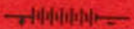
WESTERN PACIFIC

FUNDAMENTALS

OF

ELECTRICAL EQUIPMENT



Operating Department
Training Manual

The intention of this section is to provide a basic understanding of the fundamentals of the diesel locomotive electrical system.

This is not intended to be used as a trouble shooting guide for any particular type of locomotive, but as a general aid to anyone desiring to supplement his knowledge of the diesel locomotive electrical system.

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DEFINITIONS

(Some terms used in connection with Diesel-Electric transmissions)

Air Gap	A separating air space, usually applied to the space between the armature iron and pole piece of a generator, motor, or other device and through which magnetic flux must pass from one to the other.
Ampere	A unit which indicates the rate of flow of electric current. Equivalent units as applied to air and water are: cubic feet of air per minute and gallons of water per minute. In electrical circuits it is "amperes".
Arc	An electrical arc is the visible flow of electrical current between conducting pieces separated by air or other gas.
Arc Chute	Usually a box-like structure made of insulating and heat resisting materials to confine and direct an electric arc formed when contactors or switches open an electric circuit.
Arc Horn	A conducting extension piece attached to a circuit-making contact of a contactor or switch, for the purpose of elongating the arc formed when opening an electric circuit, to assist in extinguishing it.
Armature	This term is usually applied to mean the rotating part of a direct current generator or motor, but is also applied to mean that part of a contactor or relay which is caused to move by magnetic force.
Auxiliary Generator	A generator of electrical power which is to be used for driving the auxiliary equipment of diesel motive power.
Bands	A wrapping of high tensile strength wire around the armature of a generator or motor to hold the coils or other parts in place against the centrifugal forces of rotation.
Blowout	One of the electrical facts is that when a conductor is in a magnetic field and electric current is passing through the conductor, the magnetic field tends to move the conductor (that is, the action which makes an electric motor turn). Therefore, it is customary to surround the jaws of a contactor or arc-breaking switch with a magnetic field, so arranged that when an arc forms (due to breaking an electrical circuit), the arc moves and is stretched thereby in order to help in its extinguishment.
Brush	A device used for pressing against a rotating part of a generator or motor (in diesel-electric drives this is called the commutator) in order to pass current from the stationary to the rotating portions or vice versa. These brushes are usually made of carbon or graphite.

CARBON	A brush made of carbon.
CARBON PILE	A group of carbon discs so arranged that by compressing a stack of these discs the electrical resistance from on end of the stack to the other is reduced, and when the pressure on the stack is reduced, the resistance rises. This is one means of obtaining a variable resistance.
CIRCUIT	A flow of electrical current is caused when a conducting path is completed from the positive side of a generator or battery back to the negative side. This conducting path is called a circuit.
COIL	A number of turns of wire insulated from each other so that when current passes through these turns, it causes magnetic flux to pass through the center of the coil. This relation between current flow and magnetism is an electrical fact. To produce magnetism for operating a contactor the coil may have many turns of fine wire, while a coil for a generator or motor may have few turns of large wire.
COMMUTATING FIELD	It has been found that due to changes in the location of magnetism in different parts of generators or motors under varying load conditions, sparking may occur at the brushes at times. In order to eliminate excessive sparking, engineers devised the commutating magnetic field to minimize these changes.
COMMUTATING POLE	This is a steel pole piece with a coil for producing a commutating magnetic field.
COMMUTATOR	The flow of electrical current in the armature coil conductors of a generator or motor must alternate - first in one direction, then in the other - as these conductors move alternately under the positive magnetic poles and the negative poles. However, externally the current should flow in but one direction. To accomplish this change between unidirectional and alternating flow, a commutator is applied to the armature. This commutator consists of a large number of bare wedge shaped copper bars, carefully insulated from each other and mounted in cylindrical form, each connected to one or more turns of the armature coils. A set of brushes is then fastened to the stationary frame of the machine so that they press against the commutator at definite points in relation to the field poles.
COMPOUND FIELD WINDING	A combination of series, shunt and/or separately excited field coils for magnetizing a field pole.

CONDENSER	Two electrical conductors, when placed parallel to each other as closely as possible and separated by an insulator, have the characteristic of an electrical reservoir, and are capable of absorbing and holding considerable energy. A device built especially for this purpose is called a condenser, and usually consists of large areas or sheets of metal foil separated by an insulating medium such as mica or paper, and rolled into a small space.
CONDUCTOR	Any device, wire, bar, or any material which readily conducts electrical current.
CONTACTOR	A device for making or breaking an electrical circuit and usually actuated by the pull of magnetism. In its usual form, it consists of a stationary coil surrouning a steel core, and an armature moved by magnetism of the core whenever an electric current flows through the coil. The armature carries a moving contact piece which strikes and completes an electrical circuit through a stationary contact piece. While a relay may accomplish this same function in a similar manner, the term "contactor" is usually applied where the current passing through the contact pieces are of appreciable values.
CONTROL	This term is usually applied to all of the apparatus, devices, and accessories forming a complete installation required for regulating the application of power in a diesel motive power unit. The term is also applied to the method by which the engine is loaded, such as "differential control", "load control", etc.
CONTROL GENERATOR	A small generator driven by the main diesel engine and used to indicate the engine speed, and thus to actuate the control system to increase or decrease the electrical load correspondingly.
CONTROLLER	A device usually manually operated, by means of which the operator of the locomotive or rail car can increase or decrease the applied power, change the electrical connections, start the engine, etc. It usually consists of one or more cylindrical drums carrying contact plates and a set of stationary fingers, for simultaneously or successively making contact with the various drum plates as the drums are rotated by the operator, thus completing electrical circuits to accomplish the desired results.
CUMMULATIVE FIELD WINDING	On a single magnetic circuit encircled by series, shunt and/or separately excited coils, if all coils tend to magnetize the circuit in the same direction the windings are said to be cumulative.
CURRENT	A rate of flow of electrical energy in a circuit. See "Ampere", the unit of current.

DIFFERENTIAL CONTROL	A system of control whereby the loading of the diesel engine is regulated by means of a differential field winding applied to the main generator or to the exciter of the main generator.
DIFFERENTIAL FIELD WINDING	In a combination of series, shunt and/or separately excited field coils, an arrangement such that one tends to magnetize the field pole in a direction opposite to the magnetization of the others.
DIRECT CURRENT	An electrical power system in which the electrical current flow is continuously in the same direction (not alternating periodically) unless circuit changes are made or operating conditions cause reverse flow.
DRAWBAR PULL	The force which may be developed by a motive power unit for propulsion purposes is usually measured at the rims of the drivers. This is known as its "tractive force". A portion of this force is required to overcome the resistance against movement of the motive power unit itself (frictional resistance, air resistance, grade resistance, etc.). The balance which is available for pulling a train is known as "drawbar pull". Due to variations in grade, wind resistance, etc., drawbar pull may vary widely for a fixed condition of tractive force.
DRUM	A cylindrical device carrying contact plates and so arranged that by its rotation circuit changes are made.
EDDY CURRENT	Local circulating current generated in conductors or machine structures, usually serving no useful purpose.
END WINDINGS	That portion of the armature coils of a generator or motor which extends beyond the armature iron at either end.
ENERGIZE	To apply electrical voltage to a circuit, coil, or other device.
EXCITE	To pass current through a coil for the purpose of creating a magnetic field.
EXCITER	A generator especially designed to produce the electric current required for exciting another generator.
FIELD	The region where magnetic forces act is a magnetic field. Also the structure of a motor or generator which carries the field poles and coils. Also the complete assembly of poles, coils and frame.
FLASHOVER	An arc occuring between two points not supposed to be directly connected, such as from one brush holder to the next of a motor or generator, or across an insulator separating one conductor from another or from ground.

