Augie Hand

Electric Motor Maintenance and Troubleshooting

- troubleshoot electric motors of all types
- explains basic electricity and component functions
- includes time saving techniques, procedures & tips

ELECTRIC MOTOR MAINTENANCE AND TROUBLESHOOTING

Augie Hand

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ELECTRIC MOTOR MAINTENANCE AND TROUBLESHOOTING

To my wife Leanne
whose guidance and encouragement
made my books and seminars possible

INTRODUCTION

Worldwide competition has forced big changes in industry. Predictive and preventive maintenance programs have replaced reactive maintenance. These programs are important factors in the profit and, in numerous cases, the survival of many industries. The cost per hour of down time clearly illustrates the need for such programs.

This book explains electric motor theory and troubleshooting techniques. Its intent is to inform the technician in direct language without needless math and cross-references.

Effective electric motor maintenance and troubleshooting require a complete understanding of a motor's internal structure. The electric motor theory in this text is directly relatable to maintenance and troubleshooting. The math and motor theory are not meant to be used as exact formulas for designing or redesigning a motor or an electrical system. Instead, it is directly applied to motor problems and solutions.

The book covers all types of ac and dc motors. Dc motor and generator operation (and components) will be explained first, followed by ac single-phase motors, and then three-phase motors. Connections and their numbering systems are with the description of each machine.

Two troubleshooting procedures will be presented. The first procedure tests the machine's components to quickly see if it should be removed for repair. The next procedure locates the problem inside the machine.

Although electric machine problems can be difficult, there is no problem that does not have an explanation and a solution. It's just a matter of gathering all the facts, and applying the appropriate logic.

CONTENTS

CHAPTER

1

The DC Machine

The dc machines described in this chapter are motors or generators. The term *machine* is used when the test procedure is the same for both. **A motor can be converted to a generator (and vise versa), so the terms *motor* and *generator* are used only when the explanation applies to one or the other.**

DC generators produce very high-quality power, but (because of maintenance and other costs) ac powered dc drives are used for motor applications.

DC power is used for some high-voltage power transmission. DC current flows through the whole area of a wire, making it more efficient than ac for long distance transmission. High-voltage ac current uses only the outer portion of the wire. Only two transmission lines are needed with dc, and in an emergency, the earth can be used as a second conductor. At the user end, dc is converted to three-phase-power and distributed to substations.

DC generators also make the best power for arc welders. They provide steady voltage and a nonfluctuating current that flows in one direction.

The dc motor has excellent speed control with very good torque and horsepower characteristics. Because of its armature design and function, it has very smooth torque from zero rpm to base speed. The dc motor also has full-rated horsepower above base speed.

Basic Electricity as It Applies to Motors

The properties of electricity are volts, resistance, and amperes. Voltage is the driving force, resistance the work to be done, and amperes get the work done.

Volts

Voltage (electromotive force, or emf) is the driving force that causes the amperes to flow through the resistance of the load. Even if there is no circuit or path, voltage can be present. The volt can be compared to air or water pressure. When voltage is raised, more amperes will flow through the resistance (load). When voltage is lowered, fewer amperes will flow. When the voltage is varied, the amount of amperes flowing through a given resistance (load) will go up or down **with** the voltage change.

Another comparison of the volt to air or water pressure is containment. Higher voltage takes stronger (thicker) insulation.

Resistance

Resistance controls the amount of amperes that flow in a circuit. When a constant value of voltage is applied, as resistance goes up, amperes go down and as resistance goes down, amperes go up. As the resistance value varies, the amount of amperes will vary the *opposite* way. All loads have some form of resistance. The resistance of a device is measured in ohms. (Ohm's law is discussed later in the chapter.)

Two factors furnish resistance to current flow in an electric motor. First is the resistance of the wire in the coils that form the poles. Each wire size has a resistance value per thousand feet at a given temperature. Coils of wire used in the shunt field of a dc motor have enough feet of wire to limit the amperes to a safe level (and not overheat). The second factor is the interaction of the winding conductors and the magnetic circuit of the motor. This will be explained under "Counter emf" in dc motors and in Chapter 2 under "Inductive Reactance" in ac motors.

Amperes

The ampere is a measurement of the number of electrons flowing in a wire. The number of amperes flowing in a circuit is controlled by two factors: the voltage applied and the resistance of the load. The voltage and/or the resistance are varied to control the amperes. The formula called Ohm's Law (described below) calculates the number of volts and/or the amount of resistance needed to predict the number of amperes in a circuit.

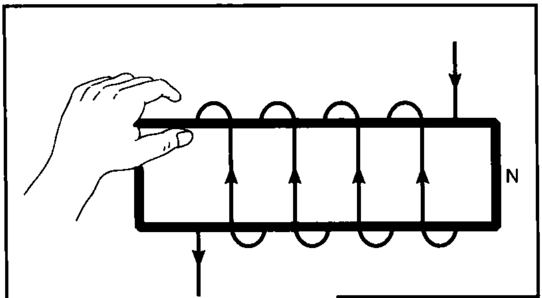

FIGURE 1.1

Left-hand rule. Place the left hand on a coil of wire with the fingers pointing in the direction of current flow. The thumb points to the north pole.

