and hoist forces. Applying excessive crowd force relative to the hoist force can result in boom jacking whereby the boom is drawn back and its support pendants go slack, causing the boom to drop. The falling boom being caught by the support system can cause tremendous stresses. The hoist motion is activated by the deck-mounted hoist motors (Figure 22).

The swing motion involves rotating the shovel's upper structure until the dipper is over the haul truck. The operator must accelerate smoothly through about the first half of the swing arc, coast and then decelerate to a smooth stop through the second half. The weight of the material in the dipper affects both the shovel's stability and the rate of acceleration and deceleration. The swing motion is activated by the swing motors mounted on the swing transmissions (Figure 22).

The propel motion is used to relocate the shovel to maintain the proper digging position relative to the bank, and to change locations within the pit. Like the crowd, hoist and swing motions, the propel motors operate in forward and reverse. The short, intermittent propels and long continuous propelling to other locations require tractive effort. Propel motor design criteria for the amount of tractive effort required include:

- Shovel weight
- Pit floor material
- Crawler shoe size
- Maximum travel speed
- Grade

The propel motion is activated by the propel motors mounted on a motor frame (Figure 23).

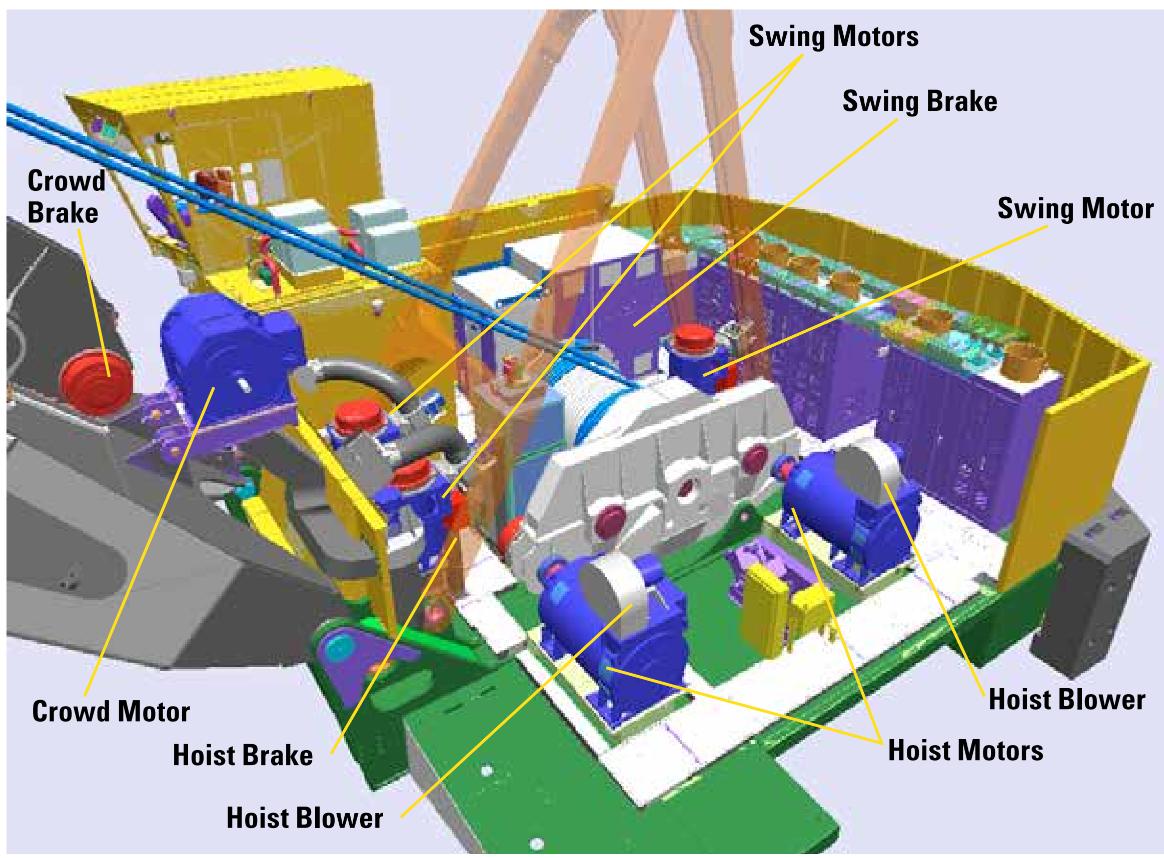


Figure 22 Motors and brakes on the deck and boom of an electric mining shovel

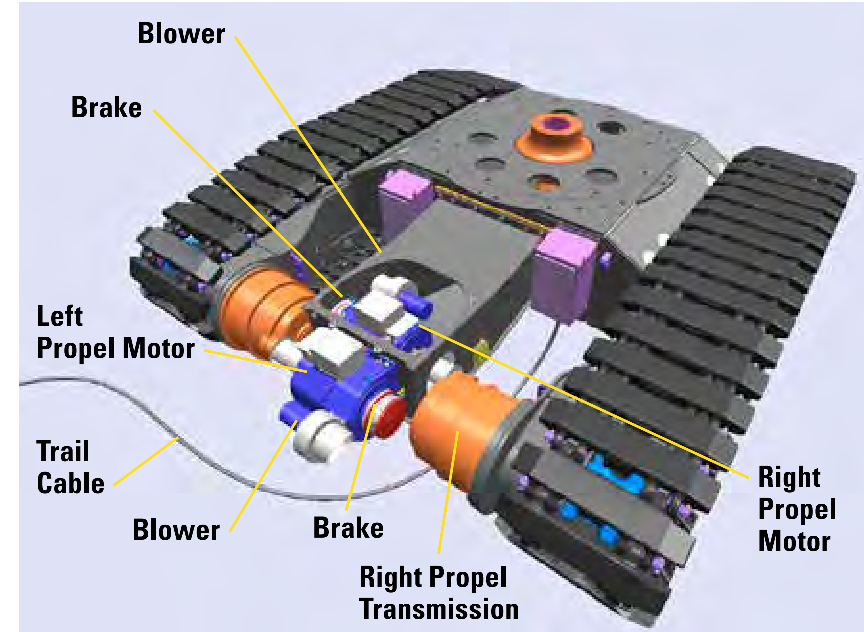


Figure 23 Propel motors & brakes

Shovel Duty Cycle

Motor speed and torque are constantly changing in response to the changing load demands and motions throughout the digging cycle. Figure 24 provides an example of the motion motors' speed and torque response in an ideal digging cycle. The motor requirements are established to provide a coordinated response from each motion to orchestrate the most productive digging cycle.

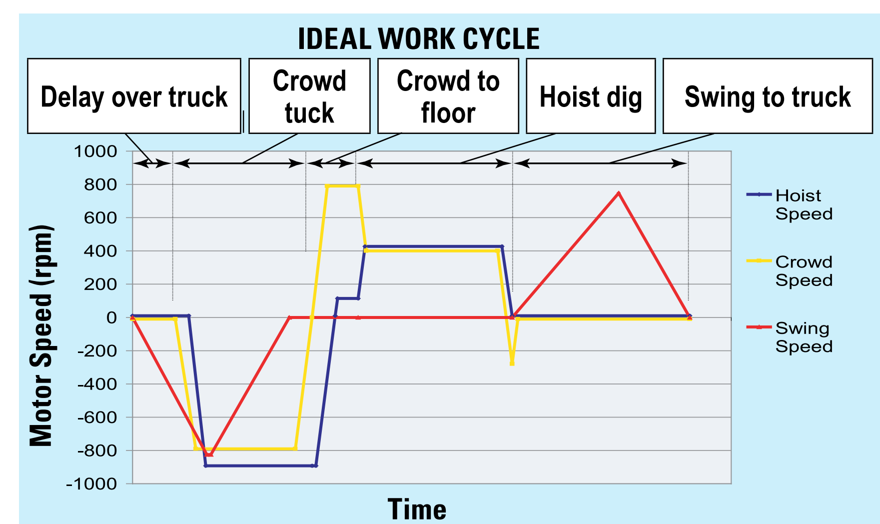


Figure 24 In an ideal digging cycle, hoist, crowd and swing motions are perfectly coordinated, as indicated by the curves. Constantly changing loads and machine motions produce less than ideal response.

Shovel motors are designed and manufactured to meet the speed and force demands for each motion in the digging cycle. Additionally, they are designed to operate in the severe conditions of a mining environment. Some manufacturers select from a limited number of commercially available mill-type motors whose performance characteristics are averaged to make them usable in a broad range of applications, such as crushers and conveyors as well as excavating equipment. Enhanced shovel performance can be optimized by designing optimum motor performance to meet the specified shovel requirements.

Shovel Motor Performance Requirements

Hoist Motor Performance

The hoist motion is produced when the hoist motors rotate the hoist drum through the hoist transmission to take up the hoist rope and pull the dipper up through the bank. The type and weight of the material being extracted affects both the hoist and swing motions.

The dipper size and configuration, and the density of the material being extracted, determine the hoist force or bail pull needed to meet the digging requirements. Cycle times and coordination with the crowd and swing motions determine the needed bail pull and bail speed. The actual digging force is a result of hoist and crowd forces (Figure 25).

The hoist motor is designed to meet the hoist performance requirement. Figure 26 represents an example of hoist bail pull and bail speed capability. Figure 27 shows the speed and torque performance of the hoist motor to meet the bail pull and bail speed requirements.

The hoist motor is designed and sized to handle operating loads and conditions based on how the motor is actually used in the duty cycle. Actual hoist performance depends on operator experience, ability and consistency. Other design factors that must be considered in hoist motor sizing and design include:

- Continuation of digging in the bank after the dipper is full.
- Excessive hoisting and lowering by the operator, resulting in higher acceleration and deceleration current.

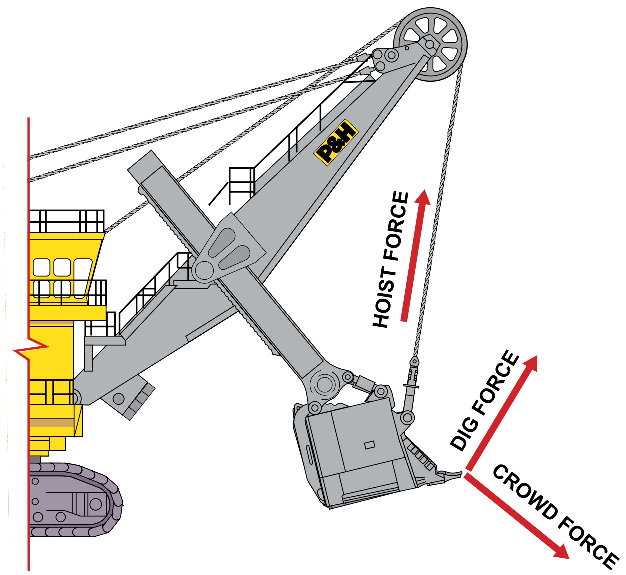


Figure 25 Electric mining shovel digging forces

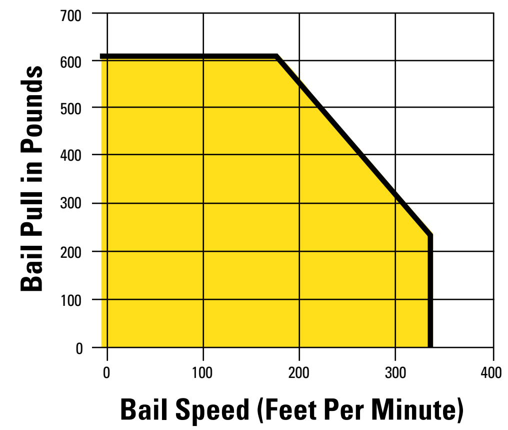


Figure 26 Hoisting Performance

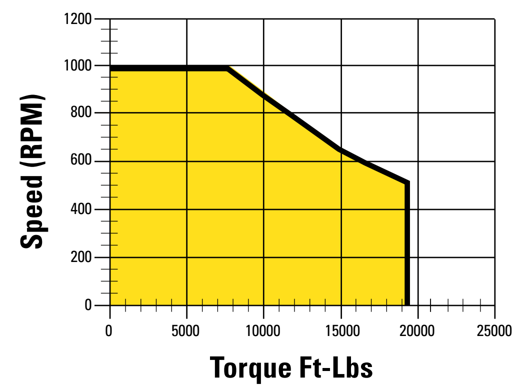


Figure 27 Hoist Speed vs Torque

- Extreme digging conditions such as highly-resistant sand-like material or unbroken rocky material due to inadequate blasting.
- Excessive suspension of a full dipper while waiting for a haul unit.
- Over-extension of the dipper handle, resulting in reduced bail pull and higher hoist currents.
- Digging sequence methodology.

Figure 28 is an actual recording of the hoist motion speed and torque (measured by armature current) during a complete digging cycle. The recording indicates a much different profile of speed and torque as compared to an ideal cycle (Figure 24). An average or RMS current level of actual hoist digging cycles is evaluated to determine the size of the motor and its ability to dissipate the heat generated by these loads.