FUSE	A fusible link connected in a circuit so that when an excessive current flows, the link will melt and open the electrical circuit to prevent overload damage to electrical equipment.
GENERATOR	An electrical machine having electrical conductors rotating past magnetic poles, so that mechanical energy may be converted into electrical energy.
GROUND	Those portions of a locomotive or car structure usually connected electrically to the rails. Also a connection from an electrical circuit to a grounded part.
INTERLOCK	A secondary electrical contact-making or contact-breaking device applied to a contactor or switch for the purpose of altering the control circuits, depending upon whether the switch is open or closed.
INTERPOLE	Commutating pole.
INSULATION	Material which does not readily pass electric current. An assembly of materials and devices for insulating a circuit.
INSULATOR	A device, usually of specific shape, by means of which a conductor may be insulated from another conductor or from ground. A characteristic of material.
JUMPER	A removable electrical connector usually used for by-passing a portion of an electrical circuit. Also a device used between units of a train for coupling or uncoupling electrical circuits carried from unit to unit.
KILOWATT	A unit of power. 1,000 watts. 1.34 horsepower.
KNIFE SWITCH	A switch consisting of one or more bare hinged blades, making contact edgewise with stationary jaws.
LEAD	A conductor leading current to or from an electrical device. Usually applied to flexible wire, cable, etc.
LOAD CONTROL	A system of control whereby the loading of the diesel engine is regulated by the speed of the engine itself, this speed reflecting the load conditions of the engine.
LOCOMOTIVES	An assembly of mechanical parts, equipped with a prime mover (or other means of obtaining propulsion power) and a transmission system, used for the propulsion of trains on rails and not suitable for carrying revenue load.
MAGNETIC BLOWOUT	Provision of a magnetic field surrounding the contact jaws of a contactor or switch, so that the arc which forms when a circuit is opened is stretched and extinguished. See "blowout".
MAGNETIC FIELD	Normally means the region where magnetic forces are acting.

MAGNETIC FLUX	Indicating the intensity of magnetic forces which act in any region.
MAGNETIC LINE OF FORCE	Indicating the direction of action of magnetic forces.
MEGGER	An instrument used for the measurement of insulation resistance. Since such resistance to the passage of electrical current is generally in the range of millions of ohms (megohms), the instrument derives its name therefrom.
MEGOHM	A large unit of resistance - a million ohms.
MOTIVE POWER UNIT	A single or permanently connected set of mechanical parts provided with apparatus for propulsion, used for hauling trains on rails.
MOTOR	An electrical machine having electrical conductors rotating past magnetic poles so that electrical energy may be converted into mechanical energy.
MOTOR NOSE	The support of a traction motor on the opposite side from the axle bearings.
MULTIPLE	In parallel relation. Thus, if two motors are connected in multiple, the current from a common source passes partly through one and partly through the other to a common point on the other side of the motors. In the operation of motive power units, "multiple" means the operation of two or more units simultaneously by a single operator.
NEGATIVE	Usually considered as the point toward which electrical current flows.
NEUTRAL	That zone on the commutator of a generator or motor where the voltage between bars is at minimum. This zone is normally stationary in respect to the field poles, even though the commutator is rotating.
OHM	The unit of electrical resistance. An electrical conductor is said to have a resistance of one ohm if a current of but one ampere flows when one volt is impressed across the conductor.
OHM'S LAW	Volts = Amperes x Ohms.
PARALLEL	Side by side. Motors are said to be in parallel when current flowing from a positive to a negative source passes partly through one and partly through the other. (see multiple)
PIGTAIL	A flexible conductor of short length attached to a contact, brush, or similar device for conducting electricity to or from the device.

POLE	Usually a projection of steel provided with a coil for producing magnetism in a motor or generator. Also used to mean the number of circuits handled by a switch or contactor; such as, double pole knife switch; single pole contactor.
POLE PIECE	The steel portion of a magnetic pole.
POSITIVE	Usually considered as the point from which electrical current flows.
RAILCAR	An assembly of mechanical parts, equipped with a prime mover and a transmission system, suited for the propulsion of trains on rails and also provided with space for revenue load.
RECEPTACLE	Usually a stationary device housing electrical terminals so arranged that electrical connections may be made to these terminals by inserting a plug or jumper head. Normally used for connecting external circuits to a locomotive or railcar for a battery charging or for multiple operation of motive power units. Also the base for electric lamp bulbs.
REGULATOR	An electrical relay whose function is to regulate the voltage of a circuit, the output of a given machine, or to maintain other conditions within prescribed limits.
RELAY	An electrical device which operates under one set of predetermined electrical conditions, to set up revised conditions in other parts of the circuit or other electrical circuits. Relays may be of various types, the title usually being indicative of their functions, such as voltage relay, reverse current relay, transition relay, overload relay, regulating relay, etc.
RESIDUAL MAGNETISM	When a piece of iron or steel is magnetized and then the magnetizing force is removed, some magnetic effect is still retained by the metal. This is known as its residual magnetism.
RESISTANCE	The property of a conductor or material which opposes the flow of current when voltage is applied to cause such current to flow. The unit of resistance is the ohm.
RESISTOR	An assembly of conductors having relatively high resistance characteristics, connected in a circuit as desired to limit the current flow.
REVERSER	A piece of apparatus used for altering the electrical connections of traction motors, to obtain reverse movement of a motive power unit. This is usually of the drum style.
RHEOSTAT	A resistor arranged for convenient variation of the resistance values.

SATURATION	The maximum value of magnetism.
SEASON	To alternately heat and cool and tighten a commutator assembly so that actual heating and cooling of service cycles will not allow the assembly to loosen or distort and thus change its cylindrical shape.
SERIES	The connections of two pieces of electrical apparatus in a circuit so that the flow of current is first through one and then through the other. For instance, if two motors are connected in series across a generator, current from the generator first flows through #1 motor and then through #2 motor before returning to the generator.
SERIES FIELD,	A field winding connected in series with the armature of the machine itself or in series with the armature of a main generator.
SERIES MOTOR	A type of motor in which the field coils are connected in series with the motor armature. This motor is self-protecting to some extent since a rise in current through the armature is accompanied by the same rise in the field. Since motor torque depends upon armature current and field strength, a relatively small rise in current results in a large increase in torque.
SHORT CIRCUIT	To short circuit a portion of an electrical circuit means to introduce a relatively low resistance path in place of the normal higher resistance path. A short circuit usually refers to an accidental and damaging by-passing of such normal circuit resistance.
SHORT FIELD	An arrangement of a traction motor field whereby the number of turns connected in the circuit may be reduced to weaken the field strength. This tends to increase the motor speed.
SHUNT	(a) A device for diverting a portion of the current from a part of an electrical circuit. (b) A piece of electrical apparatus used in connection with a meter or instrument so that the main current passes through the shunt, and only a very small portion passes through the meter or instrument. (c) To shunt a portion of an electrical circuit means to connect a shunt around it. This is usually applied to the field of a traction motor. NOTE: Perhaps no electrical term is used with as many meanings as the word "shunt". Many electrical men often refer to any field winding of low ampere capacity and many turns as a "shunt field" even though it may be separately excited. Then there are "field shunt" (not shunt field), "brush shunt", "switch shunt", "shunt transition" and many other uses too numerous to mention or define.

SHUNT FIELD	The field of a motor or generator which is energized by being connected directly between the positive and the negative terminals of the machine.
SHUNTED FIELD	A field around which a shunt has been connected to divert a portion of the current normally passing through the field. This is usually for the purpose of increasing traction motor speed.
SOLENOID	An electric coil, usually of many turns, used for the generation of a magnetic flux to draw a moveable core into the coil.
SPIDER	A permanent support for an armature assembly, also for a commutator assembly, so that the alignment of insulation and windings need not be disturbed in replacing an armature shaft.
SPLIT POLE CONTROL	A system of differential field control which follows the principles embodied in all Westinghouse differential control exciters, except that two rows of field poles are required to accomplish the results obtained by the single row of poles in the Westinghouse machine.
SWITCH	A device for opening and closing an electrical circuit. The name usually describes the construction or purpose; such as knife switch, toggle switch, pneumatic switch, magnetic switch, battery switch, cutout switch, selector switch, etc.
TORQUE CONTROL	The first system of load control, devised by Westinghouse, wherein the engine is loaded to its full permissible torque by gauging the rise or fall in engine speed. A control generator reflects engine speed, and causes a load regulator to operate to increase the electrical load if the engine speed is high and vice versa.
TRACTIVE EFFORT/ TRACTIVE FORCE	The force exerted at the rims of the driving wheels of a motive power unit for propulsion.
TRACTIVE POWER	The power developed at the rims of the drivers of a motive power unit. Very frequently misused to mean tractive force. Tractive power involves both tractive force and speed, whereas tractive force may be independent of speed.
TRAIN LINE	Electrical circuits passing from one vehicle to another of a train.
TRANSITION	A change from one system of electrical connections to another. Usually applied to the change from series connection of traction motor to parallel connection.
UNIT SWITCH	A term describing Westinghouse pneumatically operated switches for use in the main power circuits of railway vehicles.

