United States Patent

Theodore

[15] **3,670,276**

[45] **June 13, 1972**

[54] **HERMETIC TRANSFORMER**

[72] Inventor: **Charles Theodore,** Huntington Beach, Calif.

[73] Assignee: **LTV Ling Altec, Inc.,** Anaheim, Calif.

[22] Filed: **Feb. 11, 1971**

[21] Appl. No.: **114,440**

[52] **U.S. Cl.** ....**336/92,** 174/12 R, 174/17 SF, 336/94

[51] **Int. Cl.** **H01f 27/02**

[58] **Field of Search**..................336/58, 55, 90, 92, 94, 198; 174/12 R, 17 SF

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Primary Examiner—Thomas J. Kozma
Attorney—Harry R. Lubcke

[57] **ABSTRACT**

A hermetically-sealed completely oil-filled high voltage transformer of small size and rugged construction for use over a wide range of ambient temperature and ambient pressure. Required expansion bellows are desirably small because interstices between the core-coil structure and the enclosing case are filled with at least one insulating piece and numerous refractory beads in addition to oil. The oil is restricted to the internal volume that is under high electrical stress.

11 Claims, 3 Drawing Figures

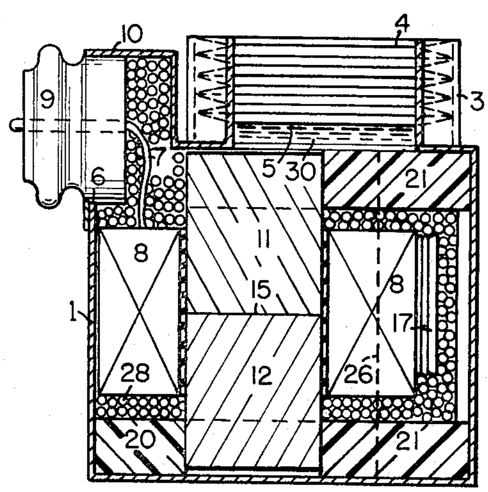

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FIG. 1.

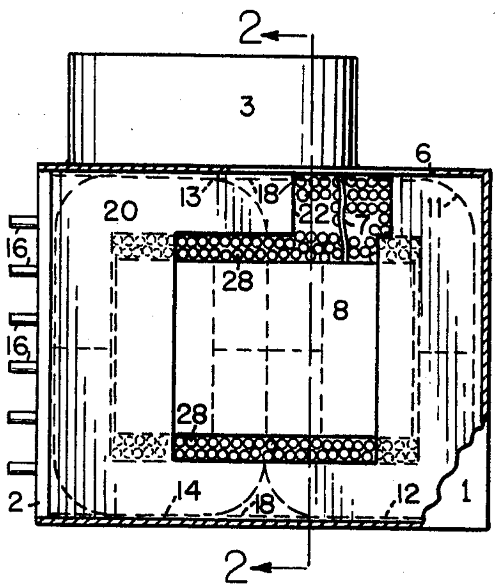


FIG. 2.

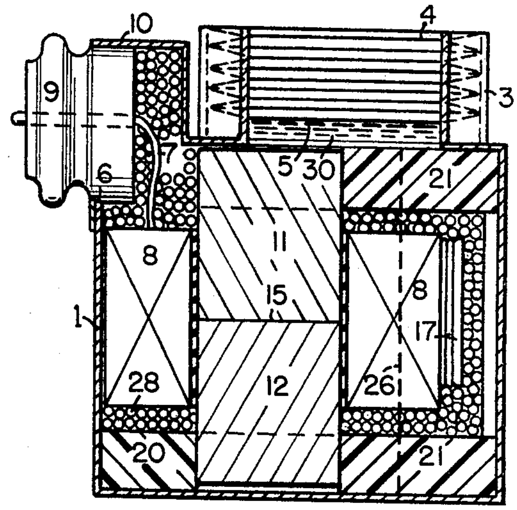
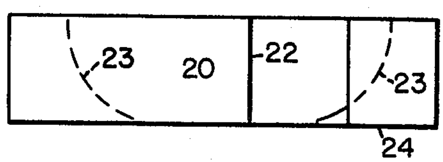


FIG. 3.



