Nov. 22, 1949 D. O. SCHWENNESEN 2,488,742

TRANSFORMER

Filed March 6, 1947

Fig. 1

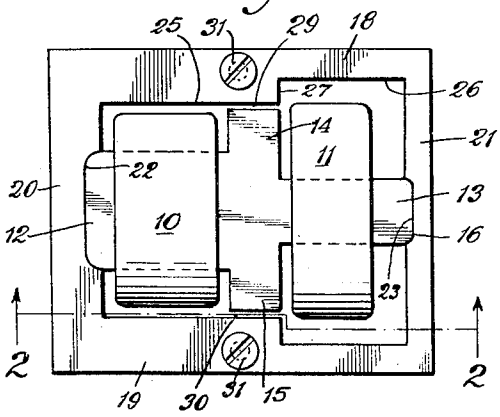


Fig. 3

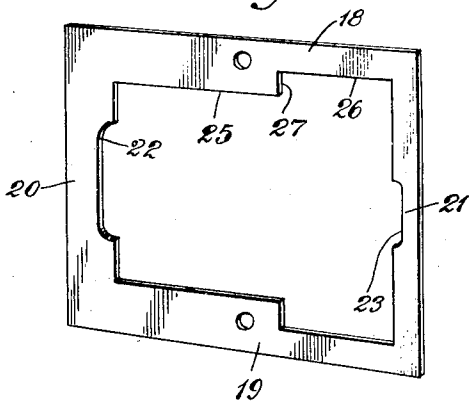


Fig. 2

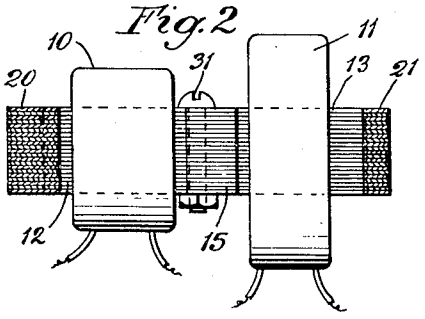
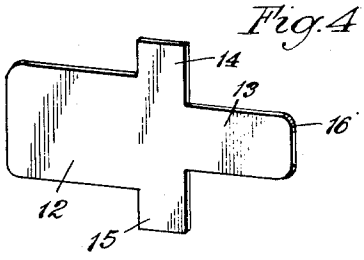


Fig. 4



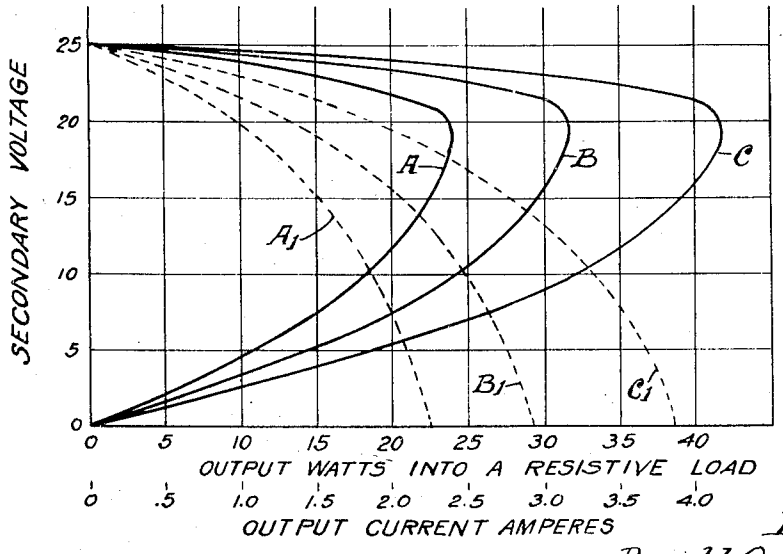


Fig. 5

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TRANSFORMER

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1 Claim. (Cl. 171—119)

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This invention relates to a transformer and particularly to a transformer having good voltage regulation from no-load to full-load and poor voltage regulation from full-load to short circuit. A transformer embodying the invention has particular application to low-voltage, low-power circuits such as are used in connection with bells, chimes and various types of control systems, such as thermostatically-controlled valves and the like.

Transformers for energizing low-voltage, low-power circuits are customarily operated from a power line such as the usual 110 volt, 60 cycle line and provide suitable output voltage under normal load conditions. Thus, as one example, 24 volt control systems are in wide use although other voltages are common. Installation and insulation requirements for conventional power circuits have generally been relaxed by Fire Underwriters and others in the case of low-voltage, low-power circuits. Corelative to the relaxed insulation requirements for such low-voltage, low-power circuits has been the requirement that transformers energizing such circuits have poor voltage regulation from full-load to short circuit. Thus, in case of over-load or short circuit, tendency to cause fires is reduced.

