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54 Improvements in induction apparatus.

57 Stationary inductive apparatus, especially an electrical transformer, comprises a core (11) surrounded by electrical windings (12) and contained within a tank (10) in which the windings are provided with a container (14) having an at least partially opened top to contain dielectric and coolant fluid; a fluid lift pump (15) is provided to raise liquid from the bottom of the tank to the container; and the tank is connected to an external condenser (18) located at a level above that of the windings so that coolant liquid vapour may pass from the tank to the condenser and, having condensed therein, be returned (under gravity) to the container (16) surrounding the windings.

Description

IMPROVEMENTS IN INDUCTION APPARATUS

This invention relates to cooling systems for stationary induction apparatus.

Stationary inductive apparatus typically comprises a magnetic core and windings which in operation have energy losses which appear as heat. It is conventional practice to enclose the apparatus within a containing tank and to provide a circulating fluid for cooling and also to provide dielectric strength. This type of apparatus includes transformers, which are static apparatus that by electromagnetic induction transform alternating voltage and current between two or more coils at the same frequency and usually at different values of voltage current.

Transformers in general use are of the oil-immersed type having hermetic sealing or vented to atmosphere. The oil serves the dual purpose of providing dielectric strength and cooling for the heat losses generated by the core and windings. The major problem with any liquid-immersed transformer is the large volume of liquid it contains which can present an environmental hazard due to the risk of leakage.

Dry-type transformers whilst eliminating liquid coolant have several technical disadvantages including poor thermal capacity, require more space for electrical and thermal reasons and are subject to environmental contamination. Further, they are relatively costly.

Transformers have been designed and tested which contain a non-condensable gas, such as SF₆, C₂F₆ or F₄F₈, which provides the dielectric strength and which in addition contain a small volume of liquid which is pumped or atomised in order to cascade over the core and windings for cooling. This arrangement results in a significant problem due to the undesirable mixing of the non-condensable gas and the vapour. Several patents have been granted which propose solutions to the mixing problem, but none of the proposals has found commercial application. High operating pressures within the transformer tank and a device with moving parts to lift the liquid are additional disadvantages. For transformers utilising only a relatively small quantity of dielectric and coolant fluid it is necessary to provide a means of raising the liquid in order that it can remove heat generated by the operation of the core and windings. Pumps driven by electric motors suffer from a relatively high degree of unreliability due to moving parts and seals. In addition transformers using small quantities of liquid require a pump of sufficient capacity to give a spray action which must ensure that all areas of the windings are wetted or a 'burn-out' may occur. This requirement suggests that prior art vapour lift pumps are inadequate in providing sufficient liquid to the surface of the conductors of the windings.

According to the present invention there is provided stationary inductive apparatus, especially an electrical transformer, comprising a core surrounded by electrical windings and contained within

a tank, in which each set of windings is provided with a container having an at least partially open top to contain dielectric and coolant fluid; a fluid lift pump is provided to raise liquid from the bottom of the tank to each container; and the tank is connected to an external condenser located at a level above that of the windings so that coolant liquid vapour may pass from the tank to the condenser and, having condensed therein, be returned (under gravity) to the container surrounding the winding.

The term fluid lift pump as used herein means static fluid lift apparatus comprising a pipe or several pipes in which liquid is lifted by boiling a portion of the liquid, the vapour formed providing lift for the remaining unvapourized liquid. Such a pump (which may also be described as a vapour lift pump) has no moving parts, valves or diaphragm.

In operation a coolant fluid is present in each container so that the windings are substantially fully immersed in the coolant fluid which should be a condensable fluid, i.e. one which is liquid at ambient temperature. During the course of operation of the inductive apparatus (hereinafter simply referred to as a transformer) heat generated in the windings causes the coolant liquid to evaporate. Vapourized coolant liquid in the condenser connected thereto) and is recirculated to the container(s) under gravity by means of suitably arranged conduits. Coolant liquid vapour condensing on the inner side walls of the tank is recirculated to the container(s) by means of the fluid lift pump(s). The amount of such condensation may be reduced by thermally insulating the side walls of the tank.

