

Dec. 5, 1939.

T. R. KENNEDY

2,181,899

TRANSFORMER

Filed Jan. 26, 1939

2 Sheets-Sheet 1

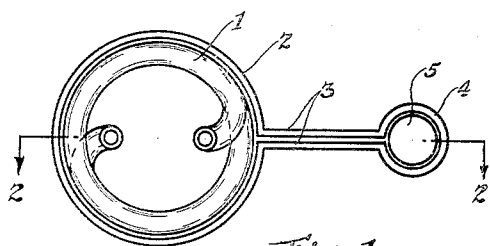


Fig. 1.

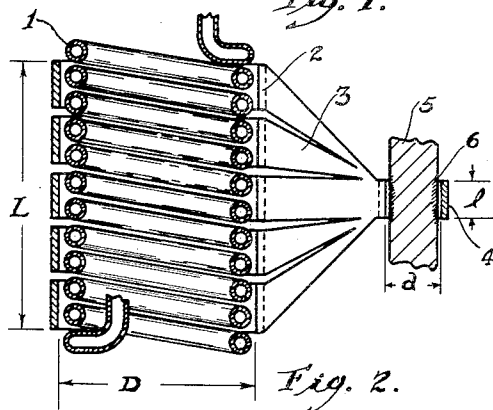


Fig. 2.

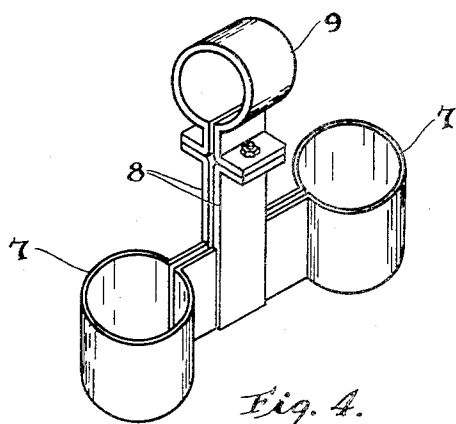


Fig. 4.

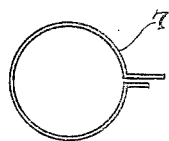


Fig. 5.

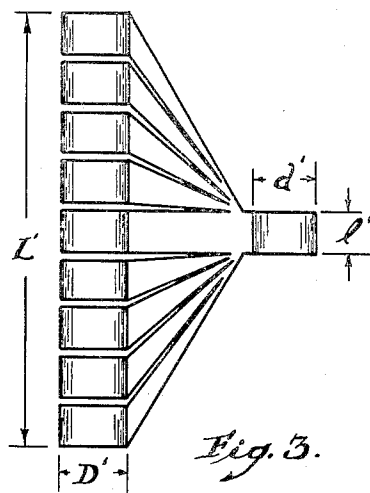


Fig. 3.

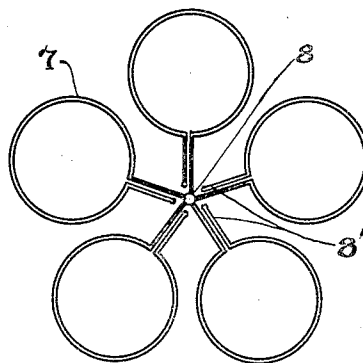


Fig. 6.

