ELECTRIC MOTOR REPAIR

A PRACTICAL BOOK ON
THE WINDING, REPAIR, AND TROUBLESHOOTING OF
A-C AND D-C MOTORS AND CONTROLLERS

SECOND EDITION

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Foreword

Today's civilized world depends more heavily than ever on one of the most efficient and most important devices ever invented—the electric motor. Without it, the wheels of industry would grind to a halt, and millions of time- and labor-saving devices would be rendered useless. No day passes without the discovery of new ways to use and control this prime motive force.

Equally important is the device which drives the electric motor—the generator. From the smallest stand-by unit to the largest hydroelectric plant, the demands of today's world for light and power are answered.

There will always be a continually increasing demand for technicians knowledgeable in these important and still growing fields.

It is the purpose of this book to show, in as clear, concise and nonmathematical a way as possible, the techniques of rebuilding and repair of motors and generators so that the reader can apply his knowledge immediately to the job at hand. The design of the book is fitted to the needs of bench-work, enabling the technician to keep it by his side at all times while engaged in his task. Many kind comments have been made about this feature.

It has been most gratifying to see, over the past few years, the reception given this book by teachers, students, and practicing electricians everywhere. I would like to take this opportunity to thank my many friends who have expressed, by letter or in person, their appreciation of my modest efforts.

Robert Rosenberg

Long Beach, New York
November 1969

Preface

For many years there has been a need for an intensely practical nontheoretical book on electric motor repair and control that could be used by men with little background of electrical knowledge. This has been only too evident in my contacts with workers over a period of many years in motor repair shops and with learners during my years as an instructor in motor repair and control in the New York City vocational high schools. It is with the hope of satisfying this pressing need that this book has been written. Inclusion of more than 900 illustrative drawings should make it particularly valuable as a direct working guide, not only to the student, but to the repairman at the bench as well.

Because the troubleshooter and repairman must learn to do satisfactory work in the shortest possible time, I have tried to point out the best and quickest methods for testing and repairing. The heading Troubleshooting and Repair at the end of each chapter should be especially helpful.

Both alternating-current and direct-current motors are treated thoroughly, and extensive consideration is given to the connections and troubles in controllers.

Although numerous changes and additions of subject matter and illustrations have been made in this revision, nearly all of the original material in the first edition has been retained. Many parts of the book have been rewritten and rearranged and new information has been added, but every effort has been made to preserve the character and objectives of the first edition. Because solid state electronic units are replacing tube-equipped motor controllers, a completely new chapter has been added devoted to Solid State Motor Control. This includes material on the numerous types of semiconductors such as diodes, transistors and SCRs. How these elements are incorporated in solid state drives is explained and discussed with the help of numerous circuits, diagrams, and sketches.

Study questions for each chapter of the book are arranged to follow the text material and sequence of information. These questions are valuable for the instructor, as well as the learner, since they can be used for quizzes, home assignments, and study purposes.

The last but by no means the least feature of the book is its physical design—a design that permits text and related illustrations to be exposed simultaneously, that enables the reader to locate any desired illustration instantlv, that allows the open book to be flat on the bench or desk, and that utilizes type large enough to be easily readable from the bench while the repairman is working on a motor. Even the cover material and the special paper inside the book were selected for their unusual sturdiness and resistance to soiling under workshop conditions.

I welcome this opportunity to express my sincere thanks to my colleagues and associates for their suggestions and help and to the many companies who have supplied much of the material, diagrams and photographs used in the book.

Robert Rosenberg

Long Beach, New York
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CHAPTER 1

Split-phase Motors

Main Parts of Motor

The split-phase motor is an a-c motor of fractional horsepower size and is used to operate such devices as washing machines, oil burners, and small pumps. This motor has four main parts. These are (1) a rotating part, called the *rotor;* (2) a stationary part, called the *stator;* (3) end plates, or brackets, which are fastened to the frame of the stator by means of screws or bolts; and (4) a centrifugal switch that is located inside the motor. The general appearance of a split-phase motor is shown in Figure 1-1. This motor is generally operated from a single-phase lighting or power circuit and is used where the starting torque requirements are moderate. The National Electrical Manufacturers Association (NEMA) defines a split-phase motor as a single-phase induction motor equipped with an auxiliary winding displaced in magnetic position from, and connected in parallel with, the main winding.

