Aug. 14, 1945. H. V. PUTMAN ET AL 2,382,172

CORE STRUCTURES FOR INDUCTIVE APPARATUS

Filed Jan. 29, 1944

Fig. 1.

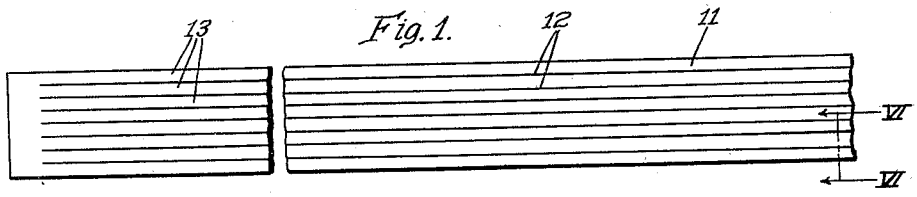


Fig. 2.

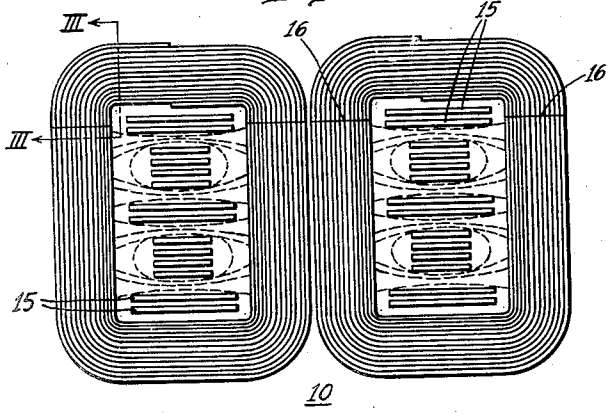


Fig. 3.

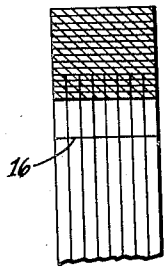


Fig. 4.

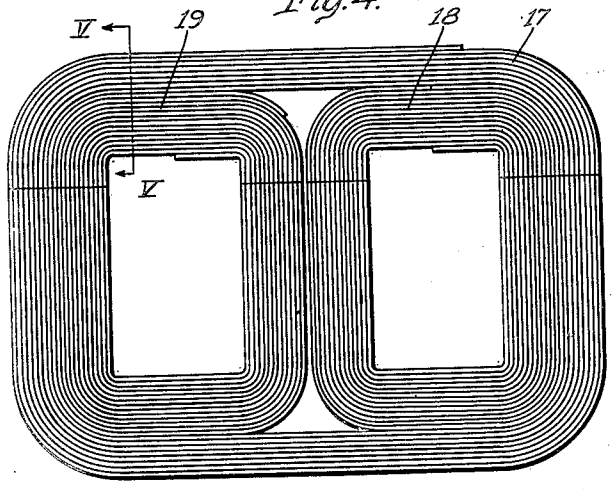
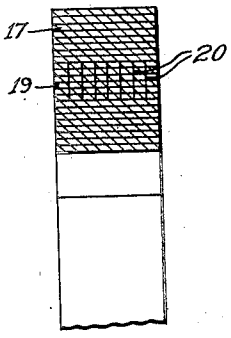


Fig. 5.



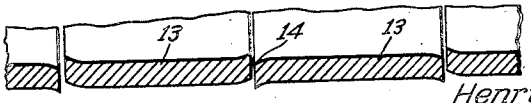


Fig. 6.

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CORE STRUCTURE FOR INDUCTIVE APPARATUS

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Application January 29, 1944, Serial No. 520,220

7 Claims. (Cl. 175—356)

The invention relates, generally, to inductive apparatus and, more particularly, to the core structure for inductive apparatus.

The object of the invention is to provide for restricting the flow of eddy currents in the cores of inductive apparatus.

A more specific object of the invention is to provide a laminated effect, transversely of the layers of a spirally wound core, to restrict the flow of eddy currents induced by stray flux.

