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Technical Update 33

Solenoid Operation & Theory

WITH THE RECENT RELEASE of our buyer's guide for solenoids and solenoid parts, we thought it would be helpful to provide some basic background on how solenoids operate.

Basic Types of Solenoids

There are two basic types of solenoids: those that are simply a relay and those that also operate a shift lever for the drive in addition to serving as a relay.

The solenoids that are simply a relay are used on Delco, Lucas and Prestolite starters with inertia-type drives as well as pre-PMGR Ford starters. This type of solenoid is used only to electrically connect the battery to the starter. It is sealed and cannot be rebuilt. It has no mechanical connection that engages the drive with the engine flywheel.

In this update, we will be talking only about the other type of solenoid — the type that operates a shift lever. These solenoids are used on Delco, Chrysler, Ford PMGR and most import starters. They have two windings: a pull-in and a hold-in winding (*Figure 1*).

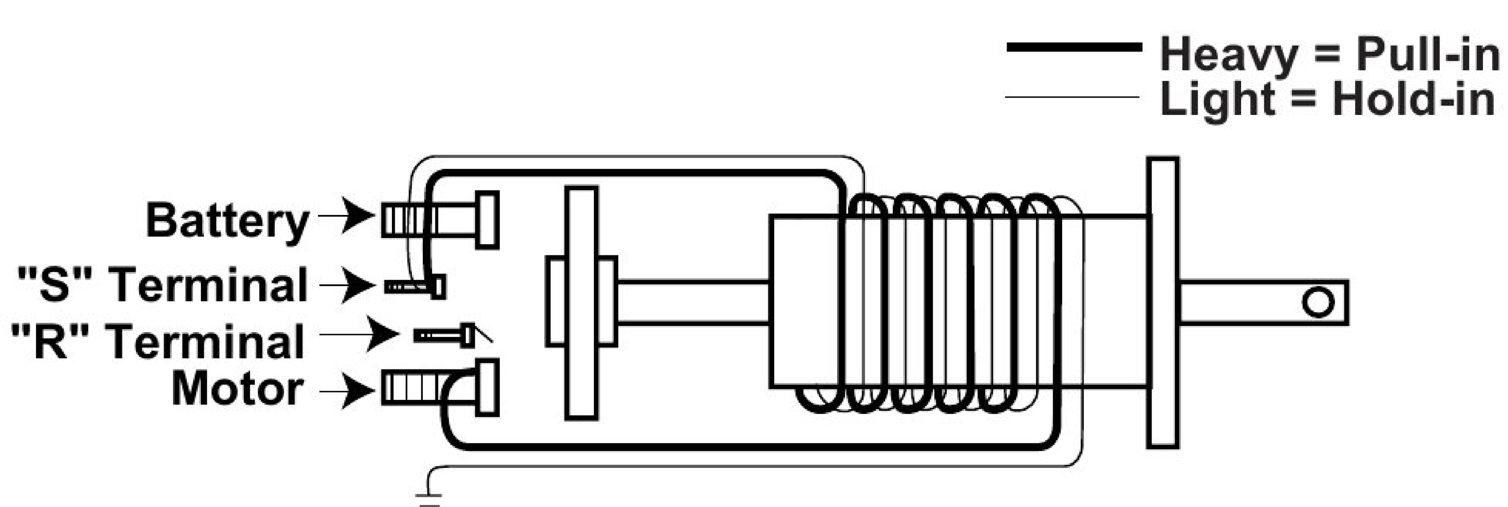

Figure 1. The pull-in winding is heavier gauge wire than the hold-in winding.

Pull-in winding: Heavy-gauge wire with the same number of turns and wound in the same direction as the hold-in winding. This winding, along with the hold-in winding, pulls the plunger in and engages the starter drive with the flywheel.

Hold-in winding: Light-gauge wire with the same number of turns and wound in the same direction as the pull-in winding. This winding holds the plunger in while the starter motor is cranking, which allows the movable contact to hold the connection between the battery and the motor terminal. As long as this connection is held, the pull-in winding has battery-positive at both ends. This stops current flow in the pull-in winding, which causes its magnetic strength to drop off completely.

How Solenoids Operate

Engagement

To engage the solenoid, current passes from the ignition switch to the S-terminal on the solenoid, through the pull-in winding to the motor terminal. From there the current travels to the motor lead, through the field coils to the insulated brushes, through the armature and finally through the ground brushes to ground, which turns the starter (*Figure 2*).