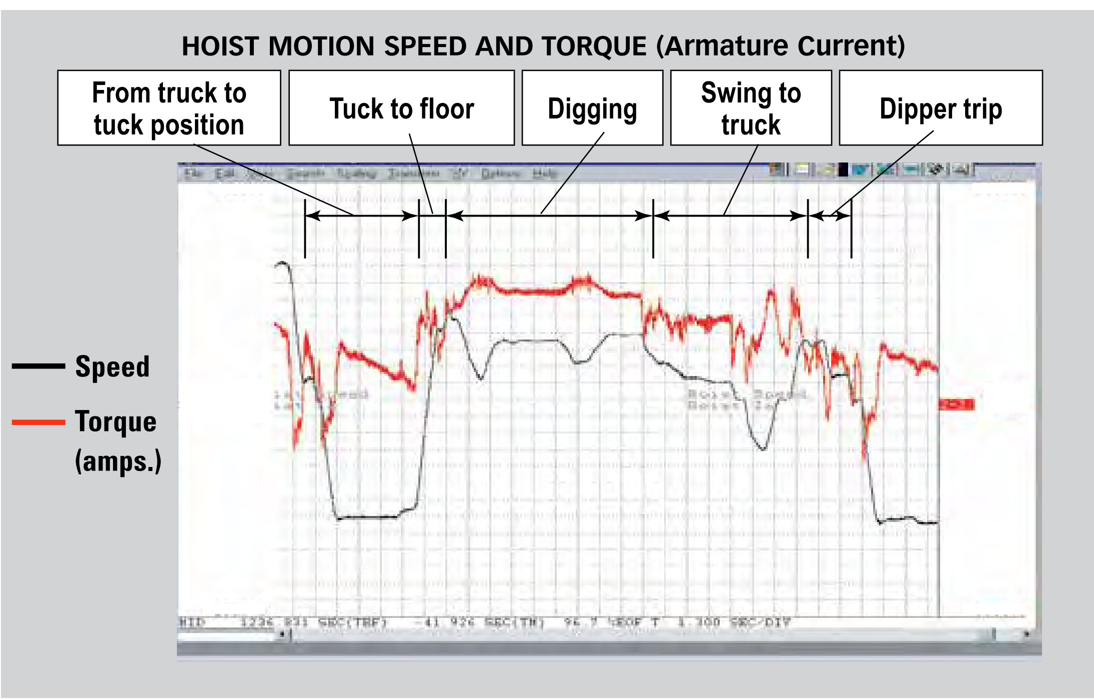


Figure 28 Recording of a hoist motion cycle

Crowd Motor Performance

The crowd motor operates in two directions: forward (crowding) to the bank, and reverse (retracting) from the bank. The forward motion requires enough force (torque and speed) to push the dipper into the bank and the dipper teeth under enough material to make effective use of the available bail pull from the hoist motion. The crowd and retract motions are also used to move the dipper into the proper tuck position at the start of the digging phase of the work cycle, and to locate the dipper over the truck for dumping the material. Excessive use of the crowd motion will result in continual acceleration and deceleration at maximum current levels and the constant adjustment of the crowd could lead to overloading of the crowd motor.

Wider dippers and lip geometry are designed to slice through banks rather than plow through them. The crowd motion is used to control the depth of the cut. The crowd motion should not be used to penetrate so deeply as to attempt to lift the entire bank. The depth of penetration should be adjusted to permit optimal fill factors (Figure 29).

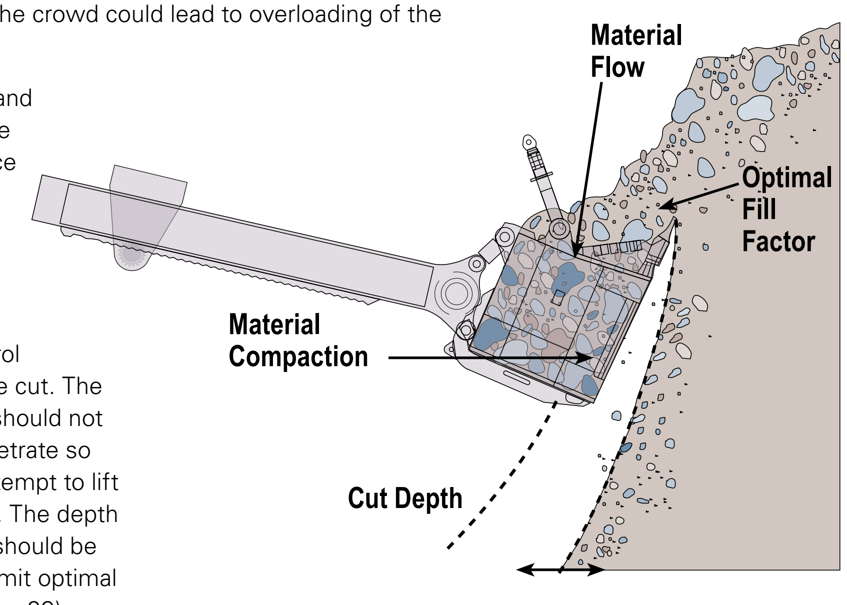


Figure 29 Optimal cut depth and fill factors

Adequate fill factors cannot be achieved without adequate penetration, yet excessive penetration will cause the hoist motor to slow or stall. A good operator will monitor the balance of crowd and hoist forces to keep the dipper moving near peak power.

If the dipper stalls in the bank, cycle times will increase. Technologies such as P&H's OptiDig™ are designed to prevent stalling by sensing an imminent stall condition and automatically adjusting the crowd position.

To provide the necessary crowd and retract response, crowd force and crowd speed (fpm of dipper handle) are generated by the crowd motor. Figure 30 shows the crowd (positive direction) and retract (negative direction) performance to meet the shovel requirements. The crowd motor is designed to a specific speed and torque profile to meet the crowd performance requirement. Figure 31 is an example of the speed and torque requirements for a crowd motor; it represents the limits within which the crowd motor will operate.

The control system regulates armature voltage, armature current and field current to keep the motor speed and torque output within these limits. Based on how these motors are actually used in the

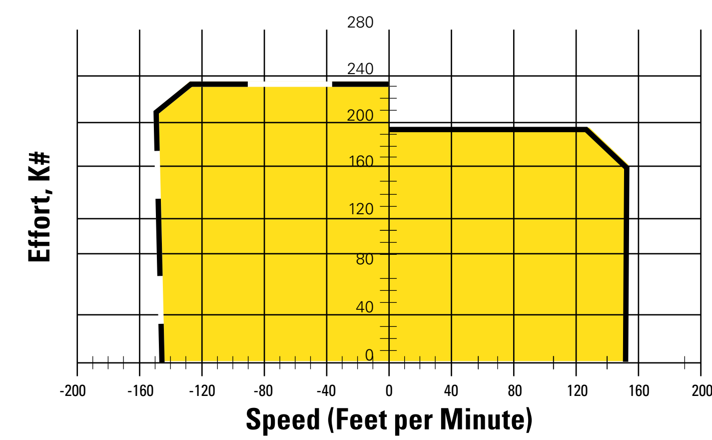


Figure 30 Crowd effort remains constant as speed changes throughout the forward motion (indicated by the positive numbers), as well as during the retract motion (indicated by the negative numbers).

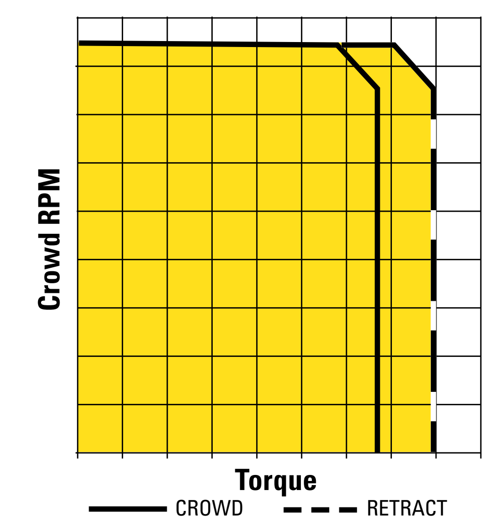


Figure 31 The crowd motor is designed to a specific speed and torque profile to meet the shovel's crowd and retract force requirements.

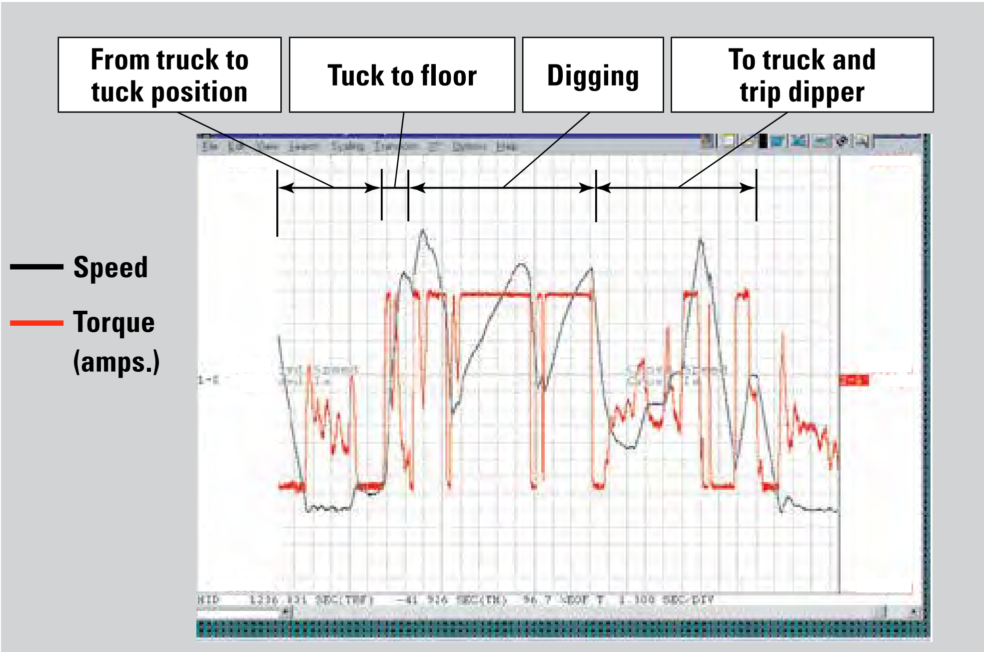


Figure 32 Recording of the crowd motion speed and armature current

duty cycle, the crowd motor is sized to handle the operating loads and digging conditions. The ideal duty cycle is one that can be achieved by the precise coordination of all motions. Actual crowd operation often consists of additional crowd movements and higher loads due to less than perfect operator skill and consistency.

Figure 32 shows an example of an actual complete digging cycle recording of the crowd motion speed and armature current. The armature current (amps) represents the amount of torque generated by the crowd motor. The recording indicates a much different profile of speed and torque as compared to an ideal cycle. The increase in crowd movements result in higher armature currents due to acceleration and deceleration. An average or RMS current level of actual digging cycles of the crowd is evaluated to determine the size and capability of the crowd motor to dissipate the heat generated by these loads.

Swing Motor Performance

The swing motion involves rotating the entire upper structure until the dipper is over the haul truck. The weight of the material in the dipper affects machine stability as well as the rate of swing acceleration and deceleration.

The swing motion begins when the dipper has cleared the bank horizontally and vertically. Acceleration should be smooth through the first half of the swing arc, and then deceleration begins (Figure 33). Acceleration and deceleration are proportional to the swing controller movement.

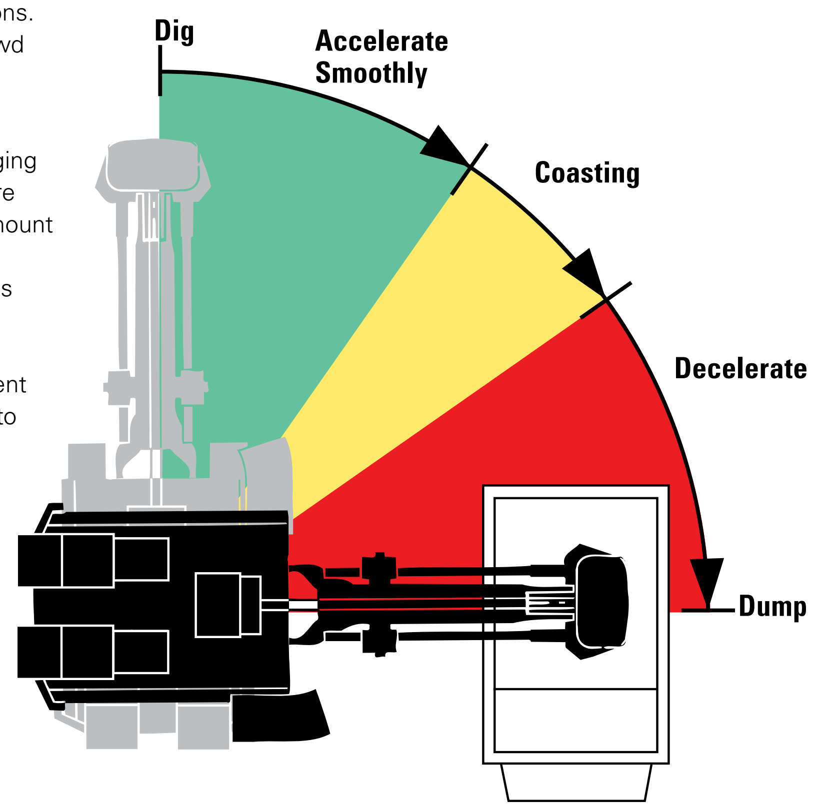


Figure 33 The weight in the dipper affects shovel stability as well as the rate of acceleration and deceleration.

Dipper size, shovel inertia, material tonnage, desired cycle time, and coordination of the hoist and crowd motion dictate the swing motor's force and rotational speed requirements. Figure 34 represents an example of the swing force in torque and shovel rotational speed requirements. The swing motor's speed and torque output are designed to meet these requirements. Figure 35 represents an example of a swing motor's speed and torque operating limits.

As compared to the ideal digging duty cycle, the actual swing performance is very similar. Operators will most likely not use all the capability of the swing due to inefficient use of the crowd and hoist motions. Dipper size, overall shovel speed and truck position can also limit the operator's use of the swing motion. Figure 36 shows a recording of a typical swing cycle. The two graphs represent the speed and current (torque) of the swing motor starting after the dipper is tripped.

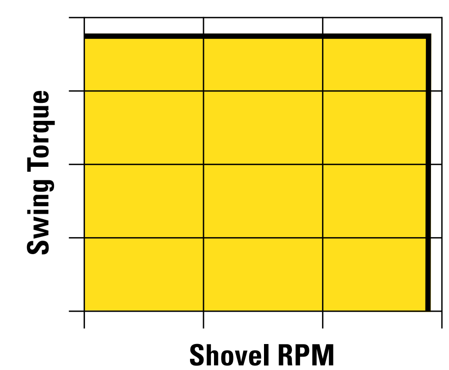


Figure 34 As swing motor speed increases, swing torque remains constant.

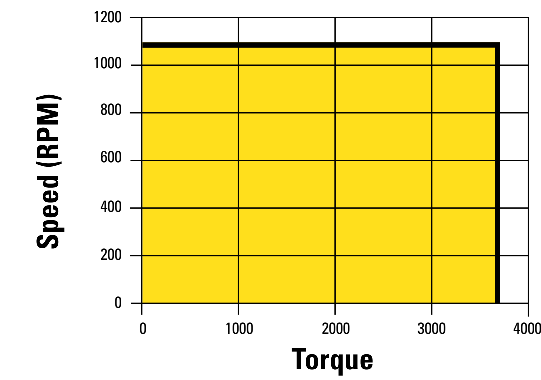


Figure 35 As swing motor torque increases, swing speed remains constant.

