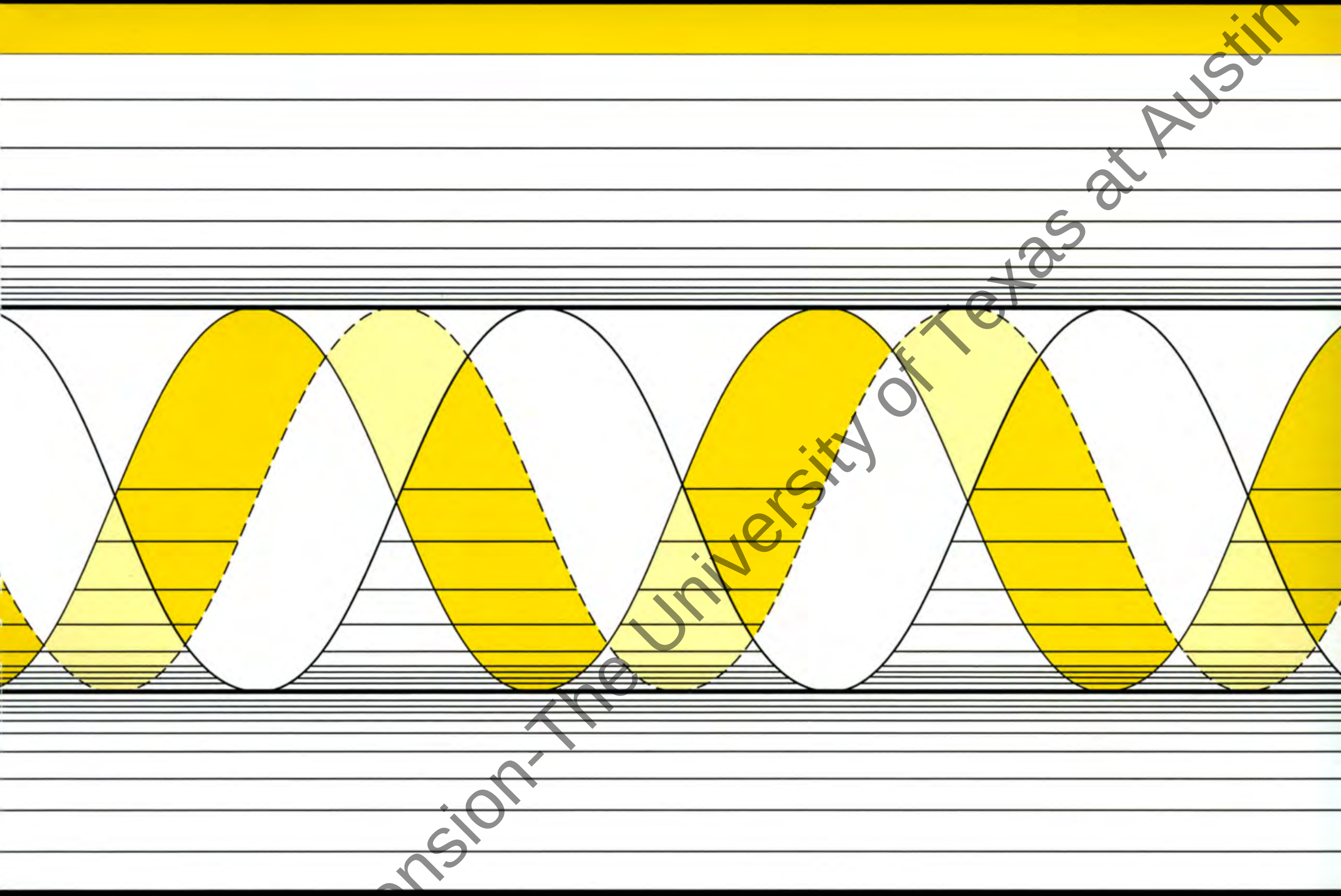


basic electricity

for the petroleum industry

2nd edition

CONTENTS

Chapter 1

WHAT IS ELECTRICITY?

Great discoveries are never brought forth overnight. Behind each one is a long history of bit-by-bit development. Sometimes over many centuries man may realize the simple beginnings that are to lead to great discoveries in the course of time. Each succeeding generation adds its small contribution, makes its own small discoveries, until many years—perhaps centuries—later, a genius of the caliber of Thomas A. Edison puts all the bits together and presents the world with the accomplished fact.

