CHAPTER 12

SHIPBOARD ELECTRICAL EQUIPMENT

Aboard modern naval ships, most auxiliary machinery and equipment is run by electricity. Regardless of rate or rating, all personnel assigned to a ship will operate some electric devices in the performance of their duties. Electrical equipment is dangerous if handled incorrectly; therefore, you must observe all applicable safety precautions when working with or around electrical equipment.

In this chapter, we will discuss basic concepts of electricity, electrical terms, electrical equipment, and applicable safety precautions. You will find additional information on the basic principles of electricity in the *Navy Electricity and Electronics Training Series* (NEETS), modules 1 and 2, NAVEDTRA 172-01-00-79 and NAVEDTRA 172-02-00-79.

INTRODUCTION TO ELECTRICITY

Some materials will conduct electricity, and some offer more resistance than others. Metals such as silver, copper, aluminum, and iron offer little resistance and are called *conductors.* In contrast to conductors, some materials such as wood, paper, porcelain, rubber, mica, and plastics offer high resistance to an electric current and are known as *insulators.* Electric circuits throughout the ship are made of copper wires covered with rubber or some other insulator. The wire conductors offer little resistance to the current, while the insulation keeps the current from passing to the steel structure of the ship.

Definite units have been established so we can measure the electrical properties of conductors. Also, there are terms used to describe the characteristics of electric currents. A brief review of these fundamentals is given in the following sections.

ELECTRIC CURRENT

The flow of current through a wire can be compared to the flow of water through a pipe. Current is the rate at which electricity flows through a conductor or circuit. The practical unit, called the *ampere,* specifies the rate at which the electric current is flowing. Ampere is a measure of the intensity or the number of electrons passing a point in a circuit each second.

ELECTROMOTIVE FORCE

Before water will flow through a pipe, there must be water pressure; before an electric current can flow through a circuit, there must be a source of electric pressure. The electric pressure is known as *electromotive force (emf)* or *voltage (E).* The source of this force may be a generator or a battery.

If you increase the pressure on the electrons in a conductor, a greater current will flow, just as an increased pressure on water in a pipe will increase the flow.

RESISTANCE

Electrical resistance (R) is that property of an electric circuit that opposes the flow of current. The unit of resistance is known as the *ohm* (Ω).

WATT

Power (P) is the rate of doing work. In a dc circuit, power is equal to the product of the current times the voltage, or P = I x E. The practical unit of power is the watt (W) or kilowatt (kW) (1,000 watts). Power in an ac circuit is computed in a slightly different way. If you are interested in how ac power is computed, see chapter 4 of *Introduction to Alternating Current and Transformers,* NAVEDTRA 172-02-00-85.

GENERATOR TYPES AND DRIVES

A large amount of electricity is required aboard ship to power machinery that supplies air,

water, food, and other services. Communications between the various parts of a ship also depend on the availability of electric power. The generator is the power source for the ship's electrical system.

A generator operates most efficiently at its full-rated power output, and it is not practical to have one large generator operating constantly at reduced load. Therefore, two or more smaller generators that are operated at high load are installed aboard ship.

Two or more generators are usually installed aboard ship for another reason. If one generator is shut down because of damage or scheduled maintenance, there is still a source of power for lighting until the defective generator has been repaired. In addition, generators are widely spaced in the engineering spaces to decrease the chance that all electrical plants would be disabled by enemy shells.

Most generators used aboard ships are ac generators. However, since some dc generators are still in service, we will briefly discuss dc generators before moving on to ac generators.

DC GENERATORS AND EXCITERS

A dc generator is a rotating machine that changes mechanical energy to electrical energy. There are two essential parts of a dc generator:

1. The yoke and field windings, which are stationary, and
2. the armature, which rotates.

In the past, ship's service generators produced direct current. At present, practically all ships have 450-volt, 60-hertz (Hz), ac ship's service and emergency generators. The dc generators used in Navy installations for ship's service or for exciters operate at either 120 volts or 240 volts. The power output depends on the size and design of the dc generator. A typical dc generator is shown in figure 12-1.

AC GENERATORS

AC generators are also called *alternators.* In an ac generator, the field rotates, and the armature is stationary. To avoid confusion, the rotating members of dc generators are called *armatures;* in ac generators, they are called *rotors.*

The general construction of ac generators is somewhat simpler than that of dc generators. An ac generator, like a dc generator, has magnetic fields and an armature. In a small ac generator the armature revolves, the field is stationary, and no commutator is required. In a large ac generator, the field revolves and the armature is wound on the stationary member or stator.

The principal advantages of the revolving-field generators over the revolving-armature generators are as follows:

- The load current from the stator is connected directly to the external circuit without using a commutator.

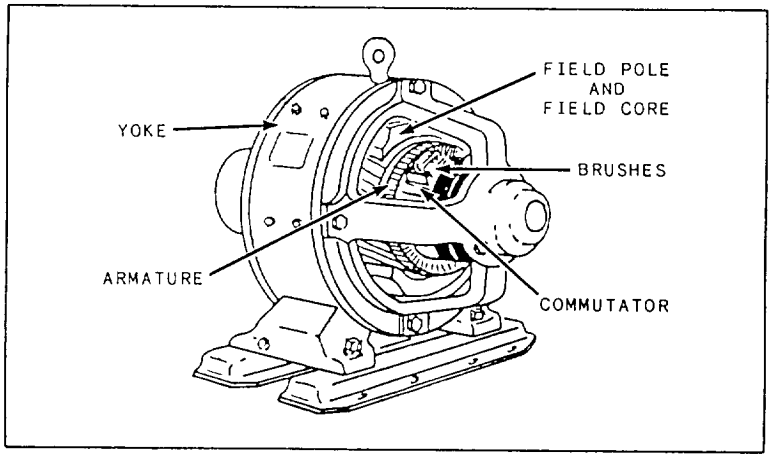

Figure 12-1.—A dc generator.

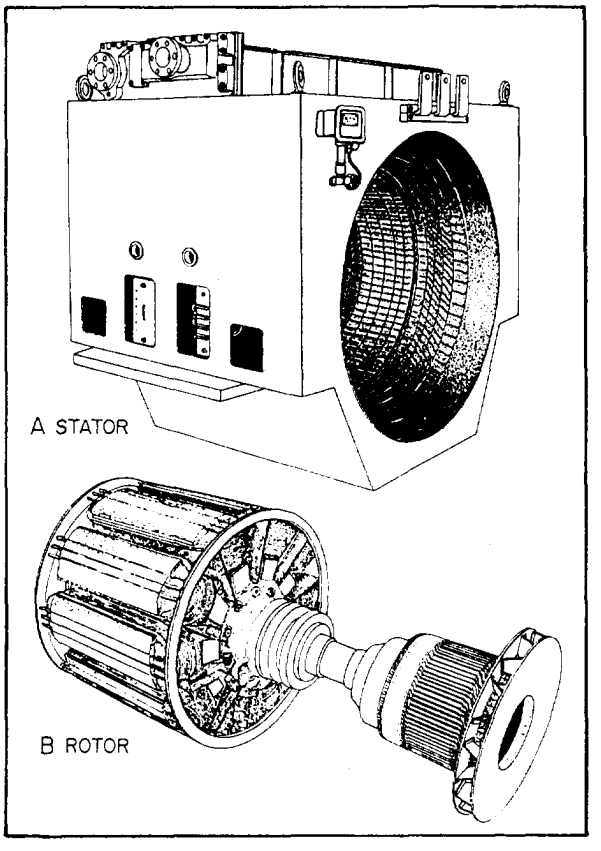

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Figure 12-2.—Low-speed, engine-driven alternator.

