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[11] **3,621,311**

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[33] **Germany**
[31] **P 19 08 457.2;**
Dec. 9, 1969, Germany, No. P 19 61 660.5

[54] MULTIPHASE DOUBLE-LAYER WINDING FOR ELECTROMAGNETIC PUMPS AND CONVEYOR TROUGHS

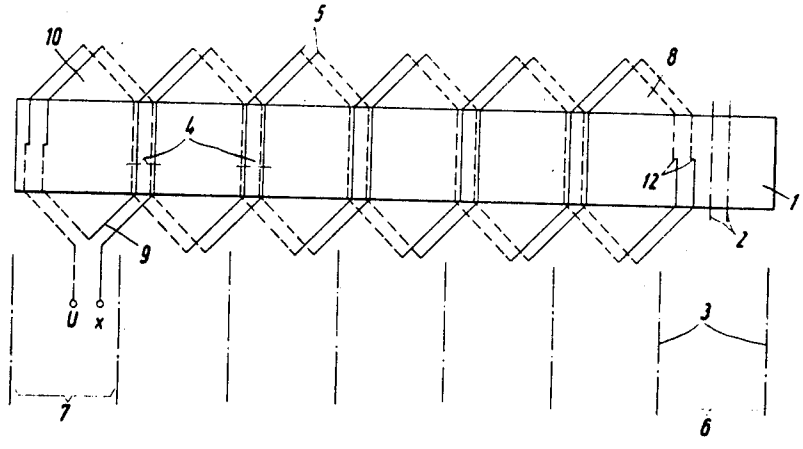
4 Claims, 13 Drawing Figs.

[52] **U.S. Cl.** **310/13,** 310/207
[51] **Int. Cl.** **H02k 3/04**
[50] **Field of Search** 310/12–13, 166, 198, 199, 202, 207, 180, 179, 201, 203, 204, 205; 318/135

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ABSTRACT: A multiphase two-layer bar wave winding having a winding head in one plane whereby half-wound end poles are provided and at least one winding per phase occupying one slot per pole beginning at the same end of the stator and progressing from pole to pole between the top and bottom layer returning to the last pole at the stator end by forming a loop and changing from one layer to the other and then proceeding back again in mirror symmetry to the beginning of the stator so that each slot has one bar of the forward going and one bar of the returning portion of the winding.



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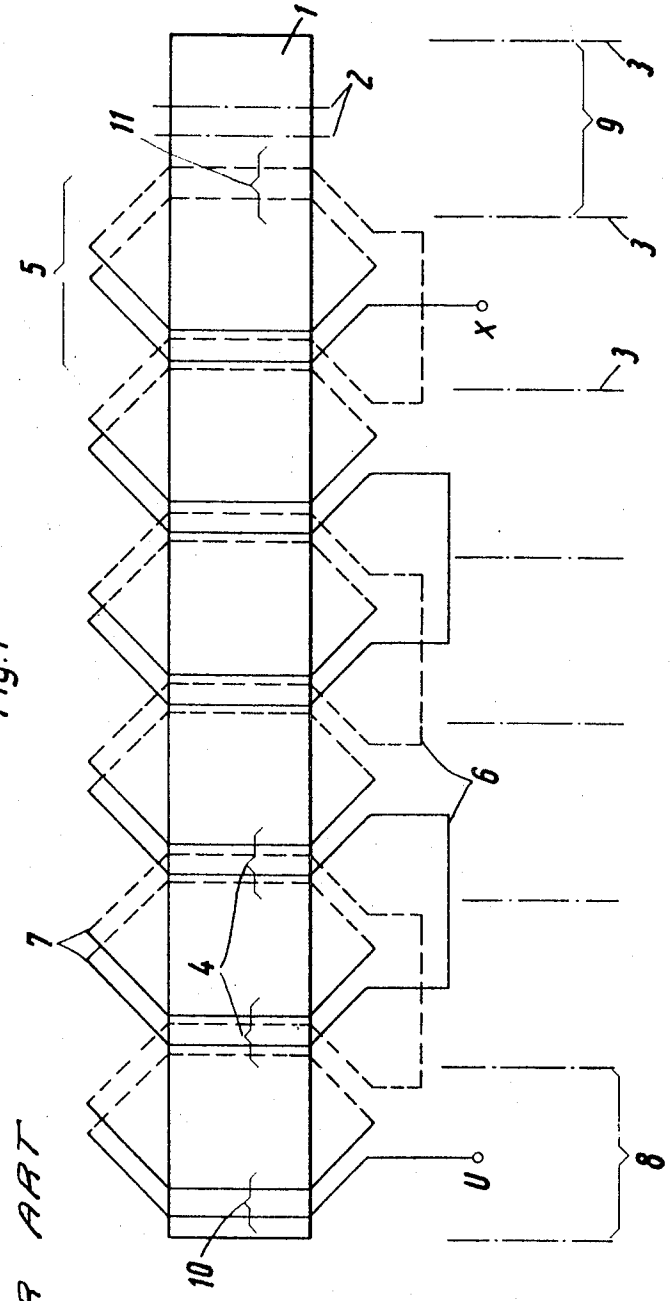


