American Railway Signaling Principles and Practices

CHAPTER IX

RECTIFIERS

Including Fundamental Theory of Alternating Currents

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General.

Recent (1930) developments in the signal field, principally the introduction of light signals, have led to the extensive use of alternating current. (In the appendix is given the fundamental theory of alternating currents.) In order to provide continuous signal operation during periods of power interruptions and for operating the direct current circuits, it is necessary to provide an auxiliary source of power. This may consist of either primary or storage batteries. When a storage battery is used, some means must be provided to keep it charged and the usual method is to change the alternating current to direct current and cause a uni-directional current to flow into the battery. Rectifiers are used for this purpose, employing the alternating current floating method which will be described later. When a primary battery is used, a rectifier may be connected across the battery terminals and adjusted to carry the normal direct current load, thereby prolonging the life of the primary battery to a considerable extent. However, provision should be made to allow a current of a few milli-amperes to flow from the battery under normal conditions to keep the battery in an active condition.

The Signal Section, American Railway Association, defines Rectifier as: A device for changing alternating current into a pulsating uni-directional current.

Types.

There are many rectifying devices on the market at present which have been found suitable for signal work: namely, mercury arc, gas tube, mechanical or vibrating, electrolytic and copper-oxide rectifiers.

Motor-Generator Sets

A motor-generator set (when used in lieu of a rectifier) consists of a motor operated from a local alternating current supply which drives a generator for supplying direct current to charge the battery. In the smaller sizes, as used in signal work, induction motors are used exclusively. Both machines are mounted on the same base and are direct-connected as shown in Fig. 1.

This method of rectifying alternating current was, perhaps, the first used in the signal field and has been used, principally, to charge batteries at power interlocking plants.

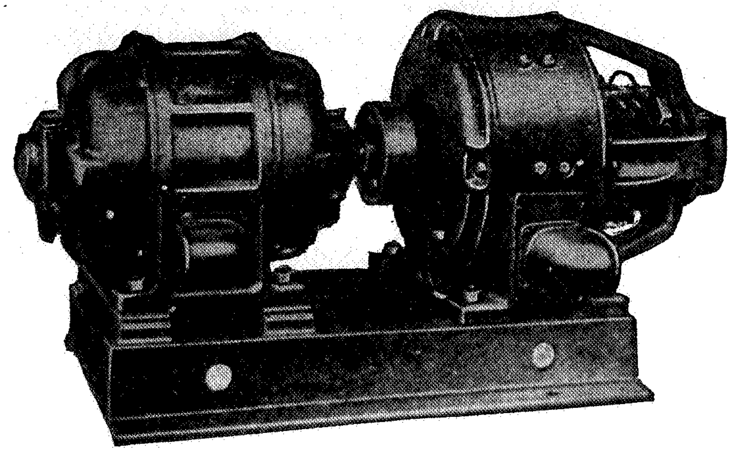

Fig. 1.
Motor-Generator Set.

In the earlier installations the batteries generally were charged at the normal rate until fully charged, at which time the charge would be discontinued, and the battery, until discharged, would carry the load. The battery would then be given another charge. This procedure is called cycle charging.

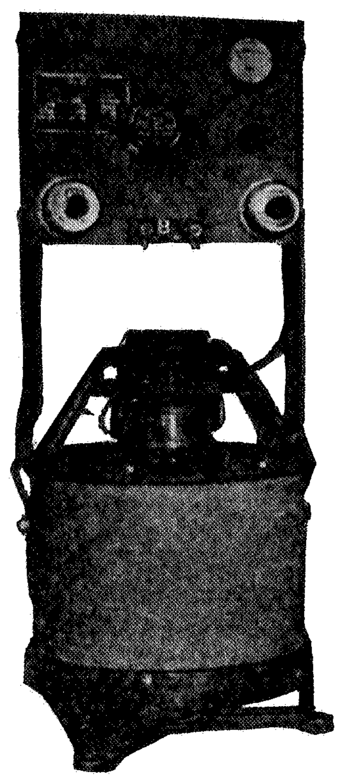

Fig. 2.
Automatic Motor-Generator Set.

The operation of the motor-generator may be arranged for either automatic or non-automatic control. The automatic panel is used where there is no attendant to shut down the set when the charge is completed, and is used in connection with what is known as a contact making ampere-hour meter. It is also equipped with a contactor which does not close until the generator voltage is higher than the battery voltage. Figure 2 illustrates a panel and motor-generator arranged for automatic operation.

To assure continuity of operation, these motor-generators are, if desired, furnished in twin sets as shown in Fig. 3, one set being operated at a time, thus providing periods of rest for each set.

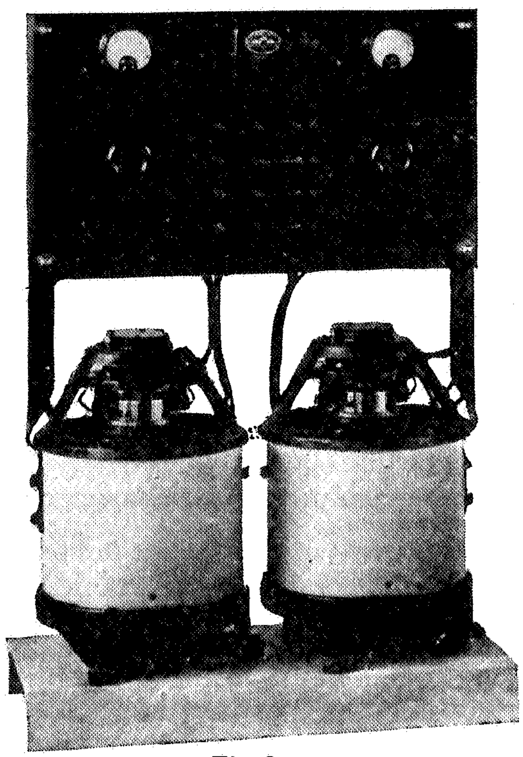

Fig. 3.
Twin Motor-Generator Set.

Instructions.

Motor-generator sets should be maintained and operated in accordance with the following instructions:

1. Motors and generators must be kept clean and dry. They must not be exposed unnecessarily to smoke, dust, grit, acid fumes, or battery gases.

2. They must, when necessary, be covered with a waterproof covering. This covering must be removed to insure proper ventilation when set is in use.

3. Voltage and current rating shown on name plate must not be exceeded.

4. Oil-wells must be kept supplied with an approved lubricating oil. Wells must be drained periodically by removing drain plug, washed with gasoline and refilled. When replacing drain plug, it must be set tight to prevent leakage.

5. Oil rings must be checked frequently when machine is running to see that they revolve freely and carry oil to the shaft.

6. Over-heating must be avoided. While machine is running the bare hand must be applied to various parts of the machine occasionally to detect excessive heating. If temperature is such that it cannot be borne by the hand, it is excessive, in which case the machine must be stopped at once and the cause of heating corrected before again starting the machine.

7. Commutator must be kept smooth, clean and dry. A chamois skin or a soft cloth free from lint must be used for cleaning commutators. After cleaning, they must be wiped with a soft cloth slightly moistened with oil or other approved lubricant.

8. Commutators which become rough and cause brushes to spark or chatter excessively must be surfaced with an approved surfacer. After being surfaced, they must be carefully cleaned to insure removal of all foreign substances.

9. Brushes must be of the quality and design recommended by the manufacturer.

10. Brushes must be kept in proper adjustment to prevent sparking.

11. Brushes must move freely in the brush holder and rest with full surface contact on the commutator or slip rings.

12. Worn brushes must be replaced before binding in the brush holder occurs.

13. New brushes must be fitted by drawing No. 00 or finer sandpaper under them, smooth side of paper to the commutator or slip rings. Paper must be drawn only in the direction of rotation of the armature.

14. After fitting brushes, commutator, slip rings, brushes and brush holders must be cleaned of all dust and grit.

15. If armature and/or field coils become wet, they must be thoroughly dried before running machine under load, as the moisture is likely to damage the windings.

16. The clearance between rotor and stator must be checked periodically.

17. Insulation resistance tests of armature, field coils and brush holders must be made at least once each year and readings recorded.

18. Minimum insulation resistance permissible is 1 megohm. If insulation resistance is less than 1 megohm, immediate action must be taken to locate and remedy the cause.

19. Fuses of specified capacity and type must be used, and a sufficient supply of tested fuses must be kept on hand for immediate use.

20. Bolts, nuts, screws, pins, binding posts, rivets, nut locks, jam nuts, etc., must be kept in place, in good condition and tight.

21. Guards and railings provided for exposed moving parts must be kept in place and in good condition.

22. Where applicable the following instructions for the installation and operation of switchboards should be followed:

General.

23. These instructions are intended to cover in a general way the important points in switchboard installations.

24. Drawings, instruction books and tags attached to the different devices must be carefully read and followed.

25. Instructions furnished with instruments and switchboards shall be left in station after completion of work for use of station operator.

Installation

Regulations.

26. Installation must comply with local requirements and the regulations of the National Board of Fire Underwriters.

Unpacking.

27. Shipping notice sent under separate cover indicates:

(a) Number of packages in the shipment.

(b) Contents of each package.

(c) Package number from which may be determined in what package any piece of apparatus is packed.

(d) Item number of each piece of apparatus in each package.

(e) Style or identification number of each piece of apparatus in each package.

28. Switchboards must be unpacked with great care so that nothing may be broken or marred, and that no screws, bolts or other parts may be left in the packing.

29. When unpacking a crated panel, the crate should be turned on its back with the front of panel up. The boards and bracing holding panel must be removed and panel lifted from crate.

30. After the parts have been unpacked they must be examined carefully to see that no foreign material has lodged in the crevices of the apparatus and that parts are in no way injured. Such parts as

will not be required immediately must be put away in an orderly manner and in a dry place.

Location.

31. Ample working space should be provided in front and rear of the switchboard. Allowances should be made for possible additions to the switchboard and to the wiring.

32. Electrically-operated switches, when not mounted on controlling board, must be placed as close as practicable to the unit controlled, due regard being given to convenience of connections, safety in handling and fire hazard.

33. Rheostats should be so located that proper natural ventilation is secured. When this is impractical, special means for ventilation must be provided.

Foundation.

34. The foundation for the switchboard must be level and heavy enough so that the panels will not be thrown out of line by settling.

35. Unless otherwise specified on the drawings, standard 6-inch channels must be used.

Assembly.

36. Supporting framework must first be set up, preferably for the first three or four panels. The first two panels must then be placed in position and bolted loosely to the supporting irons to avoid cracking the marble or slate when lining up the panels. With all panel bolts, either paper or fibre washers must be used between the panel and the iron work. The panels must then be carefully leveled and when in correct alignment, the panel bolts must be securely tightened. Similar procedure must be followed with the other panels, always having the supporting framework for one or two panels in place and lined up ahead of the panels which are being placed in position, until all panels are in place.

37. When framework is to be grounded, all joints must be scraped clean of paint and dirt before assembling.

38. The different devices which have been shipped separately must then be placed on their respective panels.

Connections.

39. The connections must be assembled on the back of the panels in accordance with the switchboard drawing.

40. All wiring must be done in a neat and safe manner.

41. All parts that are to form joints must be clean and free from moisture and burrs. Nuts on current-carrying studs must be

securely screwed against the connection bars or terminal lugs in order to give as good contact as possible.

42. After all joints are made up, all bus bars and bare copper conductors must be thoroughly cleaned with sandpaper and oil and given a coat of transparent lacquer to prevent the copper from tarnishing and to preserve a neat and bright appearance.

Recommended clearances.

43. The following table stating the clearances for live conductors in switchboard installation must be followed:

	Clearance to Ground in Inches			
Voltage	In air		On surface†	
of circuit	Recommended	Minimum	Recommended	Minimum
125	3/4	1/2	1 1/4	3/4
250	1	3/4	1 1/2	1
600	1 1/2	1	2	1 1/2
1200	2	1 1/2	2 1/2	2
2400*	2 1/2	2	..	2 1/2
3500	3	2 1/2	..	3
7500	4 1/2	3	..	..
15000	7	3 1/2	..	..

	Clearance Between Opposite Polarity in Inches			
Voltage	In air		On surface†	
of circuit	Recommended	Minimum	Recommended	Minimum
125	3/4	1/2	1	3/4
250	1	3/4	1 1/4	1
600	1 3/4	1	2	1 1/2
1200	2	1 1/2	2 1/2	2
2400*	2 1/2	2	..	2 1/2
3500	3 1/2	3	..	3 1/2
7500	5 1/2	4	..	..
15000	9	5	..	..

44. Recommended clearances must be maintained for busses and must, if possible, be used for connections between busses and circuit-opening devices. The foregoing table does not apply for wire run in duct or pipe, or for lead-covered or multiple-conductor cable.

Heating.

45. Copper connections leading directly into or in close proximity to switching apparatus, should be so arranged that with maximum sustained load, their temperatures do not rise more than 54 degrees Fahrenheit above ambient temperature. The permissible current

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* Direct current only.
† For marble and soapstone, and for slate up to 1500 volts.

density is higher on direct current than on alternating current, and lower for 60 cycles than for 25 cycles. It decreases rapidly with increasing current, especially where multiple laminations with small air gaps are used.

Insulation.

46. The main switchboard wiring for high-tension current must be insulated and carried on suitable insulators securely mounted on rigid supports.

47. To obtain accessibility and at the same time avoid danger due to trouble occurring on one conductor involving other conductors must be the aim in all switchboard wiring.

48. Sharp turns, corners and edges must be avoided as far as practicable, to prevent weakening of the insulation. The radius of bend for rubber-covered wire, varnished cambric or lead-covered cable must not be less than six times the outside diameter of the cable. With small braided conductors, the radius of bend may be five times the outside diameter of the cable.

49. All cable and wire joints must be properly insulated.

50. When conductors are carried in compartments or high enough above the station floor to preclude the danger of accidental touch or contact, they may be bare, relying on safe distances and suitable insulators.

51. The busses are an important part of the installation carrying the total energy of the plant in a confined space; extreme care must be used both in selecting the proper materials for construction and in the quality of the workmanship. When building bus compartments, arrangements should be made so that the joints are accessible for inspection and such other work as may be necessary. Connections between switches and busses are practically part of the busses, and the same care must be given to this part of the installation.

Instrument transformer wiring.

52. All secondary connections from current transformers to instruments must be metallic, the use of the earth as one of the conductors not being permissible. The potential transformers, however, with their small secondary current, may utilize the earth for one of the leads.

53. The leads from instrument transformers to the switchboard should preferably be of the double or multiple-conductor type, or if single conductors are used, they must run closely together to avoid induction. For long distances, the leads may be lead-covered or simply varnished cambric weatherproof covering and run in pipe

conduit, the latter being the usual practice. Leads of different potentials, such as current transformer and potential transformer leads, must not be run in the same conduit.

54. For secondary current wiring, where the watt loss in the secondary leads must be kept within certain limits so as to deduct as little as possible from the permissible instrument load on the transformer, it is the recommended practice to make runs up to 75 feet of 19/25 cable, corresponding in conductivity to No. 12 A.W.G. wire. For runs of from 75 to 150 feet, 19/22 cable, corresponding in conductivity to No. 10 A.W.G. wire, should be used for mechanical reasons as well as for increased conductivity. For potential transformers and control wiring, 19/25 cable may be used in practically all instances.

55. If not convenient or advisable to mount current and potential transformers on the back of the panel, they should be located with respect to convenience of wiring, accessibility and safety.

56. For potential transformers, primary fuses mounted separately from the transformers are recommended for all large stations and for all moderate and small capacity stations having voltages above 6600. Where expulsion type fuses are used above 15,000 volts for primary protection, ample headroom must be provided to permit the safe blowing of the fuses.

Connections to ground.

57. Panel supports should ordinarily be grounded except on grounded direct current systems of 750 volts or less, where only the isolated polarity is brought to the panel. If such direct current panels are installed in one board together with alternating current panels above 600 volts with oil circuit breakers mounted on panel or on panel suports, all panel supports must be grounded.

58. Switchboard devices for operating above 150 volts to ground must have their exposed bare metal parts, which are insulated from the current-carrying parts, permanently grounded unless isolated by elevation or protected by suitable permanent insulating barriers or guards. This rule covers, for example, transformer casings, operating mechanisms for switches, oil circuit breakers, air circuit breakers, rheostats, compensators, etc. Air circuit breakers above 300 volts, the frames of which are not insulated from the current-carrying parts, must be isolated by elevation.

59. Instrument transformer secondaries should be permanently grounded; however, when conditions are such that secondaries cannot be grounded, as, for instance, in the case of instruments and meters which have secondary current and primary potential coils, the secondary wiring must be insulated and installed to safely withstand primary potential.

60. A common ground bus, not less than No. 4 A.W.G. must be run across the back of the switchboard, to which apparatus mounted on the switchboard intended for grounding must be connected. The switchboard framework, except when insulated, must be connected to this ground bus, one connection being made for every three joints in series.

61. Steel work supporting high potential switching equipment must be carefully grounded at several points so as to prevent the possibility of high voltage occurring between sections of the steel work. Ground connection for this service must be not less than No. 6 A.W.G. flexible cable.

Compartments.

62. Compartments must be built according to instructions sent with the devices. Various materials have been used for bus and oil circuit breaker compartments: namely, brick, concrete, soapstone, slate and sometimes a combination of brick with one of the other materials. Unless concrete construction is being carried on at the time of installation and suitable equipment and artisans are available, brick will usually be found to be most economical.

63. Removable doors are recommended for all openings of compartments to prevent accidental contact with live parts, and in the case of oil circuit breakers to prevent the scattering of oil should it be forced out of the oil tank. Compartment doors must be made of light fireproof material and swing from the top to allow free movement in case of explosion in the compartment. Asbestos lumber with a light wood frame has proven to be the most satisfactory construction for compartment doors. Compartment doors must be considered as ground in respect to all live parts.

Illumination.

64. Sufficient illumination should be provided in the station, both for the front and the rear of the switchboard, so that the switchboard may be readily operated and instruments and meters conveniently read.

65. A separate emergency source of illumination from storage battery, lanterns or other suitable source must be provided for immediate use.

Operation

Protection for employees.

66. Where live parts having a potential over 300 volts to ground are not otherwise grounded, suitable insulating floors, mats or platforms providing good footing must be properly placed so that employees cannot readily touch the live parts unless standing on such floors, mats or platforms.

67. Before working on switchboard apparatus carrying over 300 volts it is recommended that current be cut off parts to be worked on and these parts be grounded.

68. Fibre pails filled with clean dry sand and fire extinguisher employing a chemical which is not an electrical conductor must be kept adjacent to switchboards for extinguishing fires in proximity to energizing switchboard parts or conductors. Water must not be used.

69. Umbrellas, clothing and other material must not be placed where they can come in contact with switches or other portions of electric circuits.

70. All wires and overhead conductors are to be considered alive at all times. Insulation must not be depended upon for protection against electric shock.

71. When operating high-tension disconnecting switch, rubber gloves must be worn and wood pole, provided for that purpose, used.

72. Employees must familiarize themselves with instructions for resuscitation from electric shock and with safety suggestions.

Attendance.

73. Before placing the switchboard into service, all connections to switchboard devices must be carefully traced and checked with the drawings. A preliminary trial must then be made to see that meters indicate or record in the proper direction. Before placing a switchboard into actual service, it is advisable that current be applied to all parts at reduced voltage in order to bring out any defects. Low ampere rated fuses must be used when making this test. All switchboards for 2300-volt service and higher must be given a high potential test on the assembled switchboard and the wiring in accordance with A.I.E.E. Standards.

74. When first placing the switchboard into actual service, every detail must be closely watched and anything out of the ordinary must be carefully noted and investigated. The switchboard must be subjected to periodical inspections of all parts. Attention must be given to the joints in cables, busses, connection bars, current-carrying studs and to temperature rise, insulation, cleanliness, etc.

75. In making an inspection or repairing work near live parts, special care must be exercised to avoid accidentally short circuiting or grounding any of the connections. The following instructions cover only in a general way the routine to follow, as it is obvious that details given, for instance, for a direct current power plant would not apply to a high-voltage alternating current power plant.

The operator, however, is urged to familiarize himself with these details:

(a) Before each starting of the plant, be sure that all switches and circuit breakers involved are open and that no other device is in such condition as to cause trouble when throwing voltage on the panels.

(b) After everything is adjusted and running, take frequent readings of instruments to see that no device is overloaded to a dangerous point. This applies to conductors as well as to switches and instruments.

(c) Make periodical tests of instruments and meters to locate any inaccuracies, at the same time noting any parts which may need adjusting or repairing.

(d) Regularly inspect switches, circuit breakers and relays to see that contacts are in good condition.

(e) Oil as specified must be used in oil circuit breakers. This oil is carefully prepared and specially treated and has high insulating value and high flash point. It is shipped in sealed containers, but through a carelessness in handling or during transit, or after receipt, may take up moisture. It is therefore essential, in all cases, that it be tested before being placed in oil tanks of oil circuit breakers. It should withstand a potential of 40,000 volts between ½ inch discs placed 0.2 inch apart, or a potential of 22,000 volts between 1 inch discs placed 0.1 inch apart. In case it punctures at lower values than these, it must be filtered or otherwise treated to remove the moisture and must not again be placed in service until the insulation strength complies with the above requirement. Oil must be maintained in the oil tanks at the height indicated on the outside. Oil must be inspected after heavy short circuits and generally every three months. If at any time the oil should show signs of carbonization or should any dirt or suspended matter be noticeable therein, it must be filtered and tested before being again placed in service.

(f) When circuit breakers or switches with carbon or other secondary contact are furnished, see that the secondary contacts are in good shape and properly adjusted so that they will take the final break of the arc and prevent arcing the main contact. See also that there is sufficient contact between the main brush and the contact block.

(g) Space in rear of switchboard and passageway must be kept clear of obstructions.

(h) Regularly clean switchboard, especially in buildings where there are inflammable particles flying around. In cleaning the back of a board, compressed air applied through a flexible hose and nozzle is the simplest and safest method. If this equipment is not available, a hand bellows may be used. Wiping is not recommended back of the board, although this method of cleaning may be employed on instruments on the front of the board when they are not directly connected to high-tension circuits.

(i) To renew the finish of dull black marine slate, black marine slate and marble panels, soap and cold water should be applied with a soft cloth. Natural black slate may be restored to its original freshness by rubbing with a soft cloth immersed in good engine oil.

(j) Knife switches in series with circuit breakers of the carbon break or magnetic blowout type should be closed after the circuit breakers have been closed and should be opened after the circuit breakers have been opened. When closing the switches it is well to turn the face away from the switchboard to avoid having the eyes "flashed" in case the circuit breaker should open.

(k) Disconnecting switches in series with oil circuit breakers on alternating current circuits must never be opened or closed except while the oil circuit breakers are open. Hand-operated oil circuit breakers with automatic attachments are designed for the breakers to open in case of short circuit or dangerous overload.

Synchronizing.

