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HIGH-FREQUENCY TRANSFORMER CONSTRUCTION

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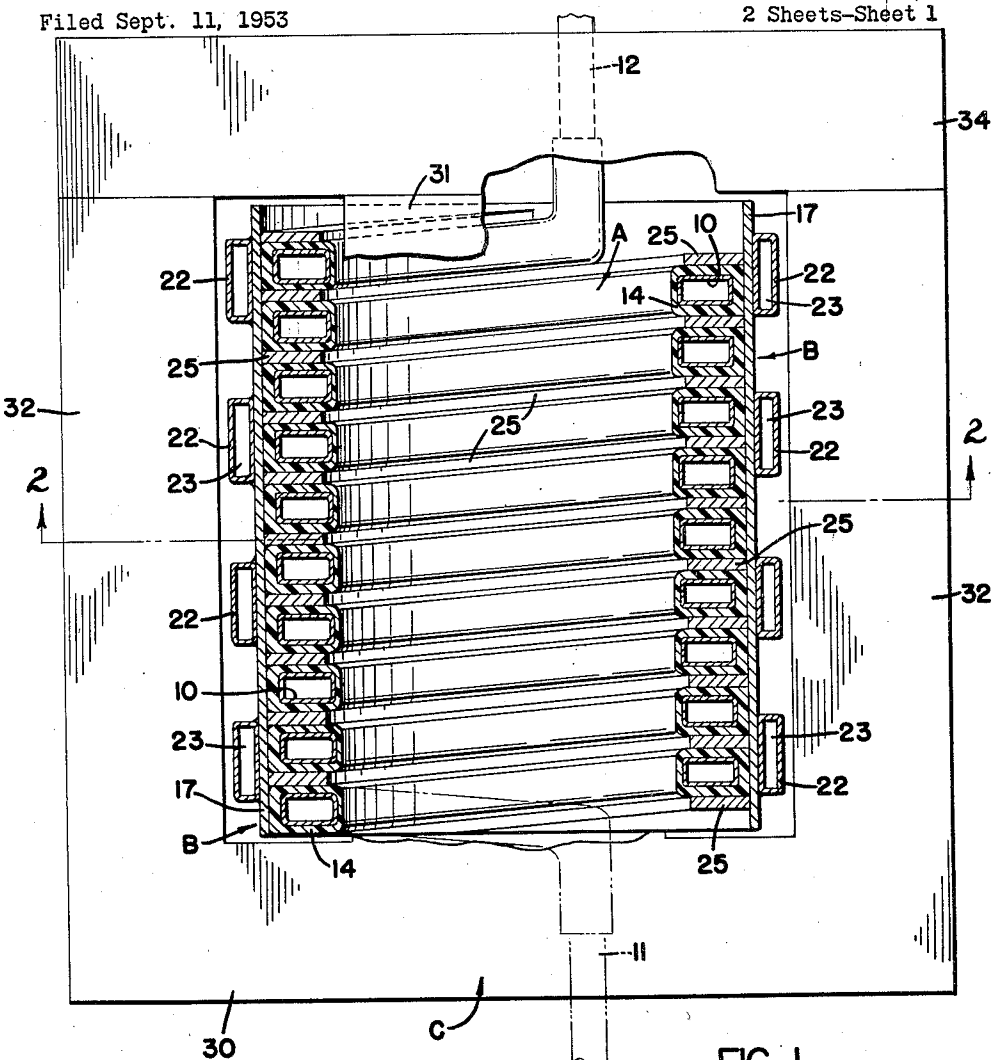

