

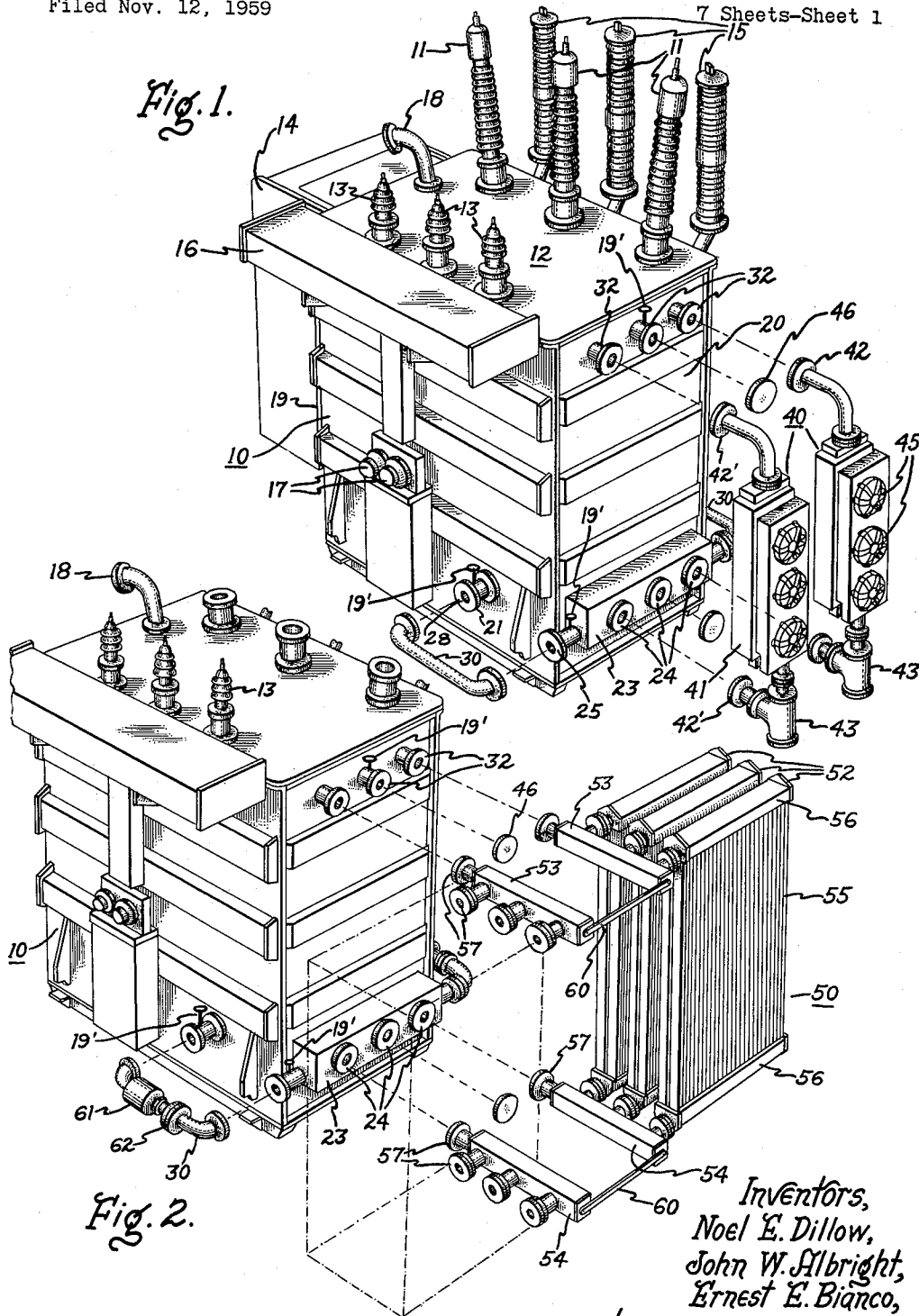
June 16, 1964

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ELECTRICAL APPARATUS

3,137,829

Filed Nov. 12, 1959

7 Sheets-Sheet 1



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Fig. 3.

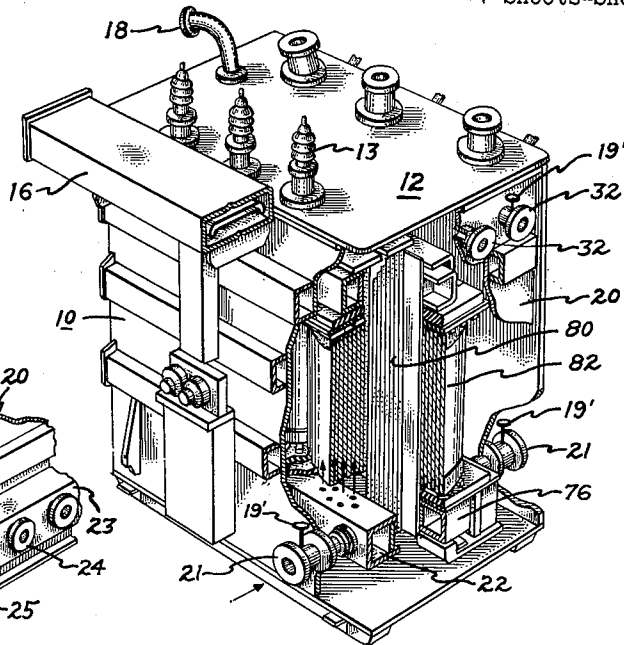


Fig. 6a.

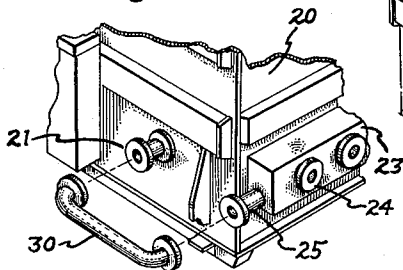


Fig. 6b.

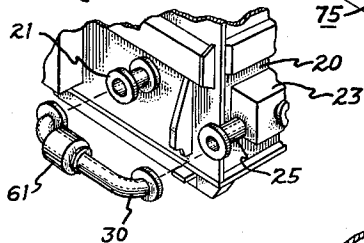


Fig. 4.

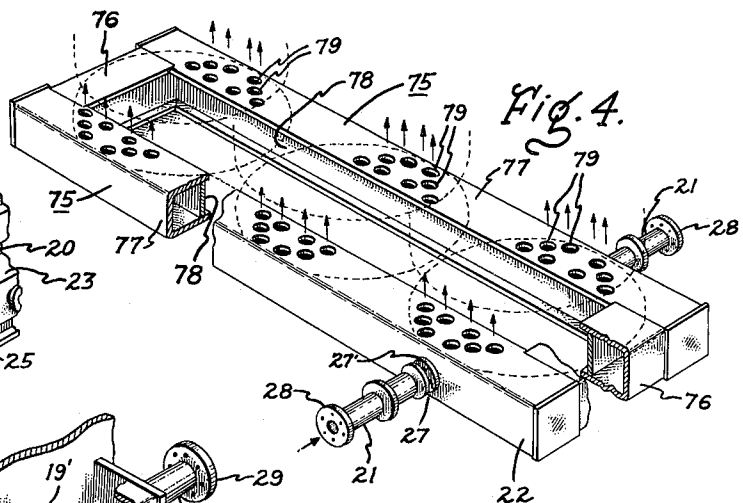
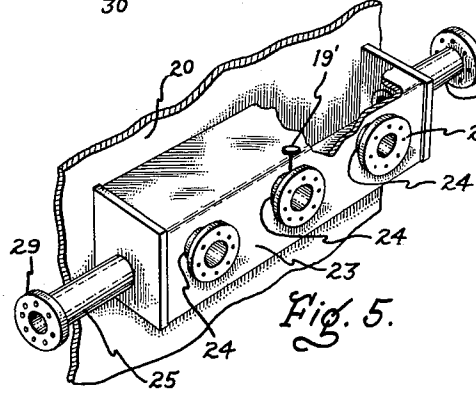


Fig. 5.