Fig. 1

PRIOR ART

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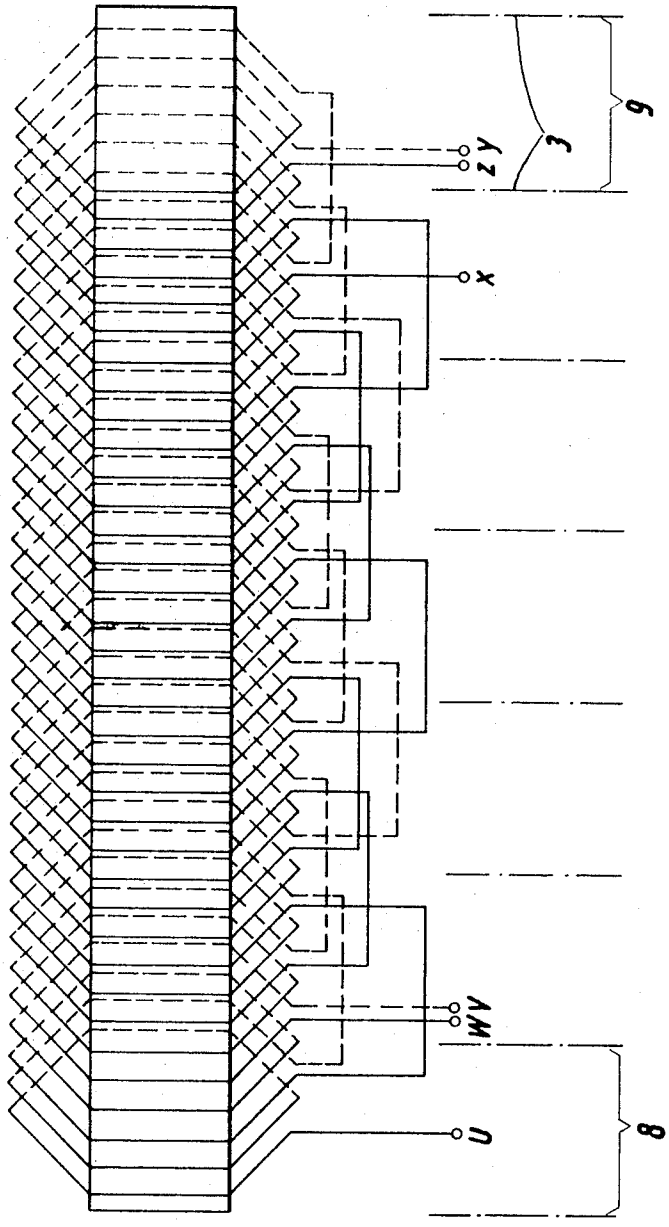


Fig. 2
PRIOR ART

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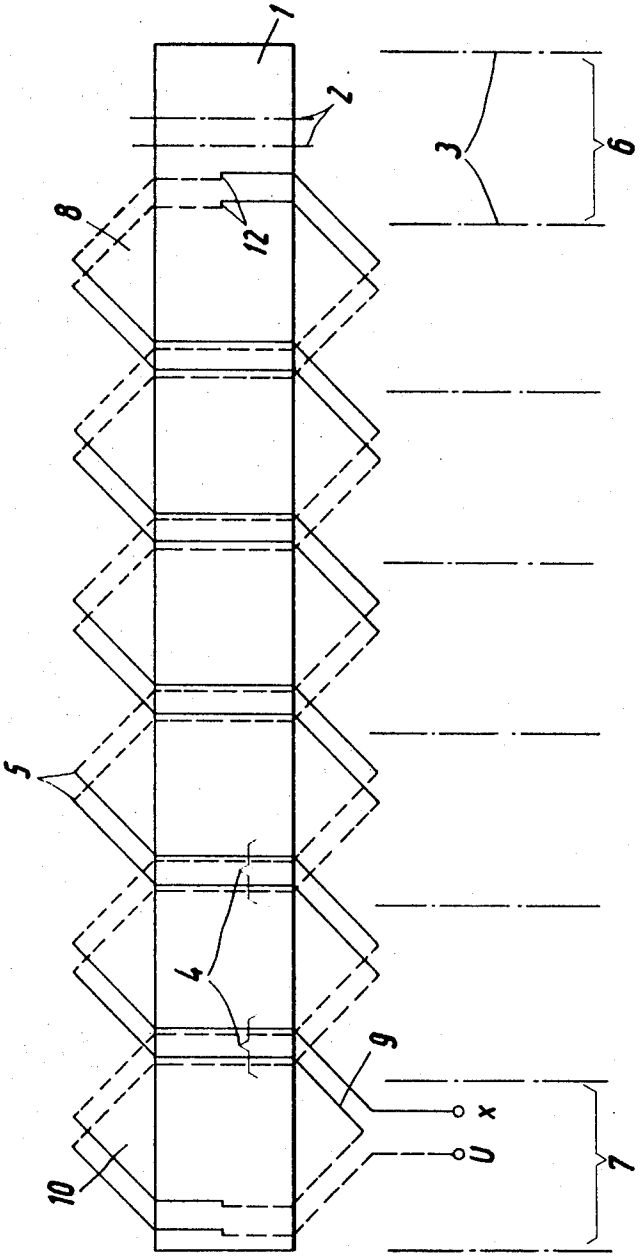


Fig. 3

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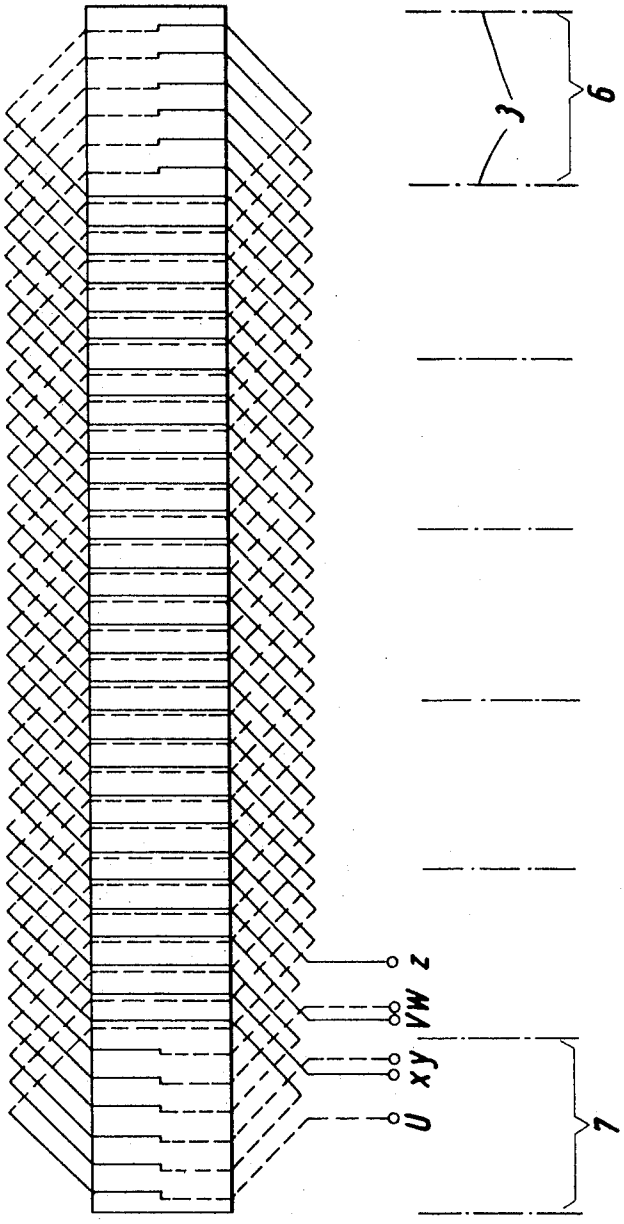


