

Oct. 19, 1965

L. MARTON

3,213,398

INDUCTION VOLTAGE REGULATOR OF THE MOVING COIL TYPE

Filed Feb. 8, 1960

2 Sheets-Sheet 1

Fig. 2

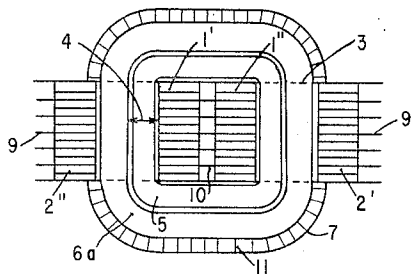


Fig. 4

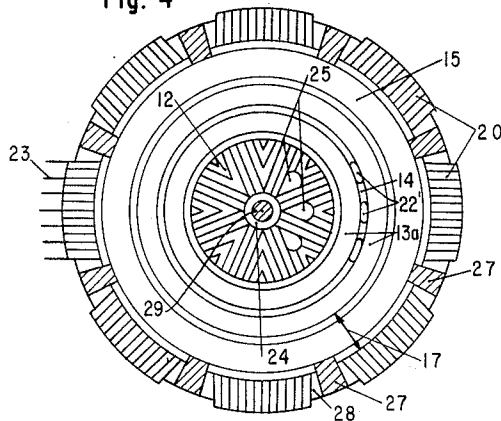


Fig. 1

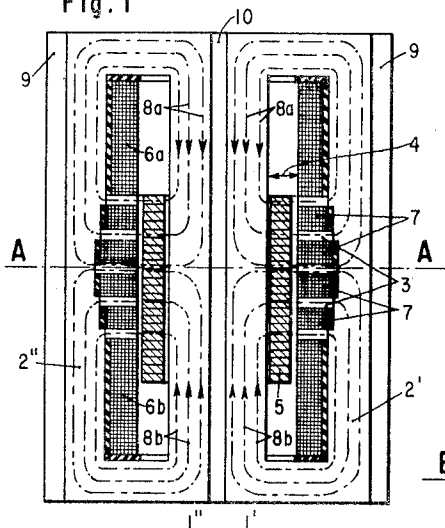


Fig. 3

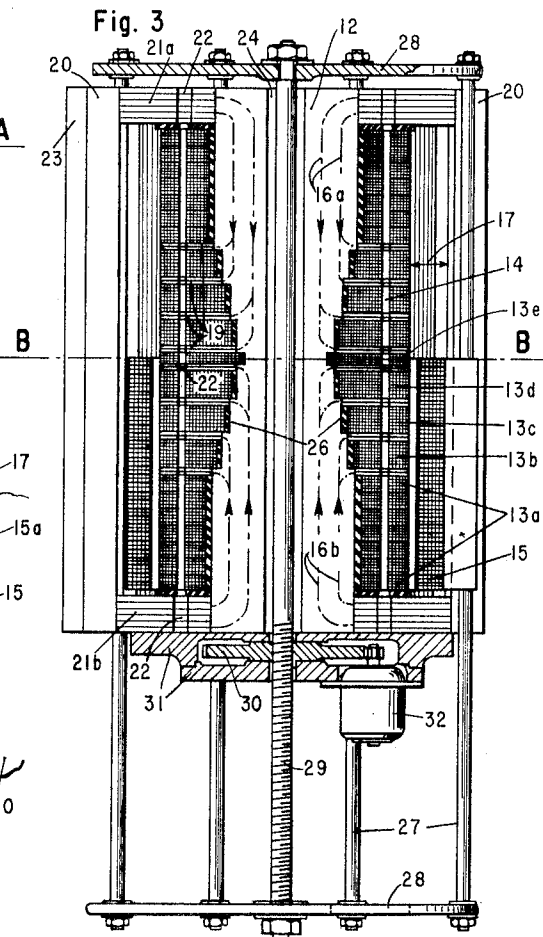
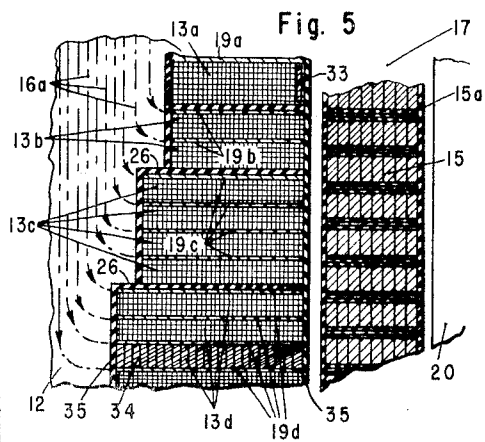