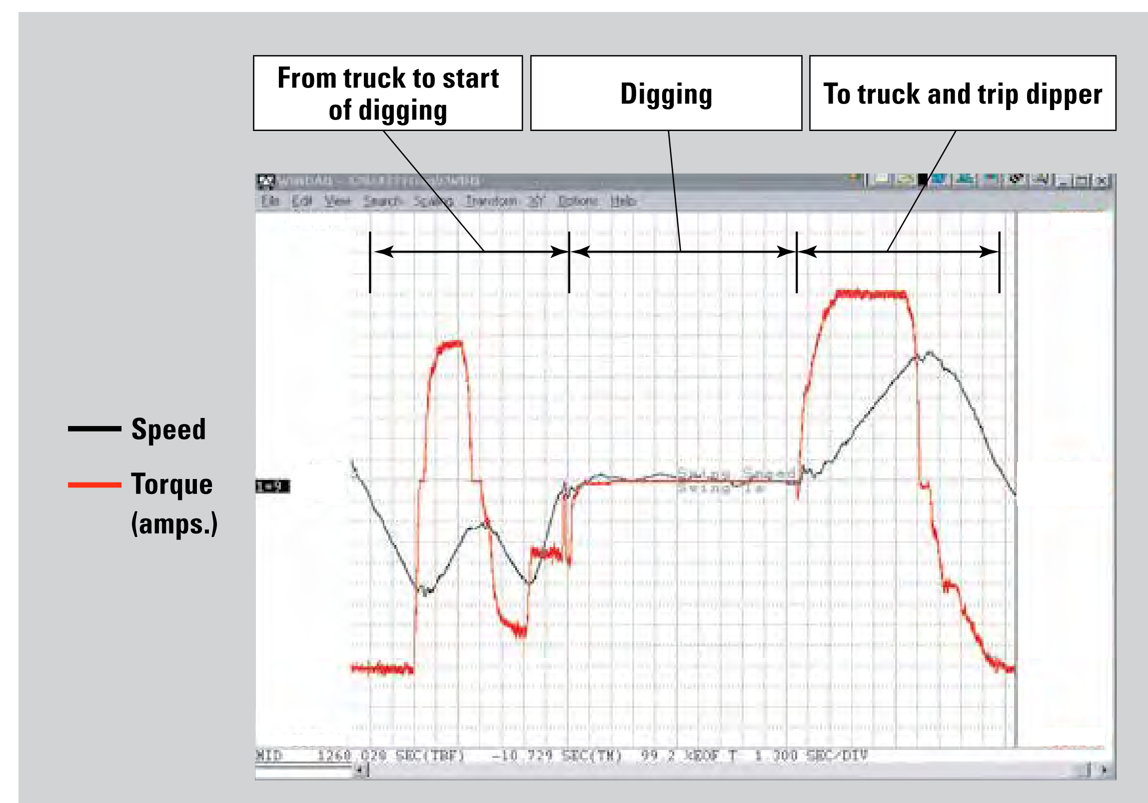


Figure 36 Typical swing cycles from and to the truck

Propel Motor Performance

The propel motion is used to relocate the shovel to maintain proper digging position, and to change locations in the pit. Propelling requires a certain amount of tractive effort, based on the following criteria:

- Shovel weight
- Pit floor material
- Crawler shoe size
- Maximum travel speed
- Grade

Propel motors are designed to provide speed and torque to produce the tractive effort required to move the shovel. Figure 37 shows an example of tractive effort and shovel speed at various grades. The design of propel motor speed vs. torque performance meets the propel requirements as shown in Figure 38.

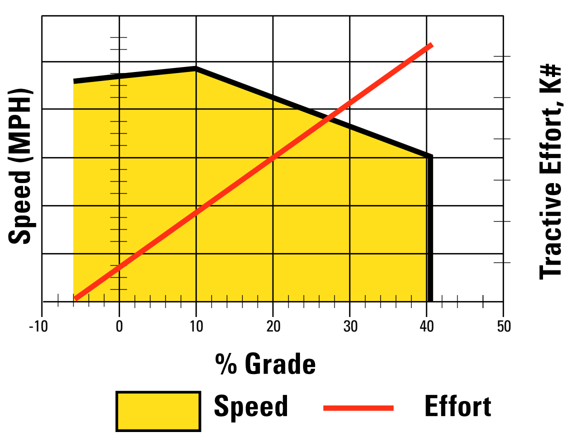


Figure 37 As the grade increases, greater effort is required to propel the shovel.

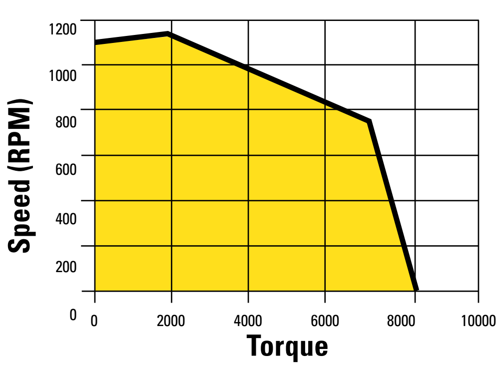


Figure 38 Maximum shovel speed is achieved at a relatively low point on the torque curve. Torque continues to increase to produce the tractive effort required to propel the shovel.

Motor Cooling

Heavy loads and fast acceleration and deceleration rates generate large amounts of heat in a shovel's motors. Excessive heat can cause thermal damage to insulation materials. Controlling the temperature rise requires close attention to motor ventilation. Shovel motion motors incorporate a centrifugal type blower mounted directly to the motor housing. Figure 39 shows a typical mounting arrangement.

As shown in Figure 40, the blower typically draws air into the inlet side of the blower and sends cooling air directly into the motor. Air flows through the motor over the coils and exits from the bottom or the end of the motor opposite the blower. The motor's internal construction is designed to provide airflow paths over and through the commutator and armature. The main pole and interpole coil construction also provides large surface areas for cooling airflow to remove heat efficiently.

The volume of air needed for shovel motors can range from 2,500 to 7,800 cfm (70.8 to 220.7 m^3/min), depending on the motor's size, application and the amount of heat it generates. The motors used to drive the blowers generally range from 4 to 20 horsepower (2.98 to 14.91 kW).

Figure 39 Typical hoist motor with a centrifugal type blower

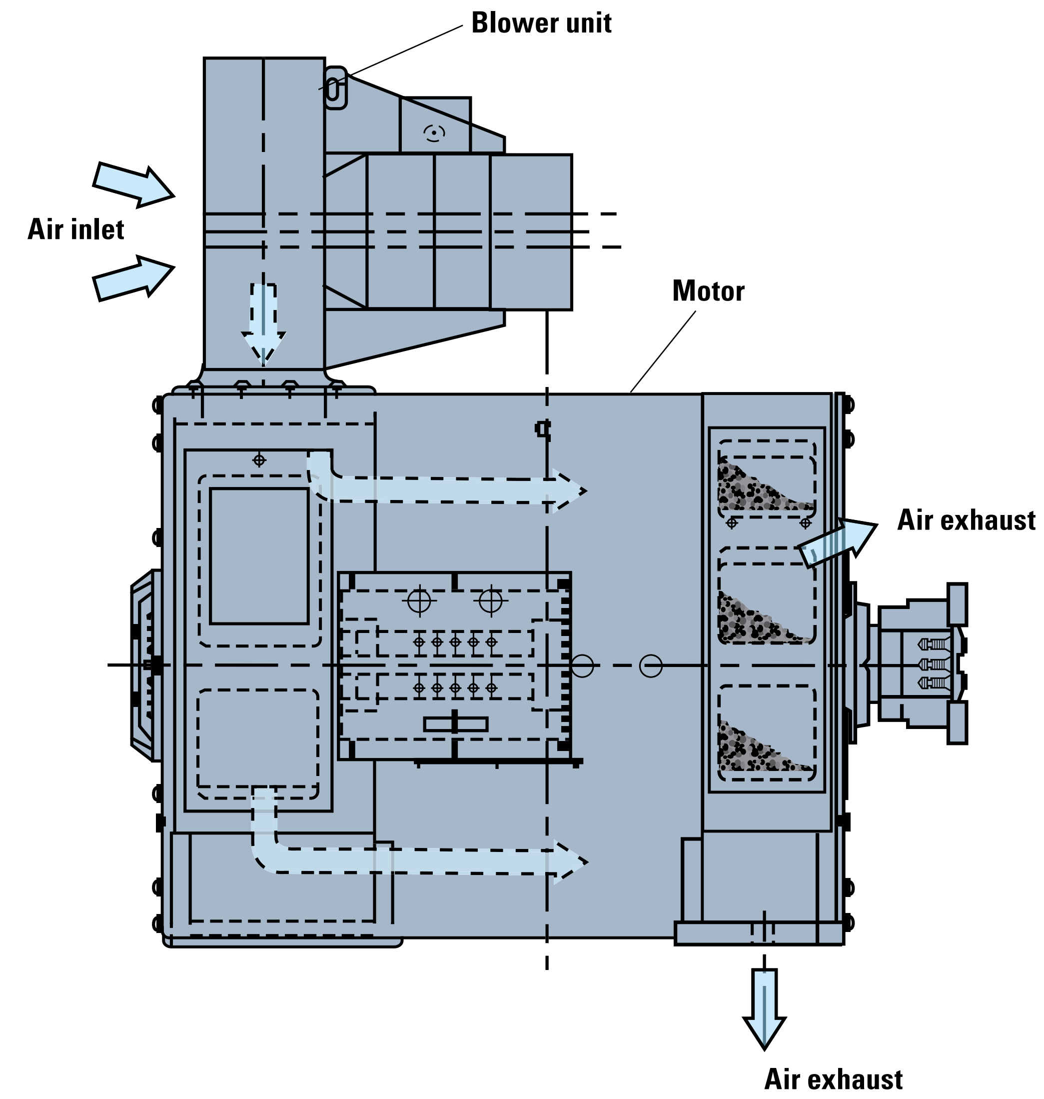


Figure 40 Typical cooling air flow in a shovel motor

4. DC Motor Control Systems

Control System Basics

To be usable on a mining shovel's DC electric motors, the pit's incoming high-voltage alternating current must be converted to direct current. Prior to the development of solid-state conversion technology, this task was performed by AC-to-DC rotary type motor/generator sets.

As shovels became larger and heavier, the motors required faster transient dynamic response times to handle new speed and torque requirements due to increased load capacities and power demands. This was accomplished with a new type of motor design based on the development of the thyristor, which replaced motor generator sets with various electrical cabinets (Figure 41).

P&H DC Electrotorque Plus Motor Control

P&H DC Electrotorque Plus drive (Figure 42) refers to a solid state electronic motor control system that uses thyristors to convert AC to DC. Thyristors, or Silicon Controlled Rectifiers (SCRs), are electronic switches used to control large amounts of electric current to be transformed into usable mechanical work. They perform this task with over 99% efficiency. A thyristor allows current to flow in the forward direction while blocking flow in the reverse direction.

The P&H Electrotorque drive system begins with the introduction of AC power to the mining shovel at mine trail cable voltage. It ends with controlled delivery of DC operating power to the armature and fields of the motion drive DC motors.