FIG. 1

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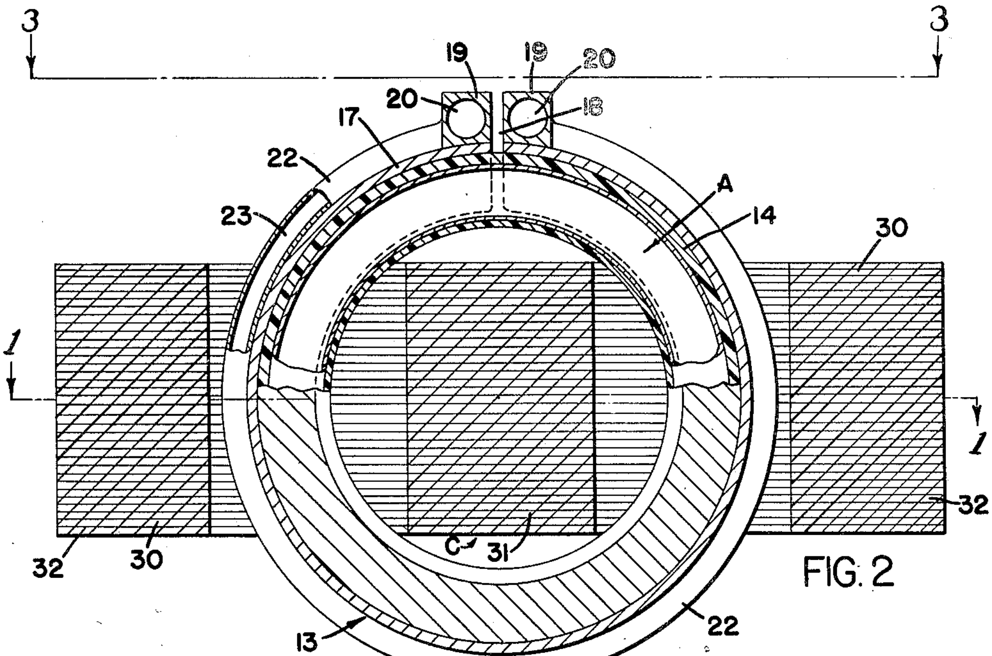
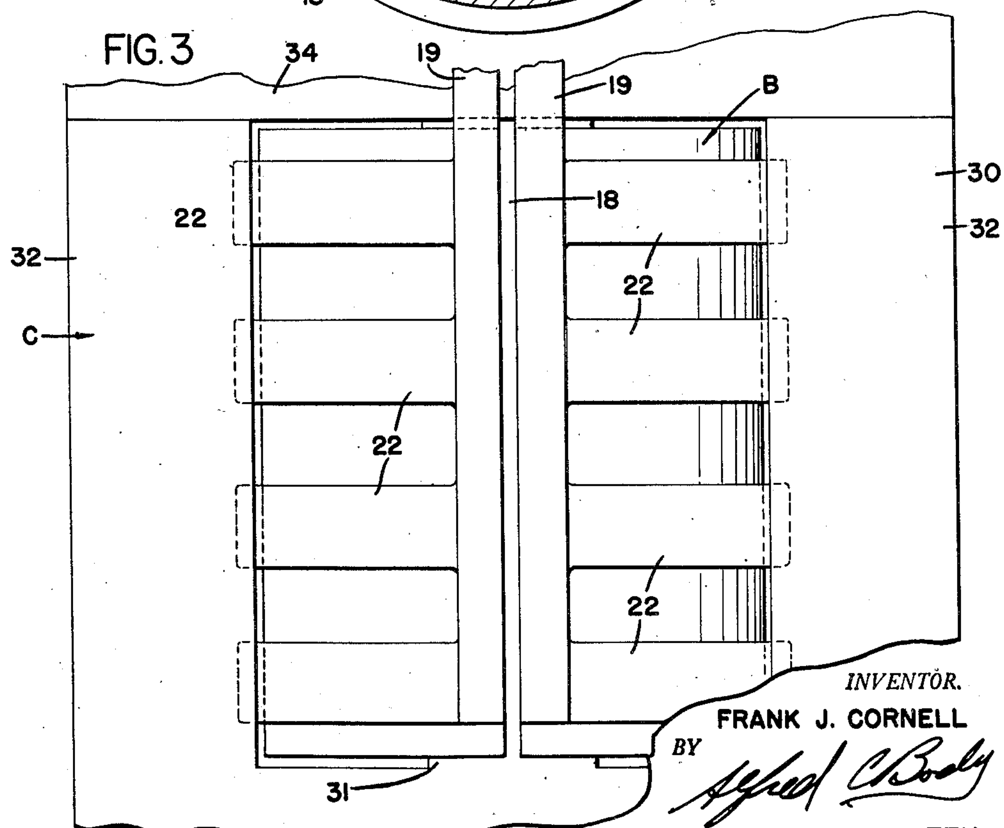