Fig. 5



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Fig. 6

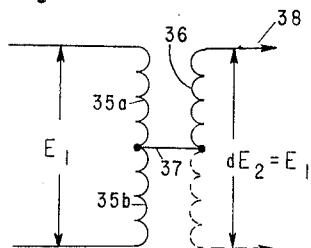


Fig. 7

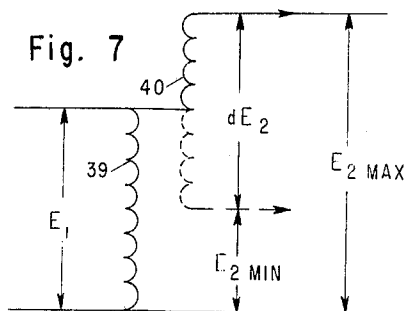


Fig. 8

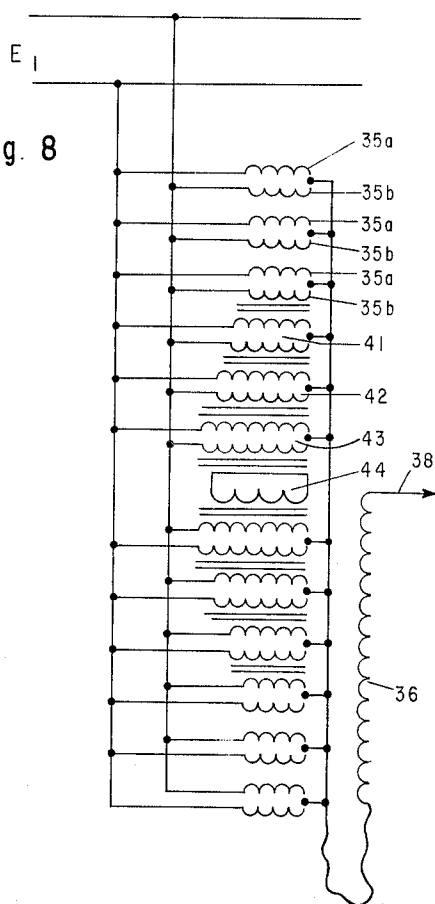
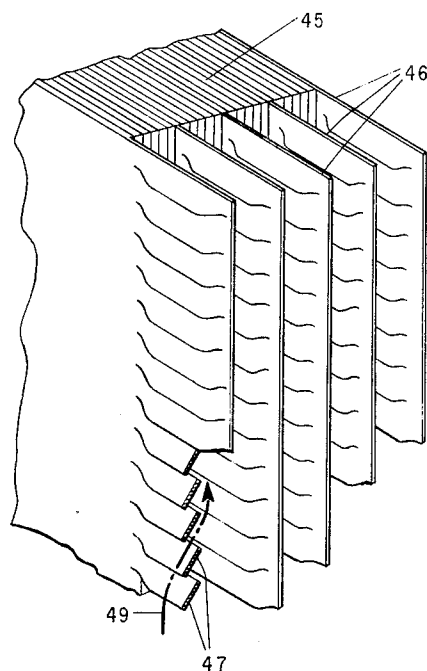


Fig. 9



1

2

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## INDUCTION VOLTAGE REGULATOR OF THE MOVING COIL TYPE

Louis Marton, 3983 Fredonia Drive, Los Angeles, Calif.  
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5 Claims. (Cl. 336-118)

The invention pertains to improvements in an induction voltage regulator of the moving coil type.

