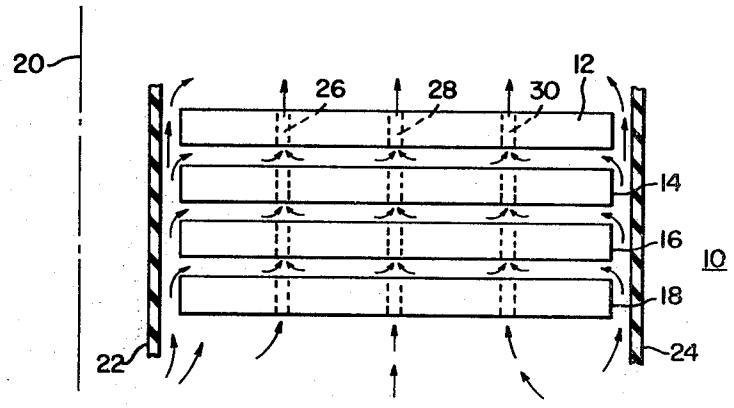
Dec. 15, 1970 R. L. SCHWAB 3,548,354

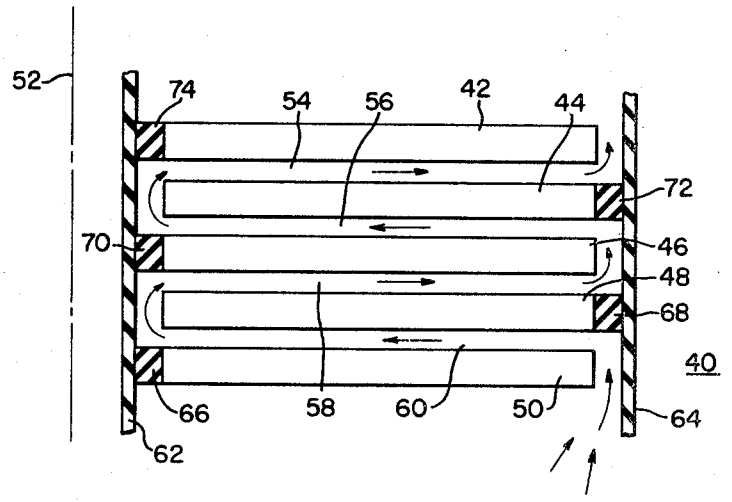
TRANSFORMER HAVING VENTILATING PASSAGES

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PRIOR ART

FIG. 1.



PRIOR ART

FIG. 1A.

WITNESSES

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TRANSFORMER HAVING VENTILATING PASSAGES

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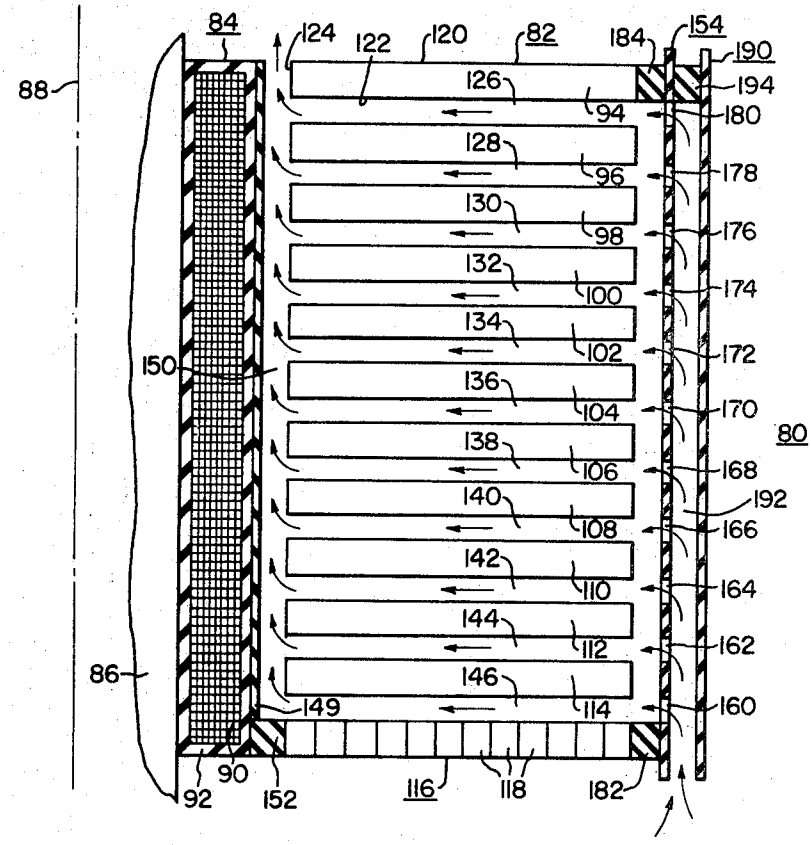


FIG.2.