The Rotor

The rotor, one of which is shown in Figure 1-2, consists of three essential elements. One of these elements is a core that is made up of sheets of high-grade electrical sheet steel called *laminations.* Another is a shaft on which the laminated iron core is pressed. The third element is a squirrel-cage winding consisting of heavy copper bars which are placed in slots in the iron core and are connected to each other by means of heavy copper rings located on both ends of the core. In most split-phase motors the rotor has a one-piece cast-aluminum winding. This type is shown in Figure 1-2.

The Stator

The stator of a split-phase motor is composed of a laminated steel core with semiclosed slots, a heavy cast-iron or steel frame into which the core is pressed, and two windings of insulated copper wire that are wound into the slots and are called the *main or running winding* and *auxiliary or starting winding.* A photograph of the stator is reproduced in Figure 1-3, and a schematic diagram of the two windings is shown in Figure 1-4. Both windings are connected to the power line when the motor is started; however, after the motor has reached a predetermined speed, the starting winding is automatically disconnected from the power line by means of a centrifugal switch located inside the motor.

The End Plates (End Shields or Brackets)

The end plates, one of which is illustrated in Figure 1-5, are fastened to the stator frame by means of screws or bolts and serve mainly to keep the rotor in position. The bore of the end plates, in which the rotor shaft rests, is fitted with either ball bearings or sleeve bearings. These sustain the weight of the rotor, keep it precisely centered within the stator, and permit rotation without allowing the rotor to rub on the stator.

The Centrifugal Switch

The centrifugal switch is located inside the motor. Its function is to disconnect the starting winding after the rotor has reached a predetermined speed. The usual type consists of two main parts, namely, a stationary part (shown in Figures 1-5 and 1-6) and a rotating part. The stationary part is usually located on the front end plate of the motor as in Figure 1-5 and has two contacts, so that it is similar in action to a single-pole, single-throw switch. On some of the newer motors, the switch assembly is mounted in the stator shell. The rotating part is located on the rotor, as shown in Figures 1-7 and 1-10.

The action of a centrifugal switch is explained as follows: Reference to Figure 1-8 shows that when the motor is at a standstill, the two contacts on the stationary part of the switch are kept closed by the pressure of the rotating part. At approximately 75 percent of full speed, the rotating part releases its pressure against the contacts and causes them to open, thus automatically disconnecting the starting winding from the circuit. A popular type of centrifugal switch mechanism is shown in Figure 1-9. Here we see the stationary switch and the rotating governor weight mechanism. The rotating part is shown in Figure 1-10 and is attached to the rotor. The operation is similar to that of Figure 1-8, except that the governor weight moves outward as the speed increases, and away from the stationary contact plate, causing the contacts to open, and disconnecting the auxiliary circuit. Figure 1-11 shows the stationary and rotating parts of another centrifugal switch.

In an older type of centrifugal switch the stationary part consists of two copper semicircular segments. These are insulated from each other and mounted on the inside of the front end plate. The rotating part is composed of three copper fingers that ride around the stationary segments while the motor is starting. These parts are illustrated in Figure 1-12. At the start, the segments are shorted by the copper fingers, thus causing the starting winding to be included in the motor circuit. At approximately 75 percent of full speed, the centrifugal force causes the fingers to be lifted from the segments, thereby disconnecting the starting winding from the circuit.

Operation of The Split-phase Motor

Generally there are three separate windings in the split-phase motor. These windings are necessary for the proper operation of the motor. One of these is on the rotor and is known as the *squirrel-cage winding*. The other two windings are on the stator and are placed as shown in Figure 1-13. Each winding of the motor illustrated has four sections or poles.