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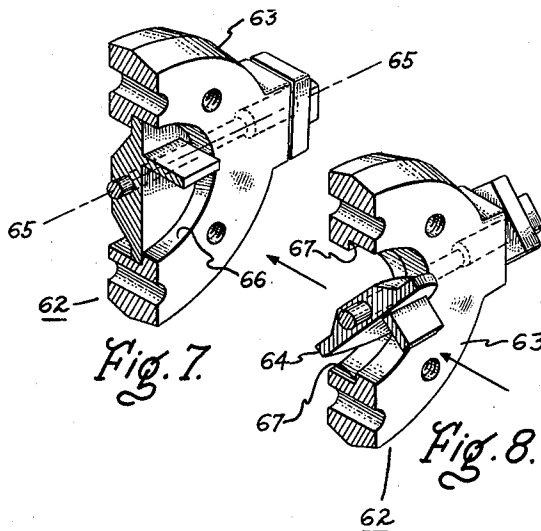
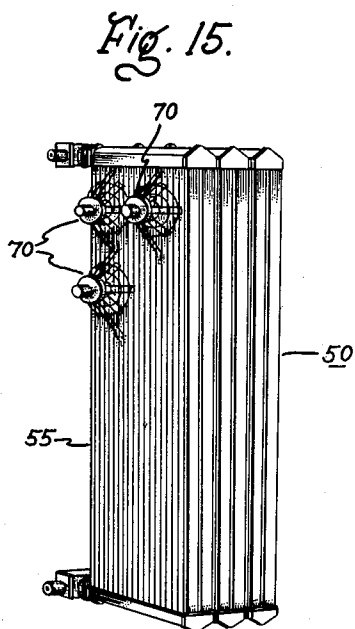
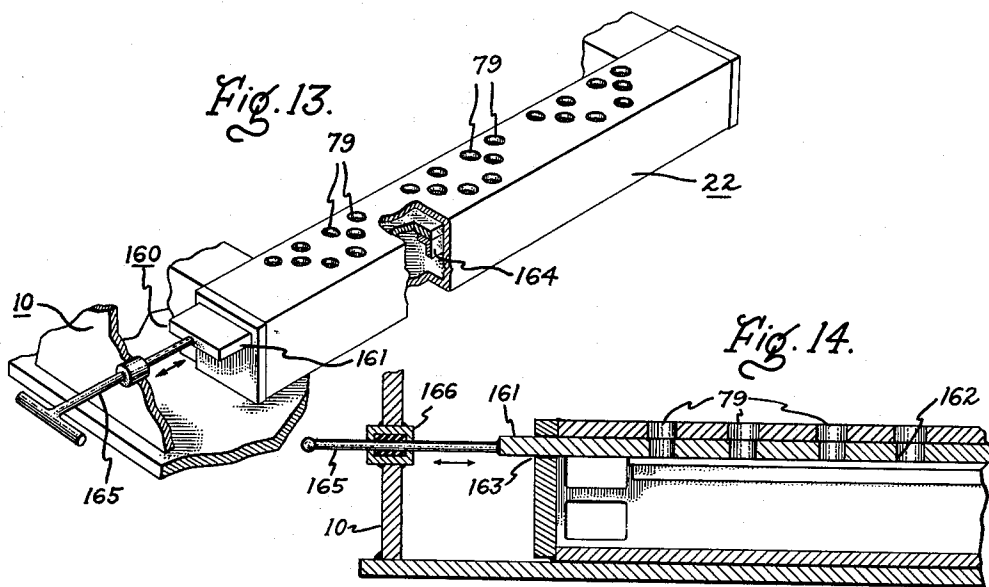
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Fig. 9.

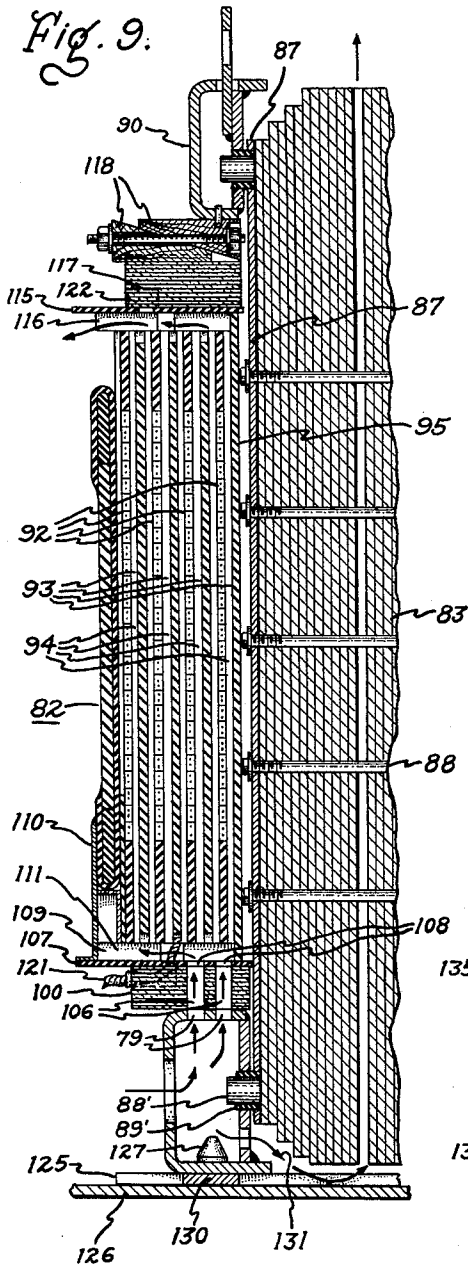
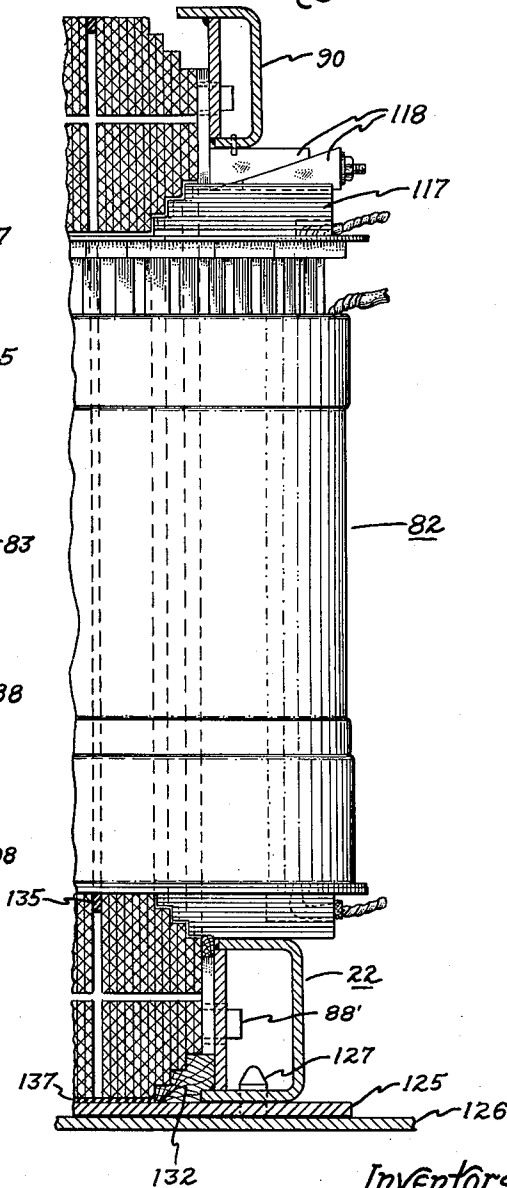


Fig. 10.