The different types of the known induction voltage regulators have a common disadvantage: the lack of magnetic balance in their coil systems. In some cases the balance changes while the coil moves; at the same time the leakage flux and the inductive voltage drop are non-uniform over the path of movement. In known regulators, heavy duty construction is necessary to prevent the harm due to unbalanced mechanical stresses in case of a short-circuit. Further in some cases the exciting current has undesirably high values. In conclusion of the aforementioned disadvantages, the known induction voltage regulator cannot be built above a limited kva. rating with the desirable dependability and economy; in addition to the limited rating, some types have undesirable working characteristics.

It is the purpose of the invention to introduce an induction voltage regulator having excellent working characteristics, and much higher limits in rating, having a uniformly balanced coil system, the inductive voltage drop and the leakage flux being constant while the moving coil changes position. No unbalanced mechanical stresses develop in case of a short-circuit. With proper construction, the exciting current can be held within a normal level. Therefore no obstacles exist in building large units for use alone (e.g., as a feeder voltage regulator) or as an auxiliary unit for converting large transformers equipped with taps to a continuously operating stepless unit. It can be used without close limitation in rating on any kind of A.C. source with excellent dependability and economy, having no contacts which are susceptible to deterioration. Since no periodical inspection or maintenance is required, it could be welded in a tank as a transformer. The outstanding economy, assured by the simple, inexpensive construction and by the elimination of the expensive tap changer under load mechanism, and by the high quality, continuous, flicker-free operation allow its application to any source.

An essential feature of the invention is represented by its arrangement employing a stationary winding for each magnetic circuit, composed of a plurality of electric current carrying coils forming a plurality of circuits, accommodated in succession along the path of the moving coil.

According to a further essential feature of the invention, particular coils of the stationary winding are provided with different numbers of turns; said turns being inversely proportional to the remaining part of the magnetic flux coupling to each of said particular coils, thereby forcing the excess part of the flux to deviate and to traverse the air gap to achieve a predetermined, substantially uniform dispersion of the flux along said air gap.

The aforementioned arrangement is able to supply the necessary ampere-turns for balancing the moving coil in any position.

Further essential features will become apparent on the basis of the following description. Various exemplary embodiments are illustrated in the accompanying drawings.

FIG. 1 is a vertical sectional view of a regulator built in accordance with the present invention;

FIG. 2 is the cross section of an exemplary embodiment of the invention, provided with a parallel laminated shell-type core;

FIG. 3 is a vertical sectional view;

FIG. 4 is a cross section of an embodiment of the invention featured with radially laminated core;

FIG. 5 is an enlarged partial detail view of FIG. 3;

FIG. 6 and FIG. 7 are schematic diagrams of two possible connections of the voltage regulator;

FIG. 8 is a wiring diagram of the connection shown in FIG. 6;

FIG. 9 is a perspective view of an exemplary embodiment of a cooling fin arrangement featured on an outside core surface.

Like characters of reference indicate like parts in the several views in the drawings.

Referring in detail to the drawings, it will be seen from FIGS. 1 and 2 that a magnetic path system comprising core 100 is built up from magnetically conducting material (e.g., steel laminations) and comprises essentially leg 1, and respective outer legs 2' and 2'' spaced from central leg 1 and connected by cross pieces 101 at the top and bottom. A plurality of fingers 3 extend inwardly from the respective legs 2' and 2'' about the mid-section thereof toward central leg 1 and terminate short of central leg 1. A stationary upper main coil 6a is received between the uppermost finger 3 and top cross piece 101 and a lower main coil 6b is received between the bottom-most finger 3 and bottom cross piece 101. The inner faces of these coils are coplanar with the ends of fingers 3. Thus, an air gap 4 exists between the aforementioned plane which includes the ends of fingers 3 and central leg 1. A portion of central leg 1 is surrounded by a moving coil 5 which is sized and positioned so as to move vertically in air gap 4 without interfering with either fingers 3 or coils 6a or 6b.