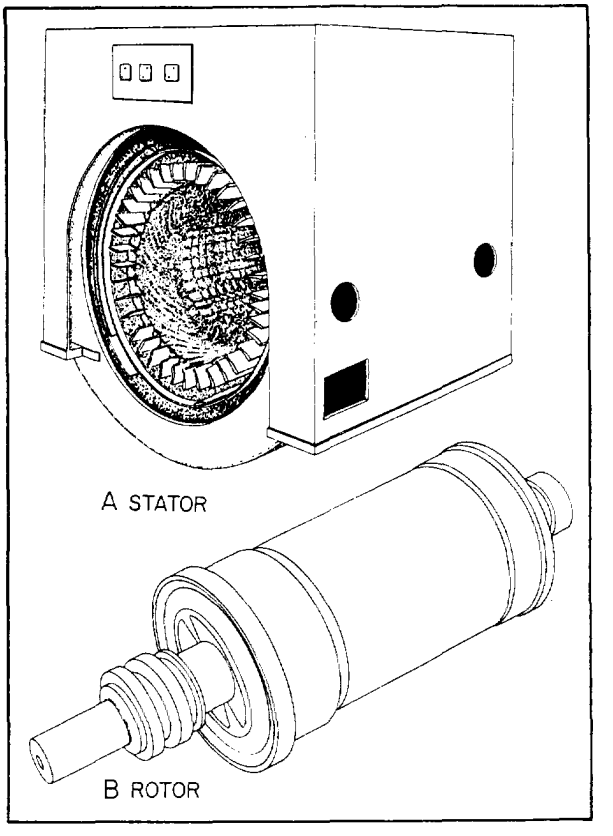

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Figure 12-3.—High-speed, turbine-driven alternator.

- Only two slip rings are necessary to supply excitation to the revolving field.
- The stator winding is not subjected to mechanical stresses that are due to centrifugal force.

The ac generators (alternators) used by the Navy are divided into two classes: (1) low-speed, engine-driven alternators and (2) high-speed, turbine-driven alternators.

The low-speed, engine driven alternator (fig. 12-2) has a large diameter revolving field, with many poles, and a stationary armature. The stator (view A) contains the armature windings. The rotor (view B) consists of protruding poles on which the dc field windings are mounted.

The high-speed alternator may be either steamer gas-turbine driven. The high-speed, turbine-driven alternator (fig. 12-3) is connected either directly or through gears to a steam turbine. The enclosed metal structure is part of a forced ventilation system that carries away the heat by circulating air through the stator (view A) and rotor (view B).

SHIP'S SERVICE TURBINE-DRIVEN GENERATORS

Ship's service generators furnish electricity for the service of the ship. Aboard most steam-driven ships of the Navy, these generators are driven by turbines. Large ships may have as many as six or eight ship's service generators and from one to three emergency diesel-driven alternators.

New cruisers and destroyers have three gas-turbine-driven ship's service generators and smaller diesel-driven emergency generators. These generators are located in three different compartments and separated by at least 15 percent of the length between perpendiculars to make sure they survive.

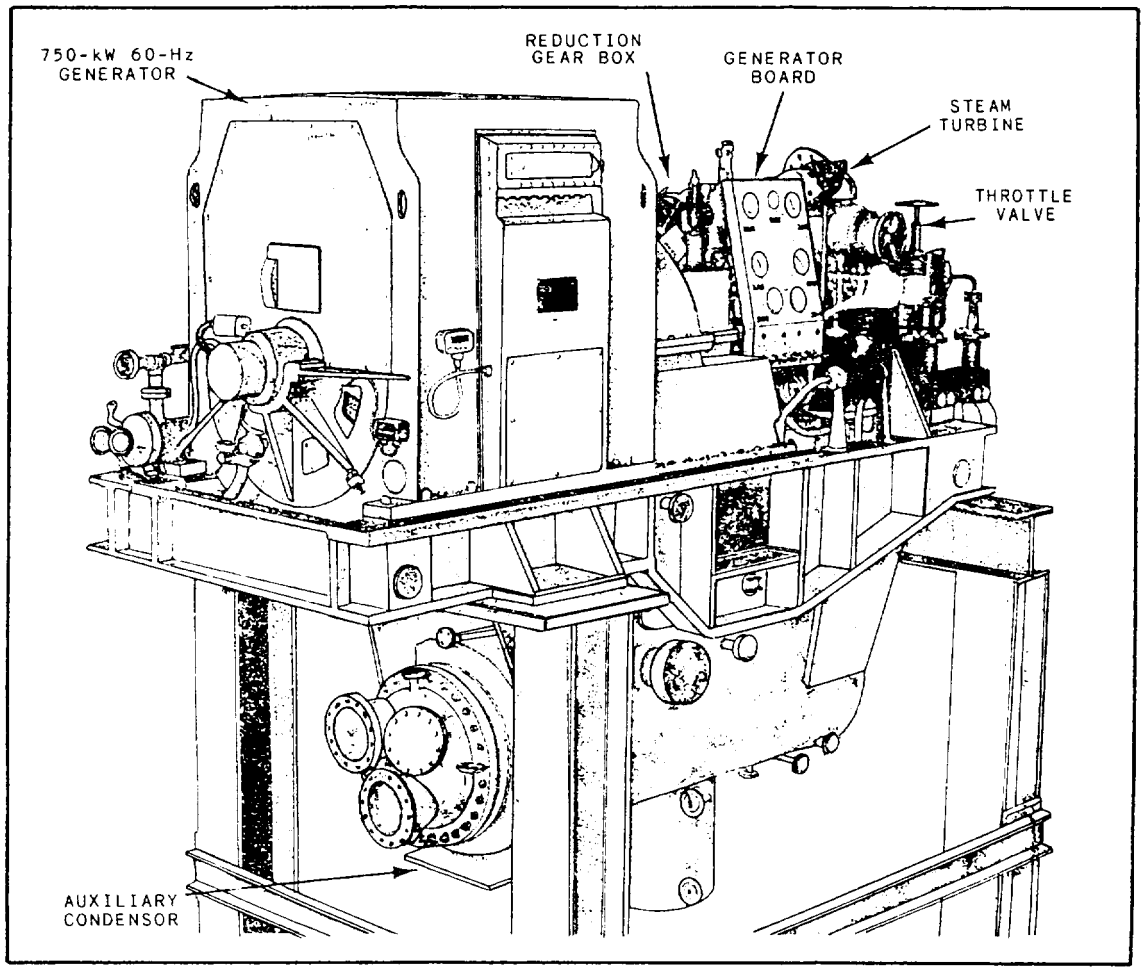

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Figure 12-4.—750-kW turbine generator set.