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2 Sheets-Sheet 2

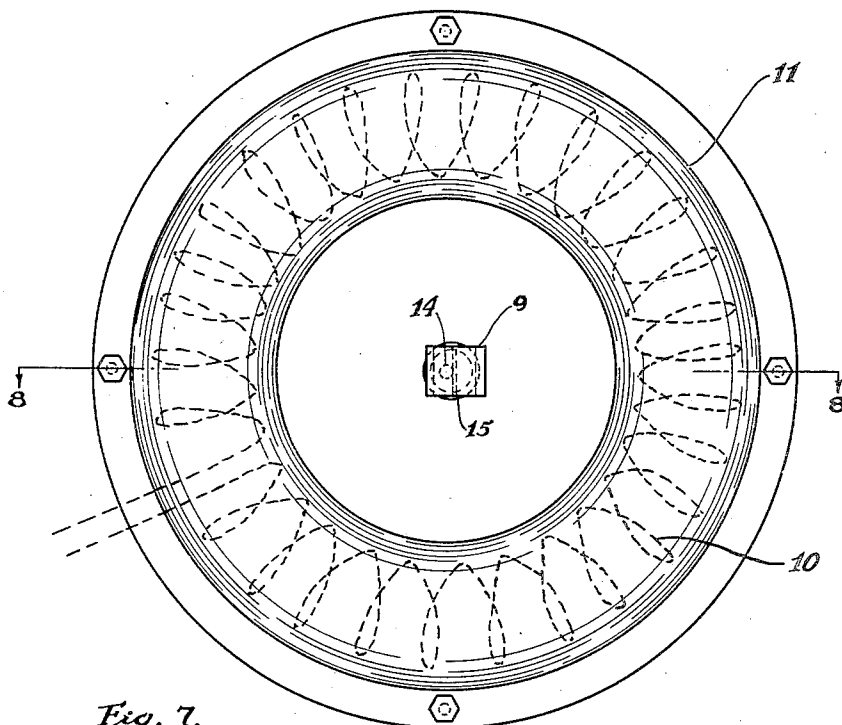


Fig. 7.

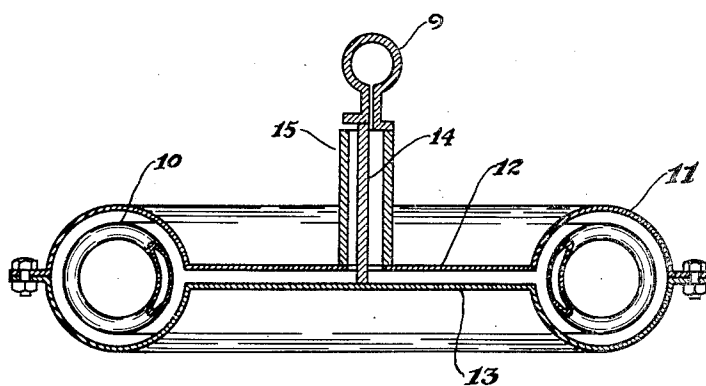


Fig. 8.

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UNITED STATES PATENT OFFICE

2,181,899

TRANSFORMER

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Application January 26, 1939, Serial No. 252,906

11 Claims. (Cl. 219-47)

This application is a continuation in part of applicant's copending application U. S. 179,219 filed December 11, 1937, (U. S. Patent 2,151,035) and deals with the construction and proportioning of transformers which are used or are useful in the inductive heating art.

5 An object of the invention is to provide a transformer or focus inductor assembly for rapid inductive heating wherein the impedance of the current collecting inductor bears an optimum relation to the impedance of the current distributing inductor of the assembly.

10 A further object is to provide a focus inductor assembly wherein the impedance of the current collecting inductor is substantially equal to the impedance of the current distributing inductor.

15 A further object, given a particular charge to be heated, is to provide a method for determining the optimum design of a focus inductor assembly for the job.

20 A further object is to provide a focus inductor assembly having a current collecting inductor of novel design and of low impedance.

25 Further purposes will appear in or be evident from the specification and the claims.

Eight figures have been used by way of illustration of the invention.

Figure 1 is a plan view of a complete focus inductor assembly in position to heat a charge.

30 Figure 2 is a sectional elevation view of the assembly of Figure 1 taken on the section 2-2 of that figure.

Figure 3 is a diagrammatic elevation view of the current collecting and distributing inductors of a hypothetical focus inductor assembly of the general type shown in Figures 1 and 2 showing proportion symbols and forming a basis for the discussion following in the specification.

35 Figure 4 is a three dimensional drawing of a pair of two current collecting inductors of a focus inductor assembly feeding a single distributing inductor according to the present invention.

Figure 5 is a diagrammatic plan view of one current collecting inductor of a focus inductor assembly.

40 Figure 6 is a diagrammatic plan view of a group of five current collecting inductors of a focus inductor assembly arranged to feed into a common distributing inductor (not shown).

50 Figure 7 is a plan view of a focus inductor of highly specialized design according to the present invention. The primary winding is shown diagrammatically.

55 Figure 8 is a sectional elevation view of the

assembly of Figure 7 taken on the section 8-8 of that figure.