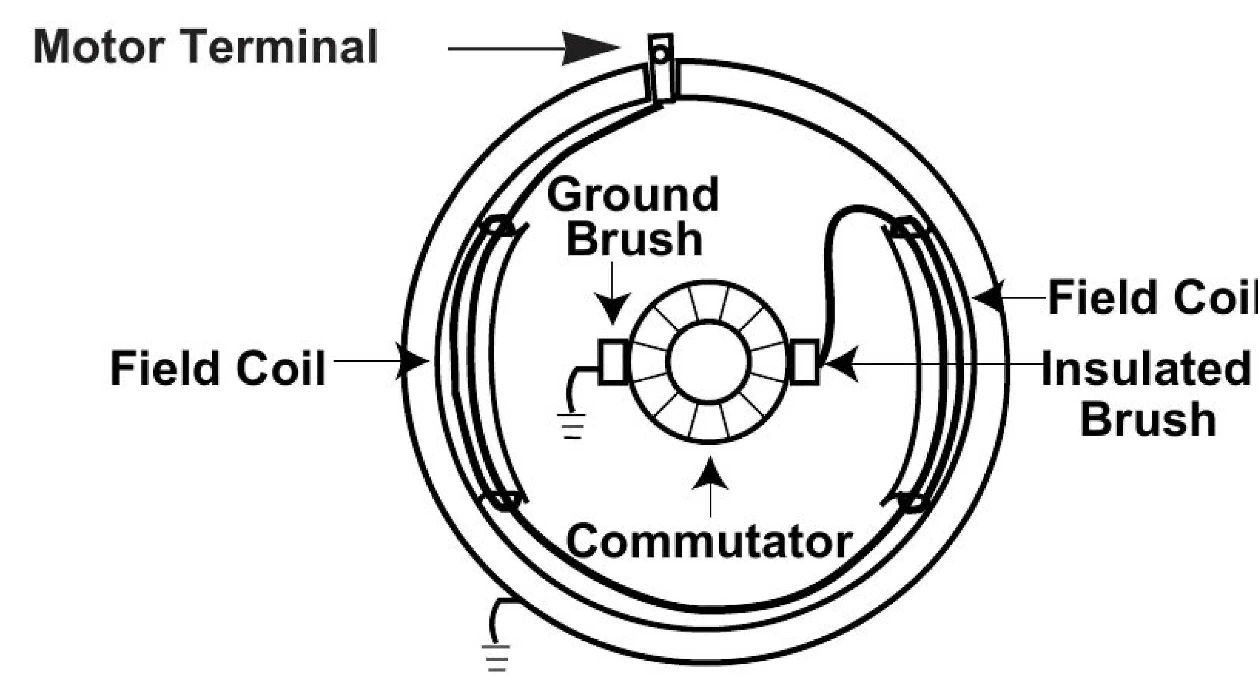

Figure 2. Current flow through the starter motor.

Simultaneously, current passes from the S-terminal through the hold-in winding to a ground that is generally inside the solenoid. Sometimes the ground is outside the solenoid, but usually it is inside (*Figures 1, 2 & 4*).

