DC Series Motors

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Series Motor Diagram

The series motor provides high starting torque and is able to move very large shaft loads when it is first energized. Figure 12-10 shows the wiring diagram of a series motor. From the diagram you can see that the field winding in this motor is wired in series with the armature winding. This is the attribute that gives the series motor its name.

Since the series field winding is connected in series with the armature, it will carry the same amount of current that passes through the armature. For this reason the field is made from heavy-gauge wire that is large enough to carry the load. Since the wire gauge is so large, the winding will have only a few turns of wire. In some larger DC motors, the field winding is made from copper bar stock rather than the conventional round wire used for power distribution. The square or rectangular shape of the copper bar stock makes it fit more easily around the field pole pieces. It can also radiate more easily the heat that has built up in the winding due to the large amount of current being carried.

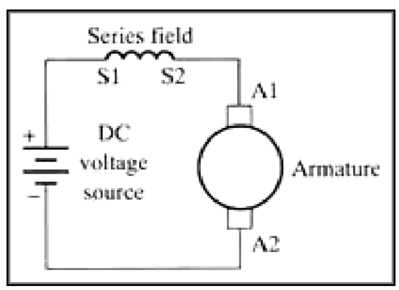

FIGURE 12-10 Electrical diagram of series motor. Notice that the series field is identified as S1 and S2.

The amount of current that passes through the winding determines the amount of torque the motor shaft can produce. Since the series field is made of large conductors, it can carry large amounts of current and produce large torques. For example, the starter motor that is used to start an automobile's engine is a series motor and it may draw up to 500 A when it is turning the engine's crankshaft on a cold morning. Series motors used to power hoists or cranes may draw currents of thousands of amperes during operation.

The series motor can safely handle large currents since the motor does not operate for an extended period. In most applications the motor will operate for only a few seconds while this large current is present. Think about how long the starter motor on the automobile must operate to get the engine to start. This period is similar to that of industrial series motors.

Series Motor Operation

Operation of the series motor is easy to understand. In Fig. 12-10 you can see that the field winding is connected in series with the armature winding. This means that power will be applied to one end of the series field winding and to one end of the armature winding (connected at the brush).

When voltage is applied, current begins to flow from negative power supply terminals through the series winding and armature winding. The armature is not rotating when voltage is first applied, and the only resistance in this circuit will be provided by the large conductors used in the armature and field windings. Since these conductors are so large, they will have a small amount of resistance. This causes the motor to draw a large amount of current from the power supply. When the large current begins to flow through the field and armature windings, it causes a strong magnetic field to be built. Since the current is so large, it will cause the coils to reach saturation, which will produce the strongest magnetic field possible.

Producing Back EMF

The strength of these magnetic fields provides the armature shafts with the greatest amount of torque possible. The large torque causes the armature to begin to spin with the maximum amount of power. When the armature begins to rotate, it begins to produce voltage. This concept is difficult for some students to understand since the armature is part of the motor at this time.

You should remember from the basic theories of magnetism that anytime a magnetic field passes a coil of wire, a current will be produced. The stronger the magnetic field is or the faster the coil passes the flux lines, the more current will be generated. When the armature begins to rotate, it will produce a voltage that is of opposite polarity to that of the power supply. This voltage is called *back voltage, back EMF* (electromotive force), or *counter EMF.* The overall effect of this voltage is that it will be subtracted from the supply voltage so that the motor windings will see a smaller voltage potential.

When Ohm's law is applied to this circuit, you will see that when the voltage is slightly reduced, the current will also be reduced slightly. This means that the series motor will see less current as its speed is increased. The reduced current will mean that the motor will continue to lose torque as the motor speed increases. Since the load is moving when the armature begins to pick up speed, the application will require less torque to keep the load moving. This works to the motor's advantage by automatically reducing the motor current as soon as the load begins to move. It also allows the motor to operate with less heat buildup.

This condition can cause problems if the series motor ever loses its load. The load could be lost when a shaft breaks or if a drive pin is sheared. When this occurs, the load current is allowed to fall to a minimum, which reduces the amount of back EMF that the armature is producing. Since the armature is not producing a sufficient amount of back EMF and the load is no longer causing a drag on the shaft, the armature will begin to rotate faster and faster. It will continue to increase rotational speed until it is operating at a very high speed. When the armature is operating at high speed, the heavy armature windings will be pulled out of their slots by centrifugal force. When the windings are pulled loose, they will catch on a field winding pole piece and the motor will be severely damaged. This condition is called *runaway* and you can see why a DC series motor must have some type of runaway protection. A centrifugal switch can be connected to the motor to de-energize the motor starter coil if the rpm exceeds the set amount. Other sensors can be used to de-energize the circuit if the motor's current drops while full voltage is applied to the motor. The most important part to remember about a series motor is that it is difficult to control its speed by external means because its rpm is determined by the size of its load. (In some smaller series motors, the speed can be controlled by placing a rheostat in series with the supply voltage to provide some amount of change in resistance to control the voltage to the motor.)