Edison's lamp could not have been made to produce electric light but for the legacy of knowledge about magnetism. The phenomenon of natural magnetism has been known since about 600 years before the beginning of the Christian era, taking its name from Magnesia, a district on the coast of what is now Greece.

It was from there that first notice of a metallic substance that had the power to attract ferrous (iron) metals was handed down in written form. The substance was magnetite, now also commonly called lodestone. It was in Greece, too, that early experiments disclosed that magnetism could be induced. The experiments showed that nonmagnetic pieces of iron could be magnetized by rubbing them with lodestone.

According to some writers, the Chinese made the first practical use of the phenomenon of magnetism. Almost 2000 years ago, they were using the magnetic-needle compass as a navigation aid. It was, however, not until the early nineteenth century that the first real breakthrough was achieved, bringing the modern-day genie, electricity, measurably nearer to realization.

OERSTED'S DISCOVERY

Hans Christian Oersted was a Danish scientist who in 1819 made one of the most important contributions to the development of electricity as we know it: the discovery of *electromagnetism*.

When Oersted brought a compass near an electrical conductor carrying a current, with the compass needle parallel to the conductor, the needle was deflected. When he reversed the current and repeated the experiment, the needle was deflected in the opposite direction. From this he concluded that a magnetic field surrounded the conductor, and that the direction of the magnetic flow was governed by the direction of the current moving in the conductor.

However, in Oersted's time, electricity was still merely an interesting laboratory phenomenon. All the developments that were to make the civilized world dependent on this form of energy were still in the future. The electricity produced in the laboratory had no practical application in everyday life. In fact, there existed no recognized need for it.

Chapter 2

FLOW OF ELECTRICITY

An electric current is a movement of free electrons through a conductor from a point that has an excess of electrons to a point that has a lack of electrons. It is only the electrons that actually move, and electric current is considered to flow from a point of negative potential to a point of positive potential. The point of negative potential is the anode, the terminal of a battery that has a negative charge; the point of positive potential is the cathode, the positive terminal of a battery.

The term "flow" as used in connection with electricity is similar to its use in connection with hydraulic systems. Figure 2.1 shows the similarity in function of the various components in an electrical system and a hydraulic system. The pump and the generator build their respective loads to high potential energy. (See Chapter 3 for a discussion of potential energy.) As the water from the pump turns the wheel, it loses potential energy, flows back into the tank, and is again built up to high potential energy by the pump. The electrons in the conductors shown at the right go through a similar cycle in operating the electric motor.