UNLOADING POINT	Diesel engines may be kept fully loaded over a wide range of train speeds by an electrical transmission system. However, when the generator reaches its maximum voltage, there is a tendency for the engine to become slightly unloaded as the train speed increases unless alterations are made in the motor connections. This is called the unloading point or unloading speed.
VOLT	The unit of electrical pressure.
WATT	This is the unit of electrical power and equals one volt multiplied by one ampere. To determine the power of a circuit, multiply the volts across the circuit by the amperes flowing (in direct current circuit). 746 watts equal one horsepower.
WEIGHT TRANSFER COMPENSATION	When tractive force is applied to the rims of the drivers for moving a locomotive or railcar, the resultant forces tend to lift weight from the forward drivers and increase the weight on the rear ones. This is called weight transfer. Since the maximum tractive force which may be exerted by a motive power unit is limited by the slipping point of the wheels on the rails, it follows that as all traction motors develop the same tractive force, the total is limited by the most lightly weighted pair of drivers. Westinghouse sometimes compensates for this differential in weight by weakening the fields of the forward traction motors and passing increased current through the rear motors. This is called weight transfer compensation.

FUNDAMENTALS OF ELECTRICAL EQUIPMENT

A study of the diesel-electric locomotive indicates that it includes both electrical and mechanical equipment in about 50-50 proportions. Mechanical and electrical devices combine to produce the power which turns the wheels.

The source of power is the diesel engine, the most efficient internal combustion engine yet devised. The diesel engine develops mechanical horsepower, most of which is used to rotate the armature of the main generator. (approximately 10% of the diesel engine's horsepower is used to operate the locomotive's auxiliary equipment such as the air compressor, cooling water fan, etc.) Rotation of the main generator's armature causes the generator to develop electrical power. This power reaches the traction motors through cables and contactors which connect the generator and motors together. The traction motors then rotate the locomotive's driving axles through gearing.

Thus, the diesel-electric locomotive's "Chain of Power" includes:

1. Diesel Engine
2. Main Generator
3. Cables and Contactors
4. Traction Motors and Gearings

Some understanding of the principles of electricity is helpful to a locomotive engineer but a thorough study of all electrical fundamentals is not necessary because only a few actually apply to the diesel-electric locomotive. Understanding electrical functions is made considerably easier if we know the answers to the following questions:

1. What is voltage and what does it do?
2. What is current and how is it made to flow?
3. What is resistance and how does it affect voltage and current?
4. How does a generator work?
5. How does a motor work?

The locomotive's electrical circuits can be very closely compared with a water circuit which consists of a water pump, pipes and water wheels. Below is a diagram of a diesel-hydraulic locomotive which has the pump, pipes and waterwheels substituted for the main generator, cables and traction motors of the diesel-electric locomotive.

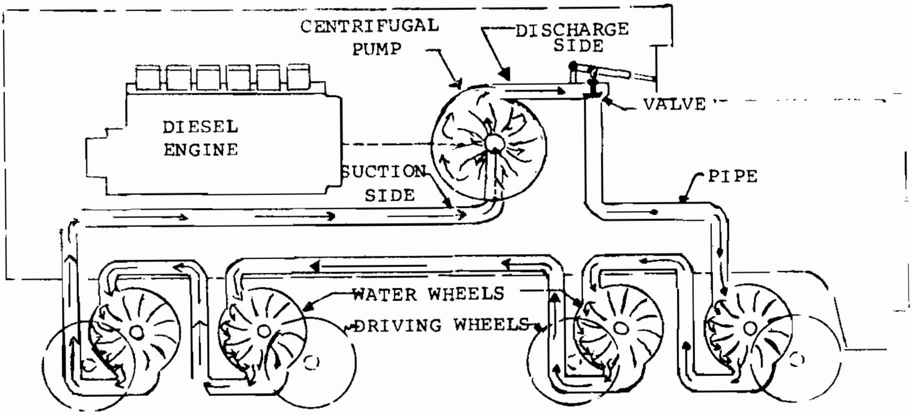


FIGURE 1

We will assume that the following conditions exist on the locomotive which is pictured above.

1. With throttle in "idle" position, the diesel engine is idling and is rotating the centrifugal pump vanes.
2. The valve is closed and no water is flowing through the pipes.
3. Pump, water wheels and pipes are full of water.
4. Water wheels are geared to locomotive driving axles.

Under these conditions the locomotive will be standing still. It cannot move unless the water in the system begins to flow in sufficient volume to rotate the water wheels and turn the driving axles. The pump, because its vanes are turning, is exerting a pressure against the water, but the pressure is unable to start the water flowing because the valve is closed.

Now let us move the throttle to notch 1. This opens the valve. As soon as the valve opens, the pressure from the pump will immediately begin pushing water through the valve and this flowing water moves through the water wheels. The system is now a circulating water system with the pressure of the pump causing a continuous flow of water against the blades of the water wheels. If the locomotive has a heavy tonnage train, it will not yet begin to move because the pump is running at low speed and its pressure is not high enough to force a large volume of water against the blades of the water-wheel. Therefore, although the water is flowing through the water-wheel casings and against the blades, there is not enough of it to move the blades and start the water-wheels turning.

The engineman now "notches up" his throttle and the diesel engine speed increases.

This, of course, drives the pump faster and the pressure increases. The added pressure forces a larger volume of water through the water wheels. If they still are unable to turn, the engineman will notch up again to increase diesel engine speed.

This drives the pump faster to further increase the pressure and still more water flows. Let us assume that we now have enough gallons per minute of water flow to move the water wheel blades. As they begin to rotate, they turn the locomotive's driving axles and the locomotive begins to move. The engineman notches up again to increase pressure, so that the locomotive will accelerate and he continues to notch up until the diesel engine is rotating at its maximum speed and the locomotive is accelerating rapidly.

If we substitute a generator, cables and traction motors for the pump, pipes and water wheels, we have a diesel-electric instead of a diesel-hydraulic locomotive. Its operation will be almost the same as that of the hydraulic system. The diagram below illustrates the locomotive as it now appears.

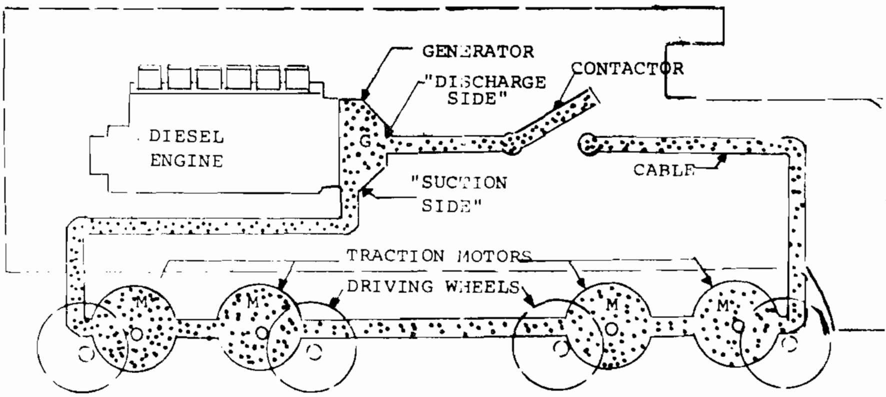


FIGURE 2

The following conditions now exist:

1. Diesel engine is idling and rotating the generator armature.
2. Contactor is open and no electric current is flowing from the generator to the motors.
3. The copper cables are full of electrons (represented by black dots).
4. Traction motor armatures are geared to locomotive driving axles.

Under these conditions the locomotive will be standing still because with no electric current flowing from the generator through the motors (electrons not moving) the motor armatures will not turn. The generator armature, because it is rotating, is exerting pressure against the electrons but they cannot move because the contactor is open.

Now let us close the contactor. (Equivalent to opening the valve on the hydraulic locomotive.) As soon as the contactor closes, the pressure of the generator forces the electrons through the contactor to the motors. The electrons are now moving through the system in much the same manner as the water moved through the hydraulic system. The generator is acting as a circulating pump and its pressure is pushing the electrons from its "discharge" side through the cables and the motors to its "suction" side. At the "suction" side it pulls them in again, builds up the pressure against them and forces them out through the system again. This constant circulation of electrons through a complete circuit is called the flow of electrical current. It is the CONTINUOUS FLOW of current THROUGH an electric motor which causes the motor armature to begin turning. However, as was the case with the hydraulic system, the volume of flow must be heavy enough to start the motors turning. If the train tonnage is light the motors will begin to turn when the diesel engine is at idle speed and the generator pressure is low. In this case although the low pressure will not force very many electrons through the motors, it only requires a few of them to turn the motors, because the tonnage which the motors must move is light. But if the tonnage is heavy, the few electrons will be unable to start movement. As was the case with the hydraulic system, the engineman will then have to notch up to increase the diesel engine speed. This rotates the generator armature faster and increases its electrical pressure. The added pressure forces more electrons through the traction motors and the motors twist all the harder. Eventually by advancing the throttle and building up the generator pressure, enough electrons will flow to move the motor armatures and this, of course, will turn the wheels and move the train.