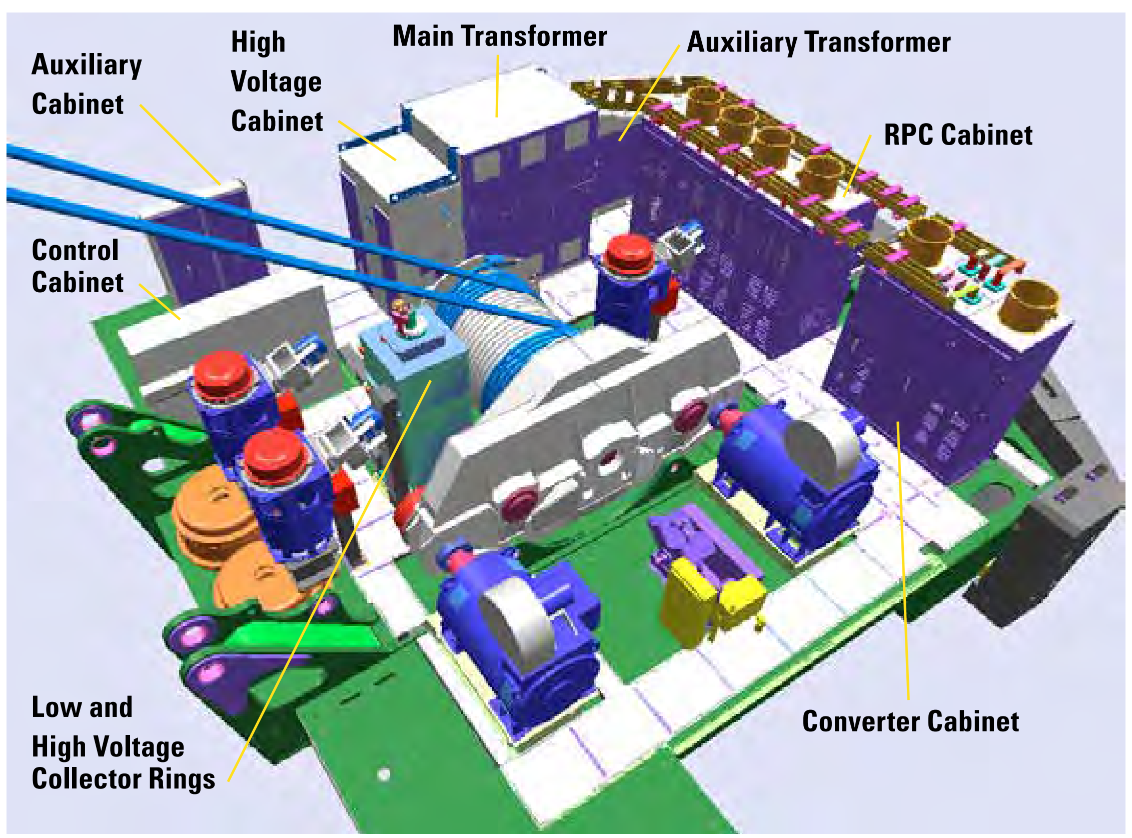


Figure 41 P&H Electrotorque® Plus digital drive system cabinets

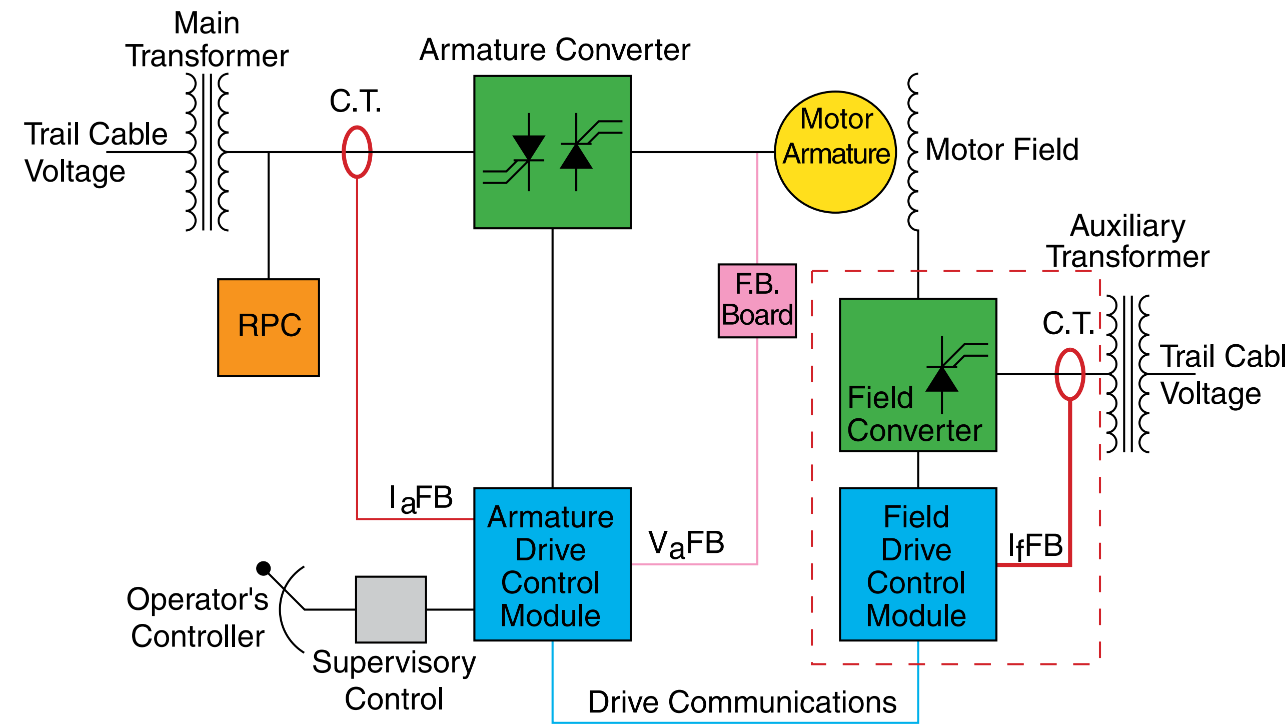


Figure 42 Block diagram of the P&H Electrotorque DC digital drive system. The system allows solid state control, including reversal, of the motors.

The motion control system regulates the amount of AC power converted to DC power based on the operator's commands by electronically applying phase control to the AC voltage sine wave (Figure 43). This results in adjustable voltage capability to the DC power.

All the converter power needs are met with the "standard" thyristor arranged in just a single configuration, the highly effective double-way or anti-parallel connection of two, three-phase, six-thyristor bridge circuits.

Standard thyristors are line (or naturally) commutated from one to the other by the polarity reversal of the AC voltage sine wave just once each cycle of the mine supply. Natural line commutation does not require commutation-forcing elements, which would only add to circuitry complexity and electrical losses. This simple bridge circuit is the basic building block of P&H DC Electrotorque drive converters.

The converter has an inherent capability to apply regenerative braking to the work motions. Braking is controlled automatically and electronically from the converter control center (Figure 44). When a DC motor is in its regenerative mode, the current regenerated from kinetic energy stored in the overhauling mechanical load is inverted to AC and introduced back into the mine distribution network in the same pattern as the three-phase AC supply.

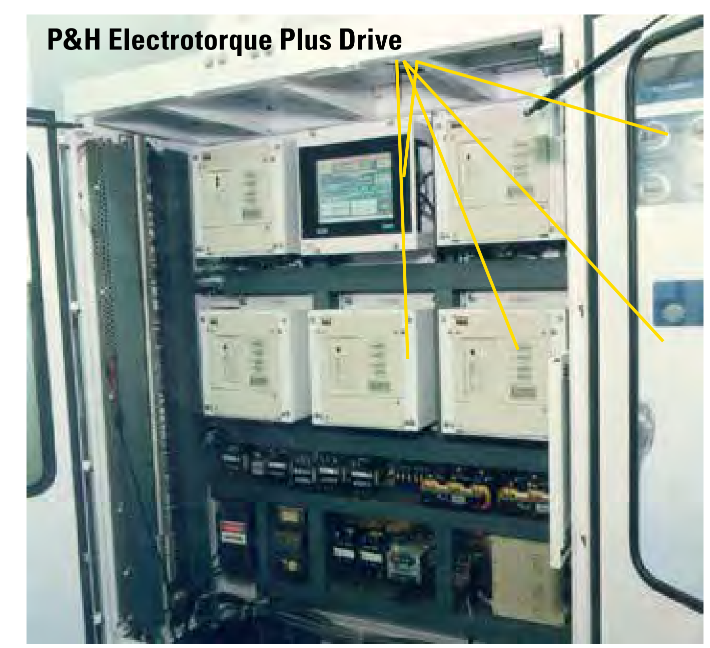


Figure 43 The P&H Electrotorque Plus digital drive system reduces shovel cycle time, wiring and electrical problems associated with analog motor drive systems.

Figure 44 he converter cabinet houses the thyristors used in converting AC power to DC power. The P&H Electrotorque system returns 10% to 15% of the original electrical energy through regeneration to the mine distribution network in the same pattern as the three-phase AC supply.

P&H uses regenerative braking for two reasons. First, it is the most effective and reliable method for controlling and decelerating shovel motion machinery loads. Second, power studies show that 10% to 15% of original electrical energy put into the work motion drive motors is recovered and put to useful work on other mine electrical loads.

The drive of the P&H Electrotorque Control System ensures maximum performance and life from all the DC motors used on P&H shovels.

5. Motion Brakes

Spring-set, pneumatically-released disc brakes (Figure 45) are the standard type used on today's electric mining shovels. They are also offered as performance enhancement packages to upgrade brake systems used on earlier electric mining shovels due to their advantages over shoe and V-type brakes. Compared to shoe and V-type brakes, disc brakes:

- Provide faster response and greater braking torque.
- Require less air pressure and air volume.
- Require less maintenance and a minimum of repair parts.

Disc brakes are designed to be used as parking or holding brakes on the shovel's various motions. They are spring-set and released by air pressure. Disc brakes are considered static brakes as compared to dynamic brakes, which are designed to stop a moving component or motion. While they are capable of stopping a system motion in a dynamic or moving condition, repeated use in this mode will lead to premature wear and/or glazing of disc brake components.

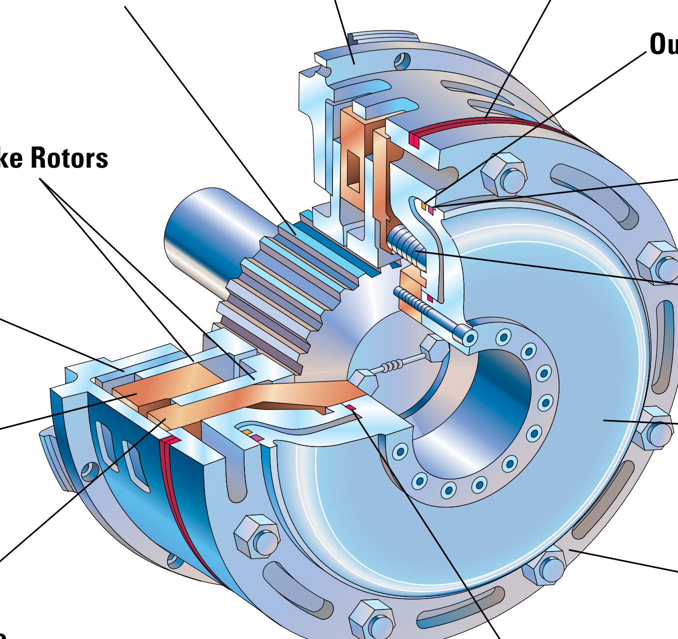


Figure 45 Spring-set, pneumatically-released disc brakes are the standard type used on mining equipment.

Hoist Brakes

Hoist brakes (Figure 46) are mounted on the hoist input shaft assemblies of the hoist gear case. When the shovel is in a park condition, with the dipper on the ground, the brakes prevent the hoist ropes from spooling off the hoist drum. They also allow the operator to suspend a loaded dipper while waiting for the next haul truck to arrive.

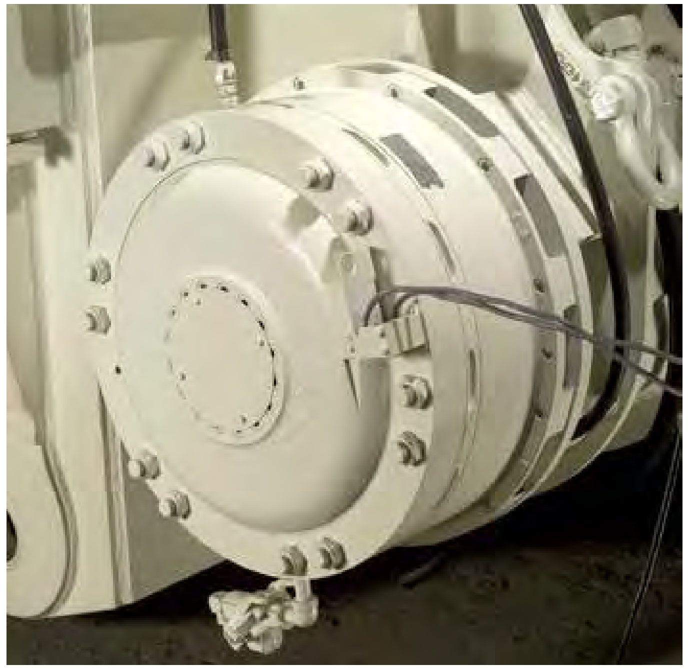


Figure 46 Hoist brake installation

The hoist brakes are automatically set if electrical power or air pressure is lost, thus stopping the movement of the dipper until power and controller reference are restored. While the ability to capture a dipper in downward travel is sometimes necessary, repeated automatic setting of the brakes while under load will lead to premature wear of the brake. Determine and repair the cause of automatic shutdowns of the machine to prevent premature wear of hoist brakes.

⚠ DANGER

The manual release of hoist brakes can cause unexpected movement of hoist and crowd components resulting in severe injury, death or damage to equipment. Ensure that all personnel and equipment are clear of the hoist drum, hoist ropes, dipper, dipper bail and dipper handle before manually releasing the hoist brake.

Crowd Brake

The crowd brake (Figure 47) is mounted on the input shaft assembly of the crowd gear case. The crowd brake, in conjunction with the hoist brake, allows the operator to suspend a loaded dipper while waiting for the next haul truck. While the hoist system controls the vertical movement of the dipper and dipper handle, the crowd system controls the retract and crowd movement of the dipper handle.

Figure 47 Crowd brake installation

The crowd brake is automatically set if electrical power or air pressure is lost, thus preventing movement of the dipper handle until power and joystick controller reference are restored. While the ability to capture a dipper in travel is sometimes necessary, repeated automatic setting of the brakes while under load will lead to premature brake wear. Determine and repair the cause of automatic shutdowns of the machine to prevent premature wear of the crowd brake.

⚠ DANGER

The manual release of the crowd brake can result in unexpected movement of the dipper handle and result in severe injury, death or damage to equipment. Ensure that all personnel and equipment are clear of the boom, dipper and dipper handle before manually releasing the crowd brake.

5. MOTION BRAKES

Swing Brakes

The swing brakes (Figure 48) prevent rotational movement of the shovel's upper structure when in a shutdown condition. They are automatically set if electrical power or air pressure is lost, thus controlling the rotational movement of the machine upper until power and controller reference are restored.

Figure 48 Swing brake installation

While the ability to control rotational movement is sometimes desired, repeated automatic setting of the brakes while under load will lead to premature wear of the brake. Determine and repair the cause of automatic shutdowns of the machine to prevent premature wear of the swing brakes.

⚠ DANGER

The manual release of the swing brakes can cause unexpected movement of the upper structure and result in severe injury, death or damage to equipment. Be sure all personnel and equipment are clear of the area before releasing the swing brakes.

Propel Brakes

The propel motion is controlled by propel controller reference and a disc brake (Figure 49) mounted on the armature shaft of each propel motor. The propel brakes prevent rearward or forward movement of the machine when digging due to digging forces of the crowd/retract and hoist motions. Additionally, the propel brakes prevent movement of the machine when it is in a shutdown mode. The propel brakes are automatically set if electrical power is lost, thus controlling the movement of the machine until power and propel controller reference are restored.

Figure 49 Propel brake installation

⚠ DANGER

The manual release of the propel brakes can cause unexpected movement of the shovel and result in severe injury, death or damage to equipment. Be sure all personnel and equipment are clear of the area before releasing the propel brakes.

