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COIL CONNECTION FOR REDUCTION OF STRAY LOSSES

Filed Dec. 18, 1963

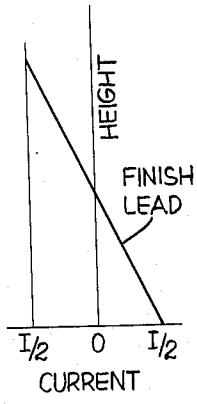


Fig. 2

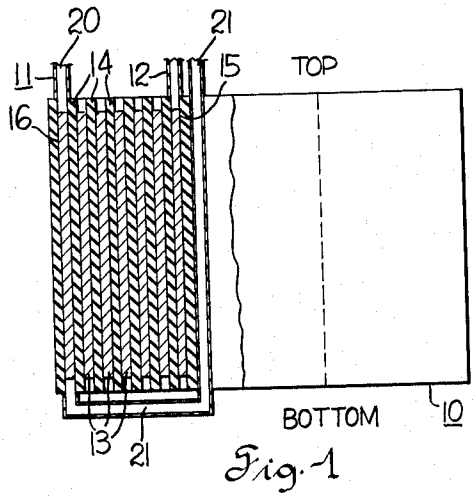


Fig. 1

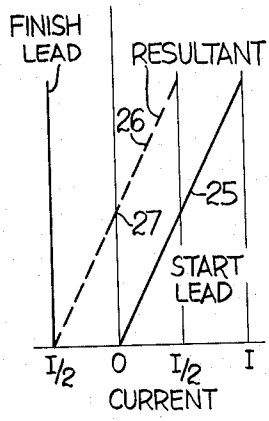


Fig. 3

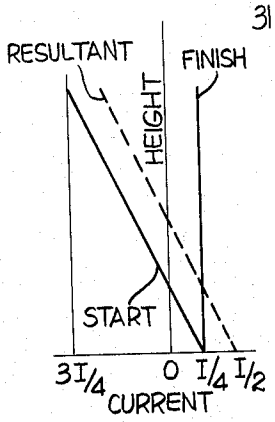


Fig. 5

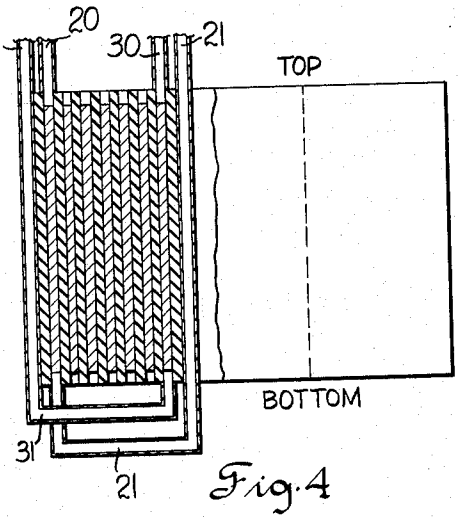


Fig. 4

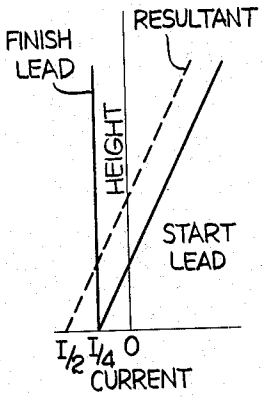


Fig. 6

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COIL CONNECTION FOR REDUCTION OF STRAY LOSSES

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This invention relates generally to inductor devices, more specifically to a transformer having its lead-in conductors arranged to reduce losses.

The stray magnetic fields associated with the conductors of a transformer cause eddy currents in nearby conductors that produce power losses and voltage drops and sometimes overheat parts of the transformer. This is particularly a problem with the lead-in conductors of a sheet wound transformer. A sheet wound transformer has its low voltage winding wound of a wide thin strip of metal sheet that forms several layers each having only a single turn. Flat strip conductors that extend axially across the width of the strip and somewhat beyond the top of the winding are attached at the start and at the finish of the coil to make connections to the external circuit. Consequently, at each end of the coil a heavy current flows in the axial direction in these flat lead-in conductors. The magnetic field associated with these lead-in conductors is perpendicular to the wide, highly conductive, sheet turns; and the lead-in conductors and their associated magnetic fields produce significant eddy current losses.

An object of this invention is to provide a lead-in conductor arrangement in which the H field of the lead-in conductors are made to cancel. It is well known to pair conductors that conduct in the opposite direction so that their H fields more or less cancel. For example, this is very commonly done with the conductors of furnace transformers. With sheet wound transformers the inductors cannot be magnetically coupled in this simple way to reduce stray loss; because each of the two end conductors extend along the entire width of the sheet. It conducts more current toward the top of the winding than toward the bottom.

