American Railway Signaling Principles and Practices

CHAPTER VIII

Transformers

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The Signal Section, Association of American Railroads, defines Transformer as: A stationary inductive device generally used for changing the ratio between voltage and current in an alternating current circuit or for insulating one part of the circuit from another.

A transformer does not generate power but merely changes the power from one voltage to another at the same frequency as the energizing circuit.

Alternating current for signaling is generally transmitted from a power station to the signal field by high-voltage mains. High voltages on the mains are changed to lower voltages by means of transformers.

One method to lower the voltage is by two successive steps; that is, to use a transformer to lower the voltage to 115 volts for signal motors, etc., and then further reduce this voltage by using another transformer to feed the track circuits and low-voltage signal lamps.

Another method is to use only one transformer to lower the voltage for all purposes.

In theory and in general construction all transformers, whether line or track, are the same and this chapter will deal principally with transformers specifically designed for railroad signal service.

Elements.

The transformer in its simplest form consists of two separate and distinct coils of insulated wire wound around a laminated iron core as shown in Fig. 1.

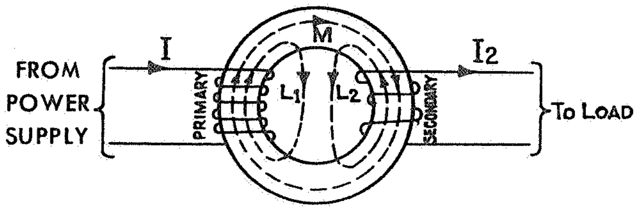

Fig. 1.
Elements of the Transformer.

One coil is attached to an outside source of energy and is the primary coil; the other coil which transmits the energy from the transformer is the secondary coil. A transformer may have more than one secondary coil, or have its secondary coil tapped at different points to produce different voltages.

When a transformer transmits higher voltage than it receives, it is known as a step-up transformer. Step-up transformers are used in power stations to raise the voltage of the generator to the transmission voltage. A transformer that transmits a lower voltage than it receives, is known as a step-down transformer. Step-down transformers are used along the transmission line at signal locations and interlocking towers to transform the higher voltages of the transmission line to lower voltages for signal purposes.

When the secondary circuit is open and an alternating current from the transmission line flows through the primary coil, it causes an alternating magnetic flux to flow in the core. This magnetic flux rapidly rising, falling and changing direction with the frequency, links both primary and secondary coils and induces a voltage in each. The voltage induced in the primary coil opposes the flow of current and is nearly equal to the voltage applied to the primary terminals. The voltage of the secondary coil is proportional to the ratio of the number of turns of wire in the secondary coil to the number of turns in the primary coil. The choking effect produced within the highly inductive primary coil allows only a small current to flow continuously through it. This small alternating current, known as exciting current, produces the varying magnetic flux in the core which in turn induces the voltage in the primary and secondary coils described. The induced voltage in the primary is usually called the counter electromotive force (e.m.f.).

When the secondary circuit is closed, a current flows through it. This secondary current is opposite to the primary current, and its magnetizing action in the core opposes and neutralizes to a certain extent the primary flux and reduces the choking effect or counter electromotive force in the primary coil. When this happens, more current rushes into the primary coil from the transmission line and balances the demagnetizing action of the secondary current. Thus, the transformer is made automatic and maintains its core flux practically constant regardless of the load on the secondary. The variation of the load through the primary varies directly with the load on the secondary.

Losses.

All the energy drawn from the transmission line by a transformer is not transformed. The small part used in this process is analogous to the energy lost in a machine through friction. In the modern well-designed transformer, the losses are so small in proportion to the normal load on the transformer that for practical purposes they are rarely considered, but it is well to know them. Energy is lost which is required to maintain a flow of flux in the core to sustain the voltages in the coils; this loss is practically constant with or without load. The alternating magnetic flux causes losses in the iron core, called iron losses and known as hysteresis and eddy current losses.

The hysteresis loss is energy spent in overcoming the friction between the molecules of iron as they move backward and forward with the change of direction of flux; this is theoretical, as some believe it is the natural resistance of the metal to the flow of flux, and that the molecules of iron do not move backward and forward.

The eddy current loss is the energy spent in the heating action of the currents induced in the iron core by the varying flux. Voltages are induced in the core by the alternating flux and these voltages produce eddy currents.

Iron losses are practically constant with or without load and are made manifest by heating.

due to the load on the transformer. The total copper loss in the transformer is (I^2R) of the primary plus (I^2R) of the secondary.

Magnetic leakage.

Reference to Fig. 1 will explain the effect of magnetic leakage. Dotted line M represents the flux which passes through both primary and secondary coils. The portion L_1 of the total primary flux which passes through the leakage path does not link the secondary coil. When current flows in the secondary, a leakage flux L_2 is developed which does not link the primary coil and usually tends to oppose the main flux M (depending on the power factor of the load circuit). The voltages induced by these leakage fluxes in their respective coils cause reactive drops in both windings analogous to the resistance drops caused by the ohmic resistances of the coils. The result is the same as if reactances were added in series with the windings of an ideal transformer having no leakage. These reactances are practically constant in value and the voltage drops caused by them therefore vary directly as the current in the respective windings.

Coil resistance and magnetic leakage are shown graphically in Fig. 2.

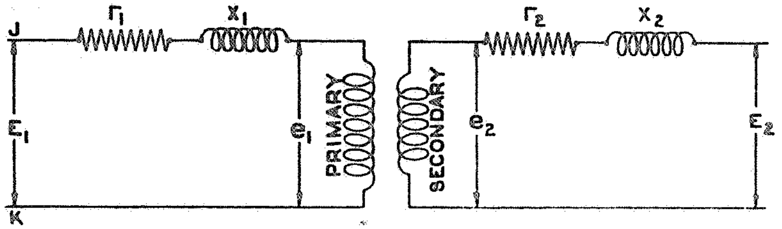

Fig. 2.
Coil Resistance and Magnetic Leakage Diagram.

E_1 is the transmission line voltage
e_1 is the primary terminal voltage after a drop caused by the ohmic resistance r_1 of the primary coil and the reactance X_1 caused by the magnetic leakage
E_1 is greater than e_1
E_2 is the net terminal voltage of the secondary
e_2 is induced voltage in the secondary before it has a drop caused by the ohmic resistance r_2 of the secondary coil and the reactance X_2 caused by the magnetic leakage

Efficiency.

The efficiency equation of a transformer is as follows:

$$\frac{\text{Power output of secondary}}{\text{Power output of secondary} + \text{transformer losses}} \qquad (1)$$

When the iron loss is small the transformers have a high efficiency on light loads. When the iron loss is equal to the copper loss the transformers have high efficiency on full-load or overload.

Input in watts of primary

Voltage relation of primary and secondary coils.