The quantity of dielectric and coolant fluid used in the apparatus of the invention may be up to 30%, but is typically less than 10% and preferably below 5% of that used in a conventional fully liquid immersed design. Under no-load conditions the quantity of fluid in the transformer is substantially the sum of the fluid within the containers, and any residual liquid in the base of the tank and the fluid lift pump. By way of example only a IMVA distribution transformer according to the present invention requires about 15 litres of liquid, compared with a conventional design requiring 600 litres.

Under operating conditions the pressure within the transformer (the tank and condenser forming a sealed unit) is substantially that of the vapour pressure of the dielectric and coolant fluid and is preferably from 100 to 1000 mbar normal load and overload conditions at internal temperatures of from 0 to 100°C. Any non-condensibles due to intent or leakage should not exceed about 25%, but preferably not greater than 10% of the volume of the free space within the transformer including the condenser. It is especially preferred that substantially all of the free space within the tank and condenser be occupied by coolant liquid or vapour. However, as discussed below, the presence of small amounts (e.g. up to 3% of the volume) of non-condensable gases can give advantages.

The referred coolant fluids for use in apparatus of the invention are liquids at ambient temperature, with suitable boiling points and operating under transformer conditions without decomposition and preferably to give pressures within the transformer in the range mentioned above. In both their liquid and vapour form they should have good electrical and thermal properties and be of low toxicity. They are preferably non-flammable and specific examples include: fluorocarbons, chlorofluorocarbons and chlorocarbons or mixtures thereof, e.g. as disclosed in GB-A-2124253.

The combination of the containment of a small volume of fluid around the windings of the transformer and a fluid lift pump without any moving parts overcomes the problems previously described. There is always adequate fluid surrounding the windings eliminating the risk of a 'burn-out'. The essence of this invention is simplicity since there are no moving parts and the transformer design is of relatively low cost.

The fluid lift pump provides intermittent action which is adequate to supply liquid which has condensed within the tank to the windings within the containment. Any loss of fluid from them is caused by removal of heat by vapourisation. Thus the pump can be of relatively poor performance.

The containers around the windings should be constructed from material which is non-magnetic, has good electrical insulating properties including high tracking resistance, low moisture absorption, high electrical strength and with thermal properties which match the operating temperature of the transformer. Suitable materials include paper and resins, glass and polyesters and fluoroplastics. The container suitably forms a casing around the windings in the form of an inner and outer cylinder with an integral base. The windings rest on a base which is sectioned to allow fluid to flow freely. The containers fit around the limb of each core and are open or semi-sealed at the top so that the vapour pressure within them is the same as that within the transformer tank and condenser.

The fluid lift pump used in the apparatus of the invention is suitably formed of a single 'U' tube fitted below the base of the transformer with one side of the 'U' extending to a height so that it can discharge liquid into the container surrounding the winding. At the base of the 'U' on the delivery side a heater is fitted which causes vapourisation of the liquid within the fluid lift pump. The formation of vapour causes liquid to be moved up the delivery pipe of the pump. The fluid lift pump heater is external to and may be fitted around a section on the delivery side of the 'U' shape and close to the lowest curved portion. The heat density provided by the element should typically not exceed about 10 Watts per cm² and should not give rise to a fluid temperature that would cause decomposition. The heat density is preferably 0.5 to 9 W.cm⁻², especially about 3 W.cm⁻². Each 'U' forming the fluid lift pump requires a heat source.

In a preferred embodiment of the invention a succession of fluid lift pumps are connected one above the other, in order to achieve increased liquid lift for larger transformers and in this case suc-

cessive pumps are preferably connected via an intermediate reservoir located at or about the delivery point of the lower pump. A single fluid lift pump can achieve a lift of about three-fold its height relative to the vertical length of the 'U' shape. The 'U' section of the fluid lift pump is situated beneath the base of the transformer tank, thus there are practical constraints to the length of the 'U' which can be accommodated. To overcome this limitation the top of the delivery side of the fluid lift pump can be formed into a further 'U' shape with the delivery pipe extended. A heating element is fitted on the delivery side at the base of the 'U'. In any event the heating elements and associate parts of the pump are preferably located externally of the transformer tank vessel.