6. BASIC MOTOR MAINTENANCE

COMMUTATOR AND BRUSH TROUBLESHOOTING GUIDE

- M Serration and grooving of commutator or slip ring
- L Excessive commutator wear - surface is blackened
- K Copper dragging
- J Excessive commutator or slip ring wear - bright surface
- I Unequal brush wear
- H Rapid brush wear - while commutation is good
- G Flexible, burnt-out or discolored brushes or springs
- F Brushes and brush holders are too hot
- E Commutator - slip ring too hot
- D Severe sparking
- C Minor brush sparking
- B Sparking at the entering edge
- A Sparking at the leading edge

- Wear of slip ring on one polarity N
- Copper picking in brush face O
- Brush chatter P
- Commutator surface is streaky Q
- Commutator has unsymmetrical burn marks R
- Commutator has symmetrical burn marks S
- Commutator has wavy lines T
- Ghost marks on steel slip rings U
- Glazed contact surface of brush V
- Pitted contact surface of brush W
- Chipping of brush edges or brush breakage X
- Failure to develop a protective skin Y
- Insufficient voltage on self-exciting machine Z

Probable Cause of the Trouble		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z		Recommended Action
1 The interpole field is too strong	1		•	•												•				•				•				1	Weaken the interpole fields by divert or by increasing air gap 1
2 The interpole field is too weak	2	•		•								•				•				•								2	Strengthen the interpole fields by reducing air gap 2
3 The interpole air gap is too small	3		•	•												•				•				•				3	Enlarge the air gap to decrease the effective interpole flux 3
4 The interpole air gap is too large	4	•		•								•				•				•								4	Reduce the air gap to increase the effective interpole flux 4
5 The air gaps are uneven, bearing may be worn	5	•	•							•						•				•				•				5	Replace the bearings and realign the machine 5
6 There was an overload of the machine	6	•				•	•	•		•	•					•					•			•				6	Reduce and limit the load on the machine 6
7 There is a vibration from an external source	7	•							•	•		•		•	•	•	•			•	•	•	•		•	•	•	7	Locate and remove the cause of the vibration or mount shock absorbers 7
8 There is a vibration from an internal source, may be out of balance or have poor alignment	8	•							•	•		•		•	•	•				•	•	•	•			•	•	8	Balance the armature and check for bearing wear 8
9 Possible quasi electrolytic wear of slip ring	9														•							•						9	Periodically reverse the polarity of the rings 9
10 There may be oil or dirt on the commutator or slip ring	10								•	•				•				•	•							•	•	10	Clean the commutator and slip rings 10
11 The resistance between brushes and brush arms is not uniform	11						•	•		•										•				•			•	11	Clean and tighten all connections 11
12 There may be abrasive grains in the brush contact face	12									•	•			•												•		12	Re-bed and clean the brush faces 12
13 Possible faults in the armature winding or equalizer connections	13	•			•		•												•	•				•			•	13	Locate and cure the faulty condition 13
14 Mica extended	14	•		•	•								•			•	•		•					•	•	•	•	14	Recess the mica or use a more abrasive brush 14
15 The commutator or slip ring is eccentric	15	•							•				•	•	•	•		•	•	•	•						•	15	Turn or regrind the commutator at near rated speed 15
16 The commutator riser connections are open circuited	16	•	•	•	•															•							•	16	Re-solder the connections 16
17 There are high or low commutator sections	17	•		•									•				•		•					•				17	Tighten the commutator, turn or regrind 17
18 The commutator is loose	18	•		•	•								•			•	•	•	•		•				•			18	Tighten the commutator, re-mica if necessary, turn or regrind 18
19 There are flats on the commutator or slip ring	19	•	•	•									•			•	•							•	•			19	Locate and remove the cause of flatting, turn or regrind 19
20 The spring pressure is too low	20	•				•	•	•	•	•	•	•	•	•	•	•	•	•	•	•			•	•		•	•	20	Adjust the spring pressure for the type brush grade 20
21 The spring pressure is too high	21					•	•		•		•	•		•												•		21	Adjust the spring pressure for the type brush grade 21
22 The spring pressure is unequal	22	•					•	•		•		•				•	•	•	•		•			•		•		22	Adjust the spring pressure for the type brush grade 22
23 The brush grade is unsuitable for the machine and duty	23	•			•	•	•		•		•	•	•	•	•	•				•			•	•	•	•		23	Select an alternative grade brush 23
24 The brush arc of contact is excessive	24	•	•	•												•				•				•				24	Reduce the effective thickness of the brush 24
25 The brush arc of contact is insufficient	25	•	•	•								•				•				•								25	Apply a suitable circumferential stagger 25
26 The brush flexible connection is faulty	26							•		•																	•	26	Install a new brush with sound flexible connection 26
27 The brush flexible connection is too short or too stiff	27	•				•		•		•										•							•	27	Use brushes that are flexible and of the correct length 27
28 There is an imperfect brush bedding	28	•	•			•				•								•								•	•	28	Properly bed the brushes 28
29 The radial brush holders are mounted at a small reaction angle	29	•		•		•	•			•		•		•	•		•		•	•		•			•	•	•	29	Adjust the holders to a radial position and correct the distance from the commutator 29
30 The reaction type holder is mounted trailing	30	•	•	•		•	•			•		•		•	•		•		•	•		•			•	•	•	30	Reverse the holders or the direction of rotation 30
31 The brush is sticking or sluggish in the brush holder	31	•	•			•		•	•	•			•			•		•	•		•			•			•	31	Check that the brush size is correct, clean the brushes and holders, remove any burs 31
32 The brushes are too loose in the brush holders, holders may be worn	32						•			•							•			•			•		•	•		32	Replace the holders if worn 32
33 The terminal connections are loose or dirty	33					•	•	•		•							•										•	33	Clean the terminals and terminal block, tighten all screws 33
34 The brush holder is mounted too far from the commutator or slip ring	34									•				•	•		•	•	•	•			•		•	•		34	Adjust the holders to be 3/32" or 2 mm from the commutator 34
35 The brush is in the incorrect position	35	•	•	•									•			•				•		•		•			•	35	Adjust the holders to the correct position 35
36 There is unequal brush holder spacing or alignment	36	•	•	•	•			•		•						•				•				•				36	Correct the spacing and alignment of the holders 36
37 Humidity is low	37								•					•			•								•	•		37	Humidify the cooling air or draw air from a normal humidity area 37
38 Humidity is excessive	38													•				•	•			•						38	Enclose the machine or draw air from a normal humidity area 38
39 Too much dust in the atmosphere	39								•		•			•												•		39	Remove the cause if possible or install a filter 39
40 Too much gas or acidic fumes in the atmosphere	40							•	•					•				•	•			•		•		•	•	40	Arrange for clean air cooling 40
41 Too long periods at low or steady loads	41	•			•	•	•					•		•		•	•						•		•	•	•	41	Change the brush grade 41
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z		

Figure 50 This chart summarizes a variety of symptoms related to commutator and brush performance, along with their probable causes and solutions. Many symptoms may indicate a range of probable causes.

6. Basic Motor Maintenance

Motor maintenance on a regular schedule is essential to peak shovel performance. Proper maintenance practices will provide good electrical performance and long motor life. The following six conditions are key to peak electrical performance.

Elements of Peak Electrical Performance

Spark-free Operation

Excessive brush sparking may be caused by a number of factors, including heavy overloads, mechanical defects in the shovel or motor, vibration, atmospheric conditions, use of the wrong type of brushes, and improper motor adjustments. Excessive sparking is often the first sign that something is wrong and needs attention.

Smooth, Uniform Commutator Surface

The commutator's surface condition is critical to the health and performance of the entire shovel. The surface film should exhibit a smooth, uniform gloss to provide good brush performance and machine operation. When the surface develops a change in appearance, it may be necessary to restore the original surface conditions. Some surface conditions are not cause for concern while others may require immediate action.

Minimal Commutator Wear

Preventing excessive commutator wear is the single most important factor in good motor maintenance. Wear damages the commutator's surface and can be caused by contamination, excessively abrasive brushes, copper pick up on brush faces, severe sparking and commutator surface burning.

Minimal Electrical & Mechanical Loss

Energy losses are a fact of life in any piece of equipment because no machine is 100% efficient. Brush friction is a chief cause of energy losses in electric shovel motors. Other causes include commutator surface film resistance and excessive localized heating. Proper brush selection and maintenance will help assure peak performance and minimize such losses.

Quiet Operation

A quiet motor indicates good contact between the commutator and brushes. Chattering or noise may indicate conditions that can degrade efficiency and performance, including flat or burned spots on commutator bars, high bars, incorrect brush tension or angle, and surface film that is too heavy. Any one of these conditions requires correction as it can lead to damage of the motor and the shovel itself.

Good Brush Life

Good brush life generally indicates good machine operating conditions, but the length of brush service depends on a variety of factors and should not be overemphasized as a gauge of motor performance. Compromising any of the above for the sake of extending brush life beyond normal parameters will be more costly in the long run than simply replacing the brushes.

Brush & Commutator Performance

Many motor performance issues can be resolved by checking the performance of the brushes and commutator (Figures 50 and 51).

Brush and Commutator Performance Guide

Peak brush performance is indicated by:	• Non-harmful sparking. • Negligible commutator wear. • Uniform film over the commutator surface. • Good brush life.
Unsuccessful brush performance can be caused by many factors. Harmful sparking is often the first sign of a problem. If harmful sparking occurs, it may be an indication of any of the following conditions:	• Failure to reverse the armature current in the armature coil undergoing commutation as it is short-circuited by the brush. Motor off neutral, interpoles not properly adjusted, and improper control settings can be contributors. • Too fast a change in current during commutation. • Loss of contact between the brush and commutator surface due to too light a spring tension or out-of-round commutator surface. • Breakdown of the commutator film or a lack of film. Contamination can have an unfavorable influence on the surface film. Many materials such as oil, sulfur, silicone, tobacco smoke, paint fumes, turpentine, acetone and alcohol can affect the film, changing the coefficient of friction and resistance. • Too much film. • Uneven film build between brush paths on the commutator surface. This can lead to selective wear, which results in uneven current balance between the brushes.
Excessive commutator wear is an indication of unsuccessful commutation performance, which may be caused by the following conditions:	• Contamination from abrasive particles between the brush and commutator. • Faulty control operation resulting in burning of the commutator surface. • Frequent resurfacing of the commutator. • High brush friction from contamination, temperature extremes, high brush pressures, light film or lack of film.

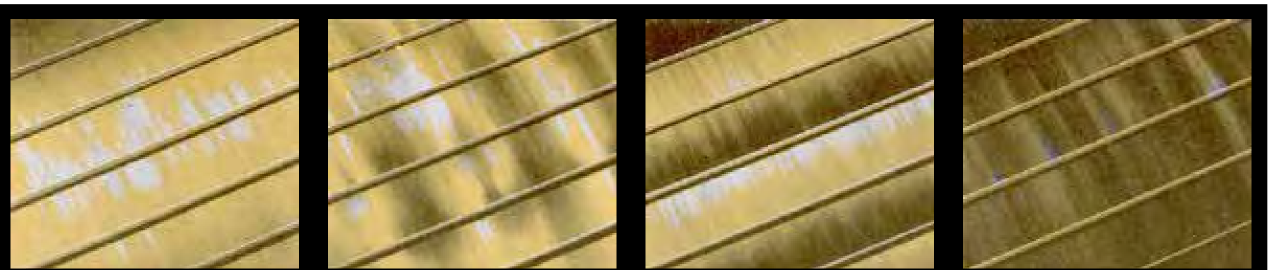
Figure 51 Brush & Commutator Performance Guide

Commutator Inspection and Maintenance

General

To ensure successful operation and long brush and commutator life, it is very important to properly care for the commutator surface. Detecting surface faults early allows them to be corrected with minimal cost and lost operating time. Unless faults such as bar burning, high bars, high mica or flat spots are corrected when first observed, accelerated wear and damage will occur. Inspection at regular intervals is the best way to avoid such problems (Figure 52).

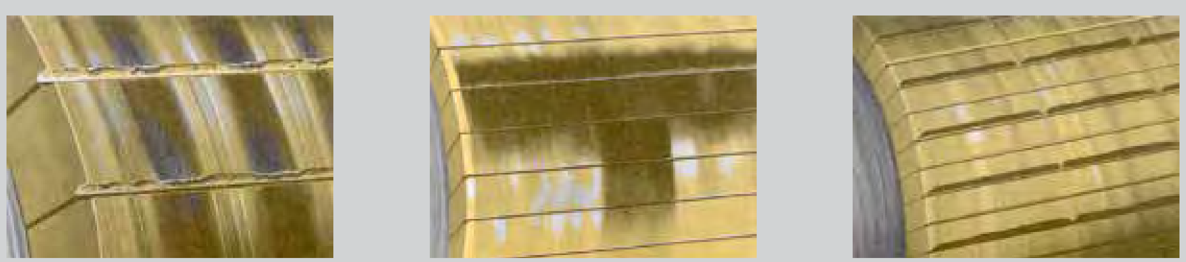
Satisfactory Commutator Surface Conditions



1. A light tan film over the entire commutator surface is often seen on properly functioning shovel motors.
2. A mottled appearance of varied patterns is common.
3. Slot bar marking with a somewhat darker film appearance has a pattern related to the number of conductors per slot.
4. Heavy film may appear over the entire surface and is acceptable if uniform.

Warning Signs

1. Streaking is an early sign of a serious transfer of metal from the brush.
2. Threading with fine lines appears when excessive metal transfer occurs.
3. Grooving is a sign of abrasive material in the brush or the atmosphere.



4. Copper Drag is an abnormal buildup of commutator material that can cause flashover.
5. Pitch Bar Marking appears as low or burned spots equal to half or all the number of poles.
6. Heavy Slot Bar Marking may involve etching of the trailing edge of the commutator bar.

Figure 52 Observing the commutator surface appearance will help determine the condition of the commutator.

Surface Appearance

Inspection of the commutator's surface appearance (Figures 52 and 53) can reveal a great deal about its condition and performance. Learning how to read the various types of appearance can help pinpoint potential and existing problems related to the commutator and brushes, and what to do about them.

First, it is important to understand that commutator surface appearances can vary widely and that some conditions are acceptable while others are warning signs of pending problems.

The commutator should exhibit a smooth, uniform gloss in the brown tones, from light tan to dark brown. This indicates that sufficient film is present for low friction operation without excessive film to restrict the proper flow of current. Color inconsistency or deformed commutator surface conditions are warning signs of potential problems which may cause premature brush and commutator wear.

One of the best ways to preserve a "just-right" film is the use of a canvas wiper on a sturdy hardwood handle. Untreated, hard-woven canvas will remove oil, grease and smudge from the commutator surface without destroying the desirable film. Holding the canvas against the rotating commutator will quickly remove surface contaminants and even out the film across the commutator surface.

Causes of Adverse Commutator Surface Conditions

	Electrical Adjustment	Electrical Overload	Light Electrical Load	Armature Connection	Unbalanced	Shunt Field	Light Brush Pressure	Type of Brush in Use		Contamination	
								Abrasive	Porous	Gas	Abrasive Dust
Streaking			●			●		●	●	●	●
Threading			●			●			●	●	
Grooving								●			●
Copper Drag						●	●	●		●	
Pitch bar marking				●		●	●	●	●		
Slot bar marking	●	●								●	

Figure 53 Commutator troubleshooting chart

⚠ WARNING

Always keep hands away from any electrically energized parts. These inspections and checks of the commutator and brushes must be performed by a qualified technician.

Roughness and High Bars

Check the commutator for roughness by placing a wood rod on top of the brush and holding it parallel to the length of the brush as the commutator rotates (Figure 54). Feel for up and down movement of the brush. Jumping brushes are a sign of high bars and of the commutator going rough (Figure 55).

⚠ WARNING

Be sure the floor is dry, stand on a rubber mat or other insulated surface and avoid bodily contact with any part of the machine when performing this test.

Check for excessive commutator wear rate, streaking, copper drag, pitch bar marking, heavy slot bar marking and commutator profile (Figure 56). Consult the manufacturer's service manual for specific TIR (Total Indicator Runout) and bar-to-bar step recommendations.