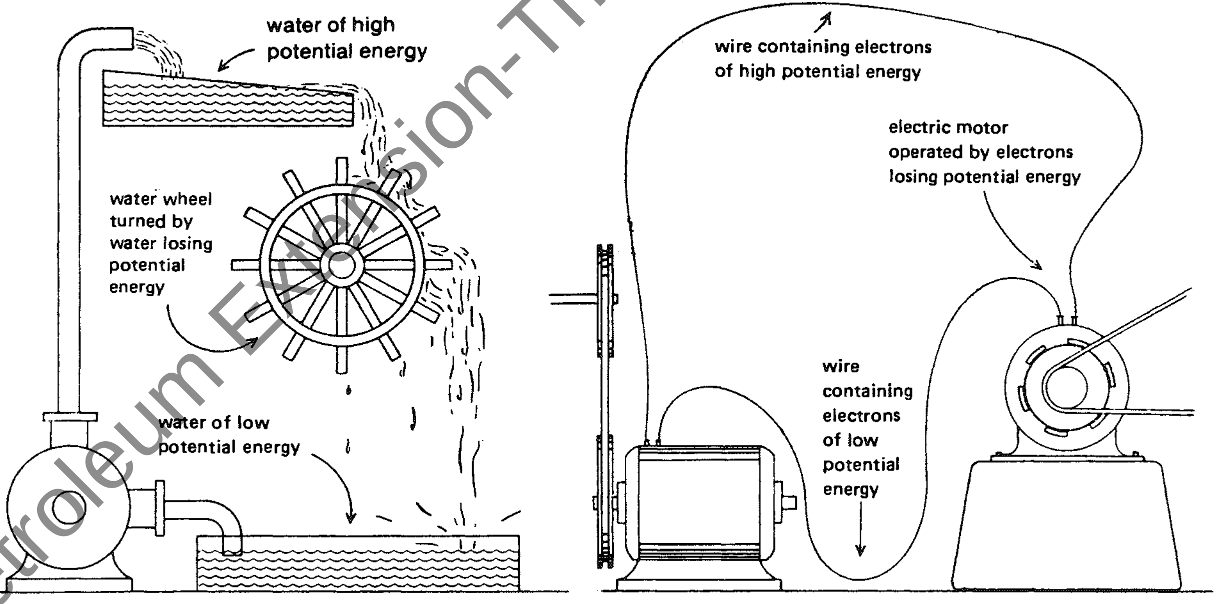


Figure 2.1. Comparison of Hydraulic and Electrical Systems

Chapter 3

POWER IN ELECTRIC CIRCUITS

All kinds of energy—mechanical, chemical, electric—have certain elements in common. Force and work are required to lift a pencil as well as to induce and transmit emf in an electric circuit.

FORCE AND WORK

Force is what makes things move. It may be a push or a pull or an attraction or repulsion used to produce or to stop motion. An automobile stops when the force of the brake is applied, but even without the opposing force of the brake or an obstacle in its path, a car in motion will eventually stop because the force of friction opposes its motion. If it were not for friction or other opposing forces, an object set in motion would continue to move with constant speed in a straight line. This is an example of Newton's first law of motion—the law of inertia: *A body continues in its state of rest or uniform motion in a straight line unless an unbalanced force acts on it.*

Similarly, static friction, the force of friction between the two objects at rest, is greater than kinetic friction, or the resistance between the two objects when one is moving over the other. Consequently, more force is necessary to set an object in motion than is required to maintain motion at a constant speed after the object is moving.

When a force acts upon a body and moves it, *work* is done. Work is the product of force times the distance through which the force acts: work = force x distance. It is proportional to both the resistance the object encounters and the distance the object is moved. Mechanical work is measured in pounds times feet (foot-pounds) or joules. One foot-pound is equal to about 1.36 joules.

When a person pushes a box across the floor against the opposing force of friction, work is done. The work performed is equal to the resistance (R) in pounds times the distance (D) in feet, or R x D, with the product given in foot-pounds or joules of work. Work is also done when an object is lifted straight up in the air against the opposing force of gravity. The work performed is equal to the weight in pounds of the object times the height it is lifted. Again, the product is so many foot-pounds or joules of work.

ENERGY

It is possible to store work: in winding an old-fashioned clock with weights, work is stored by raising a weight. In descending, the weight will turn the wheels of the clock for a length of time against the opposition of friction, giving back the stored energy more slowly and more usefully than it would by falling freely. Work stored in a raised weight need not be used at once; in fact, it can be

Chapter 4

MAGNETISM AND ELECTRICITY

Oersted's discovery of the relationship between electricity and magnetism was the preliminary step in the development of magnetic field generators. Without magnetism and an understanding of the relationship between magnetism and electricity, there would be no generators. Therefore, the study of electricity must include an understanding of magnetism.

NATURAL MAGNETS

In ancient times it was discovered that magnetite, an iron ore found on or near the surface of the earth, has the property of attracting and imparting its magnetic qualities to other pieces of iron. Probably the first practical use made of the discovery of magnetite was the use of the magnetic material in a compass when it was found that a magnet that is free to turn always aligns itself in a north-south position with the same end of the magnet always pointing toward the north.

MAGNETIC POLES

The north-pointing end of a magnetic needle is called its north pole (N); conversely, the other end is the south pole (S). Any piece of magnetized material, even a horseshoe magnet, has a north pole and a south pole. The earth itself is a magnet with magnetic north and south poles in addition to the geographic north and south poles (fig. 4.1). It is the north magnetic pole that a compass needle points to, rather than the north geographic pole. The earth's magnetic poles shift a little each year, but they never coincide with the geographic poles.