Fig. 4

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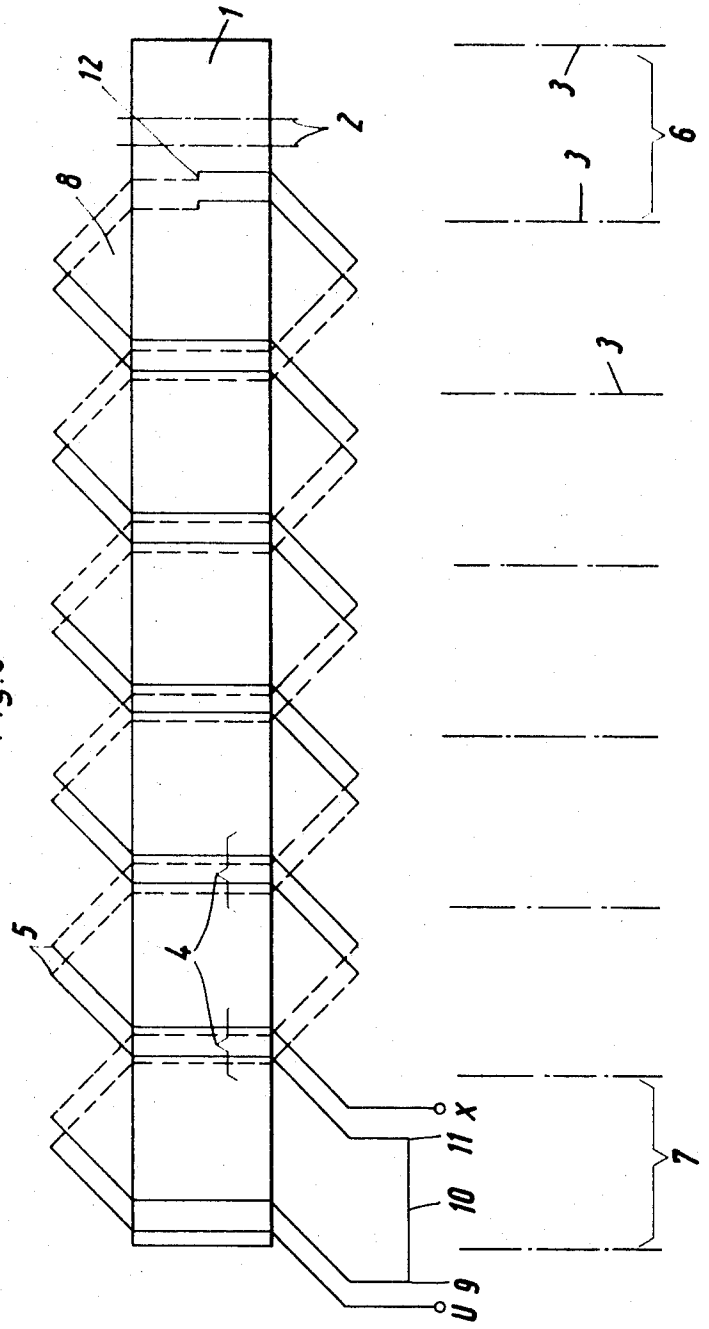


Fig. 5

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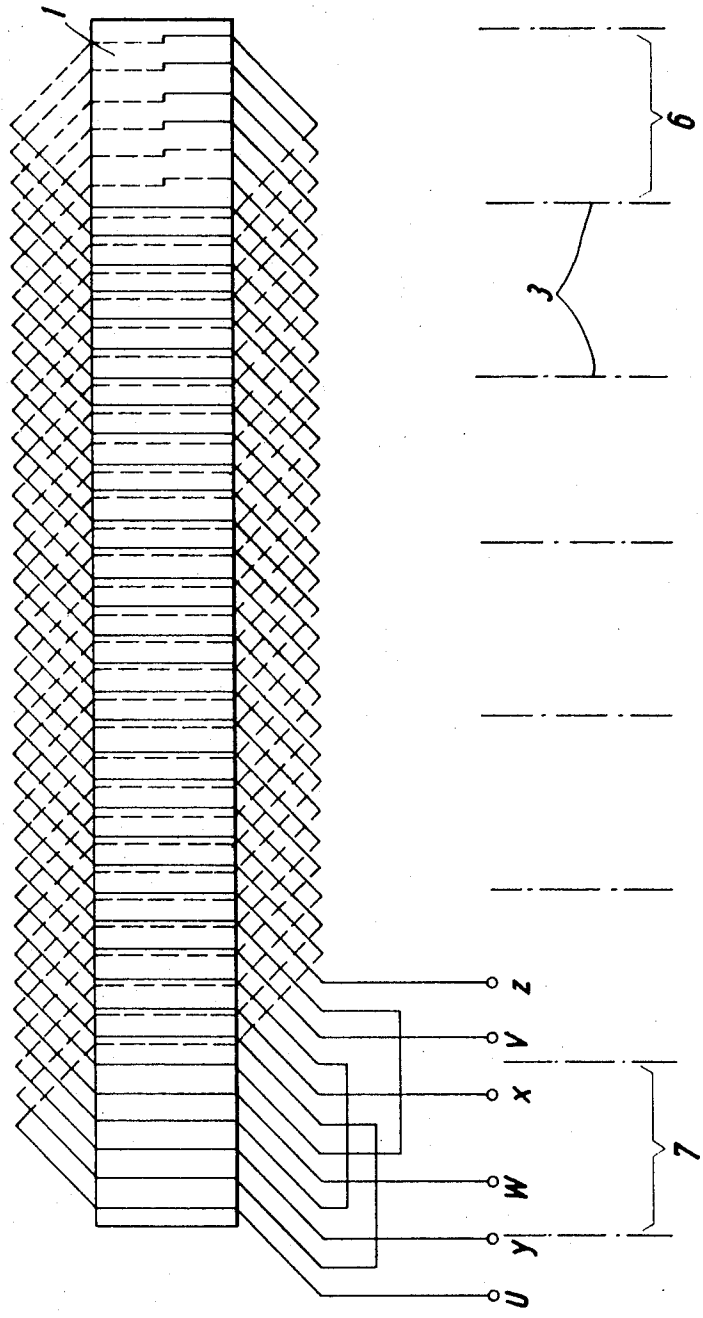