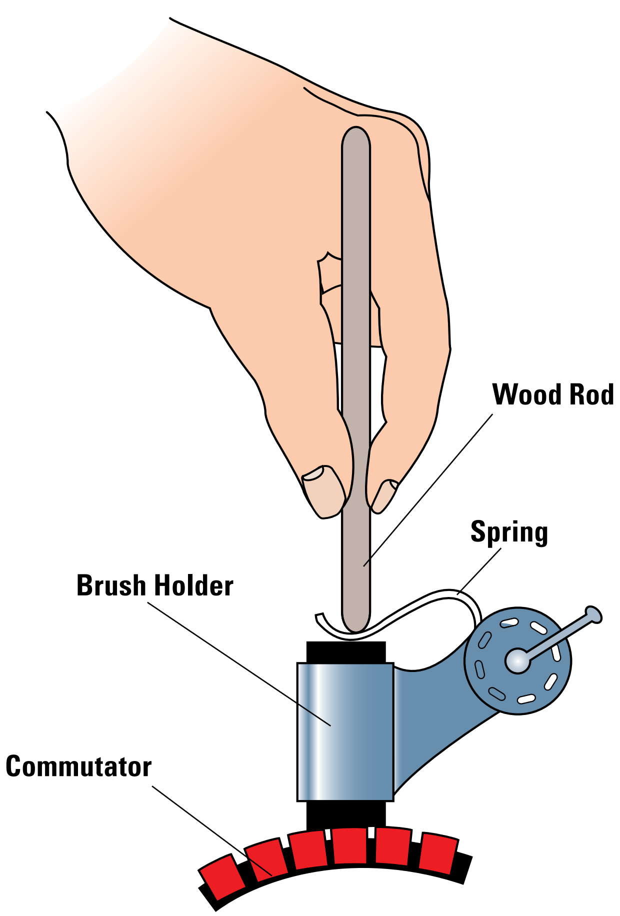


Figure 54 Checking commutator for roughness and high bars

CAUTION

NEVER use emery paper or cloth since it is conductive and the particles are likely to become embedded between the segments and cause short circuits.

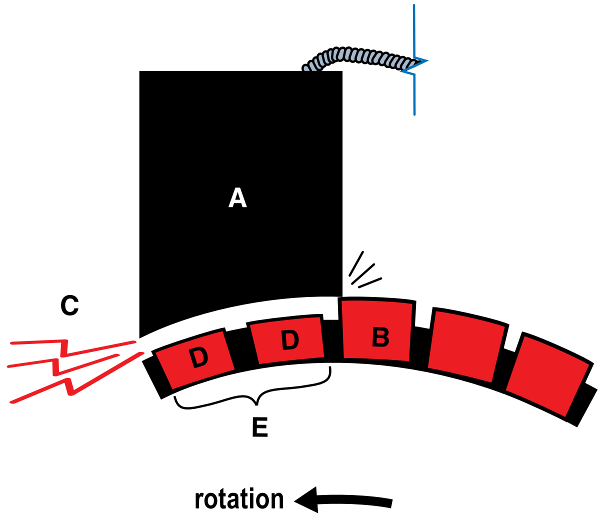


Figure 55 Brush (A) "stubs its toe" on high bar (B), produces an arc (C), drags copper from adjoining bars (D) and produces a flat spot (E), resulting in an out-of-round commutator surface and roughness.

Figure 56 Brush inspection

Heavy deposits, roughness or selective wear conditions require the commutator to be sanded or stoned. A fine-grain sandpaper (#00) should be used to avoid deep scratches and excessive removal of the copper surface.

Sandpaper will not remove even small flat spots; it will actually broaden them and generate undesirable wear surfaces on the commutator bars. A commutator stone is therefore recommended over sandpaper.

CAUTION

Never use emery paper or cloth since it is conductive and the particles are likely to become embedded between the segments and cause short circuits.

Excessively rough, out-of-round or high bars will require resurfacing of the commutator. The motor is best removed and sent to an authorized service shop to properly turn, undercut the mica, and surface finish the commutator. Undercutting of the mica is very important for proper operation. Mica is used to insulate the areas between the commutator bars. If the mica edges are left at the surface, accelerated brush wear and commutator damage will occur (Figure 57).

⚠ WARNING

Keep hands, arms and clothing away from rotating parts and electrically energized parts. Remove any jewelry and tie long hair back to avoid entanglement with moving parts.

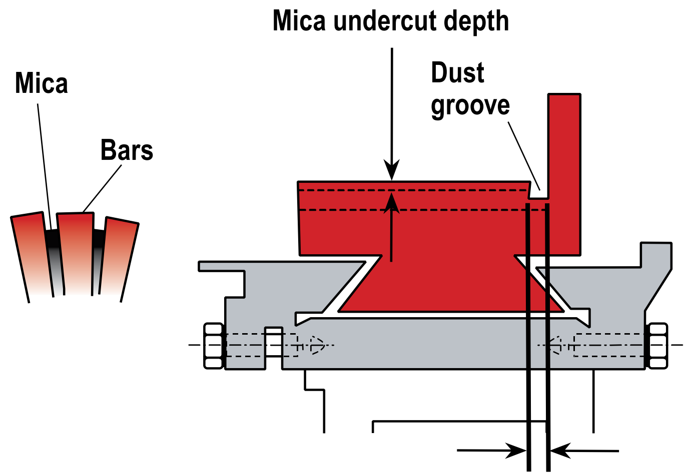


Figure 57 Enlarged view of mica and bars

Brush Inspection & Maintenance

Inspection

⚠ DANGER

High voltage and rotating motors can cause serious or fatal injury. Brushes must not be touched or replaced while the motor is energized.

Check the brush length. Replace when the brush wear marker on the pigtail reaches the top of the brush box. Inspect for worn or shiny brush clips, frayed or loose pigtails, chipped or broken brushes and check for signs of overheating of the brush or pigtail at the socket. Remove a few brushes to check the brush/commutator contact face. Burned areas indicate commutation problems. Loosen each brush in its holder. Blow out the area of the brush holder and brush holder stud insulation with clean, dry air to get rid of brush dust. Wipe the brush holder and stud insulation to remove any contamination.

Peak brush performance depends on the careful installation, fitting and adjustment of the brushes before the motor goes back into service. The following can help improve overall brush performance (Figure 58):

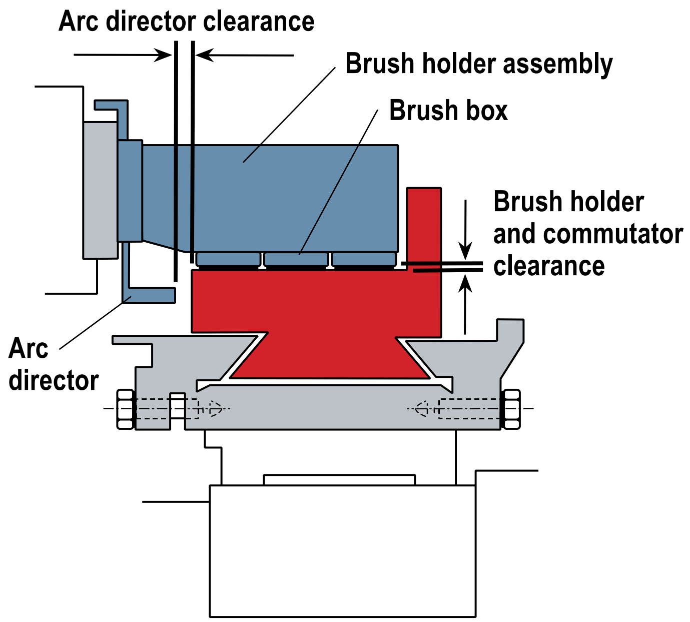


Figure 58 Arc director and brush box

- Equal spacing of brushes with good alignment of the brush holder and correct spacing from the commutator surface will ensure successful operation.
- Brush holder clearance to the commutator surface needs to be set correctly. Too little clearance could result in metal-to-metal contact or arcing from the holder to the commutator. Too much clearance can result in increased deflection of the brush resulting in double brush seating or less brush contact.
- Seating of brushes is very important to maintain maximum contact with the commutator. Improper seating can chip brush faces or cause poor commutation and brush sparking.
- Spring pressures are critical to good brush life. If spring pressures are too light, brush instability or bouncing will result, leading to increased sparking under the brush face, and electrical wear of the brush and commutator. Too much spring pressure increases the friction between the brush and commutator, resulting in high mechanical wear. If brush wear rates are a problem, spring pressures should be checked per the manufacturer's specification (Figure 59).

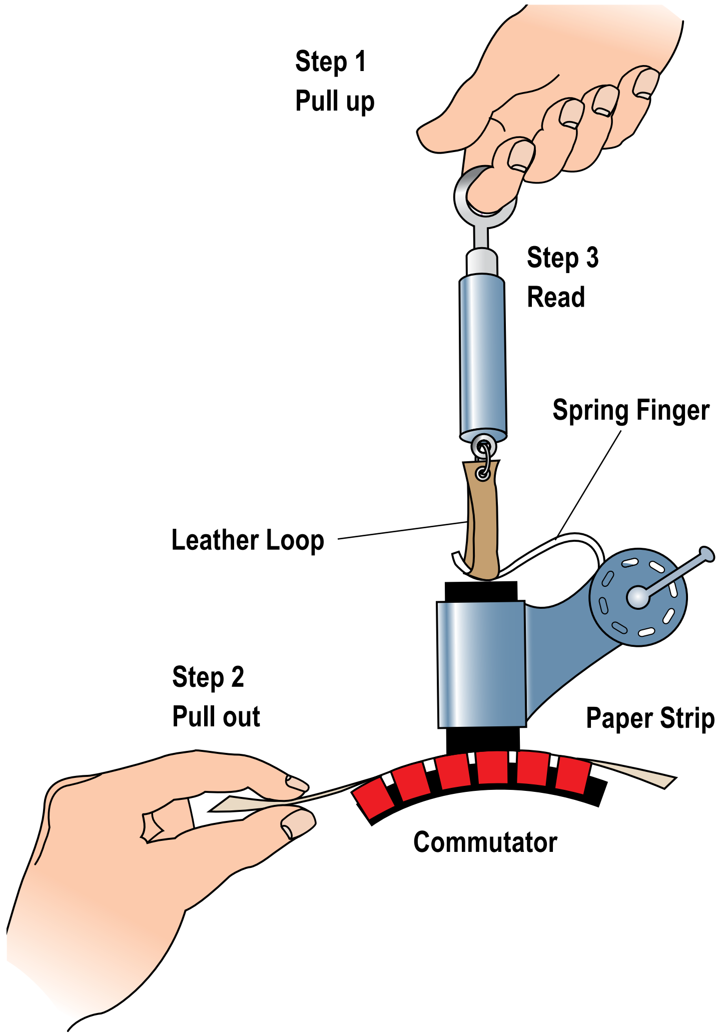


Figure 59 Checking brush spring pressure

Optional Brush Grades

Among the key issues affecting shovel motor operation are brushes, maintenance and contamination. Depending on the nature of a commutation problem, changing the type and/or grade of brushes can improve performance.

Among the multitude of brushes available, the type most commonly used on mining shovel motors is the electrographitic type. Electrographitic brush grades are created by converting uncrystallized forms of carbon to crystalline forms of graphite by baking them at a very high temperature.

Electrographitic brushes have a greater range of characteristics than other types for commutating electrical equipment. They are substantially free of abrasive properties, which allows for use in high surface speed applications. They have a high contact drop and exceptionally good commutating properties. This, plus a low coefficient of friction, allows for average current densities of 60-100 amps per square inch, which are normally specified for shovel applications.

Brushes of different styles and different grades of carbon affect the contact drop or voltage drop between the brush and commutator surface. The contact drop creates a resistance that restricts unwanted local or short circuit currents at the brush face. Excessive brush face currents going from bar to bar can lead to adverse sparking. Grades with a higher contact drop, or the use of split brushes, minimizes these currents. Split wafer brushes provide more points of conducting contact to the commutator, improving the current flow and commutation.

Special brush grades are available for motors operating in severe environments. High altitude, extreme cold and low humidity result in the need for grades that maintain a protective film on the commutator surface. Dusty conditions contribute to a lack of protective film. The protective film is maintained at normal conditions by the absorption of water vapor on the commutator and brush surface, and the formation of an oxide coating on the commutator.

These special grades feature ingredients or treatments that produce and maintain the protective film in low moisture or abrasive conditions. Refer to the machine manual for specific part numbers of brush grades and part numbers that have been used successfully in shovel motor applications.

CAUTION

Do not mix brush types or grades as this can cause unbalanced current distribution resulting in uneven wear.

Brush Replacement

CAUTION

Silicone or RTV should not be used for sealing applications on DC motors. The presence of silicone vapors causes rapid brush wear in totally enclosed motors.

CAUTION

Replacement of the brushes in the same conduction path or all brushes in one brush holder only will cause a current imbalance in that respective path. This can result in motor flashover and contribute to excessive commutator and brush wear.

Standard Brush Replacement Procedure

1. Push down slightly on the brush holder assembly, then push slightly toward the brush to release the spring from its retainer.
2. Release the brush holder spring assembly and lift out the brush.
3. Install the new brushes in the reverse order of removal.

   Replacement brushes must have their commutator contact surfaces shaped to precisely fit the commutator surface. To achieve a congruent fit, sand the brushes in each brush holder separately. With the rough side of a non-metallic sheet of sandpaper facing the brush, draw the paper under the brushes, with the brushes pressed firmly toward the commutator (Figure 60)

CAUTION

When sanding, take special care not to get carbon dust into the windings. Be sure to thoroughly blow out the motor after sanding is complete.

4. Carefully fit the brushes to the contour of the commutator with fine sandpaper (#00). The sandpaper should extend only one turn completely around the commutator with minimal overlap.