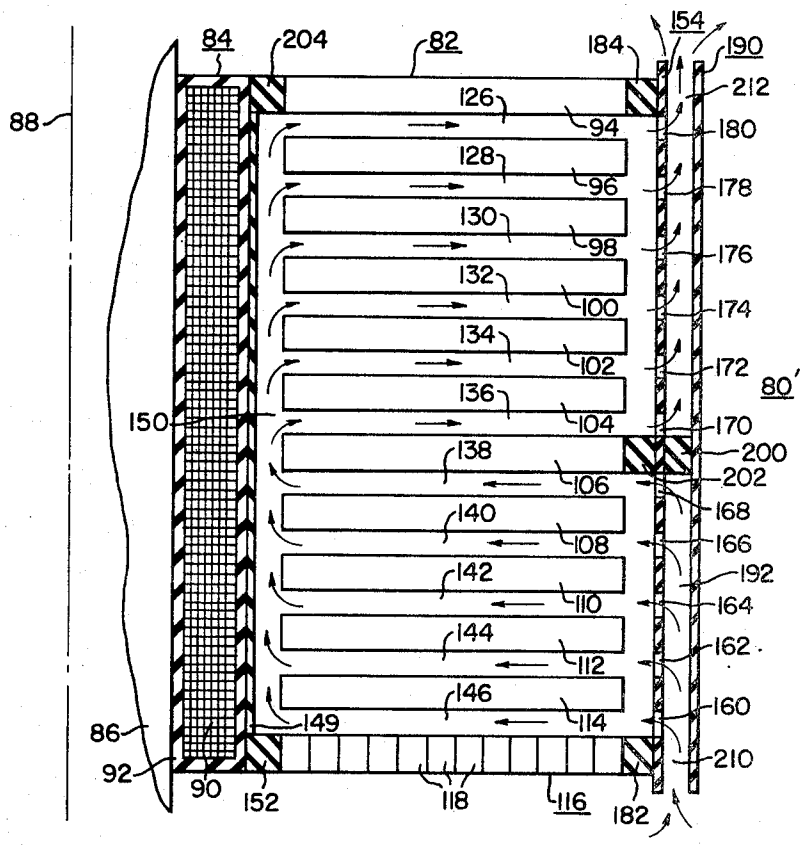


FIG.3.