Fig.6

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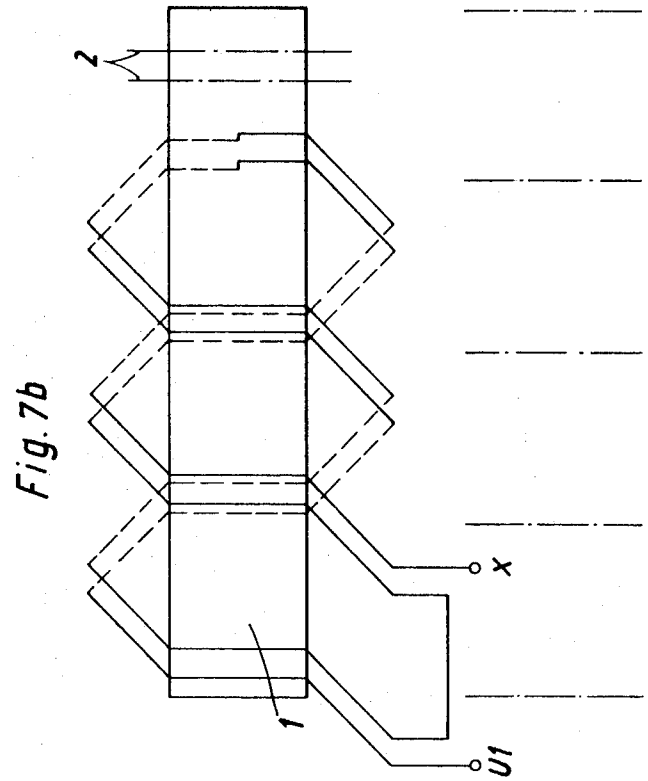


Fig. 7b

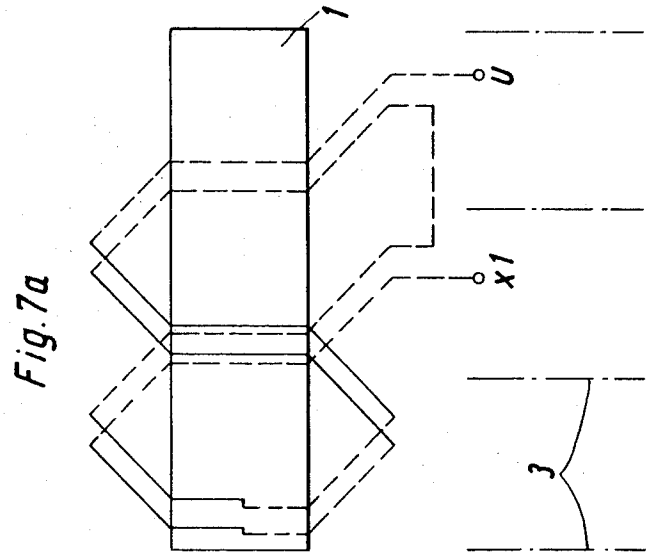


Fig. 7a

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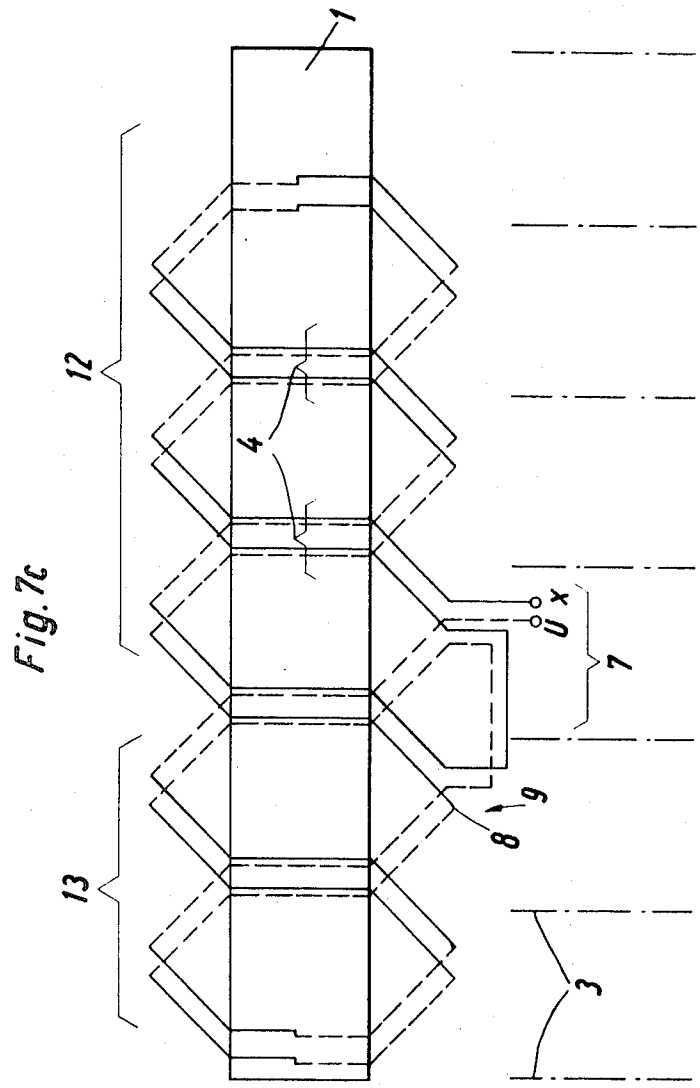


Fig. 7c

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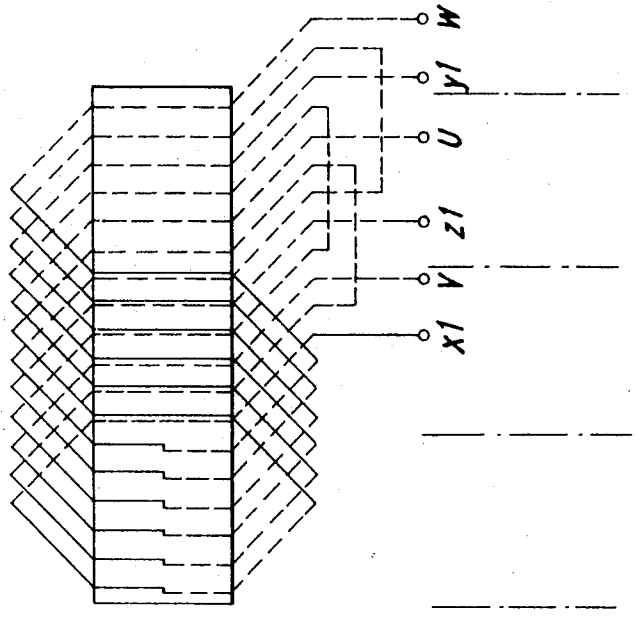