FIG. 2

FIG. 3



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HIGH-FREQUENCY TRANSFORMER CONSTRUCTION

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4 Claims. (Cl. 336—220)

This invention pertains to the art of electrical transformers and, more particularly, to a high-frequency, high-power electrical transformer.

The invention is particularly applicable to transformers of the step-down type employing a multiturn primary and a single-turn secondary such as are employed in impedance-matching, high-frequency, induction-heating apparatus wherein frequencies on the order of 1,000 to 20,000 cycles per second are employed and will be described with particular reference thereto, although it will be appreciated that the invention has broader applications.

In the art to which this invention particularly pertains, it is conventional to use a multiturn primary coil and a one-turn secondary coil in inductive relationship therewith. The primary coil is ordinarily made up of rectangular, hollow, water-cooled copper tubing. The secondary coil heretofore has taken one of two forms. For example, the secondary coil has been in the form of a sheath or sleeve of copper surrounding the primary coil and coextensive with the length thereof. This sheath or sleeve is split over its length and terminal blocks are fastened to the sheath on each side of the split so that electrical connections can be made to the secondary of the transformer. The other form of secondary coil has been in the form of individual single turns of rectangular, hollow, water-cooled copper tubing interleaved between the turns of the primary which are thus spaced from each other. The ends of the secondary single turns extend outwardly and are all connected to spaced terminal blocks so that these single individual turns are in electrical parallel relationship. This second form of transformer has somewhat greater electrical efficiency; that is, lower copper loss and less leakage reactance, than does the first form of secondary referred to. However, the cost of manufacturing the latter form of transformer is much greater than the sheath form of secondary.

It is known that high-frequency electrical currents flow only in the outer skin or on the surface of electrical conductors, this effect becoming more pronounced as the frequency increases. Thus, no matter what the cross-sectional area of the electrical conductor, only a relatively small percentage of the cross-sectional area is employed for the transmission or the carrying of the electric currents. Inefficient use of the copper results.

As the depth of penetration; i. e., the efficiency of use of a given conductor, is primarily dependent upon the frequency and not upon the amount of current being conducted, this efficiency figure is not generally employed and, in fact, copper tubing is often employed to save using undue amounts of copper. If the currents are distributed uniformly around the entire periphery of the conductor, then it is normally considered that the conductor is being used to 100 percent efficiency. However, it is also known that when one electrical conductor carrying high-frequency currents is placed in inducing relationship to another electrical conductor, the currents crowd to the adjacent side of the two conductors

to the exclusion of the other side of the conductors. Thus, it is possible to have an efficiency of use of the periphery of a conductor on the order of 15 percent or less, the exact percentage depending upon the areas in inducing relationship and their proximity.

In the sheath-type transformer, the electric currents, in accordance with these above principles, flow only on the inner side of the sheath and the outer edges of the primary turns. Unless the primary turns have a substantial axial width, a relatively large portion of the periphery of the conductor is wasted. Employing a primary conductor of such a width, however, makes for an unusually long transformer which is undesirable. At best, assuming a primary conductor of infinite axial width and zero radial width, a maximum efficiency of use of the copper of 50 percent can be obtained. Practical values of efficiency of use of 33 percent can be obtained using a conductor having an axial length two times the radial thickness of the conductor. In either event, approximately 50 percent of the sheath will be employed to carry the current.