In the parent application of which this application is a continuation the advisability of having a definite relation between the current 5 collecting and current distributing inductors of a focus inductor assembly was pointed out, and one method of constructing a focus inductor with that end in view was described. In this application the general background is repeated from the 10 earlier application and the proportioning of inductors as a whole is more thoroughly entered into. Other types of inductor assemblies according to the present invention are described.

15 The focus inductor as described in Northrup U. S. Patent 1,378,187, and elsewhere, is well known. It comprises a transformer and distributing inductor for concentrating a large block of power into a comparatively small charge piece. The primary of the transformer, like most heating 20 inductors, usually comprises a single layer helical coil of hollow copper tubing arranged for water cooling. The turns usually are edge wound to get a large number of turns into a small space. The secondary usually comprises a single electrical turn closely coupled with the primary and 25 lying either inside or just outside of same. If the secondary is of broad width it usually is subdivided with circumferentially directed openings to cut down eddy current losses. The distributing inductor, like the secondary, is usually of one 30 turn, but may be of several turns. Ordinarily it comprises a single loop, usually a hollow casting of rugged construction and small size, adapted in form to lie closely within or around the charge 35 to be heated. It is connected in series with the secondary and usually is adapted to carry an extremely heavy high frequency alternating current. Because of the high frequency of the current used in a focus inductor assembly an iron 40 core usually is not used. It may be used either in the main transformer or in the distributing inductor, or in both if desired.

45 The value of a focus inductor heating assembly lies in its ability to perform intricate, fast or unusual heating, although its efficiency is relatively low with respect to other methods of heating. Assuming that the best efficiency in ordinary induction heating is from 50 to 70 per cent, the focus inductor efficiency is of the order of 50 15 to 30 per cent, and since many applications to which the focus inductor may be applied are not of the type offering good electrical coupling, efficiencies have been known to be as low as 5 55 per cent. While efficiency is of general, it is not

of essential importance; and even in cases where the efficiency is as low as 5 per cent the use of a focus inductor is sometimes considered commercially sound. This is true because many of the applications to which the focus inductor is applied can be handled in no other way. The present invention describes a method of improving the efficiency of certain types of focus inductor equipment.

Applicant has found that as the coupling between the distributing inductor and the charge piece becomes poor, due to the small size of the charge piece or to its irregularity or physical make-up, the efficiency of the system falls off. This he attributed to the fact that with a focus inductor assembly of the usual construction the distributing inductor, instead of transmitting power to the load, forms substantially a short circuit on the secondary winding of the transformer; and because of the poor coupling between the primary and secondary windings, causes the voltage of the secondary to fall off. Applicant devised his present construction to gain a better voltage ratio under load conditions between primary and secondary.

Applicant has found that the impedance of the distributing inductor, including the load, should be substantially equal to the impedance of the current collecting inductor of the assembly for the best results, and he has effectively checked his conclusions with a number of experiments involving commercial size equipment. In actual practice, for inductive heating purposes, the impedance of the circuit is not radically different from the reactances of the inductor parts as determined by their physical dimensions and hence in his work applicant has used the latter.

Focus inductors have been made for a long time and of recent years the use of such inductors has become extremely widespread, but heretofore little or no consideration has been given to proportioning them as described by applicant. Of all designs checked, which included finished blocks made by applicant as well as a large number of drawings of assemblies made by other parties, not one design came within less than 37 per cent of the figure calculated as best by applicant. Designs of focus inductors which have gone into wide commercial use have been proportioned by applicant's employers and by several other parties with variations from the normal being as much as 11 times the optimum calculated value. In no case could a design be located where the impedance of the current distributing inductor was high enough or the current collecting inductor low enough to make the two anywhere near equal in value. While applicant intended to claim as his invention only the construction of new or unusual types of assemblies wherein the aforementioned proportioning might exist he believes that he is entitled to protection on all focus inductor assemblies designed in such manner that the impedances of collector and distributor inductors are substantially equal.

In designing focus inductor assemblies applicant has resorted to a rather simple set of formulas and empirical rules. From the job to be heated he determines the distributing inductor dimensions necessary for the job. Given these he has the figures for the diameter d and length l of that inductor. Dividing the diameter by the length he obtains a figure which he applies to a chart giving a shape factor S in terms of d/l . With the shape factor known he then calculates

the inductance of the distributing inductor by the formula

$$Id = dn^2 S 10^{-9}$$

where Id is the inductance of the distributing inductor in henrys; d is its inside diameter, in inches; n is the number of coil turns, usually unity, and S is the shape factor aforementioned.