Fig. 8a

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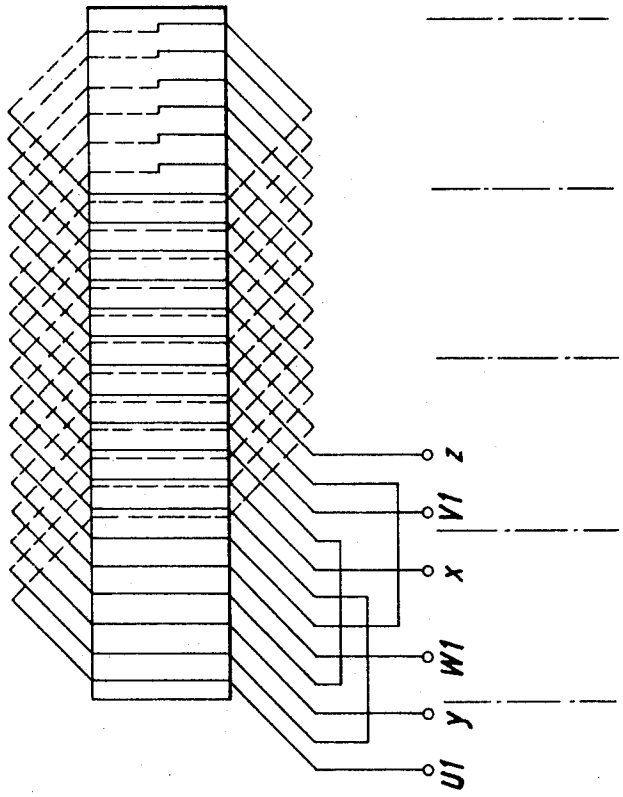


Fig. 8b

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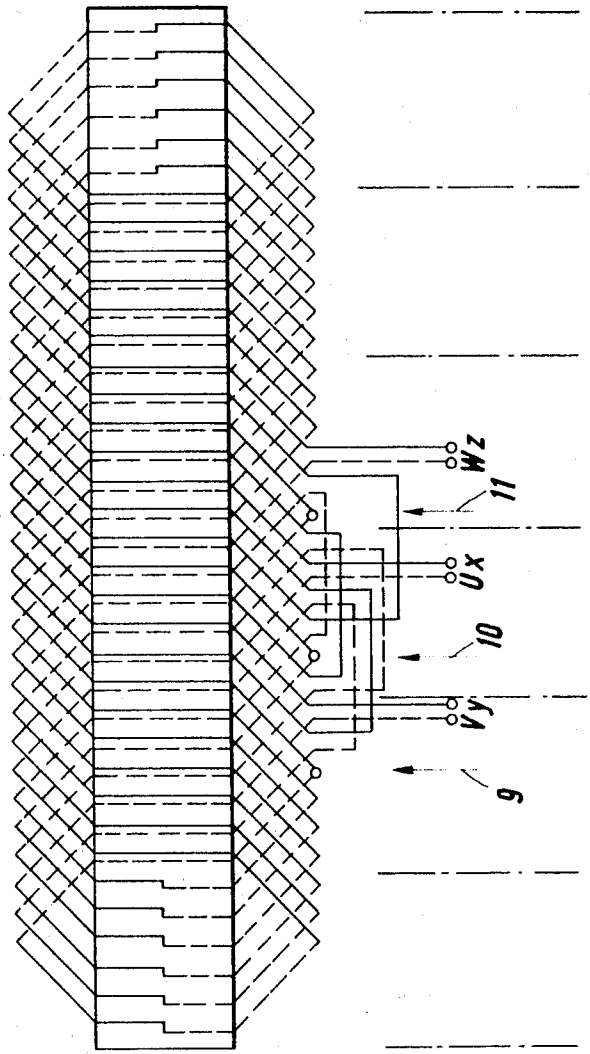


Fig. 8c

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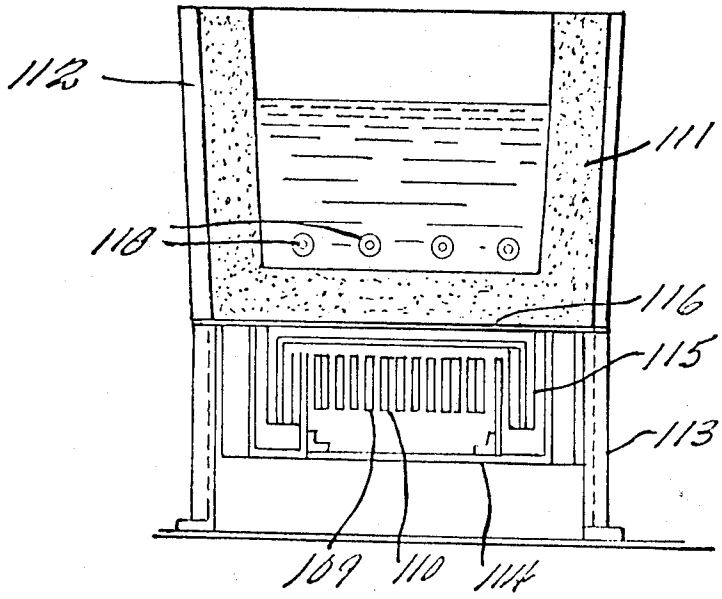


Fig. 9

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MULTIPHASE DOUBLE-LAYER WINDING FOR ELECTROMAGNETIC PUMPS AND CONVEYOR TROUGHS

This invention relates to two-layer bar wave windings having a single-tier winding head and half-wound end poles for the linear stator of an electromagnetic conveyor trough.