INVENTOR
CHARLES THEODORE
BY Harry R. Lubcke
HIS AGENT

HERMETIC TRANSFORMER

BACKGROUND OF THE INVENTION

This invention pertains to a transformer with an outer casing or housing and a liquid insulating medium.

In certain applications, such as an air-borne high voltage transformer, a hermetically-sealed completely oil-filled transformer is required. When a wide temperature range and an ambient pressure range tending toward a vacuum are also involved, along with small size and light weight requirements, it has been found to be impossible to form the required structure according to known techniques.

It is common practice to have an air or inert gas space above the oil and the windings of a transformer, which space accommodates the expansion of the insulative oil when the temperature rises. With the transformer, or equivalent inductive device, that must meet the above-mentioned specifications, such a gas space cannot be employed. This is because there is no certainty of which way is "up." In various air-borne vehicles departures of 90° and of even 180° occur from what is normally right-side-up. Moreover, because of the "*g* forces" involved in an accelerated ascent or descent or a sharp turn, the geometrical "up" ceases to be the actual "up" insofar as a liquid is concerned.

Unfortunately, even gas bubbles of any appreciable size cannot be tolerated within the working space of a high voltage transformer of this type. If such are present anywhere the "*g* forces" reorient the same into the working space, as a statistical probability. Once there, the fundamental electrostatic stresses occurring between different parts of the winding or windings and the core and/or enclosing case cause the air or gas bubbles to be drawn into the path of maximum electrostatic stress. Thus, because of what may be called a "pumping action," such as takes place in the known ion pump for creating a vacuum, the bubble migrates to the region of greatest danger.

Transformer oil inherently has a dielectric constant of two or three, whereas air has a value of one. This causes the capacitance of the bubble of air to be significantly smaller than the capacitance of an adjacent equivalent volume of oil. The voltage gradient across a capacitor of small capacitance in a group of capacitors connected in series is high, being inversely proportional to the dielectric constant thereof, other factors being equal. Accordingly, at the voltages required in the devices according to this invention, corona forms in the bubbles of gas. This ionized electric discharge has an effective resistance less than that of a good metallic conductor, thus constituting a short for the distance involved. Typically, this corona chemically disintegrates the oil adjacent to it, resulting in the emission of gas. This gas also breaks down to corona, and a process for the destructive failure of the transformer is set in motion. This process may be aided by carbonization of the oil in the vicinity of the ionized gas bubbles, making the oil a conductor rather than an insulator. That this situation actually occurred in practice was verified by transformer failures until the structure and processing of this invention was evolved.

Silica sand, often having a range of sizes of the granules, has been used in ordinary transformers, such as for stationary pole transformers for electric utility service. Since sand is less expensive than oil and as long as sufficient oil is included in the transformer for insulating and cooling purposes, this practice is permissible for this type of transformer. The usual air space is present at the top of the transformer housing, of course.

In the present invention, where no overt air or gas can be tolerated, it has been found that the use of sand is prohibited. Because the spaces between the particles of sand are relatively very small, the pumping time required to evacuate the transformer is prohibitively long for any feasible manufacturing process. It is of the order of several weeks duration.

Consideration could be given to employing a boilable gas, the vapor of which is a good insulator, such as freon. However, the space required between critical high voltage parts of the transformer would have to be greatly increased, to, say, five times greater than with oil. This is because the gas is much less effective as an insulator than is oil or than the same material in liquid form.

Of course, by making the distances between critical high voltage parts sufficiently large, voltages of the order of 15,000 to 20,000 volts can be handled with air insulation. In the present application, where altitudes of 50,000 feet or more are contemplated, a pressure type enclosure would be required, since corona forms easily in a rarified atmosphere. Such distances for insulation, typically five times greater than for oil, would be impractical because of exceeding size and weight limitations for devices of this type. Also, transformer oil is a good cooling medium and this property reduces the size and weight of the oil-filled transformer.

Should only beads be used as the oil-reducing agent in a transformer of this type it is found that the bellows required become impractically large. It has already been shown that too small spaces between the solids, such as small beads or sand, particularly of various sizes to most closely pack together, makes it impossible to evacuate the transformer in any practical period of time. Hence, this means for effectively reducing the volume of oil cannot be used.