The prior art has suggested several partial solutions to the problem of eddy current losses associated with the stray flux of the lead-in conductors. One known design technique is to subdivide each lead-in conductor into two parts. Because the eddy current losses are proportional to the square of the current, reducing the current by one-half in each of the two parts reduces the eddy current losses to about one-fourth the value without the division. In order to get the pairs of conductors to share the current equally it has been necessary to make the coil of two parallel sheets, one for each part of the lead-in conductor. These transformers are of course more difficult to assemble than single layer transformers and they require disproportionally more insulation and their coils have a poorer space factor. A more specific object of this invention is to provide a new and improved transformer with a lead-in conductor arrangement that reduces eddy current losses, but does not seriously complicate the coil design.

In the transformer of this invention one of the leads (preferably the finish lead) is made in two parts; one connected to the top of the coil and the other part is connected to the bottom. Each part conducts about one-half of the current of the winding. The bottom part is lead radially across the transformer coil and axially upward alongside the single lead for the opposite end of the coil. These two leads are positioned to be closely coupled magnetically so that their H fields cancel to the extent that their currents are equal. The currents are generally unequal because the current varies axially along

the length of the coil end. The current in the subdivided lead equals the current in the other lead at about the coil midpoint. Above the midpoint the undivided lead current is higher and below the subdivided lead current is higher. Thus, the effect of the two leads is to bias the undivided lead so that there is about half the H field at the top that there would otherwise be and there is a corresponding H field at the bottom that it would not otherwise have. Because the eddy current losses are proportional to the square of the current this biasing arrangement reduces the eddy current losses to about one-fourth the value without this arrangement. It also reduces the highest magnitude of the H field and thereby helps to prevent overheating some parts of the transformer.

In the preferred embodiment of the invention the two parts of the subdivided lead carry about equal current except in transformers in which one part must be made considerably longer than the other. In a second embodiment of the invention both the start lead and the finish lead are subdivided; this provides somewhat more flexible design for coils with unequal currents in the divided parts. Both the start lead and the finish lead of the winding are subdivided in this way and are located to be magnetically coupled to part of the lead of the opposite end of the coil.

The drawing and the detailed description of the invention will suggest other problems in constructing a suitable transformer and the associated features and advantages of the transformer of this invention.

FIG. 1 is a side view of one embodiment of the transformer of this invention;

FIGS. 2 and 3 are graphs showing the distribution of the H field along the axial length of the start and finish conductor of the transformer of FIG. 1;

FIG. 4 is a side view of a second embodiment of this invention; and

FIGS. 5 and 6 are graphs showing the axial distribution of the H field of the start and finish conductors of the transformer of FIG. 4.

FIG. 1 shows the sheet wound coil **10** and the associated leads **11** and **12** of a transformer. The transformer has an iron core that is not shown in the drawing because the stray flux that will be discussed in this description of the invention does not flow in the iron core. Winding **10** is a low voltage high current winding made up of a strip of sheet **13** and strips of insulating paper **14** that are wound together. The transformer also has a high voltage low current winding (not shown) that may be wound of wire or of sheet. The uppermost part of the coil in the drawing will be called the top and the lowermost part will be called the bottom. The radially innermost end **15** of the sheet winding will be called the start and the radially outermost end **16** will be called the finished. From a general viewpoint of the invention this terminology is arbitrary, but it aptly describes most transformers.

Finishing lead **11** and a start lead **12** are connected to the ends **15, 16** of the coil and are connected to transformer bushings that are not shown in the drawing. Leads **11, 12** may be thin strips of aluminum that are somewhat heavier than the sheet and are attached (preferably by inert arc welding) to the ends **15, 16** of the strip. Preferably, they extend along the entire width of the ends of the sheet. The start lead **12** (preferably) comprises a single conductor extending along the start end **15** and upward from the top of the coil. The finish lead **11** comprises a first part **20** similar to the start lead **12** extending from the top of the coil and a second part **21** extending from the bottom of the coil **10** radially across to about the position of start lead **12** and axially upward alongside the start lead. The start lead **12** and

part 21 of finish leads 11 are suitably insulated from each other, for example, by several layers of insulating paper 14 wound around the coil between the leads 12 and 21 and outside the finish lead 21.