In the interleaved secondary type of transformer, the efficiency of use of the primary and secondary copper is somewhat better, approaching a theoretical 100 percent for conductors of infinite radial width and zero axial lengths. Practical values using conductors of 2 times the radial thickness over the axial width of 66 percent for both the primary and secondary can be obtained.

These improvements of efficiency as pointed out above can only be obtained at a higher manufacturing cost and a bulkier transformer.

The present invention contemplates an electrical transformer of the type referred to which approaches the sheath form in simplicity and cost of construction but has improved efficiencies and lower copper losses than the interleaved form of transformer.

In accordance with the invention, there is provided a transformer having a pair of windings relatively insulated from each other and in inductive relationship. One of these windings which, for convenience, will be called a primary winding as in the case of a step-down transformer, although it could be a secondary if the transformer were to be used for voltage step-up purposes, is comprised of a multiturn winding of an electrical conductor having axially spaced turns. The other winding which, for convenience, will be referred to as a secondary winding is comprised of an electrical conductor surrounding the outer periphery of the primary conductor and extending at least partway into the space between the primary turns.

The cross-sectional shape of the secondary conductor generally conforms to the cross-sectional shape of the primary conductor so that except for electrical insulation, the surfaces of the two conductors may be in close-spaced proximity to each other.

Thus, in general, it may be said that the invention contemplates a secondary construction and arrangement with the primary such that a maximum efficiency of use of the electrical conductors can be obtained.

In preferred embodiments of the invention, the secondary conductor is in the form of a sheath as heretofore known in the art which fits closely around the outer surface of the primary winding and is coextensive therewith. This sheath has ribs of electrically conductive material on the inner surface corresponding to the pitch of the primary turns, which ribs fit in between the spaces of the primary turns generally for the entire radial width thereof. Preferably, the primary conductor is rectangular in cross-sectional shape having the maximum dimension on a radius so that the ribs may be flat in cross section. The transformer may have a minimum length. Thus, the secondary conductor surrounds and is in close-spaced proximity to the outer periphery of the primary conductor and two sides of each primary turn.

Efficiencies of use of 83 percent of the periphery of the primary conductor, assuming the same two-to-one dimension ratio referred to above, can be obtained. The same efficiency of use may be obtained for the secondary construction.

The principal object of the invention is the provision of a new and improved transformer construction particularly intended for the transforming of high-frequency electrical energy which has increased efficiencies and decreased leakage reactances for a given weight and volume of copper.

Another object of the invention is the provision of a new and improved transformer of the type referred to having the secondary and primary so relatively arranged that the high-frequency currents will be distributed over a maximum surface area of the individual winding.

Still another object of the invention is the provision of a new and improved high-frequency transformer having a multiturn winding made up of spaced turns and a second winding surrounding at least the outer periphery of the first winding and extending at least partway into the space between the turns of the first winding.

Yet another object of the invention is the provision of a new and improved transformer comprised of a primary comprised of spaced multiturns and a sheath-type secondary coaxial with and coextensive with the primary, the sheath having portions extending inwardly between the space turns of the primary.

The invention may take physical form in certain parts and arrangements of parts, a preferred embodiment of which will be described in detail in this specification and illustrated in the accompanying drawing which is a part hereof, and wherein:

Figure 1 is a front elevational view of a high-frequency transformer with the winding in section illustrating a preferred embodiment of the invention;

Figure 2 is a cross-sectional view of Figure 1 taken approximately on the line **2—2** thereof;

Figure 3 is a front elevational view of Figure 1 showing the arrangement of the terminal blocks of a transformer.

Referring now to the drawings wherein the showings are for the purposes of illustration only and not for the purposes of limiting the invention, the figures show preferred embodiments of a transformer comprising a primary winding A, a secondary winding B and a core C, all in assembled and operative relationship.