The type of ship's service generator commonly used aboard ships in the Navy is shown in figure 12-4. Although generator sets (turbo-generators) are built differently, all have the same arrangement of major parts.

Turbines used for driving the ship's service generators differ from other auxiliary turbines; they usually operate on superheated steam. The service generator turbine exhausts to a separate auxiliary condenser that has its own circulating pumps, condensate pumps, and air ejectors. Cooling water for the condenser is provided by the auxiliary circulating pump through separate injection and overboard valves.

Superheated steam is supplied to the ship's service generator turbine from either the main steam line or a special turbogenerator line that leads directly from the boiler. Aboard some ships, the turbine—in the event of condenser casualty—may be discharged directly to the atmosphere or to the main condenser when the main plant is in operation.

The ship's service generator must supply electricity at a constant voltage and frequency (hertz), which requires the turbine to run at a constant speed even when loads vary. Constant speed is maintained by a speed-regulating governor. The turbine also has overspeed and back-pressure trips, which automatically close the throttle if the turbine exceeds acceptable operating conditions. A manual trip is used to close the throttle quickly if there is damage to the turbine or to the generator. The shaft glands of the ship's service generator turbine are supplied with gland-sealing steam. The system is similar to that used for main propulsion turbines. Other auxiliary turbines in naval use are seldom, if ever, provided with gland-sealing systems.

DIESEL-DRIVEN GENERATORS

Practically all Navy ships are equipped with diesel-driven emergency generators. Diesel engines are particularly suited for this application because of their quick starting ability. Emergency generators furnish power directly to the radio, radar, gunnery, and vital machinery equipment through an emergency switchboard and automatic bus transfer equipment.

The typical shipboard plant consists of two diesel emergency generators, one forward and one aft, in spaces outside engine rooms and firerooms. Each emergency generator has its own switchboard and switching arrangement. This controls the generator and distributes power to certain vital auxiliaries and a minimum number of lighting fixtures in vital spaces.

The capacity of the emergency units varies with the size of the ship. Regardless of the size of the installation, the principle of operation is the same.

You may obtain detailed information concerning the operation of diesel-driven generators from appropriate manufacturers' technical manuals.

MOTOR GENERATORS

Aboard Navy ships, certain weapons, interior communications, and other electronics systems require closely regulated electrical power for proper operation. Special, closely regulated motor generator (MG) sets supply this power (usually 400 Hz). Any given ship has several MGs to provide power to specific loads. These MGs are often of different ratings. The rating of an MG set can be less than 1 kW or as large as 300 kW. MGs can also be used to provide electrical isolation. Isolation is required when certain loads cause distortion of the power and adversely affect the operation of other equipment.

The MG set (fig. 12-5) is generally a two-bearing unit. (Older units often consist of a separate motor and generator connected together and mounted on a bedplate.) The frame is of one-piece construction. The stationary component parts of the motor and generator are press fit into a welded steel frame. The rotating elements are mounted on a single one-piece shaft. The MG is usually deck mounted horizontally on its own integral feet; however, some specially designed, vertically mounted units are also provided. MGs with 100-kW power and larger are usually cooled by a water-air cooler mounted on top of the MG.

Solid-state voltage and, often, frequency regulating systems are provided on MGs. They are mounted either in a control box, which is directly mounted on the MG for forced-air cooling, or in bulkhead-mounted control panels. The voltage

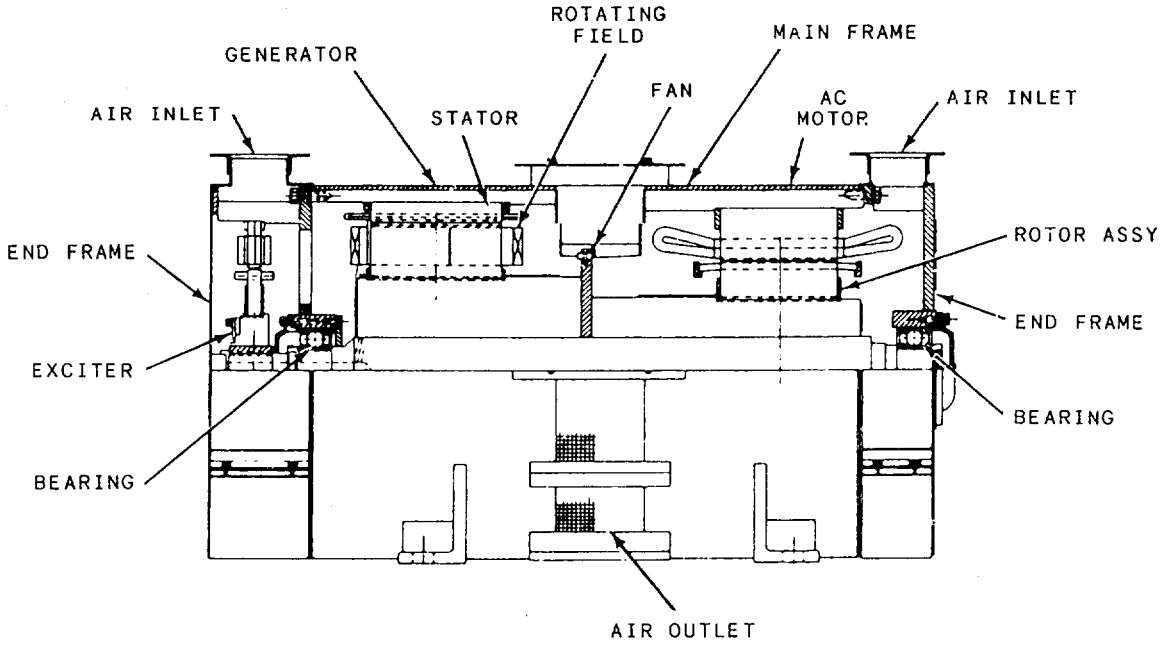

Figure 12-5.—Motor generator.