76. In using synchronizing indicators, the operator must become accustomed to the time element of the generator switch, so as to close the switch when the needle is at the proper point on the dial. There is considerable difference in the time required to close different switches and this must be taken into consideration. A heavy strain is put upon the switches and generators if the generators are out of synchronism when the switches are closed. In general it may be said, do not close the generator switch if the synchronizing indicator needle is traveling too fast, or if it is traveling away from the zero point.

Mercury Arc

Theory of operation.

The action of this rectifier is based on the peculiar property of mercury vapor which permits of a flow of current in but one direction. However, by a system of connections and reactances both waves of the alternating current line are used, resulting in higher efficiency and power factor. This rectifier has three essential parts: the rectifier tube, the main reactance and the panel. The rectifier tube, as illustrated in Fig. 4, is an exhausted glass vessel in which are two graphite electrodes (anodes A and A′) and one mercury cathode B. Each anode is connected to a separate side of the alternating current supply and also through one-half of the main reactance to the negative side of the load. The cathode is connected to the positive side. There is also a small starting electrode C connected to one side of the alternating current circuit through resistance, and used for starting the arc. When the rectifier tube is rocked, so as to form and break a mercury bridge between the cathode B and the starting anode C, a slight arc is formed. This starts what is known as the "cathode spot" and the cathode begins supplying ionized mercury vapor. This condition of excitation, or cathode spot, can be kept up only as long as there is current flowing toward the cathode. (In modern rectifiers, tubes have a pair of "holding anodes" to maintain the arc even with zero load current.) If the direction of supply voltage is reversed, so that the formerly negative electrode, or cathode, becomes positive with the reversal of the alternating current circuit, the current ceases to flow, since, in order to flow in the opposite direction, it would require the formation of a new cathode, which can be accomplished only by special means. Therefore, in the rectifier tube the current must always flow toward the cathode which is kept in a state of excitation by the current itself.

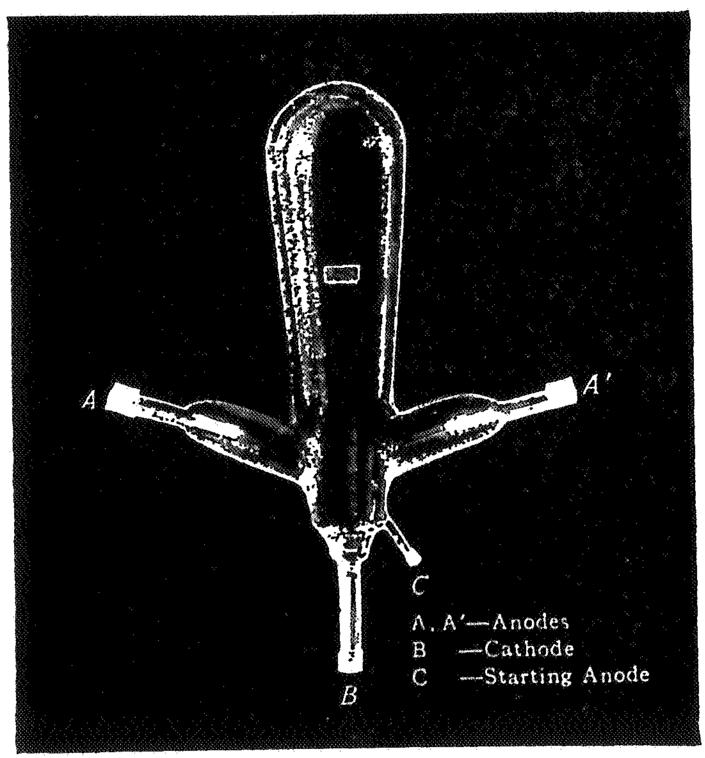

Fig. 4.
Mercury Arc Rectifier Tube.

Such a tube would cease to operate on alternating current voltage after one-half of the cycle, if some means were not provided to maintain the flow of current continuously toward the cathode.

The maintenance of the current flow is accomplished by the main reactance. As the current alternates, first one anode and then the other becomes positive, the current flowing from the positive anode through the mercury vapor, toward the cathode, thence through the battery, or other load, and back through one-half of the main reactance to the opposite side of the alternating current supply circuit. As the current flows through the main reactance, it charges it, and while the value of the alternating current wave is decreasing, reversing and increasing, the reactance discharges, thus maintaining the arc until the voltage reaches the value required to maintain the current against the counter electromotive force of the load and reducing the fluctuations in the direct current. In this way, a true continuous current is produced with very little loss in transformation.

In other words, the usefulness of mercury arc rectifiers is dependent entirely upon their ability to transmit current readily in one direction, and to act as a barrier to current flow in the opposite direction. Current is conducted through the tube by the ionized mercury vapor. This vapor consists of electrons, positive ions and negative ions moving about in all directions and colliding with each other continually. As the tubes are very carefully evacuated, the number of air and water vapor molecules present is very small. The electrons are the small negative charges of electricity which are one of the two constituents of atoms of all kinds. The ions are the mercury atoms which have lost or gained one or more electrons. Compared to electrons, the mercury ions are very large bodies, the mass of mercury ion being 368,000 times that of an electron.

Conduction of electricity through the ionized gas is accomplished by general drift of positive ions in the direction of the current and the general drift of electrons in the opposite direction. During the process of conduction electrons hit the graphite anode and flow out through it as the current. Other electrons enter the space inside the tube from the mercury cathode. This is accomplished by the formation of the cathode spot on the mercury which is the spot one observes moving continually on its surface. It requires for its maintenance a drop of about ten volts, and this voltage, which must also occur across an extremely small distance, removes the electrons from the mercury against the atomic forces tending to prevent their passage through the surface. The positive ions are produced by the electrons colliding with neutral atoms after they have left the cathode.

If the voltage on the tube is reversed, the electrons will be drawn toward the mercury and the positive ions toward the graphite electrode. This gives a pulse of current through the tube in the inverse direction. If this current is to continue, the graphite electrode must become a source of electrons. This it will not do because the voltage applied, though many times enough for the purpose, does not occur across the small distance required. Instead it is nearly uniformly distributed over the entire distance between the electrodes, leaving only a very small voltage to appear across the space in which the removal of the electrons from the graphite would have to be accomplished.

Operation.

Figure 5 illustrates an elementary diagram of connections and the operation is about as follows: Assume the instant that the terminal H of the supply transformer is positive, the anode A is then positive and the arc is free to flow between A and B. Following the direction of the arrow still further, the current passes through the battery J,

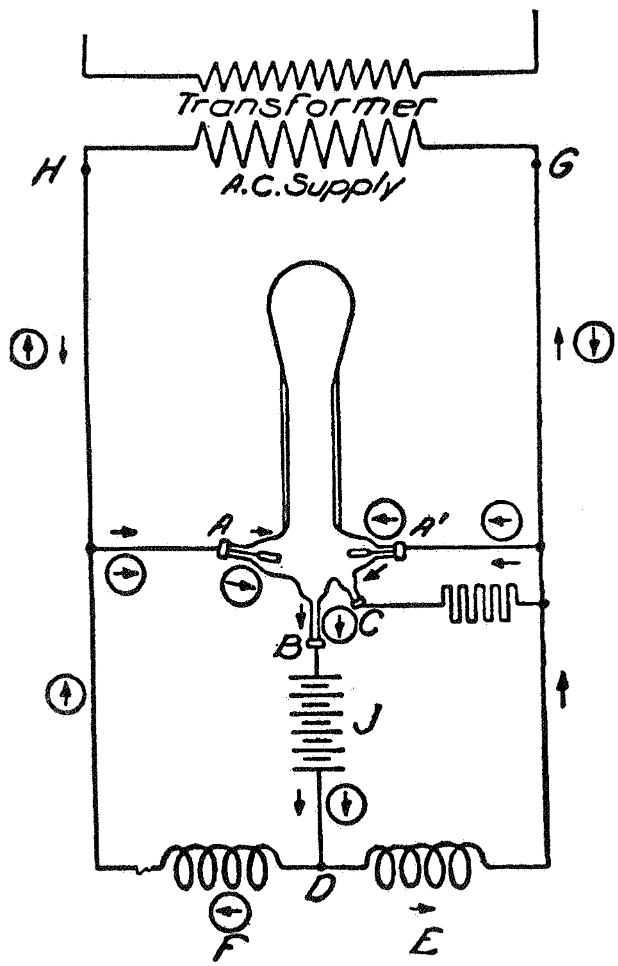

Fig. 5.
Connections for Mercury Arc Rectifier.

through one-half of the main reactance coil E, and back to the negative terminal G of the transformer. When the impressed electromotive force falls below a value sufficient to maintain the arc against the counter electromotive force of the arc and load, the reactance E, which heretofore has been charging, now discharges, the discharge current being in the same direction as formerly. This serves to maintain the arc in the rectifier tube until the electromotive force of the supply has passed through zero, reversed, and built up to such a value as to cause the anode A′ to have a sufficient positive value to start the arc between it and the cathode B. The discharge circuit of the reactance coil E is now through the arc A′-B instead of through its former circuit. Consequently, the arc A′-B is now supplied with current, partly from the transformer and partly from the reactance coil E. The new circuit from the transformer is indicated by the arrows enclosed in circles.

Figure 6 illustrates a 30-ampere mercury arc rectifier.

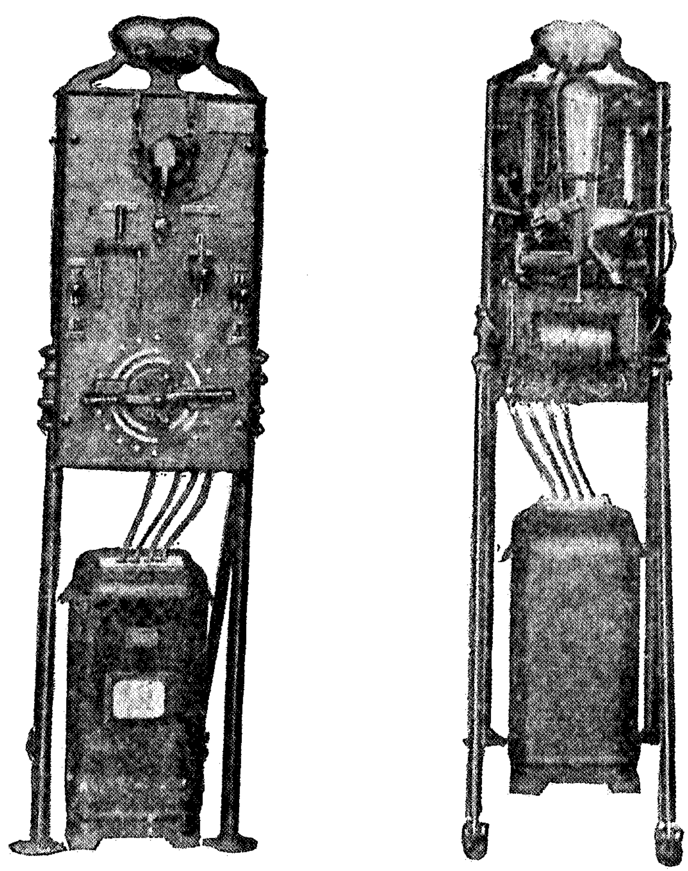

Fig. 6.
Mercury Arc Rectifier.

Instructions.

Mercury arc rectifiers should be maintained and operated in accordance with the following instructions:

1. Rectifiers must be kept clean and connections tight.

2. Voltage and current rating of rectifier tubes must not be exceeded.

3. Vacuum tests must be made of each tube when received. To test, allow mercury to roll gently about in condensing chamber. If the mercury makes a metallic click, the vacuum is good. If the sound is dull, the vacuum is wholly or partly destroyed. Tubes must also be tried in service and if required voltage and current is not given, instructions must be obtained for their disposition.

4. Tubes must be handled carefully and when not in service must be kept in shipping crate. They must be protected from sudden changes in temperature to avoid fracture.

5. Starting switch must not be held in starting position so that starting resistance is over-heated. If rectifier does not start readily, starting operations must be spaced to avoid excessive heating.

6. Dial switch adjusting arm for regulating compensator must be moved quickly from one contact to another to prevent arcing, and must not remain in a position to bridge two contacts.

7. Fuses of specified capacity and type must be used, and a sufficient supply of tested fuses must be kept on hand for immediate use.

Gas Tube

The two types of gas-filled hot cathode rectifiers in general use are the Rectigon and Tungar. The names have no particular sig-

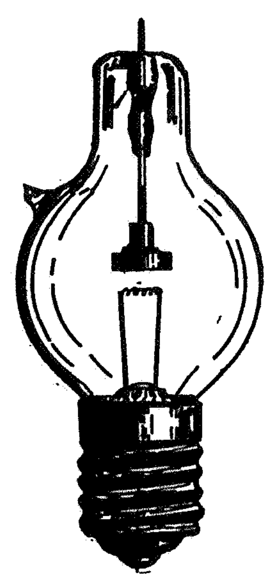

Fig. 7.
Battery Charging Bulb.

nificance and were applied in order to give them distinctive trade-names, their technical names being of too great length for trade purposes.

A vacuum tube containing a hot and a cold electrode acts as a rectifier, and following this principle these rectifiers were developed.

Theory of operation.

In the bulb there is argon, an inert gas, at low pressure, which is ionized by the electrons emitted from the incandescent filament. This ionized gas acts as the principal current carrier, with the result that the bulb operates with a very low voltage drop, 3 to 8 volts, and is capable of passing a current of several amperes, the current limit depending on the design and size of the bulb.

Figure 7 shows a half-wave bulb in which the cathode (lower electrode) consists of a filament of small Tungsten wire coiled into a closely-wound spiral, and a graphite anode (upper electrode) of relatively large cross-section. The bulbs are constructed of heat-resisting glass.

The bulb rectifies, because on the half cycle when the graphite anode is positive the emitted electrons from the incandescent filament are being forced toward the anode by the voltage across the tube, colliding with the gas molecules and ionizing them, that is, making them conductive in the direction of anode to cathode; while on the other half of the cycle, when the anode is negative, any electrons that are emitted are driven back to the filament, so that the gas in the bulb is non-conductive during that half cycle.

Bulbs of this type are carefully exhausted to the highest possible vacuum and then filled with argon gas in a high state of purity. Certain impurities, even in very small quantities, produce a more or less rapid disintegration of the cathode, and also have quite a marked effect on the voltage characteristics of the rectifier. Means must be used to insure absolute purity of the gas and to accomplish this, magnesium is introduced into the bulb at the time of manufacture to react chemically with such impurities as may be present. This reaction keeps the gas in a pure state practically throughout the life of the bulb.

The dark gray or silvery appearance of the bulb is caused by condensation of the magnesium on the interior of the bulb during manufacture. This is not in the least detrimental to the bulb and gives no indication of its life.

The general principles briefly described apply equally well to the half-wave and full-wave types of rectifiers. The half-wave rectifiers are desirable for low-wattage service on account of the lower cost of manufacture. On larger sizes the lower power factor makes them objectionable from the power supply viewpoint. Two half-wave rectifiers may be connected to power lines so as to utilize both half waves.

Figure 8 shows the connections of a half-wave rectifier in its simplest form. The equipment in this case consists of the bulb (B), with filament (cathode) (F) and anode (A), transformer, rheostat (R), and the load which is shown as a storage battery.

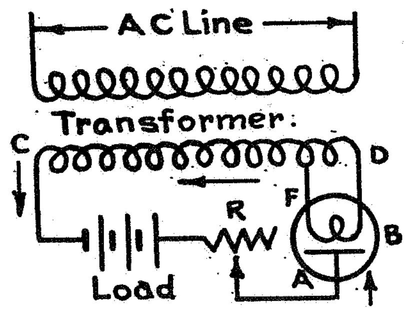

Fig. 8.
Connections of a Half-Wave Rectifier.

Assuming an instant when the side "C" of the alternating current supply is positive, the current follows the direction of the arrows through the load, rheostat, bulb, and back to the opposite side of the alternating current line. A certain amount of the alternating current is used to excite the filament, the amount depending on the capacity of the bulb. In some designs of rectifier outfits the rheostat is omitted and the regulation obtained by means of an adjustable reactor or taps on the transformer winding. In some of the higher voltage outfits the charging current is varied by a resistance. When the alternating current supply reverses and the side (D) becomes positive, the current is prevented from flowing for the reason before mentioned, *i.e.,* the current is permitted to flow from the anode to the cathode or against the flow of emitted electrons from the cathode, but it cannot flow from the cathode to the anode with the flow of electrons.

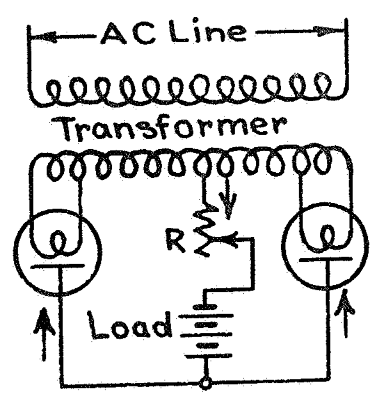

Fig. 9.
Connections for Two Half-Wave Bulbs.

Figure 9 shows the general method of connecting two half-wave bulbs with a single load. In this case both waves are used and the resultant current is a pulsating uni-directional current which may be smoothed out as much as necessary by means of reactance in series with the load. This is unnecessary, however, in ordinary battery charging.

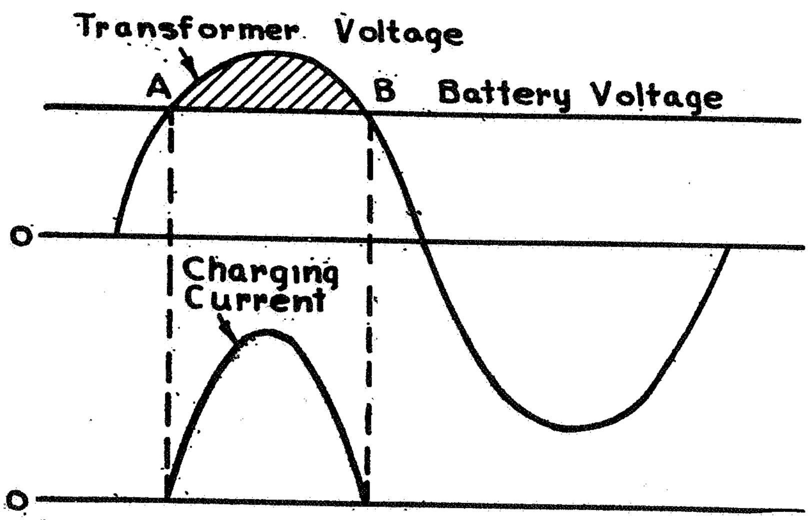

Fig. 10.
Diagram Showing One Cycle of Half-Wave Rectification.

The principle on which a storage battery is charged is shown in Fig. 10. One cycle of half-wave rectification is shown. On the upper half of the cycle when the transformer voltage exceeds the battery voltage (point A), the bulb anode becomes positive, making the bulb conductive, and the charging current flows through the battery. When the transformer voltage falls below the battery voltage (point B) the bulb is no longer conductive and the charging current ceases on the lower half of the wave.

The rated output of these rectifiers is based on readings of direct current instruments of the D'Arsonval type which give the average value of the voltage and current. A direct current ammeter indicates the true current which is effective in charging the batteries. If an alternating current instrument is used, which gives the root mean square value of the current on half-wave rectifiers, it will read from 75 to 100 per cent higher, and on full-wave rectifiers about 25 per cent higher than the D'Arsonval type instrument. Both of these instruments would read identically on a continuous or non-pulsating current.

The bulbs range in size from ½ ampere capacity at 7.5 volts, to 6 amperes at 75 volts, and 30 amperes at 50 volts. The 2 and 5-ampere bulbs are designed to charge batteries up to 120 volts at a low rate.

Instructions.

Gas tube rectifiers should be maintained and operated in accordance with the following instructions:

1. Rectifiers must be kept clean and connections tight.

2. Voltage and current rating of rectifier tubes must not be exceeded.

3. When replacing tubes, tubes of the same capacity, rating and type as the tubes to be replaced must be used.

4. Rectifiers must be used only for the alternating current voltage and frequency specified on name plate.

5. A spare tube which has been tested for at least 10 hours in actual service must be kept on hand.

6. New tubes must be tested immediately upon receipt to detect probable damage during shipment.

7. Source of energy for the rectifier must be disconnected before connecting or disconnecting batteries or making any change in the charging circuit.

8. Tubes must be checked frequently to see that they are tight in their sockets.

9. Contacts in socket and on tubes must be examined frequently to see that they are clean. They must be cleaned with fine sandpaper or crocus cloth.

10. When necessary to replace transformer, a transformer of the same capacity and rating as the one being replaced must be used.

11. Tests must be made at least once a month to determine that the back leakage, when rectifier is not charging, does not exceed maximum specified by the manufacturer.

12. Fuses of specified capacity and type must be used, and a sufficient supply of tested fuses must be kept on hand for immediate use.

Mechanical or Vibrating

The trade-names of the three principal types of mechanical rectifiers used in signal work are Valley, Leich and Magnar. The method of operation of all these is similar. The theory is that a vibrating armature opens and closes a contact at certain given times in proper relation to the alternations of the current. The contacting parts touch only at the time that the current taken from the alternating system is flowing in the proper direction to charge the battery. Certain types of mechanical rectifiers, notably the Magnar, have the armature or vibrating reed tuned magnetically by the flux of a permanent magnet. The armature is equipped with a face plate held in tension in the field of the magnet. By varying this field the natural frequency of vibration of the armature is changed. The moving contact must be flexible or have a cushion effect, so it is mounted on a light spring and given the proper tension by means of two backing springs. The contacts are generally of platinum iridium or tungsten on account of the non-oxidizing characteristics of these metals. The stationary contact is mounted on a screw; adjusting this screw gives the proper and exact opening between contacts. The alternating current actuating coil is adjustable for tuning the charging wave to the proper phase relation.

Figure 11 illustrates a Magnar battery charger.

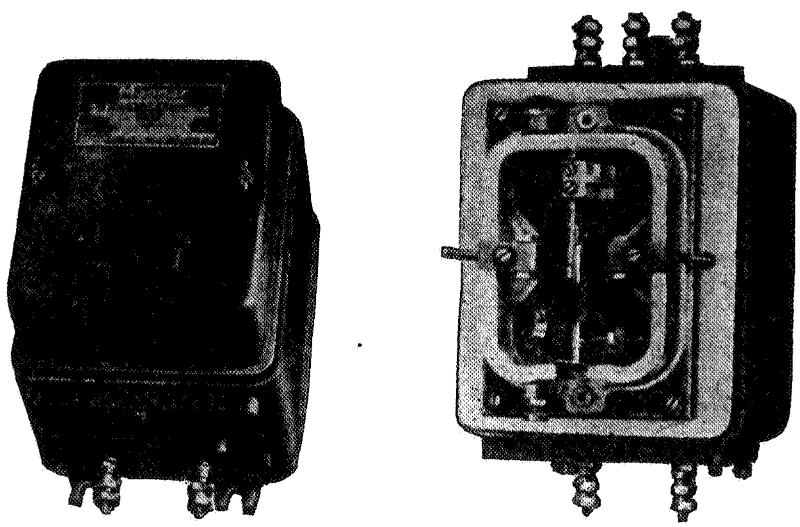

Fig. 11.
Magnar Battery Charger.