A different control coil 7 is received between each of the fingers 3 and represent the "flux traversing zone." These coils are connected in parallel. The main coils 6a, 6b may be built as one circuit for each or more advantageously as several parallel connected coils placed along the moving path of the moving coil. The main coils 6a, 6b are each connected to an A.C. source with the polarity such that two oppositely directed magnetic flux paths 8a, 8b exist in the upper, and lower part of the core, respectively. In the flux traversing zone both of the fluxes 8a, 8b extend transversely across the air gap 4 and form magnetic paths through fingers 3 and the respective legs 2', 2''. For achieving a low exciting current, the sections of the moving coil 5 may be interleaved with steel laminations as will be hereinafter described in relation to FIG. 5.

Starting at either end (i.e. the coils 6a or 6b) and advancing towards the center plane A—A, the vertical flux in leg 1 decreases to zero in the flux traversing zone gradually; no flux penetrates through the center plane A—A thereby creating a point of zero magnetic intensity. Thus substantially uniform flux density exists on both sides of the plane horizontally in the air gap all along the flux traversing zone.

Advancing toward the center plane A—A in the flux traversing zone, each control coil 7 is made with gradually increased number of turns in order to achieve substantially uniform flux density in the gap all along the traversing zone, as will be hereinafter described in detail in relation to FIGS. 5 and 8; these turns being inversely proportional to the remaining part of the controlled magnetic flux coupled to each coil 7 connected to the same source. That is, as illustrated in FIG. 1 and, with regard to the circular embodiment shown in FIG. 5, a set of control coils is associated with the respective upper and lower winding. With regard to the set associated with the upper winding 6a, control coils 7 will be connected to the source in the same manner that winding 6a is

connected to the source and each will have a different amount of turns which progressively increase until the central plane A—A is reached. Continued downward travel past plane A—A brings moving coil 5 into the region of control coils associated with the lower winding 6b. These coils will be connected to the source in the same manner that lower winding 6b is connected to the source and the number of turns of the control coils 7 progressively decrease in going from plane A—A to coil 6b.

The most advantageous length of the moving coil 5 is one-half of the total length of the entire stationary windings as shown in FIGS. 1 and 3.

The exemplary embodiment of the invention featured in FIGS. 1 and 2 is equipped with a cooling fin arrangement made by extension of one part of the core lamination distributed evenly along the stack outside 9 and inside 10 of the core. The outside surface of the coils also may be equipped with cooling fins 11 accommodated on the surface of a metal shield having good heat conducting connection to the coils.

In the preferred embodiment, winding 6a and the associated control coils 7 will be connected to an A.C. source such that the current traverses these coils in one direction. Coil 6b and the associated control coils 7 will be connected to the source so that the current traverses these windings in the opposite direction.

When the coils 6a, 6b are connected to an A.C. source in the described manner, those turns of coil 5 above plane A—A will have a voltage induced therein which is opposite in direction to the voltage induced in the turns below the plane. Thus, the resulting voltage at the terminals of coil 5 depends upon the relative position of the turns of coil 5 with respect to the center plane. When in the middle position, no voltage will appear at the terminals while at the extreme position, either opposite coil 6a or 6b, the highest voltages will be obtained. The polarity of the respective highest voltages will depend upon whether coil 5 is opposite stationary coil 6a or 6b.

Under no load conditions, the coils connected to the source produce the magnetic lines of induction 8a, 8b, taking the suitable exciting current from the source.

Loading the coil 5, a load current flows through its windings, causing a suitable load current to flow in the stationary windings by interaction of the magnetic field produced by coil 5.