Thus, we see that whether it be water in a pipe or electrons in a wire, work will be performed if we can cause the water or electrons to move. It is the CONTINUOUS MOVEMENT of water or electrons that makes a water-wheel or motor operate.

The water and electrons existed in the systems, but were doing no useful work until we applied pressure to them to make them move. Thus, before movement can occur we must have pressure. But, we noted that pressure by itself was not performing any useful work. For instance, when the diesel engine was turning the water pump rotor with the valve closed, the pump was developing pressure, but because of the closed valve the pressure could not push water through the line. The same was true of the electrical circuit when the generator was developing pressure, but no electrons were flowing because of the open contactor. In both cases, pressure was available but because nothing was flowing, no useful work was being performed. Hence, pressure alone is not enough. The pressure must be used to cause water or electrons to move before work can be performed.

In the electrical circuit the pressure is called volts, in the water circuit it is called pounds per square inch (PSI). The flow of electrons is usually referred to as the flow of current. The flow of water is usually referred to as gallons per minute.

WATER			ELECTRICITY
lbs. per sq. in.	- Pressure	- Voltage	(Volts)
gals. per min.	- Flow	- Current	(Amperes)

As pressure pushes either water or electrons through a system, the water or electrons meet with opposition. In other words, something tries to hold them back. This "something" is known as resistance in the water circuit. The diagram below represents a piece of galvanized pipe through which water is flowing. Note that the inside of the pipe is quite rough. This roughness in the pipe causes the water to set up eddies.

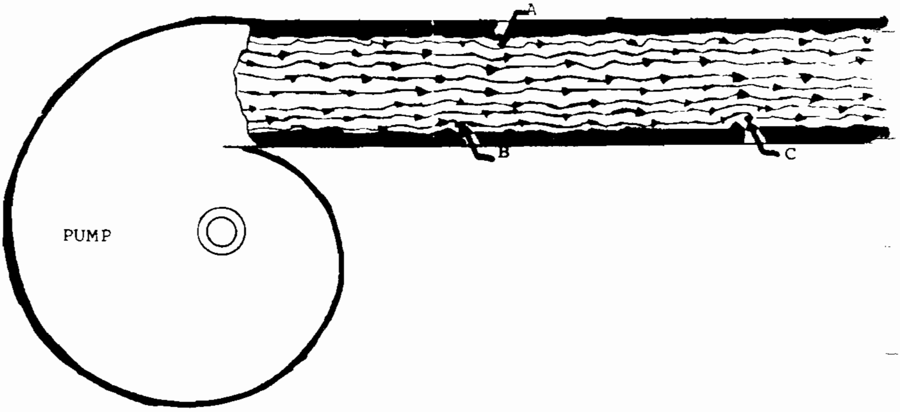


FIGURE 3

These eddies in the water are shown greatly exaggerated at points A, B and C. Note that at these points the water, in following the rough surface of the pipe, almost "doubles back" on itself. In other words, the water flow encounters opposition which deflects it and interferes with its flow. This opposition is called resistance and it actually reduces the flow of water to fewer gallons per minute than would flow if the pipe was smooth. The rougher the pipe the greater will it resist the flow of water. If we assume that one gallon per minute is being pushed through the pipe by one pound per square inch pressure and it is desired to increase this flow, there are two methods by which the flow can be increased. If we remove the roughness from the inside of the pipe (reduce the resistance) leaving a smooth surface, there will be fewer eddy currents and the water will not tend to double back on itself. With a free uninterrupted passageway, the one pound per square inch pressure could push more than a gallon per minute through the pipe. If, on the other hand, we are unable to remove the rough spots, there is only one other way to increase the flow. We must increase the pressure of the pump. One and one half pounds per square inch pressure will force more water through the pipe than one pound per square inch pressure.

The flow could be also increased by using BOTH methods at the same time. That is, if we smooth out the pipe and also increase the pressure, an even greater flow will result.

Therefore, there are three methods by which the flow of water may be increased:

1. By reducing the resistance which opposes the flow.
2. By increasing the pressure which is pushing the water.
3. By reducing resistance and increasing pressure.

Let us now look at the resistance in the electrical circuit. Assume that it is possible to look into the copper cable and actually see the basic form of matter of which copper is made. We would see many millions of atoms, each of which would resemble to a certain extent the sun and the planets of our solar system. The figure below shows fundamental diagrams of the atoms in a copper cable. The large circled "N" represents the atom's center which does not move. The small circled "e" represents the atom's electrons. The electrons are free to move and they tend to circle around the center. However, they are not held to any one center. Many of them move off through the copper, moving from one center to another apparently in an aimless manner without regard to direction.

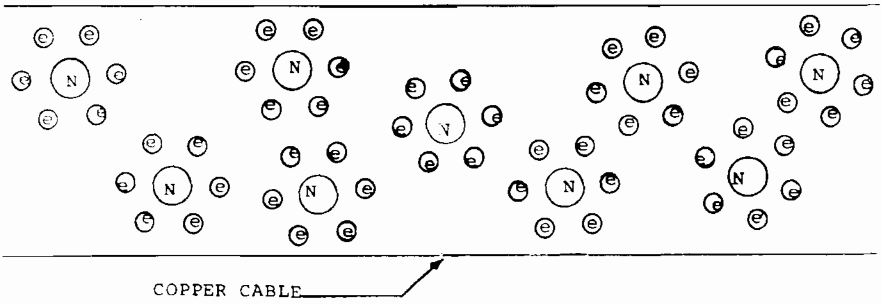


FIGURE 4

If the electrons which are moving aimlessly through the copper, can be forced to move in one direction through the wire, a definite flow of electric current (flow of electrons) will be established. This is accomplished by connecting a generator to the copper wire. The voltage of the generator will push the electrons through the wire.

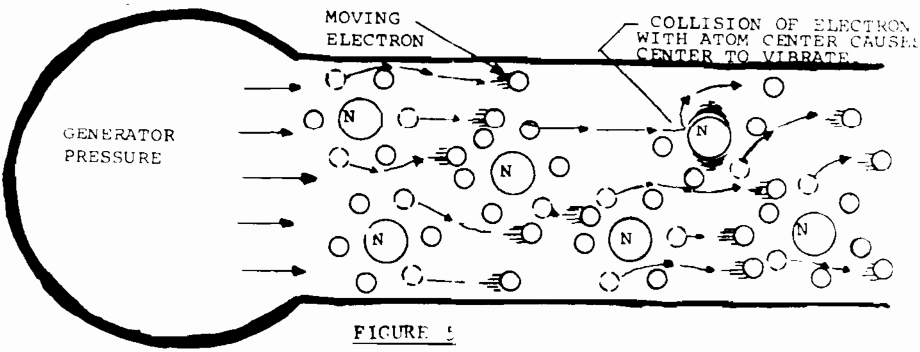


FIGURE 5

As the electrons move through the wire they occasionally collide with the center of an atom. Because the center cannot move, the electron's movement is interfered with. This is the resistance which exists in any electrical circuit.

In the galvanized water pipe the rough galvanized coating on the interior of the pipe offered some resistance to the flow of the water by setting up eddies. Cast iron pipe which has a rougher surface than galvanized pipe would set up stronger eddies, therefore, its resistance to water flow is greater than that of galvanized pipe. On the other hand, brass pipe is very smooth and offers little resistance because it does not set up many eddies. Because of this, each type of pipe will permit a different water flow for a given amount of pressure. For instance, if we assume that one pound per square inch pressure will force one gallon of water per minute through a one inch diameter cast iron pipe, we would find that one pound per square inch pressure might force one and one half gallons per minute through on inch galvanized pipe or two gallons per minute through one inch brass pipe.

In the electrical circuit we would also find that different materials offer different resistance to the flow of current. In copper, for instance, the electrons find it quite easy to move through the wire because they have only a few collisions with the atoms' centers. But in nichrome wire (nickel-chromium alloy) the fixed centers are so numerous that the electrons find it hard to slip between them and many collisions occur. In other words, the electrons meet with a lot of opposition. Nichrome wire therefore has more resistance than copper.

An interesting fact concerning the collisions of the electrons with the centers of the atoms, is that the collision causes the centers of the atoms to vibrate violently. This tends to cause heat and if there are enough vibrations, the wire will get quite hot. For instance, if we apply too much voltage to copper, it will cause so many electrons to flow, that they cannot all pass between the fixed centers and the result will be that a great number of collisions will occur. The copper will then become red hot and because it is a soft metal it will melt. Thus we see that too much current flow will overheat a wire and destroy it.