Inasmuch as low-voltage, low-power control circuits frequently operate under no-load conditions, the voltage characteristic of the transformer between no-load and full-load becomes a significant factor in regard to insulation and general design. In the conventional high leakage reactance transformers for energizing such systems, the poor regulation desired from full-load to over-load extends from full-load to no-load and results in an open circuit voltage which is substantially higher than normal full-load voltage. It is evident that the presence of abnormally high open circuit voltages will tend to defeat the relaxation of insulation requirements previously referred to or will require a low normal load voltage. In addition to the above, a wide voltage spread between no-load and full-load creates design problems in connection with apparatus in the low-voltage, low-power circuit. It follows, therefore, that a transformer for energizing a low-voltage, low-power control circuit should preferably have an open circuit potential substantially equal to a normal load potential.

This invention provides a transformer wherein the voltage regulation between no-load and full-load is good but wherein the output voltage drops rapidly with over-load. By virtue of the invention, a structure results wherein more room is provided for a secondary winding than in a conventional transformer. This results in a transformer having a higher rating than a similar transformer constructed along conventional lines or conversely permits a transformer having smaller dimensions for the same rating.

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In accordance with the invention, there is provided a transformer having separate primary and secondary windings. The magnetic structure comprises a first ferromagnetic part which is incomplete and links the primary only. A second incomplete ferromagnetic part links the secondary only and cooperates with the first incomplete ferromagnetic part to provide a closed ferromagnetic core linking both primary and secondary windings. A third incomplete ferromagnetic part is disposed in shunt to said second ferromagnetic part with the third part forming an open-core type of shunt. The third part cooperates with the two ferromagnetic parts respectively to form a closed magnetic circuit of the open-core type linking the primary and secondary respectively.

In accordance with usual practice, the reluctance of the first part of the ferromagnetic circuit is low having a conventional value and being such that the flux density in the iron is normal and the iron having a high permeability for all load conditions. The third ferromagnetic part with the open-core construction having non-magnetic gaps necessarily provides a reluctance high in comparison to the reluctance of the first part. The second part of the magnetic circuit, however, is designed so that, at no-load, the flux density throughout a substantial portion thereof is at or near saturation.

As load current flows through the secondary, demagnetizing action occurs, and this load current finally reduces the flux density below saturation in the second part and tends to force an increasing amount of flux through the open-core shunt. By proper design, the demagnetizing effect on the second magnetic part due to current in the secondary between no-load and full-load may be made quite small. Thus, while the total flux passing through the second part at no-load will always be greater than at full-load, nevertheless, this difference may be made quite small in comparison to the total amount of flux. This is done by taking advantage of saturation characteristics. Since the induced potential is proportional to the amount of flux linking the secondary, the action of the system in keeping the flux reduction in the second part between no-load and full-load small will have a tendency to reduce

the difference in induced potential between no-load and full-load.

The regulation between no-load and full-load in general will be improved by having a substantial portion of the iron in the second part at saturation between no-load and full-load. Conversely, the regulation between full-load and short circuit will be rendered poor by reducing the flux density in the second part rapidly with increase in secondary current beyond full-load. This means that, beyond full load, a substantial portion of the iron in the second part must be operated at flux densities well below saturation. Thus, an increment of added secondary current beyond full-load will have a large incremental effect in reducing the flux density in the second part.

For a more thorough understanding of the invention, reference will now be made to the drawing wherein Figure 1 is a plan view of a transformer embodying the present invention. Figure 2 is a sectional view on line 2—2 of Figure 1. Figure 3 is a perspective view of a lamination enclosing the windings. Figure 4 is a perspective view of a lamination upon which the windings are disposed, and Figure 5 shows some curves illustrating characteristics of transformers embodying the present invention.

A transformer embodying the present invention comprises primary winding 10 and secondary 11 disposed on a stack of laminations, one lamination being shown in Figure 4. Thus, primary winding 10 encloses leg 12 while secondary 11 encloses leg 13. Legs 12 and 13 are preferably integral and aligned. The aligned legs have lateral extensions 14 and 15. Leg 13 is narrower than leg 12 and has rounded end 16 for ease in fitting against the outer lamination.

The outer lamination has a generally rectangular outline and has top 18 and bottom 19 connected together by sides 20 and 21 respectively. Side 20 has cut-out 22 corresponding in shape to the free end of leg 12. Side 21 has part 23 shaped to cooperate with end portion 16 of leg 13. The outer and inner laminations are properly dimensioned so that the free ends of legs 12 and 13 will be snugly retained between sides 20 and 21 of the outer lamination.