Thus, the disturbance caused by this field will be counteracted by the field set up by the coils of the stationary winding which are adjacent the coil 5. Each control coil 7 contributes to the balancing of the ampere-turns of the moving coil 5 since they are closely coupled with the moving coil, and carry the proper current for the purpose. In the position shown in FIG. 1, load current flows mainly through coil 6b, and the associated coils 7, but coil 6a contributes little in supplying the balancing load current, being in poor coupling to the moving coil 5 owing to its large leakage flux in the remote position. When the coil 5 moves upwards, the contribution of coil 6a in supplying the load current steadily increases, while that of the coil 6b steadily decreases, until coil 5 reaches the upper extreme position.

In the position shown in FIG. 1, the main part of the load energy is supplied by the coil 6b and by the associated coils 7.

The leakage flux and the inductive voltage drop of the regulator changes very slightly while the moving coil 5 moves along its moving path, because current flows mainly through coils of the stationary winding which are positioned adjacent to the moving coil; therefore the balancing ampere-turns successively follow the movement of the moving coil, assuring steady leakage and drop conditions. The uniformity of the leakage flux and voltage drop may be raised by subdividing the stationary winding system, using many parallel connected coils

placed in succession along the moving path of the moving coil. The steady value of the inductive drop means that no forces develop in the direction of the movement in case of a short-circuit, because a short-circuit always tends to move the coils to a position which results in a higher inductive drop.

It is possible to build any form of a regulator with only one magnetic circuit, by omitting one half of both the core and stationary winding system, e.g., the one below the center plane A—A. The advantage of the low exciting current level achieved by superimposing magnetic paths and coils 7 in the flux traversing zone remains unchanged, assured by an increased cross sectional area for the air gap without increasing the dimensions. The range of the voltage regulation is one-half of what it was before with two magnetic circuits.

The moving coil may be featured either as an inside or as an outside coil. Using a radially laminated core as shown in FIG. 3 and FIG. 4, the outside arrangement of the moving coil offers special advantages. Bringing the air gap to the largest possible area, the gap induction has lower value with the same amount of flux because of the increased cylindrical surface of the flux traversing zone. This results in lower exciting current and larger cooling surfaces. In FIGS. 3 and 4 a radially laminated round leg 12 is surrounded by a plurality of regulator coils 13a adjacent the upper end of the leg and control coils 13b, 13c, 13d are provided adjacent the middle of the leg. It is to be understood that a similar arrangement is provided at the other end of leg 12. The stationary coils on leg 12 are subdivided by cooling ducts 14 and surrounded by air gap 17, in which the moving coil is accommodated. In the upper and lower parts of the leg 12, respectively, two closed magnetic paths comprising lines of induction 16a, 16b are formed, extending longitudinally through leg 12 and transversely across air gap 17 in the flux traversing zone. The moving coil 15 is one-half of the total length of the stationary windings, and its sections are interleaved with magnetically conducting material, e.g., steel laminations. The control coils in the flux traversing zone may be interleaved with magnetically conducting members 19 to decrease the magnetic resistance in the transverse flux path. Laminated split rings 21a, 21b provided with cooling ducts 22 are received on both ends of the leg 12 to complete the magnetic paths between leg 12 and outer legs 20. The legs 20 may be equipped with cooling fins 23. Leg 12 is provided with a sufficiently dimensioned axial bore 24 for cooling purposes. Cooling ducts 25, 22', may be formed in the core by using a special cut for the lamination. As the flux traverses the gap 17 along the flux traversing zone towards a horizontal plane B—B located at the center of the system, the remaining part of the flux in the leg 12, controlled by the control coils, decreases gradually to zero, and no flux penetrates through the center plane B—B. To achieve a uniform horizontal dispersion of the flux along the flux traversing zone, the control coils of that zone (13b, 13c, 13d) are wound with different, gradually increasing numbers of turns, in the sequence of mounting, toward the center of that zone, the turns being inversely proportional to the remaining part of the controlled magnetic flux coupling to each coil 13b, 13c, 13d, as will be hereinafter described in detail in relation to FIGS. 5 and 8. The short-circuited coil 13e may be placed in the center plane B—B, coupled with no flux; it may be featured with any number of turns. It is reasonable to decrease the diameter of leg 12 in the flux traversing zone adjacent a particular control coil 13 to accommodate the width of the particular coil since the radial dimension will be greater with increased number of turns due to the decreasing space factor of coils wound with smaller wires. It is reasonable to divide the leg 12 by the center plane B—B into two halves, assuring a symmetrical assembly. The mechanical support and actuating equipment of