Other types of mechanical rectifiers are similar in construction, except with regard to the vibrating contact, which is suspended from the armature supported on a shaft, no springs or reeds being used. The contact swings perfectly free and follows the reversal or alternations of the current over frequency variations up to 18 per cent above or below normal.

A transformer is enclosed in the same casing as the rectifier for transforming the line voltage to the proper value for charging the storage battery and to protect apparatus connected to the storage battery against the flow of current from the alternating current supply line. The efficiency of these rectifiers is low and they interfere with radio reception; the latter may be materially reduced by the use of a condenser bridging the vibrating contact.

When the alternating current supply is interrupted the vibrating member should assume the central or open position to prevent the battery from discharging through the rectifier. Careful maintenance is necessary to insure the proper opening of the contact.

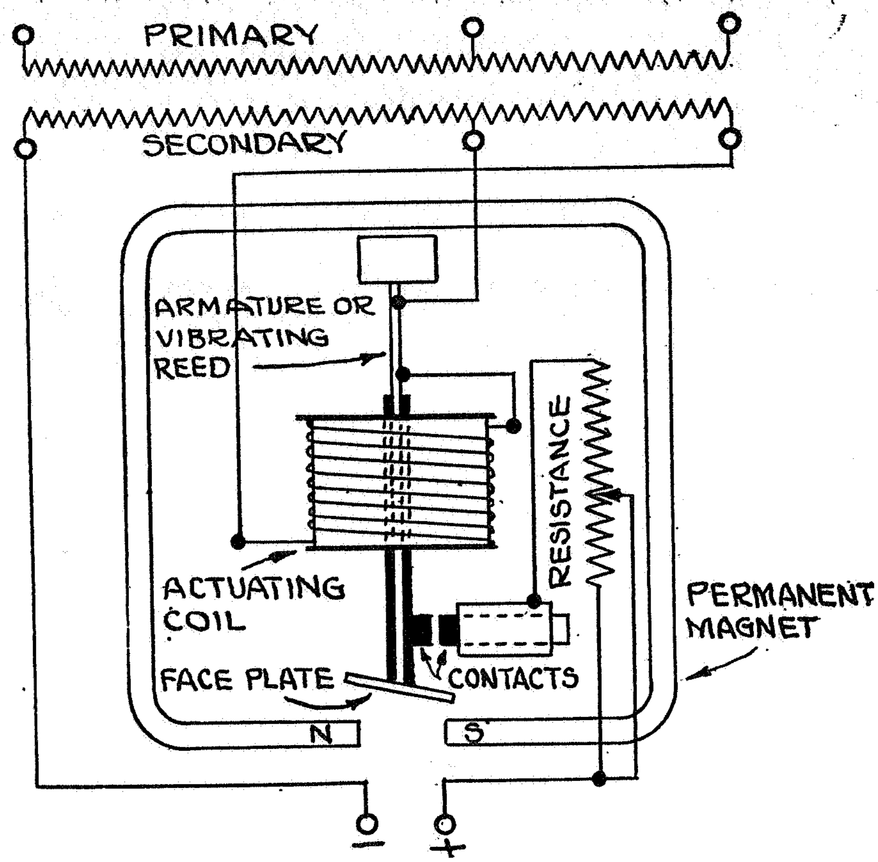

Fig. 12.
Connections for Magnar Battery Charger.

Figure 12 illustrates a wiring diagram for a Magnar battery charger.

The secondary is tapped to supply current to the actuating coil as shown in Fig. 12 and the vibrating reed extending through this coil is thereby magnetized. Due to the alternations through the coil the polarity of the ends of the reed is constantly reversing. The rapidity of this reversal of polarity is entirely dependent upon the frequency of the alternating current supply.

At the instant that the lower end of the reed to which the face plate is attached is a north pole, it will be attracted by the south pole of the permanent magnet. This will cause the reed to be pulled to the right and close the contacts. While contacts are in this position current will flow into the battery. The next instant the current through the coil reverses which in turn reverses the polarity of the reed. Then the face plate becomes a south pole and is repelled by the south pole and attracted by the north pole of the permanent magnet. This causes the reed to be pulled to the left, opening the contact. This opens the circuit to the battery and no current flows in the charging circuit at this instant. The contacts of a rectifier operating on a 60-cycle circuit would open and close 60 times per second and cause a pulsating current to flow in one direction into the battery.

Instructions.

Mechanical or vibrating rectifiers should be maintained and operated in accordance with the following instructions:

1. Rectifiers must be kept clean and connections tight.

2. Voltage and current rating of rectifier must not be exceeded.

3. Contact points must be kept adjusted to prevent excessive sparking. Burned or pitted contacts must be replaced.

4. The vibrating member must be adjusted to operate uniformly.

5. In making adjustments, instructions issued by manufacturer must be followed.

6. Rectifier must be used only for the alternating current voltage and frequency specified on name plate.

7. Source of energy for the rectifier must be disconnected before connecting or disconnecting batteries or making any change in the charging circuit.

8. The source of energy must be disconnected periodically to determine that contacts remain open when rectifier is not charging.

9. Fuses of specified capacity and type must be used, and a sufficient supply of tested fuses must be kept on hand for immediate use.

Electrolytic

Several different types of electrolytic rectifiers are theoretically possible, but so far the only one that has been developed commercially is the tantalum lead combination using sulphuric acid electrolyte with ferrous sulphate as a depolarizing agent.

Historical.

Tantalum has been known in its compounds since 1801 and relatively pure tantalum metal has been made since 1903. At that time it was used for lamp filaments and it is estimated that over 100 million tantalum lamps were used in the United States before the Tungsten lamp superseded it. Very little was done with metallic tantalum until 1922 when Dr. Balke developed a commercial process for making pure ductile tantalum at a reasonable cost.

The laboratories started intensive work to unearth uses for this newly available metal and developed the Balkite rectifier using electrodes of tantalum and lead in a sulphuric acid electrolyte. The possibilities of such a device in the radio field led to rapid commercial development and within several years hundreds of thousands of these rectifiers were in service. It is interesting to note, however, that one of the first experimental installations was in railway signal service. It was realized that this service was quite severe and would bring out the failings of the rectifier, if any, in a very short time. This rectifier is still in service and has been followed by the general use of Balkite rectifiers in similar service. The trade-name Balkite has been superseded by the trade-name Fansteel.

Some of the properties of metallic tantalum may be of interest. It is characterized by great resistance to wet chemical corrosion. No mineral acid except hydrofluoric affects it. Its melting point is very high, being 2770 degrees Centigrade. Its density is 16.6 (roughly twice that of copper). Its electrical resistance is 14.6 microhm-cm. (eight times that of copper). When pure it can be swaged, rolled and drawn cold without difficulty. Occluded gases make it difficult to work and one of the problems of its manufacture is to prevent absorption of gas by the metal.

Description of apparatus.

Each Fansteel railway signal charger consists of one or more rectifier cells and a suitable transformer. These rectifier cells are made in various sizes to meet requirements and consist of lead and tantalum electrodes supported from a hard rubber cover, immersed in a sulphuric acid electrolyte in a glass cell jar. In the small cells the cover screws onto the jar while in the larger sizes it is grooved to fit the top. The condition and operation of the cell is visible through the clear glass jar.

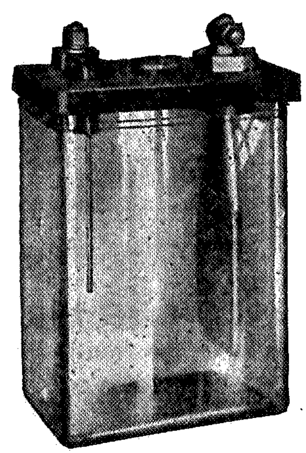

Fig. 13.
Electrolytic Cell, Type C-1.

Type C-1 cells illustrated in Fig. 13 may be used for charging track, line or signal batteries. The capacity of this cell is 3 amperes to batteries of 8 volts or less and 1 ampere to batteries of 8 to 12 volts. Twelve to fourteen-volt batteries may be charged at ½ ampere. The normal operating period is 2750 ampere hours between additions of water. The C-1 cell is 4⅜ inches by 7⅞ inches and is 12 inches high over all.

Fig. 14.
Electrolytic Cell, Type C-9.

Type C-9 cells illustrated in Fig. 14 were developed to meet the need of charging line and signal batteries where rates of ½ ampere or less were required. The capacity of this cell is ½ ampere to batteries of 14 volts or less and its normal operating period is 1350 ampere hours between additions of water. It is 4 inches by 6 inches by 7⅞ inches high over all.

The overload capacity of Fansteel cells is not primarily determined by over-heating.

Transformers for the electrolytic type of rectifier are covered later in this chapter. Fansteel transformers are made for various primary voltages and have primary taps for low-line voltage conditions.

Resistance units or transformer taps are used to control the charging rates. The standard range is from 20 per cent to full charging rate.

Theory of operation.

The theory of operation of the electrolytic rectifier is based on this fact: If an electrode of certain metals is immersed in an acid solution the metal will permit electrons to flow into the solution but not out of it, the metal thus acting as a valve which rectifies the current involving electrolytic conduction and electronic rectification. When one electrode of unformed tantalum and one of lead are placed in an electrolyte of sulphuric acid and an alternating electromotive force impressed across the cell thus formed alternating current will flow. During the half of the wave when electrons are passing out of the cell through the tantalum electrode oxygen will be liberated at the surface of the tantalum. This immediately combines with the tantalum to form a film of tantalum oxide on the surface of the tantalum electrode.

This oxide film is porous and spongy and oxygen gas is trapped in it forming a gaseous layer entirely surrounding the tantalum electrode. The electrons can move through this gas layer only by electronic conduction and the operation of the electrolytic rectifier is based on this fact.

The tantalum metal electrode can give off free electrons into this gas film. No free electrons can be present in the electrolyte, however, so that no electrons can pass from the electrolyte to the gas film. It is, therefore, evident that the electrons can pass from the tantalum electrode through the gas film into the electrolyte but cannot pass in the opposite direction and the electrolytic cell is therefore a rectifier.

The conduction of the electrons from the gas film to the lead electrode is by means of ions in the electrolyte, called electrolytic conduction. When these ions deliver their charge of electrons to the electrodes, gas is liberated at the surfaces of the electrodes. This gas liberation results in the decomposition of the water in the electrolyte and is not accompanied by any other chemical action. The

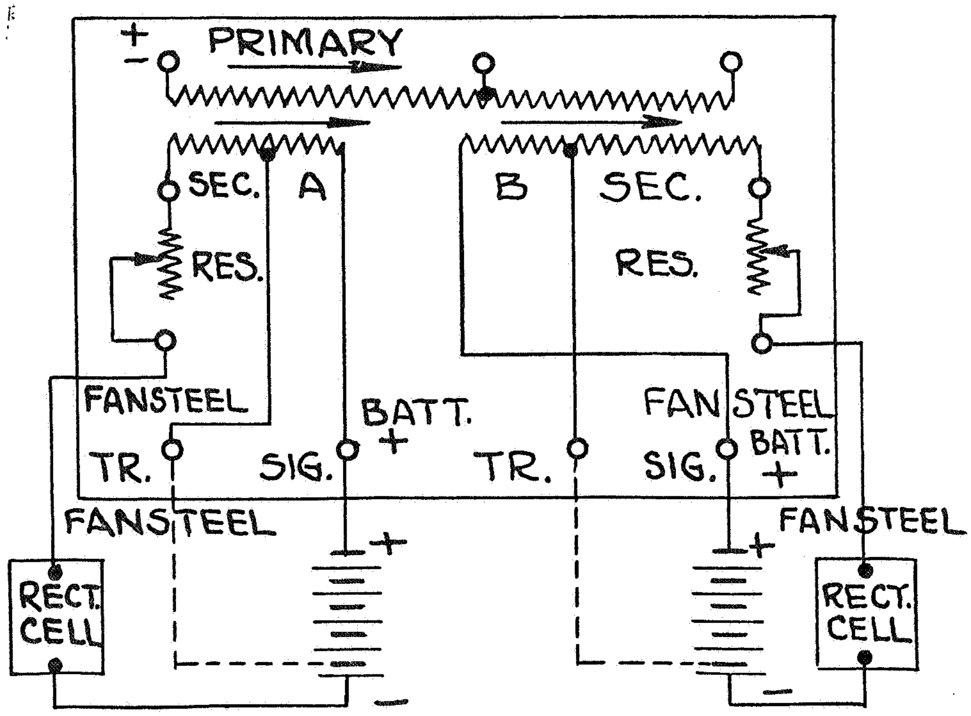

Fig. 15.
Connections for Charging Track and Signal Batteries from One Transformer and Two Rectifier Cells.

slight corrosion of the lead electrode is due to secondary chemical reactions.

The function of the ferrous sulphate depolarizing salt is to lower the counter electromotive force of the cell and thus increase its efficiency and capacity. It also stabilizes the cell so that it gives constant output under any given operating condition. A small amount of cobaltous sulphate is also added to this salt to reduce the wear on the lead electrode to a minimum. It does this by forming a closely adherent coating on the lead electrode, which coating is not attacked by the electrolyte.

In considering the foregoing theory it should be remembered that the actual movement of electrons in any circuit is in the direction opposite to the commonly assumed direction of current flow. In other words, the electrons flow into the rectifier cell through the tantalum electrode, but the current is assumed to flow out of the cell through the tantalum electrode to the battery.

Applications.

Figure 15 illustrates connections for charging a track and a signal battery from one transformer using two rectifier cells.

Figure 16 illustrates connections for charging batteries up to 14 volts using one rectifier unit. Figure 17 illustrates connections where two rectifier cells are used to obtain full-wave rectification.

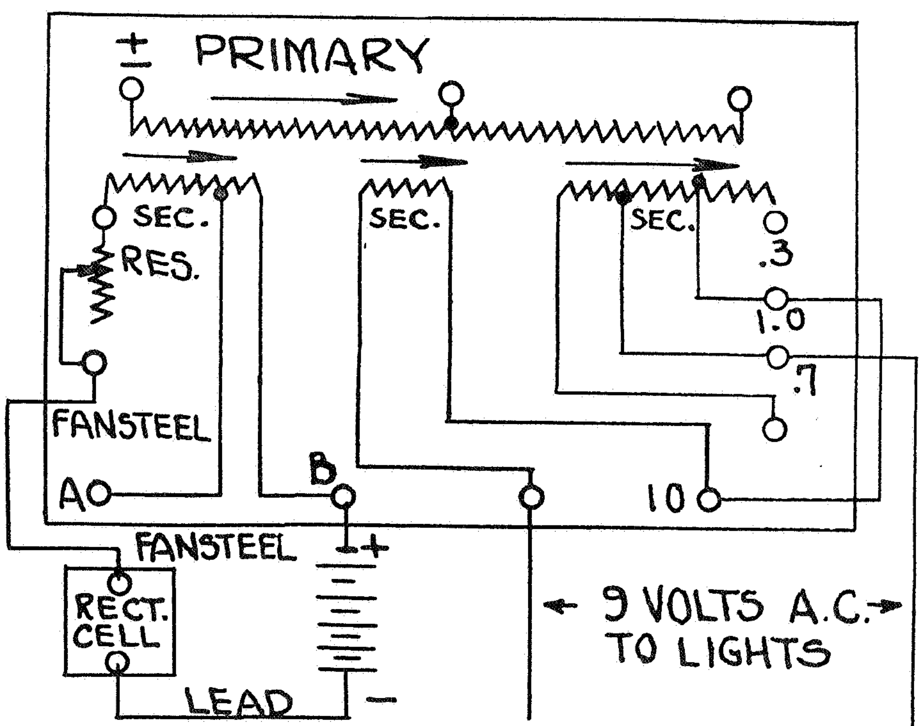

Fig. 16.
Connections for Charging Batteries up to 14 Volts, Using One Rectifier Cell.

A battery of 24 volts may be charged as shown in Fig. 18. Where the power supply is sufficiently reliable the use of a battery may be dispensed with and the apparatus operated directly from a rectifier connected as shown in Fig. 19.

A battery of 110 volts may be charged by a unit consisting of a group of electrolytic cells connected as shown in Fig. 20. Such chargers have normal charging rates of 0.5, 1, 2 or 6 amperes depending on the size of rectifier cell used. High output power units can also be used to operate 110-volt apparatus without the use of a battery.

Electrolytic rectifier cells are used in power units designed to operate direct current relays from alternating current track circuits or from alternating current power supply. The type C-8 cell is a full-wave cell designed for such service, and is connected as shown in Fig. 21. Currents up to 0.25 ampere at 15 volts can be obtained from this cell. A combination unit is supplied for lighting a flashing light signal on alternating current and also delivering direct current through the rectifier to operate a standard direct current flashing relay.

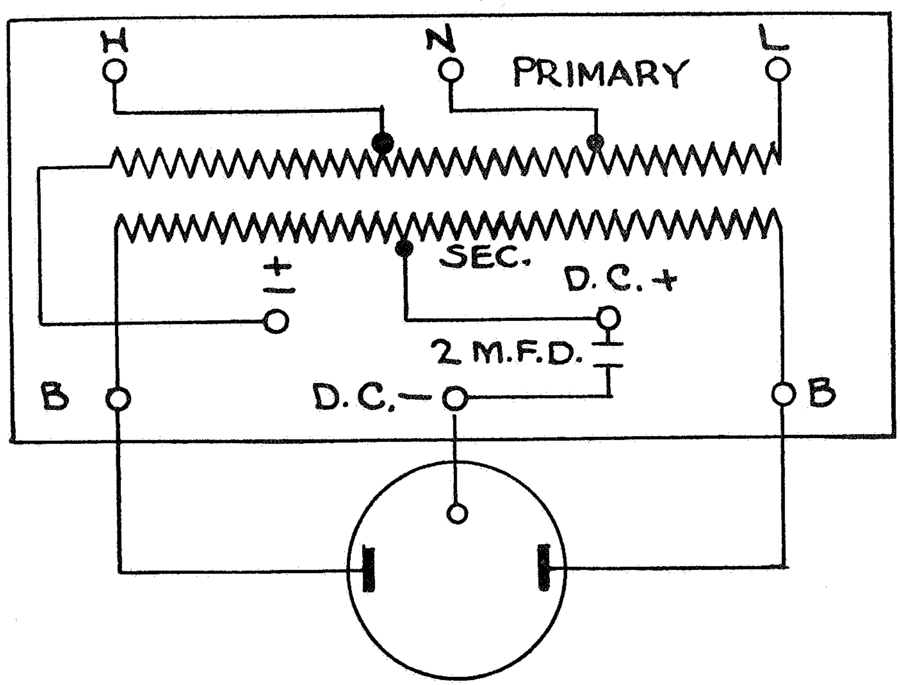

Fig. 21.
Connections for Operating Direct Current Relays from Alternating Current Track Circuits.

Instructions.

Electrolytic rectifiers should be maintained and operated in accordance with the following instructions:

1. Rectifiers must be kept clean and connections tight.

2. Connections must be coated and cups filled with petrolatum to prevent acid creepage and consequent corrosion.

3. Sulphuric acid of between 1.200 and 1.220 specific gravity must be used as electrolyte.

4. Depolarizer salt, in quantity furnished by the manufacturer for each cell, must be added to the electrolyte before oil is poured over the surface.

5. Oil poured over the surface of the electrolyte must be of the quality and quantity as furnished by the manufacturer.

6. A film of oil ⅛ to ¼ inch in depth must be maintained over the surface of the electrolyte. Liquid petrolatum (United States Pharmacopoeia) heavy, may be used when necessary to add oil.

7. Hydrometer used to test rectifier electrolyte must not be used for testing battery electrolyte.

8. Cover of rectifier cell must be kept in proper position.

9. Voltage and current rating of rectifier must not be exceeded.

10. Approved water only must be used to replace that lost by hydrolysis and evaporation. Acid should be added only to replace any that may have been spilled.

11. Electrolyte must be maintained between the minimum low and maximum high levels shown in manufacturer's instruction sheets. Electrolyte should be permitted to reach the low level before adding water.

12. When necessary to replace transformer, a transformer of the same capacity and rating as the one being replaced must be used.

13. Rectifier transformers must not be used on an alternating current voltage higher, or a frequency lower, than that specified on name plate.

14. Fuses of specified capacity and type must be used, and a sufficient supply of tested fuses must be kept on hand for immediate use.

Copper-oxide

General.

The copper-oxide rectifier is based on the discovery that when cuprous oxide is formed on copper at the proper temperature the combination allows current to flow more readily from the copper oxide to the copper than in the opposite direction. This is a property not of the copper or of the copper oxide, but of the special combination of the two materials that is obtained when cuprous oxide is formed on copper in a special way. The copper cuprous-oxide unit has a greater resistance across the boundary in one direction than in the opposite direction.

In order to make use of this elementary unit as a rectifier, it is necessary to make good contact to an extended portion of the free surface of the oxide. This can be done in a great number of ways, two of which have been used in commercial units. By one method the contact is made by pressing a piece of lead against the free surface of the cuprous oxide. By another method, a thin layer of the free surface of the cuprous oxide is reduced to copper, the reduced copper serving as the electrical contact.

To assemble a practical rectifier from either type of elementary unit, a number of these units are placed on a bolt and properly connected for series or parallel operation. When the lead contacts are used, ventilation is obtained by means of fins placed between the discs and also used for connectors. When the reduced copper is used for contact, the discs themselves can be used as ventilating surfaces. In both cases, separators are used when necessary to increase the amount of available ventilation.

Copper-oxide rectifiers used today in the signal field are made in accordance with one or the other method previously described. The principal difference between rectifiers manufactured by these methods is that the first method depends upon maintaining the pressure of the lead washer upon the copper oxide, and the second one depends upon adequate protection of the outer film from atmospheric oxidation or deterioration. Rectification takes place without any electrolytic action or other observable physical or chemical changes.

Description.

A rectifying unit, formed in accordance with the first method is shown in Fig. 22. The various parts comprising this unit are shown in this figure.

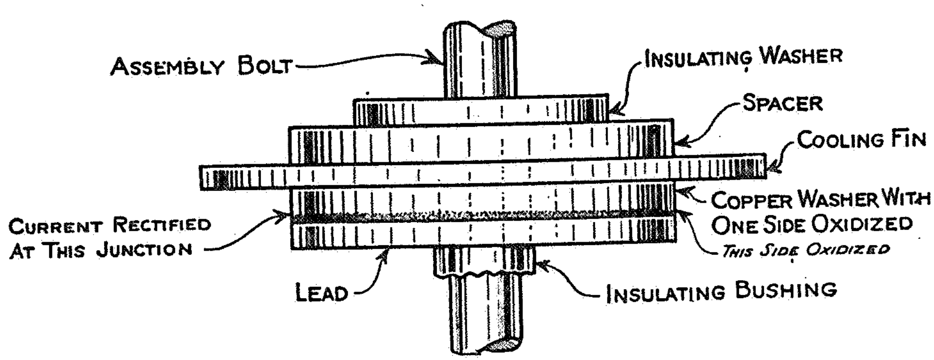

Fig. 22.
Typical Rectifying Unit.