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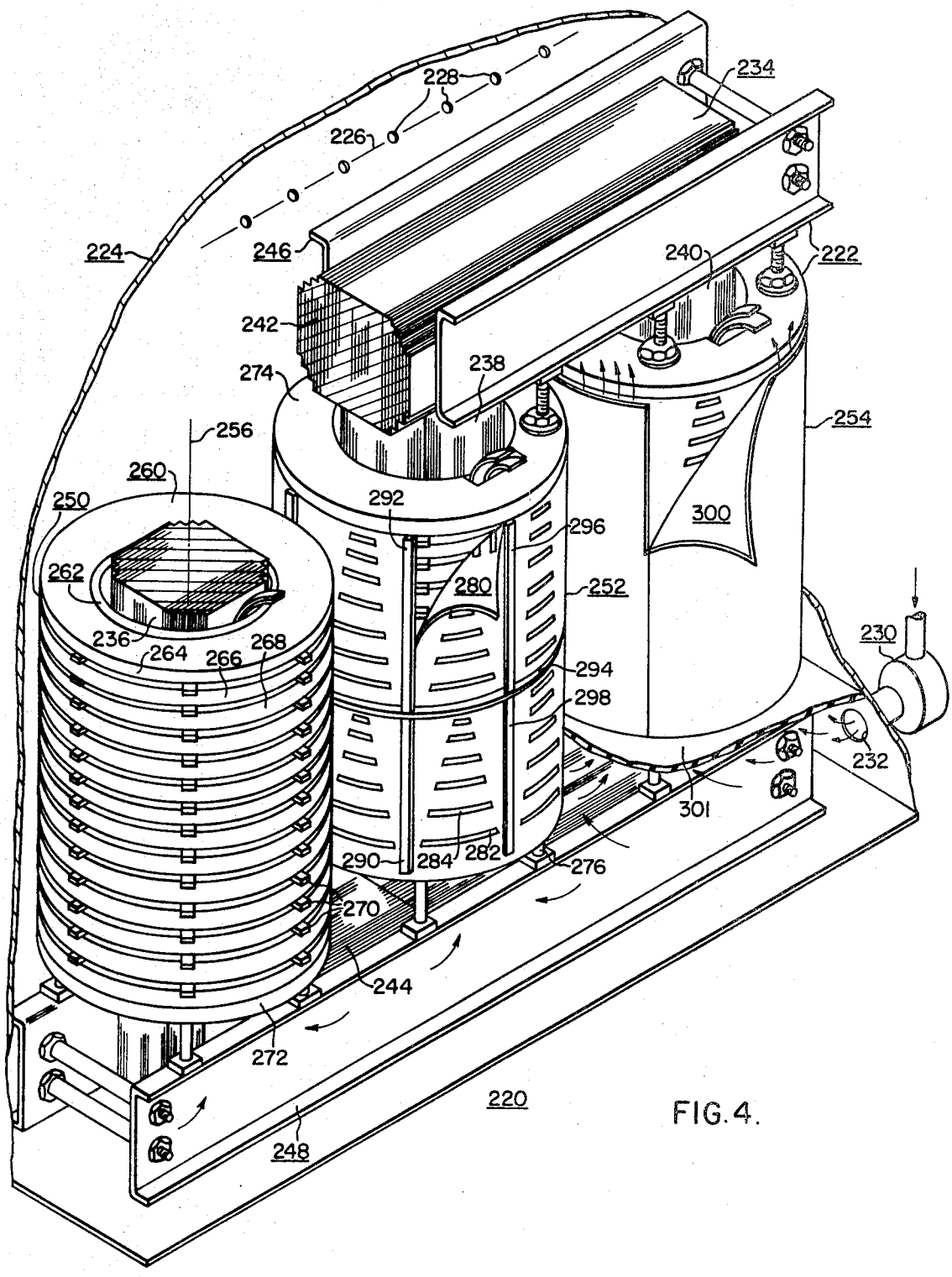


FIG. 4.

United States Patent Office 3,548,354
Patented Dec. 15, 1970

3,548,354

TRANSFORMER HAVING VENTILATING PASSAGES

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Filed June 24, 1969, Ser. No. 836,065
Int. Cl. H01f 27/10
U.S. Cl. 336—57 9 Claims

ABSTRACT OF THE DISCLOSURE

An electrical transformer of the fluid cooled type, having a winding which includes a plurality of pancake coils disposed about a vertically oriented winding leg of a magnetic core, with the pancake coils being spaced to provide horizontal coil ducts, and with a vertical duct located adjacent the openings in the pancake coils, which communicates with the coil ducts. A manifold is provided about the outer edges of the pancake coils, which is formed of inner and outer spaced tubular insulating members. The inner tubular insulating member has a plurality of openings disposed therein which are aligned with the coil ducts.

BACKGROUND OF THE INVENTION

(1) Field of the invention

The invention relates in general to electrical transformers, and more specifically to electrical power transformers of the concentric coil, core-form type.

(2) Description of the prior art

In the application of forced oil cooling to electrical power transformers of the concentric coil, core-form type, wherein the high voltage winding includes a plurality of pancake coils spaced to provide coil ducts, the prior art modifies the coils by placing duct formers between the coil turns when winding the coils, or utilizes a plurality of baffles to direct the oil flow in a zig-zag manner across the major surfaces of the pancake coils.

The former arrangement increases the manufacturing cost of the winding, adversely affects the coil space factor, and weakens the winding structure mechanically. The latter arrangement substantially increases the cost of the winding due to the labor involved in inserting the baffling arrangement required to provide the desired flow path.

Therefore, it would be desirable to be able to construct the pancake coils for transformers which are to be forced oil cooled, in the same manner as the pancake coils which are cooled by thermal siphon flow. Further, it would be desirable to be able to assemble the pancake coils into a winding assembly for forced oil cooled transformers, without requiring the additional labor of disposing a plurality of discrete baffles adjacent inner and outer edges of predetermined pancake coils.