the moving coil is shown in an exemplary embodiment in the FIGS. 3 and 4. Connecting rods 27 attached to the moving coil 15 are connected to two discs 28. The threaded bolt 29 penetrates through the hole 24 of the leg 12 connecting the two discs rigidly. A nut in the form of a cog wheel 30 is fixed positionally by the support 31, being actuated by the electric motor 32.

Motor 32 is connected to move the coil 15 to its selected position. That is, rotation of the output shaft of motor 32 rotates wheel 30 to move coil 15 through the threaded connection with bolt 29.

Any other kind of mechanical support or actuating means may be used such as chains, cables, etc. actuated by magnetic, pneumatic, hydraulic or any other energy sources.

FIG. 5 illustrates an enlarged detail of the flux traversing zone of the regulator according to FIGS. 3 and 4, incorporating notches in leg 12 to receive the control coils so their outer peripheral edges will be coextensive. The coils 13a are interleaved in this exemplary embodiment with magnetically conducting members 19a for producing uniform leakage flux conditions for each coil; the uniformity may be achieved also by using proper size of bridging strips 33 arranged between magnetically conducting members 19a. The first control coil for the flux traversing zone is the coil 13b, shown as two sections connected in series, interleaved between magnetically conducting members 19b. The coil 13b is featured with increased number of turns, e.g. 1.11 times the number of turns of the coil 13a; for this case the remaining part of the flux coupling to coil 13b is 0.90 times the total flux, the excess part (0.10 times the total flux) traverses gap 17 through coil 15 to the leg 20 through the magnetically conducting members 19b. The next coil 13c has, for example, four sections in series interleaved with magnetically conducting members. In this case the number of turns are increased by a rate 1.25; thus the remaining flux is 0.80 times the total flux, and a further 0.10 part deviates through members 19c. The rate of the deviation may be regulated optionally by the number of turns. The product of the remaining part of the flux and the number of turns always equals a constant. Thus, at the above cases:  $1.11 \times 0.90 = 1$ ,  $1.25 \times 0.80 = 1$ , etc. At the third coil 13d of the flux traversing zone using the same rate of deviation, the characteristic numbers are:  $1.33 \times 0.70 = 1$ ; the interleaved magnetic members 19d carry a further 10% of the total flux toward the air gap. The subdividing of one coil into many sections interleaved with thin magnetically conducting members effects a decrease of the magnetic resistance of the gap. The length of one coil e.g., 13c is determined by the permissible rate of change in the voltage drop. Thin copper strips 34 may be used for winding narrow coils.

The magnetic members may be connected advantageously to the next turn of the coils as potential shields. The complete coil group may be impregnated, covered with a solid insulating layer 35, building up one rigid unit. The moving coil may be impregnated including the mechanical supporting elements. The impregnation of the core parts is also advantageous in the most cases.

The voltage regulator according to the invention may be built not only by using the described forms, it is possible to use many other forms advantageously, e.g., core laminations built in cross form, or in loop form; it is possible to omit the interleaved magnetic paths in any case and guide the traversing flux exclusively by coils with different number of turns located in the traversing zone, etc.