The invention, accordingly, is disclosed in the embodiment thereof shown in the accompanying drawing; and comprises the features of construction, combination of elements, and arrangement of parts, which will be exemplified in the construction herein set forth and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description, taken in connection with the accompanying drawing, in which:

Figure 1 is a top-plan view of a portion of a silicon steel strip prepared in accordance with this invention.

Fig. 2 is a view in side elevation, showing the coils and core of a transformer constructed in accordance with this invention.

Fig. 3 is a view in section, along the line III—III of Fig. 2.

Fig. 4 is a view in side elevation of a three-phase transformer, showing the arrangement of a plurality of core sections illustrating how the teachings of the invention may be applied to cross flux conditions between adjacent cores.

Fig. 5 is a view in section, along the line V—V of Fig. 4; and

Fig. 6 is a view along line VI—VI of Fig. 1, considerably enlarged in order to show how the slitting of the main strip spaces the narrower strips.

With the advent of cold-rolled silicon steel having a preferred grain orientation into the transformer field, the practice of making transformer cores was considerably changed. Instead of building transformers from stacks of interleaved laminations, in order to take full advantage of the magnetic material having a preferred grain orientation, the practice of making the cores from strips of cold-rolled silicon steel, by winding them spirally to superimpose a plurality of turns of the strip upon one another, was adopted. Such construction is more subject to eddy currents in the inner and outer layers due to stray flux than the stacks of interleaved laminations commonly employed for cores for inductive apparatus.

When stray flux occurs in a wound transformer of this type, it enters the core from all sides. Assuming that there is a concentration of stray flux entering the core at substantially right angles to the plane of the wound strip, then an E. M. F. is induced in the strip which causes eddy currents to flow. In large transformers the concentration of stray flux is often quite great and an E. M. F. of considerable magnitude is induced in the outer layers or laminations of a wound core. This results in eddy currents which cause an appreciable rise in temperature and losses in the transformer iron which lowers its efficiency.

In Fig. 2, dotted lines have been employed to illustrate in a rather general way how the stray flux occurs in a section in the plane of the core of a shell-type transformer and how it will induce or cause eddy currents to flow through predetermined layers of the core shown at 10. Since the stray fluxes completely surround the copper coils of the transformer which are carrying current, these lines of flux enter the core from all sides. Usually the clearances between the coils and the iron of the section outside of the opening are greater than those inside the opening, as illustrated in Fig. 2, and therefore the stray fluxes are more distributed outside the opening and the eddy currents induced are smaller.

In cores built up from stacked laminations such as are generally employed, the laminated structure presents the edge of the laminations to the stray fluxes in the section shown in Fig. 2. Therefore, the effect of the stray fluxes is not so great and the eddy currents induced are smaller and consequently the losses resulting from the flow of the eddy currents do not so reduce the efficiency of the transformer.

It has been found that with wide strips in the core, the losses which result from eddy currents induced in the inner layers of the wound core are appreciable and depend on the conditions under which the transformer is operated. The losses are higher in large transformers where the concentration of leakage flux is greater.

In order to reduce losses and the heating of a transformer having a wound core due to eddy currents a laminated effect must be provided running longitudinally of the outer turns of the core. This will break up the paths along which eddy currents would flow.

Referring now to Figure 1 in particular, in

order to restrict the flow of eddy currents in the layers of the spirally wound transformer core exposed to the stray flux, the strip 11 from which the core is wound is slit longitudinally as shown at 12, cutting the main strip 11 into a plurality of narrower strips 13. In the embodiment of the invention illustrated in Fig. 1, slits are provided at one end only. Further, while the strip may be slit to the end it is preferable if the slits do not extend through the end portion, but stop within a few inches of the ends of the strip so that the end of the narrower strips 13 are held together to facilitate winding when the slit portion of the strip is to be located on the inside of the wound core 10. It is to be understood that the strip 11 may be so slit as to locate the narrower strips 13 at any predetermined place in the core. Ordinarily the slitting of the strip 11 will be at the end so that the narrower strips will be located either on the inside or the outside of the wound core, since in transformer work either the inside or the outside of the core is more subject to eddy currents induced by a stray flux. However, it is to be understood that the slits may be located in the strip 11, as desired, to meet the conditions under which the inductive apparatus is to be employed.