The fundamental equation used in the design of a transformer is as follows:

The induced voltage in secondary coil or primary coil is

$$\frac{4.44 \ f \ \Phi \ n}{10^8} \qquad (3)$$

Where:

f is the frequency in cycles
Φ is the maximum flux on the sine wave
n is the number of turns in the respective coil

The voltages in the secondary and primary coils are proportional to their respective turns as both have the same frequency and are cut by the same flux.

Due to the automatic action of the transformer which causes the core flux to remain constant regardless of load, the primary and secondary induced voltages remain practically constant. Hence neglecting voltage drops due to coil resistances and magnetic leakage:

$$\frac{\text{Voltage of primary}}{\text{Voltage of secondary}} = \frac{\text{turns of primary}}{\text{turns of secondary}} \qquad (4)$$

Voltage of primary multiplied by turns of secondary is equal to voltage of secondary multiplied by turns of primary.

The ratio of a transformer is the ratio of the number of turns in the high-voltage winding to that in the low-voltage winding, which is approximately the same as the ratio of the terminal voltages as explained in the foregoing. Thus, a transformer with 2,300-volt primary and 115-volt secondary has a ratio of approximately 20 to 1.

Ampere turns.

Ampere turns is defined by the Signal Section, A.A.R., as a measure of the magnetizing power, or magnetomotive force developed by a current of electricity in a conducting coil. It is equal to the product of the number of turns in the coil by the current in amperes, designated as NI.

The magnetizing power can be increased by increasing either the number of turns or the current, or an equivalent can be produced by increasing the number of turns and decreasing the amount of current, or vice versa.

The magnetic action of the secondary coil is proportional to the current in the secondary coil multiplied by the number of turns in that coil, designated N_2I_2.

As the magnetic action of the currents in primary and secondary coils balance each other, neglecting exciting current,

$$NI = N_2I_2 \text{ or } \frac{I}{} = \frac{N_2}{} \qquad (5)$$

For example: A transformer has 6,000 turns in the primary coil and 300 turns in the secondary coil and a power supply of 2,300 volts. We see by equation 4,

$$\text{the secondary voltage} = \frac{2{,}300 \times 300}{6{,}000} = 115 \text{ volts.}$$

When the secondary transmits 10 amperes, we see by equation 5,

$$\text{current in primary} = \frac{300 \times 10}{6{,}000} = \tfrac{1}{2} \text{ ampere.}$$

Effect of power factor.

Power factor is defined as the ratio of active power (watts) to apparent power (volt-amperes).

When the power factor of an alternating current is unity:

$$\text{Watts} = \text{current} \times \text{voltage} \qquad (6a)$$

When the power factor of an alternating current is less than unity:

$$\text{Watts} = \text{current} \times \text{voltage} \times \text{power factor} \qquad (6b)$$

A transformer transmitting 10 amperes from its secondary to do certain work when the load has unity power factor would require 20 amperes to do the same amount of work if the load had a power factor of 0.5 as often happens in signal work. For this reason, the capacity of a transformer is stated in kv-a. (1,000 volt-amperes) and not in k.w. (1,000 watts). K. is the abbreviation for kilo, a Greek prefix meaning one thousand. The capacity of a transformer is the number of kv-a.'s the transformer is designed to carry.

Where θ is the angle of lag of the secondary current
Cosine θ is the power factor of the secondary current
When the angle θ is 60 degrees, cosine θ, the power factor, is 0.5
When the angle θ is 30 degrees, cosine θ, the power factor, is 0.87
When the angle θ is 15 degrees, cosine θ, the power factor, is 0.97

Calculation of core losses.

Formulae were developed by the late Dr. Steinmetz to determine the hysteresis and eddy current losses in the core. For a given flux density it was shown that the hysteresis losses varied with the frequency and the eddy current losses varied with the square of the frequency. The calculation of core losses by these formulae would be quite complicated and it is now general practice to determine the total core loss from curves which have been prepared by the steel manufacturers. These curves, one of which is shown in Fig. 3, give the watts core loss and volt-ampere exciting current per pound of iron for a given flux density, frequency, and thickness for the particular grade of transformer steel used. The total watts obtained from such curves divided by the primary rated volts gives the

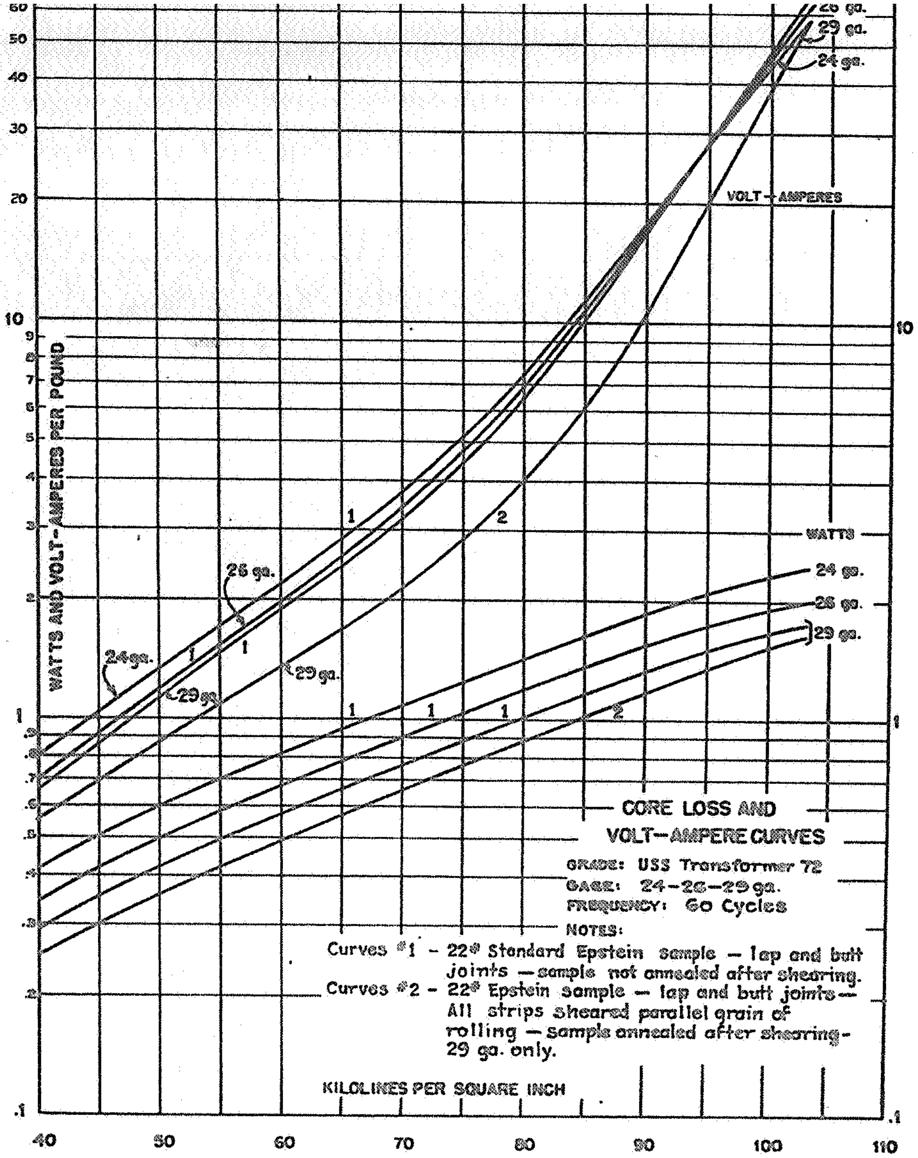

Fig. 3.
Core Loss Curves.*

Regulation.