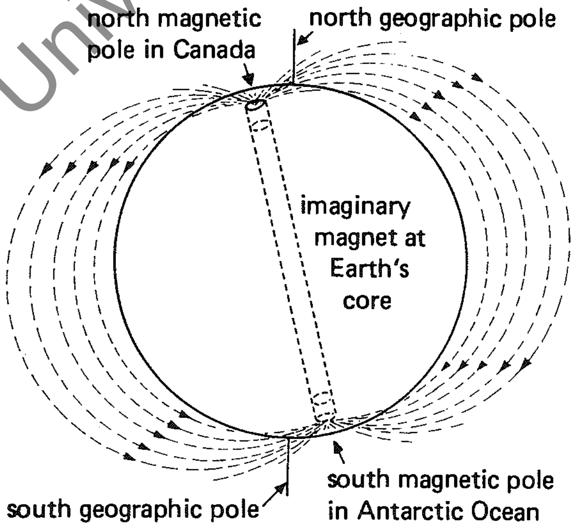


Figure 4.1. Earth's Magnetic and Geographic Poles

Similar to the behavior of positively and negatively charged atoms, like magnetic poles repel each other and unlike poles attract each other. The north pole of one magnet is attracted by the south pole of another, and the north poles of two magnets and the south poles of two magnets repel each other.

Chapter 5

GENERATION OF ELECTRICITY

It is a fundamental law of nature that energy cannot be created; however, it can be converted from one form to another. Friction, pressure, heat, light, chemical energy, and mechanical and magnetic energy can all be converted into electrical energy. Although most of these six methods of producing electricity have little or no practical application today, they are all discussed because of their historical or potential significance.

STATIC ELECTRICITY

Static electricity is sometimes called electricity of friction. Some examples of the production of electricity by friction are rubbing an amber rod with fur or wool, walking across a wool carpet with rubber-soled shoes, the flexing of tires as a car travels on a highway, discharging liquids through a pipe or hose, and by a static machine built for this purpose and used in laboratory experiments.

Static electricity occurs because of the phenomenon of the attraction of unlike charges. This attraction is readily demonstrated by the behavior of pith balls suspended on threads and charged by a static machine (fig. 5.1). The pith balls are uncharged at the left; they are neither attracted to nor repelled by each other. In the next diagram, one ball is given a positive charge and the other is given a negative charge; the balls move toward each other. When both balls are given likes charges, they move away from each other.

Static electricity has no practical application outside the laboratory, and although it occurs in many ways, it is often a hazard and is seldom welcome when it does occur. A bolt of lightning between clouds or from a cloud to earth during a thunderstorm is the most spectacular occurrence of static discharge. Less dramatic are sparks and minor shocks that accompany the discharge of static electricity from one person's hand to another's or from a hand to a doorknob.