FIG. 6 is an exemplary schematic diagram for a possible connection of the voltage regulator, as an auto-transformer. The stationary winding, divided by a center tap 37 into two parts 35a, 35b is connected to source  $E_1$ . One terminal of the moving coil 36 is connected to the center tap 37, the other terminal 38 is used as a variable

voltage source together with one of the source terminals. The complete range of the regulation,  $dE_2$  equals to  $E_1$  in this case if the turns ratio is 1:1 between coils 35a, 35b and 35.

FIG. 7 shows another possible connection as an auto-transformer. The stationary winding 39 is connected to source  $E_1$ . The moving coil 40 is connected in series in one line of the source. The range of regulation is  $dE_2$ , i.e., the voltage may reach any value between  $E_{2MAX}$  and  $E_{2MIN}$  depending on the position of the moving coil 40.

The moving coil may be connected to any point of the stationary winding, or it may be used in a separate circuit, suitable for the given purpose.

FIG. 8 is a wiring diagram for the voltage regulator of FIG. 6, using the same characters of reference. The stationary winding 35 is shown in FIG. 6 in simple schematic form, and is illustrated as a group of parallel connected different coils, as shown in FIG. 8. Each of the three coils 35a are connected in series with a respective coil 35b. Each series connection of the coil 35a and 35b is connected across source  $E_1$  and may advantageously be placed adjacent the top of the magnetic core member comprising leg 12 such as shown in FIG. 4. It is to be understood that a like connection of coils 35a, 35b are wound about core leg 12 adjacent the bottom of the leg and are connected to the source so that current will flow through these coils in a direction opposite to that in the coils at the top of the leg. Additionally, control coils 41, 42, and 43 are provided with the respective number of turns of each coil increasing. These coils are placed on core leg 12 in the flux traversing zone so that the coil with the greatest number of turns (43) will be adjacent the center of leg 12 with the remaining coils decreasing in number of turns upwardly. A similar arrangement is provided below the center of core leg 12. Again, the respective coils 41, 42, and 43 above the center of core leg 12 will be connected to the source so current will flow through them in a direction which will be opposite to the direction of current flow in coils 41, 42, and 43 located below the center of core leg 12. A short-circuited coil 44 is received in the center plane, supplying a small fraction of the balancing current for the moving coil 36 under load conditions, without having the difficulties of manufacturing coils with very large number of turns and very thin wire, as would be necessary if the coils connected to the source were used also for the very low flux area of the traversing zone.

FIG. 9 illustrates a part of a core lamination 45 equipped with cooling fins 46, featured by extending one part of the lamination beyond the contour of the core. The fins of the illustrated exemplary embodiment are divided by horizontal cuts into strips 47 with small dimension in the direction of flow of the cooling medium.

The effect of the fins featured with small strips is based on the fact, that using simple undivided fins, the cooling medium tends to form a clinging layer with growing thickness along the flow, preventing the good heat transfer between the fin and the cooling medium. The cooling medium clings in negligible thickness on the entering edge of the fin. Building up the entire cooling surface from "entering edges," no layer will develop and the heat transfer will be increased.

More effective is the arrangement in FIG. 9 if it is equipped with shields for promoting the flow through the slots (see arrow 49). Depending on the proportions of the different dimensions, a vertical shield can be used for covering all the channels to develop a chimney-effect, or many narrow shields may be used to close every second channel, vertically on the sides, or also horizontally on the ends; or may be built individual channels from two adjacent fins and a vertical narrow shield alternatively closed on the top and the bottom, or both, etc. The same is also feasible by bending two adjacent fins to each other for forming a three angle-form closed channel. Using forced circulation, the completely closed chan-

nels are the most advantageous, compelling all the cooling medium through the slots 49.

The application of the described cooling system harmonizes very well with the construction principles of the voltage regulator: for achieving low exciting current rate, the increase of the core stack and the core diameter respectively beyond the required core area and using short horizontal dimension in the direction of the lamination are the proper means. The possible cooling surfaces of the core 9, 10, 23, 24 are namely the same as, or proportional to the cross sectional area of the air gap 4, 17. The increase of the cross sectional area of the gap reduces the magnetic resistance of the gap, thus reducing the exciting current, and at the same time offers a broader possibility for the use of the described cooling system featured by extended lamination. The effectiveness of the cooling system according to FIG. 9 is so high that its application, e.g. offers possibility to convert units originally designed for oil cooling into air cooled units without any essential change in rating or in temperature rise.