Figure 12-11 shows the relationship between series motor speed and armature current. From this curve you can see that when current is low (at the top left), the motor speed is maximum, and when current increases, the motor speed slows down (bottom right). You can also see from this curve that a DC motor will run away if the load current is reduced to zero. (It should be noted that in larger series machines used in industry, the amount of friction losses will limit the highest speed somewhat.)

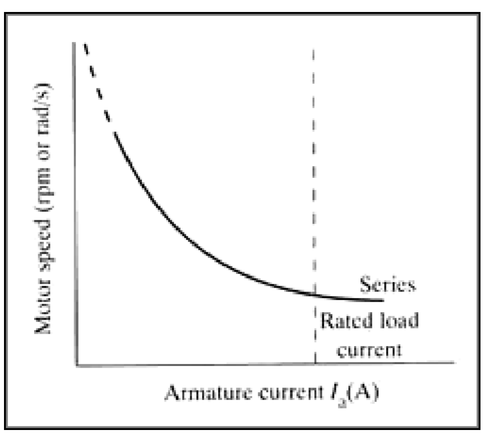

FIGURE 12-11 The relationship between series motor speed and the armature current.

Reversing the Rotation

The direction of rotation of a series motor can be changed by changing the polarity of either the armature or field winding. It is important to remember that if you simply changed the polarity of the applied voltage, you would be changing the polarity of both field and armature windings and the motor's rotation would remain the same.

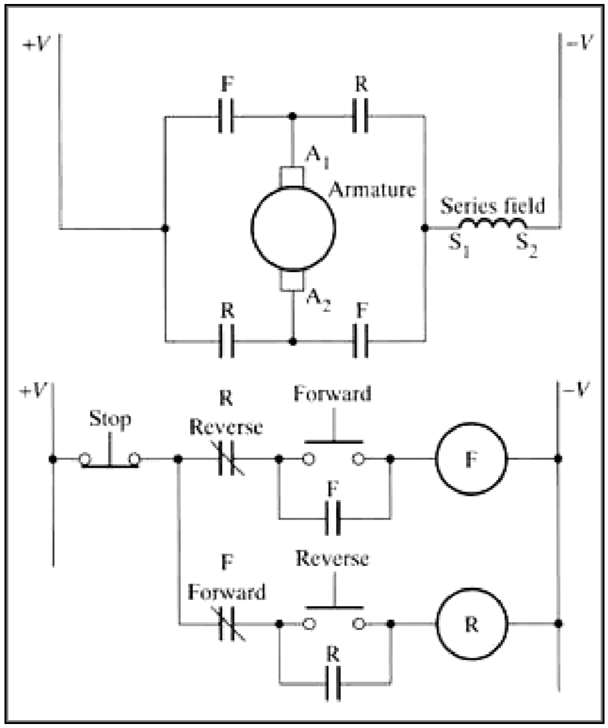

FIGURE 12-12 DC series motor connected to forward and reverse motor starter.

Since only one of the windings needs to be reversed, the armature winding is typically used because its terminals are readily accessible at the brush rigging. Remember that the armature receives its current through the brushes, so that if their polarity is changed, the armature's polarity will also be changed. A reversing motor starter is used to change wiring to cause the direction of the motor's rotation to change by changing the polarity of the armature windings. Figure 12-12 shows a DC series motor that is connected to a re-versing motor starter. In this diagram the armature's terminals are marked Al and A2 and the field terminals are marked Sl and S2.

When the forward motor starter is energized, the top contact identified as F closes so the Al terminal is connected to the positive terminal of the power supply and the bottom F contact closes and connects terminals A2 and Sl. Terminal S2 is connected to the negative terminal of the power supply. When the reverse motor starter is energized, terminals Al and A2 are reversed. A2 is now connected to the positive terminal. Notice that S2 remains connected to the negative terminal of the power supply terminal. This ensures that only the armature's polarity has been changed and the motor will begin to rotate in the opposite direction.

You will also notice the normally closed (NC) set of R contacts connected in series with the forward push button, and the NC set of F contacts connected in series with the reverse push button. These contacts provide an *interlock* that prevents the motor from being changed from forward to reverse direction without stopping the motor. The circuit can be explained as follows: when the forward push button is depressed, current will flow from the stop push button through the NC R interlock contacts, and through the forward push button to the forward motor starter (FMS) coil. When the FMS coil is energized, it will open its NC contacts that are connected in series with the reverse push button. This means that if someone depresses the reverse push button, current could not flow to the reverse motor starter (RMS) coil. If the person depressing the push buttons wants to reverse the direction of the rotation of the motor, he or she will need to depress the stop push button first to de-energize the FMS coil, which will allow the NC F contacts to return to their NC position. You can see that when the RMS coil is energized, its NC R contacts that are connected in series with the forward push button will open and prevent the current flow to the FMS coil if the forward push button is depressed. You will see a number of other ways to control the FMS and RMS starter in later discussions and in the chapter on motor controls.