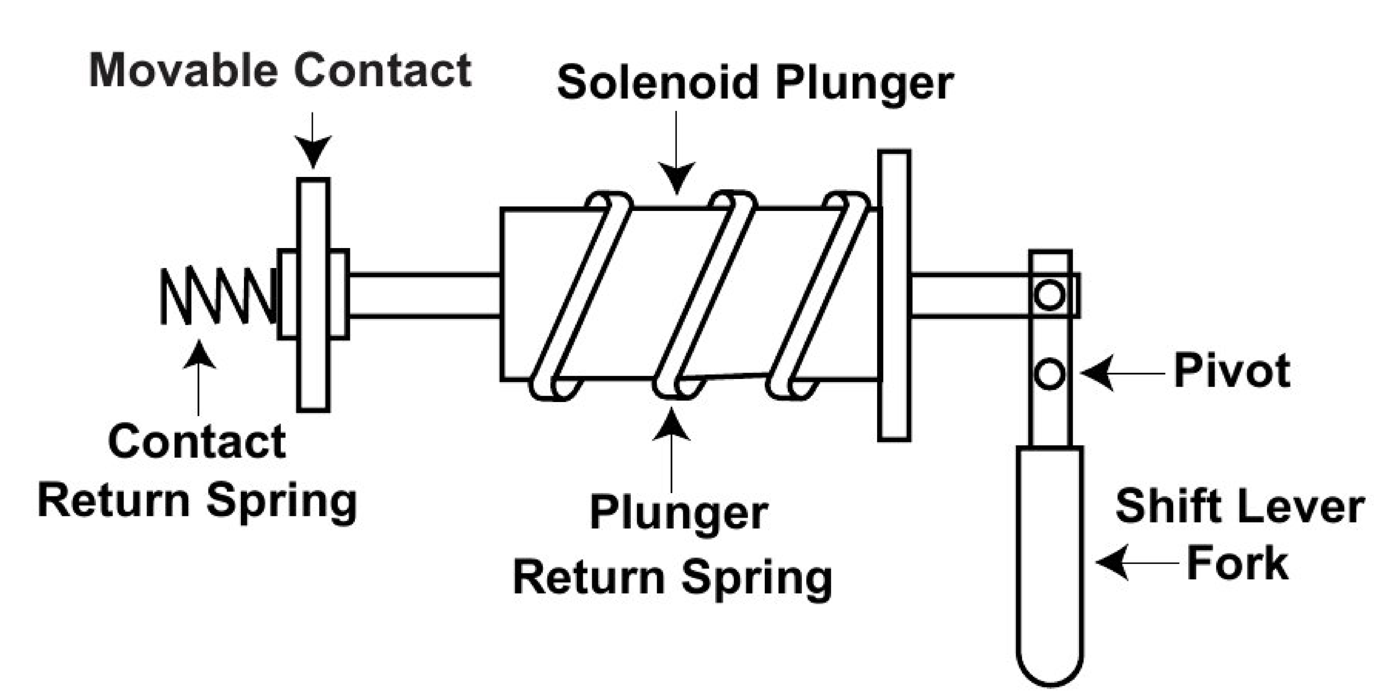

Figure 3. Major elements of solenoid operation

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These windings work together to create a very strong magnetic field that pulls in the plunger. The plunger is attached to a shift lever, which in turn moves the drive into engagement with the flywheel. As the drive is engaging the flywheel, the plunger continues to push the movable contact so it makes the connection between the battery and motor terminals. This causes the starter motor to turn and crank the engine (*Figure 3*).

If the solenoid has an active R-terminal, the movable contact closes this connection as well. In early ignition systems, the R-terminal serves as an output terminal that bypasses the ignition resistor. In later systems, it is used as a signal that the engine is in cranking mode.

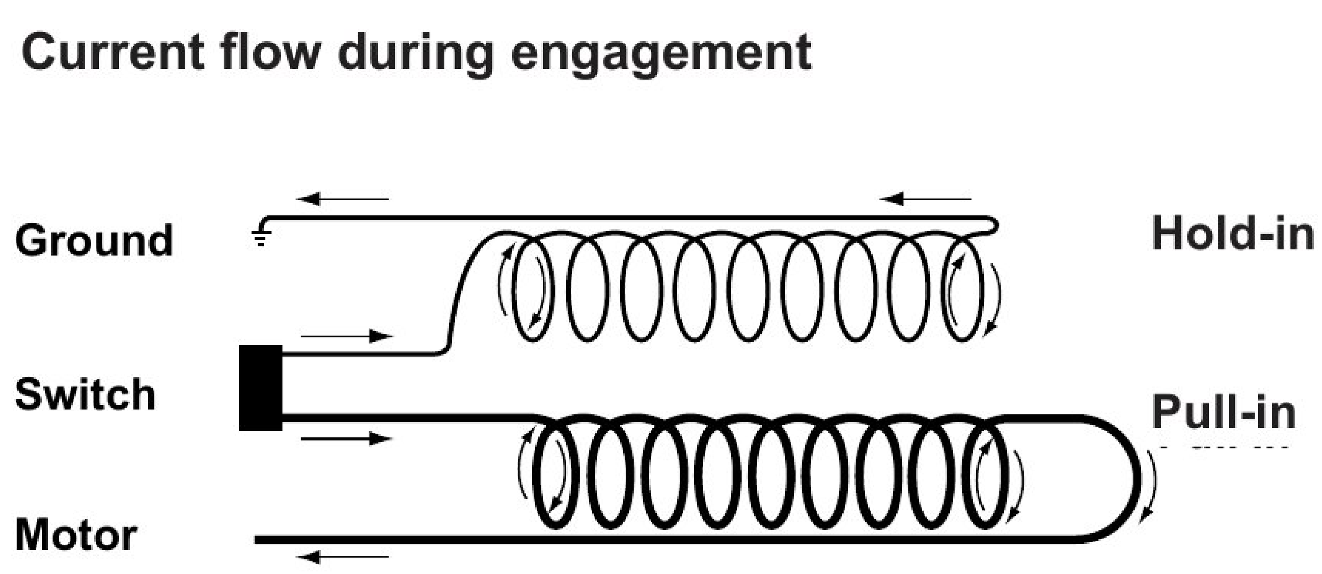

Figure 4. Current flow in pull-in and hold-in windings during solenoid engagement.