When a secondary is transmitting power and the circuit is opened, or the load removed, the voltage of the secondary will rise. The amount of rise of voltage expressed in per cent of the secondary full-load terminal voltage is called the regulation, the impressed primary voltage being constant.

For example: The secondary voltage at full non-inductive load is 110 volts and 114 volts when the load is removed.

$$\text{Regulation} = \frac{114 - 110}{110} = 3.64 \text{ per cent}$$

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them in addition to the reactive drop due to magnetic leakage.

It is often necessary to calculate the regulation from predetermined values of the resistance and reactance drop, as the quantities vary with the load and power factor.

The formula recommended by the United States Bureau of Standards at unity power factor (non-inductive load) is:

$$\text{Regulation} = \left(\frac{100\ \text{IR}}{\text{E}}\right)\% \qquad (7)$$

At 60 per cent power factor:

$$\text{Regulation} = \left[100\left(\frac{0.6\ \text{IR} + 0.8\ \text{P}}{\text{E}}\right)\right]\% \qquad (8)$$

Where:

E is the rated primary voltage (rated secondary voltage multiplied by turn ratio)

P is the reactance voltage drop at full-load

I is the full-load primary current not including the exciting current

The equivalent resistance "R" of combined primary and secondary coils is found by multiplying the secondary resistance by the square of the ratio of primary to secondary turns and adding the primary resistance.

The impedance voltage "e" is found by short circuiting the secondary and measuring the voltage required to send the full-load current through the primary.

The impedance voltage is:

$$e = \sqrt{P^2 + I^2R^2} \qquad (9)$$

Transposing:

$$P = \sqrt{e^2 - I^2R^2} \qquad (10)$$

In the design of a transformer, the regulation is improved by the use of wire of the largest possible cross-section area of copper so as to give minimum resistance in the coils, and by interlacing the primary and secondary coils to decrease the magnetic leakage. In an interlaced winding, the primary and secondary coils are wound in several sections connected in series and the sections are alternated in position on the core. The latter is not common in transformers for most applications in signaling.

Performance; rating.

Table I illustrates the performance of high-grade commercial transformers regarding losses, efficiencies and regulation at various voltages and

Kv-a.	Watts loss Iron	Copper	Full-load	½ load	¼ load	100% P.F.	80% P.F.	60% P.F
½	15	13	94.7	93.2	88.7	2.62	3.28	3.16
1	20	24	95.8	95.1	92.0	2.42	3.12	3.04
1½	25	35	96.0	95.5	92.7	2.36	3.07	3.00
2	30	42	96.5	96.2	93.8	2.12	2.88	2.86
2½	33	51	96.8	96.5	94.5	2.08	2.83	2.83
3*	34	64	96.8	96.8	95.2	2.16	2.91	2.88
4	40	75	97.2	97.1	95.7	1.90	3.00	3.12
5*	45	93	97.3	97.3	96.1	1.90	2.99	3.11
7½	62	125	97.6	97.6	96.4	1.70	2.84	3.00
10*	80	148	97.8	97.7	96.5	1.51	2.68	2.89
15*	105	212	97.9	97.9	97.0	1.44	2.63	2.85
20	131	268	98.0	98.0	97.1	1.39	2.87	3.21
25*	147	319	98.2	98.2	97.4	1.33	2.82	3.17
30	163	374	98.2	98.3	97.6	1.32	2.82	3.16
37½*	197	433	98.3	98.4	97.7	1.20	2.72	3.09
50*	240	550	98.4	98.5	97.9	1.15	2.68	3.07

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* These are A.S.A. preferred kv-a. ratings.

Transformers are rated according to the volt-amperes or kilovolt-amperes they can deliver continuously on non-inductive load without overheating. To secure uniformity in rating, the A.S.A. recommends for transformers using Class A insulation and operating continuously at full-load, that the temperature rise of the windings shall not exceed ambient temperature by more than 99 degrees Fahrenheit.

The temperature rise specified is based on the life expectancy of the insulation and assumes definite "service conditions." These service conditions consider the cooling qualities of the air and are (1) that the temperature of the cooling air (ambient temperature) does not exceed 104 degrees Fahrenheit, and the average temperature of the cooling air for any 24-hour period does not exceed 86 degrees Fahrenheit; (2) that the altitude does not exceed 3,300 feet.

Transformers, when applied at higher ambient temperatures or at higher altitudes than specified and loaded continuously to maximum capacity should have special consideration as to the effect of these variations. The manufacturer is usually consulted with respect to what reduction in rating should be applied, if any.

The average temperature of the cooling air can be determined by averaging 24 consecutive hourly readings. When the outdoor air is the cooling medium, the average of the maximum and minimum daily temperatures may be used.

In the selection of transformers for new work or replacement, it is desirable to specify capacities and voltages of preferred commercial ratings.

Figure 4 shows the characteristic curves for a 1½ kv-a. transformer.

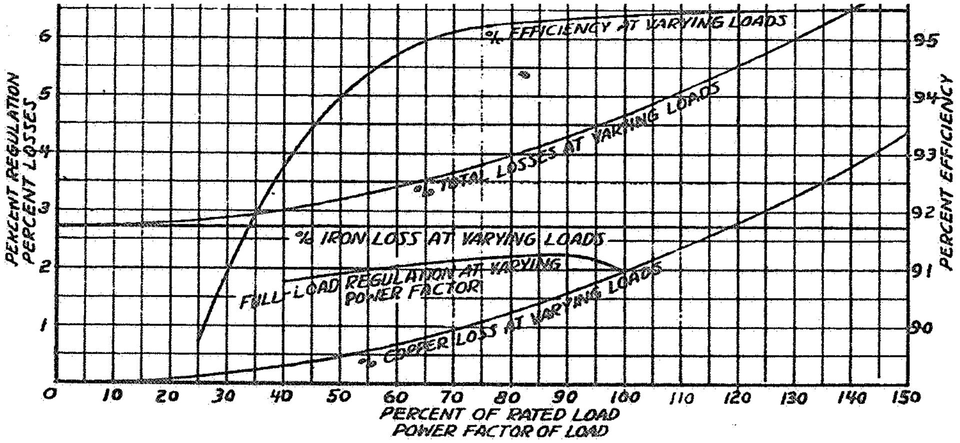


Fig. 4.

Characteristic Curves for a 2,300-230/115 Volt, 60-Cycle, 1½ Kv-a. Oil-Immersed, Self-Cooled Signal Transformer.

Different frequencies.