SUMMARY OF THE INVENTION

Briefly, the present invention is a new and improved fluid cooled power transformer of the concentric coil, core-form type, having a magnetic core-winding assembly disposed in a tank and immersed in an insulating and cooling fluid, such as oil. The magnetic core-winding assembly includes a winding having a plurality of pancake coils disposed in spaced relation with one another about

a vertically oriented leg of the magnetic core. The spaced coils provide horizontally disposed coil ducts which communicate with a vertical duct located adjacent the inner openings of the coils. Inner and outer concentrically disposed, spaced insulating tubular structures encircle the winding assembly, with the inner tubular structure having a plurality of openings therein aligned with the coil ducts, and with the two tubular structures cooperating to provide a manifold for the distribution of fluid to the coil ducts. Pumping means forces the fluid to flow from a plenum chamber at the bottom of the transformer tank into the manifold, through the coil ducts, to the vertical duct adjacent the edges of the coil openings.

BRIEF DESCRIPTION OF THE DRAWINGS

Further advantages and uses of the invention will become more apparent when considered in view of the following detailed description and drawings, in which:

FIGS. 1 and 1A are fragmentary, elevational views, in section, of typical winding arrangements of the prior art for forced oil cooled transformers;

FIG. 2 is a fragmentary, elevational view, in section, of a winding arrangement for forced oil cooled transformers constructed according to the teachings of an embodiment of the invention;

FIG. 3 is a fragmentary elevational view, in section, of a winding arrangement for a forced oil cooled transformer, constructed according to another embodiment of the invention; and

FIG. 4 is a perspective view, partially cut away, of a three-phase transformer constructed according to the embodiment of the invention shown in FIG. 3 .

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the drawings, and FIG. 1 in particular, there is shown a fragmentary elevational view, in section, of a high voltage winding **10** for a transformer of the core-form type. FIG. 1 illustrates a prior art arrangement for forced oil cooling the high voltage winding, which requires a modification of the coils of which the winding is formed.

Specifically, FIG. 1 illustrates a plurality of pancake type coils **12**, **14**, **16** and **18**, shown on only one side of a centerline **20**, since they are symmetrical, with the pancake coils being disposed with their major surfaces in a horizontal plane, and spaced from one another to provide coil ducts between their horizontal major surfaces. Baffles in the form of cylindrical insulating tubular members **22** and **24** are disposed adjacent the inner and outer edges of the pancake coils to direct the forced flow of the cooling fluid, such as oil, through the coils. The pancake coils are wound with duct formers therein such as corrugated strips of pressboard, which separate the turns of the pancake coils while providing ducts therein for the flow of the cooling fluid. For example, pancake coil **12** is illustrated with ducts **26**, **28** and **30**, and the remaining pancake coils have similar cooling ducts. The flow of coolant, illustrated by the arrows, under the urging influence of a pump, flows around the coils, through the horizontal coil ducts, and through the ducts disposed through the coil turns, to remove the heat generated in the windings. While this arrangement is functionally suitable, it has the disadvantage of requiring that the pancake coils be modified from the form in which they are used in transformers cooled by the natural

thermal siphon effect, which increases the manufacturing time and cost of the coils and winding. Further, the duct formers increase the radial build dimension of each coil, which increases the yoke dimension of the magnetic core resulting in the utilization of more core material, it increases the length of the magnetic circuit, and it adversely affects the space factor of the winding.

FIG. 1A illustrates another prior art engagement for cooling the high voltage winding of a power transformer of the core-form type, which does not require that the pancake coils be modified. Specifically, FIG. 1A is a fragmentary elevational view, in section, of a high voltage winding **40** which includes a plurality of pancake coils **42, 44, 46, 48** and **50**, which are symmetrical about centerline **52**, and spaced axially apart to provide a plurality of coil ducts between the major surfaces of the pancake coils, such as coil ducts **54, 56, 58** and **60**. Insulating baffle members **62** and **64** are disposed adjacent the inner and outer edges of the pancake coils to direct the flow of cooling fluid to the coils, and a complex arrangement of baffles is used to direct the flow of cooling fluid in a zig-zag configuration across the major surfaces of the pancake coils. For example, a baffle **66** is disposed to block the duct at the inner edge of coil **50**, a baffle **68** is disposed to block the duct at the outer edge of pancake coil **48**, a baffle **70** blocks the duct at the inner edge of pancake coil **46**, a baffle **72** blocks the duct at the outer edge of pancake coil **44**, and a baffle **74** blocks the duct at the inner edge of pancake coil **42**. The cooling fluid, indicated by the arrows, under the urging influence of a pump, is forced to flow around the outer edge of pancake coil **50**, inwardly through coil duct **60**, outwardly through coil duct **58**, inwardly through coil duct **56**, and outwardly through coil duct **54**. This arrangement is functionally suitable, but has the disadvantage of the time required to construct the intricate baffling system, with a typical winding phase requiring placing and securing in the order of 10 to 12 insulating washer shaped members adjacent the inner and outer edges of the pancake coils of the winding, in order to achieve the desired zig-zag cooling arrangement.