FIGS. 2 and 3 illustrate the stray flux distribution of the transformer coil of FIG. 1. Except for the ampere turns provided by the finish lead part 21, the H field distribution in the region of start lead 12 would be highest at the upper end of the coil where all the current flows in the start lead 12 and would be progressively less lower in the coil as current leaves the lead and flows in the coil 10. In FIG. 3 this distribution is represented by a diagonal line 25. Except for the effect of the finish lead, part 21, the diagonal line 25 would intersect the zero current axis at the zero or lowermost coil position line. The current distribution in the finish lead part 21 is axially uniform and the effect of the finish lead is to offset the H distribution on the curve of FIG. 3 to the left. If (as is usually true) the finish lead part 21 conducts half of the current of the start lead 12 the resultant H distribution line 26 would intersect the horizontal axis at the midpoint 27 of the axial length of the coil. The magnetic coupling between these two leads 12, 21 tends to maintain this current distribution. In the upper region of the graph of FIG. 3, the start lead current is higher than the finish lead current and the stray flux tends to produce a voltage drop in the start lead 12 and a voltage rise in the finish lead part 21. Similarly in the lower region of the coil the field tends to produce a voltage drop in the finish lead part 21 and a voltage rise in the start lead 12. Thus, the magnetic coupling of the two conductors tends to keep the finish lead 21 current equal to one-half of the start lead 12 current. For example, if the first part 20 of finish lead 11 is assumed to conduct all of the current, the magnetic field of start lead 12 would produce a voltage rise all along the second part 21 of the finish lead 11 and thereby cause this part of the finish lead to conduct part of the current.

As FIG. 2 shows, the arrangement of FIG. 1 causes the two parts 20, 21 of finish lead 11 to conduct equally and to produce an H field distribution that is similar to the H field distribution in the region of start lead 12.

The average magnitude of the H field in the region of the start and finish conductors 11, 12 is only one-half the value of the field in a transformer without the coupling of FIG. 1. Because eddy current losses are proportional to the square of the current, the H field distribution of the conductors of FIG. 1 gives only about one-fourth the eddy current loss of a transformer with uncoupled leads.

Because of differences in the resistance and reactance of the two parts 20, 21, the current division between the parts may not be 50–50 as was assumed in the description so far. The embodiment of FIG. 4 provides the same flux distribution with a current division of 75–25. The actual current division can be calculated or determined experimentally to select the appropriate design. In the embodiment of FIG. 4 the two parts 20, 21 of finish lead 11 are arranged as in the embodiment of FIG. 2 and start lead 12 is also subdivided into two parts 30, 31. Part 30 extends upward from the top of the coil to the bushings and part 31 extends from the bottom of the start of the winding radially over to the finish lead 11 and axially upward alongside the finish lead. The H field distribution along the axis of the coil is the same in the transformer of FIG. 4 as in the transformer of FIG. 1. However, the current distribution in the conductors is different. The upper half of the leads conducts about 75% of the current and the lower half conducts about 25% of the current. The conductors may be made to have a proportional cross section. The reason for the change in current distribution can be seen by considering what happens when start lead 12 is subdivided in FIG. 1 and FIG. 2; the H distribution at the start end of the coil is shifted because of the decrease of current in lead 12 and the distribution is shifted in the finish end because of the addition of the start winding part 31 in this region. The arrangement of FIG. 4 has the advantage that with its additional paralleling the H field distribution is more closely like the ideal representation of FIGS. 3 and 6 and is less influenced by extraneous factors such as nearby magnetic material and the geometry of the conductors.

Those skilled in the art will recognize various changes to adapt the transformer specifically disclosed to a variety of applications within the spirit of the invention and the scope of the claims.

Having now particularly described and ascertained the nature of my said invention and the manner in which it is to be performed, I declare that what I claim is:

1. An inductive winding comprising,
   - a generally cylindrical coil having a plurality of turns of conductive sheet material wound to form a single electrical turn per layer and having a first end and a second end, and
   - a first lead connected to said first end and a second lead connected to said second end whereby an axially nonuniform axial current flow region is established near each said ends,
   - at least said first lead having a first part extending from the top of said coil and a second part extending from the bottom of said coil whereby the axial current flow along said first end is divided between said parts and the stray losses in the region of said first end are reduced,
   - one of said parts being positioned to extend axially along said second coil end to oppose the magnetic field associated with axial current flow along said second end to reduce the stray losses in the region of said second end.

2. An inductive winding according to claim 1 in which the turns of said coil are each formed of a single thickness of said sheet material whereby said first and second parts are conductively connected together in the region of said first end.

3. An inductive winding according to claim 1 in which said second lead is connected to conduct all of the coil current, and
   - the other of said first lead parts is positioned to have only incidental magnetic coupling with said second lead.

4. An inductive winding according to claim 3 in which the reactance and resistance of said first and second lead parts, excluding the effect of magnetic coupling between said other part and said second lead, is such that said parts would conduct approximately equal currents.

5. An inductive winding according to claim 1 in which said second lead has a first part extending from the top of said coil and a second part extending from the bottom of said coil, one of said second lead parts being positioned to extend axially along said first coil end to oppose the magnetic field associated with axial current flow along said first end.

6. An inductive winding according to claim 5 in which the resistance and reactance of said parts, excluding the magnetic coupling between said extending parts and said ends, is such that each said extending part would conduct about 25% of the coil current.

No references cited.

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