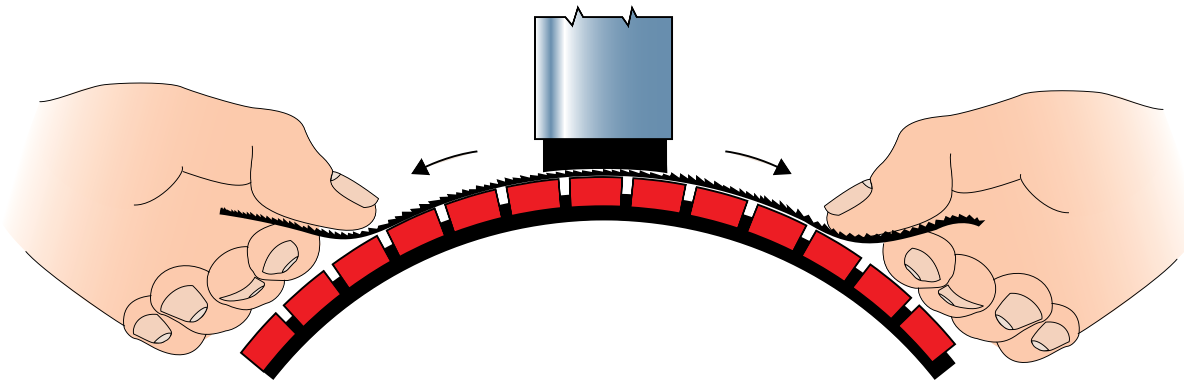


Figure 60 Seating brushes with sandpaper

CAUTION

NEVER use emery paper to clean brushes or brush holders because emery grit is a conductor.

5. After seating the brushes, remove them from the holders and clean the brushes and holders to assure free movement of the brushes in the holders. Be sure to blow out or vacuum any carbon dust from the motor after sanding.

Alternative Brush Replacement

Brushes should be replaced as described in the previous topic, but that may not always be practical. With the understanding that all brushes should be replaced at the same time, you can use this alternative to the preferred method. Refer to Figure 61 as a general guide for placement of the brushes and brush assemblies.

Brushes can be replaced on a maintenance type schedule if the order in which replacement is rotated is as shown in Figure 62, replace all number 1 brushes during the first rotation schedule, all number 2 brushes during the second rotation, and so on.

With this method, a complete maintenance inspection of the motors is required to determine the periodicity at which the brushes need to be replaced. Be sure to keep a written log to track the date and time for each replacement.

Brush holders require minimal maintenance. Whenever the brushes are replaced or removed for inspection or any other reason, be sure to check the clearance between the holders and the commutator. Check the service or maintenance manual for the proper clearance.

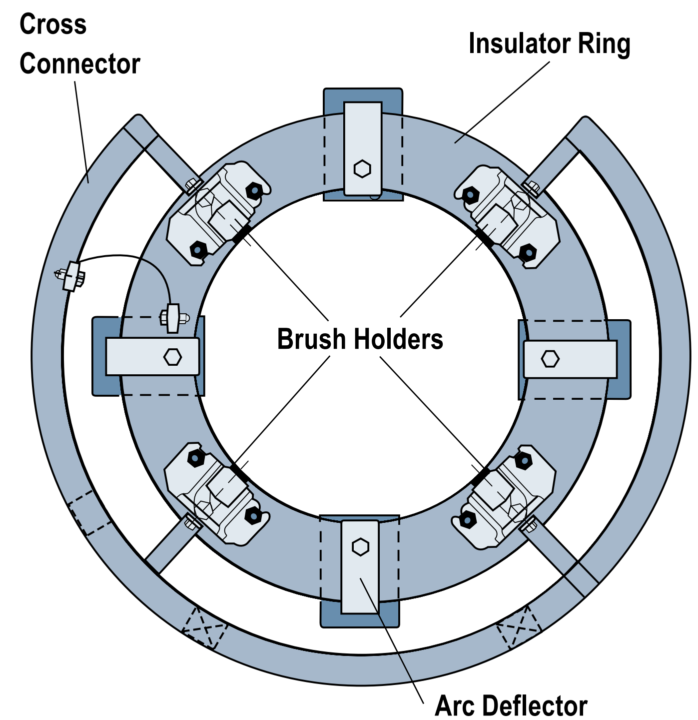


Figure 61 Brush Assembly Rigging

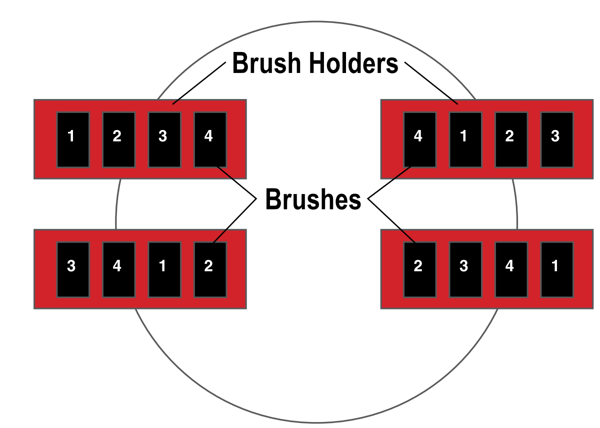


Figure 62 Brush replacement sequence

Motor Bearings

Check to see that grease or oil is not leaking from the bearing housings. If any leakage is found, correct the problem before continuing to operate the machine. Listen to a few bearings for noise. Bearings that get progressively noisy will need to be replaced at the next shutdown. Re-grease the bearings as needed.

Insulation

Perform a visual inspection of all electrical insulation. Motors in storage as well as those in active service should be tested for the presence of dust, dirt, moisture, oxidation, defective material or mechanical damage on winding surfaces. Record megger readings for comparison with earlier recordings. Any downward trend indicates appropriate maintenance steps are required.

Mechanical Considerations

If air filters are supplied, keep them in good working order and replace them as specified in the service manual. Perform a visual inspection for loose bolts, parts or electrical connections. Check pole bolt torques with a random sampling of bolts. If several bolts are loose, inspect them all.

CAUTION

Do not over-torque pole bolts as this will cause premature bolt wear and possible failure.

Periodically check interpole bolt torque.

Motor Lubrication

Motors are equipped with bearing lubrication plates similar to the one shown in Figure 63.

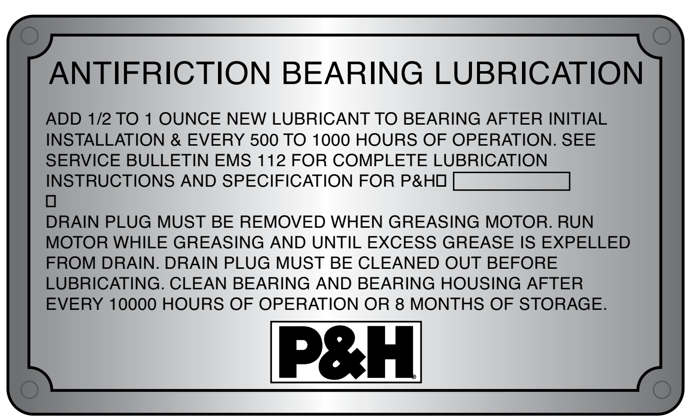


Figure 63 Typical bearing lubrication plate found on DC motors

Consult the plates as well as the service manuals for specific lubrication requirements and intervals.

⚠ WARNING

Failure to exercise care while working around rotating equipment can result in injury or death. Be sure that guards are in place, establish positive communication with the operator, and notify all personnel in the area of the impending motion.

Lubrication frequency and the amount of grease to add depend on operating conditions. As a general rule, however, adding a little grease at more frequent intervals is preferable to adding larger amounts infrequently. Ideally, grease should be added while the motor is warm and turning slowly.

Motors are designed with specific lubricant inlet and outlet fittings so that grease can be properly applied in only one way. Prior to greasing each bearing, wipe the fittings with a clean, dry cloth and clean the grease gun fitting. Remove the drain plug and remove any hardened grease with a plastic stick or a wire if needed, being careful not to break off the stick or wire in the outlet.

CAUTION

It is important not to over-grease any bearing, but it is especially important with the top bearing on vertical motors. Besides causing premature bearing failure, excess grease can drip onto the commutator and adjacent parts and cause flashover.

Pump the grease slowly and gradually, either until grease is expelled from the drain or for 20 strokes of the grease gun. With most cartridge grease guns, 20 strokes will pump approximately 1/2 ounce (14.175 g) of grease. Leave the outlet holes open and operate the motor to relieve pressure until no more grease is expelled. This will take approximately 20 minutes. Replace the plugs when finished.

CAUTION

Avoid contaminating the commutator and windings with grease. When repacking the bearings, do not completely fill the cavity; fill the cavity about 1/3 to 1/2 full.

Grease Selection

Grease must be compatible with the grease used at manufacture and must be an Extreme Pressure (EP) type with an NLGI specification of 0, 1 or 2 depending on ambient temperature conditions.

CAUTION

Under no circumstance may greases containing molybdenum disulfide (MoS2) or graphite be used in electric motor applications because of the electrical conductivity of these solids. Contamination of the commutator and adjacent parts with conductive greases will promote flashovers.

Be sure to check the motor manufacturer's specifications.

If the wrong grease is used, or if the grease is suspected of being contaminated, both the bearing and the bearing cavity should be completely cleaned. In this case, it is recommended that the motor be sent to a motor service shop. "Purging" by pumping a large volume of grease through a bearing is not recommended.

7. Motors Exposed to Detrimental Conditions

Contamination

Ventilation of DC motors forces cooling air directly into the motor, exposing the commutator, carbon brushes and coils to whatever is in the air. It is very important to maintain good air quality since certain airborne contaminants can cause excessive brush wear, damage to the commutator, dielectric failure of the commutator, or other problems. Contaminants and the problems they can cause include the following.

- **Sulfur compounds** such as sulfur dioxide and hydrogen sulfide react with the copper commutator bars and may form non-conductive films. Such films may increase friction and brush chatter, causing damage to the brushes and commutator.
- **Chlorine** used in bleaching agents reacts with the commutator copper and produces results similar to those caused by sulfur compounds.
- **Acids** used in cleaning agents also react with the copper, producing poor filming.
- **Abrasive dust** shortens brush life and causes excessive commutator wear (Figure 65).
- **Lack of moisture** or very dry conditions result in the lack of film development, causing high brush and commutator wear. Alternative brush grades with film-promoting qualities for low humidity environments are available.
- **Silicone sealants**, greases and oils can cause extremely rapid brush wear, even with small concentrations in the air.

Unusual operating conditions can result in premature shovel motor damage or failure. The major culprits are contamination, extreme environmental conditions, improper motor control settings, improper maintenance, excessive vibration, and operator misuse (Figure 64).

Figure 64 Improper maintenance, abuse or other detrimental conditions can lead to catastrophic motor failure.

Extreme Environmental Conditions

Temperature extremes affect shovel motors in various ways. Extreme cold conditions degrade the viscosity of standard lubricating greases, causing a lack of lubrication on motor bearings. Cold weather greases are available to prevent such problems. Cold conditions also mean low humidity, which reduces the film build on the commutators. Film-promoting brush grades are available if reduced brush life or commutator wear occurs.

The purpose of electrical insulation is to isolate the electrical conductors from the environment. Ambient temperatures above 50°C (122°F) can damage a motor's insulation system. Increases in ambient temperature have a direct effect on the operating temperature of the coils. Coil temperatures can exceed insulation design limits in high ambient conditions, reducing insulation life.

Figure 65 Shovel operation in dusty conditions

Insulation materials used in shovel motors require high dielectric strength, high thermal rating, chemical stability and good mechanical strength. Insulation systems are classified by their ability to withstand maximum temperatures, as defined by NEMA (the National Electrical Manufacturers Association). The insulation classes are listed in Figure 66. Insulation materials used in shovel motors are mostly Class H rated.

A rule of thumb is that for each 10°C a motor is operated above its normal rated temperature, its insulation life is cut in half. It is extremely important, therefore, that adequate ventilation is provided to keep temperatures within design limits. Inspection of the blower unit is necessary to assure that the blowers are operating in the correct direction and that there are no restrictions or openings in the duct work that would reduce air flow through the motor. Signs of overheating include:

- Darkened varnish/paint on the coils.
- Brittle cable, varnish or insulation materials.
- Blue or purple tint of the commutator copper.
- Cracks in the varnish.
- Looseness of varnish bond to the coils.

Low humidity at high altitudes or in very cold or desert-like conditions can result in an inadequate film build on the commutator. Without adequate film, brush life can be drastically reduced due to increased friction between the brushes and commutator.

Insulation Class	Maximum Operating Temperature
A	105°C (221°F)
B	130°C (266°F)
F	155°C (311°F)
H	180°C (356°F)

Figure 66 Motor Insulation Classes

Improper Control Settings

Maintaining specified motor control settings help ensure proper motor operation. Deviating from the recommend armature and field current limits may result in overspeed, overloading or mechanical damage to the drive system components.

Improper Maintenance

Improper or inadequate DC motor maintenance will result in shorter motor life and increased operating costs. Proper maintenance includes:

- Monitoring brush wear and correct replacement of brushes.
- Maintaining brush spring pressures and a concentric and clean commutator.
- Keeping bolted connections torqued to manufacturer specifications.
- Proper greasing of motor bearings.
- Keeping the motor clean.

CAUTION

Do not use liquid solvents since they will wash contamination into areas that cannot be reached.

Cleaning the motors by initially vacuuming the dust, dirt and carbon prior to blowing will reduce dirt build up. Solvents also leave a conductive residue, which may be hard to remove. Early recognition of potential problems will result in less severe conditions in the future.

Excessive Vibration

Excessive vibration can loosen bolted connections, cause structural or mechanical failures, reduce insulation life, and break down the bonding of the coils to the insulation materials. High vibration may be the result of loose mounting bolts, coupling misalignment or vibration sources for other equipment.

Operator Misuse

The shovel is intended to operate under specific conditions to provide high performance and high productivity. Use of a shovel in abnormal ways, such as excessive plugging or reversals, excessive stalling or use of the machine beyond its design limits can damage the motors. Overloading, high motor temperature or flashing of the motor can occur if the shovel is misused. Good hands-on training and refresher courses can help improve operator technique and productivity while reducing maintenance and repair costs due to misuse of equipment.

8. Motor Removal and Installation

Motor removal and installation procedures vary with each type of motor and shovel model but general principles apply. Consult the shovel manufacturer's service manual for specific procedures. Below is a brief overview of a procedure for removing and reinstalling a hoist motor.

Removal

Prior to removing any motor, be sure to abide by all safety and operational preparations as specified by the manufacturer, as well as your company's policies. For example, preparation for removing the hoist motors requires lowering the dipper until it is resting on the ground, setting the brakes and de-energizing the motors. Remove hatch covers and canopy sections as needed.

DANGER

High voltage can cause severe injury or death. Use lockout/tagout procedures and test before disconnecting electrical connections.

Typical removal includes (Figure 67):

1. Mark and remove electrical connections from the blower motor.
2. Remove the blower and blower motor.
3. Mark each set of coupling halves before separation to assure that they are returned to the same position during reassembly.
4. Remove the hoist motor coupling guard and coupling bolts.
5. Mark and disconnect the electrical connections to the motor.
6. Remove the hoist motor mounting capscrews and loosen the adjusting screws on the motor base.
7. Lift the motor from its base.
8. Mark the location of shim pads under the motor mounting pads for return during reinstallation.
9. Remove the coupling half from the motor shaft (Figure 68).