The oxidized copper washers are mounted in units on a steel rod from which they are insulated as illustrated in Fig. 22. A connecting rod is soldered to the rim of the cooling fins thus permanently connecting the required number of rectifying units for series, multiple, or series-multiple operation.

A rectifying plate formed in accordance with the second method is shown in Fig. 23 in which "A" is the sheet of pure copper, "B¹" and "B²" are layers of copper oxide, and "C¹" and "C²" represent the outer film of copper.

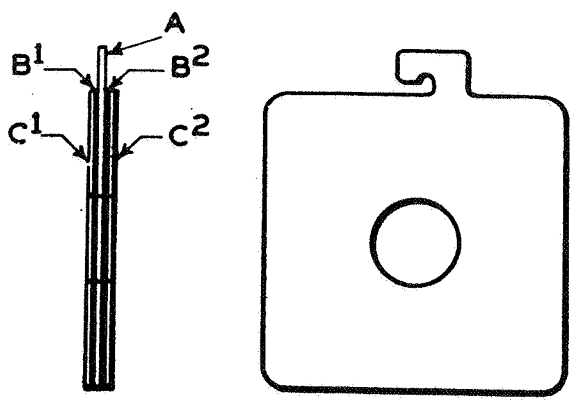

Fig. 23.
Typical Rectifying Unit.

The electrical connector has a lug extension on one side arranged for soldering or spot welding to the copper tip of the adjoining plate. In this manner the required number of plates, after assembly upon an insulated stud, are connected for series, multiple, or series-multiple operation.

Any number of individual elements may be assembled in series and in multiple into rectifier groups for any desired value of current and voltage. The two standard methods of connecting rectifiers for full-wave rectification are shown in Figs. 24 and 25.

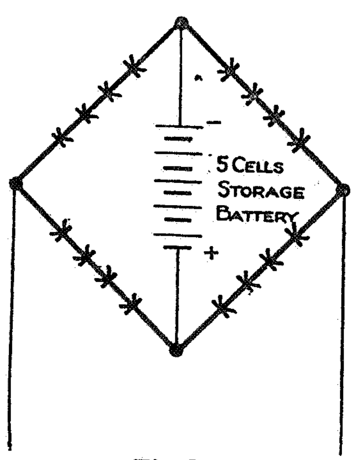

Fig. 24.
Rectifying Units in Series.

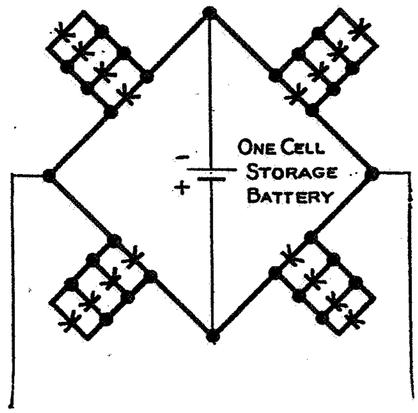

Fig. 25.
Rectifying Units in Multiple.

Theory of operation.

The theory of operation of the copper-oxide rectifier is not yet fully understood. This much has been established experimentally: The rectification takes place at the boundary between the copper and the cuprous oxide, that is, the condition at the boundary is such that current flows very much more readily from the oxide to the copper than it does in the opposite direction. To say that the current flows from the oxide to the copper corresponds to saying that electrons move more readily from the copper into the oxide. It is as if there were at the boundary a check valve, which allowed the electrons to pass freely from the copper into the oxide, but which closes when the electrons try to pass from the oxide into the copper.

In terms of resistance we can say that the boundary has a high resistance in the direction from copper to oxide and a low resistance in the opposite direction. Physically this means that more work is required to move an electron across the boundary from oxide into copper than it takes to move it across the boundary in the opposite direction. The details of the mechanism at the boundary which results in a free passage of electrons in one direction and not in the other is not yet understood. However, the results obtained with the rectifier both in the laboratory and in service have shown conclusively the action is entirely electronic and does not involve any chemical changes which result in the decomposition of the rectifier elements.

The current input to the battery is in the form of positive pulsations which are somewhat distorted from the shape of the charging wave because of the battery's potential. If, however, the charging circuit is connected to a resistance load and not to a load with a natural electromotive force, the form of the wave would be similar to that of the alternating current wave, with the exception that it would be continuously positive and not alternately positive and negative. Figure 26 shows the relation in wave form between direct current output and alternating current input.

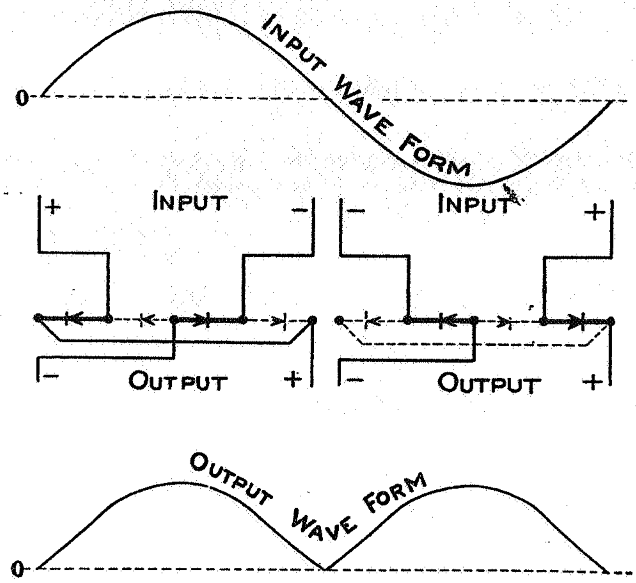

Fig. 26.
Current Flow with Relation to Input Wave Form.

Application.

In placing on the market the different types of rectifiers for use in railway signal work, the voltage and charging ranges have been selected as meeting the recognized service requirements of the Signal Section, American Railway Association.

Figures 27, 28, 29 and 30 illustrate rectifiers used for charging batteries of various voltages and amperes.

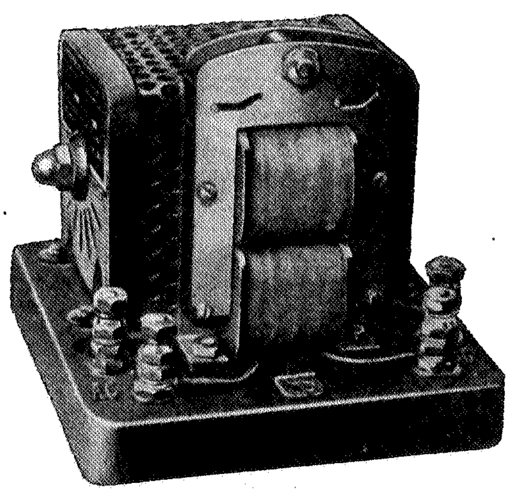

Fig. 27.
Rectifier for Charging 3 to 13.5 Volt Batteries.

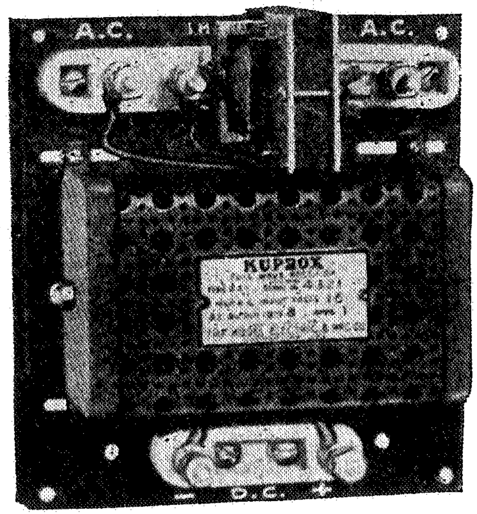

Fig. 28.
Rectifier for Charging 1.5 to 17.2 Volt Batteries.

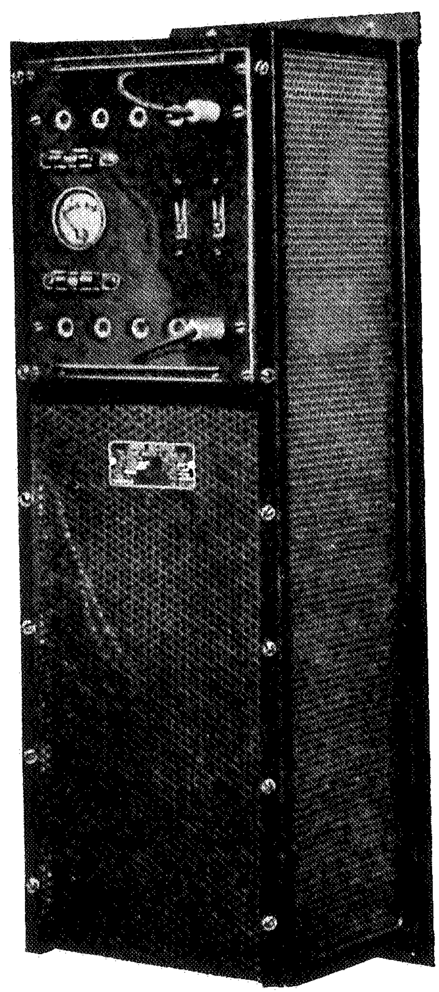

Fig. 29.
Rectifier for Charging 80 to 120 Volt Batteries.

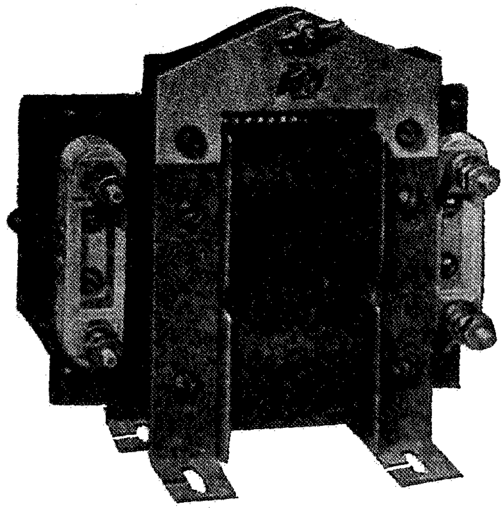

Fig. 30.
Rectifier for Charging 1.5 to 25.8 Volt Batteries.

This type may be used for charging signal or track batteries as determined by the following tabulated rating:

D.C. Output — Volts		D.C. Output — Amperes		A.C. Input	
Max.	Min.	Max.	Min.	Volts	Cycles
3.0	2.0	1.40	0.25	110	60
13.5	8.0	0.35	0.08	110	60
13.5	8.0	0.35	0.08	220	60
3.0	2.0	1.40	0.25	220	60
13.5	8.0	0.35	0.08	110	25
13.5	8.0	0.35	0.08	110	42
3.0	2.0	1.40	0.25	110	25
13.5	8.0	0.35	0.08	110	100

D.C. Output — Volts		D.C. Output — Amperes		A.C. Input
Max.	Min.	Max.	Min.	Volts
....	1.5	1.0	0.15	5
2.15	...	1.0	0.15	5
....	3.0	1.0	0.15	5
4.3	4.5	0.5	0.06	6
		1.0	0.12	6
6.45	6.0	0.5	0.06	12
		1.0	0.12	13
8.6	9.0	0.5	0.06	20
		1.0	0.12	20
10.75	10.5	0.5	0.06	20
		1.0	0.12	20
12.9	12.0	0.5	0.06	20
		1.0	0.12	20
15.05	15.0	0.5	0.06	25
17.2	16.5	0.5	0.12	25

D.C. Output				A.C. Input	
Volts		Amperes			
Max.	Min.	Max.	Min.	Volts	Cycles
120.0	80.0	2.25	0.35	220	60
120.0	80.0	3.00	0.35	440	60

D.C. Output				A.C. Input	
Volts		Amperes			
Max.	Min.	Max.	Min.	Volts	Cycles
2.15	1.5	1.0	0.12	110	60
4.30	3.0	0.5	0.06	110	60
4.30	4.5	1.0	0.12	110	60
6.45	6.0	0.5	0.06	110	60
6.45	6.0	1.0	0.12	110	60
8.60	9.0	0.5	0.06	110	60
8.60	9.0	1.0	0.12	110	60
10.75	10.5	0.5	0.06	110	60
10.75	10.5	1.0	0.12	110	60
12.90	12.0	0.5	0.06	110	60
12.90	12.0	1.0	0.12	110	60
15.05	15.0	0.5	0.06	110	60
17.20	16.5	0.5	0.06	110	60
19.35	19.5	0.5	0.06	110	60
21.50	21.0	0.5	0.06	110	60
23.65	24.0	0.5	0.06	110	60
25.80	25.5	0.5	0.06	110	60

The fundamental construction of the copper-oxide rectifier lends itself to flexibility of application with but slight modification in the assembly of parts, should it be desirable to use rectifiers for charging batteries of other voltages than those listed above. Consequently, other designs may be built to meet special conditions.

Instructions.

Copper-oxide rectifiers should be maintained and operated in accordance with the following instructions:

1. Rectifiers must be kept clean and dry, and connections tight.

2. Rectifiers must be mounted so that their cooling fins are in a vertical plane and in a location allowing fairly free circulation of air. The temperature of surrounding air must not exceed the maximum value specified by manufacturer. Where resistors, reactors and transformers are furnished as a part of rectifier unit, the mounting must be so arranged that such devices are not placed below the rectifier unit so as to increase temperature of rectifier by their dissipated heat.

3. Rectifier must not be adjusted to charge at more than its rated current nor must it be used for charging a battery whose voltage is higher than the rated voltage of the rectifier.

4. Rectifiers must not be used on an alternating current voltage higher, or a frequency lower, than that specified on name plate.

5. Source of energy for the rectifier must be disconnected before connecting or disconnecting batteries or making any change in the charging circuit.

6. Tests must be made periodically to determine that the back leakage, when rectifier is not charging, does not exceed maximum specified by the manufacturer.

7. Fuses of specified capacity and type must be used, and a sufficient supply of tested fuses must be kept on hand for immediate use.

8. When necessary to replace transformer, a transformer of the same capacity and rating as the one being replaced must be used.

9. Bolts, nuts, screws, pins, binding posts, rivets, nut locks and jam nuts must be kept in place, in good condition and tight.

10. In making adjustments, instructions issued by manufacturer must be followed.

Transformers

Motor-generator sets and mercury arc rectifiers are designed generally to operate on commercial voltages. No special transformer is necessary.

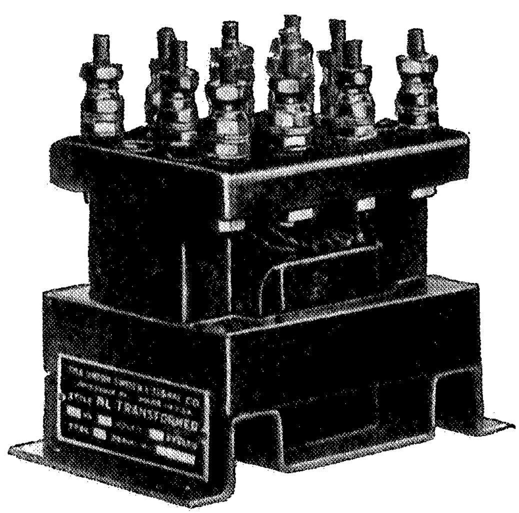

Fig. 31.
Transformer.

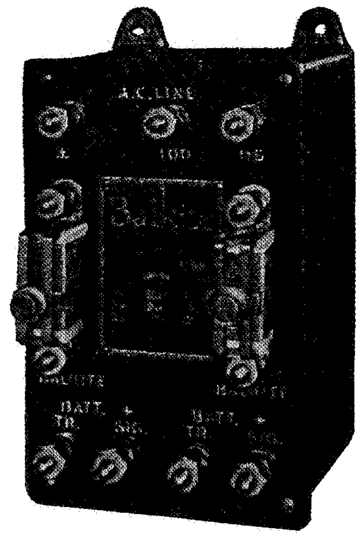

Fig. 32.
Transformer.

Mechanical, Rectigon and Tungar rectifiers are furnished with the transformers built into the unit.

Electrolytic rectifiers are operated from transformers separate from the rectifying unit. In the copper-oxide type of rectifiers, transformers may be self-contained or a separate unit.

Figures 31 and 32 illustrate two types of transformers used with these rectifiers as separate units. Secondaries are provided with various taps so that proper charging voltages may be obtained. Figure 27 shows a rectifying unit with transformer self-contained. The theory of operation of these transformers is the same as explained in Chapter VIII—Transformers.

Alternating Current Floating Storage Battery System

The Signal Section, American Railway Association, defines Alternating Current Floating Storage Battery System as: A combination of alternating current power supply, storage battery and rectifying devices so constructed as to continuously charge storage battery and at the same time furnish power for the operation of signal devices.

For the generation and distribution of electrical power the alternating current system is the most feasible and economical due almost solely to the fact that this form of power can be transformed from one voltage to another by the simple use of a transformer. For power consumption or utilization direct current is generally accorded an equally high position and in some cases is even superior to alternating current.

The alternating current floating battery system of signal power supply is a combination of the alternating current system of power distribution and the direct current system of power consumption. At each signal location rectifiers and batteries form the connecting links between the alternating current power supply and the signal and track circuits. Figure 33 is a typical layout from the generating station to the signal circuits and Fig. 34 is an elementary wiring diagram.

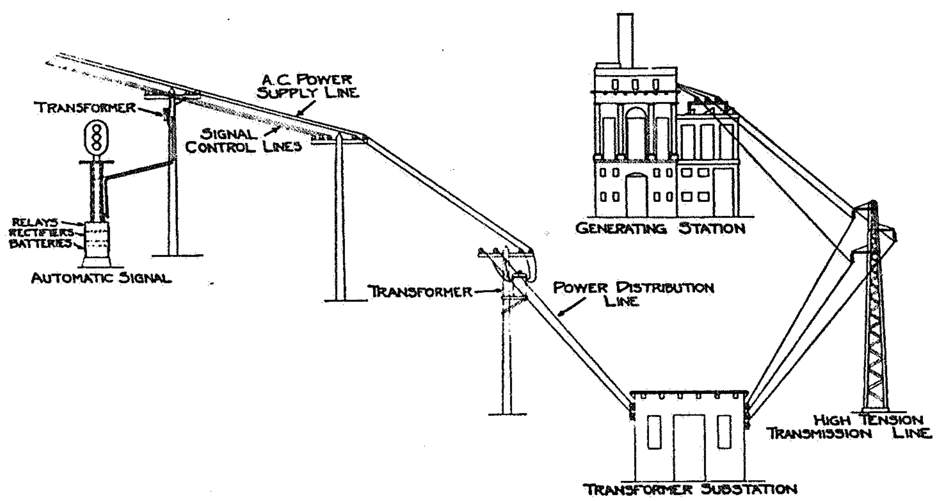

Fig. 33.
Typical Layout from Generating Station to the Signal Circuits.

One of the most popular methods of explaining the flow of electrical power in an electrical conductor or wire is by comparison or analogy to the flow of water in a pipe line, wherein the pressure exerted by a column of water is compared to the pressure in volts of the electric circuit and the flow of water through the pipe is compared to the flow of current in amperes in the electrical circuit.

This hydraulic similarity or analogy can be applied to explain the principle and operation of the alternating current floating battery system. Figure 35 is a simple water supply plant or system. Assume that it is utilized for some manufacturing purpose and must supply a small steady stream of water continuously, and a larger flow or stream over short periods of time, intermittently. To protect the manufacturing process against a failure of water supply, in case of breakdown of the boiler room or pump, the storage tank becomes a necessary part of the water supply plant.

The best way to operate this water supply plant would be to regulate the speed of the pump so as to keep the tank approximately full at all times, but without an excessive overflow of water from the tank; that is, the speed or output of the pump would be adjusted to meet the average demand for water. There might be periods of time when the intermittent demand for water would be large and during this time the level of the water in the tank would drop. Again, if the intermittent demand is small, the level lost during periods of large intermittent demand would be restored; that is, when the intermittent valve is closed the tank would gain in level until it overflowed and there would be a small continuous overflowing of the

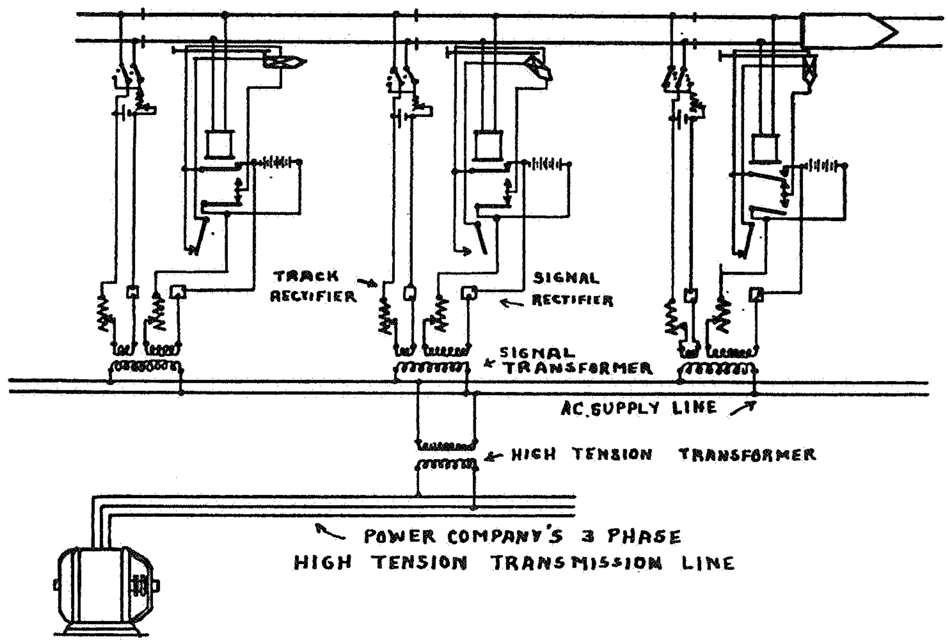

Fig. 34.
Elementary Wiring Diagram for Floating Storage Battery System.

tank until the intermittent valve is again opened. In fact all of our city water supply systems of today are built and operated upon this principle.