Most electrical breakdowns involve ampere flow. When insulation breaks down, heat created by ampere flow destroys it. Excessive amperes flowing in a wire cause a wire to become hot.

The amperes flowing through a coil controls the coil's magnetism. As the amperes change, the coil's magnetic strength will vary **with** the change.

The direction of ampere (current) flow determines the polarity of the coil. Figure 1.1 shows the left-hand rule for determining the polarity of a dc coil.

The right wire size is a very important part of motor design. The wire size is determined according to its cross-sectional circular mil area. The number of amperes that flow in a motor's circuits and the motor's cooling ability determine the wire size.

The coils used in the shunt field of a large dc motor have much larger wire size (circular mils per amp) than the coils used in single- or three-phase induction motors. This is because the coils have a large mass and do not cool easily. It's common to find a thousand (or more) circular mils per amp in the shunt field coils of a large dc motor. It is also common for single- and three-phase motors to have 300 to 350 circular mils per amp. The following chart shows the wire size converted to circular mils plus other data.

Additional Information on Copper Wire

This wire table can be remembered very easily if a few simple points are kept in mind:

1. A wire three sizes smaller than another wire has half the area of the larger wire. For instance, No. 20 AWG copper wire has half the area of No. 17 AWG. Therefore, two No. 20 wires in parallel have the equivalent area of one No. 17.
2. A wire three sizes smaller than another wire has twice the resistance of the larger wire.
3. A wire three sizes smaller than another wire has half the weight of the larger wire.
4. A No. 10 AWG copper wire is approximately 0.10 inch in diameter, has an area of approximately 10,000 circular mils and has a resistance of 1 ohm per 1000 feet.

If there are too few circular mils per amp, the coils will overheat and the motor's insulation will deteriorate prematurely. Excessive heat increases copper loss and lowers the motor's efficiency. Copper gains resistance as its temperature rises. As copper resistance goes up, the amperes go down, lowering the motor's horsepower output.

AWG	Diameter, Inches	Circular Mils	Pounds per 1000 ft	Ohms at 68°F per 1000 ft
0000	0.4600	211,600.0	640.5	0.0490
000	0.4096	167,800.0	507.9	0.0618
00	0.3648	133,100.0	402.8	0.0779
0	0.3249	105,500.0	319.5	0.0982
1	0.2893	83,694.0	253.3	0.124
2	0.2576	66,370.0	200.9	0.156
3	0.2294	52,630.0	159.3	0.197
4	0.2043	41,740.0	126.4	0.248
5	0.1819	33,100.0	100.2	0.313
6	0.1620	26,250.0	79.46	0.395
7	0.1443	20,820.0	63.02	0.498
8	0.1285	16,510.0	49.98	0.628
9	0.1144	13,090.0	39.63	0.792
10	0.1019	10,380.0	31.43	0.998

AWG	Diameter, Inches	Circular Mils	Pounds per 1000 ft	Ohms at 68°F per 1000 ft
11	0.09074	8,230.0	24.92	1.260
12	0.08081	6,530.0	19.77	1.588
13	0.07196	5,170.0	15.68	2.003
14	0.06408	4,107.0	12.43	2.525
15	0.05707	3,257.0	9.858	3.184
16	0.05082	2,583.0	7.818	4.016
17	0.04526	2,048.0	6.200	5.064
18	0.04030	1,624.0	4.917	6.385
19	0.03589	1,288.0	3.899	8.051
20	0.03196	1,022.0	3.092	10.15
21	0.02846	810.1	2.452	12.80
22	0.02535	642.4	1.945	16.14
23	0.02257	509.5	1.542	20.36
24	0.02010	404.0	1.223	25.67
25	0.01790	320.4	0.9699	32.37
26	0.01594	245.1	0.7692	40.81
27	0.01420	201.5	0.6100	51.47
28	0.01264	159.8	0.4837	64.90
29	0.01126	126.7	0.3836	81.83
30	0.01003	100.5	0.3042	103.2
31	0.00892	79.70	0.2413	130.1
32	0.00795	63.21	0.1913	164.1
33	0.00708	50.13	0.1517	206.9
34	0.00630	39.75	0.1203	260.9
35	0.00561	31.52	0.09542	329.0
36	0.00500	25.00	0.07568	414.8
37	0.00445	19.83	0.0601	523.1
38	0.00396	15.72	0.04759	659.6
39	0.00353	12.47	0.03774	831.8
40	0.00314	9.888	0.02990	1,049.0

Ohm's Law

The relationship of voltage, amperes, and resistance is explained with a formula called Ohm's Law. The following formulas, in which E (electromotive force) = volts, I (intensity of current) = amperes, and R = resistance, predict the results when designing electrical devices:

Volts divided by resistance equal amperes ($E \div R = I$)

Volts divided by amperes equal resistance ($E \div I = R$)

Amperes multiplied by resistance equal volts ($I \times R = E$)

Varying the voltage or the resistance controls amperes.