It is further preferred that the delivery pipe of any fluid lift pump be thermally insulated since this has been found to provide for better and more reliable pumping action, especially at start-up.

In a further embodiment of the invention a relatively small quantity of a substantially non-condensable gas is present in the transformer vessel in order to prevent boiling of the dielectric and coolant fluid within the containers of the windings on each phase and the residual liquid within the base of the transformer tank. Generally, this non-condensable gas should provide an additional pressure not greater than that required for adequate dielectric strength, typically about 50-150 mm at 20°C. Such gases can be He, N₂, CO₂, CF₄, C₂F₆, C₄F₈, SF₆ or combinations thereof. Within the transformer these gases will be mixed with the vapours of the dielectric and coolant fluid which will give rise to an improvement to their dielectric strength. The prime purpose of the inert gas is to prevent the liquid around the windings from boiling until its vapour pressure and resultant dielectric strength provide sufficient integrity.

In yet a further embodiment of the present invention a wicking material is used in order to ensure that heat generating components not normally submerged under the dielectric and coolant fluid are wetted so that heat removal by vapourisation can take place. Such areas include surfaces of the core and connections which carry current resulting in heating. A preferred wicking material is woven glass cloth. Generally the cloth is wrapped around conductors which emanate from the windings to the bushings and can also be laid on the surface of the core. There must always be sufficient sections of wicking material immersed within the liquid of the containers to ensure capillary action.

In a further embodiment a sensor is provided to control the operation of one or more fluid lift pumps of the transformer. When transformers may be evaluated for selection many users apply capitalisation of losses as a major consideration. Evaluations of this kind are based on iron losses being typically between 5-10 times the value of the losses due to the load current in the windings. Thus in many situations it is important that the fluid lift pump operates as a transformer load-dependent device. As well as using electrical load of the transformer for the sensor references such as vapour pressure or

temperature either as an absolute or differential value may be provided. In some cases it may be advantageous to operate the fluid lift pumps by using the fluid level within the container of one of more of the phases as a reference for the sensor.

In the following description reference will be made to the accompanying drawings in which:-

Figure 1 is a side sectional view of a transformer according to this invention;

Figure 2 is a detailed view of the contained windings in combination with a fluid lift pump according to this invention;

Figure 3 shows a modified lift pump; and

Figure 4 shows a preferred form of pump.

As shown in Figure 1, a transformer comprises a containerised tank 10 containing a core 11 and windings 12 which windings are surrounded by a container 13 and filled with a dielectrical coolant fluid 14. Residual fluid 14 is contained at the base of the transformer tank 10 and the 'U' section 15 of a fluid lift pump. Fitted around the 'U' section 15 on delivery side is a heating element 16 which causes fluid 14 within the 'U' section 15 to partially vapourise under transformer operating conditions via a sensor 17 which can monitor temperature, pressure or fluid level within the container 13 in order to provide a reference to control the operation of one or more fluid lift pumps comprising of the 'U' section 15 and heating element 16. When the transformer is carrying electrical load the core 11 and windings 12 produce heat which is dissipated by vapourisation of the fluid contained in tank 13. The vapour enters condenser 18 through inlet 19 and returns via outlet 20 as condensate into the container 13. The fluid lift pump may be operated continuously whilst the transformer is in operation or can be controlled by the sensor 17. With an overhead condenser 18 the condensate is directed so that it can return to the container 13 thus with this arrangement the pumping requirement is significantly reduced as only the condensate lost on the tank surfaces of the transformer has to be replenished into container 13. Fluid 14 from the fluid lift pump can also be directed onto the core.

Figure 2 shows a sectional arrangement consisting of the core 11 windings 12, fluid 14 and the fluid lift pump 15 with its heater 16 contained below the transformer tank 10. The windings 12 comprise two coils both of which are fully immersed in the fluid 14 which gives dielectric strength and removes heat from the surfaces of the coils by vapourisation. The heater 16 is positioned on the delivery side of the 'U' section 15. The heat partially vapourises the liquid providing lift for the remaining liquid 14 to be delivered into the container 13.

Figure 3 shows arrangement whereby two fluid lift pumps are so connected that they provide additional lift to the liquid 14 and can be utilised for larger power transformers.