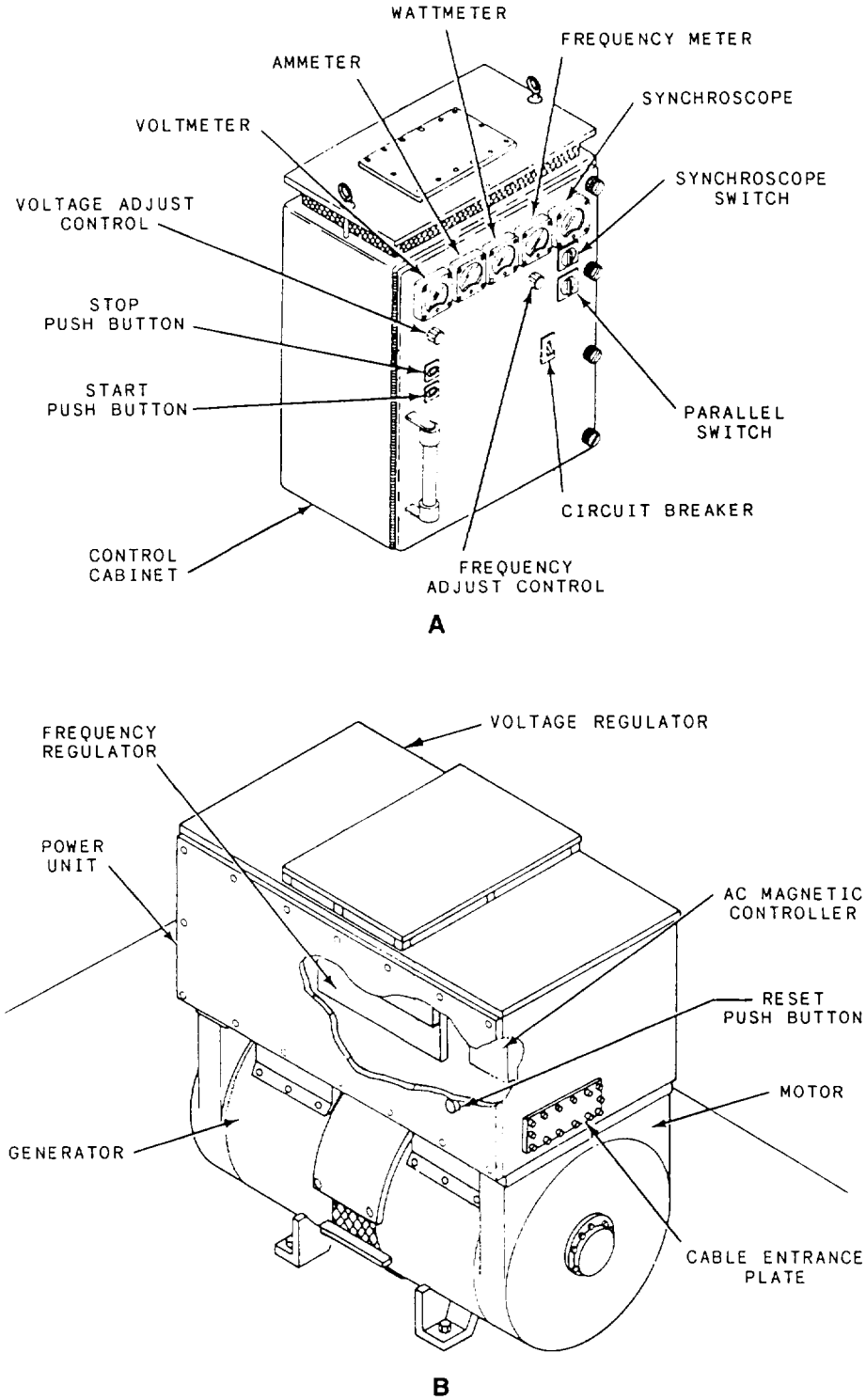

Figure 12-6.—3O-kW motor generator.

regulator (fig. 12-6) controls the voltage output of the generator portion of the MG. This voltage may be either 450 volts or 120 volts, depending on the application. The frequency regulator controls the speed of the MG motor, and therefore the output frequency of the MG. Voltage- and frequency-sensing circuits continuously sample the output of the MG and provide feedback to their respective regulators. By doing this, they maintain the output voltage and frequency at the required level (usually to plus or minus one-half percent of the rated value). A magnetic controller is provided to start and stop the unit. It also protects the MG from operating at continuous overload and removes power to the MG if there is an undervoltage condition.

STATIC FREQUENCY CHANGERS

Frequency changers step up and refine the frequency of the ship's 60-Hz electrical power to 400 Hz. Most of the frequency changers installed on board combat ships are static frequency changers. Static frequency changers have no rotating parts—they are all solid state. Static frequency changers are reliable and efficient; they are the only ones that provide the high-quality power demanded by modern weapon systems.

A static frequency changer usually consists of a three-phase rectifier and a three-phase inverter. The rectifier changes the 60-Hz ac incoming power. The inverter converts the dc power delivered by the rectifier into 400-Hz output power through the use of many input filters and transformers.

SHIPBOARD POWER DISTRIBUTION

Most ac power distribution systems in naval ships are 450-volt, three-phase, 60-Hz, three-wire systems. The ship's service generator and distribution switchboards are interconnected by bus ties. This arrangement makes it possible to connect any switchboard to feed power from its generators to one or more of the other switchboards. The bus ties also connect two or more switchboards so that the generator plants can be operated in parallel. In large installations (fig. 12-7), distribution to loads is from the generator and distribution switchboards or switchgear groups to load centers, distribution panels, and the loads, or directly from the load centers to some loads.

On some ships, such as large aircraft carriers, zone control of the ship's service and emergency distribution is provided. A load center switchboard supplies power to the electrical loads within the electrical zone in which it is located. Thus, zone control is provided for all power within the electrical zone. Emergency switchboards may supply more than one zone.

GENERATOR AND DISTRIBUTION SWITCHBOARDS

Ship's service 450-volt, ac switchboards are generally of the dead-front type (no live connections exposed). These switchboards are built to provide efficient and safe operation of the electrical system. A typical power distribution system in a destroyer consists of four generators (two forward and two aft) and two distribution switchboard. The distribution switchboards are set up so that each one controls two generators. All the necessary apparatus for generator control and power distribution is incorporated in its associated switchboard (fig. 12-8).

The ship's forward distribution switchboard is also used as the control switchboard. This switchboard has instruments and controls for the aft generators. These instruments and controls are necessary to parallel the generators to equalize the load. An automatic voltage regulator is mounted on each switchboard to control the generator field excitation and to maintain a constant ac generator voltage during normal changes in load.

Two emergency diesel generator sets provide electric power for limited lighting and for vital auxiliaries if the ship's service power should fail. These units are located in the forward and aft emergency generator rooms. The forward emergency switchboard is normally energized from the forward ship's service switchboard. The aft emergency switchboard is normally energized from the aft ship's service switchboard.