When the shift lever moves the drive toward engagement with the flywheel, the drive often does not engage, but hits the flywheel teeth head-on. When this happens, an indexing mechanism in the drive and/or shift lever allows the plunger to continue to move so it closes the solenoid contacts. This causes the starter motor to turn, which in turn allows the drive to become aligned properly for engagement with the flywheel.

There are three main kinds of indexing mechanisms: spring-and-collar type, spring-loaded-gear type and positorque type.

In a spring-and-collar type, the shift lever pushes on a collar, which pushes on a spring, which in turn pushes the drive toward engagement with the flywheel. If the teeth do not engage, the spring collapses, allowing the plunger to continue to move and close the solenoid contacts. Once the drive teeth are aligned with the flywheel teeth, the spring pushes the drive into engagement (*Figure 5*).

In the case of a spring-loaded-gear type of indexing mechanism, if the drive does not engage with the flywheel, the spring behind the gear collapses so the gear can move back on the drive shaft. This allows the contacts to close and the starter motor to turn. Once the teeth are

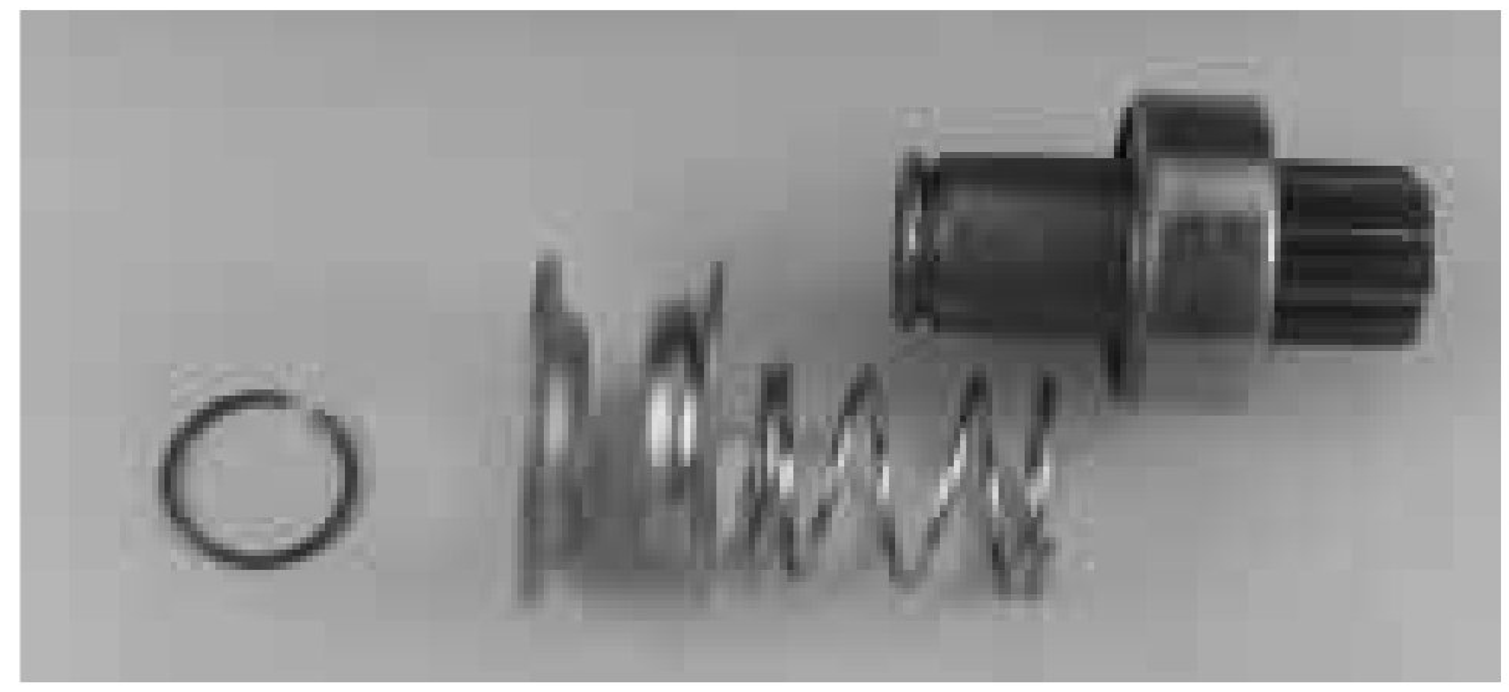

Figure 5. Spring-and-collar type indexing mechanism.