MAGNETISM

The generation of electrical voltage is accomplished by causing a conductor to move through a magnetic field. This will be fully explained under "Generator Action".

A magnet tends to attract certain types of metals. Iron can be magnetized very readily. So can steel. If, for instance, a bar of hardened steel is placed within a coil of wire and current is passed through the coil, the bar will become magnetized. It will remain magnetized after the flow of current stops and is thus called a "permanent magnet". It will retain its magnetism for a long period of time.

Another type of magnet is called a "temporary magnet". This type is used in the main generator of the locomotive. A temporary magnet is made of soft iron or soft steel. When a bar of this material is placed within a current carrying coil, it too will magnetize, but when the current stops flowing, it will immediately lose its magnetism. Thus, it is called a temporary magnet.

The figure below illustrates an iron bar which is being magnetized by the flow of current through the coil of wire. Current flow from the small generator "E" is indicated by arrows with vanes.

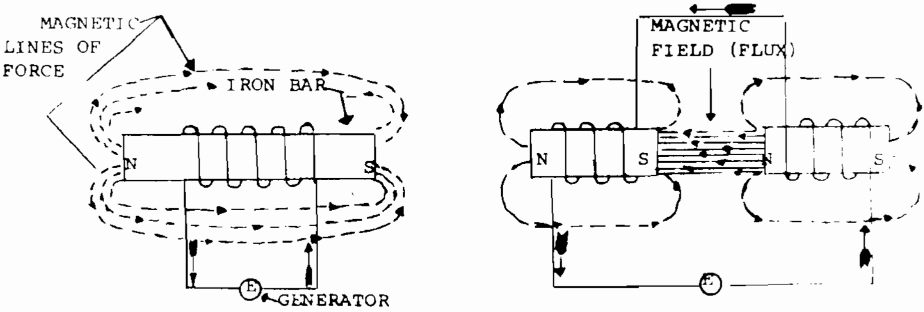


FIGURE 6

GENERATOR ACTION

We have mentioned the fact that a generator is little more than a pump. Like a pump, it is useful only when it is developing pressure. The main generator of the locomotive is useful only when its voltage (pressure) is being used to push current down to the traction motors.

The generator will generate voltage only when its armature is being rotated by the diesel engine. The armature is a cylindrically shaped device with slots cut lengthwise in its surface. The diagram below shows an end view of an armature. Each slot contains a copper conductor which is held in the slot by a wedge and by banding wire. The armature shaft is mounted in a roller bearing on the commutator end and is directly coupled to the diesel engine crankshaft on the opposite end. When the diesel engine is running, the armature, of course, rotates with the crankshaft.

As the armature rotates, the copper conductors cut through the magnetic lines of force. These magnetic lines come from the iron pole pieces which are bolted to the main frame of the generator. Each conductor will have a voltage generated in it whenever it cuts through a magnetic line. The strength of the voltage which is generated in the conductors will depend on how many magnetic lines they cut through in a given length of time. The more lines they cut, the stronger will be the voltage.

The iron pole pieces of the generator are normally not magnets, but they become magnetized by the flow of current through the coil of wire which is wrapped around each pole piece. The coils are usually referred to as the "generator field winding" and the current which passes through them is called "field current". Passing current through them is called "field current". Passing current through the field winding is often called "exciting the field". The small generator "E" which supplies the field current is called the "exciter".

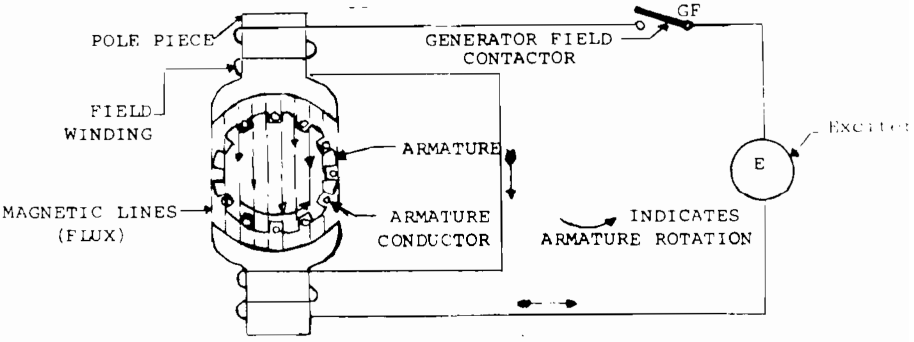


FIGURE 7

We have previously mentioned that by speeding up the water pump more pressure is developed. The same is true of the gnerator. If its armature speed is increased (this is done by speeding up the diesel engine), the conductors will cut through the magnetic lines more frequently and by cutting more lines, a greater voltage will be generated in the armature conductors. However, this is only one method of changing voltage. It can also be done without changing the armature speed. If the speed remains constant, the number of lines can be increased and then the conductors will cut through more lines even though they are not rotating any faster.

The number of lines depend on the strength of the magnet. A weak magnet produces only a few lines and a strong magnet produces many lines. The magnet can be made strong if a lot of field current passes through the field winding, or weak, if only a little current is passed through the field winding.

If a large change in voltage is desired, both methods can be used at the same time. For instance, if it is desired to greatly increase the voltage of the generator. the diesel engine can be speeded up to increase armature rotation and at the same time the field current can be increased to produce more magnetic lines.

Thus we see that the rules for generation of voltage are:

1. Rotate the armature
2. Excite the field

The rules for changing the voltage are:

1. By changing the armature speed, or
2. By changing the field current, or
3. By changing both speed and field current at the same time.

The voltage which is generated in the armature conductors is useful only if it can be used to push current to the traction motors. We have seen that the electrons in a copper conductor will move to cause a current flow, but only if they can be pumped through a "circulating system" by the generator. In order to allow the voltage to push the current to the motors, a method must be provided by which the current can be pushed out of the rotating armature conductors to the motors and then pulled back into the armature conductors to be recirculated again. Such a method is provided by a commutator and brushes as illustrated below. Here we see a side view of the generator. For clarity only two of the conductors are shown. Note that they are connected together across the back end of the armature.

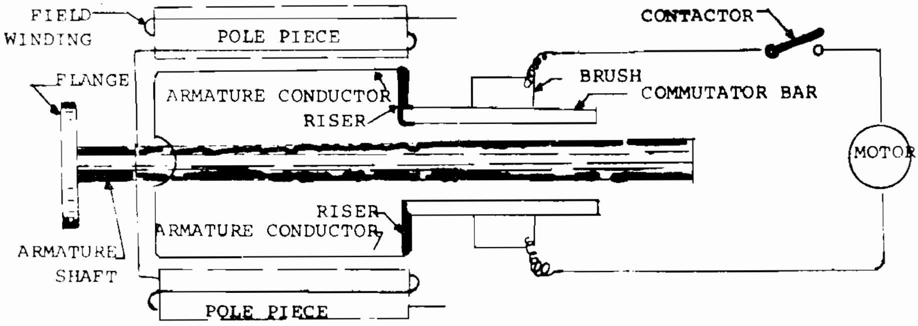


FIGURE 8

The front end of each conductor is connected to a copper commutator bar by a copper riser. The carbon brushes are fixed in position and cannot move. As the armature rotates, the copper bars will contact the two brushes. At the instant the contact is made, the voltage in the conductor will push current through the riser, to the bar, then into the brush to the motor. It passes through the motor and then travels back through the brush to the opposite commutator bar into the riser and conductor. It thus comes back where it started and it is immediately recirculated through the same circuit. The contactor in the figure above will set up this circuit whenever it is closed.

Thus we see that to cause current flow we must:

1. Rotate the armature
2. Excite the field
3. Give the current a complete circuit to flow through

In other words, if we already have voltage, current can be made to flow by merely giving it a complete path to flow through.

The engineman can move his locomotive whenever he desires, merely by pulling the throttle from "Idle" position to 1st notch. This action of the throttle automatically causes the S1, S21 and GF power contactors to close. As shown below, with GF closed, current from the small exciting generator flows through the main generator's field of winding to produce magnetic lines. As the diesel engine is already rotating the generator armature, the closing of GF thus causes voltage to be generated. The closing of S1 and S21 allows the voltage to push current through numbers 1 and 3 traction motors and through numbers 4 and 2 traction motors. The flow of current is indicated by the arrows. This current flow causes the motors to turn.