Top and bottom 18 and 19 of an outer lamination are divided into wide and narrow portions 25 and 26 respectively. The two portions meet at step 27. Lateral extensions 14 and 15 extend toward the end of wide portions 25 adjacent step 27. As shown in Figure 1, lateral extensions 14 and 15 do not reach the inside edges of the outer lamination but form air gaps 29 and 30.

The stack of laminations are maintained in any suitable fashion, such as by bolts 31. The inner stack of laminations upon which the windings are disposed may have a bolt through any portion thereof for maintaining the stack intact, or reliance may be had upon the windings and the clamping action within the outer stack for maintaining the assembly intact. Inasmuch as it is customary to impregnate such transformers in wax or other compound, all laminations may be retained in position independently of bolts.

It will be evident that leg 12, side 20 and wide portions 25 of the outer laminations form the first part of an incomplete ferromagnetic circuit linking primary 10. At wide parts 25 adjacent steps 27, two magnetic paths are provided in shunt to each other to complete the first portion of the magnetic circuit. Thus, narrow portions 26, side 21 and leg 13 is a second or shunt ferromagnetic path incomplete in itself but completing a closed core magnetic circuit for primary 10. Air gaps 29 and 30 and lateral extensions 14 and 15 comprise a third or open-core path. It is evident that the open-core shunt is common to open-core magnetic circuits for the primary and secondary respectively.

The ferromagnetic shunt path consisting of narrow portions 26, side 21 and leg 13 will have more reluctance than the first portion of the magnetic path linking primary 10. The amount of iron in the ferromagnetic shunt path is reduced to the point where, at no-load, a substantial portion thereof will operate at or near saturation when the first portion of the magnetic path consisting of wide portions 25, side 20 and leg 12 will be operating at normal flux densities below saturation customarily used in transformers.

There will be a division of magnetic flux between the two shunt paths at all times. The open-core shunt will carry flux even when the ferromagnetic shunt is saturated.

Due to the presence of the air gaps in the open-core magnetic shunt, it is possible to maintain the reluctance of this open-core shunt substantially constant over a wide range of flux density in the open-core shunt. It follows that, when current flows in secondary 11, the demagnetizing action due to such current will tend to reduce the flux density in the ferromagnetic shunt and thus drive the magnetic flux through the open-core shunt. By taking advantage of saturation characteristics of ferromagnetic materials, it is possible for an increment of added secondary current from no-load to full-load to cause but little decrease in flux in the second part of the transformer core due to demagnetization. Inasmuch as the potential induced in secondary 11 is a function of the total flux lines passing through the ferromagnetic shunt, it follows that the small decrease in flux due to secondary current will have a small effect on induced potential in secondary 11.

As secondary current increases, the demagnetizing action on the second ferromagnetic part will increase and reduce the flux density below saturation. This will result in a reduction in total magnetic lines of force passing through the ferromagnetic shunt and the potential induced in secondary 11 will drop. With increase in demagnetizing action in the ferromagnetic shunt, there will be an increasing tendency for magnetic lines of force generated by primary 10 to pass through the open-core shunt.

In general, the first portion of the magnetic circuit linking primary 10 is designed to have low reluctance and high permeability with the flux density below saturation and in the range customarily used for transformers. The ferromagnetic shunt has substantially greater reluctance than the first magnetic portion, this reluctance under no-load conditions resulting in a high flux density substantially of a saturating value. It is understood, of course, that some small portions of the ferromagnetic shunt need not necessarily be saturated. The open-core shunt, on the other hand, has a higher reluctance than the ferromagnetic shunt under no-load conditions, and the reluctance of the open-core shunt remains substantially constant throughout the operating range of the transformer, namely from no-load beyond full-load.

It is understood that, under various load conditions, the total number of flux lines and the flux

density in the first portion of the magnetic circuit, namely wide parts 25, side 20 and leg 12, will not necessarily be constant. As the total effective reluctance of the entire magnetic system varies, there will be some variation in the flux density in the first portion of the magnetic circuit. This variation, however, will generally follow along conventional lines. It is the distribution of total flux between the two shunts which varies with load and determines the peculiar and desirable characteristics.

As one example of a transformer, the following dimensions are herewith given, it being understood that these are merely exemplary. The material is transformer silicon steel. Thus, the outer lamination had an over-all length of three inches and width of 2.5 inches, the dimensions being along the outside edges. The width of portions 25 was .425 inch, while the width of portions 26 was .225 inch. The width of side 20, disregarding cut-out 22, was .4 inch, while the width of side 21, disregarding extension 23, was .2 inch. Leg 12 had a width of .9 inch and leg 13 had a width of .5 inch. Leg 12 had a length of 1.125 inches to the near side of extensions 14 and 15. Leg 13 had a length of 1.075 inches. The length of the inner lamination along legs 12 and 13 was 2.450 inches. Lateral extensions 14 and 15 projected .351 inch beyond the side of leg 12 providing air gaps of .024 inch. The width of lateral extensions 14 and 15, this being the dimension parallel to the axis of the inner lamination along legs 12 and 13, was .4 inch. Step 27 was substantially in line with a lateral extension as shown. Primary 10 consisted of 562 turns of number 27 wire, and secondary 11 consisted of 135 turns of number 22 wire.