Theoretically, spherical beads of uniform size regardless of what that size may be as long as the container is very large with respect to the bead size provide a fixed ratio of the volume of the beads to the total volume of 69 percent. In practice, the oil that will occupy the unfilled volume is less than the theoretical, it is 40 percent. Notwithstanding, this is more oil than can be accommodated with respect to the expansion capabilities of small bellows. When the bellows are suitably increased in size to handle a greater maximum volume the external transformer structure becomes undesirably large and the modification becomes self-defeating. The increase required is roughly eight times over that for applicant's structure employing solid insulating pieces plus beads. As the range in volume of the bellows is increased the free space for the expansion and contraction of the bellows is increased and so more oil must be used to always fill the internal volume of the enclosing case and bellows.

SUMMARY OF THE INVENTION

The failure of a number of obvious structures and modes of processing for manufacturing the desired transformer device has been set forth above.

Applicant's successful arrangement involves the fabrication of a roughly cubical enclosing case to withstand external reduced pressure and internal increased pressure. The large spaces therein not occupied by the transformer core and windings are occupied by insulating pieces formed to fill as much space as possible. At least one such piece is employed; typically, two such pieces with possibly one or more additional smaller pieces are also fitted in. These pieces are shaped to avoid those parts of the internal volume where high voltage stress is to be found.

After the assembly of these elements within the enclosure the remaining space is filled with beads; typically impermeable, spherical, and of a single size. The case is then thoroughly evacuated.

For the expansible member, typically expansible spring-loaded metal bellows, these are normally fabricated to be a part of the enclosing case. These are set at an expansion corresponding to the ambient temperature and oil is filled into the case to replace the vacuum. The enclosing case is then sealed.

With this technique the bellows may be comparatively small and the transformer reliably operative over a long period of time regardless of ambient conditions of temperature, pressure or *g* forces. While nominal ranges in the values of the parameters involved are allowable, any of the prior known techniques have been found to lead to quite rapid breakdown of the insulation of the transformer and so cannot be followed to arrive at the subject inventive structure and mode of processing.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevation of the complete transformer, with the forward side of the enclosing case broken away to show significant internal parts.

FIG. 2 is an end elevation of the transformer along section lines 2 — 2 of FIG. 1, in which end elevation further internal parts are shown.

FIG. 3 is a plan view of a typical shaped insulating piece, this being the one shown with surface shading at the front of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The transformer enclosing case 1 of FIGS. 1 and 2 is formed by welding, deep drawing, or casting a suitable metal, such as stainless steel, steel,brass, or aluminum. The inserted side 2, which must be initially separate in assembling the case, carries the internal parts. Side 2 is hermetically sealed in place as one of the last steps in the construction by welding, brazing, soldering, or by bolting with an "O" ring seal.

The top of enclosure 1 carries a cylindrical section 3, having a length that is only a fraction of the diameter of the cylinder. Stainless steel is preferred for the material of the case and the cylinder, and the two are welded together, with a corresponding hole in the top of the case. Mechanically expansible member metal bellows 4 is welded to the top of cylinder 3, circumferentially. The other (lower) end of the bellows is provided with an essentially non-flexible diaphram 5. Thus, outside air pressure is found down into bellows 4 and inside oil pressure is found below diaphram 5. In the sectional view of FIG. 2 part of the bellows is seen directly, while the spring-like peripheral part is shown dotted behind the surface of cylinder 3.

Enclosing case 1 has another aperture 6 to accommodate high voltage lead 7 from transformer 8. In FIG. 2 high voltage bushing 9, with auxiliary closure 10 to the rest of the case, is shown. In FIG. 1, however, elements 9 and 10 have been omitted for clarity with respect to the case itself and the internal construction behind the high voltage bushing.

This invention is primarily concerned with the thermal aspects of a high-voltage hermetically-sealed transformer or inductor that is subject to any effective orientation in space and requiring the effectiveness of wholly liquid insulation. As a consequence, a typical transformer structure is here presented, but it is to be understood that this may be varied to meet particular needs or applications without altering the applicability of this invention.