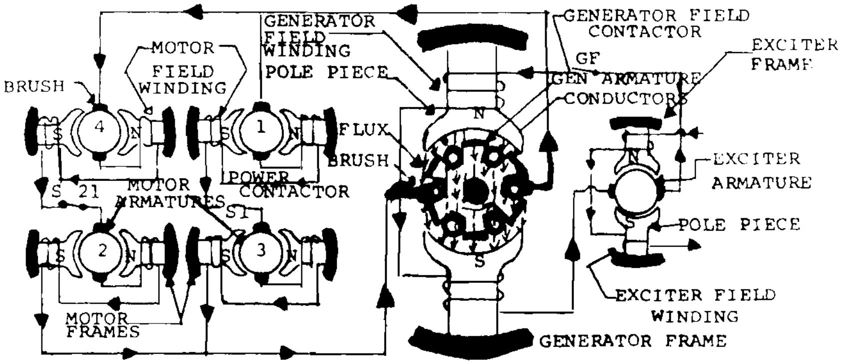


FIGURE 9

MOTOR ACTION

The traction motors are similar to the generator in that each has an armature and each has a field winding. Construction is about the same except that the motor's armature and field winding are smaller than those of the generator. However, the action of the two machines is different. In the generator we used the diesel engine to rotate the armature, but the traction motor armature will be rotated by the passage of current through the motor. In the preceding diagram note that the current which is coming from the main generator armature (heavy lines) passes through both the armature conductors and field winding of each motor. As the current passes through the armature conductors, it sets up circular magnetic lines around the conductors, as the diagram below illustrates. After leaving the conductors the current then passes through the motor field winding. This magnetizes the motor pole pieces, just as the generator field current magnetized its pole pieces. Thus, we have two different magnetic fields. One surrounds the armature conductors; the other is set up between the pole pieces. The diagram below, an end view of a motor, illustrates the action of these magnetic fields. Note that the magnetic lines, which normally try to travel in a straight line from the north pole of the top magnet to the south pole of the bottom magnet are pushed out of their normal path. The circular lines are traveling clockwise around the top conductor. They tend to push the normally straight line from the pole piece to the right of the conductor. The circular lines around the bottom conductor are traveling counter-clockwise. This tends to push the normally straight line from the pole piece to the left of this conductor. The normally straight lines are bent from their normal path and they act like stretched rubber bands. In other words, they tend to straighten out and in straightening out, they push the conductors in a counter-clockwise direction and this rotates the motor armature.

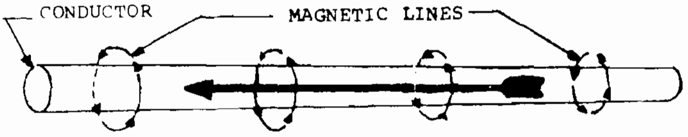


FIGURE 10

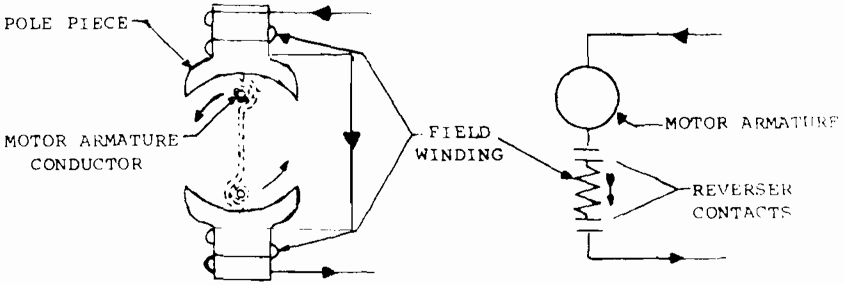


FIGURE 11

When a current carrying conductor is in a magnetic field, it tends to move out of that field.

Thus, we see that it is actually the opposing or pushing action of two different magnetic fields which acts to produce motor rotation. Be sure to note that the two different magnetic fields are set up by the same current. The current is first passed through the armature conductors to cause the circular lines and then passed through the field winding to set up the "straight" lines.

Motors of this type are called "Series-wound" or "Series" motors because the armature conductors are in "series" with the field winding. The term "series" is used to describe an electrical current flow through two or more devices which are connected in such a manner that the current which flows through one device is forced to flow through the other. Because the current which flows through the armature conductors of the traction motor also flows through the field winding, the motor is called a series motor.

Series motors are universally used in diesel-electric locomotives because they develop a very strong starting torque or twisting effort. This strong torque is, of course, necessary because of the heavy tonnage trains which must be started by the locomotive. The passing of heavy current through the armature conductors and field windings of the series motor, develops strong magnetic fields which push apart with such force that high starting torque (high starting tractive effort) is developed. One of the most desirable characteristics of the diesel-electric locomotive is its ability to start heavy tonnages. This characteristic results from the use of the series traction motor.

REVERSING THE MOTOR

The preceding diagram illustrates a motor armature which is traveling in a counter-clockwise direction. The traction motors of the diesel-electric locomotive must, of course, operate in the reverse direction whenever it is desired to back up.

The series motor can be easily reversed by reversing the direction in which current is flowing through its field winding. The diagram below shows the action which takes place when this is done.

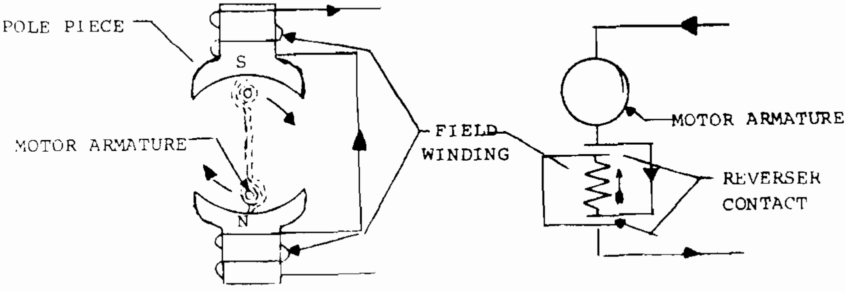


FIGURE 12

Note that the magnetic lines are bent around the conductors in such a manner to cause clockwise rotation of the conductors. This has been accomplished by reversing the current flow through the field winding. By use of the right hand rule, note that the bottom pole is now a north pole and the top pole is now a south pole. The magnetic lines are now traveling from bottom to top instead of top to Bottom. However, because the direction of current flow through the armature conductors is the same, the circular magnetic lines still travel clockwise around the top conductor and counter-clockwise around the bottom one. In this case the circular lines force the "straight" lines to bend around the opposite sides of the conductors. This causes the two magnetic lines to push the conductor clockwise instead of counter-clockwise and the armature, of course, is turning in the reverse direction.

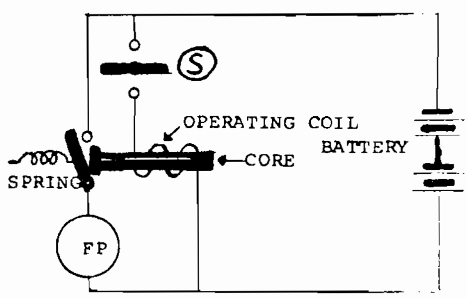
On the locomotive, the engineman accomplishes this by pulling his reverser handle to "reverse" position, and then pulling the throttle from "idle" to notch 1. This causes the reversing switch to throw to reverse position. The reversing switch contacts then route current through the motor fields in reverse direction and the traction motors change their direction of rotation.

The voltage of the generator can push current to the traction motors whenever the circuit between generator and motors is complete. A complete circuit includes a power contactor.

A power contactor is a remotely controlled switch. When the engineman desires to move his locomotive, he operates controlling levers which automatically cause power contactors to close to pass current from the generator to the traction motors. It is necessary that the contactor be remotely controlled, because of the fact that several locomotive units, each incorporating its own diesel engine, main generator and traction motors, may have to be operated from one throttle stand. Obviously, the engineman could not walk through the various units, manually closing the power contactors of each unit. Instead of this, the contactors must all be controlled from his position in the leading unit.

The figure below illustrates the remote control circuit which operates a contactor. When it is desired to run the fuel pump motor, the switch "S" is closed to allow battery current to flow through the operating coil of the contactor. This flow of current magnetizes the core and the latter then pulls the contact to closed position to permit current to reach the fuel pump motor. This power contactor is called a magnetic contactor.

FIGURE 13



Magnetic contactors are used in the fuel pump motor circuit, generator field circuits, and other small motor circuits. However, if the contactor is to be used in a traction motor circuit, it will be called upon to pass very heavy currents and it is important that the contactor contacts are pressed together very tightly. For this reason, pneumatic contactors are used.