Electrically conductive liquids, such as metals, are frequently conveyed from one location to another in induction pumps or conveyor troughs, wherein traveling magnetic waves are generated which interact with currents induced in the metal to generate forces which move the liquid. These waves are preferably generated by flat elongated inductors, each consisting of a transversely slotted, laminated sheet iron core and a polyphase winding of insulated electrical conductors mounted in the slots in the core. In principle such an inductor may be regarded as a linear development of a stator of a conventional alternating current motor that has been cut open along one of its generating lines, and is therefore frequently referred to as a linear stator. Moreover, the polyphase winding is conventionally so constructed that when a sinusoidal polyphase electrical voltage is applied to the winding, the resultant electrical current will generate a traveling magnetic field in the form of an approximately sine-shaped wave progressing along the inductor surface. The conductors which form the winding usually are hollow, copper conductor tubes which have water flowing through them for cooling, which are inserted into the slots of the laminated core, and are electrically connected together in an appropriate manner at the core edge. The totality of all these connections forms the winding head. Because of electrical and structural considerations it is advantageous to mount two of the tubular conductors, one above the other, in each slot and a number of these conductors in each phase are preferably connected in series. In the design of electric machines such windings are generally known as bar-wound two-layer windings.

Designing and arranging such polyphase windings follow basically the same rules applicable to the design of electric motors and generators. First, the entire length of the stator is divided into an integral number of equal poles each of which in turn contains a whole number of grooves which is evenly divisible by the number of phases. Thus, within each pole, each phase is assigned the same winding space which is normally expressed as a number of slots per pole per phase and which is filled by being wound with a corresponding conductor group. Further, the conductor groups of the different phases must alternate regularly around the stator surface transverse to the slots, and the direction of the field at any given moment must reverse from conductor group to conductor group assuming each phase is fed with a direct voltage current.

In the electrical industry, both lap and wave windings are recognized as feasible in a polyphase two-layer bar-wound winding. A lap winding normally consists of a number of individual flat coils having a number of turns equal to the number of slots per pole per phase in the polyphase winding. Each turn of such a flat coil usually consists of two parallel bars spaced according to the pitch of the poles and of the associated end conductors. Several such turns together form a coil having two parallel sides and the corresponding end connectors. The space within the cell, which remains internally open, is wide enough to permit another coil of another phase to be placed within the space. The parallel sides of each coil are so inserted into the slots of the insulated core that one side of the coil forms part of the top and the other side forms part of the bottom conductor in the slots of the core. The connection between the upper and the bottom conductors is provided by the end connection in the winding head, and the beginning and end of each coil is brought out of the winding head for proper interconnection to other coils. When the stator is assembled, all the coils are usually inserted consecutively in phase rotation so that the top layer of each coil forms the bottom layer of the previously inserted coil of the same phase. According to the usual rule the coils are then connected together according to phase either in series or in parallel.

In a wave winding a continuous circuit is produced by connecting one conductor in each slot of one pole to a conductor in the corresponding slot of the next pole. Consequently, the circuit has the external appearance of a schematically drawn wave. This wave may repeatedly run through a circular stator before returning via an interconnection and passing in reverse through each of the slots already partly occupied by the forward running wave. In a two-layer bar-wound wave winding the serially connected conductors likewise change over in the slots from the bottom into the top conductor layer and inversely from pole to pole. The connections of the several conductors in the winding head in a lap, as well as in a wave, winding may be disposed in one, two or three planes. However, usually the winding head is contained in one plane, each individual connection being taken through an offset or stagger from the top to the bottom layer.

The bar-wound two-layer lap winding commonly used in the construction of electric machines as hereinbefore described can also be used as the linear stator of an induction pump or trough. Although the final pole at each stator end will then be only half wound, i.e. it will have only one conductor per slot, this characteristic of the winding is nevertheless desirable because it causes a gradual rise and decline of the traveling magnetic field generated by the energized polyphase winding to be achieved at the stator ends.

FIG. 1 and 2 of the accompanying drawing illustrate the construction of a bar-wound two-layer lap winding with a single tier winding head for the linear stator of an electromagnetic pump or conveyor trough in the form of a diagrammatic representation of the stator from above. The conductors indicated by discontinuous lines are understood to be contained in the bottom layer, whereas those shown in full lines are in the top conductor layer.

FIG. 3 and 4 illustrate the construction of a two-layer bar-wound wave winding according to the invention of this application.

FIG. 5 and 6 illustrate another embodiment of the invention.

FIG. 7*a*, 7*b*, 7*c*, 8*a*, 8*b* and 8*c* illustrate an embodiment of the invention whereby current can be made to flow through only part of the windings.

FIG. 9 shows a cutaway view of a furnace body having a traveling field inductor serving as an agitating coil and in which inductor a two-layer bar wave winding according to the invention of this application is used.

FIG. 1 represents one phase of a three-phase winding. The flat transversely slotted and laminated sheet iron core 1 is provided conventionally with slots which are not specially shown, but which are indicated at only one point by center lines 2. Within each pole a winding space of two slots per phase is available and this space is occupied by a conductor group 4. The flat individual coils 5 consisting of two half-conductor groups and the corresponding end connectors in the winding head are electrically joined together in series by interconnections 6. The input terminal at the beginning of the winding is labeled U and the terminal at the end is labeled X. The winding head connections of the individual coils 5 change over at their points 7 from the upper into the bottom layer. The conductor groups 10 and 11 in the outer poles 8 and 9 at the stator ends contain only one conductor per slot.

FIG. 2 is the same stator as in FIG. 1 but completely wound with all three phases. The terminals at the beginnings of the three windings are marked U, V and W and at the ends they are marked X, Y and Z.

Although this two-layer bar-wound lap winding can be easily assembled, tapped and connected it has only a limited possibilities for electromagnetic pumps and conveyor troughs because the large number of interconnections entail substantial electrical loss and increased reactive power. Moreover, the interconnections are structurally complicated and difficult to accommodate. For these reasons it is desirable for electromagnetic pumps and conveyor troughs to use a two-layer bar-wound wave winding without such complicated interconnections. Moreover, this type of winding cannot be directly

analogous to a circular stator of an electrical machine applied to a linear stator, because the entire winding would comprise a plurality of individual waves.

The invention accordingly relates to a two-layer bar-wound wave winding with a single plane winding head which is particularly suitable for the linear stator of an electromagnetic pump or a conveyor trough. Further it is contemplated that the outer poles at the inductor ends will in conventional manner be only half wound, i.e. contain only one conductor per slot. Furthermore one aspect of the invention provides for the winding to be tapped, for example for the purpose of permitting the conveyed melt to be discontinuously metered or closed.