The primary A is comprised of a continuous length of a rectangularly shaped copper tubing **10** wound into a multiturned helix with the individual turns being uniformly spaced as will appear. At the ends of the helix, the tubing **10** is bent at approximately right angles and extends in an axial direction from the winding to form the terminals **11**, **12** of the coil for the primary. Plumbing connections not shown may also be provided whereby cooling water may be circulated through the length of the tubing **10** from one end of the helix to the other.

The tubing **10** is insulated over its entire length from the terminal **11** to the terminal **12** by means of insulation **14**. This insulation **14** may be of any known type such as insulating tape wound in a continuous overlapping manner around the tube **10**, by a tube of insulating material which has been slipped over the length of the tube **10** either before or after coiling to the shape shown or by means of dipping the tube **10** in a liquid insulating material which is subsequently baked or hardened or by any combination of the above. The spacing or pitch of the individual turns of the tube **10** are such that even with the insulation **14**, there still remains a space between the individual turns.

The secondary winding B is generally a single turn and is comprised of a sleeve or tube **17** of electrically conductive material such as copper of a length generally corresponding to the axial length of the primary coil A and having a split **18** over its entire length at one point in its circumference. Terminal blocks **19** are fastened to the sheath **17**, one at each side of the split **18**, by any suitable means such as brazing. The electrical connections for the secondary B are made to these terminal blocks **19**. It will be noted that with a single-turn secondary, a stepdown ratio to one of whatever the number of turns the primary is made up of will always result.

The terminal blocks have as is conventional in transformers of this type longitudinally extending passages **20** therethrough through which cooling water may be circulated. In a like manner, the outer surface of the sheath has copper tubing **22** brazed to the outer surface and extending around the outer sides thereof from one terminal block **19** to the other. This tubing **22** has an internal passage **23** communicating at each end with the passages **20** in the terminal blocks **19**. Suitable plumbing connections to the terminal blocks **19** provide means for circulating water into the passages **20** and **23** for the purpose of cooling the entire secondary B.

Generally, it may be said that the primary winding A and secondary winding B as described to here are relatively conventional with the possible exception of the spacing between the primary turns, the purpose of which will now be described.

The inner surface of the sheath **17** has a plurality of spaced conductors in the form of fins extending radially inwardly into the space between the primary turns of the primary winding A. These fins **25** are generally rectangular in cross section and may be integral with the sheath **17** or brazed thereto as is desired. These conductors have a pitch corresponding to the pitch of the primary coil A and a width corresponding to the spacing of the primary turns, taking into account that each primary turn has a width including that of the insulation thereon. These fins **25** are each in the form of a single turn terminating adjacent the split of the sheath. They are generally solid in cross section as it has been found that they do not need artificial cooling in actual practice. Because of the current distribution therein which is relatively uniform, they do not tend to heat and any heat which is generated therein is conducted readily through the fins **25** to the sheath **17** and thus to the cooling water in the passage **23**.

It will thus be seen that a primary winding comprised of a plurality of spaced turns is provided in combination with a secondary winding having a surface coaxial with and in close space to the outer periphery of the tube **10** together with portions extending at least in part between the primary turns. In fact, in the embodiment shown, the primary turns are incased on three sides by the secondary winding. Extremely low leakage reactance results, and extreme uniformity of current distribution throughout both the primary and secondary results so that the copper losses will be a minimum.

In the embodiment of the invention shown, the primary and secondary are each constructed independently of the other. Subsequently, the primary winding is threaded into the interior of the sheath or secondary B. This is possible with the cylindrical shape shown.

It is also possible that the primary and secondary each have a different cross-sectional shape such as rectangular, oval or otherwise. In this event, however, the secondary B is preferably made in two half sections which are bolted together along one edge after the primary and secondary are finally assembled. With such a construction, it is appreciated that the fins **25** will have a gap adjacent the bolted or fastened portions of this secondary but it has been found that this is not objectionable in practice.