In Figures 1, 2 and 3 the fluid lift pump is shown schematically as comprising a simple U-tube with an appropriately positioned heating element. A more preferred form of pump is shown diagrammatically in Figure 4 and, as shown, comprises a downcomer 14 connected the bottom of a tank 10 and in turn

connected with the lower part of thermally insulated rise or delivery tube 15, heat being supplied to the pump by means of cartridge heater 46 inserted in well 42 in the lower end of riser 18.

Claims

1. Stationary inductive apparatus comprising a core (11) surrounded by electrical windings and contained within a tank (10) characterized in that the windings are provided with a container (14) having an at least partially open top to contain dielectric and coolant fluid; a fluid lift pump (15, 16) is provided to raise liquid from the bottom of the tank to the container; and the tank is connected to an external condenser located at a level above that of the windings so that coolant liquid vapour may pass from the tank to the condenser and, having condensed (18) therein, be returned (by gravity) to the container surrounding the winding.

2. Stationary inductive apparatus as claimed in claim 1 characterized in that it is in the form of an electrical transformer.

3. Stationary inductive apparatus as claimed in claim 1 or claim 2 characterized in that it has two or more fluid lift pumps in series to raise liquid from the bottom of the tank to the container.

4. Stationary inductive apparatus as claimed in any one of the preceding claims characterized in that the rising delivery pipe of any fluid lift pump is thermally insulated.

5. Stationary inductive apparatus as claimed in any one of the preceding claims characterized in that the tank and condenser form a sealed unit substantially filled with a condensible dielectric coolant or its vapour, the windings being substantially immersed in the coolant liquid.

6. Stationary inductive apparatus as claimed in claim 5 characterized in that up to 30% of the free space in the tank/condenser assembly is occupied by a non-condensable gas.

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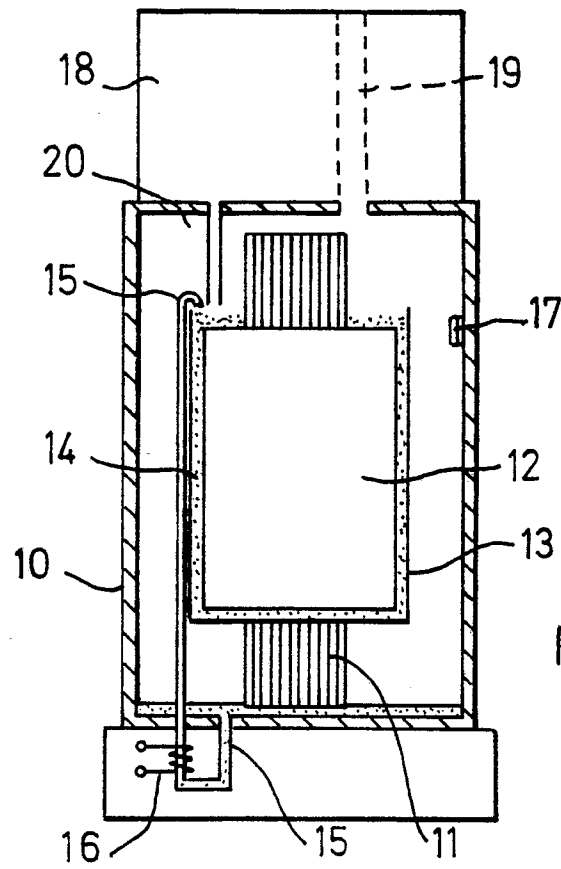


FIG. 1.