Referring to Figure 5, some characteristic curves are shown of transformers designed along the general lines shown above. Thus, curve A shows the output watts into a resistive load of one transformer. Curve A_1 shows the output current for the same transformer. Curves B and C and B_1 and C_1 are the corresponding curves for transformers of different ratings. It will be noted that the output watts drops gradually from open-circuit output potential of 25 to a full-load potential of about 20. With increasing load beyond full-load, the output power falls sharply, this accompanying a sharp drop in potential and an increase in output current. In a conventional transformer where the ferromagnetic shunt is not reduced in cross section or does not have increased reluctance with respect to the first portion of the magnetic circuit, the drop in voltage between no-load and full-load is sharper. The curves are merely illustrative. It is possible to secure an even flatter curve from no-load to full-load.

It will be evident that some variations in design are possible. Thus, as an example, it may be possible to retain one-half of the magnetic structure with reference to the horizontal axis of the transformer as seen in Figure 1. This, of course, would mean only one lateral extension and one air gap as well as one wide portion 25 and narrow portion 26. Some variation in the disposition of the windings is also possible.

With a transformer core construction such as illustrated in the drawing, the window opening for secondary 11 is substantially greater than would normally be the case (substantially equal to the window for primary 10). With proper design, more copper may be used in the primary or secondary or both to give a higher rating for the same structure. Conversely, a transformer having the same rating may be made with smaller physical dimensions.

The transformer so far described has a core of one ferromagnetic material, such as transformer steel. It is possible, however, to make the transformer core a composite structure. Thus, wide portions 25 and side 20 as well as leg 12 may be made of conventional silicon steel capable of carrying considerable flux before saturation occurs. Portions 26, 21 and 13 may be made of a readily saturable metal as Mumetal for example. Such readily saturable materials generally have a rather sharp knee in the B-H curve. Such a sharp knee is desirable for a transformer embodying the present invention.

It will be understood that, if readily saturable materials are used as stated, then there will be no necessity for decreasing the cross section of portions 26, 21 and 13, as shown in the drawing. In fact, it may be necessary to have a larger sectional area at these portions of the magnetic circuit than at the first portion of the magnetic circuit, namely parts 25, 20 and 12. The objective in all cases is to have the first portion of the magnetic circuit operate at flux densities normal for transformers over the entire load range of the transformer. The second portion of the transformer core consisting of parts 26, side 21 and leg 13 will, at no-load and may under some load, operate at saturation. The dimensions of lateral extensions 14 and 15 within substantial limits is not important, it being understood, however, that these lateral extensions do not saturate except possibly at extreme conditions of short circuit. Since the major portion of the reluctance is in the air gap, considerable lee-way in the dimensions of the lateral extensions and the nature of the ferromagnetic material is possible.

In the determination of the reluctance of the various portions of the magnetic core, it is understood that, while the reluctance of one part of the core has been stated as having a certain value, it is understood that this is with reference to the entire magnetic structure. Thus, the reluctance of part one of the magnetic core is low considered as a part of the entire reluctance of the core. Similarly, the reluctance of the second part has been considered as being initially high, also with reference to the entire magnetic core. It is to be understood, therefore, that the designation of reluctances and flux densities in one part or another part of the magnetic structure is with reference to a complete transformer.

What is claimed is:

A transformer comprising a ferromagnetic core having an outer portion forming a generally O-shaped structure and having an inner portion of a generally cruciform shape, said inner portion having two aligned legs forming a substantially continuous ferromagnetic path along one axis of said outer structure, said inner structure having two aligned stubs forming the remaining two arms, said stubs providing air gaps between the stub ends and the outer core portion, a primary winding around one of said legs, a secondary winding around the other leg, said core being constructed so that the reluctance of the leg within the primary and the adjacent portions of the outer core extending around the primary is substantially less than the reluctance of the leg within the secondary and portions of the outer core around the secondary, the difference in reluctance being sufficiently great and the stubs

and air gap having a sufficiently high reluctance so that, on no-load, primary exciting current generates a flux which goes predominantly along the outer core portions and aligned legs with the portion linking the secondary being at or near saturation and wherein increasing load on the secondary reduces the flux density in the core portion linking the secondary and diverts flux across said air gaps and stubs whereby said transformer has substantially good regulation from no-load to a predetermined secondary load and poor regulation beyond said predetermined load to short circuit.

DONALD O. SCHWENNESEN.

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