The lower the frequency the larger must be the transformer in order to deliver a given output without overheating. The frequencies generally used in signal work are 60 and 100 cycles. In some instances a frequency of 25 cycles is used.

A transformer designed for a certain work at 25 cycles would perform the same work on a 60-cycle transmission line with less heat than on the 25-cycle transmission line; the same applies to a 60-cycle transformer used on a 100-cycle transmission line. A 25-cycle transformer connected to a 60-cycle transmission line would have its coils cut by the magnetic flux more than twice the rate they would be cut by a 25-cycle transmission, therefore requiring less lines of force to perform the function of sustaining the voltage in the coils and a smaller iron core to accommodate them. It is, therefore, evident that transformers designed for a certain frequency should not be used on lines having a lower frequency as excessive current will flow in the primary coil thus causing overheating.

Vector diagrams.

The vector diagrams of an ideal transformer working on no-load are shown in Fig. 5.

The ideal transformer is considered as having no losses and a resistance so small as to be negligible. The flux generated in the iron core varies periodically and accompanies in phase the magnetizing current which produces it.

The voltages induced in the primary and secondary coils by the changing flux are 90 electrical degrees ahead in time phase (leading) with respect to the flux produced by the magnetizing current because the induced voltage is the maximum when the flux is changing most rapidly at the zero point by the primary magnetizing current M. The secondary voltage has been shown opposite in phase to the primary voltage, instead of in phase, for convenience in making up the diagrams and in keeping wth the method that has been used in the past by many authors of texts on electrical theory. E_1, the voltage applied at the primary terminals, is the same as e_1 in the ideal transformer. Similarly, the voltage at the secondary terminals E_2 is the same as e_2 since there is no current flowing in the secondary.

The actual transformer vector diagram for the no-load condition is shown in Diagram B of Fig. 5. The eddy currents in the iron core have an effect similar to a small amount of secondary load current and thus cause the primary to draw additional current to balance out the demagnetizing effect of these currents. Because of the eddy current and hysteresis losses, an iron-loss component MI_0, in phase with the applied voltage, is added to the magnetizing current OM. The resulting total current OI_0 is the no-load current, which is also called the exciting current. The voltage drop due to this small current in the primary resistance and leakage reactance is usually negligible.

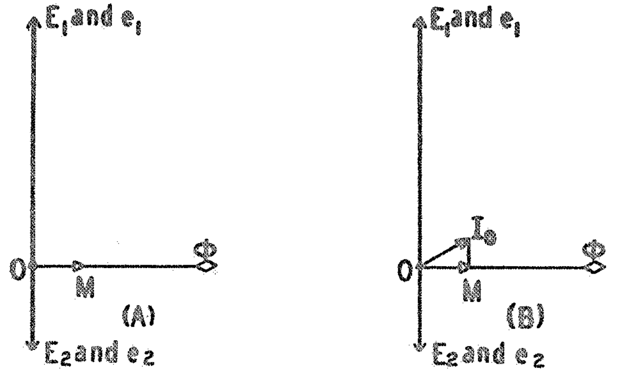


Fig. 5.

Vector Diagrams of Transformer Working on No-Load.

The total primary no-load current is OI_0. The two components OM and MI_0 cannot be added arithmetically as they are not in phase, but are added geometrically combined by the parallelogram of forces.

When a transformer is supplying power at approximately unity power factor, the secondary current is approximately in phase with secondary voltage. The corresponding load current component in the primary is opposite to and balances the secondary ampere turns to maintain the automatic transfer of power between primary and secondary. These relations are shown in Diagram A of Fig. 6.

When the secondary is operating at nearly unity power factor on a non-inductive load, the total primary current OI_1 is much nearer in phase with the primary impressed voltage than the no-load current OI_0. When the secondary is feeding highly inductive load at a low power factor, the secondary current OI_2, in Diagram B, lags far behind the secondary voltage E_2 and consequently the total primary current OI_1 lags farther behind the primary

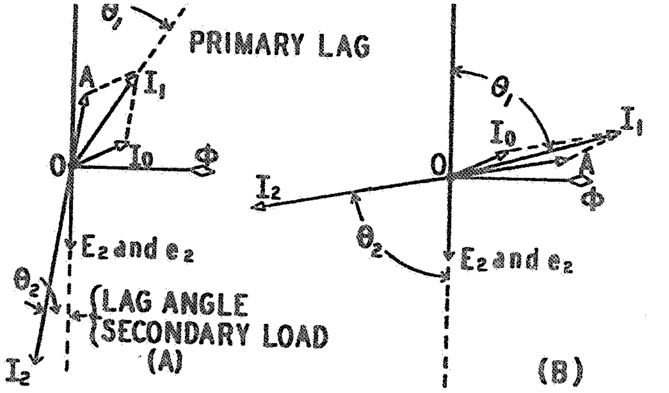


Fig. 6.
Effect of Secondary Power Factor on Primary Current Vector.

OI_2 is the secondary current
OA is the balancing primary load current
OI_0 is the no-load primary current
OI_1 is the total primary current composed of load and magnetizing components OA and OI_0
OE_1 is the impressed primary voltage

A complete transformer vector diagram is shown in Fig. 7.

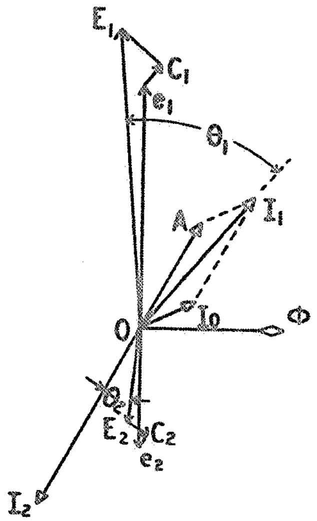


Fig. 7.
Complete Transformer Vector Diagram.

Oe_2 = induced e.m.f. in the secondary (hypothetical)
Oe_1 = induced e.m.f. in primary, proportional to Oe_2 by ratio r
r = ratio of transformation of the transformer
$O\Phi$ = useful flux
OI_0 = primary no-load current
OI_1 = total resultant primary current

$\cos \theta_2$ = power factor of load on secondary
OE_1 = total voltage to be applied at primary terminals
e_2C_2 = secondary resistance drop in volts in phase with OI_2
E_2C_2 = secondary reactance drop in volts due to secondary leakage flux, at 90 degrees to OI_2
OA = primary load current; opposed and proportional to OI_2 by ratio $1/r$
OE_2 = net secondary terminal voltage
$\cos \theta_1$ = power factor of primary current

The voltage OE_1 must be larger than Oe_1 by an amount necessary to overcome e_1C_1 plus E_1C_1.

The secondary terminal voltage OE_2 is less than the full induced secondary voltage Oe_2 by the amount lost in the resistance drop e_2C_2 plus the reactance drop E_2C_2. These losses must be subtracted from the original induced voltage Oe_2, thus the net terminal voltage of the secondary OE_2.