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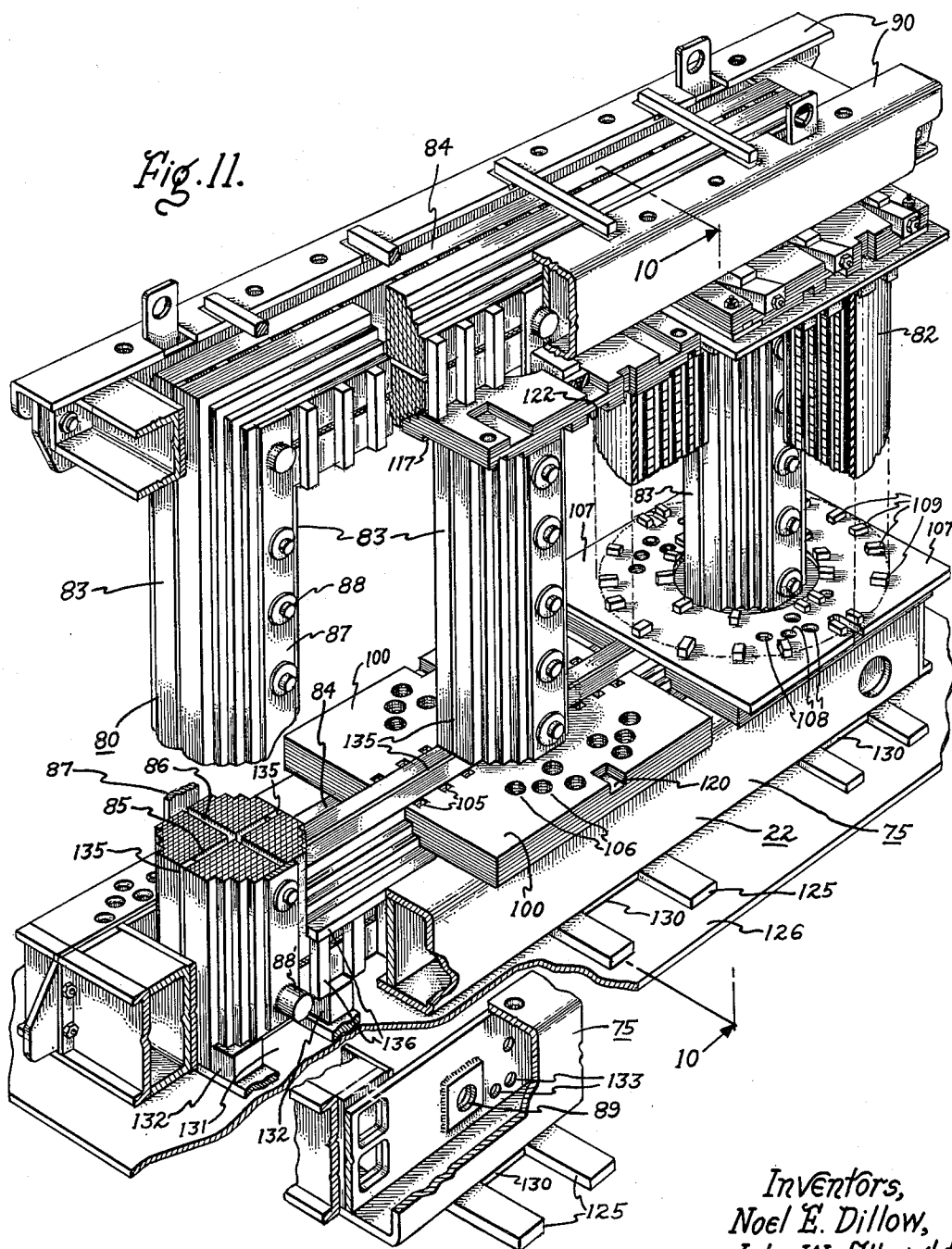
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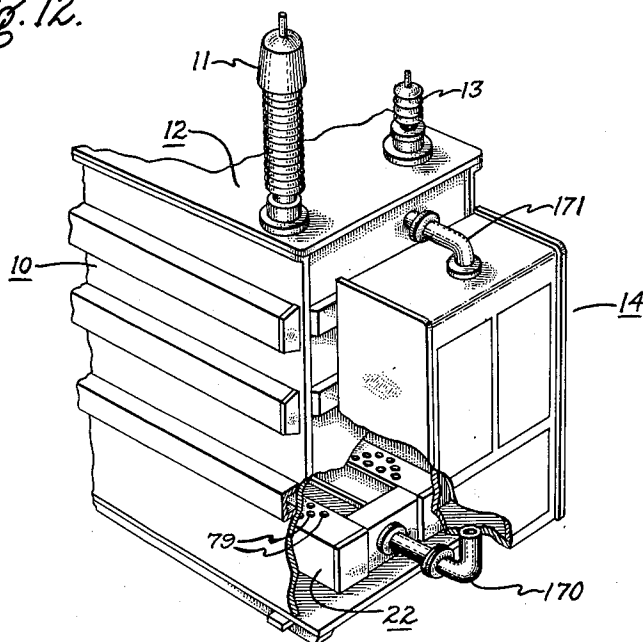
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Fig. 12.



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Fig. 16.

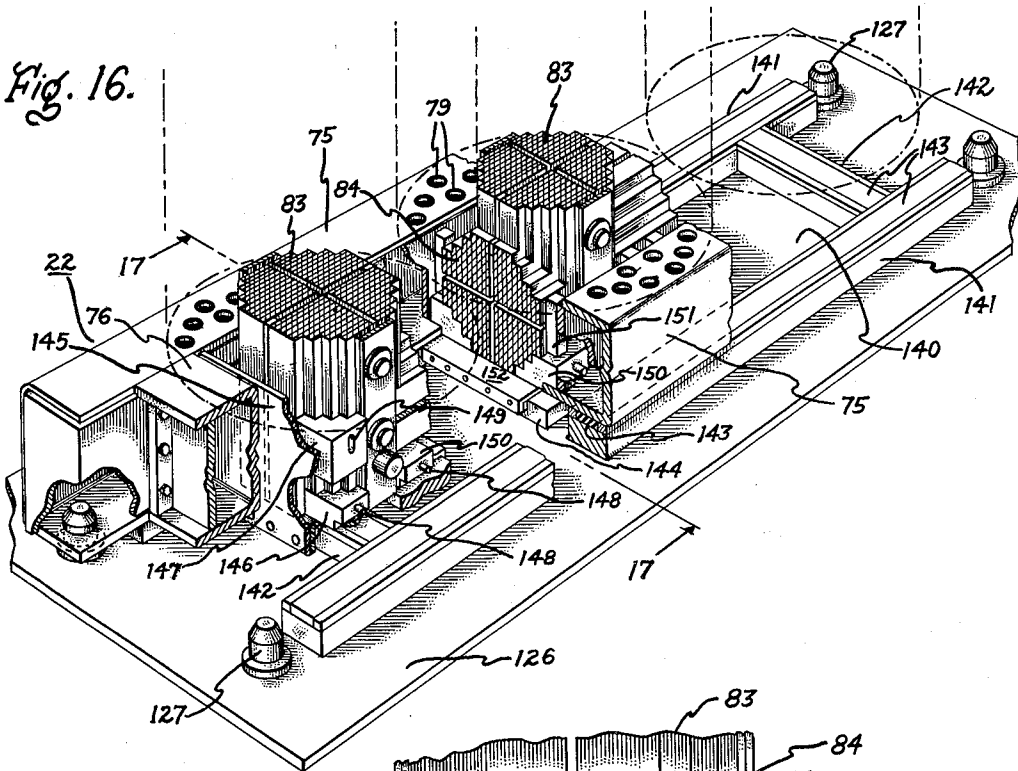
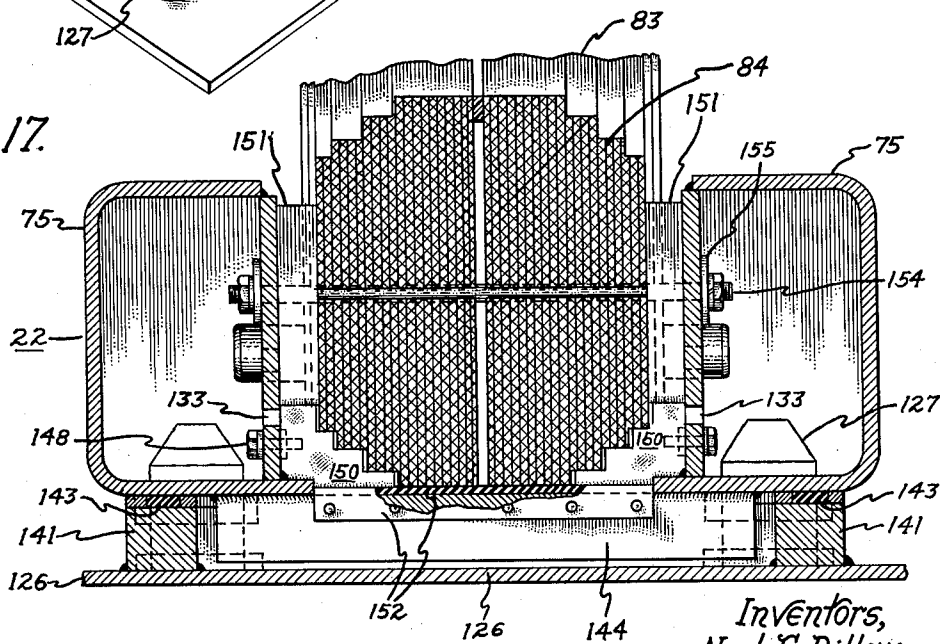


Fig. 17.



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3,137,829

ELECTRICAL APPARATUS

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Filed Nov. 12, 1959, Ser. No. 852,301
9 Claims. (Cl. 336-57)

This invention relates to electrical apparatus and more in particular to an improved cooling fluid circulating arrangement for such apparatus.

It is fundamental that electrical apparatus generate heat in proportion to the current that passes through them. Consequently, severe limitations are placed on the design of many types of electrical apparatus because their current carrying capacity is limited by the heat that they produce, since the heat tends to break down the insulation around the apparatus. In the past, many types of cooling systems have been devised for such apparatus in an effort to dissipate the heat produced so that the apparatus can carry greater current loads without breaking down its insulation. This problem is especially acute in stationary electrical induction apparatus, and in particular in transformers, which we have chosen as an illustration of apparatus to which our invention can be applied.

Transformers are conventionally rated in kva., which, in effect, can be considered as a measure of the amount of power they can transmit without causing a breakdown in their insulation. Kva. stands for kilo volt amperes and is computed by multiplying the voltage at which the transformer operates by the number of amperes of current that the transformer transmits and dividing this product by 1,000. Since the electrical power distribution systems in this country essentially always operate at a fixed voltage (usually 110 or 220 volts), the only variable in the transformer rating quotient kva. is the current passing through the transformer. As previously stated, the heat generated by a transformer is proportional to the current that passes through it. Thus, as the kva. output of a transformer is increased (because it transmits more current), the heat generated by the transformer increases, and more cooling facilities must be applied to the transformer to dissipate the increased heat.

Transformers are conventionally cooled by passing a heat absorbing fluid through their windings and core. The fluid is usually a dielectric liquid or an electronegative gas. In the past, transformer cooling systems have employed an external tank or enclosure which surrounds the transformer and confines the fluid therein. The transformer enclosure conventionally has channels or conduits associated therewith for directing the flow of the fluid through the transformer. In some types of transformers heat exchange means of one type or another, such as radiators or refrigerating units, have been externally connected to the tank surrounding the transformer, and the heat absorbing fluid has been circulated through such heat exchange means to dissipate the heat it absorbs from the transformer. This general type of cooling arrangement is shown in U.S. Patent 2,685,677 which issued to K. K. Paluev on August 3, 1954, and which is assigned to the assignee of this application.