aligned, the spring engages the drive with the flywheel. With this type of mechanism it is very important that the drive moves freely along the splines of the shaft (*Figure 6*).

Positorque indexing mechanisms have a pinion that moves along a spiral set of splines inside the drive. The pinion turns as it is pushed into the drive body, which allows the teeth to align themselves. Once the teeth are aligned, the pinion moves back out and the drive continues to move on the armature until the drive teeth

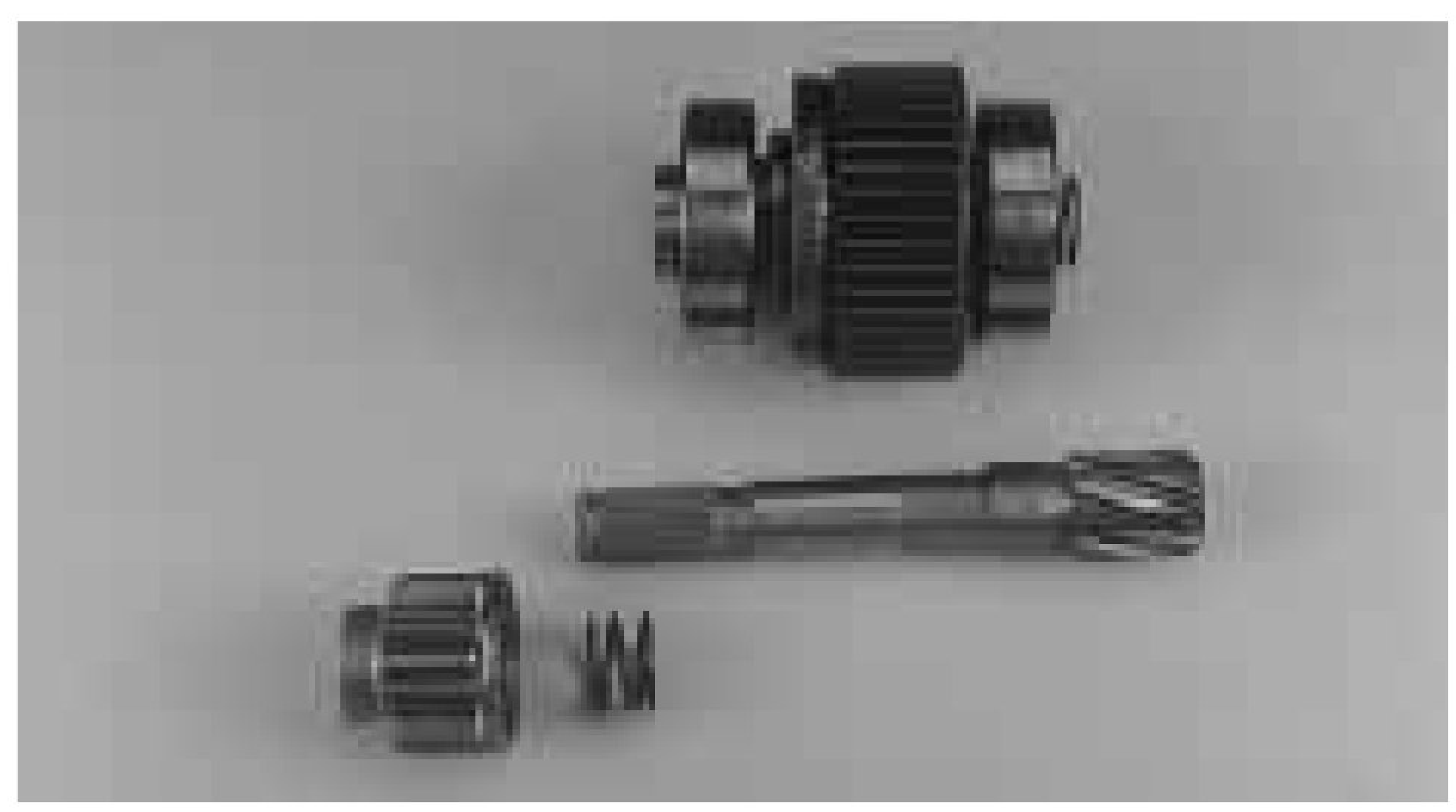

Figure 6. Spring-loaded gear type indexing mechanism.

become fully engaged with the flywheel. The plunger then closes the solenoid contacts and current flows to the starter motor.