Dc power distribution systems are in use on some older ships that have large deck machinery loads. These systems, which consist of the ship's service generator and distribution switchboards, are similar to the ac systems. On newer ships, dc power is provided at the load with rectifiers that change the ac power to dc power, when required.

COMPONENTS OF A SWITCHBOARD

Each switchboard includes one or more units, such as a bus tie unit, a power distribution unit, lighting distribution units or transformers, and

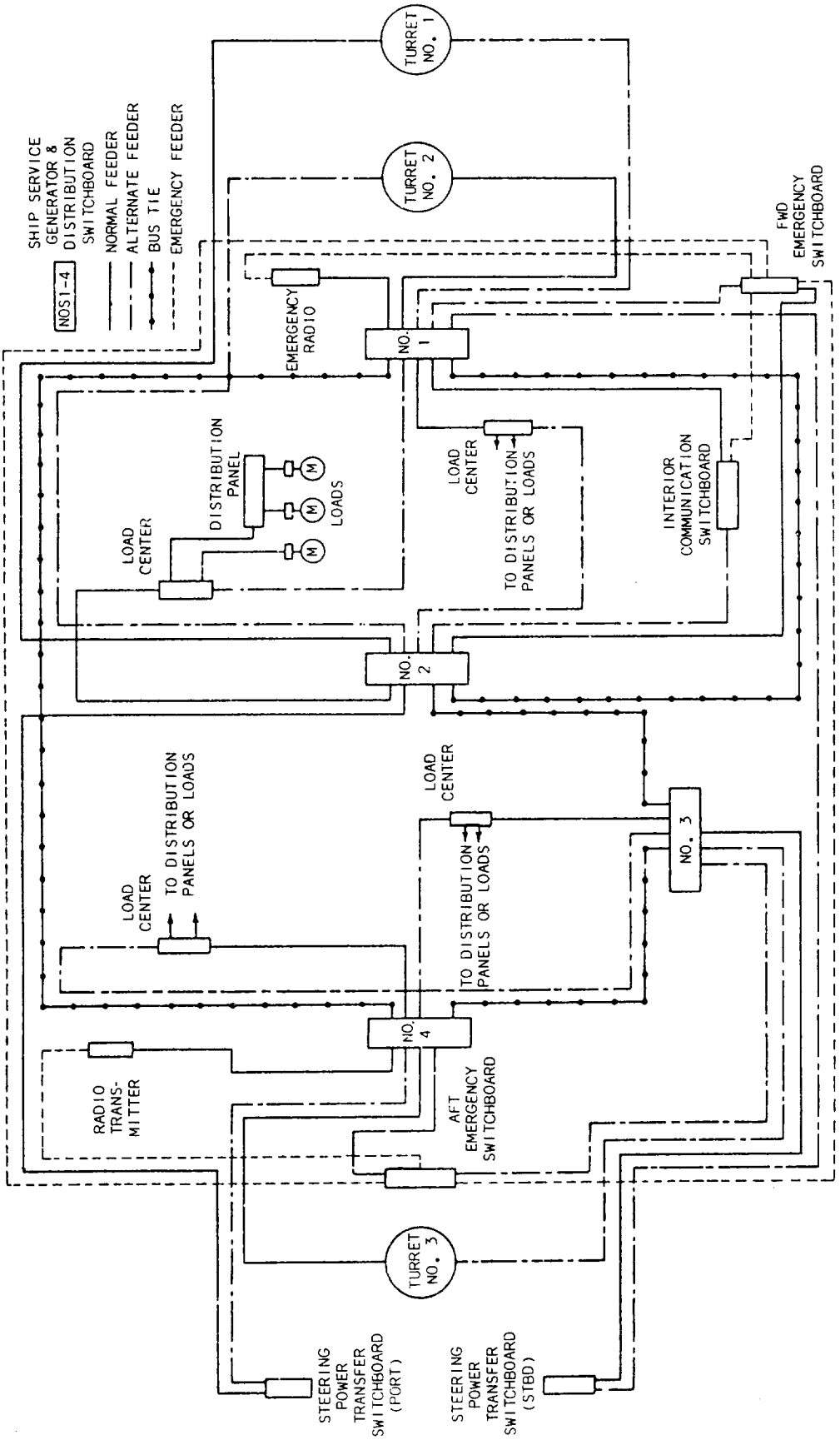

Figure 12-7.—Power distribution in a large combatant ship.