More particularly, the embodiment described below has a polyphase, two-layer bar wave winding comprising a single plane or tier winding head for a linear stator of an electromagnetic pump or a conveyor trough, comprising half-wound end poles and wherein at least one winding per phase occupying one slot per pole is provided, beginning at the same end of the stator, and progressing to the other end of the stator in waves and alternating from pole to pole between the top and the bottom layer, returning in the last pole at the stator end by forming a loop and changing from one layer to the other and then proceeding back again in mirror symmetry to the forward-going part of the winding at the beginning of the stator in such manner that each slot contains one bar of the forward-going and one bar of the returning portion of the winding.

If a winding includes several windings per phase each occupying one slot per pole, then according to the invention a number of such windings equal to the number of slots per pole per phase are electrically interconnected by return laps in the pole at the stator beginning. At the same time, the winding in the return lap changes from the bottom to the upper layer.

FIGS. 3 and 4 of the accompanying drawings illustrate one construction of a two-layer bar-wound wave winding according to the invention comprising a single tier winding head for the linear stator of an electromagnetic pump or conveyor trough, the drawing being a schematic view of the stator from above. The conductors indicated by discontinuous lines are understood to be in the bottom layer and the conductors shown in full lines in the upper layer of conductors.

FIG. 3 shows the winding of only one phase of a three-phase winding in which the slots in the flat transversely slotted and laminated sheet iron core 1 are not being specially shown, but are indicated at one point by center lines 2.

The entire length of the sheet iron core 2 is divided at the dot-dash lines 3 into seven equal poles. For each phase a winding space at two slots is available in each pole and this is occupied in each pole by a conductor group 4. The winding begins at the left hand end of the inductor in the first pole 7 of the laminated core 1 at the terminal U and consecutively comprises one conductor in a corresponding slot in each of the several poles. At the points of the winding head end connections 5 the winding changes over from the upper to the bottom layer and journeys through the laminated sheet iron core in the form of a wave. In the last pole 6 at the end of the stator the winding reverses by forming a lap 8 at a point 12 at which it also changes over from the bottom to the upper layer. The winding then reverses direction and passes through the stator back to the first pole 7 at the beginning of the stator in substantially mirror symmetry to the forward-running wave, filling the slots which had been only partly filled by the latter. The end 9 of the winding of the double wave thus formed passes through a return lap 10 into a second double wave which is constructed in exactly the same way as the first. The connection X at the end of this second double wave is brought out of the winding head. The terminal poles 6 and 7 of the laminated sheet iron core 1 contain only one conductor in each slot. FIG. 4 shows the FIGS. stator as in FIG. 3 but completely wound for all three phases. In FIG. 4 the beginning of the three windings are marked U, V and W and the ends X, Y and Z.

It will be understood from the comparison of FIGS. 2 and 4 that a winding is thus obtained for a linear stator which has no interconnections, and which is therefore extremely simple. The electrical loss hitherto caused by the interconnections is avoided and the general construction is simpler and more compact.

In electromagnetic pumps and conveyor troughs it is frequently desirable for design reasons to shift the phase terminals of the stator winding away from the end of the laminated core further towards the center.

According to one aspect of this invention this problem can be resolved in a winding comprising several slots per pole per phase by electrically interconnecting several of the previously proposed double waves corresponding in number to the number of slots per pole per phase at the beginning of the stator so that the winding of the first pole comprises only one layer of conductors.

Such a winding is constructed similarly in principle to the winding hereinbefore described and illustrated in FIGS. 3 and 4, but differing therefrom in that there is no change over from one layer to the other at the first pole of the stator. This is achieved by establishing the transition from one double wave to the next not through a return lap, but through an interconnection outside the winding head.

FIGS. 5 and 6 of the accompanying drawings are a schematic view of the stator from above illustrating the construction of such an individual winding. Again the conductors represented by discontinuous lines are in the bottom layer and the full line conductors are in the top conductor layer.

FIG. 5 shows the winding for one phase of a three-phase winding. As in the other figures, in the flat transversely slotted laminated sheet iron core 1, the slots are not shown in detail and are indicated at only one point by center lines 2. The entire length of the sheet iron core 1 is divided at the dot-dash lines 3 into seven equal poles. In each pole a winding space of 2 slots is available per phase and contains a conductor group 4. The winding circuit beings at the left-hand inductor in the first pole 7 of the laminated core 1 at terminal 8 and consecutively provides one conductor in a corresponding slot in each of the several poles. At the points of the end connection in the winding head 5 the winding changes over from the upper to the bottom conductor layer and thus extends through the entire length of the core 1 in the form of a wave in the final pole 6 at the stator end the circuit reverses in a lap 8 and changes over from the bottom to the top layer inside a slot 12. The circuit then returns substantially in mirror symmetry to the forward part of the wave back to the first pole 7 at the beginning of the stator, filling the slots which had been only half filled by the forward part of the wave. The end of the circuit 9 of the first double wave thus formed is connected in series through a bridge 10 to the beginning 11 of the winding of a second double wave which is constructed exactly like the first. The connection X at the end of this second double wave is brought out of the winding head. The terminal poles of the laminated core 1 each contain only one conductor per slot. FIG. 6 is the same stator as that in FIG. 5, fully wound for all three phases. The beginnings of the three phases are marked U, V and W, and their ends are at X, Y and Z.

The combination of two individual windings shown in FIG. 6 to form a fresh complete winding having terminals that can be located practically anywhere along the stator length is achieved by telescoping together the two constructed ends having a relatively mirror symmetrically constructed end. The two similar individual windings are inserted into the slots of a common stator and the first pole which contains only a top layer of one individual winding is combined with the first pole of the other individual winding which contains only a bottom layer, thereby forcing an overall winding that is evenly distributed in the slots of the stator. Owing to the contraction of one pole of each of the two individual windings, the number of poles of the overall winding is one less than the sum of the poles of both individual windings. By connecting the ends of one individual winding to the corresponding beginnings of the

second individual winding the required electrical interconnection to form the fresh polyphase overall winding is produced, and the terminals of this overall winding can then be located at practically any point along the length of the stator winding to comply with design and operating requirements.