The pneumatic contactor makes use of a solenoid and an air valve. When the engineer pulls his throttle from "Idle" to notch 1 the throttle closes a small contact which supplies voltage and current to a solenoid. When current flows through the solenoid coil, it moves the solenoid core by magnetic attraction and the moving core opens an air valve. The air valve admits control air pressure to the contactor's air cylinder where the air causes a piston to push the main contacts together. Proper control air pressure ensures that the contacts will be pressed together tightly.

The solenoid and air valve are usually mounted in the same assembly. The assembly is called a "magnet valve".

When low current circuits must be controlled remotely, a relay is used. A relay operates in the same manner as a magnetic contactor. However, its contacts are much lighter in construction than those of the magnetic contactor. This is true because the relay contacts rarely have to pass more than a very few amperes and therefore need not be heavily constructed.

ELECTRICAL CIRCUITS

The locomotive's circuits may be classified in two types:

1. Power circuit
2. Control circuit

The power circuit includes only the main generator, traction motors and the contactors and cables which connect them together. Dynamic braking resistors are included in the power circuit of those locomotives which are equipped with dynamic braking equipment.

The control circuits include lighting circuits, excitation system, battery charging circuit, governor control circuits, relay and contactor coil circuits and small motor circuits.

Power circuits may operate over a range from 0 to 900 volts and may have several thousand amperes of current flow. Control circuits operate on low voltage and the current in any one circuit is usually a few amperes or less.

All electrical circuits include three major components:

1. Source of supply (Battery or Generator)
2. Device which is operated by current from the source of supply (motor, lamp bulb, contactor coil, relay coil, etc.)
3. Wire or cable to carry the current from the source of supply to the device which is to be operated, and a similar cable to carry the current back to the source

All circuits function as "circulating systems". Current circulates through the system under pressure of the battery voltage or generator voltage.

AMMETERS

Ammeters may be compared to flow meters which are used to measure the flow of water. A flow meter is connected into a pipe line in such a way that the water flows through the meter and indicates how many gallons per minute of water are flowing through the meter. The ammeter may be connected in a circuit so that the circuit current is forced to flow through the meter. The meter needle then indicates how many amperes of current are flowing. Figure A below illustrates the use of such a meter. If it is desired to measure current flow in a high current circuit, it would be possible to use a meter of this type, but because of the heavy current which would flow through the meter, it would have to be large and cumbersome. Instead of a direct reading ammeter, a small meter is used in conjunction with a "shunt". Figure B illustrates such a meter hook-up. Assume that 1000 amperes are flowing from the generator to the motor. The current flows from the generator to the shunt and there divides, part of the current flowing around and part through the meter. However, the resistance of the meter is much higher than the resistance of the shunt. For this reason about 999.9 amperes will flow through the shunt and only .1 ampere (100 milliamperes) will flow through the meter. Because a certain definite percentage of the total current will flow through the meter, the latter can be used to determine how much current is flowing in the circuit. In this case, when .1 ampere flowed through the meter we would know that 1000 amperes were flowing through the circuit.

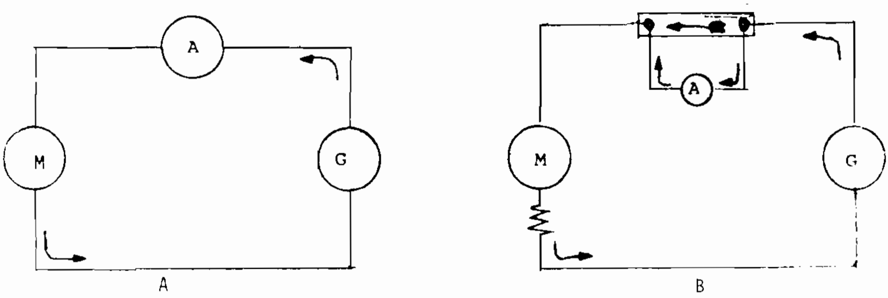


FIGURE 14

TRANSITION

When the engineman is ready to move his train, he places the reverser handle in either the forward or reverse position, the selector handle in Position1 and then pulls the throttle from "idle" to notch 1. This movement of the levers causes two of the power circuit's pneumatic contactors, S-1 and S-21, to close. They allow current from the main generator to flow through the traction motors. These contactors connect the traction motors in a series-parallel circuit. This allows half the generator current to reach each motor. The figure below shows how this circuit would be drawn on a schematic wiring diagram.

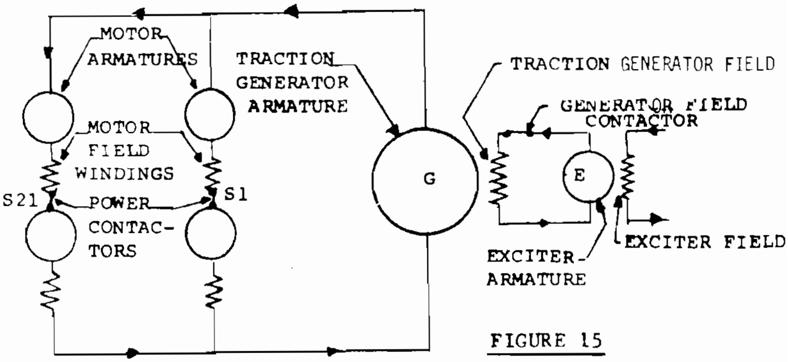


FIGURE 15

With the throttle in notch 1, the diesel engine is rotating the generator armature at idle speed. It is also rotating the armature of the exciter through a gear train or belt drive.

The exciter is thus supplying field current to the field winding of the main generator through the generator field contactor "GF" which also closed when the throttle was put in notch 1.

With its armature rotating at idle speed the main generator is supplying about 600 amperes to the power circuit. Half of this current, 300 amps, reaches each motor. This amount of current will be enough to move the locomotive and perhaps take some slack, but if the train has more than a few cars, 300 amps per motor will not be enough to move out the train. The engineman then moves the throttle to 2nd notch. This speeds up the diesel engine and generator armature. It also increases the exciter armature speed and this increases the field current. The result of more field current and faster armature rotation is increased generator voltage and the current flow is built up to 1100 amps (550 amps per motor). The motors now try to "twist" harder.

After pulling out all slack, the engineman continues to advance the throttle until enough current flows through the traction motors to enable them to move the train. He advances the throttle rapidly enough to get his train moving in the shortest possible time, but no so fast that he will cause wheel slippage. In the event that the wheels slip, he "notches down" (reduces throttle) at least one notch until the wheel slippage stops and then immediately "notches up" again.

BACK VOLTAGE

Just as soon as the motor armatures begin turning, the train, of course, begins to move, but the motors begin to act as generators. That is, they begin to generate a voltage in their armature conductors, just as though they were generators. One of their magnetic fields, the one with the magnetic lines traveling from one field pole to the other field pole, is the same type of magnetic field as the one in the generator of Figures 7 and 9. Compare these two diagrams and note that in both cases, the magnetic lines leave one pole piece and travel across to the opposite pole piece. In Figures 7 and 9 the generator conductors have a voltage generated in them when they cut through magnetic lines. In Figures 11 and 12 the motor armature conductors cut through magnetic lines, also, and therefore they too must have a voltage generated in them.

As far as the generation of voltage is concerned, it makes no difference whether a diesel engine rotates an armature, whether the armature rotates itself, whether it is rotated by hand cranking or whether it is rotated by any other method, voltage will be generated in armature conductors when they cut through magnetic lines.

The voltage which is generated by the traction motors is called "back voltage" or "counter voltage", because it "pumps back" against the generator voltage. In other words, it works to push current to the motors but the back voltage, in "pumping back" against the generator, opposes the flow of current. Naturally, the stronger the back voltage becomes, the more it will oppose the flow of current from the generator.

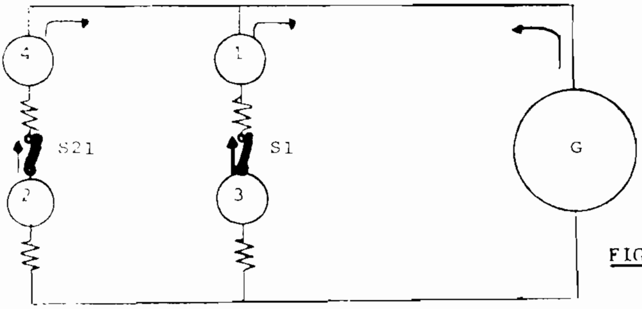


FIGURE 16

Arrows indicate direction in which voltages are pushing. They do not indicate current flow.