The transformer shown is also provided with a core C which is relatively conventional and forms no part of the present invention. Suffice it to say that the core is made up of a stack of magnetic laminations **30** of E shape with the center leg **31** extending axially through the center of the primary A and the outer two legs **32** extending in parallel relationship along each side of the sheath **17**. A keeper leg **34** is provided abutting the ends of the center leg **31** and the two end legs **32** to complete and close the magnetic circuit. Obviously, this core C will be electrically insulated from the windings A and B.

If desired, the individual laminations can vary in the widths of their legs so that the final assembled stack will conform to the inner shape of the primary A and the outer shape of the secondary B as is shown in Figure 2. If desired, however, all of the individual laminations can be of similar shape and insulating spacer members provided to accurately position the assembled primary and secondary on the core.

The tubing **10** is shown as having a radial width approximately twice the axial width. Obviously, any other shape of tubing could be employed or any other proportion of width to height. The particular cross section shown has proven to be effective in practice.

With the shape and construction of the primary and secondary shown, the currents flowing in the tubing **10** will be distributed evenly over three sides thereof which is a substantial improvement over transformers having a conventional sheath without the fins **25** or with interleaved individual secondary turns as has heretofore been the practice. Furthermore, the secondary has had a very, very substantial increase in the surface thereof which can and will carry the high-frequency electric currents induced therein. In either event, a substantial reduction in copper losses results together with decreases in the cooling problems of the transformer.

The transformer shown has employed both a water-cooled primary and water-cooled secondary. Obviously, if less powers are to be handled, this water cooling can be omitted. Also, if desired, the fins **25** can be water cooled. Further, the primary tubing **10** can be manufactured without electrical insulation and the electrical insulation mounted only on the inner surface of the sheath **17** together with the fins **25**.

It will also be appreciated that it is possible to divide the sheath **17** and terminal blocks **19** along their axial length at any number of points.

The present invention can be used either with or without the core C shown, depending upon the frequency of electrical power with which the transformer is to be employed. Also, if desired, the core C can also be artificially cooled by means of water-cooled laminations interleaved with the magnetic laminations.

The invention has been particularly described with reference to a preferred embodiment thereof. Obviously, modifications and alterations of this embodiment and radically differing in appearance therefrom will occur to others upon a reading and understanding of this specification. It is my intention to include all such modifications and alterations insofar as they come within the scope of the appended claims.

Having thus described my invention, I claim:

1. A transformer comprised of a pair of coils in mutual inductive relationship, one of said coils being comprised of a plurality of axially spaced turns of electrically conductive material, the other of said coils being comprised of a conductor peripherally and axially coextensive with the turns of said first coil and having conductive portions extending at least between the turns thereof, the portions and the turns being alternately disposed.

2. A transformer comprising a primary winding and a secondary winding, said primary winding being comprised of a plurality of axially spaced turns, said secondary winding being comprised of an electrically conductive sheath coaxial with said primary winding and having electrically conductive portions extending between the turns of said primary winding, the portions and the turns being alternately disposed.

3. A high-frequency transformer comprised of a primary winding and a secondary winding, said primary winding including a plurality of axially spaced turns, said secondary winding including an axially split sheath coaxial with said primary winding and having conductive portions extending radially between said primary turns, the portions and the turns being alternately disposed.

4. In a transformer, a first winding comprised of a single layer of axially spaced turns, a second winding comprised of an electrically conductive sheath coaxial with said primary and having conductive fins extending between the turns of said first winding the fins and the turns being alternately disposed.

References Cited in the file of this patent

UNITED STATES PATENTS

2,128,086	Gakle	Aug. 23, 1938
2,362,470	De Rosa	Nov. 14, 1944
2,535,554	Thurston	Dec. 26, 1950
2,592,817	McKechnie	Apr. 15, 1952
2,663,827	Baker	Dec. 22, 1953

FOREIGN PATENTS

171,836	Great Britain	Dec. 1, 1921