FIG. 2 is a fragmentary elevational view, in section, of a phase **80** of a transformer of the core-form type, constructed according to a first embodiment of the invention, which provides efficient cooling of the windings without modification of the pancake coils, and without requiring an intricate baffling arrangement. Specifically, phase assembly **80** includes high and low voltage windings **82** and **84**, respectively, disposed about a vertically oriented leg **86** of a magnetic core, with the windings **82** and **84** and leg **86** being symmetrical about vertical centerline **88**. Low voltage winding **84** includes a plurality of conductor turns, indicated generally at **90**, which are insulated from the magnetic core leg **86** by insulating means **92**. The high voltage winding **82** includes a plurality of pancake coils, such as pancake coils **94, 96, 98, 100, 102, 104, 106, 108, 110, 112, 114** and **116**, each having a plurality of radially superposed conductor turns such as turns **118** in pancake coil **116**. The pancake coils, such as pancake coil **94**, have first and second major opposed outer surfaces **120** and **122**, joined by an opening **124** which extends between these outer surfaces. The pancake coils are all disposed on a vertically oriented winding leg **86** of the magnetic core with their openings in alignment, and they are axially spaced to provide horizontal coil ducts between their major surfaces, such as coil ducts **126, 128, 130, 132, 134, 136, 138, 140, 142, 144** and **146**.

Means, such as circumferentially spaced insulating members space the edges of the coil openings from the high-low insulation **142** between the high and low voltage windings **82** and **84**, to provide a vertical cooling duct **150**, which communicates with the plurality of horizontally disposed coil ducts between the major surfaces of the pancake coils. The vertical duct **150** is blocked at its lower end, in this embodiment, with suitable insulating means **152**, such as an insulating washer member, while the upper end of this duct is open.

Then, instead of a solid external wrapper or tubular baffle about the outer periphery of high voltage winding **82**, as is common in prior art cooling arrangements, an external insulating wrapper or tubular barrier member **154** is provided which has a plurality of openings therein, which openings are aligned with the horizontal coil ducts between the pancake coils. More specifically, barrier **154** has a plurality of axially spaced rows of openings, with each row having a plurality of circumferentially spaced openings adjacent one of the horizontal coil ducts. Further, as will be hereinafter explained, the circumferential length of the openings changes from row to row, in order to effectively equalize the length of the parallel cooling paths, resulting in a highly efficient and uniform cooling of the phase assembly **80**. FIG. 2 illustrates one of the openings of each of the axially spaced rows of openings with these openings being given the reference numerals **160, 162, 164, 166, 168, 170, 172, 174, 176, 178** and **180**. Barriers **182** and **184**, such as washer shaped insulating members, are disposed between barrier **154** and the lower and upper pancake coils **116** and **94**, respectively, to direct the cooling fluid to the horizontal coil ducts through the openings in barrier **154**.

The next step in creating the new and improved cooling system for phase assembly **80**, is to create a manifold about the high voltage winding **82**, from which cooling fluid may enter the openings in barrier **184**. The manifold is created by an outer wrap or tubular insulating barrier member **190** which is disposed about and spaced from the barrier **154**. Suitable vertically oriented spacers may be attached to the outer periphery of barrier **154**, or to the inner surface of barrier **190**, at predetermined selected circumferential increments, to provide the desired space between the two barriers, and define a space or manifold **192** between the barriers which is blocked at its upper end by blocking means **194**, and open at its lower end. Thus, as illustrated by the arrows in the figure, the cooling fluid under the urging influence of a pump, is directed by suitable baffles into the lower end of manifold **192**. From manifold **192** the fluid flows into the plurality of openings in each of the axially spaced rows of openings, to flow in the horizontal coil ducts to the vertical duct **150**. The fluid then flows upwardly through vertical duct **150**, and is ejected from the winding assembly **80** at the upper end of this duct.

The embodiment of the invention shown in FIG. 2 has many advantages over prior art cooling arrangements. The pancake coils do not require modification. Ducts between the turns of the coil are not required. The pancake coils for the forced cooled transformer may thus be made in the same way as the pancake coils for transformers which are cooled by the natural thermal siphon effect. Further, an intricate baffling arrangement is not required. The only insulating washer members required are disposed at the extreme ends of the winding structure. Thus, very little additional labor is required to construct the phase winding assembly **80**. The embodiment of the invention shown in FIG. 2 also has the advantage of introducing fluid into each coil duct at substantially the same temperature, as the fluid enters each horizontal coil duct from a manifold which draws the fluid from the cool fluid in a plenum chamber near the bottom of the transformer tank. The fluid is not required to proceed from coil duct to coil duct, picking up heat and temperature as it goes, as the fluid is directed through only one coil duct and then discharge from the winding structure. Thus, the cooling of the winding is more efficient and uniform than prior art methods.