In the typical transformer one or more high voltage leads, such as 7, act of prime concern. The transformation ratio is immaterial. However, a high voltage transformer suitable for energizing a magnetron vacuum tube is typical and may have a step-up ratio of 75 to 1, with a primary capable of accepting a pulse of 200 volts and a secondary delivering a pulse of 15,000 volts. Again, the voltages may be sinusoidal or otherwise insofar as this invention is concerned.

While any mode of winding the primary-secondary coil 8 may be used, the interleaved type of winding is preferable, along with the back-winding technique, both known to the art. In such winding the primary is wound at more than one point and is in close relation to the secondary for maximum magnetic coupling. With the back-winding, the secondary is wound out from the core for the first half in one direction of the turns, high voltage lead 7 is brought out as shown, and the second half of the secondary is wound in the opposite direction from lead 7 to the external surface of coil 8. This has the advantage of retaining the inner and the outer surfaces of the coil at essentially the ground potential of the core and the case. If desired, the secondary may be wound in a bifilar fashion, with two adjacent leads 7, having, say, a 12 volt differential between them, which may be used for energizing the filament of the magnetron, if used. Typically, the halves of a back-wound secondary are connected in parallel for use in the high-voltage pulse electrical circuit, and are in series, essentially as mere conductors, to supply voltage for a filament or heater from an external source. This source may then be at ground potential at all times although the heater element is at high voltage during the pulse.

An efficient core for a typical transformer may be formed of two "C" core pairs, or of the geometrically equivalent "E-I" lamination core. In either arrangement a full cross-section of core passes through the central aperture of coil 8, with a half cross-section passing top and bottom and external to the coil on each side. This results in a shell-type core-coil structure.

In FIGS. 1 and 2 the top "C" of the right-hand section of the core is identified as 11, the bottom C as 12. Grain-oriented silicon steel tape is continuously wound on an appropriate mandrel to provide the shape and cross-section desired. The tape core is then annealed and becomes a monolithic element. In order that it be inserted through the aperture in the center of coil 8 the core is cut in half at line 15 in FIG. 2 to make two "C's" out of one oval "O." This cut is polished and etched to give intimate contact for low magnetic reluctance. The same process is carried out for the other C halves 13 and 14. All four parts are then assembled with coil 8 as shown in FIG. 1. It is usual to employ a pair of copper bands around each assembled C core pair to hold them in intimate contact. These extend completely around cores 11 and 12; also around cores 13 and 14, as separate entities. Additionally, a single such band 18 is placed around both cores and terminates at side 2 to enable the transformer to be easily inserted into the remainder of the enclosing case 1. Low voltage terminals 16 are provided in the form of refractory-bead-insulated-conductors passing through holes in side 2. This is a hermetic construction. Certain low voltage primary leads, 17, often of flat copper tape the same as the winding, are shown in FIG. 2.

One or more shaped insulating pieces 20 and 21 are normally employed to occupy all possible volume within the enclosing case 1 that is not occupied by the coil and core of the transformer, save that part of the coil that is at high voltage. In the configuration that has been described the high voltage area is at the margins (edges) of the coil, particularly at the center of the margins, midway between the core and the enclosing case.

These insulating pieces are preferably formed of cast or molded epoxy plastic with a glass content in order to have good electrical insulating properties, to be stable mechanically, and to be inert chemically. The coefficient of thermal expansion should be as small as possible in order not to contribute to that coefficient of the insulating fluid. Ceramics are also good in this respect.

Typically, two large molded pieces are employed, one on each side of the core-coil assembly, and shaped insofar as possible to fill the volume between that assembly and the enclosing case. The front piece 20 is shown in all of the figures and the similar rear piece 21 is shown in FIG. 2. In FIGS. 1 and 3, particularly, slot 22 is noted in the upper portion. This is to accommodate high voltage lead 7. The overall shape of the piece is that of a rectangular parallelopiped. The internal shape is curved, at 23, being largely hollow to fit over one side of coil 8.

The glass content of the pieces may be obtained by inserting glass beads having a diameter in the one-half to 2 millimeter range in a mold and then pouring in the epoxy. In order to obtain a close fit the pieces may be ground somewhat on the side next to the enclosing case; side 24 in FIG. 3. By arranging this side to be the top in the mold the glass particles are absent from this side and the grinding process is most easily accomplished. Emerson & Cuming No. 1263 is a satisfactory epoxy. To remove trapped air the pieces are cured in a vacuum.