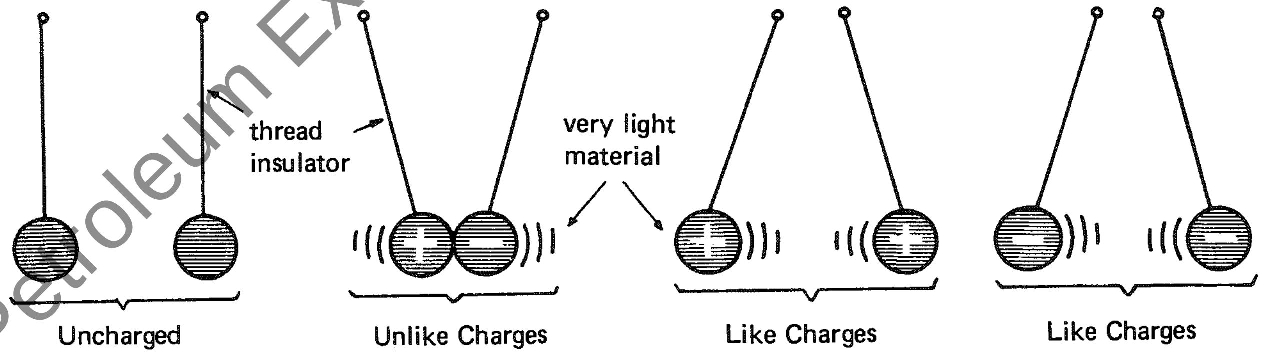


Figure 5.1. Effect of Static Charges on Pith Balls

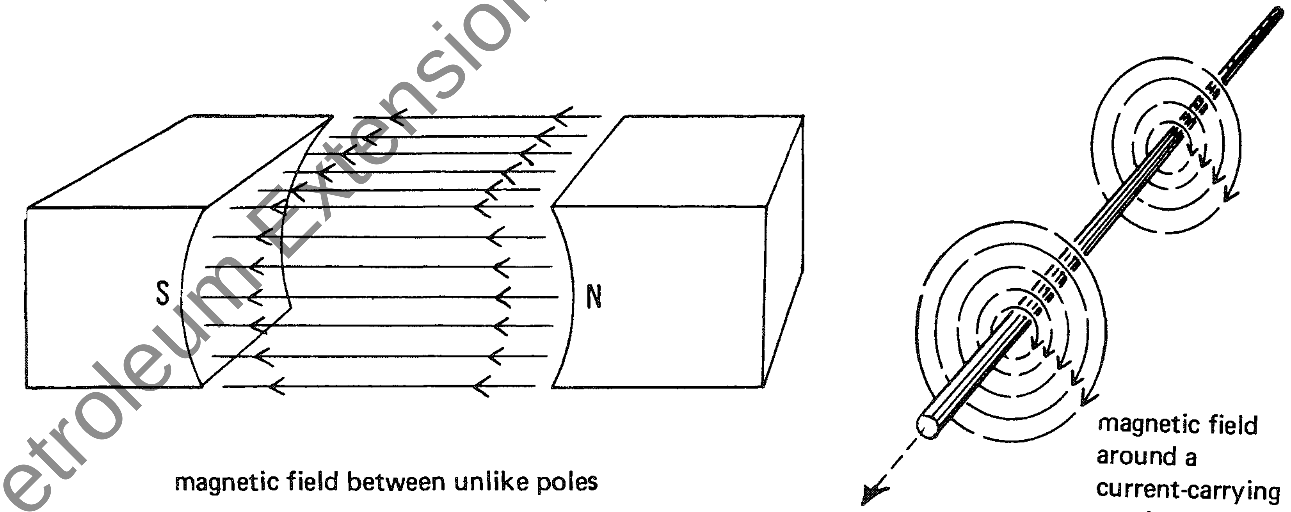
Chapter 6

ELECTRIC MOTORS

The purpose of the generator studied in the preceding chapter is to convert mechanical energy into electrical energy, whereas the purpose of the electric motor is to convert electrical energy into mechanical energy. In mechanical design, the generator and the simple DC motor do not differ essentially from each other. Each has an armature rotating in a magnetic field. In the generator, the armature is caused to rotate by some external mechanical force, and the electricity is generated in the armature coils. In the simple DC motor, the armature is an electromagnet, cutting lines of force produced by another electromagnet serving as a field. When current from a generator or other source is led into the motor, two magnetic fields are produced: one in the armature and one in the field magnet. It is the reaction between these two magnetic fields—the magnetic flux created in the armature and the magnetic flux of the field poles—that causes the armature of the electric motor to rotate.

PRINCIPLES OF MOTOR OPERATION

A magnetic field forms between unlike poles, and a current-carrying conductor produces a magnetic field around it. In figure 6.1, examples of both these magnetic fields are shown. In the magnetic field between unlike poles, the direction of flux is always from



magnetic field between unlike poles

magnetic field around a current-carrying conductor

Figure 6.1. Magnetic Fields

Chapter 7

TRANSFORMER OPERATION AND CONSTRUCTION

Without transformers, it would not be practical to transmit electric power over great distances. The generation and transmission system of Hoover Dam provides an excellent example of how transformers are used. The generators at the foot of the dam produce alternating current at 13,000 volts. This voltage is stepped up through transformers to 187,500 volts for transmission to Los Angeles, 200 miles away. There, it is stepped down to 480, 240, and 120 volts for use in industry, homes, and offices.

The purpose of this stepping up and stepping down of voltage leads back to a review of some fundamental concepts discussed earlier in this manual:

1. When current passes through a conductor, there is a loss of energy through heating effects.
2. The magnitude of the loss is proportional to the number of amperes of current. The loss also depends on the size of the conductor: the larger the conductor, the less resistance there is, and the lower the heat loss.
3. Power is measured in watts. The number of watts is equal to the number of volts multiplied by the number of amperes.