It is applicable also on tank walls, inside or outside as well.

I am aware that various changes may be made in certain of the details of the present construction, and I therefore do not intend to be limited except as defined by the scope and spirit of the appended claims.

I claim:

1. In a transformer construction of the type having a stationary winding arranged to create magnetic flux in at least one direction, and coil means having output terminals, said coil means movably associated with respect to said stationary winding to be movable in an air gap which is traversed by said magnetic flux to establish flux linkages at various positions relative to said stationary winding to vary the output voltage appearing at the output terminals: the improvement comprising said stationary winding consisting of a first plurality of adjacent coils and a second plurality of adjacent coils, said first and second plurality of coils being disposed in axial alignment relative to each other, each of said first plurality of coils containing the same number of turns and each of said first plurality of coils being connected in parallel to a source of energy; each of said second plurality of coils having a different number of turns, each of said second plurality of coils being positioned so the number of turns of each of said second plurality of coils increases in a direction away from said first plurality of coils, the number of turns of each of said second plurality of coils diverting a proportionate share of the magnetic flux through the air gap to reduce the magnetic flux substantially to zero at that one of the second plurality of coils having the greatest amount of turns, each of said second plurality of coils being connected in parallel with each other and with said first plurality of coils and adapted to be connected to a source of energy such that current will flow through said second plurality of coils in the same direction as current flow through said first plurality of coils, whereby the magnetic flux disperses substantially uniformly through the air gap adjacent the second plurality of coils.

2. A transformer construction of the type having the improvement defined in claim 1, and magnetically conducting members between each of said second plurality of coils for decreasing the magnetic reluctance in the path adjacent each of said coils.

3. In a transformer construction of the type having a stationary winding including a first half arranged to create magnetic flux traveling in a first direction and a second half arranged to create magnetic flux in the opposite direction, and coil means having output terminals, said coil means movably associated with respect to said stationary winding to be movable in an air gap which is traversed by said magnetic flux to establish flux linkages at various positions relative to said stationary winding to vary the output voltage appearing at the output terminals: the improvement comprising said first and second halves of the stationary winding each consisting of a first plurality of adjacent coils and a second plurality of adjacent coils, said first and second plurality of coils being disposed in axial alignment relative to each other, each of said first plurality of coils containing the same number of turns and each of said first plurality of coils being connected in parallel to a source of energy; each of said second plurality of coils having a different number of turns wherein each coil is positioned so that the number of turns associated with each coil increases in a direction away from said first plurality of coils toward the second plurality of coils associated with the other half of said stationary winding, the amount of turns of each of said second plurality of coils being such that each of said second coils diverts a proportionate share of the magnetic flux associated with that half of the stationary winding through said air gap to reduce the magnetic flux substantially to zero between said halves, each of said second plurality of coils being connected in parallel with each other and with said first plurality of coils and adapted to be connected to a source of energy such that current will flow through said second plurality of coils in the same direction as current flow through said first plurality of coils; each half of said stationary winding adapted to be connected to a source of energy such that current flow through said first half will be in a direction opposite to current flow through said second half.

4. A transformer construction of the type including the improvement defined in claim 3, and magnetically conducting members interposed between each of said second plurality of coils for decreasing the magnetic reluctance in the path adjacent said coils.

5. In a transformer construction of the type having the improvement defined in claim 3, wherein the number of turns of each of said second plurality of coils is inversely proportional to the remaining part of the controlled flux coupling to the remaining one of said second plurality of coils in that particular half in a direction away from said first plurality of coils.

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JOHN F. BURNS, *Primary Examiner*.

MILTON O. HIRSHFIELD, *Examiner*.