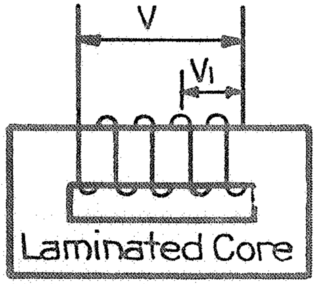
Types of transformers.

The essential parts of a transformer are: the coils with their insulation, the iron core, the terminal board and leadout wires, and the case, if any, with its insulation.

Transformers used in signal work may be either the dry type, self-cooled, or oil-immersed, self-cooled, depending on the capacity of the transformer. Dry type transformers are generally used with primary voltages up to 660 volts. Above 660 volts, oil-immersed transformers are usually used.

Formerly some railroads on center fed track circuits used track transformers with adjustable magnetic leakage blocks in their cores. This enabled the use of a resistor or reactor as limiting device between track secondary and track to be eliminated. The leakage block produced the same effect as a reactor in series with the secondary of the transformer, the amount of reactance being adjustable by movement of the block. This type of transformer has been generally superseded by the use of constant potential transformer with an external resistor or. reactor as the limiting device. At present the use of reactive transformers, that is, transformers with adjustable leakage blocks, has been practically limited to dry type rectifiers for charging batteries.

Another type of transformer used in signaling is the auto-transformer as shown in Fig. 8.



The ratio depends upon the number of turns in each part.

V is the primary

V_1 is the secondary

This form of transformer is hazardous on high voltage and should be used only where there is a small variation between the primary and secondary, or on low voltage.

Another type of transformer used in signal work is the insulating transformer which has the same number of turns in the primary and secondary winding (usually called one-to-one transformer). This type is used generally as lightning, surge or ground protection between the transmission lines and operated units, or where power is purchased from an outside source of supply, as additional protection between the outside source of supply and the transmission line.

There is also the series or current transformer, shown in Fig. 9.

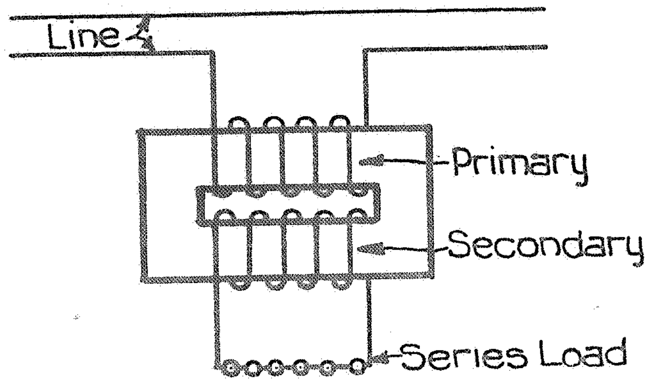


Fig. 9.
Series or Current Transformer.

In the series or current transformer, the primary coil is in series with one of the line wires, and the secondary in series with the apparatus to which it transmits its energy. When the current in the primary varies, the current in the secondary varies proportionally. This type of transformer is used generally to operate ammeters and wattmeters. Such current transformers are usually designed to give a current of 5 amperes through the meter in the secondary circuit for a specified full-load current in the primary circuit. The ammeter scale is calibrated in terms of the primary full-load current.

The relative arrangement of core and coil divides the transformers generally used for signal work, into core type, shell type and distributed core type.

The three types are shown in Fig. 10.

The core type has both vertical legs surrounded by a winding. Half the primary and half the secondary are wound one over the other on each leg.

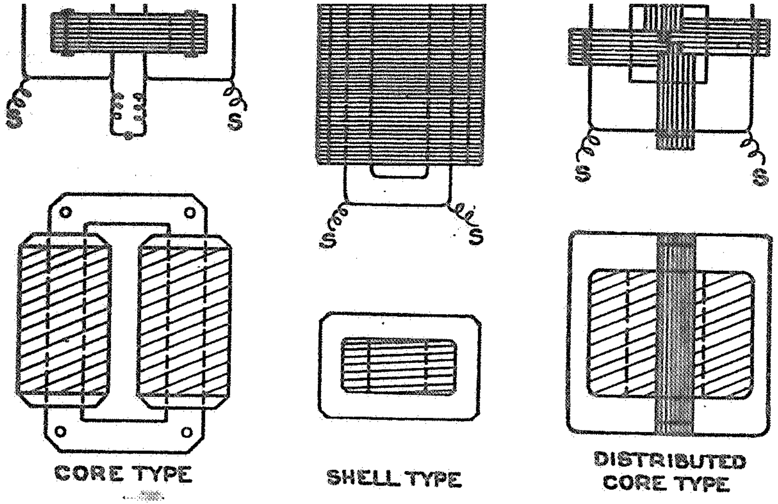


Fig. 10.
Transformer Core Construction.

The shell type has both primary and secondary wound interlaced, one with the other, over the center leg of the iron core which almost entirely surrounds the coils.

Figure 11 illustrates the shell transformer. The transformer and terminal board are shown at the left and the transformer enclosed in iron case, with lid off, is shown at the right.

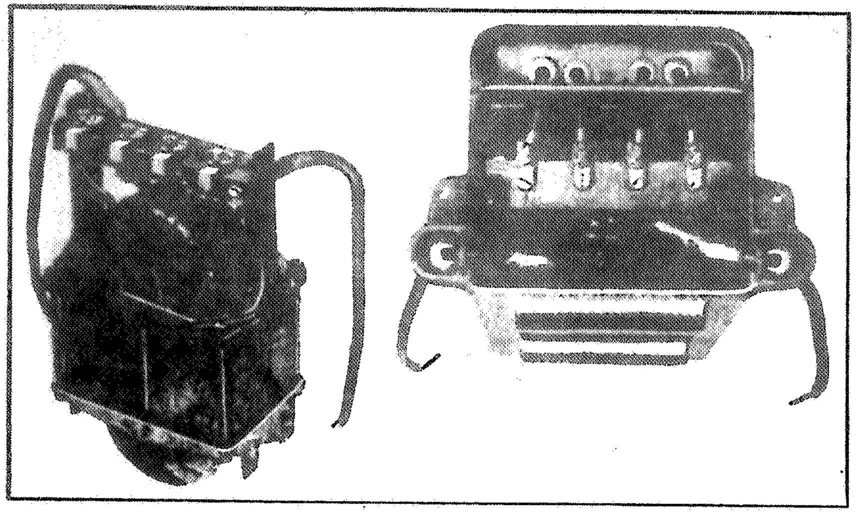


Fig. 11.
Shell Transformer.

The distributed core type transformer is a combination of the core and shell types. The iron core consists of four magnetic circuits of equal reluctance in multiple. Each circuit consists of a separate core. One leg of each magnetic circuit is built up of two different widths of punchings coil at equal distance from the center on the four sides. The complete core with its coils is shown in Fig. 12.