With the inductance of the distributing inductor known he then assumes a collecting inductor diameter D and computes the S value from the above formula. From the chart he obtains a D/L value, and knowing D , solves for L . If he has assumed too large or too small a value for D he repeats the calculation with a greater or lesser value and arrives at a current collecting inductor dimension of suitable proportion for the particular job.

If a current collecting inductor of satisfactory dimensions cannot be arrived at by the foregoing method, as is usually the case where the load to be heated is of small size, then other means must be employed to design an appropriate collecting inductor.

If the current collecting inductor is to be of the divided turn type described in the parent application its inductance may be calculated by the same formula but n instead of being unity as for a single turn will become unity divided by the number of sections into which the turn is divided and the inductance will decrease inversely as the square of the number of such divisions. Assuming then the number of divisions and the diameter, an appropriate design usually can be reached.

If it is not desired to use a divided turn inductor then the current collecting inductor may be adapted as hereinafter described. The collecting inductor may be made of a plurality of complete single turn inductors each surrounding or surrounded by an integral portion of the primary winding of the assembly and each feeding into a common set of buses to the distributing inductor. The inductance of each section would be calculated by the formula as before, but the total inductance of the group would be but unity divided by the number of such sections times the inductance of any one section. The inductance of the current collecting inductor as a whole would therefore be less and a suitably proportioned assembly could be found as before.

The particular advantage of the construction just described is that it enables one to design an inductor assembly for concentrating a great deal of energy into a small space without going to an exceptionally long or to an exceptionally large diameter primary winding; also that the individual coil sections may be kept within reasonable and symmetrical dimensions without entailing the unbalancing of the system and resultant large eddy current losses which are involved when leads must be brought from the ends and middle portions of a long current collecting inductor to a relatively small distributing inductor.

Referring to Figures 1 and 2 a primary inductor is shown spaced within the current collecting inductor 2 of a focus inductor assembly. When the primary coil is energized by a suitable source of alternating current a corresponding current is picked up by the inductor 2 and is conducted through leads 3 to the distributing inductor 4. This distributing inductor in turn induces current into the charge piece 5 as shown by the shaded area 6. The construction shown in Figures 1 and 2 is that ordinarily used and heretofore

fore described for rapid induction heating operations. The d and l symbols denote the diameter and length respectively of the distributing inductor and D and L represent the corresponding dimensions of the collecting inductor. While both collecting and distributing inductors are of one electrical turn the larger or collecting inductor is divided to cut down eddy current losses.

By the nature of the work which these inductors are called upon to do it will be evident that the distributing inductor must conform to close dimensions and there is little that can be done to vary its length and diameter. There are no such limitations however for the primary and current collecting inductor and consequently a wide variety of designs may be selected from. In general a coil of proportions somewhat as shown in Figure 2 is desired.

If, on calculation, the situation illustrated in Figure 3 results it may be advisable to go to a special design. In Figure 3 it may be assumed that the d' and l' values of the distributor have been set by the required job and that to make the impedances of the collecting and distributor inductors substantially equal a coil of length L' and diameter D' will be required. Such a length L' may be objectionable for mechanical reasons or it may be objectionable because the system is thrown out of balance electrically by the considerably longer current paths to the distributing inductor from the ends than from the middle of the collecting inductor.

To offset the trouble illustrated in Figure 3 a construction as illustrated in Figure 4 may be used. In Figure 4 the primary inductor is not shown but it would be made up of coils such as 1 in Figures 1 and 2 which would be placed within each of the collector inductor sections 7. These coils probably would be connected in series although they might be connected in parallel. The collector inductors are symmetrical in design and each feeds into a pair of connecting buses 8. These connecting buses are connected to the distributing inductor 9.

It will be obvious from an inspection of Figures 4, 5 and 6 that an assembly may be made having but one section as shown in Figure 5, five sections as shown in Figure 6 or any reasonable number of sections depending upon the impedance required in a particular case; also that by the construction illustrated the sections as a whole form a symmetrical mechanical and electrical construction.