Consider 960 watts of power, for example. Any combination of volts and amperes is possible that, when multiplied together, give 960 as the product:

120 volts x 8 amperes = 960 watts
240 volts x 4 amperes = 960 watts
480 volts x 2 amperes = 960 watts
960 volts x 1 ampere = 960 watts

In this case, the most desirable conditions for transmission of power would be at 960 volts and 1 ampere, because low amperage results in less heat loss.

From these considerations comes the general rule that *when alternating current is to be transmitted, the most efficient condition is that of higher voltage and a correspondingly reduced number of amperes.*

Stepping up of voltage to very high values and stepping it down again near the point of use may require several stages and several banks of massive equipment; or only one stage may be needed, as in residential areas. In all cases of transmission of alternating current, line loss is so serious at relatively low voltage and high amperage that transformers are used almost everywhere. This permits the use of smaller conductors in transmission lines and smaller components of every kind, so the resulting savings in construction costs more than offset the cost of the transformers.

Figure 7.1 shows the typical use of transformers between the generating station and the electric motor on an oil well pumping site. The first bank of transformers at the dam steps the generated voltage of 13,200 up to 66,000 volts (to use typical figures). The second bank has booster transformers, used to raise the

Chapter 8

PRACTICAL ASPECTS OF TRANSFORMER OPERATION

Efficient operation of a transformer depends to a great extent on the effectiveness of the insulation and design for cooling, and it can be enhanced by the selective use of auxiliary equipment. This chapter will deal with the effect of these variables on transformer operation and will provide a brief explanation of the most commonly used transformer connections.

COIL AND CORE FASTENING AND INSULATION

The magnetic forces in medium to large transformers are very large and, under short circuit conditions, amount to hundreds of thousands of pounds in the larger transformers. This makes it necessary to clamp and securely fasten the core in place and to mount the coils solidly on the core. The solid insulation must be strong enough mechanically to withstand the thrust and distorting forces on the coils under these conditions. Figures 8.1 and 8.2 show how thoroughly the coils and core are insulated. Without such insulation, the distorting forces tend to make the coils take a circular shape if they are not circular and to shift them along the core. Loose laminations or coil sections may cause noisy operation of the transformer under normal operating conditions. If windings become loosened, the insulation may be damaged.

Each turn of wire in the coils of a transformer has to be insulated from the other turns, and each layer or section of coil must be insulated from the other sections. Extra insulation is needed between the primary and secondary windings and between the coils and core sections. Many materials are used for insulation. Dry air is a reasonably good insulating medium; transformer oil and synthetic liquids are also used as insulating and cooling material in transformers. Transformer oil is a much better insulator than air, and it works to quench arcs on current surges. It also flows into breaks in the insulation and acts to prevent arcing or shorting across turns.

The individual wires are varnished or coated with insulating material, and they may be wrapped with oil- or resin-coated insulating cloth or paper if the voltage is high. The coils and coil sections are usually wrapped and coated as a unit with insulating spacers between coils, coil sections, and the core (figs. 8.1, 8.2). The transformer is subjected to voltage much higher than the rated operating voltage by switching of line loads, surges, lightning surges, and other line conditions. For this reason, the insulation is usually rated to withstand at least double the rated voltage.

Chapter 9

AUXILIARY EQUIPMENT FOR ELECTRICAL DEVICES

The use of electrical equipment often involves auxiliary devices such as capacitors, rectifiers, resistors, and so forth. Figure 9.1 shows a distribution line with capacitors, a fuse cutout to interrupt service when a fault occurs on the line, and a lightning arrester to protect the circuit from lightning surges. These and other auxiliary apparatus will be discussed in this chapter.