Squirrel-cage Winding

The squirrel-cage winding consists of a number of heavy copper bars that are fitted into slots in the laminated iron core. The ends of each bar are welded to heavy copper rings that complete the electrical circuit. Most split-phase motors have a cast aluminum winding on the rotor, as shown in Figure 1-2.

Stator Windings

The stator windings consist of (1) a winding of heavy insulated copper wire, which is generally located at the bottom of the stator slots and is known as the *running* or *main winding;* and (2) a winding of fine insulated copper wire, which is usually located on top of the running winding and is known as the *starting* or *auxiliary winding*. These two windings are connected in parallel. When the motor is started, both stator windings are connected to the line, as shown in Figure 1-14(a). Upon reaching approximately 75 percent of full speed, the centrifugal switch opens, as shown in Figure 1-14(b) and disconnects the starting winding from the circuit, thereby causing the motor to operate on the running or main winding only.

At the start, the current flowing through both the running and the starting windings causes a magnetic field to be formed inside the motor. This magnetic field rotates and induces a current in the rotor winding, which in turn causes another magnetic field. These magnetic fields combine in such manner as to cause rotation of the rotor. The starting winding is necessary at the start in order to produce the rotating field. After the motor is running the starting winding is no longer needed and is cut out of the circuit by means of the centrifugal switch.

Procedure for Analyzing Motor Troubles

When a motor fails to run properly, a definite procedure should be followed in determining the repairs necessary to put it into running condition; that is, a series of tests is made on the motor to discover the exact trouble. These tests enable the repairman to tell quickly whether or not the motor needs minor repairs, such as new bearings, new switches, new leads; or whether it needs partial or complete rewinding.

Analysis Procedure

The following steps in analyzing motor troubles are given in the logical order to be followed in determining what repairs are required for reconditioning the motor:

1. Inspect the motor to detect such mechanical troubles as broken or cracked end plates, badly bent shaft, broken or burned leads.

2. Test the motor for bearing troubles. To do this, try to move the shaft up and down in the bearing as in Figure 1-88. Any such movement indicates a worn bearing. Next, turn the rotor by hand to determine whether it rotates freely. A shaft that does not rotate freely indicates bearing trouble, a bent shaft, or an improperly assembled motor as shown in Figures 1-92 and 1-93. In any case, a fuse is likely to burn out should the motor be connected to the power line.

3. Examine the motor to discover whether or not the internal wires are touching the iron cores of the rotor or stator. This is called a *ground test* and is accomplished by using a test lamp as shown in Figure 1-78(a) and (b).

4. After determining that the rotor turns freely, the next test is to run the motor. The power line wires are connected to the terminals of the motor and the switch is closed for a few seconds. If there is something wrong internally, the fuse may blow, the windings may smoke, or the motor may rotate slowly or noisily or may not turn at all. Such symptoms always indicate trouble inside the motor, usually a burned-out winding. The end plates and rotor are then removed, and the windings tested more carefully. Should the trouble be a badly burned winding, the winding itself will look burned and will also feel and smell burned.

Rewinding the Split-phase Motor

After previous tests have shown that the windings of the motor are burned out or are severely shorted, rewinding is required in order to recondition it. Before the motor is taken apart, the end plates and frame are marked with a center punch so that it may be reassembled properly. One center-punch mark is made on the front end plate and the adjacent frame, and two marks are made on the back end plate and also at a corresponding point on the frame as shown in Figure 1-15. The motor is then disassembled and made ready for repair.

Repair of a split-phase motor with a damaged winding consists of several separate operations, the most important of which are (1) taking data, (2) stripping the windings, (3) insulating the slots, (4) rewinding, (5) connecting the winding, (6) testing, and (7) baking and varnishing.