The Lucas M50 has a unique method of indexing. This starter has a separate (4th) coil and a solenoid with an additional set of contacts that allow current to flow only in this 4th coil. This allows the armature to turn slowly and the drive to engage properly with the flywheel. After full engagement, the other contacts close and the starter cranks with its full power.

Disengagement

When the ignition switch is released, current stops flowing to the S-terminal, but until the movable contact breaks the circuit, current continues to flow from the battery terminal through the contact disk to the motor terminal, back through the pull-in winding to the S-terminal and through the hold-in winding to ground.

Note in *Figure 7* that current is flowing through the pull-in winding in the opposite direction from when the solenoid was in engagement mode. However, it continues to flow in the same direction in the hold-in winding. The coils are now in series.

Because the coils are now in series, the amperage flow in each coil will be the same. And because they have the same number of turns, their magnetic strength measured in ampere-turns is also the same (see below*). This means that the magnetic forces in the coils now cancel each other, which allows the plunger-return spring and/or movable-contact spring to break the circuit and return the plunger and drive to the stationary position. As the engine starts, the flywheel also assists in disengaging the drive.

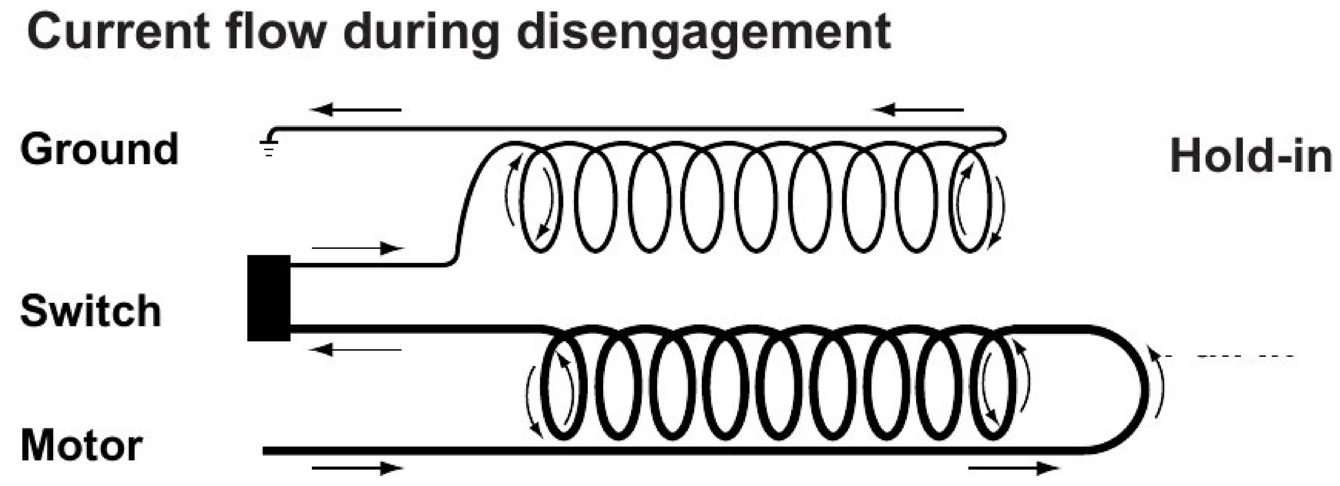

Figure 7. Current flow in pull-in and hold-in windings during solenoid disengagement.

**Ampere-turns is a measurement of the strength of an electromagnetic coil. It is equal to the number of turns in the coils multiplied by the number of amps flowing through the coil. For example:*

200 turns x 3 amps = 600 ampere-turn coil

100 turns x 6 amps = 600 ampere-turn coil

Testing Solenoids

To test solenoids you need a solenoid tester or another tester that is suitable for taking amperage-draw readings up to 50 amps.

Before you begin testing, please note that, because of relatively low resistance, the amperage will be fairly high during a test. This will cause the solenoid to heat up, so do not test for a long period of time or you may destroy the solenoid. Also, as solenoids heat up, resistance increases and current flow drops. Take this into account when you are comparing solenoid tests.