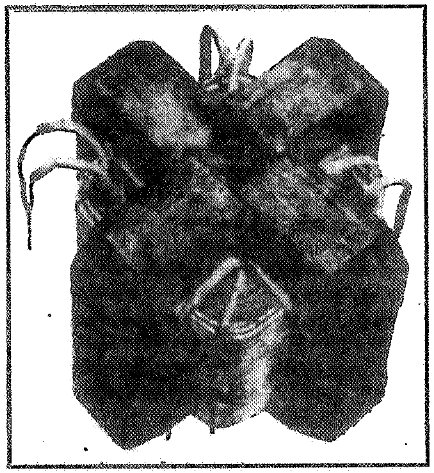


Fig. 12.
Distributed Core Transformer.

Relative advantage of core and shell types.

The core type has a lighter core of smaller sectional area than the shell type, so that more copper with a larger number of turns is required with the core type, although the turns are of a lesser mean length. Then again, cylindrical form wound coils can be rapidly wound for the core type; these coils have a large surface exposed for cooling. The core type is better suited for high voltages which may require many turns and considerable insulation. The shell type is suited for moderate voltages requiring few turns and little insulation. The distributed core type combines the best features of both core and shell type, *i.e.*, a short mean length of turns in the coil and a short length of magnetic circuit.

Modern types of transformers.

Recent improvements in design and in the technique of manufacture have resulted in reduction in size and weight of transformers of the distribution type. These developments have produced cores in which the magnetic flux is parallel to the direction of rolling in all parts of the core which enables marked reduction in core loss to be obtained.

These new core structures are obtained in four ways:

1. Assembling cores from strips of steel sheared in the direction of rolling.
2. By winding continuous strip steel through the opening of a preformed coil.
3. By winding cores of strip steel and then winding coils around the core by means of a motor-driven collapsible coil forming fixture.
4. By winding cores on a form from continuous strip steel, then saw-

of producing high voltage on the low-voltage winding because of breakdown of the insulation. Such a failure could be hazardous to persons handling the signal apparatus and might cause damage to the apparatus. Interlacing the windings makes it more difficult to provide adequate insulation between the primary and secondary.

Cotton-covered wire is commonly used for the windings. When this becomes saturated with the impregnating compound or varnish, it provides good insulation between adjacent turns of the winding. Additional insulation, such as layers of insulating paper or cloth, is required between the primary and secondary windings and is sometimes used between layers, especially on a high-voltage winding with a large number of turns.

After the core is completely wound, it is thoroughly dried by heating in a vacuum tank, after which a hot insulating compound is forced by high pressure into every part of the winding until it is thoroughly saturated. A varnish may be substituted for the insulating compound and applied to the windings under pressure, or in small transformers, the windings are dipped in the varnish. This process is to make the windings moisture-proof.

Dielectric requirements.

Transformers for railway signal service are required to withstand the following 60-cycle r.m.s. tests:

1. Dry type, self-cooled transformers.

(a) Assembled transformer shall withstand for 1 minute a 60-cycle insulation test, at place of manufacture, of 3,000 volts between each winding and other metallic parts insulated therefrom, except where specified otherwise.

(b) Transformer winding rated more than 175 volts shall withstand for 1 minute a 60-cycle insulation test at place of manufacture of 10,000 volts between such winding and other metallic parts insulated therefrom, except that windings rated more than 175 volts but less than 250 volts may, when designed to be connected to a local line or load, be tested to withstand 3,000 volts.

(c) When a secondary has an associated adjusting secondary, the insulation between them shall withstand for 1 minute a 60-cycle insulation test, at place of manufacture, of 500 volts.

(d) A surface leakage distance sufficient to withstand dielectric tests in paragraphs 1-a and b shall be provided between any exposed metallic part of the apparatus carrying current and any other metallic part thereof. Surface leakage distance shall be not less than ⅜ in.

(e) A potential of twice the normal operating requirements at a suitable frequency shall be impressed across the windings for 1 minute, without any excessive flow of current indicating a short circuit.

2. Oil-immersed, self-cooled transformers.

(a) Transformer windings shall be insulated to meet the usual dimarking of its external leads depends on how they are brought out of the case from the windings, either direct or from their binding posts.

The standard marking for external leads in accordance with A.I.E.E. and A.S.A. Standards for indicating the polarity of external leads of a transformer is illustrated in Fig. 13 by the symbols H_1 and H_2 for the high-voltage leads and X_1, X_2 for the low-voltage leads. H_1 and X_1 indicate leads of positive polarity, H_2 and X_2 leads of negative polarity. Fig. 13 is a diagrammatic plan view looking down on a transformer showing in simplified form the manner in whch transformers are wound and the relative position and manner of bringing out the high and low-voltage leads. Arrows indicating the relative direction of current flow in the windings with plus (+) and minus (—) signs are shown merely to indicate the polarity of the ends of the coils and not to be used as polarity markings for the external leads.

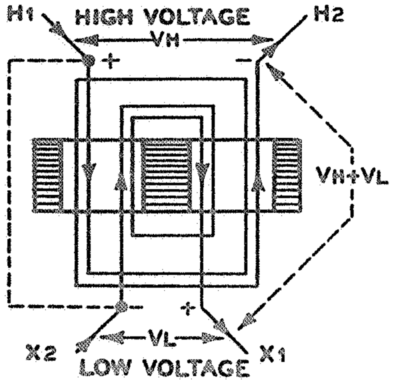


Fig. 13.
Polarity of a Single-Phase Line Transformer.
Additive polarity illustrated.

Assuming the instantaneous direction of current flow in lead H_1 is "in," as shown by the arrow and plus sign, it is seen that at the same instant the current flow in low-voltage lead X_2, as shown by the arrow and minus sign, is also "in." This holds true because the direction of instantaneous current flow in two parallel wires of the high-voltage and low-voltage windings on the same side of the core must be opposite. Since the current flow from the source that feeds the high-voltage winding is from instantaneous positive to instantaneous negative, the lead H, where the current flows in is positive and lead H_2, where the current flows out is negative. As the current flow from the low-voltage winding to its external circuit is also from instantaneous positive to instantaneous negative, as shown, it is evident that lead X_1 is positive and lead X_2 is negative.

Calling voltage between leads of the high-voltage winding VH and voltage between the leads of the low-voltage winding VL it is seen that when voltage VH is impressed upon the high-voltage winding and leads H_1 and X_2 are connected together, that a voltage VH plus VL will be indicated by a voltmeter connected between leads H_2 and X_1. This arrangement of leads is said to have additive polarity. (If the ends of the low-voltage polarity would be subtractive.) The method of test is named "polarity by alternating-voltage test."

The general practice for indicating polarity of windings of dry type, air-cooled, signal transformers that have binding posts on a terminal board without leads therefrom is either to designate the positive post of each winding with a plus sign with no designation on the minus end or to show a plus sign at the positive post and a minus sign at the negative post of each winding.

Assembly.

Practically all transformers have terminal boards attached to the core, to which are attached the primary and secondary coil leads, but where the primary voltage is very high the primary leads are not brought to a terminal board. When the transformer is put into a case, it is firmly attached to the case to keep it steady during transit.