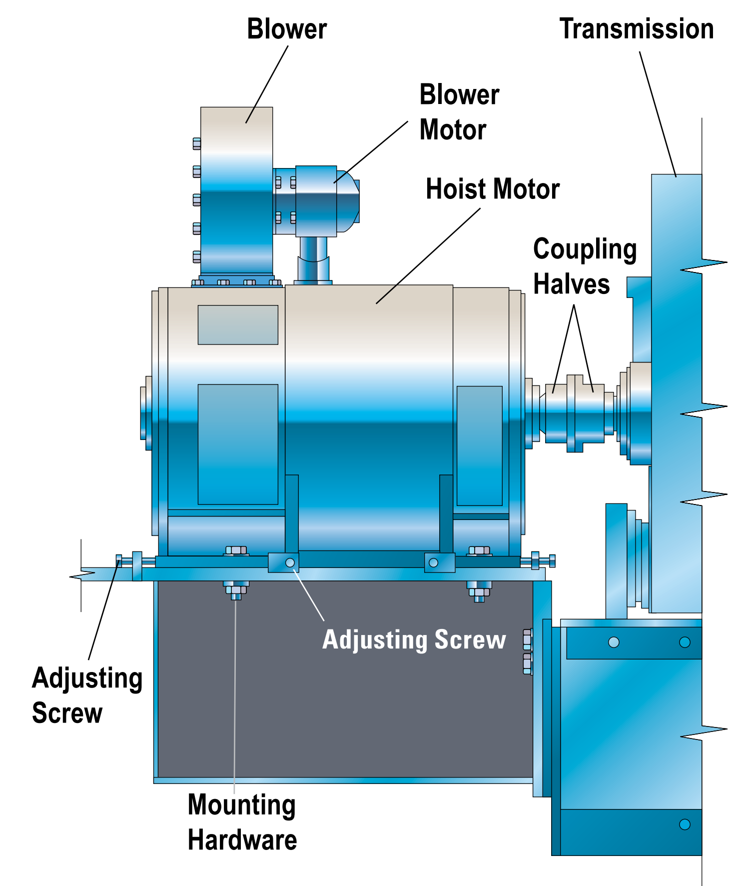


Figure 67 Before removing a motor, mark all electrical connections and each set of coupling halves to assure proper reinstallation.

DANGER

A hoist motor weighs approximately 15,000 lbs (6,800 kg). Dropping a raised load can cause serious injury or death and equipment damage. Be sure lifting equipment capacity exceeds the weight of the motor being lifted and that the lifting equipment is securely attached to the equipment being lifted. Stay clear when lifting, lowering or moving components.

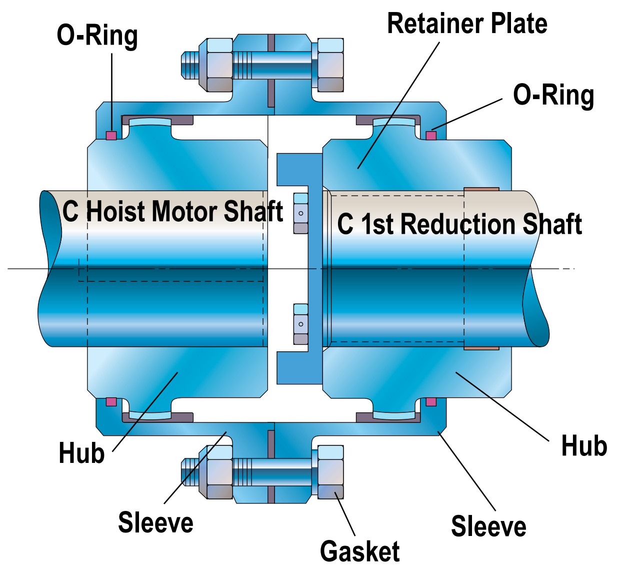


Figure 68 Typical hoist motor coupling

Installation

Typical motor installation includes:

1. Install the motor base shim packs to their original location and lift the motor to the base.

CAUTION

The motor may overheat if not properly ventilated. It is critical that some covers are removed and others are left on.

2. Refer to the manufacturer's cover installation specifications and verify that the proper ventilation covers are removed.
3. Using the alignment screws, position the motor on the base so that the gap between the coupling hubs meets the manufacturer's specification.
4. Align the motor to the transmission. When reinstalling a motor, the motor and transmission couplings must be parallel and axially aligned (Figure 69). This may be done using either lasers or gauges. The crowd and swing motors are self-aligning, so coupling alignment is really an issue for the hoist and propel motors. Check the manufacturer's specification for correct alignment indicator readings.
5. When the couplings are properly aligned, install the hand hole covers.
6. Make the electrical connections to the motor.
7. Connect the coupling halves and grease them.
8. Install the blower and blower motor and make the electrical connections to the blower motor.
9. Replace all machinery house roof panels, curtain wall panels, and canopy sections.

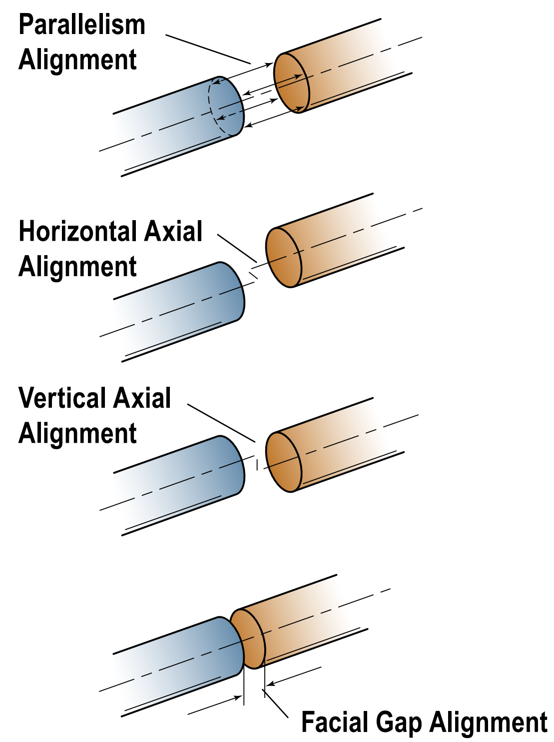


Figure 69 Motor shaft and gearcase input shaft alignment

9. Motor Repair and Rebuild Options

Komatsu operates fully equipped motor repair and rebuild facilities in key mining regions of the world staffed with experienced, factory-trained technicians (Figure 70). All facilities offer traditional repair and return service and many offer a motor exchange program.

Overview

Motor repair and rebuild operations involve a comprehensive, structured process starting with receiving, visual inspection and disassembly. Beginning with the receiving steps, a photographic record is maintained to document all defective parts and necessary repairs, including visual damage such as broken motor feet, cracked frame, broken shafts, etc (Figure 71).

Depending on the nature of the repairs to be done, services include field frame analysis and mechanical inspection of the armature and shaft, bearing cap and bearing cartridge, frame rabbet, glass bands, and wedges. Electrical inspection includes tests of insulation resistance, polarization index, armature surge, high potential tests, and AC drop tests on shunt fields and interpole coils. Motor leads are inspected for flexibility as well as for nicks, cuts and cracks.

Whether for repair or rebuild, Komatsu provides all these services as well as shaft straightening/replacement, keyway restoration, component metalization, vacuum pressure impregnation (VPI), load testing, and repair of bearing caps and cartridges.

Komatsu motor repair and rebuild services additionally include armature rewinding and coil installation (Figure 72), commutator repair and finishing, banding (Figure 73), dynamic balancing, field frame overhaul, motor assembly, final testing and preparation for shipment (Figure 74).

P&H Encore Motor Exchange Program

The P&H Encore Motor Exchange Program is part of an overall service designed to reduce operating costs by eliminating the purchase and associated carrying costs of spare components, including motors and transmissions. The P&H Encore program

Figure 70 Komatsu motor repair and rebuild facilities are strategically located worldwide.

Figure 71 Motors are steam cleaned and inspected upon arrival at a Komatsu rebuild center.

Figure 72 Armature coil installation

Figure 73 Motor armature banding

includes the exchange of the customer's corresponding remanufacturable component and all the services described above.

Komatsu motor service centers are available in select regions of the world and provide prompt delivery of hoist, crowd, swing, propel, combination crowd/propel, and blower motors. Remanufactured motors are stocked at centrally located warehouses for next-day or even same-day delivery to return customer equipment to productive operation as quickly as possible.

All Encore motors are completely disassembled, steam cleaned, inspected, tested and remanufactured to original specifications and backed with the same warranty as new P&H motors.

All electrical and mechanical functions and connections are rigorously examined and performance tested. The commutator is cleaned and undercut, the armature is dipped and baked, and new bearings and brushes are installed. Additional replacements may include the field coils, armature shaft and/or the commutator.

All the latest design improvements are incorporated into the motor during remanufacturing to provide state-of-the-art performance and reliability. The motor is tested to new motor specifications, painted and prepared for shipment.

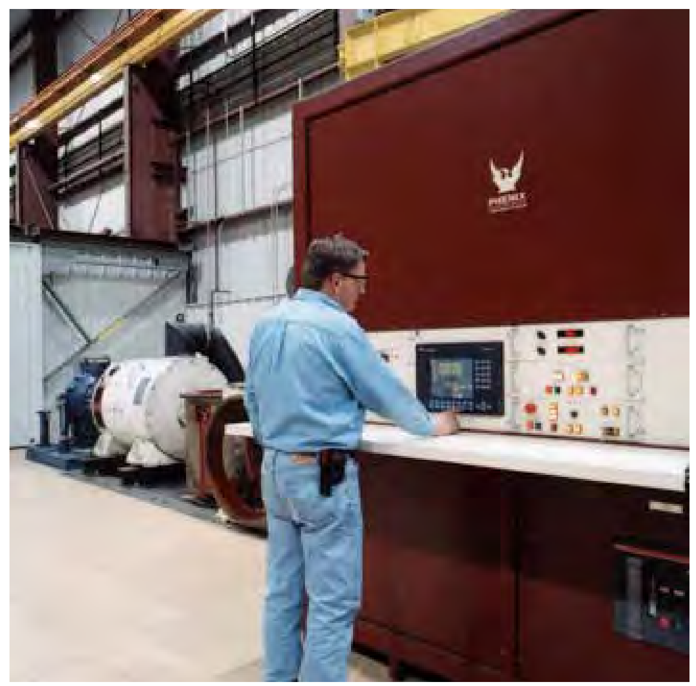


Figure 74 Motor testing prior to shipment

Glossary

ARC, ARCING - An electrical discharge between two conductors.

ARMATURE - The rotating component of a DC motor.

BRUSH - A current-conducting material usually made of carbon or graphite. Brushes ride directly on the motor's commutator surface and conduct current from the power supply to the armature windings.

COMMUTATION - The process of reversing the direction of current in the windings of a DC motor armature.

COMMUTATOR - A cylindrical device mounted on the armature shaft. The motor brushes ride on the outside edge of the commutator and electrically connect and switch the armature coils to the power source.

COUPLING - The mechanical connector that joins the motor shaft to the transmission drive to operate the shovel.

CURRENT - The flow of an electrical charge, measured in amps (amperes).

CURRENT DENSITY - The amount of current (amps) in a given area, e.g. amps per square inch.

DC DIRECT CURRENT - Current that flows in a circuit in one direction only. The current's direction may be reversed through the process of commutation.

EMF (ELECTROMOTIVE FORCE) - Another term for voltage; also used as an indicator of motor speed.

FIELD - A term used to describe the stationary member of a DC Motor. The field provides the magnetic field with which the rotating member (armature) interacts.

FIELD WEAKENING - The introduction of resistance in a DC motor to reduce the voltage and current, which weakens the strength of the magnetic field to increase the motor speed.

FLASHOVER - A destructive short circuit of a motor through the conductance of the plasma developed in an electric arc. It usually starts when commutation is interfered with, by mechanical shock or an electrical transient, to such an extent that an arc is formed from the trailing edge of the bar to the trailing edge of the brush. Once the arc occurs, the resistance of the arc column (plasma) decreases with increasing current and the energy available in the circuit will dissipate. With the whole power of the machine available, the discharge may be extended until it reaches the next brush, at which time there is a direct short circuit through the arc plasma. Severe destruction of brushes, brush holders, commutator and windings can result.

FLUX - The magnetic field which is established around an energized conductor or permanent magnet. Flux density is a measure of the strength of the magnetic field.

INDUCTANCE - The process of varying the current in an electrical circuit. Inductance produces a varying magnetic field, causing voltages in the same circuit or a nearby circuit.

MEGGER TEST - A measure of an insulation system's resistance. The resistance is usually tested by passing a high voltage at low current through the motor windings and measuring the resistance of the various insulation systems. The result is measured in megohms.

MICA - An inorganic material that has very good dielectric insulation characteristics and is used as insulation in high voltage or severe applications. In DC motors mica is used in the commutator assembly as insulation between the commutator bars.

P&H ELECTROTORQUE® Plus - A DC digital motor drive system.

PHASE - The space relationships of windings and changing values of the recurring cycles of AC voltages and currents. Due to the positioning (or the phase relationship) of the windings, the various voltages and currents will not be similar in all aspects at any given instant. Each winding will lead or lag another, in position. Each voltage will lead or lag another voltage, in time. Each current will lead or lag another current, in time. The most common power supplies are either single or three phase.

REACTIVE POWER COMPENSATION (RPC) - A system on a shovel that helps to ensure a "smooth" flow of power to the shovel motors from the main transformer.

SHUNT WOUND DC MOTORS - Shunt wound motors are normally used where the primary load requirements are for minimum speed variation from full-load to no-load and/or constant horsepower over an adjustable speed range at constant potential. Shunt motors are suitable for average starting torque loads.

SILICON CONTROLLED RECTIFIER (SCR) - See Thyristor.

THYRISTOR - An electrical switch used to convert AC current into DC current to be used by the motors. Also known as a Silicon Controlled Rectifier (SCR).

TIR - Total Indicator Runout

VOLTAGE - The electrical pressure or force that causes a current to flow through a circuit.

Index

It is our hope that you have found the information in this handbook helpful, but we recognize that every mine has its own methods of operation and no single handbook can answer everyone's needs.

If you have suggestions, tips or techniques other mines might find helpful for achieving peak performance from electric shovel motors, we would be pleased to consider them for inclusion in a future edition.

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