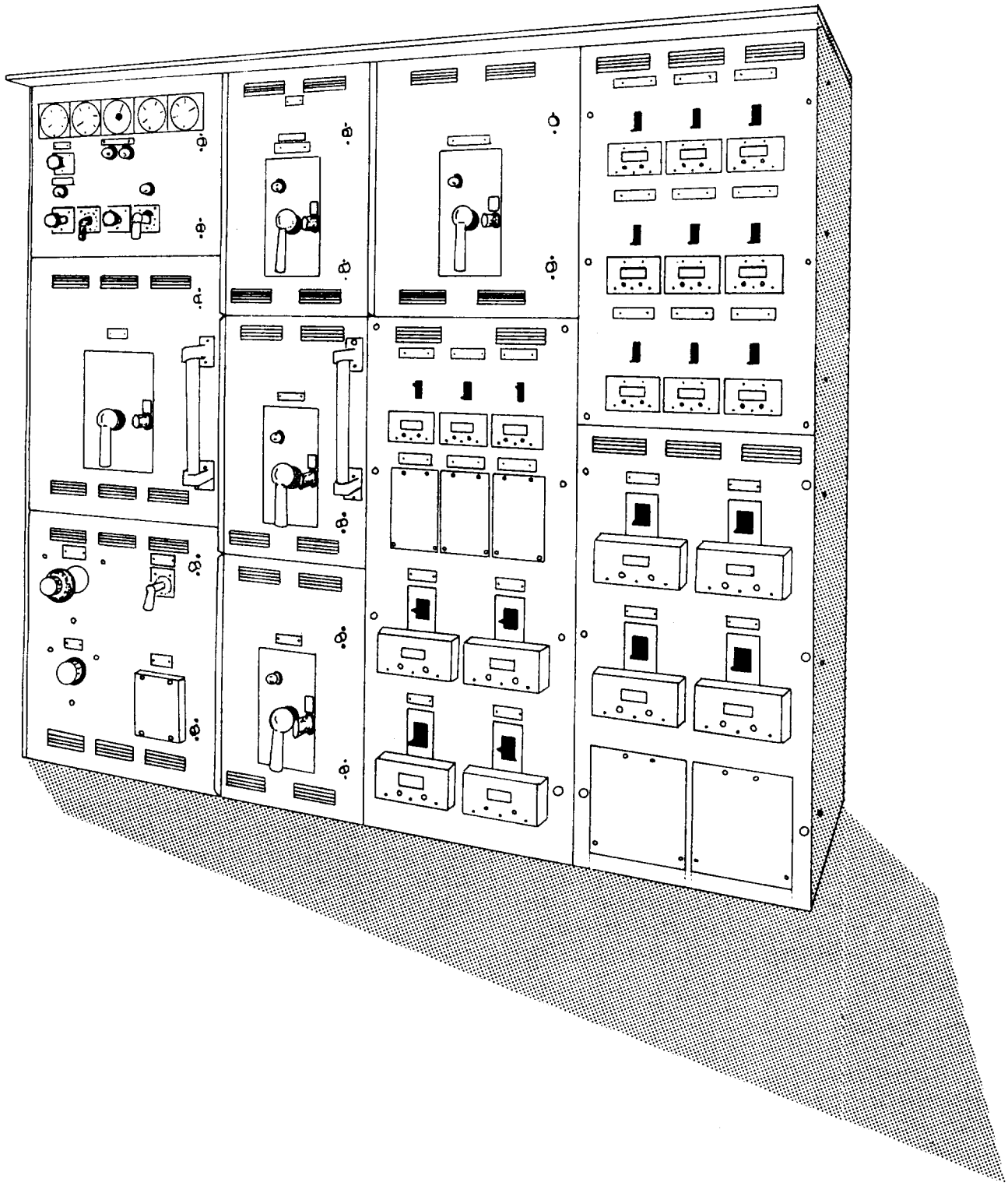

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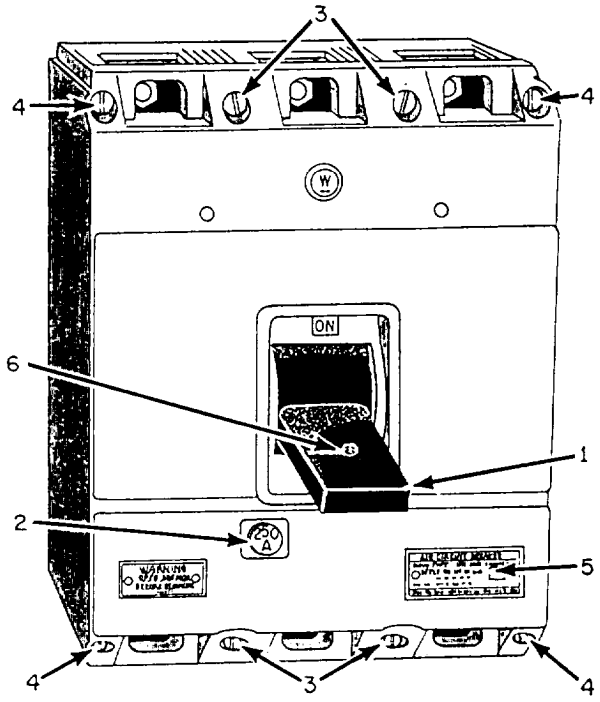
Figure 12-8.—1SB ship's service switchboard, DDG-2 class destroyer.



1. Operating handle shown in latched position
2. Ampere rating marker
3. Mounting screws
4. Cover screws
5. Breaker nameplate
6. Cotter key hole

Figure 12-9.—Circuit breaker.

lighting distribution panels. Large circuit breakers connect ship's service and emergency generators to the power distribution system. They are also used on bus ties and shore connection circuits. Smaller circuit breakers, rated according to the load they handle, are also installed on switchboards and on distribution panels throughout the ship.

Circuit Breakers

Circuit breakers (fig. 12-9) are used to isolate faulty circuits, to provide a mechanical means to disconnect the electrical power for equipment maintenance, and to serve as overload protection. These circuit breakers are part of the switchboard equipment. Circuit breakers, rather than fuses, are used in circuits that carry large currents. They can be operated for an indefinite period, and their action accurately controlled.

Circuit breakers open automatically when the current (load) on the circuit exceeds a preset value, Circuit breakers used with shipboard equipment are not susceptible to tripping when subjected to heavy shocks (such as those caused by gunfire). Circuit breakers are used on all rotating electrical machinery and feeders to vital loads, such as gun mounts and searchlights.

In addition to overload relays, reverse power trip relays are provided on ac generator circuit breakers. These units are designed to open and prevent motorizing a generator in the event of a power reversal. They are mounted within the generator switchboard.

Voltage Regulators

Voltage regulators are installed on the associated switchboards. They are used for ac ship's service and emergency generators. A voltage regulator maintains generator voltage within specified limits. The switchboard operator adjusts or sets the generator voltage at any value within certain limits. When additional loads are applied to a generator, there is a tendency for the voltage to drop. The automatic regulator keeps the voltage of a generator constant at various loads.

Indicating Meters

All the important switchboards aboard ship are provided with electrical meters. Electrical meters, somewhat like gauges and thermometers, show the operator what is taking place in the electrical machinery and systems. Electrical meters are of two general types—installed meters (on switchboards) and portable meters. Some of the most common meters used are voltmeters, ammeters, kilowatt meters, and frequency meters (fig. 12-10).

ELECTRIC MOTORS

Electric motors are used aboard ship to operate guns, winches, elevators, compressors, pumps, ventilation systems, and other auxiliary machinery and equipment. There are many reasons for using electric motors: they are safe, convenient, easily controlled, and easily supplied with power.

A motor changes electrical energy into mechanical energy. There are important reasons for changing mechanical energy to electrical energy and back again to mechanical energy. One reason is that electric cables can be led through decks and bulkheads with less danger to