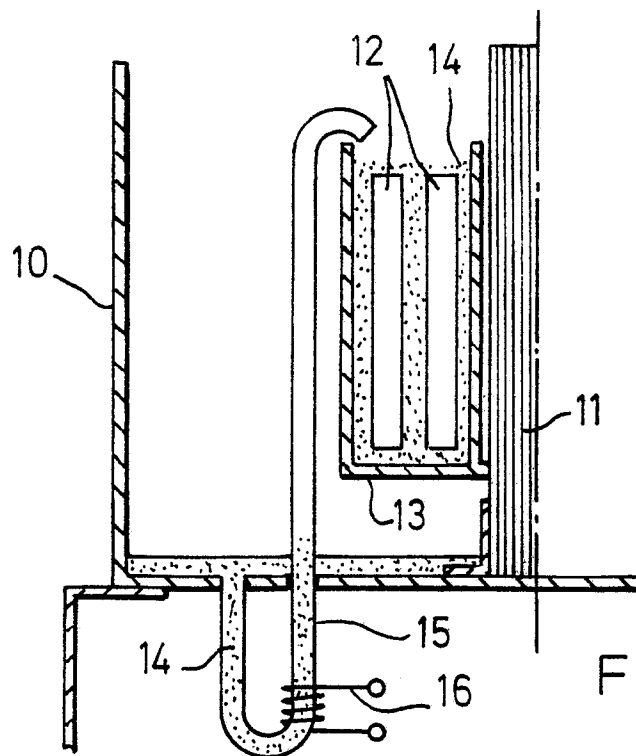


FIG. 2.

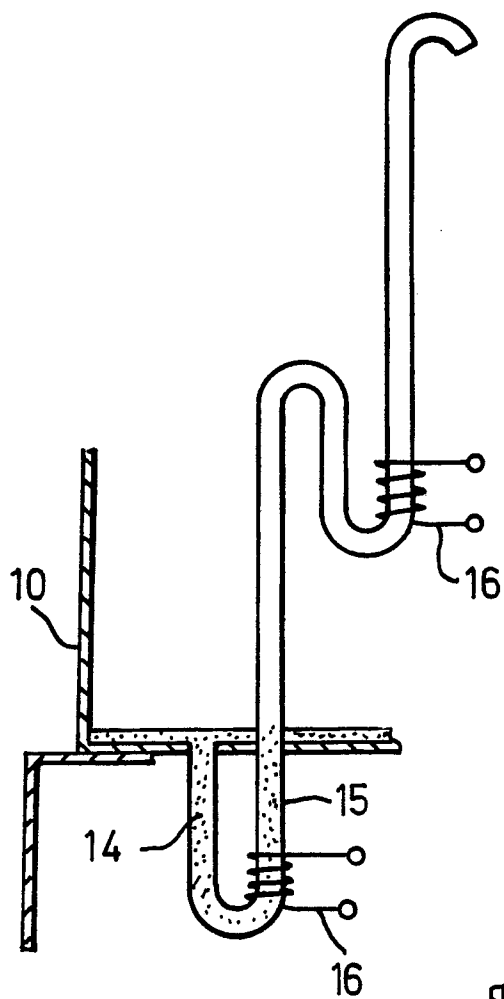


FIG. 3.

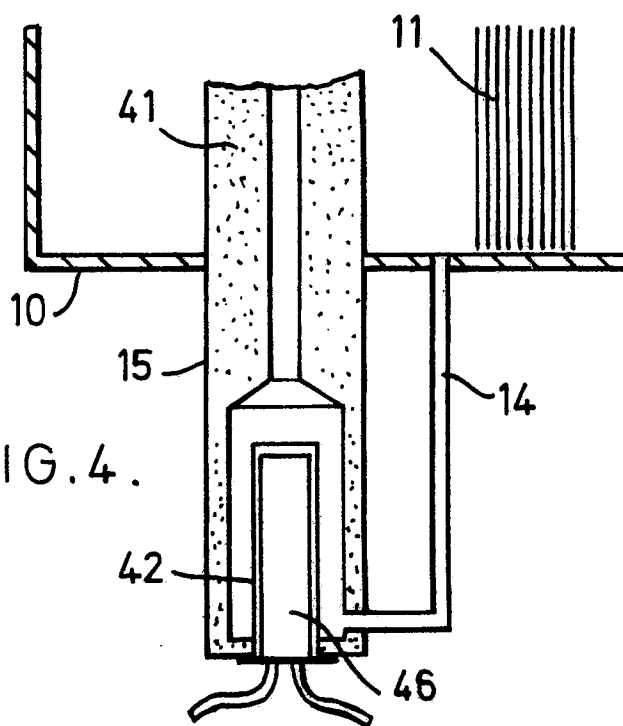


FIG. 4.