Installing and Troubleshooting

Since a series motor has only two leads brought out of the motor for installation wiring, this wiring can be accomplished rather easily. If the motor is wired to operate in only one direction, the motor terminals can be connected to a manual or magnetic starter. If the motor's rotation is required to be reversed periodically, it should be connected to a reversing starter.

Most DC series motors are used in direct-drive applications. This means that the load is connected directly to the armature's shaft. This type of load is generally used to get the most torque converted. Belt-drive applications are not recommended since a broken belt would allow the motor to run away. After the motor has been installed, a test run should be used to check it out. If any problems occur, the troubleshooting procedures should be used.

The most likely problem that will occur with the series motor is that it will develop an open in one of its windings or between the brushes and the commutator. Since the coils in a series motor are connected in series, each coil must be functioning properly or the motor will not draw any current. When this occurs, the motor cannot build a magnetic field and the armature will not turn. Another problem that is likely to occur with the motor circuit is that circuit voltage will be lost due to a blown fuse or circuit breaker. The motor will respond similarly in both of these conditions.

The best way to test a series motor is with a voltmeter. The first test should be for applied voltage at the motor terminals. Since the motor terminals are usually connected to a motor starter, the test leads can be placed on these terminals. If the meter shows that full voltage is applied, the problem will be in the motor. If it shows that no voltage is present, you should test the supply voltage and the control circuit to ensure that the motor starter is closed. If the motor starter has a visual indicator, be sure to check to see that the starter's contacts are closed. If the overloads have tripped, you can assume that they have sensed a problem with the motor or its load. When you reset the overloads, the motor will probably start again but remember to test the motor thoroughly for problems that would cause an overcurrent situation.

If the voltage test indicates that the motor has full applied voltage to its terminals but the motor is not operating, you can assume that you have an open in one of the windings or between the brushes and the armature and continue testing. Each of these sections should be disconnected from each other and voltage should be removed so that they can be tested with an ohmmeter for an open. The series field coils can be tested by putting the ohmmeter leads on terminals Sl and S2. If the meter indicates that an open exists, the motor will need to be removed and sent to be rewound or replaced. If the meter indicates that the field coil has continuity, you should continue the procedure by testing the armature.

The armature can also be tested with an ohmmeter by placing the leads on the terminals marked Al and A2. If the meter shows continuity, rotate the armature shaft slightly to look for bad spots where the commutator may have an open or the brushes may not be seated properly. If the armature test indicates that an open exists, you should continue the test by visually inspecting the brushes and commutator. You may also have an open in the armature coils. The armature must be removed from the motor frame to be tested further. When you have located the problem, you should remember that the commutator can be removed from the motor while the motor remains in place and it can be turned down on a lathe. When the commutator is replaced in the motor, new brushes can be installed and the motor will be ready for use.

It is possible that the motor will develop a problem but still run. This type of problem usually involves the motor overheating or not being able to pull its rated load. This type of problem is different from an open circuit because the motor is drawing current and trying to run. Since the motor is drawing current, you must assume that there is not an open circuit. It is still possible to have brush problems that would require the brushes to be re-seated or replaced. Other conditions that will cause the motor to overheat include loose or damaged field and armature coils. The motor will also overheat if the armature shaft bearing is in need of lubrication or is damaged. The bearing will seize on the shaft and cause the motor to build up friction and overheat.

If either of these conditions occurs, the motor may be fixed on site or be removed for extensive repairs. When the motor is restarted after repairs have been made, it is important to monitor the current usage and heat buildup. Remember that the motor will draw DC current so that an AC clamp-on ammeter will not be useful for measuring the DC current. You will need to use an ammeter that is specially designed for very large DC currents. It is also important to remember that the motor can draw very high locked-rotor current when it is starting, so the ammeter should be capable of measuring currents up to 1000 A. After the motor has completed its test run successfully, it can be put back into operation for normal duty. Anytime the motor is suspected of faulty operation, the troubleshooting procedure should be rechecked.

DC Series Motor Used as a Universal Motor

The series motor is used in a wide variety of power tools such as electric hand drills, saws, and power screwdrivers. In most of these cases, the power source for the motor is AC voltage. The DC series motor will operate on AC voltage. If the motor is used in a hand drill that needs variable-speed control, a field rheostat or other type of current control is used to control the speed of the motor. In some newer tools, the current control uses solid-state components to control the speed of the motor. You will notice that the motors used for these types of power tools have brushes and a commutator, and these are the main parts of the motor to wear out. You can use the same theory of operation provided for the DC motor to troubleshoot these types of motors.

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