If it is desirable to direct the cooling fluid through two coil ducts before being discharged from the winding assembly, the manifold may be axially divided into first and second vertically spaced sections, with the fluid being

directed from the first section of the manifold through the communicating horizontal coil ducts, and into the inner vertical ducts, and then from the inner vertical duct into the remaining coil ducts which communicate with the vertical duct, and then into the second section of the manifold. This embodiment of the invention is shown in FIG. 3, with like reference numerals in FIGS. 2 and 3 indicating like components.

The phase winding assembly shown in FIG. 3 is given the reference numeral **80'**, in order to indicate that it is a modification of the phase winding assembly **80** shown in FIG. 2. Winding phase **80** of FIG. 2 may be modified to provide winding phase **80'**, by removing the blocking means **194** from the upper end of manifold **192**, by disposing blocking means, such as an insulating washer member **200** between insulating barriers **154** and **190** at substantially the mid-point of the axial length of high voltage winding **82**, to provide first and second axially spaced sections in manifold **192**, referenced **210** and **212**, respectively, by disposing blocking means **202** between the outer periphery of the pancake coil located at the mid-point of winding **82**, such as pancake coil **106**, and the inner wall of barrier **154**, and by blocking the upper end of vertical duct **150** with means **204**, such as an insulating washer member.

In the modified phase winding structure **80'**, the cooling fluid enters the bottom of the first section **210** of manifold **192**, and enters the horizontal coil ducts **146, 144, 142, 140** and **138**, through openings **160, 162, 164, 166** and **168**, respectively. The fluid flows inwardly through these openings in their associated horizontal coil ducts until reaching the vertical duct **150**, and flows upwardly therein and into the horizontal coil ducts **136, 134, 132, 130, 128** and **126**. The fluid flows outwardly in these coil ducts to the second section **212** of manifold **192**, and then upwardly where the heated fluid is discharged from the phase winding assembly **80'**. This arrangement enables the cooling fluid to enter and leave the phase winding assembly **80'** adjacent the outer periphery at the ends of the structure, which in some instances may be preferable to the embodiment of the invention shown in FIG. 2 wherein the heated fluid exits the phase winding assembly **80** adjacent the inner edge of the high voltage winding.

FIG. 4 is a perspective view of a three-phase transformer **220** of the core-form type, shown partially cut away in order to illustrate the teachings of the invention. Transformer **220** is constructed according to the teachings of the invention shown in the embodiment of FIG. 3, and will more fully illustrate the construction of the phase winding assemblies which equalizes the lengths of the oil flow paths, and thus improve the cooling efficiency and the uniformity of the cooling, of the disclosed arrangement.

More specifically, transformer **220** includes a magnetic core-winding assembly **222** disposed in a tank **224**, with the tank **224** being filled to a level **226** with an insulating and cooling fluid, such as mineral oil, or one of the synthetic cooling fluids, such as those containing chlorinated diphenyl and trichlorobenzene, with level **226** being selected to completely immerse the magnetic core-winding assembly **222** in the insulating and cooling fluid. The tank **224** has a plurality of openings **228** disposed at level **226**, which are connected to external coolers or heat exchangers (not shown), which are mechanically connected to predetermined outside walls of the tank **224**. The cooled fluid from the heat exchangers is collected in suitable headers, and pumped back into the tank **224** near the bottom thereof, such as via pump **230** through opening **232** in the casing **224**. The transformer **220** may have a plurality of heat exchangers and pumps, as required by the specific application.

Magnetic core-winding assembly **222** includes a three-phase magnetic core **234**, having winding legs **236, 238** and **240** connected at their ends by upper and lower yoke portions **242** and **244**, respectively.

Magnetic core **234** is formed of a plurality of stacked metallic laminations, such as grain oriented silicon steel, with the winding legs having a cruciform cross-sectional configuration in order to more efficiently couple windings having round openings therein. The stacked laminations are held in assembled relation by upper and lower end frame assemblies **246** and **248**, respectively.