While the principle of circulating a heat absorbing fluid through a tank enclosed electrical apparatus, and transferring the heat absorbed by such fluid by externally connected heat transfer means has proved to be a satisfactory method of cooling transformers, this arrangement has led to serious problems that have hampered the low cost distribution of electrical energy. The cost of transformers, and in particular the large sized transformers used in great urban and industrial power distributing systems, has been exceedingly high because of design and manufactur-

ing difficulties encountered in fashioning cooling systems to satisfy the requirements of large size transformers. Because the kva. needs of various power distributing systems vary widely, transformers have had to be virtually individually designed and tailor-made to fit the kva. needs of each individual electrical energy distribution system. This is evident when the needs of a small town, as far as electrical energy is concerned, are compared with the needs of a great city. Consequently, in this age of standardized manufacture and mass production line efficiency, transformer manufacturers have been forced to individual design, and so to speak, "hand make" each large sized transformer because a flexible transformer design capable of standardization, and yet permitting varying transformer kva. rating, has not been previously developed.

Still another, and perhaps more serious drawback of the previous methods of designing and manufacturing transformers is the inability of such transformers to significantly vary their kva. output once they have been manufactured and installed in a power distribution system. The primary reason for the inflexible kva. output of the old type transformers is the fact that their cooling systems were designed to absorb the heat produced by a specific kva. load that was anticipated at the time the transformer, its component parts, such as its core, windings, and internal fluid circulating structure, were designed to produce the kva. output required by the power distributor for a particular application; after the internal structure of the transformer was designed the amount of heat that it would produce under its design kva. load was computed, and a system for cooling the transformer was then designed. This cooling system was intended to operate essentially only at the temperature ranges anticipated under design kva. conditions. Consequently, if at a later time, the power distributor wished to significantly alter the kva. his transformers were supplying, he had to order and have produced new transformers, because each transformer and its cooling system were integrally designed to operate only at a single kva. output. Of course, it is understood that by single kva. output it is meant that the transformer operated within a small range of varying kva. outputs that changed during the day and from day to day as the power load on the distributing system changed; previously designed transformers were not intended to produce significantly varying kva. outputs, such as 10,000 kva. to 50,000 kva. Transformers produced in accordance with our invention, however, are capable of operating at significantly varying kva. loads merely by changing the number or kind of the diverse types of cooling units that can be externally attached to them. This unique arrangement is accomplished by standardizing the design of the transformer itself, and by standardizing the design and sizes of the external cooling units that can be applied to the transformer, in accordance with modern production line techniques that employ interchangeable parts.

By the use of what we call the "Black Box" concept, we have provided a transformer cooling and clamping system that permits standardization of parts and sizes, and the use of mass production line techniques that reduce greatly the cost of transformers, and hence ultimately reduce the cost of electrical power to consumers. The "Black Box" concept requires that the transformer itself, including the windings, core, internal fluid circulating system, and surrounding tank, be of one simple design for a great variety of kva. power carrying capacities. The external cooling or heat transfer system through which the heat absorbing fluid flows is the only structure that varies under this concept; the individual units of the cooling system, however, are also standardized to fit on the transformer, and more or less heat transfer units of diverse types can be added or subtracted in accord-

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ance with the heating load placed on a transformer by varying kva. requirements. Thus, the standardized transformer itself can be regarded as a "Black Box" that has certain cooling requirements determined by the kva. power load it carries; because the transformer is an unthinking "Black Box" it does not know and it does not care what external heat transfer units are attached to it to satisfy its needs. Thus, the external cooling devices that are attached to such a transformer, because it is of standard construction and size, and because the external heat transfer units are themselves of standardized construction, can be varied or altered as the cooling needs of the transformer vary or are altered. The use of the "Black Box" concept has enabled manufacturers of transformers to employ mass production line techniques in constructing the "Black Box" transformer units. After a "Black Box" transformer unit is constructed, the external heat transfer units can be attached in accordance with the kva. power requirements dictated by the power distribution system in which the transformer will be used. Furthermore, if the kva. requirements of the power distribution system change after a "Black Box" transformer has been installed therein, the kva. output of the "Black Box" transformer can be altered to coincide with the new requirements merely by replacing the external heat transfer or cooling units with other cooling units capable of satisfying its changed cooling needs. Consequently, new transformers need not be obtained by the power distributing system every time its needs change.

Transformers are conventionally constructed with vertically disposed core elements, and winding elements are placed over the core elements. Because variations in the current flowing through the winding elements causes variable electromagnetic forces to act upon the winding elements that expand or contract the winding elements, it has been found necessary to vertically clamp the winding elements on the core. A further aspect of our invention that will become apparent from the detailed description that follows is the provision of a clamp for the winding elements and core that serves the dual function of also being a conduit for distributing heat absorbing fluid throughout the transformer. In accordance with the basic principle of this invention the clamping element is also of standardized design.

Accordingly, it is an object of our invention to provide a new and improved cooling and clamping arrangement for use with electrical apparatus.

It is a further object of our invention to provide a transformer of standardized design adapted to be produced by mass production techniques.

It is a further object of our invention to provide a transformer which has a standardized design that is capable of satisfying varying kva. power requirements by the addition or subtraction of standardized cooling units from its exterior.

In accordance with one aspect of our invention, we provide a transformer in which the core and windings thereof are enclosed in a tank. The windings and core of the transformer are clamped by means of a clamping element that serves as a conduit for a heat absorbing fluid that circulates through the tank and dissipates the heat generated by the transformer. The clamp-conduit and the interior of the tank are coupled to external connections upon which standardized heat transfer units of diverse types can be connected, as dictated by the kva. power requirements of the distribution system in which the transformer is to be used.

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter which we regard as our invention, it is believed that the invention will be better understood from the following description taken in connection with the accompanying drawings.

In the drawings:

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FIGURE 1 is a perspective exploded view of a transformer according to one embodiment of the invention.

FIGURE 2 is a perspective exploded view of a transformer illustrating another embodiment of the invention.

FIGURE 3 is a perspective partially cross sectional view of a portion of the transformers of FIGURES 1 and 2.

FIGURE 4 is a perspective partially cross-sectional view enlarged of the internal plenum chamber of the transformer of FIGURE 3.

FIGURE 5 is a perspective partially cross-sectional view of a portion of the transformers of FIGURES 1 and 2, and illustrating the external plenum chamber thereof.

FIGURES 6a and 6b are perspective views illustrating additional modifications of the embodiment of FIGURE 2.

FIGURE 7 is a perspective partially cross-sectional view of a full valve of the transformer of FIGURE 3 in the closed position.

FIGURE 8 is a perspective cross-sectional view of the full valve of the transformer of FIGURE 3 in open position.

FIGURE 9 is a cross-sectional view of the core and windings of the transformer of FIGURES 1, 2, and 3 taken along the mid-point of the winding legs thereof.

FIGURE 10 is a cross-sectional view of the transformer of FIGURES 1-3 taken along the line 10-10 in FIGURE 11.

FIGURE 11 is a perspective partially cross-sectional and partially exploded view of the core and windings of the transformer of FIGURES 1-3.

FIGURE 12 is a perspective view showing a load tap changer connected to the transformer of FIGURE 2.

FIGURE 13 is a perspective partially cross-sectional view of a modification of the internal plenum chamber of the transformer of FIGURES 1-3.

FIGURE 14 is a cross-sectional view of the modification of FIGURE 13.

FIGURE 15 is a perspective view of a modification of the radiator bank for the embodiment of FIGURE 2.

FIGURE 16 is a perspective partially cross-sectional and partially exploded view of a modification of the transformer of FIGURES 1-3, and

FIGURE 17 is a cross-sectional view taken along the line 17-17 in FIGURE 16.

Referring now to the drawings, and more in particular to FIGURE 1, therein is illustrated a transformer comprising a sealed enclosure or tank 10. The sealed enclosure or tank 10 is occupied by a heat absorbing fluid, such as a dielectric liquid or an electronegative gas. The tank 10 may be exteriorly provided with any of the conventional accessories, such as high voltage bushings 11 extending through the top cover 12 to provide external connections for the high voltage windings, and the low voltage bushings 13 also extending to the cover 12 to provide connections for the low voltage windings. Similarly, a load tap changing enclosure 14 may be provided on one end 19 of the tank 10 to provide means for regulating the voltage of the transformer, and lightning arresters 15 may be provided connected to one side of the tank 10 and extending upwardly to facilitate their interconnection with the high voltage bushings 11. Additional accessories, such as an oil preservation tank 16 for the dielectric liquid and various meters and gages 17 may also be provided on another side of the transformer tank 10 according to conventional practice. A pressure relief valve 18 may be added according to conventional practice. It is to be noted, however, that these accessories have been located upon the transformer tank in such a manner that one end 20 of the tank is available for use of an external fluid circulation system, to be disclosed in more detail in the following paragraphs.