To test the amperage draw in the pull-in winding, connect the positive test lead to the S-terminal and the negative test lead to the motor terminal. Record your reading.

To test the amperage draw in the hold-in winding, connect the positive test lead to the S-terminal and the negative test lead to ground (the solenoid case). Record your reading.

To conduct a balance test, connect the positive test lead to the motor terminal and the negative test lead to ground (the solenoid case). During this test the plunger must be free to move, with no magnetic pull.

Note that certain Nippondenso starters have a shunt coil in the field case that is electrically connected in parallel to the hold-in winding of the solenoid (*Figure 8*). To conduct a balance test on this solenoid you must connect the shunt coil from the S-terminal to ground. Then connect the test leads as described in the preceding paragraph.

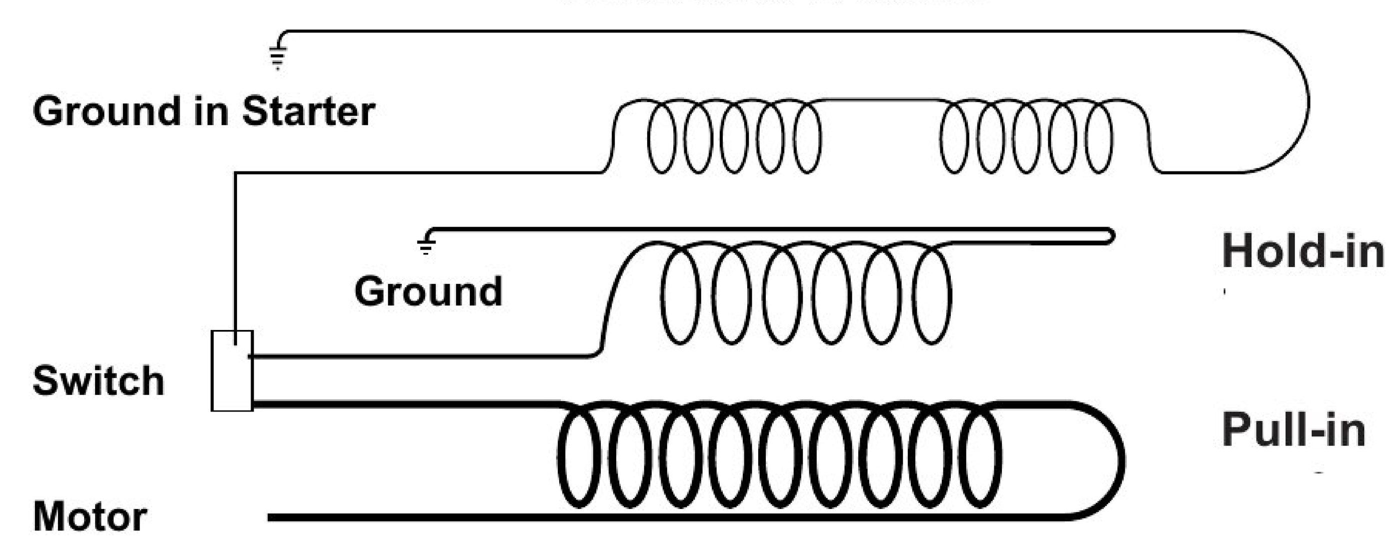

Figure 8. Some Nippondenso starters have a shunt coil in the field case that is electrically connected in parallel to the solenoid hold-in winding.

Unusual Situations

PMGR Solenoids: Movable Contact

Because of the high peak-amperage required by PMGR starters, movable contacts in the solenoids for these units can be inclined to stick — that is, to weld to the stationary contacts. To remedy this, some PMGR solenoids have the movable contact attached to the plunger so it has the added force of the plunger-return spring to help it break free of the stationary contacts.

Ford Solenoids: Diode in S-Terminal Circuit

Some Ford solenoids have a diode molded into the cap that is connected in parallel to the hold-in winding. This diode clamps the spike voltage that is created in the hold-in winding when the solenoid is deactivated. For details on how to test for this diode, see *Technical Update 13* (September 1993) and *Technical Update 25* (January 1995).

Note that you can install a solenoid that has a diode to replace one that doesn't have a diode. All this does is add the feature of being able to clamp spike voltage.