The number and length of the slits 12 made in a strip, preparatory to winding a core, will depend on the conditions to be met. The size of the core will, to some extent, control the width of the strip. It has been found that, in building cores for transformers to have a capacity of from ten to fifteen kilowatts, strips of magnetic material three to four inches wide are satisfactory. In larger transformers, where losses due to eddy currents are greater, wider strips are generally employed. In building up the cores of larger transformers, a number of wound cores may be placed side by side to provide the required iron. A core structure such as shown in copending application, Serial Number 520,221, filed January 29, 1944, the name of John K. Hodnette may be employed.

The production of electrical sheet steel having a preferred grain orientation brought the wound core into extensive commercial use and with it came a specific problem of determining losses due to eddy currents for design purposes. We have considered the effect of sheet width of Hipersil, an oriented electrical sheet steel on stray losses resulting from flux penetrating the sheet normal to its surface in order to determine the number of slits 12 that should be provided. In considering this problem, assume a sheet is positioned in a magnetic field of strength H and intensity B.

Consider a portion of the sheet of width w and length l.

Then the induced voltage in the section of width w as established in the art is:

$$E=\sqrt{2}\pi fBwl10^{-8}$$

This causes a current flow along the sheet which is determined by the voltage E and resistance R where

$$R=\frac{\rho l}{wt}$$

when ρ=resistivity and t=thickness of the sheet.

Then neglecting penetration effects, and demagnetization, the boundary loss condition is

$$W\ (\text{watts})=E^2/R=\frac{2\pi^2f^2B^2w^3lt10^{-16}}{\rho}$$

or for a given flux intensity the loss increases as the width of the sheet cubed.

Therefore, with this information, anyone skilled in the art can arrive at the number of slits 12 to meet predetermined loss requirements.

The slitting of the strip 11 may be performed in any suitable manner and is preferably carried out with the slitter employed for cutting the strips 11 from wider sheets. When a slitter is used it converts the strips 11 into a plurality of narrower strips which are separated from one another by more or less continuous gaps 14, best illustrated in Fig. 6. The providing of a plurality of narrower strips 13 gives a result somewhat similar to that of the old laminated interleaved cores.

It will be readily appreciated that in slitting a slightly ragged depending edge will be formed on the narrower strips. In some instances, it may be desirable to etch these ragged edges in order to prevent short-circuiting of the layers, however, such practice is generally not required. If etching is resorted to, it may be preferable to etch electrolytically, using a phosphoric acid electrolyte which will coat the burrs or depending edges with a phosphate which will effectively insulate the turns from one another. However phosphate coatings may be applied by other methods well known in the art.

Referring to Figs. 2 and 3, the spirally wound cores 10 illustrated may be bonded in the process of making them by some suitable resinous material which will stand the heating conditions to which the inductive apparatus may be exposed. In practice it has been found that good results in bonding are obtained by the use of vinyl resins. When wound cores are employed, the best method of applying the coils 15 is to cut the cores as shown at 16, thus providing upper and lower core sections. When the cores have been cut as illustrated, the upper sections may be removed and preformed coils 15 set in position and the upper sections of the cores replaced. In building inductive apparatus in this manner, some suitable type of strap will be employed to tie the core sections together. Since straps of this type are well known and do not constitute any part of the invention, they are not illustrated.

In building multiphase apparatus such, for example, as the three-phase transformer core illustrated in Fig. 4, in which the outside core section 17 contains two inner core sections 18 and 19, it has been found that eddy currents are induced in the meeting or adjacent portions of the core sections. In order to restrict the flow of eddy currents in this type of structure, the slit portion of the strip 11 employed in making the outer section 17 will be disposed in the inner turns of the core section; while in winding the core sections 18 and 19, the slit portion of the strip 11 employed in making these sections will be disposed in the outer turns of these sections. Thus, when the cores 17, 18 and 19 are fitted together, the slit portions of the core sections 17, 18 and 19 will be adjacent one another, as illustrated at 20 in Fig. 5. Tests have been made on this type of structure and it was found that losses have been reduced as much as 30%.