The external fluid circulating system includes a pair of intake ducts 21 having coupling means, such as flanges

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28. The intake ducts 21 are provided on opposite sides of the tank 10, and are disposed in alignment nearer the bottom of the tank 10 adjacent the end 20 thereof. The ducts 21, as illustrated in FIGURE 3 extend outwardly through the side walls of the tank 10, and are connected to opposite sides of an internal plenum chamber 22, to be disclosed in more detail in the following paragraphs. Referring again to FIGURE 1, an external plenum chamber 23 is provided adjacent the bottom of the end 20 of the tank 10. The external plenum chamber 23, which may be more clearly seen in FIGURE 5, may have a substantially rectangular cross-section, and may extend for substantially the entire width of the end 20 of the tank 10. If desired, the end 20 of the tank may comprise one wall of the chamber 23. Thus, there is no direct connection between the inside of the chamber 23 and the inside of the tank 10. A plurality of fluid entry ports 24, having coupling means such as flanges 24', are provided extending from the external plenum chamber 23 normal to the surface of the end 20 of the tank 10. A fluid discharge duct 25 having coupling means such as a flange 29 is also provided extending from each end of the chamber 23 horizontally and substantially parallel to the end 20 of the tank. As illustrated in FIGURE 1, the flanged discharge ducts 25 are aligned with each other in substantially the same horizontal plane as the flanged intake ducts 21 on the sides of the tank 10; the ducts 21 and 25 face in the same direction. A conduit 30 is provided extending between and connected to each pair of flanged ducts 21 and 25, thereby providing a connection for fluid flow between the internal plenum chamber 22 and the external plenum chamber 23. Thus, the fluid entry ports 24, external plenum chamber 23, fluid discharge ducts 25, conduits 30 and intake ducts 21 form a fluid intake means for conveying heat absorbing fluid from externally located heat transfer elements to the internal plenum chamber 22 for distribution through the windings and core. It should be noted that each external fluid connection on the enclosure tank 10 may be provided with a shut off valve, as indicated at 19' in FIGURES 1-3 and 5, so that fluid may be sealed in the enclosure 10 when external elements are being added or changed.

The upper portion of the end 20 of the tank 10 is provided with a plurality of fluid exit ports 32. The ports 32 extend through the end wall of the tank, as illustrated in FIGURE 3 and are substantially vertically aligned with the flanged fluid entry ports 24 of the external plenum chamber 23. The fluid exit ports 32 may be provided with suitable coupling means such as the flanges 33. The fluid exit and entry ports are thus arranged so as to form vertically aligned pairs of fluid passages between which external heat transfer means may be removably connected.

In the embodiment shown in FIGURE 1, the external heat transfer means 40 extends between the vertically aligned flanged ports 32 and 24. The heat transfer means 40 may be comprised of conventional forced fluid cooling units 41 having heat radiating tubes (not illustrated) connected to the fluid exit ports 32 of the tank 10 by way of conduits 42, and connected to the lower flanged ports 24 by way of suitable pumps 43. The units 41 may be provided with suitable coupling means such as the flanges 42'. The tank 10 is filled with a dielectric liquid, such as transformer oil, and the pumps 43 are arranged to draw the dielectric liquid downwardly into the forced fluid cooling units 41 from the top of the tank 10, into the external plenum chamber 23, thence through the conduits 30 and flange connections 21 into opposite sides of the internal plenum chamber 22. One or more fans 45 may be provided to force air across the surfaces of the unit 41. If desired, more ports 32 and 24 may be provided than heat transfer means 40, the additional ports being plugged by any suitable means such

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as plates 46 in order to permit future modification of the circulation system of the transformer, as for example, by the addition of other external cooling units of a different type.

In the modification of the invention illustrated in FIGURE 2, radiator units 50 have been used in place of the fluid cooling units 41. In this modification, the radiator units 50 may be comprised of one or more banks 52 of radiator tubes extending between and connected to upper headers 53 and lower headers 54. The upper headers 53 are connected to the fluid exit ports 32, and extend outwardly from the tank 10 and normal to the end 20 of the tank. The lower headers 54 also extend outwardly of the tank and substantially normal to the ends 20 and are connected to the fluid entry ports 24 on the external plenum chamber 23. Coupling means, such as flanges 57, may be employed to facilitate connection of the units 50. The banks 52 may be comprised of a plurality of radiator or heat exchange tubes 55 extending between upper and lower tube headers 56, the tube headers being connected to the upper and lower headers 53 and 54 respectively. The specific structure of the radiator units 55 forms no part of the present invention but may, for example, be of the type disclosed in co-pending application of C. M. Cederstrom, Serial No. 802,682, filed March 30, 1959, and assigned to the assignee of the present invention.

In order to permit the connection of the maximum number of heat exchange tubes 55 to the enclosure tank 10, the units 55, which are preferably substantially coplanar, extend in parallel spaced-apart planes outwardly from the tank 10, the planes being parallel to the end 20 of the tank 10. In the illustration of FIGURE 2, the radiator unit 50 connected to the left-hand headers 53 and 54 has been illustrated in phantom in order to more clearly illustrate the invention. While only three banks 52 have been illustrated in FIGURE 2 as connected between each pair of headers 53 and 54, it will of course be obvious that more or less banks may be connected in this manner without departing from the spirit or scope of the invention. The headers 53 and 54 may be braced by any suitable means, such as braces 60 extending between respective pairs of headers, in order to provide sufficient mechanical support for the assembling. The headers 53 and 54 are preferably vertically aligned, and the banks 52 are also preferably symmetrical about horizontal axis extending through their mid-points in order to facilitate manufacture and assembly of the circulation system without the necessity for designating either end as the top or bottom. Similarly, if the fluid exit ports 32 on the tank enclosure 10 extend outwardly from the tank the same distance as the fluid entry ports 23, the banks of radiator tubes 55 in combination with their respective headers 53 and 54 may be employed on either side of the tank 20 without modification, since a unit such as the right-hand unit illustrated in full lines in FIGURE 2, could be placed on the left-hand side of the transformer merely by turning it upside down.

In the modification of the invention illustrated in FIGURE 2 each of the conduits 30 has been provided with a pump 61 and a valve 62. The pumps 61, which may be of any conventional construction, are connected to draw dielectric liquid from the external plenum chamber 23, through the conduit 30, end valve 62 and then force the liquid into the internal plenum chamber 22. The valve 62 which is more clearly illustrated in FIGURES 7 and 8 is of the type permitting flow in one direction, while preventing flow in the other direction. For example, the valve 62 may be comprised of an annular body member 63 adapted to be bolted between the flanges on the conduit 30. A vane 64 is pivoted about an axis 65 extending through the aperture 66 in the body member 63 in the plane of the member 63. The aperture 66 in the body member 63 is provided with valve seats 67 and the axis 65 is offset from the center of the body member 63, so that when a fluid flows toward the right, as illustrated

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in FIGURE 7, the fluid will force the vane 64 against its valve seats 67 to prevent flow therethrough, and as illustrated in FIGURE 8, when fluid flows toward the left, the vane 64 is open to permit the flow of fluid therethrough. Referring again to FIGURE 2, the valves 62 are connected to permit the flow of fluid toward the internal plenum chamber 22 only and to prevent the flow of fluid toward the external plenum chamber 23.

In the modification of the transformer of FIGURE 2 as illustrated in FIGURE 6a, the conduit 30 may be provided without the valve 62 and pump 61 and in the modification of FIGURE 6b the valve 62 is omitted but the pump 61 may be retained. As a further modification of the transformer of FIGURE 2, as illustrated in FIGURE 15, suitable fans 70 may be provided on the outermost bank 52, to force air therethrough. The exact number of fans used may be more or less than are illustrated in FIGURE 15, depending on the thermal load on the radiator unit 50.

Referring now to FIGURE 3, the internal fluid circulating system includes an internal plenum chamber 22 positioned in the bottom of the enclosure tank 10. The chamber 22, which may be more clearly seen in FIGURE 4, is comprised of a pair of substantially parallel, elongated tubular members 75 extending longitudinally of the enclosure 10 and joined at their ends by a pair of transversely extending tubular members 76. The longitudinal tubular members 75 may, for example, be formed from channel-shaped elements 77 of structural material with plates 78 being welded between the edges of the elements 77 to form a chamber having a substantially rectangular cross-section, it being understood that other cross-sectional configurations are equally suitable. The members 75 are preferably arranged with the plates 78 facing each other, and the transverse end members 76, which may be formed in a similar manner, also may be positioned with the welded plates facing each other. The resultant structure of the pairs of members 74 and 76 forms a closed substantially parallelepiped chamber having two straight substantially parallel portions defined by longitudinal members 75 interconnected at the ends by two relatively short substantially parallel sections defined by the transverse members 76. The upper surfaces of the members 75 are substantially flat and in the same plane, and are provided with pluralities of groups of fluid exit apertures 79 extending therethrough, the number of groups of apertures in each member being equal to the number of legs 83 on the core 80. The flanged ducts 21, which extend outwardly through the side walls of the enclosure tank, may extend through fluid inlet openings at 27' in the sides of the members 75. The ducts 21 are preferably in aligned relationship, and preferably near one end of the members 75. Each of the ducts 21 is connected to the member 75 nearest the side of the tank 10 through which the duct 21 extends. A preferred manner of connecting the flanged ducts 21 to the plenum chamber 22 by means of a spring urged annular sealing element 27, which forms no part of the present invention, is disclosed and claimed in Patent 3,059,043 granted October 16, 1962 on a co-pending application Serial No. 853,895 of E. Bianco and F. Zieba, filed November 18, 1959 and assigned to the assignee of the present invention.