It is often necessary, for instance for discontinuously metering liquid metals, to tap the stator winding of an electromagnetic pump or conveyor trough so that current will flow through only one continuous part of the winding when an electrical voltage is applied between the tap and the beginning of the winding. This can be done when the winding is composed of two individual windings in the manner hereinbefore described and the tappings are provided at the point of electrical interconnection of each phase of the individual windings.

When in such circumstances a polyphase voltage is applied between those tappings and the ends of the windings, then only one of the individual windings and hence only a consecutive component part of the stator will be energized by the current. FIGS. 7*a*, 7*b* and 7*c* and 8*a*, 8*b* and 8*c* of the accompanying drawings illustrate the combination of two individual windings according to the invention to form a fresh overall winding in a schematic view of the stator from above. The discontinuous lines relate to conductors in the bottom layer and the full lines to conductors in the top layer.

FIGS. 7*a*, 7*b* and 7*c* illustrate the winding circuit of one phase in a three-phase winding, FIG. 7*a* being one phase of an individual three-pole winding and FIG. 7*b* the corresponding phase of an individual four-pole winding in which the terminals are mirror symmetrically located to those of the three-pole winding. FIG. 7*a* shows the manner in which the two individual windings in FIGS. 7*a* and 7*b* are combined to form a six-pole overall winding.

In the flat transversely slotted and laminated sheet iron core 1, the slots again are not specially shown but indicated only at one point by center lines 2. The entire length of the sheet iron core is divided at the dot- dash lines 3 into poles of equal size. In each pole there is available per phase a winding space of two slots occupied by a conductor group 4. The corresponding winding circuits of one phase of each individual winding are constructed in principle in the same way as the winding circuits in FIG. 5. The terminal at the beginning of the winding of the three-pole arrangement in FIG. 7*a* is marked U and that of the four-pole arrangement in FIG. 7*b* is marked U1. The corresponding terminals at the winding ends are marked X1 and X. When these two individual windings according to FIGS. 7*a* and 7*b* are combined to form a total winding according to FIG. 7*c* the top facing poles of the individual windings will combine to form a terminal pole 7. The two individual windings are electrically interconnected at point 8 where in the individual windings the terminals X1 and U1 are previously located.

When the pump or trough is required discontinuously to meter the metal melt, an electrical tapping indicated by arrow 9 is provided at point 8. If an electrical voltage is then applied between point 9 and X current will flow through only the four-pole winding 12. A current can also be sent through the three-pole winding 13 by applying a voltage between the tapping 9 and the terminal U. The total winding according to FIG. 7*c* carries an electrical current which has the same magnitude throughout when a voltage is applied between the terminals U and X. FIGS. 8*a*, 8*b* and 8*c* of the accompanying drawings show the same arrangement as in FIGS. 7*a*, 7*b* and 7*c* when it has been completed by adding the two other phases. The terminals at the beginning in FIG. 8*a* of the three-pole individual windings are marked U, V, W, whereas the terminals at the winding ends are marked X1, Y1 and Z1. Accordingly, the terminals of the five-pole individual windings in FIG. 8*b* are marked U1, V1, W1, and X, Y, Z respectively. When these two have been combined as shown in FIG. 8*c*, the terminals U, V, W at the beginnings and X, Y, z at the ends remain. The points where tappings can be provided are indicated by the arrows 9, 10 and 11.

FIG. 9 shows a cutaway view of a furnace body having a traveling field inductor serving as an agitating coil, and in which inductor a two-layer bar wave winding according to the invention of this application is used. The furnace body includes a self-supporting fire-resistant trough 13 in which melt 21 flows, and as is customary, trough 13 is enclosed by a furnace wall 14 which rests on a furnace frame 15. Below the bottom of the trough—mounted in frame 15—a traveling field inductor (shown in the figure in cross section) has been arranged with its stack of sheets 16 and the conductors 17, 18 connected in the winding head 19 to the inductor winding. In order to avoid a destruction of the inductor winding through accidental breakout of the liquid metal 21 through fire-resistant trough 13, a partition sheet 20 constructed from non-magnetic material has been provided between the bottom of the trough 13 and the inductor, the sheet being separated from the inductor by a layer of insulating material.

To agitate the metal melt 21 the inductor is connected, for example, in such a way that it will produce an electromagnetic traveling field progressing perpendicularly out of the plane of the drawing. In the area in which this traveling field penetrates, a current of the same direction indicated by 22 is induced in metal melt 21, the current causing a reflux in direction roughly opposite in the remaining areas of the melt. Favored by the wall effect of trough 13, additional flow components will be created at the same time in such a manner that altogether a very effective agitation of the metal melt 21 is achieved.

Many changes and modifications of the above embodiments can of course be made without departing from the scope of the invention. Accordingly, that scope is intended to be limited only by the scope of the appended claims.

What is claimed is:

1. In a multiphase two-layer bar wave winding with a winding head in one plane for a traveling field inductor with half-wound boundary poles, the improvement where at least one winding train has been provided per phase, said train starting each time at the same end of the inductor, passing through said inductor in the form of a wave progressing forward in the direction toward the other end of the inductor, engaging in the upper or lower layer in each pole a groove assigned to the pertinent layer and alternating from pole to pole, reversing itself in the last pole at the end of the inductor, changing over from one layer to the other in the form of a lap and then returning to the starting end of the inductor, progressing backwards in a part developed quasihomologously in relation to the winding part running forward, so that every groove receives a bar of the part of the winding train progressing forward and of the part progressing backward.

2. In a multiphase two-layer bar wave winding as in claim 1, the further improvement that the winding has several grooves per pole and phase and a number of such winding trains corresponding to the number of grooves per pole and phase are connected electrically with one another via reversing laps in the initial boundary pole, so that the winding train in the reversing lap additionally passes from the lower to the upper conductor layer.

3. In a multiphase two-layer bar wave winding as in claim 1, the further improvement that all bars of the first pole each time across their entire length are arranged in the same winding layer and in that the winding trains pertaining to the same phase and beginning at said pole are connected electrically with one another outside the actual winding head.

4. In a multiphase two-phase bar wave winding as in claim 3, the further improvement that two equal individual windings are inserted into the grooves of a common stack of sheets of the inductor, whereby the starting boundary pole of one of the individual windings, wound only in the upper layer, has been nested with the starting boundary pole of the other individual winding, wound only in the lower layer, for the purpose of forming an evenly distributed total winding in the grooves of the inductor, and in that the ends of the winding of one individual winding are connected electrically with the beginnings of the winding of the other individual winding.

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