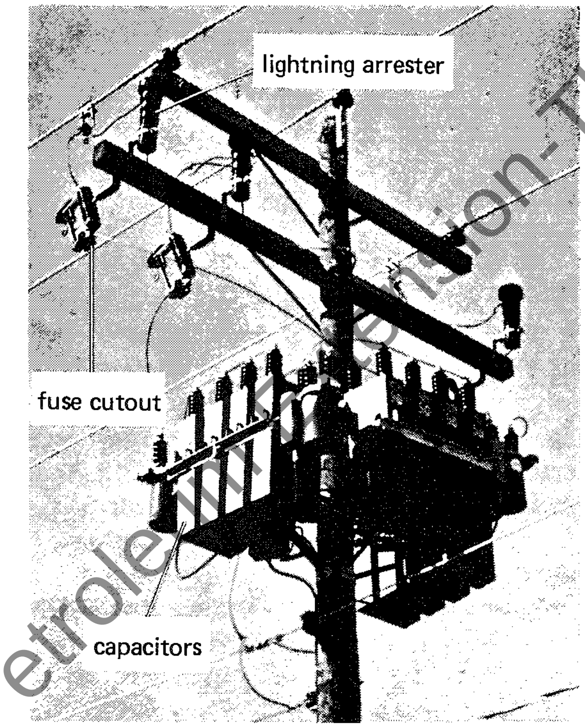


Figure 9.1. Distribution Line with Auxiliary Equipment

CAPACITORS

Another name for capacitor is condenser. The latter term is more commonly used in discussions of small equipment, as in radio and communications work or in electrical ignition systems. When reference is made to motors, such as those used for power in the oil industry, the term capacitor is used. The Leyden jar, a simple form of capacitor for storing static electricity, is discussed in Chapter 5. A Leyden jar has two conductors (the metal foil on the inside and the outside of the jar), which are separated by a dielectric, or insulator, which is the glass jar. The principle of the operation of the capacitor is described in Chapter 3 in the section "Capacitance."

Capacitors are used in oil field installations either to improve the power factor or to start capacitor motors. When inductance causes a current lag in an AC circuit, installation of the proper capacitor will bring the current into phase with the voltage, and a higher power factor will result. In a DC circuit, the flow of current tends to decrease with transmission over a distance, but because the capacitor can receive and store a charge and then discharge it into the line, use of a capacitor on a DC circuit can stabilize the power output and tend to keep it at a constant level.

Chapter 10

MOTOR CONTROLS

The motor control has three jobs to do: (1) it closes the circuit to start the motor and opens the circuit to stop the motor; (2) it controls the running speed of the motor; (3) it protects the motor against abnormal operating conditions. These purposes are accomplished by a suitable combination of components arranged for the job to be done. They may range from very simple to very complex; they may be purchased in the form of an integrated unit from the manufacturer, or they may be purchased in the form of single components.

Figure 10.1 shows a control cabinet fully equipped for use on a pumping well in the oil field. Motor controls may be operated manually, magnetically, or electronically; they may be run by relays to operate electrical equipment sequentially or in interlock; and there are devices to provide feedback on automated control mechanisms.

SWITCHES

Switches, starters, and contactors are the devices used to put a motor in service. They establish, carry, and interrupt the flow of power in the motor circuit. They may be operated manually, or they may be controlled automatically. Remote operation is possible through magnetic or electronic relays. Normal stopping of the motor is achieved with the same apparatus that is used to start it by reversing the action to open the circuit.

KNIFE SWITCHES

Most manually controlled switches used in the oil field are knife switches, which are either two-pole or three-pole switches. Figure 10.2 shows a two-pole knife switch; the lower switch is open, and the upper switch is closed. Contact is established by means of moving a copper blade into position between two sides of a copper spring clip; the spring ensures a close contact between the elements.

Operation of such switches is by means of a handle extending through the metal wall of the case that encloses the switch itself. Most models cannot be operated when the door of the switch box is open; this is a safety device designed to protect the operator. Knife switches can be equipped for operation with a hook-stick for installation in inaccessible locations.

MERCURY SWITCHES

Use of mercury switches has many advantages, especially in automatic operations. They are especially safe in that there is no danger of an arc, such as often occurs in the operation of a knife switch. They are also easily adapted for operation with magnetic devices. The mercury switch has been incorporated into a number of pressure- and temperature-sensitive devices that are widely used in the operation of pumping equipment,

Chapter 11

MEASUREMENT OF VOLTAGE AND CURRENT

The instruments described in this chapter are discussed primarily in terms of their use in measuring current in electric circuits; however, most of them can be adapted to measure voltage also. An instrument that indicates current flow can be calibrated to read directly in volts, because current is proportional to the voltage applied to a circuit.

BASIC PRINCIPLES OF METERS

There are two basic methods of measurement: positive and inferential. An example of positive measurement is measuring water with a gallon bucket. There is no question and no calculation required to determine that a gallon measure, when filled, contains one gallon of liquid. Other examples are positive displacement meters for measuring gas and flowing streams of liquids.