The magnetic core-winding assembly **222** also includes phase winding assemblies **250, 252** and **254**, disposed about winding legs **236, 238** and **240**, respectively. Each of the phase winding assemblies includes concentrically disposed low and high voltage windings, as shown more clearly in FIGS. 2 and 3, and each of the high voltage windings have a plurality of axially spaced pancake coils. For example, phase winding assembly **250** includes high and low voltage windings **260** and **262**, respectively, with high voltage winding **260** having a plurality of pancake coils, such as pancake coils **264, 266** and **268**, which are axially separated by spacer members, such as spacer member **270**, which spacers extend radially outward from the openings in the pancake coils to the outer periphery of the coils, and circumferentially spaced about the major surfaces of the pancake coils. Spaces **270** may extend outwardly past the outer periphery of the pancake coils, to space the first outer wrap or tubular barrier member from the edges of the pancaker coils, if desired. The plurality of pancake coils are mechanically held together at each end of the winding assembly by pressure rings or plates, such as pressure plate **272** shown at the bottom of phase winding assembly **250**, and pressure plate **274** shown at the top of phase winding assembly **252**. Suitable means, such as bolts **276** which are connected to the end frame, apply pressure to discrete points about the upper and lower pressure plates of each phase winding assembly, to provide the necessary force to hold the windings together and prevent them from distorting during short circuit stresses.

The three phase winding assemblies in FIG. 4 illustrate various steps in the construction of a cooling system according to the teachings of the invention. For example, phase winding assembly **250** illustrates high voltage winding **260** immediately after the pancake coils have been assembled in spaced relation, phase winding assembly **252** illustrates the first wrap of insulation being applied to the winding assembly, and phase winding assembly **254** illustrates the second or outer wrap of insulation being applied to the winding assembly.

More specifically, the first step in constructing the cooling system according to the teachings of the invention, illustrated relative to phase winding assembly **252**, is to provide an insulating structure or barrier member **280** which includes a rectangular sheet of insulating material precut to include a plurality of axially spaced rows of openings, with each row of openings including a plurality of spaced openings, and with the sheet of insulating material being preassembled with the spacer members required to space barrier member **280** from the next outer barrier member, which will be hereinafter described.

More specifically, since this embodiment is similar to the embodiment of the invention shown in FIG. 3, wherein the manifold is axially divided into two spaced sections, two similar patterns of openings are provided, one for each section of the manifold. If the manifold has only one section, like the embodiment of the invention shown in FIG. 2, there would only be one basic pattern, which would extend completely across the axial length of the winding assembly. Each row of openings includes openings of a similar circumferential length, but the circumferential length of the openings in different rows of the pattern are different. Specifically, the circumferential length decreases from row to row as the pattern extends vertically upward. Thus, as shown in FIG. 4, the first row of the first or bottom pattern includes a plurality of cir-

cumferentially spaced openings **282** each having a predetermined uniform circumferential length, and each aligned with the coil duct between the first two pancake coils at the bottom of the high voltage winding. The next row of openings has the same number of circumferentially spaced openings as the first row, aligned with the next coil duct, but the circumferential length of these openings, such as opening **284**, is less than the circumferential length of the openings in the first row. This pattern of progressively shorter openings is repeated across the first section of the manifold, and then the same pattern is repeated across the second section of the manifold. The progressively shorter openings equalize the effective length of the flow paths from the manifold. Starting with the first section of the manifold, the longest flow path is from the bottom opening, while the shortest is from the top opening. Therefore, the circumferential length of the openings are progressively decreased from row to row as the first section of the manifold is progressed vertically upward, in order to make the effective length of the flow paths the same, to equalize the fluid flowing through the horizontal ducts, and to obtain uniform and efficient cooling. The same basic pattern is repeated in the second section of the manifold, as the manifold for the second section is the upper half of duct **150**, and the longest flow path from this manifold is through the bottom row of openings associated with the upper manifold section.

The insulating barrier **280** may have spacer members attached to its outer surface, such as spacers **290** and **292**. Two spacers, with a small gap between their adjacent ends, are required for the complete axial length of the structure, since a circumferential washer member **294** is disposed about barrier **280** at its midpoint, which divides the manifold into the two axially spaced sections. A plurality of additional spacer members, such as spacer members **296** and **298**, are disposed at selected increments about the circumference of the barrier, to adequately space the next barrier member from barrier member **280**.

Next, a solid sheet of insulating material is wrapped about the inner barrier member **280**, to provide insulating barrier **300**, which is illustrated relative to phase winding assembly **254**. The outer wrap or barrier member **300** is spaced from barrier **280** by the spacer members and washer member, hereinbefore described, to define a manifold having first and second axially spaced sections.