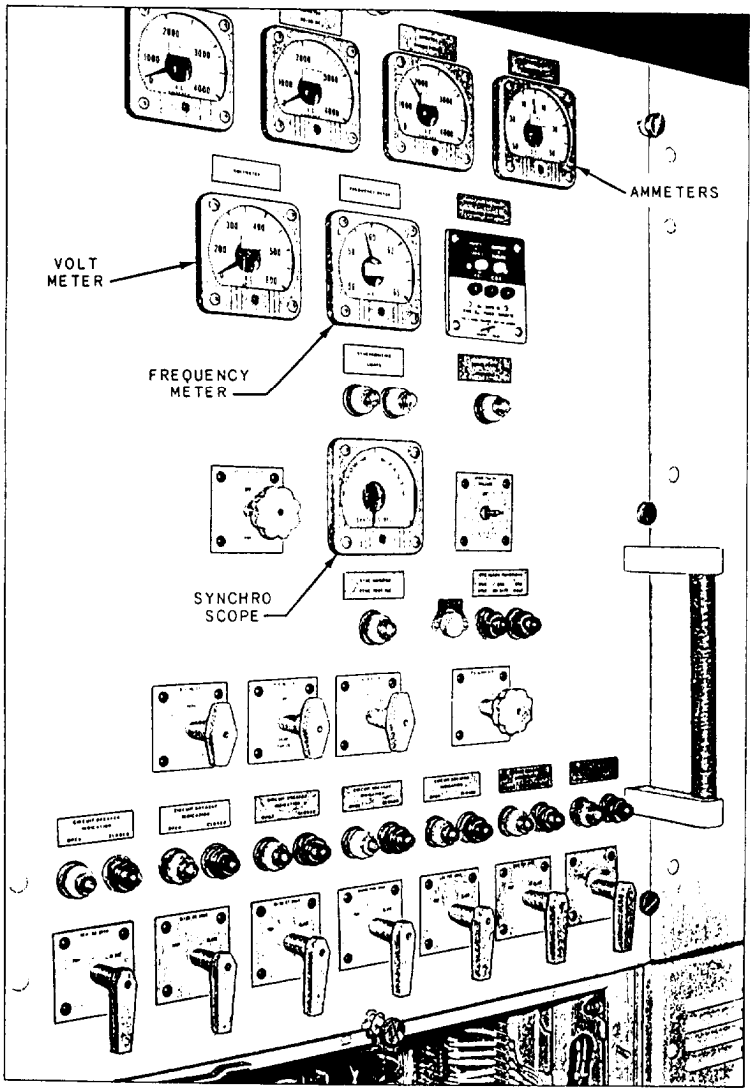


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Figure 12-10.—Switchboard indicating meters.

watertight integrity than steam pipes or mechanical shafts. Another reason is that damage to a steam line can cause steam to escape, resulting in personnel injury. If an electric cable is used and a fault occurs, the circuit breaker protecting the cable opens automatically. The ac motor is used extensively by the Navy because it is smaller and requires less maintenance than the dc motor.

Most ac motors used aboard ship use three-phase, 60-Hz, 450-volt power. Although most ac motors operate at a single speed, some motors, such as the prime movers for fuel oil pumps, lube oil pumps, and ventilation fan motors, have two operating speeds.

MOTOR CONTROLLERS

Controlling devices are used to start, stop, speed up, or slow down motors. In general, these controllers are standard equipment aboard ship and are operated either manually, semi-automatically, or automatically. They are drip-proof and shock resistant. In some installations, the controllers are operated by remote control, with the switch at a convenient location.

Motor control devices (controllers, master switches, and electric brakes) protect the equipment to which they are connected. Controllers provide protective and governing features for every type of shipboard auxiliary. Various types of master switches are used to govern the

controllers. Electric brakes are used to bring a load to rest, or to hold it at rest, when electric power to the motor is cut off. Aboard ship, electric brakes are used primarily on hoisting and lowering equipment such as cranes, winches, and windlasses.

Most controllers function simply to start or to stop auxiliary machinery; but, some controllers also provide for reversal of direction or multispeed operation. Motor controllers, sometimes called *starters*, have overload protective devices to prevent burning out the motor. Most controllers cut out automatically when the electric power fails, and they have to be restarted manually. This type of motor controller is called a low-voltage protection (LVP) controller. Another type of motor controller, which is used primarily with vital loads, is called a *low-voltage release (LVR) controller*. The LVR controller disconnects the motor from the supply voltage if the supply voltage drops below a predetermined level. When the supply voltage returns to a normal level, the LVR controller automatically restarts the motor.

BATTERIES

Aboard ship, batteries are one of the sources for emergency and portable power. Storage batteries are used to power emergency equipment, ship's boats, and forklifts. The storage battery is also used as a source of energy for emergency diesel generators, gyrocompasses, and emergency radios.

You should be familiar with safety precautions you must follow when you work around batteries. Batteries must be protected from salt water, which can mix with the electrolyte (the acid solution) and release poisonous gases. Salt water in the electrolyte also sets up a chemical reaction that will ruin the battery. If a battery is exposed to salt water, notify the electric shop immediately.

Storage batteries, when being charged, give off a certain amount of hydrogen gas. Battery compartments should be well ventilated to discharge this gas to the atmosphere.

WARNING

Flames or sparks of any kind, including lighted cigarettes, should never be allowed in the vicinity of any storage battery that is being charged.

When the battery is in a low or discharged state and does not perform properly, you should notify the Electrician's Mate (EM).

PORTABLE ELECTRICAL EQUIPMENT

Aboard ship, you will perform many jobs using small, portable electrical tools. Because portable electrical tools are commonly used under a variety of conditions, they are subject to damage and abuse.

The Navy has a good electrical tool safety program. This program is carried out by qualified EMs. However, EMs can only make safety checks on tools that are brought to their attention. Electrical handtools should be inspected before each use to make sure the power cord is not nicked or cut, and the plug is connected properly. Electrical handtools should be turned in to the electricians as prescribed by the electrical safety program.

BATTLE LANTERNS

Relay-operated hand lanterns (fig. 12-11, view A), usually called *battle lanterns*, are powered by dry-cell batteries. Hand lanterns are provided to give emergency light when the ship's service and emergency/alternate lighting systems fail. These lanterns are placed in spaces where continual illumination is necessary, such as machinery spaces, control rooms, essential watch stations, battle dressing stations, and escape hatches. All auxiliary machinery with gauge boards should be provided with a battle lantern to illuminate the gauge board in the event of a casualty. The battle lantern should not be removed from its mounting bracket except in an emergency. **Do not use it as a flashlight in nonemergency situations.**

The relay control boxes for battle lanterns are connected to the emergency lighting supply circuit (or to the ship's service lighting circuit) in which the lantern is installed. If power in the circuit fails, the relay opens and the batteries energize the lantern.

Relay-operated battle lanterns are capable of operating for a minimum of 10 hours before the light output ceases to be useful.

Similar hand lanterns (fig. 12-11, view B), which are not connected to relays, are installed throughout the ship to provide light in stations