In the embodiment illustrated it was found that a space remained between cores 13–14 and side 2 adjacent to terminals 16. This is suitably filled by insulating piece 26, which has a length equal to these cores and a square cross-section of the order of 1 centimeter. Thus, three or more insulating pieces may be employed to the end that all spaces of appreciable size are filled thereby.

A preferred manner of assembling the transformer can be inferred from what has gone before, but this will be here recapitulated prior to the step of inserting the loose beads.

Coil **8** is assembled on the pair of double C cores, which latter are then bound together; primary and any other low voltage leads are then soldered, spot-welded or brazed to hermetic terminals **16**. The core-coil assembly is fastened to side **2** of the case with band **18**. This assembly is then inserted into enclosing case **1**. Side **2** is then welded to case **1**, as by traversing an electron beam along the seam in a vacuum.

The many loose glass beads **28** are then poured into the case, which is then shaken to distribute the beads as widely as possible.

Bushing **9** is welded in place and high voltage lead **7** connected thereto.

The interior volume of the case **1** is evacuated.

Bellows **4** are externally set for the temperature existing and an electrical insulative liquid is introduced to replace the vacuum in the voids within the external structure.

Case **1** is hermetically sealed.

Beads **28** are typically 2 millimeters in diameter and are obtainable from Potters Bros., Inc. Other suitable beads may be the known impact beads, Pyrex or Kimex glass beads, or high alumina ceramic beads, preferably not porous. The 2 millimeter diameter is dictated by evacuation requirements, but these may be somewhat smaller if longer evacuation time can be tolerated and vice versa.

As soon as the enclosing case is otherwise sealed, with the loose beads therein, it is evacuated by fastening two ¼-inch diameter vacuum lines at spaced-apart positions on the enclosing case. A suitable pump to draw the vacuum is connected to these lines, its capacity and type being related to the speed of pumping desired.

Coil **8** is originally baked and exhausted in a vacuum chamber to remove moisture and gas according to know coil manufacturing techniques.

It was originally calculated that an evacuation period of 48 hours is required to adequately exhaust the transformer, and this has been confirmed in practice. A vacuum of the order of 100 microns is obtained. The whole is heated to about 100° C.

For the **−55°** to **+ 125°** C temperature range considered typical for a high performance transformer considered herein, Dow-Corning 550 silicone oil is satisfactory. This oil does not becomes more than a jell at **−65°** C. Usual transformer oil becomes solid at **−20°** C. For a less rigorous lower temperature limit other oils of the Dow-corning series may be employed, or even other oils. The oil is noted as a liquid **30** just below bellows diaphram 5 in FIG. **2**.

Certain relations are established between the expansive characteristic of the oil and the expansion capacity of the bellows. It is desirable to have the former slightly smaller or the same as the latter. A slight pressure is arranged upon the oil when the case is sealed. Any slight porosity in any of the welds of the enclosing case, or even in the metal itself, will exude an infinitesimal amount of oil, but outside air will not enter the case. If any degree of vacuum was maintained within the case air would ultimately seep in and the useful life of the transformer would be decreased.

Suitable bellows **4** are commercially obtainable from the Metal Bellows Co. These are preferably of stainless steel, of approximately 0.002-inch thick material. The bellows structure has a shape similar to a plurality of Belleville (spring) washers alternately placed back to back and welded around each joining periphery, save that the commercially obtainable bellows nest one into the other at full contraction. This construction provides an inherent spring arrangement, tending to distend the bellows to its fully expanded configuration. This characteristic provides pressure upon the oil.

In FIG. **2** the bellows are shown in a largely expanded configuration. This corresponds to a relatively low temperature. The travel of the bellows is approximately one-half inch (slightly over 1 centimeter). The change in volume for full travel is approximately 15 cubic centimeters, the bellows being approximately 4.5 cm in diameter. With an internal case size of 3×2¾×2⅝ inches (7.7 × 7 × 6 cm.) about 60 cubic centimeters of oil is contained in what free space remains within the enclosing case. An expansion volume of from zero to approximately 20 – 25 percent increase is thus provided. At the neutral position of the bellows (i.e., at room temperature) an internal pressure of 5 pounds per square inch is nominal. This increases to 10 lbs./sq. in. at the maximum temperature, with bellows **4** fully compressed upward. The pressure remains above zero at the minimum temperature, with bellows essentially fully extended downward.