Auxiliary Relays

Auxiliary relays are used when the current required by the solenoid windings is more than can be handled by the ignition switch and other switches in the circuit. These relays take very low current to engage and provide a short path so the current can flow directly from the battery to the S-terminal in the solenoid (*Figure 9*).

These relays are found on Delco 42MT IMS (Integral Magnetic Switch) systems and some industrial Nippondenso and Mitsubishi starters. They can also serve as a fix when the voltage drop in the vehicle wiring to the S-terminal is too great.

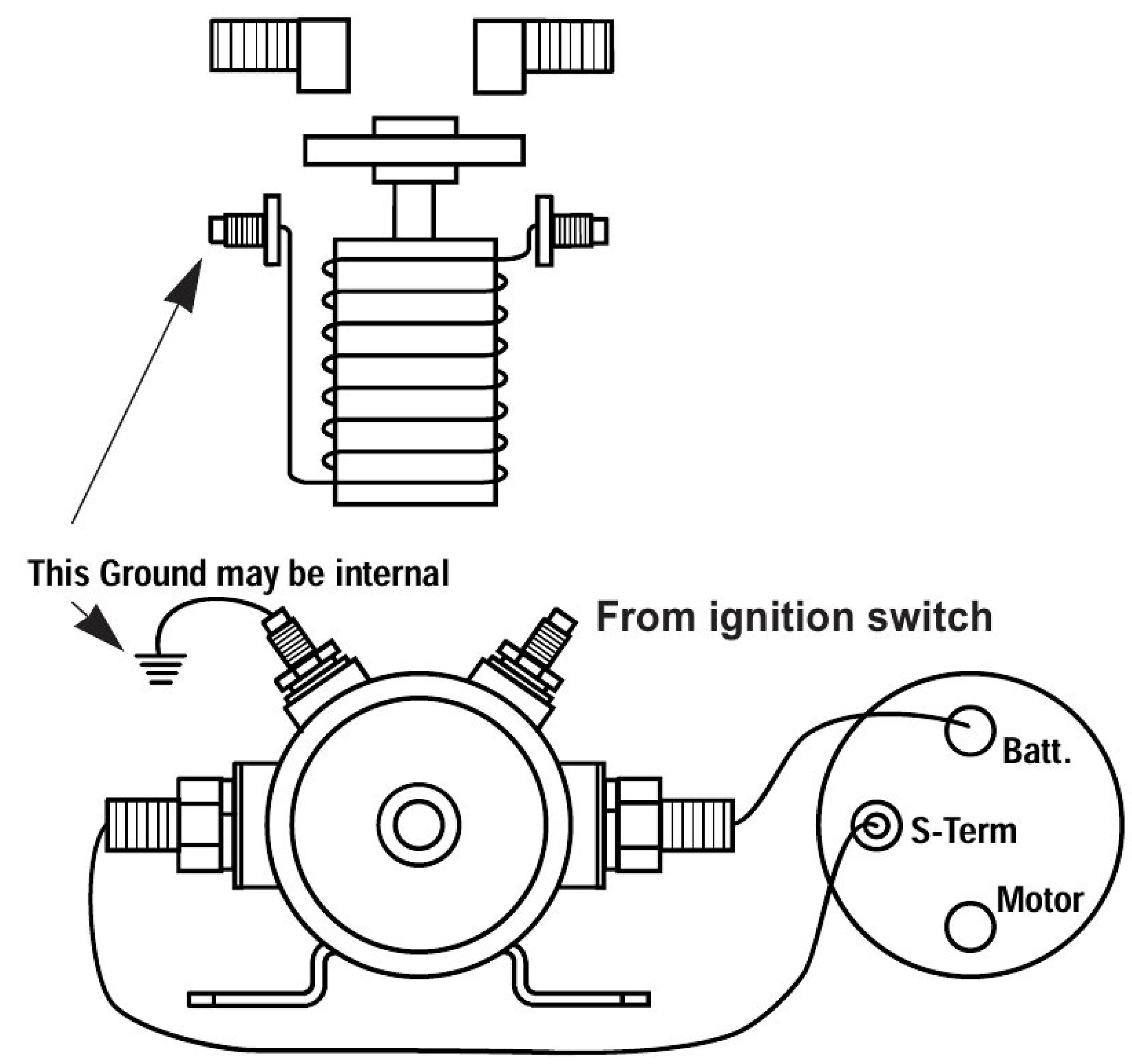

Figure 9. Auxiliary relays can help boost current flow to the solenoid in heavy-duty applications.

Watch for *Technical Update 34* to get more information about solenoids and their peculiarities.