Referring again to FIGURE 3, a magnetic core 80 is provided within the tank 10, the core 80 having one or more winding legs 83, according to conventional practice, with the winding legs being surrounded by one or more electric windings 82. As is true of all electrical apparatus, the core and windings generate heat in proportion to the energy passing through them.

The physical relationships between the components within the tank 10 may be more clearly understood by reference to FIGURE 11 of the drawings. In FIGURE 11 the core 80 is illustrated as being comprised of three vertical, parallel winding legs 83 extending and connected to a pair of horizontal yoke members 84. The core may be formed

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from stacks of flat strips of magnetic material having grained orientation in the lengthwise direction as is the usual practice. The core members preferably have cruciform cross-sections and are provided with canals extending therethrough for the circulation of a heat absorbing fluid. For example, various lamination layers of the core may be separated to form one or more canals 85 extending parallel to the planes of the laminations, and the lamination strips may be transversely split to form one or more canals 86 extending in planes transversely of the planes of the laminations. Opposite sides of the winding legs 83 may be provided with tie plates 87 bolted to the winding legs by means of bolts 88 extending through the canals 86 in order to hold the laminations of the winding legs together. The lower yoke 84 of the core 80 is positioned between and parallel to the members 75 of the internal plenum chamber 22. The plenum chamber 22, which serves as the lower element of the clamp for the core, is rigidly held to the lower yoke, for example by means of buttons 88' affixed to the tie plates 87. The buttons 88' extend through openings 89 in the plenum chamber 22. The members 75 may be electrically insulated from the core by sleeves 89'. A clamp comprising non-fluid carrying, elongated, structural members 90 is also provided for clamping the upper yoke 84 of the core 80 in the same manner that the lower yoke 84 is held by the plenum chamber 22. While the upper core clamp may also be formed of channel shaped members, with rounded corners in order to more uniformly distribute electrical stresses, it is not necessary from a standpoint of the present invention that the upper core clamp comprise an enclosed chamber.

Each of the legs 83 is surrounded by an electrical winding 82, as has been previously stated, the windings being omitted from several of the winding legs in FIGURE 11 for the purpose of clarity of the drawing. The winding 82, which may be more clearly seen in the cross-sectional view of FIGURE 9, is comprised of a plurality of layers 92 of electrical conductor turns radially spaced apart by means of insulating cylinders 93 and axially extending spacers 94 to provide a plurality of annular concentric canals having axes extending vertically through the winding. The winding 82 surrounds an insulating cylinder 95 which is radially spaced from the core winding leg 83 to form a canal surrounding the core leg.

Referring again to FIGURE 11, solid insulating means such as blocks 100 are provided resting on the top surfaces of the members 75 of the internal plenum chamber 22. The insulating blocks 100 are provided in the region of each winding leg of the core, and have flat upper surfaces that are at least as high as the uppermost portions of the lower core yoke 84. The internal edges of the blocks 100 may be shaped, as illustrated in FIGURE 11, to conform substantially to the shape of the adjacent surfaces or edges of the magnetic core, and each pair of blocks 100 in the vicinity of any given winding leg may have a generally square outline, when viewed from above, with the blocks in the vicinity of each winding leg being spaced apart from the blocks in the vicinity of the other winding legs. Canals 105 may be provided extending vertically between adjacent portions of the core yoke and the blocks 100. The blocks 100 also are provided with vertically extending apertures 106 aligned with the apertures 79, as shown in FIGURE 9, so that all dielectric liquids flowing upwards through the apertures 79 must pass through apertures 106 in the blocks 100.

A flat insulating plate 107 conforming generally to the periphery of each pair of blocks 100 is provided surrounding each winding leg of the core and resting on the top of the blocks 100. The insulating plate 107 is provided with apertures 108 aligned with the apertures 106 in the blocks 100. A plurality of insulating blocks 109 are provided mounted on the upper surface of the plate 107, and as illustrated in FIGURE 9, the lower end of the winding

82 rests upon the insulating blocks 109, and is thus spaced vertically from the plate 107.

Referring again to FIGURE 9, the insulating cylinder 95 separating the winding 82 from the core extends downwardly and rests upon the upper surface of the plate 107. An annular insulating cylinder or shield 110 closely surrounding the lower portion of the winding 82 also extends downwardly from the winding and rests upon the upper surface of the plate 107. The plate 107, insulating cylinder 95, and annular insulating member 110 thus define an annular chamber 111 disposed beneath the winding 82, so that all dielectric fluid forced upwardly through the apertures 79, 106, and 108 must enter the chamber 111 and thence be forced upwardly through the ducts in the winding 82. The blocks 109 on the upper surface of the plate 107 are preferably spaced to permit substantially equal flow of liquid through each of the winding ducts and so that the portions of the ducts most remote from the apertures 108 also receive a substantial portion of the liquid flow.

An insulating plate 115 similar to the plate 107, is provided above each winding 82, and is spaced therefrom by suitable insulating blocks 116. The plates 115 and blocks 116 are arranged above the winding so that all liquid flowing from the upper ends of the winding ducts passes radially outwardly from the winding beneath the plate 115 into the upper end of the enclosure tank 10. Insulating blocks 117 and adjustable clamping means such as wedges 118 are provided between the insulating plate 115 and the upper core clamp 90 to provide axial clamping pressure on the winding 82. A preferred arrangement for clamping the windings by means of the adjustable wedges 118 that forms no part of the present invention is disclosed and claimed in co-pending application Serial No. 853,853, filed November 18, 1959, by S. Koza and assigned to the assignee of the present application. The axial clamping pressure on the winding 82 is thus transmitted to the upper end of the winding by means of the adjustable wedges 118, insulating blocks 117, plate 115, and blocks 116. The axial clamping pressure on the windings is transmitted by the rods 87 and buttons 88' to the upper surface of the plenum chamber 22 by way of blocks 109, insulating plate 107, blocks 100. Thus, the plenum chamber 22 and upper clamping members 90, because they are structurally connected to the elongated tie rod elements 87, form a fluid carrying clamp that prevents axial expansion of the windings.

In order to connect leads to the winding 82, notches 120 may be provided in the upper surfaces of the blocks 100 (see FIGURE 11), the leads 121, passing through the notches 120, upwardly through the insulating plate 107 and chamber 111 to the windings, as shown in FIGURE 9. In order to prevent escape of liquid through the notches 120, these notches are preferably filled in with suitable insulating material closely surrounding the leads 121. Connections to the upper end of the winding may be made in a similar manner through notches 122 in the lower surface of the blocks 117.

The lower sides of the internal plenum chamber 22 rest upon a plurality of transversely extending bars 125, as illustrated in FIGURES 9 and 11, and the bars 125 rest upon the bottom 126 of the tank 10, as illustrated in FIGURES 9 and 10. The bars 125 thus support the entire weight of the core and windings of the transformer. In order to positively align the plenum chamber 22 in the correct location in the bottom of the tank 10 and prevent horizontal displacement thereof, a plurality of pins 127 may be provided affixed to the bottom 126 of the enclosure tank 10 and extending upwardly through holes into the bottom of the chamber 22.

As illustrated in FIGURE 11, a pair of the transversely extending spaced-apart bars 125 may be provided beneath each winding leg of the core beyond opposite sides thereof. The bars 125 may extend beyond the outer extremities of the internal plenum chamber 22. The

spaces between adjacent bars 125 beneath the plenum chamber members 75 are filled in with blocks 130, disposed beyond the other opposite sides of the core legs, thereby providing a plurality of sealed fluid chambers 131 beneath each core leg and between adjacent bars 125. Insulating blocks 132, as illustrated in FIGURES 10 and 11, are provided on the bars 125, the blocks 132 being shaped to conform to the outside surface of the core, and thereby preventing any substantial flow of liquid between adjacent chambers 131, and also preventing escape of liquid from the end-most chambers 131 into the tank. Other fluid exit apertures 133 extending through the plates 78 of the plenum chambers permit a flow of fluid from the plenum chamber 22 into the chambers 131 beneath the core. The core canals open into the chambers 131, so that fluid may be forced from the chambers 131 into the canals to cool the core. As shown in FIGURE 11 the edges of the duct in the winding legs and bottom yoke that are exposed within the tank may be sealed by a suitable insulating block 135 in order that the liquid is forced to flow vertically through all the ducts in the core. Suitable clamping blocks 136 may also be provided spacing the plenum chamber 22 from the lower yoke and permitting liquid to flow from the chamber 131 into the ducts in the side of the lower yoke without permitting its escape upwardly around the sides of the lower yoke. Insulating means 137 may be provided beneath the core to electrically insulate same from the bars 125 and tank bottom 126.