A horizontally disposed sheet-like member **301** is disposed to provide a plenum chamber at the bottom of the tank for the cooled fluid returning from the heat exchangers. Member **301** is disposed at a level which coincides with the bottom of the winding assemblies **250**, **252** and **254**, and has openings therein which are in communication with the bottom openings to the manifolds defined by the spaced barrier members, such as barrier members **280** and **300**. Thus, the cooled fluid from the external heat exchangers is directed into the plenum chamber at the bottom of the tank, and into the manifold associated with each phase winding assembly. The fluid flows into the lower section of the manifold, and then through the horizontal coil ducts to the inner vertical duct. The fluid then enters the horizontal coil ducts which are in communication with the upper section of the manifold, it flows outwardly to the second section of the manifold, and then it leaves the winding assembly as illustrated by the arrows in FIG. 4, to flow to the outlets **228** connected to the external heat exchangers.

In summary, there has been disclosed a new and improved electrical transformer which has a highly efficient structure for uniformly force cooling the phase winding assemblies thereof, which has several advantages over arrangements of the prior art for accomplishing the same function. For example, the pancake coils of the high voltage winding assemblies may be constructed in the same manner as though the transformer were to be cooled by the natural thermal siphon effect, and the baffling system required is minimal and simple, thus adding very little to the manufacturing cost of the transformer. Further, the cooling fluid is distributed to the horizontal coil duct via a manifold, which introduces fluid of substantially the same temperature to each of the ducts communicating with the manifold, and the openings in the barrier associated with the manifold which communicate with the horizontal coil ducts are arranged to equalize the flow paths through the various coil ducts, resulting in uniform cooling of the pancake coils across the winding structure.

Since numerous changes may be made in the above described apparatus and different embodiments of the invention may be made without departing from the spirit thereof, it is intended that all matter contained in the foregoing description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

I claim as my invention:

1. An electrical transformer comprising:

a tank,

an insulating and cooling fluid disposed in said tank,

a magnetic core-winding assembly disposed in said tank and immersed in said fluid,

said magnetic core-winding assembly including a magnetic core having at least one winding leg, and at least one winding which includes a plurality of pancake coils, each of which have first and second major opposed surfaces and an opening which extends between the major surfaces, said at least one winding leg of the magnetic core being disposed through the openings in said plurality of pancake coils, with said winding leg being oriented and said pancake coils being spaced to provide horizontal coil ducts between their adjacent major surfaces,

first means providing a vertical duct adjacent the edge of the inner openings of said pancake coils, which communicates with the horizontal ducts,

second means disposed about the outer periphery of said pancake coils having a plurality of axially spaced rows of circumferentially spaced openings therein, which communicate with the horizontal ducts,

third means disposed in spaced relation about said second means, said second and third means defining a manifold filled with said fluid,

and means blocking the manifold to provide a fluid flow path which includes the manifold, the horizontal ducts, and vertical duct provided by said first means.

2. The electrical transformer of claim **1** including pump means which forces the fluid to flow from the manifold, through the coil ducts, and upwardly through the duct provided by the first means.

3. The electrical transformer of claim **1** wherein the means blocking the manifold is at the upper end thereof, and including means blocking the vertical duct at the lower end thereof.

4. The electrical transformer of claim **1** wherein the means blocking the manifold divides the manifold into first and second axially spaced sections, and including means blocking the vertical duct at its upper end, providing a predetermined flow path for the fluid which includes the first section of the manifold, the coil ducts which communicate with the first section of the manifold, the vertical duct provided by the first means, the coil ducts which communicate with the second section of the manifold, and the second section of the manifold.

5. The electrical transformer of claim **4** wherein the circumferential lengths of the openings in the second means progressively decrease from row to row across the first section of the manifold in a vertically upward direction, with the pattern being repeated across the second manifold in the vertically upward direction.

6. The electrical transformer of claim **4** including pump means which forces the fluid to flow in the predetermined flow path.

7. The electrical transformer of claim **1** wherein the circumferential lengths of the openings in the second means in any predetermined row are substantially the

same, but being of different circumferential lengths in different rows.

8. The electrical transformer of claim 7 wherein the different circumferential lengths of the openings in the second means in different rows is predetermined to equalize the effective lengths of the flow paths through the winding.

9. The electrical transformer of claim 7 wherein the circumferential lengths of the openings in the second means progressively decrease from row to row across the manifold in a vertically upward direction.

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THOMAS J. KOZMA, Primary Examiner

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