Still another form of construction useful for obtaining a low impedance secondary or current collecting member is shown in Figures 7 and 8. In this construction the primary winding 10 takes the form of toroidal ring or substantially closed magnetic circuit and may or may not be wound on an iron core. The secondary member 11 completely surrounds the primary and the two together form a completely symmetrical construction insuring an extremely low impedance and a minimum of eddy current loss. The current collecting winding is connected to the distributing inductor through the discs 12 and 13 and the connecting pieces 14 and 15. While the current collecting inductor is shown outside of the primary winding it need not be so placed, and with a more involved mechanical assembly it can be placed within the ring formed by the primary. Obviously to avoid structural difficulties the parts may be made with wide variation from that shown.

Applicant believes that he is the first to make

focus inductor or transformer assemblies as and for the purposes described and he requests that United States Letters Patent be granted to him for all that is claimed.

What is claimed is:

1. A focus inductor assembly comprising a primary winding a secondary winding coaxially coupled with same and a distributing inductor connected in series with said secondary winding the impedances of said secondary and distributing members being substantially equal.

2. A focus inductor assembly comprising a primary winding a secondary winding coaxially coupled with same and a distributing inductor connected in series with said secondary winding the inductances of said secondary and distributing members as calculated from their physical dimensions being substantially equal.

3. A focus inductor assembly comprising a plurality of spaced primary windings a plurality of secondary windings each coaxially coupled with a primary winding, said secondary windings being connected in parallel with each other and in series with a distributing inductor, the impedance of said secondary windings as a group and of the distributing inductor being substantially equal.

4. A focus inductor assembly comprising a plurality of spaced non-coaxial primary windings a plurality of secondary windings each coaxially coupled with a primary winding, said secondary windings being connected in parallel with each other and in series with a distributing inductor, the impedance of said secondary windings as a group and of the distributing inductor being substantially equal.

5. A focus inductor assembly comprising a plurality of spaced non-coaxial primary windings, a plurality of secondary windings each symmetrical in form and coaxially coupled with a primary winding, said secondary windings being connected in parallel with each other and in series with a distributing inductor, the impedance of said secondary members as a group and of the distributing inductor being substantially equal.

6. A focus inductor assembly comprising a plurality of spaced non-coaxial current collecting members and a current distributing inductor, each current collecting member being closely coupled with a section of primary winding but spaced from the others, connections placing the current collecting members in parallel with each other and in series with the distributing inductor, the impedance of the collecting and distributing members being substantially equal.

7. A focus inductor assembly comprising a plurality of spaced non-coaxial current collecting members and a current distributing inductor, each current collecting member being closely coupled with a section of an air core primary winding but spaced from the others, connections placing the current collecting members in parallel with each other and in series with the distributing inductor, the impedance of the collecting and distributing members being substantially equal.

8. A focus inductor assembly comprising a primary winding of substantial toroid form the turns of said primary lying in planes passing generally through the axis of said toroid, a secondary member of one turn substantially surrounding the primary, itself of substantial toroid form but having an annular opening around the inside portion of the ring, discs electrically connecting the parts of the secondary turn immediately adjacent said annular opening and a dis-

tributing inductor connected across said discs.

5 9. A focus inductor assembly comprising a primary winding having a closed electromagnetic path a secondary current collecting member in
10 good electrical coupling with said primary comprising one electrical turn and substantially surrounding the whole electromagnetic path of said primary winding, and to an opening extending all the way around said member on its inside periphery breaking the electrical circuit of said
15 secondary, a pair of substantially parallel plates connecting the respective ends of the secondary turn and a distributing inductor connected across said plates.

10. A focus inductor assembly comprising primary and secondary windings and a distributing inductor the primary and secondary windings being shaped substantially as toroids with one

substantially enclosing the other, the secondary member being of one physical and electrical turn the ends of which are connected to the terminals of the distributing inductor through discs and leads connected to said discs.

11. A focus inductor assembly comprising primary and secondary windings and a distributing inductor the primary and secondary windings being shaped substantially as toroids with one substantially enclosing the other, the secondary member being of one physical and electrical turn the ends of which are connected to the terminals of the distributing inductor through discs and leads connected to said discs the impedances of said secondary and distributing members being
15 substantially equal.

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