Watt

The word *watt* is short for joules per second. A watt is the measurement of power being used to do work. Watts are found by using the formula volts × amperes = watts. A power meter (which determines power cost) multiplies volts × amps and measures the time involved. The cost is determined by the kilowatthour (1000 watts for 1 hour).

A motor converts electrical energy directly into mechanical energy. One horsepower (hp) equals 746 watts. [One horsepower has the ability to lift 550 pounds (lb) 1 foot in 1 second.]

Watts and horsepower are directly related to the physical size of motors. Some motors are rated in kilovolt amperes (kVA) instead of horsepower. All transformers are rated in kVA.

The formula (volts × amperes = watts) shows that when watts are constant: As volts go up, amps go down. For example, assume 1000 watts are required for a given load. If the power supply were 10 volts, it would take 100 amperes to produce 1000 watts of power. The wire size would have to be large to carry 100 amperes. With a 100-volt power supply, only 10 amperes are needed to produce 1000 watts. The wire size required would be much smaller. This is the reason large electric motors are designed to operate on high voltage.

Low amperes allow smaller wire to be used. Power lines are a good example of this. On the high-voltage (power line) side of a transformer, the wires are very small compared to those on the low-voltage side (load side).

Magnets and the Magnetic Circuits

The Bar Magnet

The bar magnet in Fig. 1.2 shows the invisible lines of force (flux) going out one pole and completing a magnetic circuit to the other pole. Lines of force will go through air, insulation, and nonmagnetic materials.

The bar magnet is at full magnetic strength when its molecules are in alignment, as seen in Fig. 1.3.

The Electromagnet

A piece of iron with a coil of wire wound around it makes a basic electromagnet (Fig. 1.4). Magnetic strength is controlled in an electromagnet by raising and lowering the amperes. Reversing the current flow will reverse its polarity.

The Magnetic Pole

A pole in the stator of a dc machine is a coil of wire wound around a piece of iron (called a pole shoe or pole iron), as shown in Fig. 1.5.

A pole is equal to 180 electrical degrees. One north

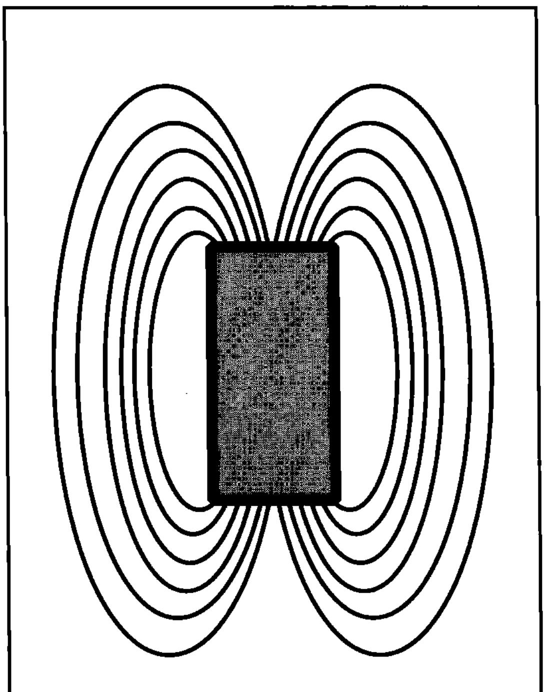

FIGURE 1.2

A bar magnet has lines of force that go from one pole to the other, through the air.

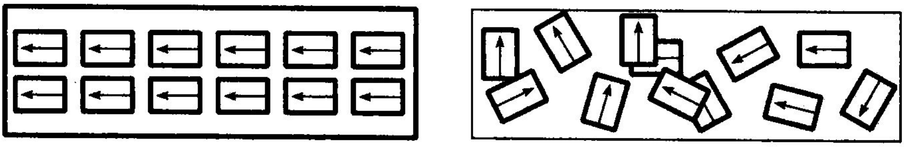

FIGURE 1.3

The magnet is fully magnetized if the molecules of the iron are aligned.

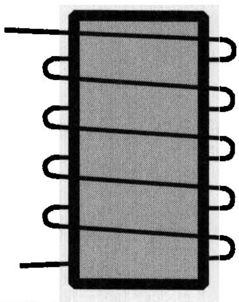

FIGURE 1.4

An electromagnet consists of an iron bar with a coil of wire around it.

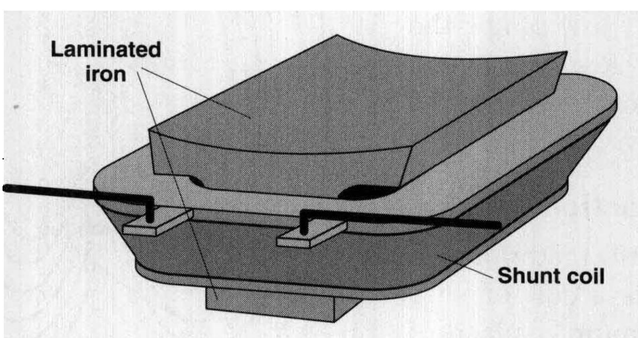

FIGURE 1.5

A field pole consists of laminated iron and a coil of wire.