When thus completed the volume between the transformer structure and the case is 60 percent filled by insulating pieces **20**, **21** and **26**; 30 percent by loose beads **28**; and only 10 percent by oil **30**. It is seen in FIGS. **1** and **2** that loose beads **28** are around the top and bottom margins of coil **8** and surrounding high voltage lead **7**. This means that these areas are essentially immersed in oil for good insulation, since every bit of space between the spherical beads is full of oil.

An alternate embodiment is possible with respect to the fabrication of insulating pieces **20**, **21** and **26**. After the transformer core-coil and terminal assembly is completed, removable molding-process pieces are inserted around high voltage lead **7** and at the upper and lower margins of coil **8**. These are shaped to extend to the outer periphery of the structure so that they can be removed. With the aid of a collapsible mold taking the place of the inside of enclosing case I, the specified epoxy with glass beads material is poured in. This gives an essentially enclosing epoxy-glass group of insulative "pieces" all in one piece. The removable pieces are then removed and the process of final assembly carried on as previously outlined. The resulting physical structure is so closely the same as that shown in FIGS. **1** and **2**, that the drawing for the same would only duplicate these figures.

The nesting bellows previously described are preferred in that the internal pressure on the oil is uniquely determined by the spring rate characteristic thereof. Alternately; however, one wall of case I may be formed with a thin diaphram for temperature-pressure equalization. This arrangement is more dependent upon the external ambient pressure, which may change very greatly in aeronautical use.

A further alternate arrangement is to physically separate bellows **4** from case **1**, placing the bellows at another desired location adjacent to the case and joined thereto by a hermetic tubing, preferably of small internal diameter to minimize the volume occupied by oil alone.

I claim:

1. A hermetically-sealed inductive device comprising;

a. a ferromagnetic core (**11–14**),

b. a coil (**8**) having at particular areas a different electrical potential than that of said core, said coil mounted on said core,

c. an enclosing case (**1**, **2**).

d. a mechanically expansive member (**4**) hermetically sealed to said case,

e. at least one shaped insulating piece (**20** and/or **21**) fitted between said case and the core-coil structure and shaped to avoid said particular areas,

f. refractory particles (**38**), small with respect to other elements of said inductive device, disposed in interstices between said other elements, and

g. an electrical-insulative liquid (**30**), completely filling remaining interstices within said enclosing case to provide insulation for the coil structure, particularly at said particular areas.

2. The sealed device of claim **1** in which;

a. said mechanically expansible member is a spring bellows (**4**), maintaining pressure upon said electrical-insulative liquid.

3. The sealed device of claim **2** in which;

a. said bellows have a relaxed configuration which reduces the interior volume of said enclosing case.

4. The sealed device of claim **1** in which;

a. the said at least one insulating piece is shaped to fill substantially half of the total volume existing between said core-coil structure and the enclosing case.

5. The sealed device of claim **1** in which;

a. one said insulating piece having a coefficient of expansion less than that of said electrical-insulative liquid is employed on each side of said core-coil structure to substantially fill the volume between that structure and the adjacent side of the enclosing case.

6. The sealed device of claim **1** in which;

a. the said at least one insulating piece is molded in one piece to substantially fill the volume between the core-coil structure, save that part of said coil (**8**) having said different electrical potential.

7. The sealed device of claim **1** in which;

a. said refractory particles (**28**) are essentially spherical in shape.

8. The sealed device of claim **1** in which;

a. each of said refractory particles (**28**) are essentially the same size.

9. The sealed device of claim **1** in which;

a. said electrical-insulative liquid is transformer oil.

10. The sealed device of claim **1** in which;

a. the expansibility of said mechanically expansible member (**4**) increases the volume within said enclosing case by approximately one-fifth.

11. The sealed device of claim **1** which additionally includes;

a. a cylindrical extension (**3**) to said enclosing case (**1**) to which said mechanically expansible member (**4**) is attached.

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