In this water supply plant the water and steam pressure actuating the pump corresponds to the alternating current power; the pump corresponds to the rectifier; the storage tank to the battery; the steady stream or supply of water corresponds to the steady load on the signal system such as the output to a track circuit, the holding coil of a semaphore signal, relays, or the signal light where it is continuously lighted with direct current; and the intermittent supply of water corresponds to the intermittent load on the signal system, such as the track circuit drain with a train in the block, the motor current of the semaphore signal, the signal light current in

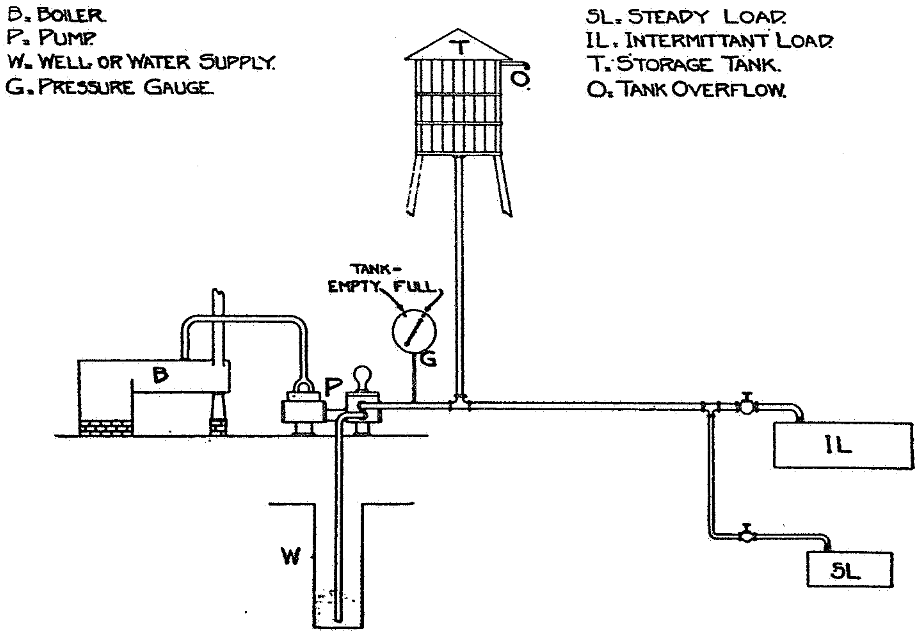

Fig. 35.
Simple Water Supply Plant System.

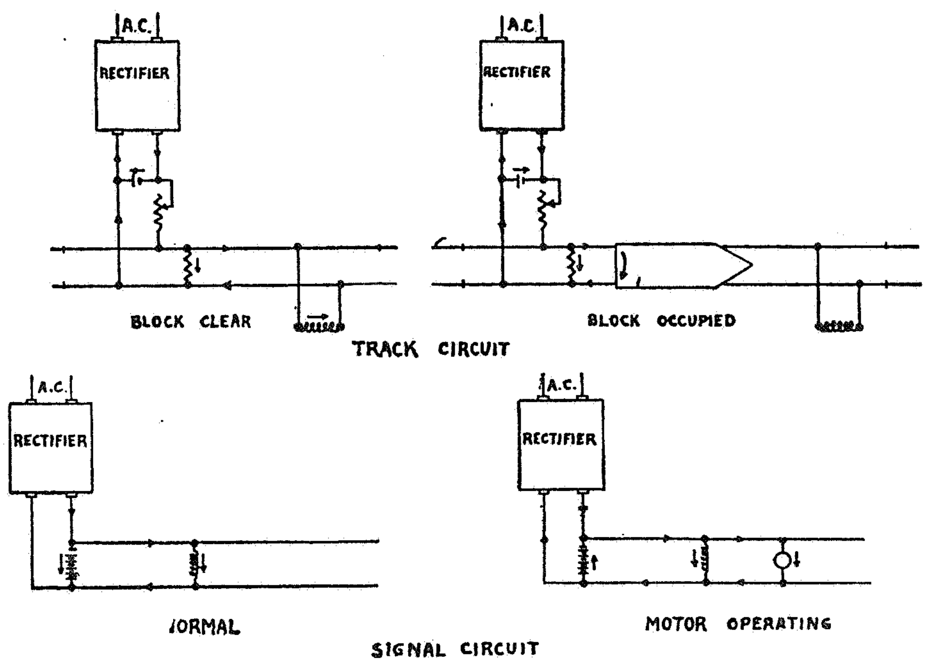

Fig. 36.
Rectifier and Battery Connected to a Track and Signal Circuit.

approach lighting or where alternating current power-off relays are used, which operate on an interruption in the alternating current supply, and the loss of water in the operation of the plant, due to leakage and evaporation, corresponds to the internal loss or local action within the storage cell or battery.

Figure 36 shows a rectifier and battery connected into a track circuit and a signal circuit. In the unoccupied block it will be noted that the rectifier furnishes the total output to the track circuit and is also charging the battery; that is, the battery is doing no work whatever at this time. When a train occupies the track circuit the battery discharges to furnish most of the extra current drawn because of the fact that the track circuit is short circuited. In the signal circuit, as shown, the rectifier supplies the steady connected load and charges the battery when there are no signal movements. When the signal motor operates, the battery discharges to supply practically all the current for the operation.

The rectifier must supply a steady current or floating rate equivalent to the sum of three different currents as follows:

1. A current to supply the steady connected load.
2. A current to return to the battery the amount taken out during the intermittent discharges.
3. A current to make up for the local action or loss within the battery.

The total output or the floating rate of the rectifier, whatever it may be for any particular location, should be sufficient to maintain the battery in an approximately fully charged condition. In the alternating current floating battery system the voltmeter corresponds to the pressure gauge in the water supply system and is the most satisfactory method of checking the floating rate. Gassing of the electrolyte corresponds to the overflow of the water tank.

Instructions.

Alternating current floating storage battery system should be maintained and operated in accordance with the following instructions:

1. Rectifiers must be adjusted to provide a charging rate sufficient to keep the battery fully charged.

2. Frequent tests must be made by taking a voltage reading across the terminals of each cell, while rectifier is charging, to determine that the cell is fully charged.

3. Voltage across each cell of lead type battery must be maintained at an average of 2.15 volts.

4. Voltage across each cell of nickel, iron, alkaline battery must be maintained at an average of 1.5 to 1.6 volts.

5. A battery record form must be kept for each cell, on which the date and voltage reading of each cell must be entered each time check is made.

6. Adjustment of charging rate must not be made each time it is found a cell is outside the voltage limits specified in Instruction 3 or 4. If, however, the voltage is found to be consistently low or high on three consecutive checks, adjustment must be made as necessary.

7. It is advisable that the charging rate be first set at a safe maximum and reduced as necessary. In this way the possibility of exhausted cells, during interval of adjustment, will be eliminated.

8. Voltmeter used for these tests must be kept in calibration to less than 5 per cent error.

9. If necessary to add water to batteries during freezing weather, a syringe must be used to mix the water with the electrolyte.

10. Fuses of specified capacity and type must be used, and a sufficient supply of tested fuses must be kept on hand for immediate use.

11. Lead acid type storage batteries should be installed, maintained and operated in accordance with the instructions covered in Chapter V—Batteries.

12. Nickel, iron, alkaline storage batteries should be installed, maintained and operated in accordance with the instructions covered in Chapter V—Batteries.

APPENDIX

FUNDAMENTAL THEORY OF ALTERNATING CURRENTS*

In connection with the study of rectifiers and certain other signal apparatus, it is desirable to possess a working knowledge of the physics and mathematics of alternating currents. Unfortunately, there seems to be a general impression that this subject is a bit too abstruse for anyone not a mathematician or a college graduate. Naturally, the designing engineer must have a thorough and detailed knowledge of physics, mathematics and electricity; in addition, he must have a broad practical experience before his theoretical training will be of much value, for there are many pitfalls not mentioned in the text-books. Most of the fundamental facts, however, are within the grasp of almost everyone, and this subject-matter will, therefore, be devoted to a presentation of such alternating current theory as will enable the signalman to understand the most important factors entering into the workings of alternating current apparatus.

Generation and Characteristics of Alternating Current Waves

Simple alternator.

A generator which produces alternating current is known as an alternator. Alternators generate currents on exactly the same principle as direct current dynamos, and in fact, the two types of machines are alike in all important respects, with the exception that, whereas the direct current machine is provided with a commutator to maintain the direction of current constant in the external circuit, the alternator supplies current to the external circuit just as it is generated without rectification of direction. Currents are, therefore, said to be direct or alternating in character, depending on whether they flow always in one direction with a steady value, or whether their direction and strength vary periodically.

A simple form of alternator is shown in Fig. 37, where N and S are the poles of a field magnet, which latter, in some cases, may be a permanent magnet, as for example, in telephone or automobile magnetos, but which is always a large electromagnet, excited from some direct current source, in the case of power generators; the point to be remembered is that the field magnet is of constant polarity. Rotating on a horizontal axis in the magnetic field whose flux lines pass from N

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to S as indicated by the arrows, is a loop of wire terminating in two metallic rings, R and T, carried on, but insulated from, the same shaft which drives the wire loop. R and T are known as slip rings, and brushes A and B bearing on them, conduct the current generated in the loop away to the external circuit to which electric power is to be delivered. It is understood, of course, that the alternator shaft carrying the wire loop is provided with a pulley to be driven from an engine or some other source of mechanical power.

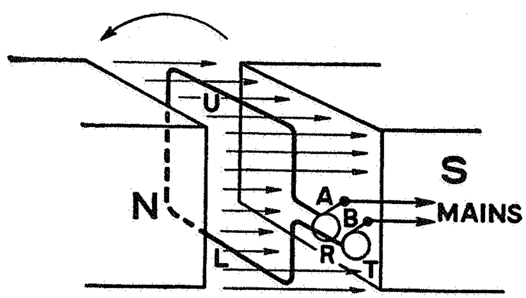

Fig. 37.
Simple Bi-Polar Alternator,
No-Voltage Position.

Voltage generated by simple alternator.

It is a fundamental fact that when a wire is forcibly moved across a magnetic field so as to cut the lines of magnetic flux, an electromotive force is generated in the moving conductor. The electromotive force so generated is proportional to the strength of the magnetic field and the speed at which the conductor is moved; or more simply, the voltage varies with the rate at which the lines are cut. When a conductor cuts 100,000,000 flux lines in one second, one volt is generated in that conductor. Of course, when the rotating wire loop consists of many turns, the total voltage generated in the coil is the voltage generated in one conductor, multiplied by the number of conductors moving in the magnetic field, for the conductors comprising the coil may be considered as a number of batteries connected in series. In the case of the two-pole alternator shown in Fig. 37, the voltage generated is:

$$E = \frac{2n\Phi Z}{100{,}000{,}000} \qquad (1)$$

Where E is the voltage across slip rings R and T, and n is the speed in revolutions per second at which the loop, consisting of a total of Z conductors (such as U and L), is being moved in a field of Φ lines of magnetic force streaming from pole N to pole S; the Greek letter Φ (pronounced "phi") is universally used in electrical calculations to represent the total number of flux lines constituting the magnetic field. The factor 2 n in the above formula, representing the speed in half revolutions per second, is introduced because it is during a half revolution that each conductor cuts a total of Φ lines. If, therefore, the shaft of the simple alternator shown in Fig. 36 is revolving at a constant speed of 50 revolutions per second and there are a total of two conductors (one on either side of the loop) cutting a magnetic field of 1,000,000 flux lines, then the electromotive force generated will be two volts. Equation (1) serves as the basis for the design of all generators, large and small.

Shape of generated wave.

It will now be of interest to investigate the form of the electromotive force wave generated by an alternator such as that shown in Fig. 37, which, by the way, may be considered as representative of commercial machines, for purpose of analysis and calculation. Keeping in mind the fact that the electromotive force generated at any point in the revolution of the loop depends on the rate at which the lines of magnetic flux are being cut, it will be seen that when the

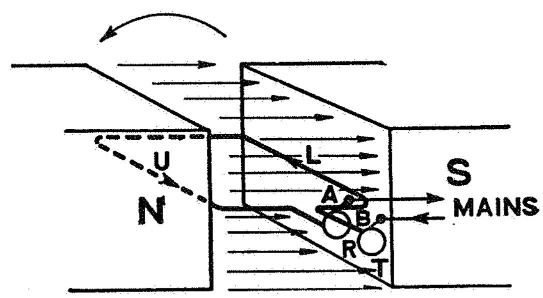

Fig. 38.
Simple Bi-Polar Alternator,
Full-Voltage Position.

loop is exactly vertical, as shown in Fig. 37, both the upper conductor U and the lower one L, merely slide along the magnetic lines for an instant without actually cutting through them, under which circumstances, of course, no voltage is generated in either conductor. However, the moment after the loop leaves the vertical position it begins to cut the flux lines at a low rate for the first few degrees of the revolution, because the movement of the conductor is more horizontal than vertical; in other words, the action is still a sliding one, rather than a cutting action. As the loop progresses in its revolution, the cutting action becomes more and more marked, until the loop is horizontal, as shown in Fig. 38, when the conductors are moving at right angles to the flux lines and the rate of cutting is the greatest; consequently, the highest voltage is generated when the loop is swinging through the horizontal position. Naturally, as the conductors leave this horizontal position, the rate of cutting the lines falls off again and finally, when the loop is again vertical, but upside down, the conductors are once more sliding along the lines and no voltage is generated. It will thus be evident that, during each full revolution of the loop, the generated voltage falls to zero twice and twice reaches a maximum.

In addition to the changes in the *value* of the generated electromotive force, there are also changes in its *direction,* which must be considered. If the loop in Figs. 37 and 38 is revolving in the opposite direction to the hands of a clock, then conductor U will be cutting the flux lines in a downward direction and conductor L will be cutting them in an upward direction during the first half of the revolution; this action is, of course, reversed during the second-half of the stroke, for then, after the loop has been turned upside down, conductor U is moving upward and conductor L is moving downward. Now, it is an experimental fact that the direction of the voltage generated in a conductor moving in a magnetic field depends upon the direction in which the conductor is moving with respect to the flux lines, and no better way of representing the relative directions of flux lines, movement of the conductor and resultant generated voltage exists than that offered by a simple law known as "Fleming's Right-Hand Rule," illustrated in Fig. 39, where the forefinger Y of the

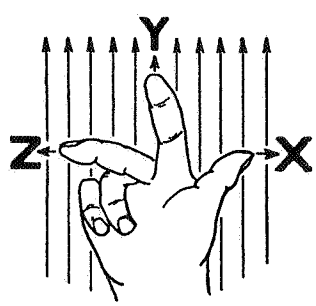

Fig. 39.
Fleming's Right-Hand Rule.

right hand indicates the direction of the flux lines, the thumb X shows the direction in which the conductor is moving in the magnetic field, and the middle finger Z, bent at right angles to both thumb and forefinger, points in the direction in which the voltage is being generated. Applying this rule to Figs. 37 and 38, it will be seen that during the first half of the revolution the voltage generated in conductor U tends to send a current from back to front of that conductor and from front to back in conductor L as the latter is cutting the flux lines in the opposite direction, the direction of the flux lines, of course, remaining the same at all times as previously stated. On the other hand, during the second half of the stroke when conductor U is moving upward, the voltage generated in U tends to send a current from front to back, while in conductor L the opposite is the case. It is also worthy of note that, due to the fact that conductors U and L are connected in series, the voltage generated in one of them tends to send a current around the loop so as to help the voltage generated in the other conductor; hence, the voltage across slip rings R and T is double that generated in one conductor. To sum up, therefore, the voltage generated in such an alternator rises in one direction from zero to a maximum, falls off again to zero, then rises in the opposite direction to a maximum and falls once more to zero, once during each revolution of the alternator shaft.

The above discussion covers only the nature of the changes in the direction of the generated electromotive power without reference to magnitude. The successive changes in the magnitude and direction of the voltage generated during one revolution of the loop shown in Fig. 37 is graphically illustrated in Fig. 40, where the line OP, re-

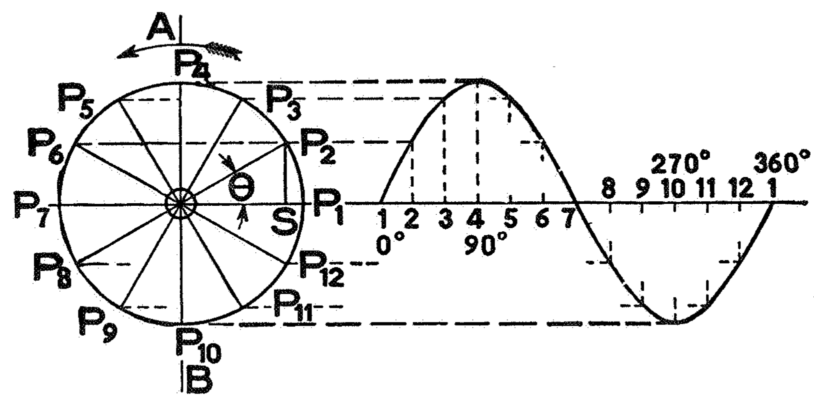

Fig. 40.
Sine Wave Development.

volving counter-clockwise about point O, represents to scale the maximum voltage generated by the loop (the electromotive force generated when the loop is in the horizontal position in Fig. 38), and the various angular positions of the line OP correspond to similar positions of the loop during its revolution. It is now proposed to represent, in pictorial fashion, the rise and fall in voltage during one revolution of the loop, and for this purpose the circle in which point P swings is divided in twelve parts, P_1, P_2, P_3 — P_{12}. Then a horizontal line at the right of the circle is divided also into twelve equal parts; the line may be drawn to any length, as that is merely a matter of scale. The point to be grasped is that these horizontal positions mark the passage of time as the loop swings through the corresponding angles.

Now, the voltage generated at any point in the revolution of the loop is proportional to the projection of line OP at that point against the vertical line AB, that is, perpendiculars dropped from points P_1, P_2, P_3, etc., against AB, represent the voltages generated in the loop at those positions; this results from the fact that the number of lines of force being cut at any given instant are directly proportional to the corresponding projection of the swinging vector OP on the vertical axis AB. To plot the electromotive force wave generated in the loop as the latter swings through one complete revolution, it is, therefore, only necessary to project points P_1, P_2, P_3, etc., horizontally to the right until they meet their corresponding time verticals. Beginning at position P_1, which represents the vertical position of the loop as shown in Fig. 37, no voltage is being generated, as previously described; the time is zero, since the loop is just on the point of starting its revolution, and, when P_1 is projected horizontally to the right, it coincides with point 1, indicating zero voltage at that time. As the loop continues its revolution, the voltage increases until at P_4, when the loop has turned through 90 degrees and occupies the horizontal position shown in Fig. 38, the maximum voltage is being generated and the projection of the line OP_4 is equal to the length of the line itself. Then, as the loop swings downward, the voltage begins to fall off, until at point P_7, when the loop is upside

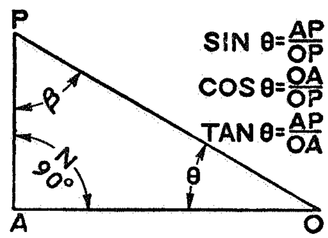

Fig. 41.
Functions of the Right-Angle Triangle.

down, the voltage is zero. Here the loop begins to generate voltage in the opposite direction and the projection of P_8 is below the horizontal line; the voltage once more rises to its maximum and passes through the same set of values as before, only in the opposite direction, and finally the zero position is again reached and the loop is at the starting position for the next revolution. When the loop is in the first half of its revolution, it will be evident that all projections of the line OP are above the main horizontal axis of the diagram, and the corresponding voltage values will be considered as positive (+); when the loop is in the second half of its stroke, the projections are below the horizontal axis and the voltage values are then negative (—). Of course, the voltage passes through the same variations in strength and direction during the second and all succeeding revolutions.

The sine wave.

For purposes of calculation, it is desirable to reduce the relations shown in Fig. 40 to mathematical form, and an understanding of the trigonometrical functions of right-angle triangles will render this analysis easy. A right-angle triangle, such as that shown in Fig. 41, is a triangle in which one of the angles is a right angle, *i.e.*, one of 90 degrees; the other two angles are known as acute angles, and are each less than a right angle. The side OP, opposite the right-angle end in Fig. 41, is known as the "hypotenuse," while the other two sides PA and OA are the legs of the triangle. The quotient obtained by dividing the length of the leg AP by hypotenuse OP is known as the *sine* of angle Θ (Greek letter "theta"). The quotient obtained by dividing leg OA by the hypotenuse OP is known as the *cosine* of Θ. The quotient obtained by dividing leg AP by leg OA is known as the *tangent* of Θ. In right-angle triangles, therefore, the fraction obtained by dividing the side opposite a given angle by the hypotenuse is the sine of that angle; the cosine of that angle is the fraction obtained by dividing the leg adjacent to that angle by the hypotenuse; and the tangent is obtained by dividing the length of the leg opposite the angle by the length of the leg adjacent to that angle. A little study of Fig. 41 will make it plain that the sine of angle Θ is the cosine of angle β, and that, vice versa, the sine of angle β is the cosine of angle Θ. The sine of angle Θ is generally abbreviated to *sin* Θ; the cosine of the same angle to *cos* Θ; and the tangent to *tan* Θ. For an angle of given size, the above values are always constant, regardless of the size of the triangle. For example, the sine of a 30 degree angle is 0.500, and the cosine is 0.866, and the tangent 0.577; for a 45 degree angle, the sine is 0.707, as is also the cosine, the tangent being 1.

With the above facts in mind, and referring again to Fig. 40, it will be evident that, as line OP swings around from P_1 to P_2, an angle, say Θ, is covered, and that the vertical projection P_2S of line OP_2, representing the voltage generated at point P_2 is simply equal in length to the ratio $\frac{P_2S}{OP_2} \times OP_2$, which is no more or less than the sine of angle Θ, through which the loop has moved from its starting position, multiplied by the maximum voltage generated when the loop is horizontal as in Fig. 38. At any other point in the revolution, the voltage generated is equal to the sine of the corresponding angle through which the loop has moved from the starting position multiplied by the maximum voltage generated as before. Therefore:

$$e = E \sin \Theta \qquad (2)$$

where *e* is the voltage being generated at any instant, E is the maximum voltage and Θ is the angular position at the loop at that instant.

With the generator shaft revolving at constant speed, there is, of course, a fixed relation between time and angular position of the loop, and, therefore, angle Θ is capable of further analysis. The unit of length is the foot, and linear speed is often given in feet per second, but, obviously, such a system of measurement would not apply to angular speed, and, consequently, angular speed is always given in radians per second in mechanics. Taking a circle of any diameter, an angle like a piece of pie can be cut out so that the part of the circumference of the circle which the angle cuts out is just equal in length to the radius of the circle; that angle, called a radian, is used as the unit of angular measurement, and is of constant value for circles of all diameters, since the circumference varies directly with the diameter. As everyone knows, the circumference of a circle is 3.1416 times the diameter; the constant 3.1416 is generally represented by the Greek letter π (pi). Since the diameter is twice the radius, a little reflection will show that there are 2π radians in a circle of 360 degrees; a radian is consequently equal to $\frac{360}{2 \times 3.1416} =$ 57.30 degrees. If, therefore, the shaft of the alternator shown in Fig. 37 is turning at a speed of n revolutions per second, its angular speed is:

$$p = 2\pi n \qquad (3)$$

where p is the angular speed in radians per second. After t seconds, reckoning time for position P_1, in Fig. 40, as the starting point, the shaft will have turned through some angle, say θ, of $p \times t$ radians. Hence, at any time t in the revolution the voltage generated will be

$$\begin{aligned} e &= E \sin \theta \qquad (4) \\ &= E \sin pt \end{aligned}$$

Definitions.