A much more commonly used method of measurement is inferential measurement, which consists essentially of observing the effect of a flow on a mechanism, from which effect an inference is drawn with respect to the magnitude of the flow. For example, when a temperature rise takes place in a metallic element because of the passage of electricity, the increase in temperature provides a basis for an inference regarding the magnitude of the current.

The principle of inference is frequently used in measuring electrical phenomena. An obstruction in the form of a resistance or a load is placed on the emf or the current of a circuit, and by observing the effects of the circuit on the resistance, it is possible to place a quantitative value on the emf or the current by inference.

In order of complexity, there are three categories of electrical measurement instruments: verification indicators or detectors, quantity indicators, and quantity recorders.

VERIFICATION INDICATORS

Verification indicators simply verify the presence or absence of an emf or current. The earliest recognized verification indicator is shown in figure 11.1. The compass needle's deflection in the presence of an energized conductor is evidence of the presence of electrical energy. Figure 11.2 shows the more pronounced deflection of the needle in the environment provided by a coil. This second device does not measure quantity, but it suggested the need for quantity determination.

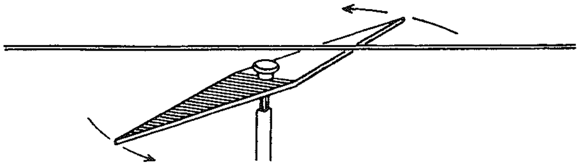


Figure 11.1. Compass Needle and Straight Conductor

Chapter 12

MEASUREMENT OF OTHER ELECTRICAL VARIABLES

In addition to measuring current and voltage, it is sometimes necessary to take quantitative readings of the resistance of a circuit or insulation, power and power factor, and frequency of the circuit. This chapter will discuss these types of measurements, the uses of recording meters, and the necessary precautions for handling electrical meters.

RESISTANCE

OHMMETERS

An ohmmeter is a rugged, portable instrument used to measure the resistance or check the continuity of a circuit. This instrument is basically a galvanometer that makes use of a dry cell battery to provide a standard source of voltage. With the voltage standardized and the current indicated, the scale of the meter can be calibrated to read ohms of resistance because resistance is proportional to current and voltage. An ohmmeter is provided with two leads that are connected to the device in which the resistance is to be measured.

The unknown resistance R_X is connected as shown in figure 12.1. The letter A represents the meter calibrated in ohms of resistance. The diagram on the left shows a series ohmmeter; the ohmmeter circuit on the right is a shunt circuit because the unknown resistance is connected in parallel with the measuring meter.

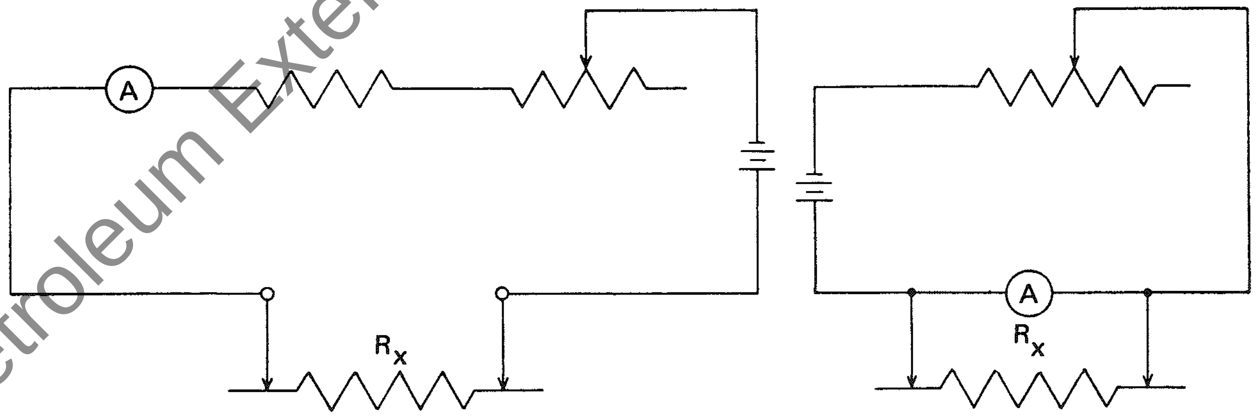


Figure 12.1. Series and Parallel Ohmmeter Circuits

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