Transformers for outdoor service are provided with leads of insulated copper wire or terminal bushings sealed into the case.

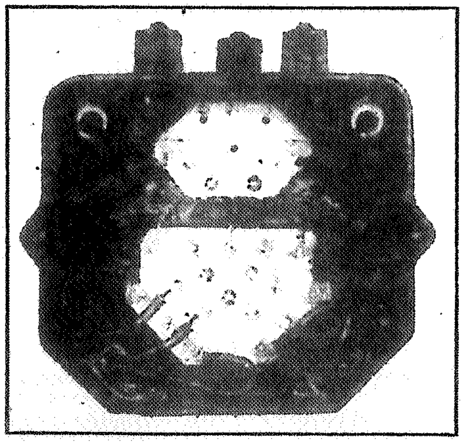
Oil-immersed, self-cooled transformers.

Transformers having windings rated higher than 660 volts or in sizes larger than 2 kv-a. at the lower voltages usually are assembled in liquid-tight, cast-iron or sheet metal cases that permit the core and windings to be immersed in a fine grade of mineral oil free from acids, alkalies and moisture.

The case provides mechanical and weather protection for the core and windings while the oil keeps moisture out of the windings, provides insulation and a medium for rapid transfer of heat from core and windings to the metal case to be dissipated from thence to the surrounding atmosphere, oil being a much better medium than air for heat transfer.

A dry type, self-cooled transformer would have to be considerably larger than an oil-immersed, self-cooled transformer of the same kv-a. rating in order to maintain the same temperature rise for core and windings.

See Figs. 14 and 15 for oil-immersed, self-cooled transformers.



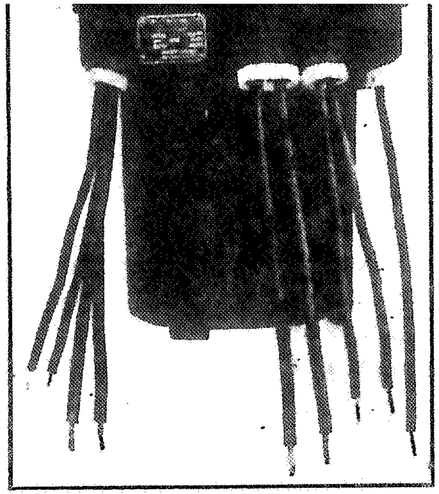


Fig. 15.
L High Tension Line Transformer.

Dry type, self-cooled transformers.

Transformers having primary voltages of 660 or less and capacities of 2 kv-a. or less are generally of the dry type, self-cooled. The windings are

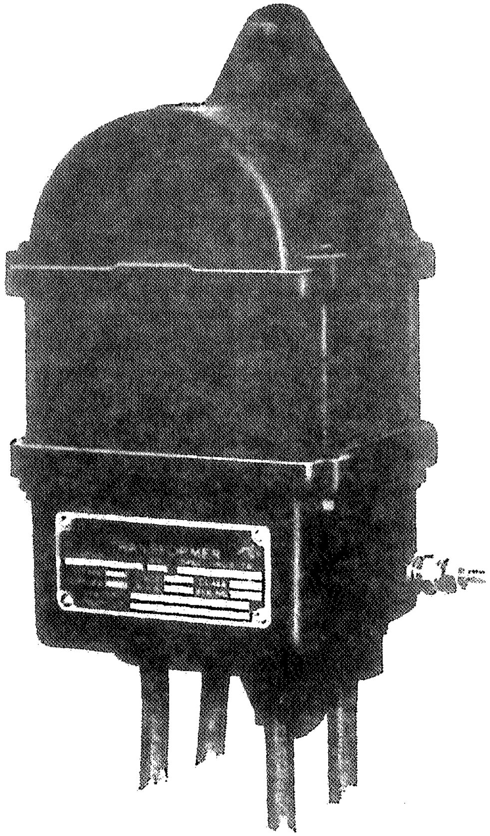


Fig. 16.
Dry Type, Self-Cooled Transformer for Cross-Arm Mounting.

cast-iron end bells to protect the windings, or the core and coil assembly is enclosed in a moisture-tight sheet steel case, and are usually arranged for cross-arm mounting or to be bolted against a wall. External leads of double braid insulated wire are brought out of the lower end bell or bottom of the case through insulating bushings. These transformers when used for cross-arm mounting are generally connected directly to signal transmission lines, and are known as line transformers. See Fig. 16.

For indoor mounting, particularly in the smaller ratings, the core and coil assembly is commonly enclosed in a sheet steel case, which may have ventilating holes, with a terminal board of insulating material such as molded bakelite on the top or front of case, as illustrated by Fig. 17.

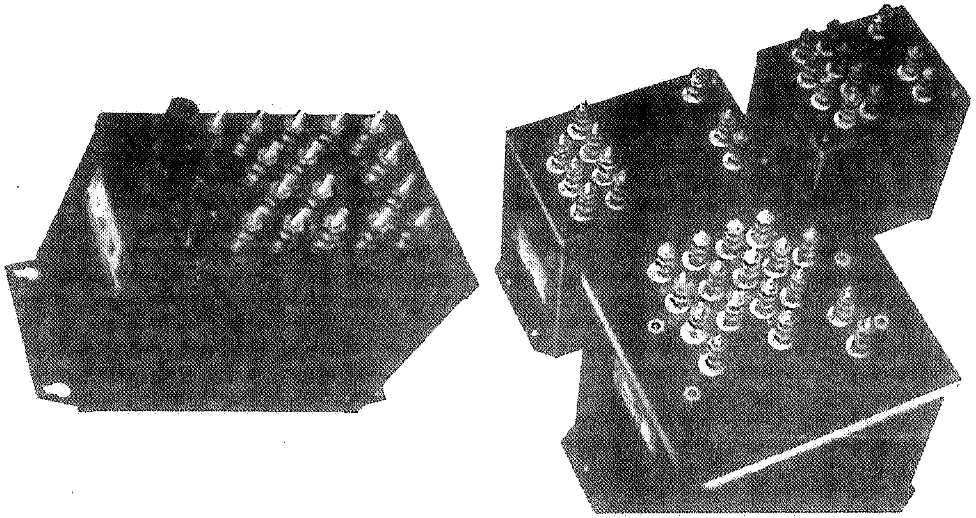


Fig. 17.

Dry Type Track and Signal Lighting Transformers for Indoor Service.

Dry type transformers for indoor service are generally used for track and signal lighting purposes. These transformers may be built for 25, 60, or 100 cycles. Figure 17 shows transformers of this type. The capacities of these transformers with single secondaries and primary voltage of 115 volts or less are as follows:

	Capacity in volt-amperes		
Size	25 cycles	60 cycles	100 cycles
W5	75	150	200
W10	150	300	400
W20	300	600	800

If more than one secondary is used or if the primary is insulated for higher voltages, the above capacities will be somewhat reduced. The secondary may be wound for the usual voltages required for track, signal lighting or rectifier service, and provided with taps for voltage adjustment. The primaries are usually wound for 57.5 volts or even multiples thereof

For 250-volt or higher primary voltages, insulated primary leads are brought out of the case through an insulating member.