It will be readily appreciated that, in manufacturing wound cores for multiphase apparatus, the slit portions of the strip employed for winding the cores can be so located in the strip as to dispose the narrower strips, as desired, in the core section. The designer of the cores can readily predetermine where he desires to have the slit portions of the strip located.

Since certain changes may be made in the here-

inbefore described structure and different embodiments of the invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description, or shown in the accompanying drawing, shall be interpreted as illustrative and not in a limiting sense.

We claim as our invention:

1. A core for inductive apparatus comprising, in combination, a strip of silicon steel having preferred grain orientation, a portion of the strip being slit to provide a plurality of spaced narrower strips, the strip being wound into a core having a number of turns slit and a number of turns unslit, the unslit turns serving to carry the slit turns, the slits in the strip being made at a predetermined position in the strip to locate the slit turns to meet predetermined operating conditions and to restrict the flow of eddy currents transversely of the strip, the unslit turns being located in the core where it is sufficient to restrict the flow of eddy currents from turn to turn.

2. In inductive apparatus, in combination, a strip of silicon steel having preferred grain orientation, a portion of the strip or silicon steel being slit to provide a plurality of spaced narrower strips, the slits separating the narrower strips constituting in effect gaps, the strips being wound into a core having a plurality of turns slit and a plurality of turns unslit, the strip being so wound that the turns of the slit strip are disposed in a predetermined position in the core to cooperate in restricting the flow of eddy currents induced by stray flux.

3. In a transformer, in combination, a core structure wound from a silicon steel strip having preferred grain orientation, the portion of the strip forming the inner turns of the core being slit longitudinally providing a plurality of narrower spaced strips, the gaps between the narrower strips produced by the slitting of the strip cooperating to restrict the flow of eddy currents, the turns of the core which are slit being carried by a plurality of turns of the strip which are unslit.

4. In a transformer core structure, in combination, a strip of silicon steel having preferred grain orientation wound into a core of predetermined shape, the end portion of the strip on which the core is started being provided with a plurality of slits separating the main strip into a plurality of narrower strips, the narrower strips being carried by a plurality of turns of the strip which are unslit, the inner portion of the core thereby comprising a plurality of narrower strips in spaced relation, the number of turns of narrower strips provided by slitting the main strip being predetermined by the depth of the core necessary to cooperate in restricting the flow of eddy currents that may result from stray flux.

5. In a transformer, in combination, a strip of silicon steel or preferred grain orientation, the strip of silicon steel being slit to provide a plurality of spaced narrower strips with a gap between each two narrower strips, a core made by winding the silicon steel strip to provide a predetermined number of superimposed turns of slit strip and a predetermined number of turns of unslit strip, the strip being so wound and slit as to locate a predetermined number of turns of the narrower strips in a predetermined location in the core to cooperate in restricting the flow of eddy currents induced by stray flux.

6. In a transformer, in combination, a plurality of core sections, each core section consisting of a plurality of turns of a silicon steel strip having a preferred grain orientation, the strip from which any core section is made being of a length adequate to provide a predetermined number of superimposed turns and having a portion slit to provide a plurality of spaced narrower strips carried by a plurality of turns of unslit strip, whereby the core section made from a strip having a slit portion will include a number of turns of the narrower strip disposed in a predetermined location in the core to cooperate in restricting the flow of eddy currents induced by the stray flux.

7. In a multiphase transformer, in combination, a plurality of wound core sections, the core sections being wound to a predetermined shape and size to fit together in cooperative relationship in a transformer assembly, each core section comprising a strip of silicon steel having a preferred grain orientation wound upon itself to provide a predetermined number of superimposed turns, a portion of the silicon steel strip utilized for making a core section being slit to provide a plurality of narrower strips, the strip being so wound as to locate the narrower strips in a predetermined position in the core section, the turns of the narrower strips being carried by a plurality of turns of unslit strip, the turns of slit strip of one core section thereby being disposed to cooperate with the slit turns of another core section to restrict the flow of eddy currents induced by stray flux.

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