The following definitions are derived from the foregoing discussion:

An *alternating current,* or electromotive force, is one which varies continuously with time from a constant maximum value in one direction to an equal maximum value in the opposite direction, repeating the cycle of values over and over again in equal intervals of time. Alternating currents are not necessarily purely sinusoidal, as shown in Fig. 40, but most commercial alternators produce waves which closely approximate pure sine curves; for our purpose it will be satisfactory to base our calculations on sine waves.

The *period* of an alternating current is the time taken for the current to pass through one complete set of positive and negative values, as shown in Fig. 40.

When an alternating current passes through a complete set of positive and negative values, as shown in Fig. 40, it is said to pass through a *cycle.*

The *frequency,* or number of cycles, per second, is the number of periods per second.

The number of *alternations,* generally given per minute, is the number of times the current changes direction from positive to negative, and from negative to positive, per minute. Obviously, in each cycle, there are two alternations. Frequency may, therefore, be given either in cycles per second or alternations per minute. On this basis, a 60-cycle generator gives 7200 alternations per minute.

Commercial multipolar alternators.

The above rules and definitions have been deduced from a consideration of the simple alternator shown in Figs. 37 and 38, but they may be applied equally well to all alternators, no matter how large or complicated. Of course, few commercial generators, with the exception of alternators direct driven from high-speed turbines, are as simple as the one discussed. Where heavy reciprocating engines are used to drive alternators, the speed is, of necessity, comparatively low, and for commercial frequencies and voltages a generator with a large number of field poles, like that shown diagrammatically in Fig. 42, is used.

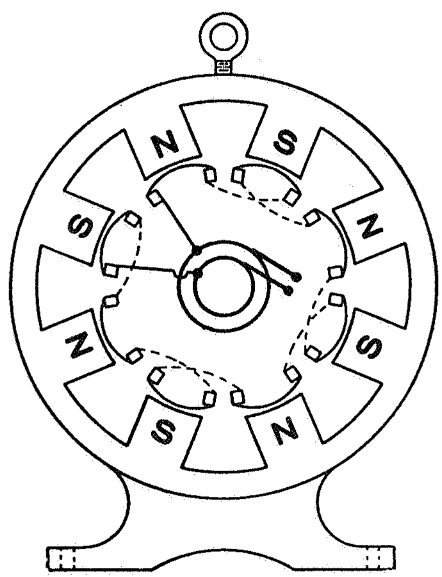

Fig. 42.
Armature Winding, Eight-Pole Alternator.

The alternator in Fig. 42 has eight field poles magnetized by direct current fed from a separate small direct current generator, known as an *exciter,* which latter is generally driven from the same shaft as the armature of the alternator, as at the left in Fig. 43, which shows a large multipolar alternator complete with its slip rings and exciter. It is to be observed in Fig. 42 that the voltages generated in adjacent

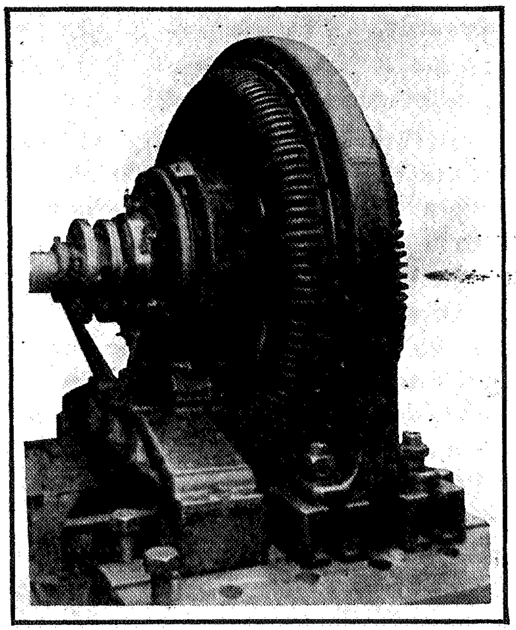

Fig. 43.
Alternator with Exciter at Left.

armature coils are in opposite directions at each instant, but by reversing the connections of alternate coils, as indicated by the dotted lines, these electromotive forces act in series and do not oppose each other. In multipolar alternators the frequency is:

$$f = \frac{P}{2} \times \frac{n}{60} \qquad (5)$$

where P is the total number of field poles and *n* is the speed of the armature in revolutions per minute. If the alternator in Fig. 42 is running at a speed of 375 revolutions per minute, the frequency would be

$$f = \frac{8}{2} \times \frac{375}{60} = 25 \text{ cycles per second}$$

In such multipolar alternators, the total voltage generated across the slip rings is

$$E = \frac{KP\Phi nZ \text{ Volts}}{100,000,000} \qquad (6)$$

where K is a factor depending on the ratio of breadth of pole face to the spacing of the poles, as well as on the distribution of the winding on the armature, P is the number of poles, Φ is the magnetic flux per pole, *n* is the armature speed in revolutions per minute, and Z is the total number of armature conductors. This equation, it will be seen, is simply a development of the equation given previously for the simple alternator.

Turbo-alternators.

Steam turbines operate most efficiently at high speeds and, in order to accommodate the alternators to these conditions with the commercial frequencies of 25 and 60 cycles, the number of field poles must be reduced to a minimum. Many of these turbo-alternators run at speeds as high as 3600 revolutions per minute, and have but two field poles. In these cases, the field magnet is the rotating element, as it is easier to support and insulate the high-voltage armature conductors on the outside stationary member; it is hardly necessary to elaborate on the fact that it makes no difference which element rotates, as only relative motion between field and armature is necessary. On account of their high speed, these machines generate a tremendous amount of power for their size, as compared with reciprocating engine-driven alternators.

Measurement of alternating currents and voltages.

With currents and electromotive forces varying so widely in magnitude from instant to instant as do alternating currents, or electromotive forces of sinusoidal form, what is the meaning of the terms *ampere* and *volt* when used in connection with alternating current circuits? The current at any instant t is known as the *instantaneous* current at that time, and is designated as i; the instantaneous electromotive force is similarly denoted as e. *The maximum* voltage, as before explained, is generated when the number of flux lines being cut is the greatest, and is designated as E, while the maximum current is denoted as I. Referring to Fig. 40, which for the present discussion we shall take to represent an alternating current of electricity, the *average* value of that current is, of course, simply the average of all the vertical ordinates, or heights, of the half wave extending along the horizontal axis between points 1 and 7; that is, the horizontal half period axis 1-7 would be divided into, say, seven equal parts, as shown, and the average current would be found by adding up the lengths of all seven vertical lines drawn upward to the wave outline from points 1, 2, 3, 4, 5, 6 and 7, and then dividing the sum of these lengths by 7; the average value of the voltage would be similarly found.

None of these values are, however, convenient for purposes of calculation. In direct current circuits, the rate at which heat is generated by a steady current of I amperes flowing through a resistance R ohms is equal to the square of the current, multiplied by the resistance, or I^2R. Likewise, the rate at which heat is generated by an alternating current of instantaneous value i, through the same resistance, is i^2R; that is, the average rate at which heat is generated in that circuit is R multiplied by the average value of i^2. Now, a steady direct current which would produce the same heating effect as the above alternating current would be one whose square is equal to the average value of i^2 of the alternating current; the actual value of the alternating current would, therefore, be equal to the square root of its average i^2. Thus, instead of taking the average of a large number of ordinates, or heights, of the half wave, as in the previous case, we must now take the square root of the average of the squares of all these ordinates. This square root of the average of the squares of the alternating current over a complete period is called the *root mean square,* or the *effective* value of that alternating current. On this basis, one ampere alternating current will produce the same heating effect in a given resistance as will one ampere direct current. Similarly, the square root of the average of the squares of an alternating electromotive force over a complete half period is called the effective value of that alternating electromotive force.

In specifying the value of an alternating current as so many amperes, or an alternating electromotive force as so many volts, these effective values are always meant, unless something is stated to the contrary. The principal reason for selecting this particular function of the instantaneous values of an alternating current or electromotive force as the practical measure of current or voltage, is that the deflections or readings of all ammeters or voltmeters used in alternating current measurements are directly proportional to these effective values; furthermore, it makes the direct current ampere and the alternating current ampere equal, in that they will produce the same heating and do the same work in passing through a given resistance. All alternating current instruments indicate effective values, which are obviously quite different from average values.

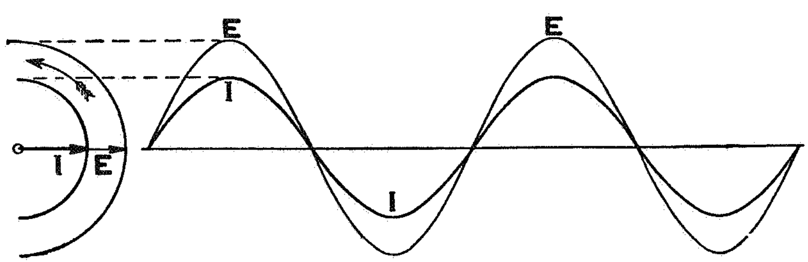

Fig. 44.
Current and Voltage in Phase.

Phase Relations—Vector Diagrams

Phase.

When an alternating electromotive force is impressed across a dead resistance, the current varies instantaneously with the voltage; in other words, as the voltage rises and falls, and changes direction, the current flowing through the resistance rises and falls, and changes direction, at the same time as the voltage. This condition is clearly shown in Fig. 44, where current I and electromotive force E are said to be in *phase,* because their maximum and zero values occur at the same instant.

Lagging and leading currents.

In many cases, however, alternating electromotive forces are impressed across coils consisting of many turns of wire often wound around iron cores, and in these cases the current is choked back when it tends to increase as the voltage rises, and persists when the voltage falls, as will hereafter be explained. The coil of wire produces an *inductance* effect in the circuit, and causes the current to *lag* behind the electromotive force, as shown in Fig. 45. The base

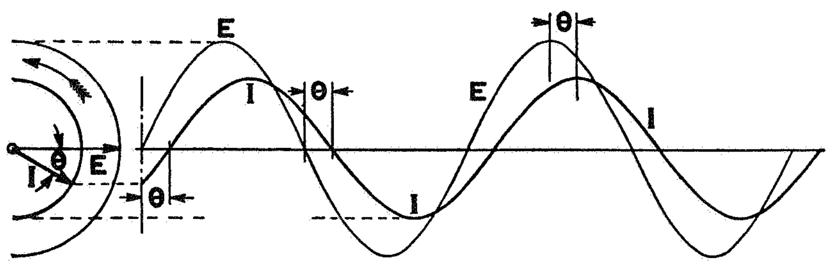

Fig. 45.
Current Lagging Behind Voltage.

line along which the curves are laid is divided off into degrees—360 degrees for each cycle to correspond to one complete revolution of the loop shown in Fig. 37. The number of degrees by which the current lags behind the voltage is known as the *lag angle* of the current with respect to the voltage, and is designated as θ in Fig. 45. Conversely, the electromotive force *leads* the current, and in the same sense the angle θ is the *lead angle* of the voltage with respect to the current. Again, the current and voltage are said to be *out of phase* by an angle of θ degrees.

Vector diagrams.

Alternating currents and voltages may be represented by the length, position and direction of a line, called a *vector.* Thus, two currents may be represented (1) in magnitude by two lines having lengths proportional to the intensities of the currents; (2) in relative angular position, or phase, by the angle at which the lines, extended if necessary, intersect; and (3) in direction by arrow heads placed upon the lines. Vectors may be combined or resolved into components by the well-known parallelogram of forces.

Vector diagrams of sinusoidal currents and voltages render the study of phase relationships quite simple. Simple diagrams of this character are shown at the left of Figs. 44 and 45, where lines OE and OI revolve at a uniform rate of *n* revolutions per second, equal to the frequency in cycles per second, about point O in the direction of the arrow; since the lengths of the vectors OE and OI are constant the paths of the end of these lines will be circles, not necessarily of the same radius, as there is no connection between the scales to which OE and OI are drawn, one representing in length the maximum volts, and the other, maximum amperes. The rotating lines OE and OI, from whose vertical projections the current and voltage waves shown in Figs. 44 and 45 are constructed in the same manner as the sine curve shown in Fig. 40, are said to "represent" the sinusoidal current I, and the sinusoidal electromotive force E, respectively. In such diagrams, rotation is always assumed as taking place in the counter-clockwise direction, as indicated by the arrow; when two vectors are separated by a given phase angle, the vector farthest around in the counter-clockwise direction is said to be leading in phase, the other vector naturally lagging by the same angle.

The proper representation of alternating electromotive forces and currents by means of the vector diagram requires that:

1. The given currents and voltages must be of the same frequency, and, in addition, they must be of *harmonic* character; that is, at any instant, the current or voltage must be proportional to the length of the projection of the line OP against the vertical, as shown in Fig. 40.

2. The direction of voltages and currents must be indicated by arrow heads on the vectors.

3. The different vectors entering into the construction of the diagrams must be constant in their angular relations to each other.

4. In addition to the above, it is desirable to scale the lines of a vector diagram in terms of effective values, rather than maximum values, because effective values are always given by measuring instruments and are used in numerical calculations; of course, when laying out sine waves, as in Figs. 44 and 45, it is more convenient to use maximum values, as the corresponding instantaneous values can be secured by simple projection.

For example, in Fig. 44 the current and electromotive force are in phase, and, consequently, their vectors shown at the left of the figure are not separated by any phase angle; this relationship is maintained throughout the revolution. On the other hand, in Fig. 45, the vectors OI and OE are separated throughout their revolution by phase angle Θ, by which the current lags behind the electromotive force.

Vector addition of electromotive forces.

Take, for example, two alternators A and B (Fig. 46) connected in series, and assume they are similar in all respects, being driven at the same speed and possessing equal frequency. If the three voltmeters are connected as shown, voltmeters E_1 and E_2 will indicate, respectively, the volts due to alternators A and B, whereas E will measure the volts across the two machines in series. If the volts measured by E are equal to the arithmetical sum of E_1 and E_2, the two alternators would, of course, be in phase, but as a rule the reading of E will be smaller than the simple sum obtained by adding E_1 and E_2. We will suppose these three values, E_1, E_2 and E, to be known. From the center O of Fig. 46, describe a circle of radius

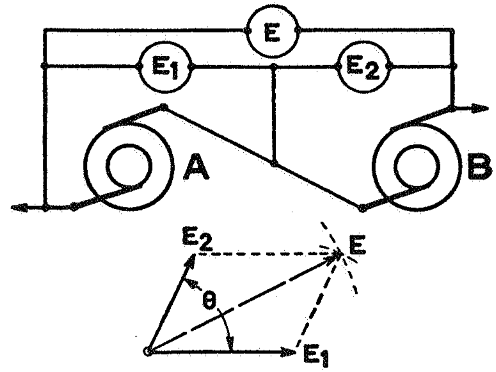

Fig. 46.
Vectorial Addition of Voltages.

OE, the length of which represents the voltage E. Now, draw OE_1 in any direction to represent the volts E_1. From E_1 as a center, describe an arc of radius E_1E, the length of which is proportional to the volts E_2; it will cut the arc already drawn at point E. Join OE and complete the parallelogram OE_1EE_2. The angle θ between the two component vectors OE_1 and OE_2 is then the angle of lag, and is, therefore, the phase difference between the two voltages produced by alternators A and B.

The question of compounding two or more alternating forces in an electric circuit now becomes a very simple matter. Thus, in Fig. 46, had we been given the two voltages E_1 and E_2 and the phase difference θ (instead of the three voltages), we could have calculated the total electromotive force E and have ascertained its phase relation to its two components by merely constructing the parallelogram of forces OE_1EE_2 in the usual manner.

As an example, let us suppose that there are three distinct alternating electromotive forces—A, B and C—of the following values, all combining to produce one resultant electromotive force in an electric circuit:

$$A = 200 \text{ volts}$$
$$B = 150 \text{ volts}$$
$$C = 100 \text{ volts}$$

We shall also assume that B lags behind A by exactly 90 degrees, while C leads A by 35 degrees. Draw the three vectors OA, OB and OC in Fig. 47 to a suitable scale, and in such directions that the angles AOB and AOC are, respectively, 90 degrees and 35 degrees,

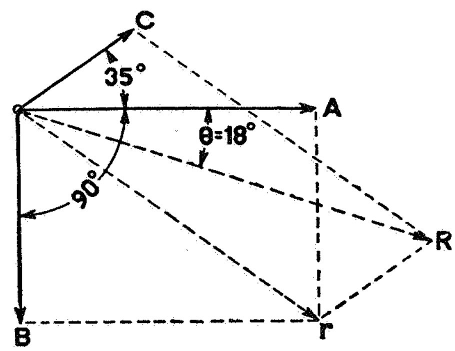

Fig. 47.
Determination of Resultant Voltage.

bearing in mind that OB must be drawn behind OA, while OC must be drawn in advance, lead angles being laid off in a counter-clockwise direction, as previously explained. First construct the parallelogram of forces OBrA, giving Or as the vector resultant of voltages OB and OA, then combine resultant Or with voltage OC by parallelogram OCRr, giving OR as the final resultant of all three initial voltages. The length of the line OR, measured by the same scale as the three component vectors, gives us the value of the resultant electromotive force, in this case 297 volts. If angle AOR is scaled it will be found that the resultant voltage OR lags behind component OA by 18 degrees.

Circuits Containing Resistance, Inductance and Combinations Thereof

Ohm's Law applied to alternating current circuits.

In direct current circuits Ohm's Law is expressed as:

$$I = \frac{E}{R} \text{ and the corollary } E = IR \qquad (7)$$

Where I is the current in amperes caused to flow in a circuit of R ohms by E volts. The same law holds also in alternating current circuits, providing the proper interpretation is put on the term R, for, due to certain inductance effects, presently to be described, the apparent resistance in alternating current circuits is often many times the dead or ohmic resistance in the circuit and Ohm's Law has to be amplified to:

$$I = \frac{E}{Z} \text{ and } E = IZ \text{ and } Z = \frac{E}{I} \qquad (8)$$

where Z is the *impedance*, representing the total apparent resistance of the circuit in ohms.

Case I—Circuits containing resistance only.

In the case of a circuit containing a dead resistance R only, Z = R and equation (8) becomes:

$$I = \frac{E}{R} \text{ and } E = IR \text{ and } R = \frac{E}{I} \qquad (9)$$

The current and voltage are in the phase. The vector diagram and the corresponding current and voltage waves in proper phase relationship are shown in Fig. 44.

Example: An electromotive force of 220 volts, frequency 60 cycles, is impressed on a circuit of a total dead resistance of 100 ohms. What is the current?

From equation (9) it will be evident that this current in the above circuit will be the quotient obtained by dividing the voltage 220 by the resistance 100 ohms, or 2.2 amperes.

Case II—Circuits containing inductive reactance only.

Electric circuits possess inertia. In order to form a mental picture of this property of an electric circuit, consider a flywheel rotating in a perfectly frictionless manner. Such a flywheel, once it has been put in motion, will continue to revolve for any length of time at undiminished speed, without requiring a further application of force. But a force had to be applied to bring it up to speed, and exactly the same amount of energy as was put in it is now available for doing work and will be given back by the time the flywheel has been brought to rest.

The above is a fair physical analogy of what happens in the case of an alternating current generator impressing an electromotive force on a coil of wire. It is assumed that the reader is aware of the fact that, when a current flows in a wire, that wire is surrounded circularly by a magnetic field of flux lines; when the current starts to flow, the flux lines spring outward circularly with the wire as a center, just like the ripples of water which are created when a stone is thrown into a pond. The intensity of the magnetic field about the wire at any point is dependent on the strength of the current flowing in the wire, as well as the distance of the point from the wire. If the current alters its value, the field is also altered, increasing with increase of current and decreasing with decrease of current, finally collapsing on the wire again when current ceases.

It will be evident, therefore, that, when an increasing electromotive force is impressed across a coil of many turns of wire, and a current starts to flow, lines of magnetic flux spring outwardly in expanding circles from each turn of the coil, and cut the other turns, producing in them a secondary electromotive force, which will be found counter or in direct opposition to the impressed electromotive force driving the current through the coil; this action cuts the value of the current at any instant down below what it would otherwise have been, for part of the impressed voltage is taken to balance this counter electromotive force. On the other hand, when the impressed voltage falls, and the current tends to decrease in turn, the flux lines start to collapse toward their respective turns, and in so doing cut the other turns, generating in them a voltage in the same direction as, and tending to assist, the falling impressed voltage to maintain the current above what it otherwise would be.

The magnetic field is a definite seat of energy and requires for its production, therefore, a definite expenditure of energy, determined in amount by the flux and the turns in the coil with which the flux circles are linked. These linkages of flux with turns constitute one of the most important factors in alternating current circuits. The number of such linkages for an electric circuit carrying one ampere is known as the *coefficient of self-induction,* or, briefly, the *self-inductance* of the circuit, being denoted by the symbol L. When the number of linkages of flux with turns due to one ampere flowing in the circuit is 100,000,000, the circuit is said to have a self-inductance of one *henry*. Stated in another way, a circuit has an inductance of one henry when one volt, exclusive of the electromotive force required to overcome dead resistance, will cause the current to change at the rate of one ampere per second. The choking effect due to self-induction is the seat of an apparent increase in the resistance of the circuit and in this, of course, the frequency is an important factor. As a matter of fact a mathematical analysis will show that in a circuit having a self-inductance of L henrys the apparent increase in resistance due to self-inductance is Lp ohms where $p = 2\pi n$, *n* being the frequency as in equation (3).

So long as the current in the circuit remains constant in value, there is no expenditure of energy in maintaining the field; this, of course, excludes the energy dissipated as heat in the electric circuit itself. If, however, the field increases, a reaction will be developed which must be overcome, requiring an expenditure of energy in the circuit. If, on the other hand, the field diminishes, there will be a reaction in the opposite direction to that first considered, and, in virtue of this, energy will be returned to the circuit. This reaction in each case takes the form of an electromotive force, called the electromotive force of self-induction, whose magnitude depends on the rate of change of linkages of flux and turns of wire. Every signalman has noticed that, when the circuit of a pair of high resistance slot magnet coils or relay coils carrying current is opened, there is a bright spark and a "back kick" which is capable of giving a considerable shock; this counter electromotive force, which is many times the original impressed voltage, is simply due to the lines of magnetic flux collapsing on the coils, and thus generating a high voltage when the current is suddenly interrupted. Similarly, if an attempt were made to suddenly stop a heavy rotating flywheel by slipping a bar between the spokes and the engine frame, disastrous results would follow, due to the quick dissipation of the energy stored up in the rotating mass.

Obviously, therefore, in the case of a circuit conveying an alternating current, there will be an alternate increase and decrease in the energy of the magnetic field, and this will give rise to inductance voltages. Considering a complete period of the current, it will be found that during one-half of this period energy is supplied by the circuit to the field, and during the other half of the period energy is returned by the field to the circuit. When the current is increasing in value, the establishment of energy in the field sets up an opposing electromotive force, which does two things: first, it makes the current reach a given value later than would be the case provided no such electromotive force existed; and, second, it diminishes the maximum value which the current reaches in a complete period. When the current is decreasing, the field contributes energy to the circuit; the value of the current at any instant, however, is not as small as it would be if no energy of the magnetic field were given back to the circuit, and, for this reason, the current again lags with respect to the value which it would have were no such induced electromotive force present. Again, the greatest negative value which the current reaches is less than the value which it would attain provided no energy from the field were returned to the circuit. In the flow of a sinusoidal current in a self-inductive circuit, the value of the current will be less than if the self-induction were not present and the current will lag by a certain angle with respect to the impressed voltage. In this sense, an alternating current circuit containing inductance possesses inertia just as does the rotating flywheel above mentioned.