FIGURES 16 and 17 illustrate a modified embodiment of the interior of the transformer of FIGURES 1-3. In this modification the heat absorbing fluid that flows through the core elements 83 first flows from the internal plenum chamber 22 into a common pool 140. Instead of each core element having an independent fluid chamber beneath it, such as the chamber 131 illustrated in FIGURE 11, heat absorbing fluid flows through exit apertures 133 into the pool 140 defined by longitudinal supporting members 141 and transverse supporting members 142. The internal plenum chamber 22 rests upon these supporting members 141 and 142, and fluid is prevented from leaking between the plenum chamber and supporting members by gasket means such as resilient strips 143 disposed in slots in the upper ends of the members 141 and 142.

The resilient gasket strips 143 initially extend upwardly beyond the upper surface of the members 141 and 142. However, when the plenum chamber 22 is lowered onto the supporting members 141 and 142 the gasket strips are depressed until their upper surfaces are in substantially the same plane as the surface of the supporting members. The above arrangement provides an efficient seal for preventing the heat absorbing fluid from escaping from any opening that could occur because the lower surface of the plenum chamber 22 does not exactly mate with or contact the upper surface of the supporting members 141 and 142. Since the supporting members 141 and 142 are welded to the bottom of the tank 146 as indicated in FIGURE 17, a complete seal is provided preventing the heat absorbing fluid from escaping from the common pool 140.

The members 75 are rigidly connected together by means of cross bars 144 which may be welded or otherwise suitably attached thereto. The cross bars 144 are not quite as tall as the supporting members 141 and 142 and hence do not rest on the bottom 126 of the tank 10, as illustrated in FIGURE 17. Thus the pool 140 is unobstructed along the bottom of the tank 126 between the members 141 and 142. The core elements 83 may be insulated from the plenum chamber 22 and supporting members 141 and 142 by means of insulation sheets 145. The sheets 145 may be held in place by suitable blocks 146 and 147 of insulating material which are wedged between the core and the insulating sheets at the four corners defined by the members 141 and 142. The

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blocks 146 and 147 may be held in place by pins 148 extending through the inside faces of the member 75 and mating with apertures 149 in the blocks.

The core yoke 84 may be clamped in place between the members 75 of the internal plenum chamber 22 by means of suitable fillers such as insulating blocks 150 and 151, the blocks 150 being held in place by mating pins and apertures similar to those employed on the blocks 146 and 147. The cross bars 144 may be insulated from the core by means of suitable channel shaped covers 152 of insulating material. In order to provide increased clamping pressure on the core yoke, bolts 154 may extend through the internal plenum chamber, insulating blocks, and core, the bolts 154 being insulated from the chamber 22 by washers 155. The internal plenum chamber 22 may be positioned on the bottom of the tank 126 by locating pins 127 affixed to the bottom of said tank, said pins mating with holes in the bottom of the plenum chamber 22.

In all other respects the transformer of this modification is identical to that disclosed in the preceding figures, the windings being shown in phantom and the extreme right-hand core element being eliminated for the sake of clarity.

Thus, the plenum chamber 22 serves the dual function of a winding and core clamp and also serves as a chamber for distributing a heat absorbing fluid, such as dielectric liquid coolant, for the desirable flow through the winding and core canals. The chamber 22 is of course rigidly affixed to the core and windings, and thus during assembly of the transformer is lowered into the transformer enclosure tank 10 with the core and windings as a unit. Since the internal plenum chamber is completely sealed, except for the aforestated apertures directing flow of fluid into the various core and winding canals, it is not necessary to provide any seal between the core and windings and the enclosure tank except the seals between the bottom of the chamber 22 and the bottom of the tank. This arrangement, therefore, facilitates the assembly of the transformer, as well as providing a more economical structure than previously employed arrangements in which the entire lower portion of the tank formed a sealed chamber. By providing the fluid exit apertures 79 and 133 on both tubular members 75 of the plenum chamber 22, a uniform flow of liquid through the winding and core canals is assured. In addition, a provision of two fluid inlet openings 27' to the internal plenum chamber 22 on opposite sides of the enclosure tank 10 provides further advantages that will be disclosed in more detail in the following paragraphs.

The external plenum chamber 23 serves as a distribution center for the external heat absorbing fluid circulation system. By employing such a chamber, it is possible to employ any desired type of external circulation system. For example, as illustrated in FIGURE 1, heat transfer means 40 having their own liquid pumps and fans may be connected between the external plenum chamber 23 and the upper portion of the enclosure 10. In this arrangement, the conduit 30 connecting the external plenum chamber 23 to the internal plenum chamber 22 is not provided with any pumps or valves. Since all of the external heat transfer units are connected to the common external plenum chamber 23, the liquids will be equally distributed into both sides of the internal plenum chamber 22 regardless of any variations in the flow characteristics of the units. If the pump in one of the units fails to operate, the pumps of the remaining units will continue to force liquid through the core and windings in the usual manner.

As an alternative, as illustrated in FIGURE 2, it may be desirable to employ radiator units 50 instead of the forced liquid cooling units 41. In such a case, the fluid may flow through the radiators by natural gravity or thermal head circulation if no pumps are provided in the conduit 30, as illustrated in FIGURE 6a, or forced cir-

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ulation may be employed by inserting pump 61 in the conduit 30. Thus, the use of the conduits 30 interconnecting the internal and external plenum chambers facilitates the economical and rapid variation of the kva. rating of the transformer without requiring any variations in the radiator structure. Thus, for a complete range of desired heat characteristics it is necessary to provide only two standard types of external heat transfer devices, i.e., forced liquid coolers as in FIGURE 1 and the radiators as in FIGURE 2. Intermediate variations in the heat transfer characteristics may be provided independently of the heat transfer structure by employing pumps in the conduits 30, and by employing fans 70 on the radiators as illustrated in FIGURE 15. It will be understood, however, that other diverse types of heat transfer means, such as refrigerating units, may also be employed.

Since two entrances are provided into the internal plenum chamber 22, it is possible to employ two circulating pumps 61 as in the arrangement of FIGURE 2 of the drawing. This permits the use of smaller more economical pumps, and also provides the safety feature that all of the forced circulation is not lost when one of the pumps becomes disabled. The valves 62 of the arrangement of FIGURE 2 have been provided in order to prevent the backward flow of liquid from the internal plenum chamber to the external plenum chamber through a disabled pump. When only one of the pumps is operating, the liquid will still be forced through all of the radiators since the radiators are connected to the common external plenum chambers 23. In one example, when the valves 62 were employed, it was found that with a single pump operating, a transformer rated 50,000 kva. produced 96% of the rated kva. output. When the valves 62 are omitted, as in the modification of FIGURE 6b, one operating pump 61 will force a small portion of liquid backward through a non-operating pump, due to the interconnection between the ends of the members 75 of the internal plenum chamber. The flow will not be great, however, in view of the hydraulic resistance offered by the U-shaped liquid path between the internal and external plenum chambers. In this type of arrangement, it has been found that with a single pump operating a transformer rated 50,000 kva. produced 94.5% of its rated kva. output. Therefore, it is seen that the omission of the valves 62 is made practical by the arrangement of the present invention due to the hydraulic resistance of the connections between the plenum chambers.

The fluid exit apertures 79 in the upper surfaces of the plenum chamber 22 may have different diameters in order that the flow of liquid into the ducts of the windings more remote from the flanged connector 21 will be substantially the same as that flowing through the winding ducts of the closer windings. The chambers 111 into which the liquid flows below the windings serve to permit the equal distribution of the fluid flow into all portions of the winding canals. Since the liquid within the chambers 111 can escape only by way of the canals in the windings, all of the fluid forced through the apertures 79 must pass through the winding canals. Since the chamber 111 has substantially the same radial dimensions as the windings, the problem of sealing to prevent by-passing of the fluid flow around the windings is greatly reduced as compared with previously employed arrangements requiring barriers extending between the windings and tank.

The barrier between the bottom of the plenum chamber 22 and the bottom 126 of the enclosure tank 10, which includes the bars 125 and blocks 130 in the modification of FIGURES 9-11, and the members 141, 142 in the modification of FIGURES 16 and 17, provides a readily fabricated and uniquely simple seal to prevent escape of fluid from the chambers 131 or pool 140 except by way of the canals in the core. Since the canals in

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the core are provided with the insulating means 135 and 137, all of the liquid that enters the chambers 131 or pool 140 is forced upwardly through the magnetic core.

In FIGURE 12 a load tap changer is shown connected to the fluid circulating system of the transformer enclosure tank 10. Fluid circulating through the internal plenum chamber 22 may be forced into the load tap changer 14 through an intake means such as the conduit 170, and out of the load tap changer 14 and into the upper end of the tank 10 through an outlet conduit 171. In the arrangement shown in FIGURE 12 current carrying means such as a reactor or transformer used in the load tap changer 14 would be cooled by the same fluid and circulating system that cools the core and windings of the transformer. Of course, it will be appreciated that the intake means 170, instead of being connected to the plenum chamber 22, could merely be connected to the interior of tank 10, as the outlet means 171 is connected. In this case, however, the advantages of forced fluid feeding and cooling obtained by connecting the inlet means 170 to the internal plenum chamber 22 would not be obtained.