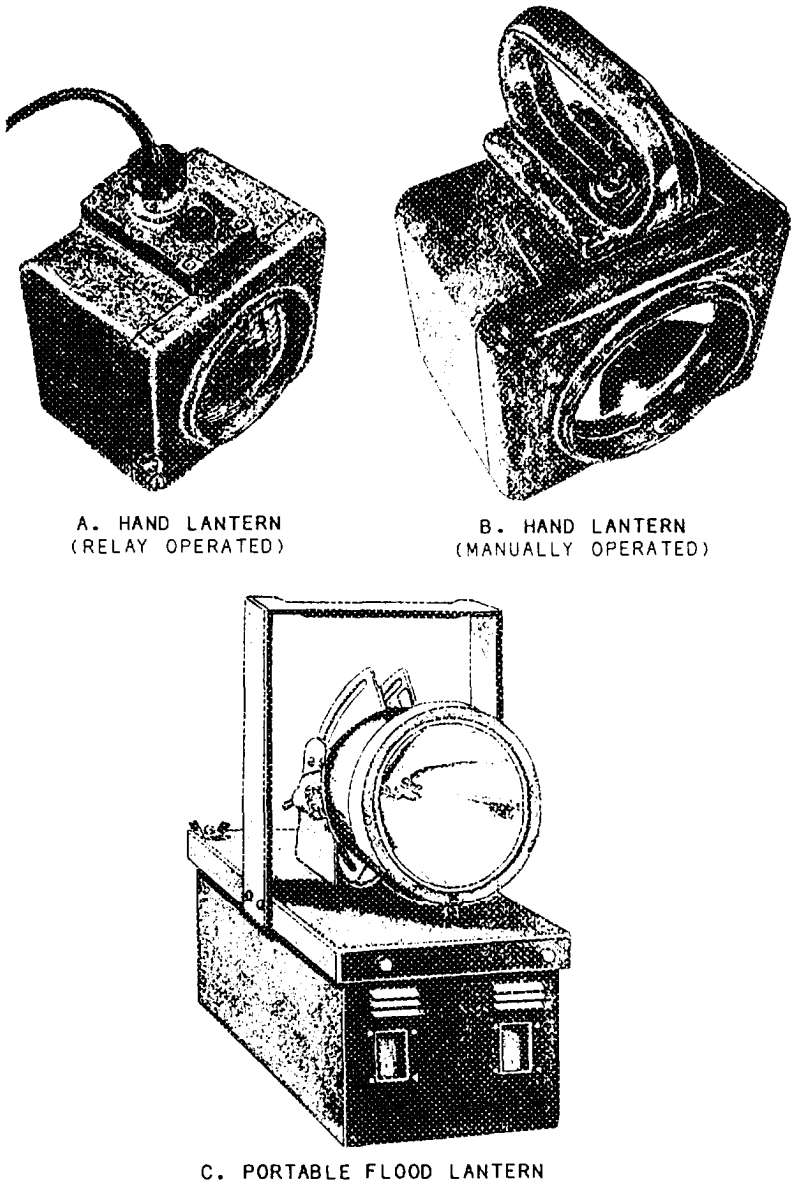

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Figure 12-11.—Special lights.

that are occasionally manned. These lanterns are manually operated. If used in an emergency, the manually operated hand lanterns should ALWAYS BE RETURNED TO THEIR ORIGINAL LOCATION.

SEALED-BEAM LIGHTS

Sealed-beam lights are a type of flood lantern (fig. 12-11, view C). These lanterns are used to give high-intensity illumination in damage control or other emergency repair work. These units consist of a sealed-beam light similar to that used for automobiles. The sealed-beam light, powered by four small wet-cell storage batteries, is mounted in the battery case and fitted with a handle for convenient carrying. A sealed-beam lamp will operate for 3 hours before the batteries require recharging. When the batteries are at full charge, the beam has an intensity similar to that of the headlight on an automobile. At the end of 3 hours, the light output will gradually drop to about one-half its original brilliance. These sealed-beam lights are normally stored in the damage control repair lockers.

SHIPBOARD ELECTRICAL SYSTEMS AND CONNECTIONS

As a Fireman, you should be familiar with the power and lighting distribution systems, and shore power connections. You will find greater detail on this and other shipboard electrical equipment in chapter 320, *Naval Ships' Technical Manual.*

POWER DISTRIBUTION SYSTEMS

A power distribution system carries power from the generator switchboards to every part of the ship. This system consists of feeders, mains, submains, load center panels, and distribution boxes. The most important auxiliaries are supplied with normal, alternate, and emergency feeders through automatic bus transfer units, each with a separate source of power. Casualty power systems are installed aboard ship to provide electrical connections when both ship's service and emergency electrical systems are damaged.

LIGHTING DISTRIBUTION SYSTEMS

Lighting distribution systems are necessary to light the ship and to assist personnel in controlling damage. Two lighting systems are installed aboard combatant ships. These are ship's service lighting and emergency lighting. The ship's service lighting normally supplies all lighting fixtures. Emergency lighting circuits are supplied to vital machinery spaces, the radio room, the combat information center, and other vital spaces. The emergency lighting system receives power from the ship's service generators; but if normal power is lost, the emergency system is automatically powered by the emergency generators. Lighting distribution systems are similar to power distribution systems except for the following differences:

1. They are more numerous.
2. They have lower voltages (120 volts).
3. They have smaller panels and cables.

If an emergency power system is not installed, alternate supplies from another ships' service source can provide for services selected according to the basic principles of an emergency lighting system.

SHORE POWER CONNECTIONS

Shore power connections are installed at or near suitable weather deck locations. At these locations, portable cables from the shore, or from a ship alongside, are connected. Power can be supplied through these connections to the switchboard when ship's service generators are not in operation.

ELECTRICAL SAFETY PRECAUTIONS

There are certain safety precautions you should observe when working with or around electrical appliances and equipment. The following are some of the most common electrical safety precautions all shipboard personnel are required to follow:

Do not attempt to maintain or repair electrical equipment yourself. Leave the electrical work to the EMs and IC electricians.

- Check personal electrical equipment through the EMs to see if it can be used aboard ship.
- Observe and follow all pertinent instructions and electric warning signs aboard ship.
- Observe all safety precautions regarding portable electric lights and tools. (Use rubber gloves and goggles.)
- Remember, 120-volt electricity is very dangerous, especially aboard ship.
- Do not touch or operate any device that has a danger or caution tag attached to it without first contacting the EOOW.
- Do not go behind electrical switchboards.
- Do not touch bare electric wires or connections; assume all circuits to be **ALIVE.**
- Do not remove steamtight globes from lighting fixtures.
- Do not remove battle lanterns from their locations.
- Do not use manually operated hand battle lanterns for unauthorized purposes. Each person should have his/her own flashlight.

- Do not use electric cable runs to hoist or support any weight.
- Do not use the wireways for storage.
- Do not permit water to get into electrical equipment.
- Remember, a flame, spark, or lighted cigarette can cause a disastrous battery explosion.
- Remember, electrolyte from a storage battery can cause severe burns and can damage equipment and clothing.
- When you repair equipment that is driven by a motor, have an electrician disconnect the circuit and tag it as out of commission.
- Do not start or operate electrical equipment when flammable vapors are present.
- Learn the electrical safety precautions applicable to your assigned duties and duty station. By thoroughly understanding electrical safety precautions, you will help prevent injury to yourself and damage to equipment.
- If YOU are ever in doubt about the operating condition of electrical equipment, **CALL AN ELECTRICIAN.**

SUMMARY

This chapter has introduced you to shipboard electrical equipment and systems. It has given you information about electricity, generators, shipboard power distributions, electric motors, controllers, batteries, port able electrical equipment, shipboard electrical systems and connections, and electrical safety precautions. You should pay particular attention to the safety precautions that have been included within this chapter and in all other chapters. Even though electricity has made our lives easier, it can kill you in an instant if it is not used properly.