As has previously been stated, the voltage generated in a conductor is proportional to the rate at which the flux lines cut that conductor. Now, when an alternating current is flowing through a coil, the rate at which the flux lines spring outward from their respective turns is greatest when the current is just starting to rise from zero, whether in one direction or the other; then the current is increasing most rapidly, for there is an instant when the current increases from zero to a definite quantity—from nothing to something, and then the rate of increase of current, and consequent magnetic flux, which varies simultaneously with the current, is the greatest. Conversely, when the current is at its maximum, it is steady for an instant at the top of the wave, and there the rate of increase in current and flux is zero. The electromotive force of self-induction, resulting from the change in magnetic flux, is, therefore, greatest when the current is zero. Now, if any current is to flow through the coil, this counter electromotive force of self-induction must be balanced by an equal and opposite electromotive force from the generator.

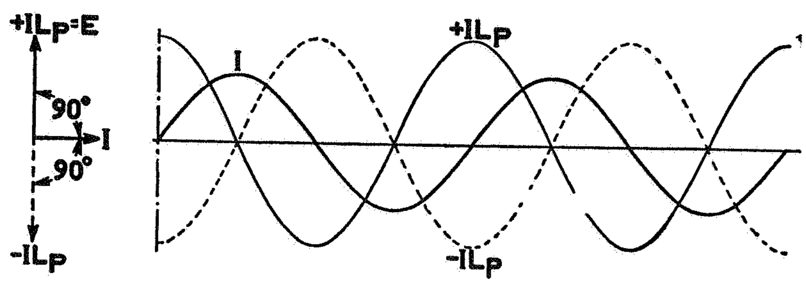

Fig. 48.
Circuit Containing Inductance Only.

This is illustrated in the wave diagram in Fig. 48, where I represents the current wave and —ILp the electromotive force of self-induction, which, it should be noted, is at its maximum when the current is zero, and is zero when I is maximum; also, since —ILp is a counter electromotive force, it is laid off negatively, as it is opposing the change in current. The balancing component wave +ILp must be laid off in opposition and equal to —ILp: a voltage E equal to +ILp volts, must therefore be impressed on the circuit in order that current I may flow.

The above conditions are represented vectorially at the left of Fig. 48, which diagram may easily be derived from the current and voltage waves, or may be constructed independently, as follows: first, lay off the vector I horizontally to correspond in scale to the given current. As before stated the equivalent resistance of the inductance L is numerically equal to the quantity Lp in ohms, where $p = 2\pi n$, as shown in equation (3). The term Lp is known as the *inductive reactance of* the circuit, and is always expressed in ohms. The reactive voltage drop in Lp is equal to the *inductive reactance* Lp multiplied by the current I, that is ILp volts, just as the drop in a dead resistance R is IR volts. This reactive drop vector —ILp lags 90 degrees back of the current, as previously explained, the balancing impressed electromotive force vector +ILp being exactly equal in length and opposite in direction to —ILp. When the two vectors are separated by an angle of 90 degrees, such as I and —ILp or I and +ILp, they are said to be in *quadrature*. In such a circuit, containing only pure inductive reactance, as just described, Ohm's Law in equation (8) becomes:

$$I = \frac{E}{Lp} = \frac{E}{X} \qquad (10)$$

$$E = IX \qquad (11)$$

$$X = \frac{E}{I} \qquad (12)$$

where X denotes the reactance Lp.

Case III—Circuit containing capacity reactance only.

We have now to consider briefly the case of a circuit containing pure *capacity reactance,* this latter effect accompanying the alternate charging and discharging of a condenser whose two terminals are connected to an alternator. The capacity might consist of a *condenser,* formed by a long dead-ended cable containing two conductors carefully insulated from each other, or the condenser might be composed of a number of sheets of tinfoil piled up with sheets of glass or paper between them, alternate layers of tinfoil being connected together to give the effect of two large metal sheets close to, but thoroughly insulated from each other just as in the case of the cable; in either case as long as the alternating current is flowing in a positive direction, current flows into the condenser, which, therefore, becomes charged, but, as soon as the current reverses, the condenser begins to discharge. The maximum charge of the condenser, and, consequently, its maximum back pressure or counter electromotive force occurs just at the moment when the current is about to reverse, and this back pressure or counter electromotive force, therefore, tends to help the current reverse, the latter growing to a negative value much quicker than it otherwise would do; this is just the opposite of what occurs in a circuit containing inductive reactance, and, as a consequence, in a circuit containing pure capacity reactance, the current leads the impressed voltage E by a quarter of a period, or 90 degrees, whereas, as previously explained, the current lags 90 degrees behind the impressed voltage E in a purely inductive circuit.

Capacity effects are so minute in signal work as to be negligible, with the single possible exception of transmission systems, and then only in the case they are very long; if, however, by any chance it becomes necessary to run the transmission underground in a cable, the capacity effect will be more noticeable, and had best be investigated. The cable manufacturers will furnish data covering the capacity reactance of their product, and from this the capacity reactance drop may be calculated, this latter, of course, helping to neutralize the inductive reactance voltage, with the result that a less voltage will have to be impressed on the transmission to force the required current through it than would be the case if capacity were not present.

Case IV—Circuits containing resistance and inductance.

In Case I we considered a circuit containing resistance only, and in Case II, one containing pure inductance only; the latter case is purely theoretical, as all circuits contain some resistance, however small, and, conversely, all circuits, particularly alternating current signal circuits, contain inductance. The general case, therefore, is one in which the circuit contains resistance and inductance.

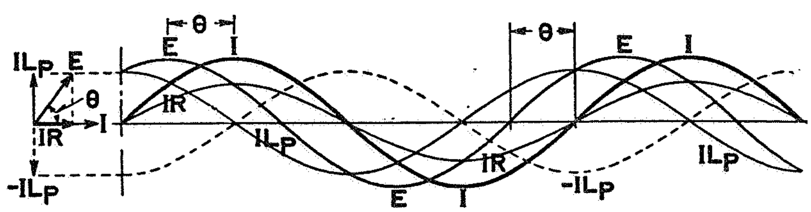

Fig. 49.
Circuit Containing Resistance and Inductance.

Figure 49 illustrates this general case, I being the current wave, —ILp the wave of the counter electromotive force of self-induction, ILp the balancing wave for the latter, and IR, naturally in phase with the current, the wave corresponding to the drop in the given resistance R. In order that current I may flow through this circuit, the alternator must not only supply enough voltage to compensate for the resistance drop IR, but, in addition, it must supply the component wave ILp to balance the inductive drop; the total impressed voltage E must, therefore, be equal to IR + ILp, the wave E, therefore, being plotted by adding, algebraically, the verticals of waves IR and ILp at each instant along the horizontal time axis, due attention being paid to the fact that IR and ILp are sometimes in opposition.

The corresponding vector diagram is shown at the left of Fig. 49, which diagram may be derived directly from the current and voltage waves, or may be constructed independently, as follows: first, lay off the current vector I horizontally, and superimpose on it the voltage drop IR, obtained by multiplying the current I amperes by R ohms, I and IR, of course, being directly in phase. The impressed voltage for balancing the inductive reactance voltage is ILp volts in quadrature with and leading the current. The total impressed voltage E is the vectorial sum of IR and + ILp, and is simply the diagonal of the parallelogram of which IR and ILp are two right-angle components. This resultant E is the hypotenuse of a right-angle triangle, and is equal, in volts, to the square root of the sum of the squares of IR and ILp, since the hypotenuse of a right-angle triangle is equal to the square root of the sum of the squares of the two legs.

Therefore,

$$E = \sqrt{(IR)^2 + (ILp)^2} \tag{13}$$

and by Ohm's Law, equation (8)

$$I = \frac{E}{Z} \tag{14}$$

$$= \frac{\sqrt{(IR)^2 + (ILp)^2}}{Z} \tag{15}$$

and

$$Z = \frac{\sqrt{(IR)^2 + (ILp)^2}}{I} \tag{16}$$

$$= \sqrt{(R)^2 + (Lp)^2} \tag{17}$$

$$Z = \sqrt{R^2 + X^2} \tag{18}$$

finally,

$$X = \sqrt{Z^2 - R^2} \tag{19}$$

where Z is the total apparent resistance, called the *impedance* of the circuit and the quantity X is the abbreviation for the term Lp, the inductive reactance.

From the explanation of trigonometrical functions given in the first part of this appendix, it will be evident, from Fig. 49 that the lag angle Θ of the current I, with respect to the impressed total electromotive force, can be easily calculated in advance for:

$$\text{Cos}\ \Theta = \frac{IR}{E} = \frac{IR}{\sqrt{(IR)^2 + (ILp)^2}}$$

$$= \frac{IR}{\sqrt{I^2 (R^2 + X^2)}}$$

$$= \frac{R}{\sqrt{R^2 + X^2}} \tag{20}$$

and on looking up the number representing this ratio in the table of cosines, the corresponding angle in degrees will be found.

Amplitude factor.

It is to be noted that equations (10) to (20), inclusive, are based on effective values, whereas the vector diagrams in Figs. 48 and 49 are laid out with vectors representing maximum values, in order to show their direct connection with the development of the current and voltage waves. Of course, effective values are less than the corresponding maximum values, but there is a definite relation between the two values. The ratio of the maximum value to the effective value is known as the *amplitude factor,* which, for sine waves, is equal to 1.414. Therefore, in the above case the maximum values shown in the diagrams in Figs. 48 and 49 may be arrived at by multiplying the values in equations (10) to (20) by 1.414.

Practical measurement of impedance and reactance.

In actual practice, the numerical value of X can be determined as follows: The dead resistance of the wire in the coil or instrument in question can be calculated when the length of wire and its resistance per foot is known, or the same result can be arrived at by passing a direct current of I amperes through the wire; by Ohm's Law, equation (7) R, the resistance of the coil in ohms, is equal to the voltage E, necessary to force the current through the coil, divided by the current I in amperes. When an alternating electromotive force E volts of a given frequency is impressed across the same coil or instrument, a certain current of I amperes will flow, which may be measured by an ammeter, so that, by equation (8), $Z = \frac{E}{I}$ ohms; then, since R is already known, the inductive reactance X in ohms is $X = \sqrt{Z^2 - R^2}$ from equation (19). With a higher frequency, X would be greater, since $X = Lp$ and $p = 2\pi n$, where n is the frequency in cycles per second, as per equation (3). With a lower frequency, the term X would be smaller, since n is smaller. In fact, if n were zero, as would be the case with a direct current, then the term X, the inductive reactance, would disappear entirely, and then the flow of current would be limited by dead resistance only. So, with a given voltage, the current flowing through a coil of wire will increase in volume with decrease in frequency, and will fall off as the frequency increases.

Calculation of the inductance of a coil of wire.

The inductance of a coil wound on a given spool is proportional to the square of the number of turns N of wire. For example, a given spool, wound with No. 16 has 500 turns and an inductance, say, of 0.0025 henry; the same spool wound with No. 28 wire would have about eight times as many turns, and its inductance would then be about 64 times as great as before, or 0.16 henry. The inductance of a coil of given form is also proportional to its linear dimensions, the number of turns remaining constant. For example, say a given coil has an inductance of 0.022 henry, a coil three times as large in diameter, length, etc., but having the same number of turns of wire, has an inductance of 3 × 0.022, or 0.066 henry.

The inductance in henrys of a coil of wire wound in a thin layer on a long wooden core of a length of *l* centimeters and a radius of *r* centimeters, is

$$L = \frac{4\pi^2 r^2 N^2}{l \times 1,000,000,000} \qquad (21)$$

in which N is the total number of turns of wire in the coil. The equation is strictly true for very long coils wound in a thin layer; but the same equation is also useful in calculating approximately the inductance of short thick coils. Thus, a coil of 50 centimeters long, containing 100 turns of wire wound around an average radius of 4 centimeters, has an inductance closely equal to:

$$L = \frac{4 \times (3.1416)^2 \times (4)^2 \times (100)^2}{50 \times 1,000,000,000} = 0.00013 \text{ henry} \qquad (22)$$

Of course, if the wire in the above coil were wound around an iron core instead of one of wood, the inductive action would be enormously increased in proportion to the permeability of the iron core.

Power in Alternating Current Circuits

Apparent power or volt-amperes.

In direct current circuits, the power W in watts is:

$$W = EI \qquad (23)$$

Where E is the electromotive force necessary to force a current of I amperes through the circuit. In alternating current circuits, the same equation holds, provided the current and voltage are in phase, which, however, is rarely the case. Of course, the instantaneous power is:

$$w = ei \qquad (24)$$

where *e* and *i* are the instantaneous volts and amperes respectively, but sometimes the generator is supplying power to the circuit, and at other times the circuit is returning power to the generator, as has previously been explained. What we are interested in is the average power supplied to the circuit.

In an alternating current circuit, the *apparent power* is given in *volt-amperes,* this term covering the simple product of the volts E necessary for forcing a current of I amperes through the circuit, the voltage and current values being effective values, as indicated by the ordinary meters.

$$\text{Volt-amperes} = IE \qquad (25)$$

The apparent power in volt-amperes is greater than the true or average power, because part of the apparent power is returned to the generator.

True power or watts.

It will be shown below that the true *watts* or *average power* delivered to the circuit is:

$$W = IE \cos \Theta \qquad (26)$$

Where I and E are the effective current and impressed voltage, respectively, and Θ is the phase angle between the current I and the voltage E.

Power factor.

The quantity cos Θ is known as the *power factor,* and is the ratio of the true power or watts to the apparent power in volt-amperes.

$$\text{Power Factor} = \cos \Theta = \frac{W}{IE} \qquad (27)$$

Of course, the power factor cos Θ can never be more than unity, since the watts cannot be greater than the volt-amperes.

Case V—Power in an alternating current circuit containing resistance only.

In this case, the current and impressed electromotive force are in phase, as has been pointed out. In the general equation (26) for power in an alternating current circuit, W = EI cos Θ but when the current and electromotive force are in phase, the lag angle Θ is zero, and its cosine is unity. Therefore, the power equation becomes, simply,

$$W = EI \qquad (28)$$

The above equations are illustrated graphically in Fig. 50 where the watt curve is obtained by multiplying the instantaneous volts

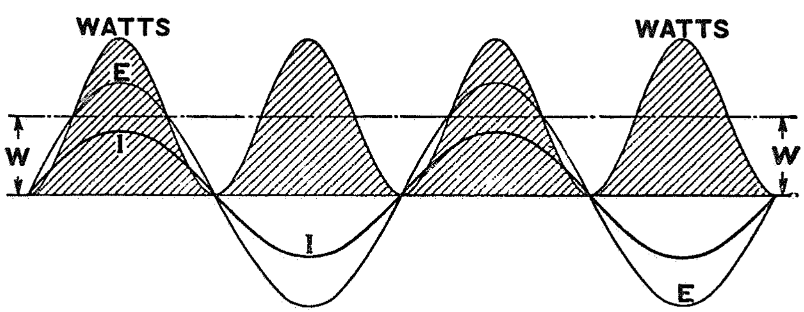

Fig. 50.
Power in a Circuit Containing Resistance Only.

and amperes at the various points in the period. It is to be noted that the power curve is a wave of double frequency, as compared with the curves of electromotive force and current. The axis of symmetry of this power curve is distance W, corresponding to the average watts above the axis of the electromotive force and current waves. Of course, the product *ie* is always positive, even in the second or lower half of the period, because the product of two negative numbers (—e) × (—i) is always positive, in value; looking at the matter from what physically takes place, the circuit is always receiving power positively, and is never delivering power back to the generator. The apparent power in volt-amperes is equal to the watts, and, consequently,

$$\text{Power Factor} = \frac{EI}{EI} = 1 \qquad (29)$$

Case VI—Power in a circuit containing inductive reactance only.

Of course, it would be impossible practically to create a circuit ccntaining inductive reactance only, due to the fact that all circuits must have some resistance, no matter how small; at the same time, the study of what takes place in such a circuit is instructive, for here the current lags 90 degrees behind the impressed electromotive force and the two are, therefore, in quadrature.

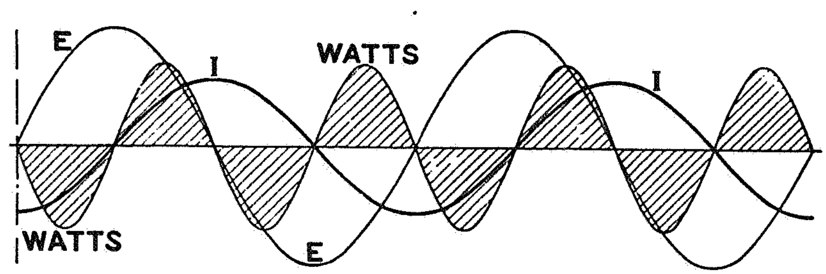

Fig. 51.
Power in a Circuit Containing Inductance Only.

This condition is illustrated in Fig. 51, where the sine curve W, obtained by multiplying the instantaneous volts and amperes, with due regard to positive and negative values [a positive (+i) multiplied by a negative (—e), and vice versa, gives a negative (—w)], is a sine curve of double frequency, and its axis of symmetry coincides with the axis of electromotive force and current.

Here the power:

$$\begin{aligned} W &= EI \cos \theta \\ &= EI \times 0 \qquad (30) \\ &= 0 \end{aligned}$$

because the cosine of the lag angle 90 degrees is zero. An examination of the watt or power curve in Fig. 51 will show that the average power is zero, because, during the complete period, just as much power is returned to the generator as it delivers to the circuit; the negative and positive portions of the power curve are equal, and their sum is therefore zero.

The power factor (abbreviated P.F.)

$$\text{P.F.} = \frac{\text{EI} \cos \theta}{\text{EI}} = \frac{\text{Watts}}{\text{Volt-amperes}} \qquad (31)$$
$$= \frac{0}{\text{EI}}$$
$$= 0$$

Case VII—Power in a circuit containing resistance and inductive reactance.

This is the general case, met with in alternating current circuits. The resistance R and inductive reactance X are such as to cause the current to lag θ degrees behind the impressed electromotive force, as shown in Fig. 52, where θ is an angle such that

$$\cos \theta = \frac{R}{\sqrt{R^2 + X^2}} \text{ as per equation (20).}$$

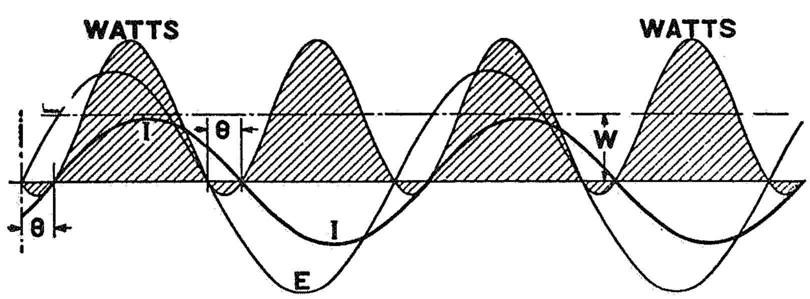

Fig. 52.
Power in a Circuit Containing Resistance and Inductance.

This condition is shown graphically in Fig. 52, plotted in the manner previously described, where it will be seen that the power curve is again a curve of double frequency with its axis at a distance W above the axis of the electromotive force and current waves. At certain instants, the power is negative, at certain other times positive, and the average power is the difference between the two. This is shown on the diagram by the loops in the power curve coming part below and part above the axis of the electromotive force and current curves. The average power is found by subtracting the total area below from the total area above the axis of the electromotive force and current waves. It is important to note, therefore, that in the ordinary alternating current circuit the power is fluctuating.

Part of the time the generator delivers power to the circuit, and the rest of the time the circuit is returning power to the generator to run it as a motor. This, then, is the general case, where:

$$W = EI \cos \Theta \qquad (32)$$

and the value of cos Θ is somewhere between zero and unity.

American Railway Signaling Principles and Practices

QUESTIONS ON

CHAPTER IX

RECTIFIERS

Including Fundamental Theory of Alternating Currents

QUESTIONS ON CHAPTER IX
RECTIFIERS

Including Fundamental Theory of Alternating Currents

General.

1. What recent principal developments in the signal field have led to the extensive use of alternating current?
2. Why is an auxiliary source of power generally provided? Of what does it consist?
3. When storage battery is used, what means must be provided to keep it charged?
4. May a rectifier be used with primary battery and what is accomplished?
5. How is a rectifier defined by the Signal Section, American Railway Association?

Types.

6. What are the various types of rectifiers found suitable for signal work?

Motor-Generator Sets

7. Of what does a motor-generator consist?
8. At what rate was battery on the earlier installations charged and what was that method called?
9. May the operation of a motor-generator set be arranged for automatic or non-automatic control? Where is the automatic panel used?
10. Are twin sets sometimes used? If so, why?

Instructions.

11. How must generators be kept?
12. To what must they not be exposed unnecessarily?
13. With what, when necessary, must they be covered?
14. Must covering be removed when set is in use? Why?
15. What voltage and current rating must not be exceeded?
16. What attention must be given oil-wells?
17. What attention must be given oil rings?
18. What attention must be given to over-heating of machine?
19. How may over-heating be detected?
20. What action must be taken in event of over-heating?
21. What attention must be given to commutator?
22. When, and how, must commutator be surfaced?
23. Of what quality and design must brushes be?
24. What attention must be given brushes to prevent sparking?
25. How must brushes fit in brush holders and how must they rest on commutator or slip rings?

26. When must brushes be replaced?
27. How must new brushes be fitted?
28. After fitting brushes, what must be done?
29. If armature or field coil becomes wet, what action must be taken?
30. When must clearance between rotor and stator be checked?
31. How often must resistance tests of armature field coils and brush holders be made and recorded?
32. What is the minimum permissible insulation resistance?
33. What must be done when insulation resistance is lower than that permissible?
34. What are the requirements as to fuses?
35. What parts must be kept tight and in good condition?
36. How must guards and railings for exposed moving parts be kept?

General.

37. What data must be carefully read and followed?
38. What data must be left in station after completion of work?

Installation

Regulations.

39. With what requirements and regulations must installation comply?

Unpacking.

40. What data is indicated on shipping notice?
41. What care must be taken when unpacking switchboards?
42. Describe proper method of unpacking a crated panel.
43. What examination is necessary to be made of parts following unpacking?

Location.

44. What space should be provided around a switchboard?
45. What attention must be given to locating electrically-operated switches, when not mounted on controlling board?
46. What attention must be given mounting of rheostats in regard to ventilation?

Foundation.

47. What is necessary in switchboard foundations?
48. What size channels must be used, unless otherwise specified on the drawings?