In FIGURE 13 a modification of the internal plenum chamber 22 of the transformer of FIGURES 1-3 is illustrated. In this modification the volume of fluid flowing from the plenum chamber 22 into the core or windings of the transformer can be controlled by the use of a slide valve 160. As has been previously stated, the upper part of the chamber 22 is provided with a plurality of fluid exit apertures 79. The slide valve comprises an elongated member 161 which has a plurality of openings 162 therein, and the spacing between the openings 162 is substantially identical to that between the apertures 79; the openings 162 may also be substantially the same size as the apertures 79. The elongated member 161 passes through an opening 163 in the side of the plenum chamber 22 and is slidably supported internally of the plenum chamber 22 by any suitable means such as a channel member 164. The dimensions of the opening 163 are substantially the same as those of the sliding member 161, except that sufficient clearance is provided to allow the member 161 to slide therethrough. One end of the sliding member 161 is connected to means such as a shaft 165 which passes through an opening in the side of the enclosure tank 10. Although the shaft 165 is manually slidable back and forth through the wall of the tank 10, fluid is prevented from leaking from the interior of the tank by suitable gasket means 166. Thus, when a transformer requires less cooling capacity, the fluid passing through the core and windings can be reduced by restricting the apertures 79. This is accomplished by sliding the member 161 so that the openings 162 therein do not line up exactly with the apertures 79, and thus reduce the effective size of the aperture 79. It is apparent that the use of the slide valve 160 provides a virtually unlimited number of adjustments that can be made in the size of the apertures 79. Consequently, fluid flow through the windings can be regulated as dictated by either external temperature conditions or by the heating load carried by the windings. Thus, the flow of fluid can be proportioned between the windings and core in varying amounts. The slide valve 160 may be conveniently mounted through the end 19 of the tank 10 which is opposite to the end 20 where the external cooling units are attached.

In the above disclosed arrangements for circulating the heat absorbing fluid through a transformer, it is seen that a readily fabricated and economical arrangement is provided for forcing the fluid to pass only through the canals of the winding and the core, and that the combination of the internal plenum chamber, which also serves as the winding and core clamp, and the external plenum chamber permits numerous variations in the circulation system of the transformer with a minimum number of different types of equipment being required.

It will be understood, of course, that, while the forms

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of the invention herein shown and described constitute a preferred embodiment of the invention, it is not intended to herein illustrate all of the possible equivalent forms or ramifications thereof. It will also be understood that the words employed are words of description rather than of limitation, and that various changes may be made without departing from the spirit or scope of the invention herein disclosed, and it is aimed in the appended claims to cover all such changes as fall within the true spirit and scope of the invention.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. Stationary electrical induction apparatus comprising aligned core elements upon which current carrying windings are disposed, said windings and core elements generating heat in proportion to the current passing through them, an enclosure surrounding said core elements and windings on all sides thereof, a heat absorbing fluid occupying said enclosure, an internal plenum chamber for circulating said heat absorbing fluid located in said enclosure supported by the bottom thereof, said internal plenum chamber comprising a pair of elongated, substantially parallel tubular members extending longitudinally of said enclosure, and a pair of substantially parallel transversely extending tubular members connecting the first mentioned tubular members at their adjacent ends, said tubular members thus defining between the inner facing sides thereof a closed chamber of substantially parallelepiped configuration, said internal plenum chamber having a fluid inlet opening on the outer face of each longitudinal tubular member adjacent one end thereof, the inlet openings each being substantially aligned transversely of said apparatus, said inlet openings communicating with the exterior of said enclosure by means of outwardly extending ducts, there being a group of exit apertures in the upper surface of each longitudinal member for each core element comprising said apparatus, insulating means resting on said longitudinal tubular members and having apertures therein aligned with said exit apertures to provide a first exit path for said heat absorbing fluid passing out of said internal plenum chamber, said windings comprising turns of electrical conductors that are radially spaced to provide canals therebetween through which said heat absorbing fluid flows, said windings resting on said insulating means so that one end of each of said canals opens into said first fluid exit path, the other end of each of said canals opening into the upper end of said enclosure, said core elements also having fluid canals extending therethrough, said core elements each having an end thereof located within the parallelepiped closed chamber defined by said tubular members, the core fluid canals opening into the last mentioned chamber, each of said longitudinal tubular members having other fluid exit apertures on the inner face thereof that open into said last mentioned chamber thus providing a second fluid exit path enabling said heat absorbing fluid to flow upwardly through said core to the upper end of said enclosure, said enclosure having exit ports for said heat absorbing fluid in an end wall thereof at said upper end, an external plenum chamber attached to said enclosure end wall below said exit ports, said external plenum chamber having fluid entry ports in a wall thereof that is substantially parallel to said enclosure end wall so that said enclosure exit ports and said chamber entry ports face in the same direction, the last mentioned exit and entry ports being arranged to form vertically aligned pairs of fluid passages between which heat transfer means are removably connected to said enclosure, each pair of aligned exit and entry ports being the same distance apart so that said heat transfer means can be selected from a group of diverse types of units having couplings separated a predetermined distance equal to the distance separating said ports, the number of pairs of ports connected to heat transfer units being determined by the heat generated by the current passing through said apparatus, means

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sealing any pairs of ports that have no heat transfer units connected between them, said external plenum chamber having fluid discharge ducts at opposite sides thereof, the discharge ducts on each side of said external plenum chamber facing in the same direction as said outwardly extending ducts connected to said internal plenum chamber, the external chamber discharge ducts being substantially aligned with each other and with said outwardly extending ducts to form horizontally aligned pairs of fluid passages between which conduit means are connected, the respective pairs of ducts being the same distance apart thus enabling them to be coupled by various diverse conduit means of predetermined length equal to the distance spacing said inlet and outlet ducts, whereby the specific type of heat transfer element and conduit means selected from said diverse types, and the number of selected elements attached to said apparatus can be varied in accordance with varying amounts of heat produced by said apparatus as varying amounts of current are passed through said core and windings.

2. Apparatus as recited in claim 1 in which an upper clamping member exerts downward pressure on said core elements, means structurally connecting said upper clamping members to said internal plenum chamber so as to form with said internal plenum chamber a fluid circulating core clamp.

3. Apparatus as recited in claim 1 in which said conduit means comprises a valve that permits said fluid to flow in one direction only from said external plenum chamber to said internal plenum chamber.

4. Apparatus as recited in claim 3 in which said valve comprises a vane pivoted on an axis in the interior of said conduit means, said axis being offset from the center of said conduit means, and said conduit means having valve seats therein adjacent said vane for preventing said vane from pivoting in a direction that permits said fluid to flow from said internal plenum chamber to said external plenum chamber.

5. Apparatus as recited in claim 1 in which said internal plenum chamber has means associated therewith for varying the size of said exit apertures.

6. Apparatus as recited in claim 5 in which the aperture size varying means comprises an elongated member having openings therein, said openings being substantially the same size and substantially the same distance apart as the exit apertures on said internal plenum chamber, said elongated member slidably extending through an opening in said plenum chamber in such a manner that the first mentioned openings register with said exit apertures, means internally of said plenum chamber slidably supporting said elongated member, means connected to one end of said elongated member extending through a side of said enclosure, whereby movement of last mentioned means will cause said elongated member to slide

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with relation to said plenum chamber and cause misalignment of the openings therein with said exit apertures, thus reducing the effective size of the exit apertures in said plenum chamber for permitting fluid to flow therefrom.

7. Apparatus as recited in claim 1 in which said internal plenum chamber rests upon a plurality of transversely extending bars, said bars being grouped in pairs beyond opposite sides of each core element, longitudinally extending blocks being disposed between said pair of bars beyond the other opposite sides of each core element so as to define a fluid chamber beneath each core element, said other fluid apertures opening into said chamber so as to permit the fluid flowing through the last mentioned apertures to flow only through the canals in said core elements.

8. Apparatus as recited in claim 1 in which said internal plenum chamber rests upon a pair of longitudinally extending supporting members and a pair of transversely extending supporting members, said supporting members defining a common pool beneath said core elements, said other fluid apertures opening into said common pool so as to permit the fluid flowing through the last mentioned apertures to flow only through the canals in said core elements, said supporting members being sealingly secured to the bottom of said enclosure, and gasket means extending between said supporting members and said plenum chamber to prevent the escape of said fluid therebetween.

9. Apparatus as recited in claim 8 in which each of said supporting members has a slot in the upper end thereof, said gasket means being disposed in said slot and initially extending above the upper surface of said supporting members, whereby when said plenum chamber is lowered onto said supporting members said gasket means will be compressed between said supporting members and plenum chamber so as to form a seal between said chamber and members even though the adjacent surfaces thereof do not contact each other at all points therealong.

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