When the locomotive first begins to move, the motor armatures are turning very slowly. The motor armature conductors, because of their slow speed, do not cut through enough magnetic lines to produce a very strong back voltage. But, as the motor armatures rotate faster and faster in speeding up the locomotive, the armature conductors cut more and more magnetic lines. Thus, the back voltage increases as the armatures go faster. This increasing of back voltage causes the flow of current from the generator to weaken gradually as the locomotive speeds up. The engineman, by watching the loadmeter (ammeter) can see the current flow to his motors becoming weaker as his locomotive speed increases.

Despite the fact that the current flow weakens, the locomotive will continue to accelerate for a time. However, when a speed of about 18 miles per hour is reached, the back voltage will have become so strong that it will have weakened the current flow, and the locomotive will no longer be able to continue speeding up. Unless something is done to weaken the back voltage, further acceleration would be impossible.

The engineman must move the selector handle from Position 1 to Position 2 at 18 miles per hour. This may be done with the throttle in any position. It is not necessary to make any throttle adjustment as the selector handle may be moved regardless of throttle position.

Movement of the selector handle to Position 2 causes four more contactors (M1, M2, M3, M4) to close. These contactors allow a part of the motor field current to be "shunted" or passed around the motor field winding, as shown below. With less current now going through the field winding (weaker motor field current), fewer magnetic lines will be produced. With fewer lines to cut through, the back voltage in the motor armature conductors will be weakened. The flow of current from the generator to the traction motors will then increase because the weaker back voltage can no longer oppose the current flow as strongly as it formerly did. This action is usually referred to as "shunting the motor fields".

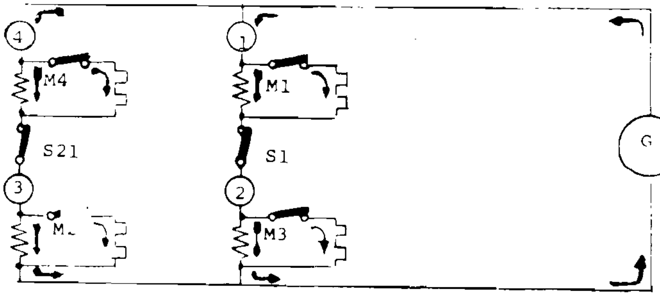


FIGURE 17

Arrows indicate current flow. Note how part of current bypasses the motor fields.

The stronger current flow from generator to motors, now causes the motors to continue speeding up and the locomotive moves faster.

However, as the motor armatures speed up, they continue to cut through the magnetic lines. It is true that the lines are fewer in number than before the fields were shunted, but as the armature speed rises, the conductors cut through these fewer lines at an ever increasing speed. So, the back voltage begins to creep up again. By the time the locomotive reaches a speed of 24 miles per hour, the back voltage will have again increased enough to have weakened the current flow.

When this condition existed at 18 miles per hour, the back voltage was reduced by shunting the motor fields. It is not practical to reduce it again by that method. There is a better method.

With the traction motors connected to the generator in series-parallel, note that motors 1 and 3 are combining their back voltages. The back voltage of number 3 motor is added to the back voltage of number 1 motor. The same is true of motors 4 and 2. Their back voltages are also added together. The back voltage will now be reduced by reconnecting these motors to the generator in such a manner that no motor will be able to add its back voltage to that of another motor. If the back voltages are not added together, as they are in series-parallel, the generator current flow of the motors will increase.

At 24 miles per hour, the engineman moves the selector handle to Position 3. This action reconnects the generator and traction motors with a parallel motor connection. The "S" and "M" contactors are dropped out to break the series-parallel connection and 4 new contactors, P1, P2, P21, P22, are closed to make the new parallel connection. Note that no two motors can combine their back voltages. The back voltage which is working against the generator current flow is therefore weakened considerably, with the result that the current flow from generator to motors increases immediately upon the closing of the parallel motor contactors.

The stronger current now allows the motors to increase their speed and accelerate the locomotive.

Although back voltage has again been weakened, it still exists and as the motor armatures turn faster, it again builds up. At about 49 MPH the armatures are turning so fast that each individual motor is exerting a back voltage which is as strong as the combined back voltages of two motors were at 18 and 24 MPH. Again the current flow to the motors will now be weakened enough to prevent further locomotive acceleration.

To weaken the back voltage for the final time, the engineman moves the selector handle to position 4. This action closes the same M1, M2, M3, M4 contactors which closed when the handle was moved to position 2 at 18 MPH and with the same result. The traction motor fields are shunted to reduce the field current. Back voltage then weakens and generator current flow again strengthens to accelerate the locomotive further.

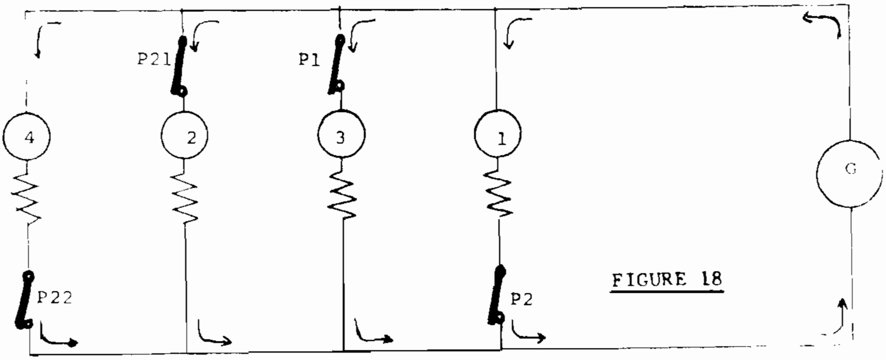


FIGURE 18

At about 65 MPH, the back voltage will have again weakened current flow enough to stop further acceleration, but nothing is done to stop this action because the locomotive is at its maximum rated speed and any further acceleration would rotate the traction motor armatures so fast that centrifugal force might cause the armature banding wire to loosen.

The engineman in operating the selector handle at certain locomotive speeds merely acts to lower the back voltage which is developed in the traction motor armatures. The speeds at which he moves the handle to a higher position are speeds at which the back voltage has become so strong that it weakens the current flow to the motors enough to prevent the motors from further accelerating the locomotive.

All passenger locomotives and some freight locomotives are equipped with "automatic transition" equipment. On these locomotives the engineman does not have to move the selector handle at certain locomotive speeds. Instead, he places the selector handle in position 1 to start, and a small generator which is driven by one of the locomotive's driving axles automatically causes the contactors to connect the motors with the necessary connections at the proper locomotive speeds.

DIESEL-ELECTRIC FUNDAMENTALS

1. The purpose of the main generator in a Diesel-Electric locomotive is to convert the mechanical horsepower developed in the Diesel engine into electrical power.

2. The generator cannot put out more power than the engine is developing.

3. The generator and traction motors are just an electrical transmission of the power that the Diesel is developing in its cylinders by burning fuel oil.

4. The horsepower output of the Diesel engine and generator is controlled, and held to a fixed amount for each throttle position, by the action of the governor and load regulator.

5. The power output of the engine and generator increases as the throttle is advanced, because more fuel is being injected into the cylinders.

6. This power is measured in watts, which is the product of the voltage (pressure) x amperage (current) of the generator. For example, 150 volts x 100 amperes = 15,000 watts.

7. The traction motors divide this power equally; if there are four motors attached to a generator, each motor gets one quarter of the power coming from the generator.

8. This is true whether the motors are in series or parallel.

9. The motors will draw a heavy current (amperage) when starting a train, or while running at slow speed.

10. To keep from overheating the generator by drawing too much amperage from it when starting a train, the motors are "hooked up" in series.

11. When motors are in series, the current from the generator flows through one after the other - the same current flows through all.

12. This can be compared to a compound steam engine where the steam is used over again in succession in the various cylinders.

13. The current, or amperage, produces a powerful turning force, or torque, in the motors. This will start the wheels turning.

14. All motors develop back pressure (counter EMF) as their speed increases. Because the motors are in series, their combined back pressures buck the generator pressure, limiting the amount of current that can flow into the motors.

15. Unless transition from series to parallel is made, the developed horsepower of the engine and generator will begin to drop off. This is due to the generator's having a limited pressure capacity, and if transition is not made the locomotive will not be able to take a train up to its rated speed.

16. The motors are then "hooked up" in parallel by moving the engineer's transition lever.

17. This allows the full generator pressure to be put upon each motor individually. This continues to force current into the motors, causing the train to increase speed.

18. But when motors are in parallel, each motor has a direct source of current from the generator, and if the train speed should decrease due to a grade it is possible to overload the generator.

19. When the speed of the train decreases due to a grade the motors are put back in series.