Assembly.

49. Describe how switchboard must be assembled.
50. When framework is to be grounded, what must be done?

Connections.

51. In what manner must wiring be done?

52. What attention must be given parts that are to form joints?

53. What attention must be given bus bars and bare copper conductors after all joints are made up, and why?

Recommended clearances.

54. What are the recommended and minimum clearances between line conductors and ground in inches on circuits for the following voltages: 125, 250, 600, 1200, 2400, 3500, 7500 and 15000?

55. What are the recommended and minimum clearances between live conductors of opposite polarity in inches on circuits for the following voltages: 125, 250, 600, 1200, 2400, 3500, 7500 and 15000?

56. What clearance must be maintained for busses?

57. What clearances must be maintained between buses and circuit opening devices?

58. Does the table in Instruction 43 apply to wires run in duct, cable, etc.?

Heating.

59. How should copper connections leading directly into or in close proximity to switching apparatus be arranged as to temperature, with maximum sustained load?

60. Is the permissible current density higher on direct or alternating current? On 60-cycle or 25-cycle?

Insulation.

61. What consideration must be given main switchboard wiring for high-tension current?

62. What is the aim in all switchboard wiring?

63. What must be avoided in forming insulated conductors to prevent weakening insulation?

64. What is the minimum radius of bend for rubber-covered wire, varnished cambric or lead-covered cable in respect to diameter? Of small braided conductors?

65. Must cable and wire joints be properly insulated?

66. Under what conditions may bare wire be used?

67. What attention is necessary in building bus compartments?

Instrument transformer wiring.

68. May earth be used as one of the conductors of secondary connections from current transformers to instruments?

69. May earth be used for one of the leads to potential transformers?

70. What attention must be given to the selection of wire for leads from transformers to switchboard?

71. May leads of different potentials, such as current transformers and potential transformers, be run in the same conduit?

72. What attention must be given to the selection of wire for secondary circuits?

73. Where should current and potential transformers be located when it is not convenient or advisable to mount them on back of panel?

74. What type of fuse mounting is recommended for potential transformers?

75. What must be provided where expulsion type fuses are used for primary protection?

Connections to ground.

76. What consideration must be given to grounding panel supports?

77. What consideration must be given to grounding switchboard devices?

78. What consideration must be given to grounding instrument transformer secondaries?

79. Describe common ground bus and its connections to switchboard.

80. In what manner must steel work supporting high potential switching equipment be grounded?

Compartments.

81. How must compartments be built? What materials may be used?

82. Describe proper door construction of compartments.

Illumination.

83. What illumination should be provided?

84. What emergency source of illumination should be provided?

Operation

Protection for employees.

85. What must be provided to protect employees?

86. What is recommended to be done before working on switchboard apparatus carrying over 300 volts?

87. What must be provided to extinguish fires on energized switchboard parts or conductors? May water be used?

88. What must not be placed where it may come in contact with switches or other parts of electric circuits?

89. In what condition must all wires and overhead conductors be considered?

90. May insulation be depended upon for protection against electric shock?

91. What must be used when operating high-tension disconnecting switches?

92. With what must employees familiarize themselves?

Attendance.

93. What attention must be given switchboard, before placing it in service? When first placing it in actual service?

94. In making an inspection or repairing work near live parts, why must special care be exercised?

95. Before each starting of plant, what must be done?

96. What should be done after everything is adjusted and running?

97. What attention must be given instruments, meters, switches, circuit breakers, and relays?

98. What oil must be used in oil circuit breakers?

99. What qualities has the oil that is specified?

100. What may result to the oil through carelessness in handling?

101. What potential should oil withstand?

102. What action should be taken in event of oil punctures on lower potential values?

103. How must oil be maintained in oil tanks? How often inspected?

104. What attention must be given contacts of circuit breakers, etc.?

105. How must space in rear of switchboard and passageway be kept?

106. How must switchboard be cleaned, and how often?

107. How may the finish of switchboard panels be renewed?

108. In what sequence should knife switches be opened and closed in respect to circuit breakers of the carbon break or magnetic blow-out type?

109. What precaution should be taken to avoid possibility of having eyes "flashed"?

110. When may disconnecting switches in series with oil switches be opened or closed?

Synchronizing.

111. Why is it necessary to become accustomed to the time element of generator switch, and what must be taken into consideration?

112. What occurs if the switches are closed when the generators are out of synchronism?

113. In general, when may it be said that generator switch should not be closed?

Mercury Arc

Theory of operation.

114. Upon what is the action of this rectifier based?

115. What three essential parts has this rectifier?

116. Describe the rectifier tube and its action.

Operation.

117. Draw an elementary diagram of connections and explain the operation of a mercury arc rectifier.

Instructions.

118. How must rectifiers and connections be kept?

119. Is it permissible to exceed the voltage and current rating of rectifier tubes?

120. When must vacuum tests be made?

121. How are these tests made and what must be done if they indicate that the vacuum is wholly or partly destroyed?

122. How must tubes be handled, and when not in service? Where must they be kept?

123. What must they be protected from to avoid fracture?

124. What care must be exercised to avoid over-heating the starting resistance?

125. If rectifier does not start readily, what must be done?

126. How must the dial switch adjusting arm for regulating the compensator be operated?

127. What are the requirements as to fuses?

Gas Tube

128. What two types of gas-filled hot cathode rectifiers are in general use?

129. Why were the names applied?

130. How does a vacuum tube containing a hot and a cold electrode act?

Theory of operation.

131. Describe the operation of the gas tube.

132. Of what does the cathode consist?

133. Of what does the anode consist?

134. Of what are the bulbs constructed?

135. Why does the bulb rectify?

136. How are the bulbs filled with argon gas?

137. How are the effects of impurities counteracted?

138. What causes the dark gray or silvery appearance of the bulb?

139. Is this appearance detrimental, or does it indicate the probable life of the bulb?

140. Are the general principles of operation the same in the half-wave and full-wave types of rectifiers?

141. In what service are the half-wave rectifiers desirable?

142. Why are they objectionable in the larger sizes?

143. Can two half-wave rectifiers be so connected as to utilize both halves of the wave?

144. Draw a diagram showing the connections of a half-wave rectifier in its simplest form, and describe its operation.

145. Draw a diagram showing the connections of two half-wave bulbs with a single load.

146. What is the result of this application?

147. Explain by diagram the principle on which a storage battery is charged.

148. On what is the rated output of these rectifiers based?

149. What does a direct current ammeter indicate?

150. What is the result if an alternating current instrument is used?

151. How do the bulbs range in size and for what purpose are they designed?

Instructions.

152. How must rectifiers and connections be kept?

153. Is it permissible to exceed the voltage and current rating of rectifier tubes?

154. When replacing tubes, what tubes must be used?

155. For what current, voltage and frequency only must rectifiers be used?

156. What kind of tube must be kept on hand?

157. When must new tubes be tested, and for what purpose?

158. What must be done before connecting or disconnecting batteries or making any change in the charging circuit?

159. For what purpose must tubes be checked frequently?

160. What are the requirements as to cleaning contacts in sockets and on tubes?

161. When necessary to replace a transformer, what transformer must be used?

162. How often must tests for back leakage be made and for what purpose?

163. What are the requirements as to fuses?

Mechanical or Vibrating

164. Give the trade names of three principle types of mechanical rectifiers.

165. What is the theory of their operation?

166. Describe the Magnar.

167. How do the other types differ from it?

168. Where is the transformer located and what is its purpose?

169. What are some of its disadvantages?

170. How may interference with radio reception be materially reduced?

171. What position should the vibrating member assume when the current supply is interrupted, and why?

172. What is necessary to assure the proper opening of the contact?

173. Draw a diagram showing the connections for a Magnar rectifier.

174. Describe its operation.

Instructions.

175. How must rectifiers and connections be kept?

176. Is it permissible to exceed the voltage and current rating?

177. What are the requirements as to contacts?

178. How must the vibrating member be adjusted?

179. In making adjustments, what instructions must be followed?

180. To what current, voltage and frequency must the use of a rectifier be confined?

181. What must be done before connecting or disconnecting batteries or making any change in the charging circuit?

182. For what purpose must energy be disconnected periodically?

183. What are the requirements as to fuses?

Electrolytic

184. How many types of electrolytic rectifiers have been developed commercially?

Historical.

185. How was the Balkite rectifier developed?

186. What trade name superseded Balkite?

187. What are some of the properties of metallic tantalum?

Description of apparatus.

188. Describe the Fansteel battery charger.

189. What is the capacity of the C-1 cell?

190. What is the capacity of the C-9 cell?

191. For what voltages are Fansteel transformers made?

192. What is used to control the charging rate?

Theory of operation.

193. On what is the theory of operation of the electrolytic rectifier based?

194. When one electrode of unformed tantalum and one of lead are placed in an electrolyte of sulphuric acid and an alternating electromotive force is impressed across the cell thus formed, what will be the result?

195. During the half of the wave when electrons are passing out of the cell through the tantalum, what will be liberated at the surface of the tantalum?

196. What action does the oxygen, which is liberated, take?

197. What is the condition of the oxide film and what effect does it have on the oxygen gas?

198. What causes the electrons to move through this gas layer?

199. What can the tantalum metal electrode give off into this gas film?

200. Can free electrons be present in the electrolyte and can electrons pass from the electrolyte to the gas film?

201. Why is the electrolytic cell therefore a rectifier?

202. By what means is the conductance of electrons from the gas film to the lead electrode, and what is it called?

203. When these ions deliver their charge of electrons to the electrodes, what is liberated at the surface of the electrodes?

204. What chemical action takes place when gas is liberated in the electrolyte?

205. What causes the slight corrosion of the lead electrode?

206. What is the function of the ferrous sulphate depolarizing salt?

207. What is added to this salt to reduce the wear on the lead electrode to a minimum, and how is it accomplished?

208. In considering the foregoing theory, what should be remembered in regard to the actual movement of electrons in any circuit compared to the commonly assumed current flow?

209. Through what electrode do the electrons flow into the rectifier cell and through what electrode is current assumed to flow to the battery?

Applications.

210. Draw a diagram showing connections for charging a track and a signal battery from one transformer using two rectifier cells. (Fig. 18.)

211. Draw a diagram showing connections for charging batteries up to 14 volts using one rectifier unit. (Fig. 19.)

212. Draw a diagram showing connections where two rectifier cells are used to obtain full-wave rectification. (Fig. 20.)

213. What voltage battery may be charged with connections as shown in Fig. 18 and when may the use of the battery be dispensed with and the apparatus operated directly from a rectifier connected as shown in Fig. 19?

214. What voltage battery may be charged by a unit consisting of a group of electrolytic cells connected as shown in Fig. 20 and what normal charging rates have such rectifiers?

215. What power units can also be used to operate 110-volt apparatus without the use of a battery?

216. Where are electrolytic rectifier cells used?

217. Describe the type C-8 cell and make a diagram showing how it is operated?

218. What current and voltage can be obtained from the C-8 cell?

219. For what purpose is a combination unit supplied?

Instructions.

220. In what condition must electrolytic rectifiers be kept?

221. What must be done to prevent acid creepage and consequent corosion?

222. What specific gravity acid must be used as electrolyte?

223. What must be added to each cell and to what extent before oil is poured over the surface?

224. What quality and quantity of oil must be poured over the surface of the electrolyte?

225. What must be the thickness of oil maintained over the surface of the electrolyte and what oil must be used?

226. What is the restriction on hydrometer used to test rectifier electrolyte?

227. In what position must cover of rectifier cell be kept?

228. What is required in regard to voltage and current rating of rectifier?

229. What water must be used to replace that lost by hydrolysis and when only must acid be added?

230. Between what low and high levels must electrolyte be maintained and at what point should electrolyte be before adding water?

231. When necessary to replace a transformer, what restriction is there?

232. What restriction is there in using rectifier transformers in regard to voltage and frequency?

233. What are the requirements as to fuses?

Copper-oxide

General.

234. On what discovery is the copper-oxide rectifier based?

235. Upon what principle does the property of this rectifier depend?

236. How does the resistance of the copper cuprous-oxide unit across the boundary in one direction compare with that in the opposite direction?

237. In order to make use of this elementary unit as a rectifier, what is necessary and to what extent can it be done?

238. By what two ways can a good contact be made to an extended portion of the free surface of the cuprous-oxide?

239. How is a practical rectifier assembled from either type of elementary unit?

240. When lead contacts are used, how is ventilation obtained and what is used for connections?

241. When the reduced copper is used for contact, what may be used as ventilating surfaces?

242. What is used, when necessary, to increase the amount of available ventilation?

243. In accordance with what method are copper-oxide rectifiers, used today in the signal field, made?

244. What is the principal difference betwen rectifiers manufactured by the two methods described?

245. Does rectification take place without electrolytic action or other observable physical or chemical changes?

Description.

246. How are the oxidized copper washers mounted?

247. How are the required number of rectifying units connected for series, multiple, or series-multiple operation?

248. How is the electrical connector arranged for soldering or spot welding to the copper tip of the adjoining plate?

249. How are the required number of plates connected for series, or multiple, or series-multiple operation?

250. How many individual elements may be assembled in series and in multiple into rectifier groups and for what value of current and voltage?

Theory of operation.

251. Is the theory of operation of the copper-oxide rectifier fully understood?

252. Where does the rectification take place?

253. How does the current flow from the oxide to the copper compare with the current flow in the opposite direction?

254. With what does it correspond to say that current flows from the oxide to the copper?

255. By what comparison do electrons pass freely from the copper into the oxide, but do not pass from the oxide into the copper?

256. In terms of resistance, what is the effect at the boundary in the direction from copper to oxide and what is the effect in the opposite direction?

257. Physically, what is meant by the resistance at the boundary?

258. Are the details of the mechanism at the boundary, which result in the free passage of electrons in one direction and not in the other, understood?

259. How is it known that the action is entirely electronic and does not involve any chemical changes which result in the decomposition of the rectifier elements?

260. In what form is the current input to the battery?

261. How do the positive waves compare in shape with the charging wave, and why?

262. If the charging current is connected to a resistance load and not to a load with a natural electromotive force, how would the form compare with that of an alternating current wave?

263. Make a diagram showing the relation in wave form between direct current output and alternating current input.

Application.

264. In placing on the market the different types of rectifiers for use in railway signal work, what consideration was given the voltage and charging ranges?

265. To what extent would it be necessary to modify copper-oxide rectifiers should it be desirable to use them for charging batteries of voltages other than those listed?

Instructions.

266. In what condition must rectifiers be kept?

267. What must be considered when selecting a location to mount copper-oxide rectifiers?

268. What precaution must be used when adjusting the charge from a rectifier or selecting one to charge a battery?

269. What restriction is there in using rectifier in regard to voltage and frequency?

270. What must be done in regard to source of energy for the rectifier before connecting or disconnecting batteries or making any change in the charging circuit?

271. When and how must tests be made for back leakage?

272. What are the requirements in regard to fuses?

273. When necesary to replace a transformer, what transformer must be used?

274. What parts must be kept tight and in good condition?

275. In making adjustments, what instructions must be followed?

Transformers

276. How are motor generator sets and mercury rectifiers usually designed?

277. Is special transformer necesary?

278. How are mechanical, Rectigon and Tungar rectifiers furnished?

279. How are electrolytic rectifiers operated?

280. How are copper-oxide type rectifiers operated?

281. How are transformers provided so that proper charging voltages may be obtained?

Alternating Current Floating Storage Battery System

282. How is alternating current floating storage battery system defined by the Signal Section, American Railway Association?

283. For the generation and distribution of electric power, what system is the most feasible and economical, and why?

284. What is alternating current floating battery system of signal power supply?

285. At each signal location what forms the connecting link between the alternating current power supply and signal and track circuits?

286. Draw a diagram of a typical layout from the generating station to the signal circuit.

287. Draw an elementary wiring diagram.

288. What is one of the most popular methods of explaining the flow of electrical power in an electrical conductor or wire?

289. What similarity or analogy can be applied to explain the principle and operation of the alternating current floating battery system?

290. Draw the figure of a simple water supply plant or system, assuming that it is utilized for some manufacturing purpose and must supply a small steady stream of water continuously, and a larger flow or stream over short period of time intermittently.

291. To protect the manufacturing process against a failure of water supply, in case of breakdown of the boiler room or pump, what becomes a necessary part of the water supply plant?

292. What is the best way to operate this water supply plant?

293. In this water supply plant, what corresponds to the alternating current power?

294. To what does the pump correspond?

295. To what does the storage tank correspond?

296. To what does the steady stream or supply of water correspond?

297. To what does the intermittent supply of water correspond?

298. Draw a diagram showing a rectifier and battery connected into a track circuit and a signal circuit.

299. What does the rectifier do in the unoccupied block?

300. What occurs when a train occupies the track circuit?

301. What does the rectifier do in the signal circuit as shown in the sketch?

302. What happens when the signal motor operates?

303. What must the rectifier supply?

304. What should be the total output or the floating rate of the rectifier?

305. To what does the voltmeter in the alternating current floating battery system correspond?

306. To what does gassing of the electrolyte correspond?

Instructions.

307. What must rectifiers be adjusted to provide?

308. How must frequent tests be made?

309. What voltage must be maintained across each cell of a lead type battery?

310. What voltage must be maintained across each cell of a nickel, iron, alkaline battery?

311. What record must be kept of each cell?

312. When must adjustment of charging rate not be made?

313. What must be done if voltage is found to be consistently low or high on three consecutive checks?

314. How should the charging rate be first set, and why?

315. In what calibration must voltmeter be kept for these tests?

316. How must water be added to batteries during freezing weather?

317. What are the requirements in regard to fuses?

318. How should lead acid type storage batteries be installed, maintained and operated?

319. How should nickel, iron, alkaline storage batteries be installed, maintained and operated?

FUNDAMENTAL THEORY OF ALTERNATING CURRENTS

320. In connection with studying rectifiers and certain other signal apparatus, what working knowledge is necessary?

321. What working knowledge must a designing engineer have?

322. Does a signalman need the theory or facts?

Generation and Characteristics of Alternating Current Waves

Simple alternator.

323. What is an alternator?

324. What types of current are there and distinguish between them?

325. Name the necessary parts for a simple bi-polar alternator and describe their functions.

326. When the plane of the conductors is at right angles to the field, what is the voltage induced?

Voltage generated by simple alternator.

327. How is an electromotive force generated?

328. How does the voltage vary?

329. Give the equation for the voltage generated and define all symbols.

330. If the shaft of an alternator is turning at 100 revolutions per minute, the total conductors are 4 and the magnetic field 2,000,000 flux lines, what is the generated voltage?

Shape of the generated wave.

331. When the plane of the conductors is parallel to the flux lines, what is the voltage induced?

332. What changes take place during one revolution of the coil in the magnetic field?

333. What is "Fleming's Right-Hand Rule"?

334. How are the conductors connected?
335. Describe a graphical method of producing a sine wave.
336. Give the functions of a right-angle triangle.

The sine wave.

337. Why are sine waves assumed in making alternating current calculations?
338. Give the equation for instantaneous voltage generated.
339. How is angular speed given?
340. How many degrees in one radian?
341. Give the equation for angular speed.

Definitions.

342. What is an alternating current?
343. What is the period of an alternating current?
344. What is a cycle?
345. What is meant by frequency?
346. What is an alternation?

Commercial multipolar alternators.

347. Do commercial alternators as a rule generate sine waves?
348. What are the results if heavy reciprocating engines are used to drive alternators?
349. What is an exciter?
350. How is the frequency determined?

Turbo-alternators.

351. What are the commercial frequencies?
352. In a turbo-alternator, what is the rotating element?

Measurement of alternating currents and voltages.

353. What is meant by average alternating current?
354. What is the average value of an alternating current wave over one complete cycle?
355. What is meant by effective or root mean square value of alternating current waves?
356. Why are effective values always used in alternating currents?
357. Are the effective amperes of alternating current and direct current the same?

Phase Relations—Vector Diagrams

Phase.

358. What is meant by a current and a voltage being in phase?

Lagging and leading currents.

359. What effect causes the current to lag behind the electromotive force?
360. In what terms is phase difference expressed?

Vector diagrams.

361. What is a vector?

362. Why are vectors used in alternating current diagrams?

363. What direction of rotation is assumed?

364. How is the value of the wave determined at any instant?

365. What is the relation of the speed of the rotating vector to the circuit frequency?

Vector addition of electromotive forces.

366. How are the vectors added?

Circuits Containing Resistance, Inductance and Combinations Thereof

Ohm's Law applied to alternating current circuits.

367. Does Ohm's Law apply to alternating current circuits? Explain.

Case I—Circuits containing resistance only.

368. Give equation for current, voltage and resistance or impedance.

369. How are the voltage and current related?

Case II—Circuits containing inductive reactance only.

370. What causes an increase of resistance?

371. What effect does inductance in an alternating circuit have upon:

(a) The phase angle between the current and voltage?
(b) The magnitude of the current?
(c) The magnitude of voltage?

372. Give the equations for current, voltage and inductive reactance.

Case III—Circuit containing capacity reactance only.

373. What causes the effect of capacity reactance?

374. What effect does the capacitance in an alternating circuit have upon:

(a) The phase angle between the current and voltage?
(b) Transmission?

Case IV—Circuits containing resistance and inductance.

375. Give an equation expressing the value of the total impressed voltage.

376. Draw a circuit showing inductance and resistance in series and multiple.

377. Draw a typical wave diagram showing the voltage across the resistance; voltage across the inductance and total impressed voltage.

378. Give the formula for finding impressed voltage from a right-angle triangle.

379. Give formulae for finding current, impedance and lag angle Cos. Θ.

Amplitude factor.

380. What is the amplitude factor and its value?

Practical measurement of impedance and reactance.

381. What are two practical methods of determining the impedance of a wire line?

382. How is the reactance determined?

Calculation of the inductance of a coil of wire.

383. If on a certain wood spool a coil of wire is wound with 400 turns and having an inductance of 0.01 henry, what would be the inductance of a coil of wire wound on the same wood spool having 1600 turns?

384. If the wire in the above question was wound on an iron spool, how would the inductive action be affected?

Power in Alternating Current Circuits

Apparent power or volt-amperes.

385. To what is the power in direct current circuits equal?

386. In alternating circuits, to what is the instantaneous power equal?

387. Are we interested in the instantaneous power?

388. What is the difference between apparent power and true power?

True power or watts.

389. Give the equation for finding true power. Define all symbols.

Power factor.

390. What is the Cos. Θ called?

Case V—Power in an alternating current circuit containing resistance only.

391. To what is the power equal, and why?

392. To what is the power factor equal?

Case VI—Power in a circuit containing inductive reactance only.

393. Is a circuit containing pure inductance possible, and why?
394. To what is the power equal?
395. To what is the power factor equal, and why?

Case VII—Power in a circuit containing resistance and inductive reactance.

396. Is this a general case in alternating circuits?
397. Of what frequency is the power curve?
398. Draw a wave diagram showing the voltage, current and power waves.
399. How is the average power found?
400. Give the equation for finding the power.
401. What is the power factor and on what does it depend?