Reactive transformer.

A reactive transformer is one in which an adjustable magnetic leakage block of laminated iron is provided to divert an appreciable part of the magnetic flux originating in the primary from the secondary portion of the core. The amount of flux diverted can be varied by adjustment of the leakage block and the ultimate effect is the same as would be obtained by using an adjustable reactor in series between the secondary and load.

Figure 18 shows one form of reactive transformer which is used as a component part of a dry plate battery charging rectifier. This transformer supplies proper voltage to the rectifier cell assembly and the required reactive ballast for adjustment of the charge rate.

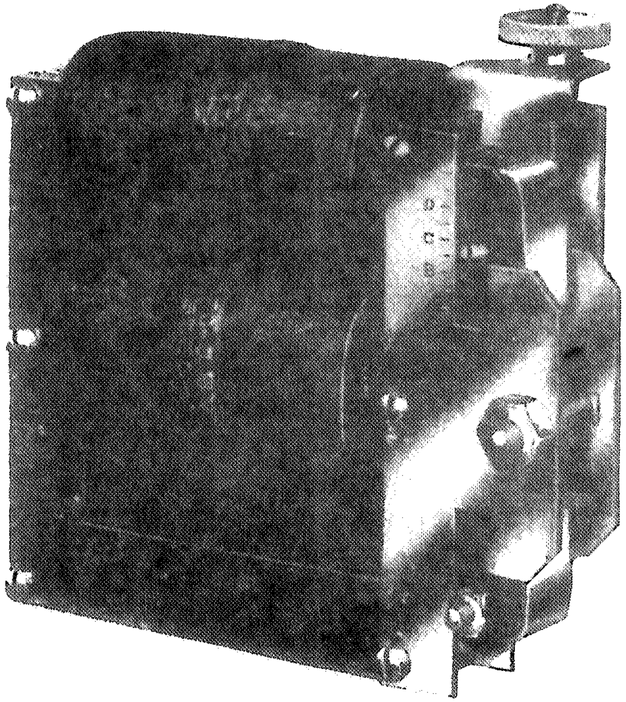


Fig. 18.
Reactive Transformer for Use with Dry Plate Type Rectifier.

Line transformers.

Transformers connected directly to the transmission line are called line transformers. These are generally dry type if the line voltage is 660 volts or less and oil-immersed if the line voltage is over 660 volts. Formerly oil-immersed line transformers were sometimes furnished with two secondaries, one for 110 volts and a second for track voltage; however, this practice in

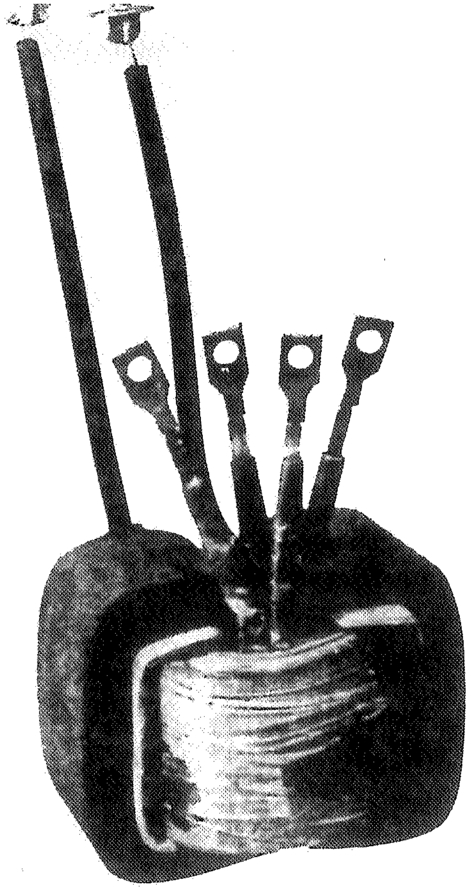


Fig. 19.
Assembled Coil and Cores, Oil-Cooled Line Transformer.

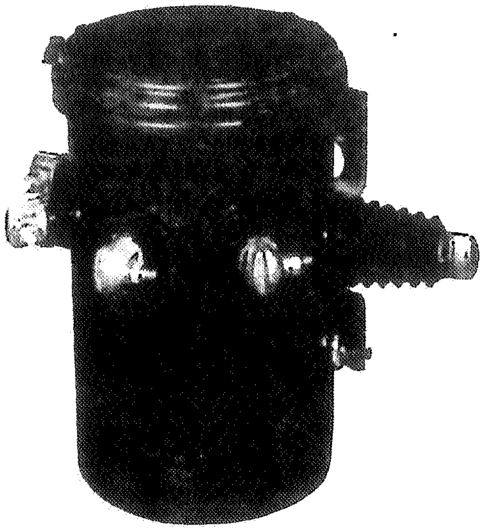


Fig. 20.

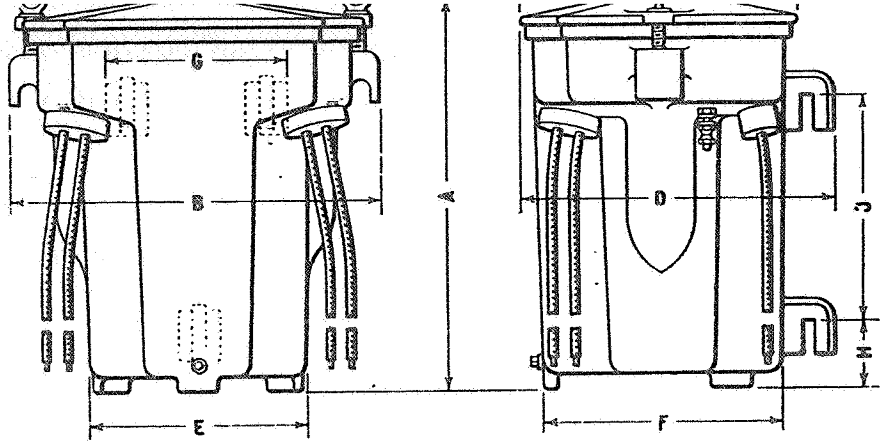


Fig. 21.

L Transformer.

Size	A Inches	B Inches	C Inches	D Inches	E Inches	F Inches	G Inches	H Inches	J Inches
1	13⅝	12¾	10	11¼	7⅞	8⅝	6½	2 5/16	8
2	15½	13⅝	11 13/16	13 1/16	8⅝	10	6½	3 9/16	8
3	18⅝	14⅞	13 13/16	14 15/16	9⅞	12	6½	6⅛	8
4	21⅜	18¼	17⅛	18⅜	11½	13⅜	8½	5⅜	9¾
5	25	21	17	18⅝	13⅛	15¼	8½	8½	9¾
6	32⅛	25¼	21½	23	15½	18¼	11	7	17