Taking Data

Taking data is one of the most important of the above operations. It consists of noting certain specific information concerning the old winding, so that no difficulty will be encountered when the motor is rewound. The information is recorded before and during the process of stripping the stator core of its windings. The best procedure is to obtain as much data as possible before the stripping operation. The information that should be obtained for both the running and starting windings includes (1) name-plate data, (2) the number of poles, (3) the pitch of the coil (the number of slots that each coil spans), (4) the number of turns in each coil, (5) the size of the wire on each winding, (6) the kind of connection (that is, series or parallel), (7) the position of each winding in relation to the other winding, (8) the type of winding (whether hand, form, or skein), (9) slot insulation, both size and kind, and (10) number of slots.

The information listed above must be recorded in such manner as to enable any motor repairman to rewind the motor without loss of time because of inadequate data regarding the original winding. To explain the workmanlike manner of obtaining the desired information, it will be assumed that a 32-slot, four-pole motor requires rewinding. The well-trained repairman would proceed as follows to gather the necessary data.

Record the name-plate data on a data sheet such as shown on page 8. The information contained on the name plate is very important. It tells at a glance the make of the motor, the horsepower, the voltage on which it must be operated, and the speed at full load. Among other things it indicates whether it is an a-c or d-c motor, the current it draws at full load, the type, and serial number. The last is especially important if it is necessary to order new parts. The minimum amount of information on a name plate of a single-phase motor should be (1) manufacturer's type and frame designation, (2) horsepower output, (3) time rating, (4) temperature, (5) r.p.m. at full load, (6) frequency, cycles per second-(Hertz)*, (7) number of phases, (8) voltage, (9) full load amperes, (10) code, (11) design letter for integral horsepower motors, (12) for motors equipped with thermal protection, the words "thermally protected," and for motors rated more than 1 h.p. a type number, and (13) service factor. For explanation, p. 122.

Figure 1-13 shows a 32-slot, four-pole stator of a split-phase motor as it would look if viewed from one end. Each winding consists of four sections. These sections are known as *poles*, or *groups*.

* Hertz = cycles per second.

To determine the number of poles in the motor, count the number of sections in the running winding. In Figure 1-13 the four sections of the running winding indicate a four-pole motor. If there were six sections in the running winding, it would indicate a six-pole motor. The number of poles in an induction motor governs the speed of the motor, and it is therefore essential that the correct number be recorded. A two-pole motor will rotate just below 3,600 r.p.m.; a four-pole motor about 1,750 r.p.m.; a six-pole motor just under 1,200 r.p.m., and an eight-pole motor slightly under 900 r.p.m. These speeds apply only when the motor is supplied with 60-cycle alternating current; different speeds will prevail for other frequencies.

Should the winding assembly be cut at one point and rolled flat, the winding would appear as in Figure 1-16. Notice the location of the running winding with respect to the starting winding. The starting winding overlaps two poles of the running winding. This is always true in split-phase motors, regardless of the number of poles or the number of slots in the motor. *Noting and recording the location of the running winding with respect to the starting winding is highly important.* If they are placed in any different location in rewinding, the motor may not start properly. Actually, the running and starting windings are separated by 90 electrical degrees. This is true no matter how many poles the motor has. However, the number of mechanical degrees between windings will differ with the number of poles in the motor. In the four-pole motor the windings are 45 mechanical degrees apart, and in a six-pole motor they are 30 mechanical degrees apart.

If a pole of either the running or starting winding of the motor is examined closely, it will be found to consist of three separate coils that have been wound one at a time, as illustrated in Figure 1-17. Also, each coil is wound in two slots that are separated by one or more other slots. The number of slots separating the sides of a coil, including the slots in which the winding lies, is called the *pitch*, or *span*, of a coil and is recorded as "1 and 4," or "1 and 6," or "1 and 8," as the case may be. This is shown in Figure 1-18. These coils protrude a certain distance from the ends of the slots. This is called the *end room*. This distance should be measured and recorded. It is important that the new coils do not extend beyond the slots any farther than this distance; otherwise the end plates may press against the coils and cause a ground.