Nov. 11, 1969 R. S. SEGSWORTH 3,478,156

POLYPHASE STIRRING OF MOLTEN METAL

Filed Feb. 15, 1968 2 Sheets-Sheet 1

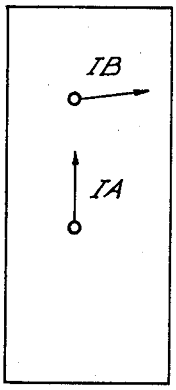

Fig. 1a

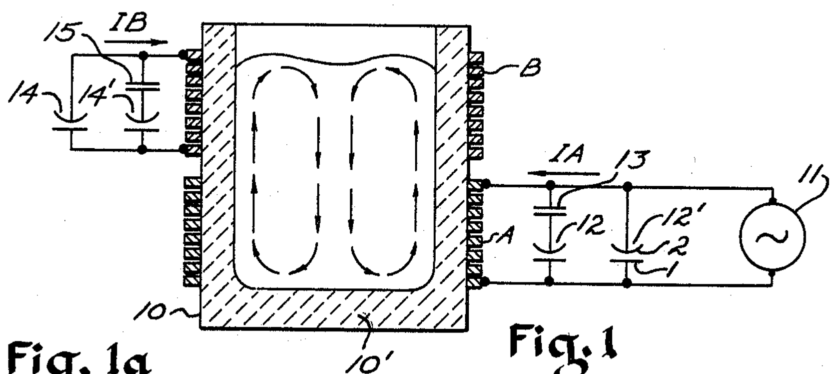

Fig. 1

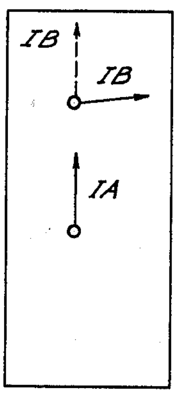

Fig. 2a

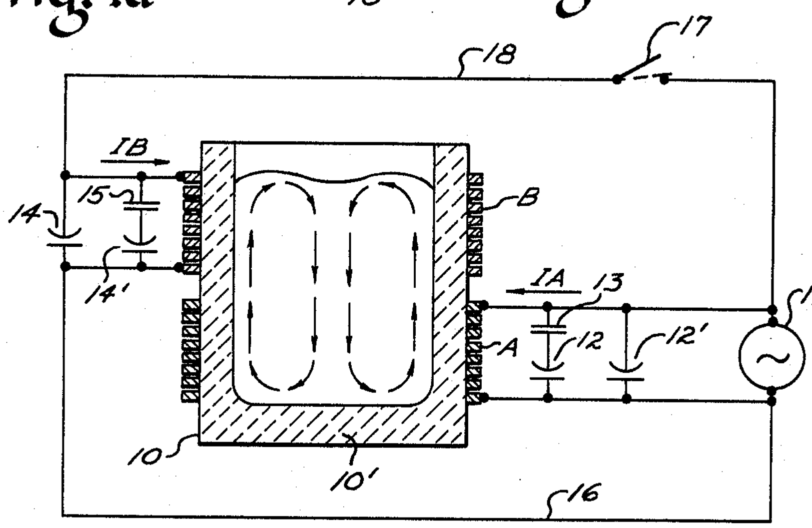

Fig. 2

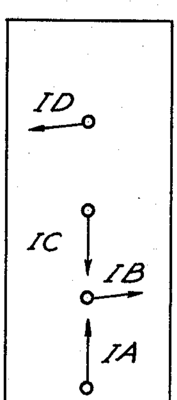

Fig. 3a

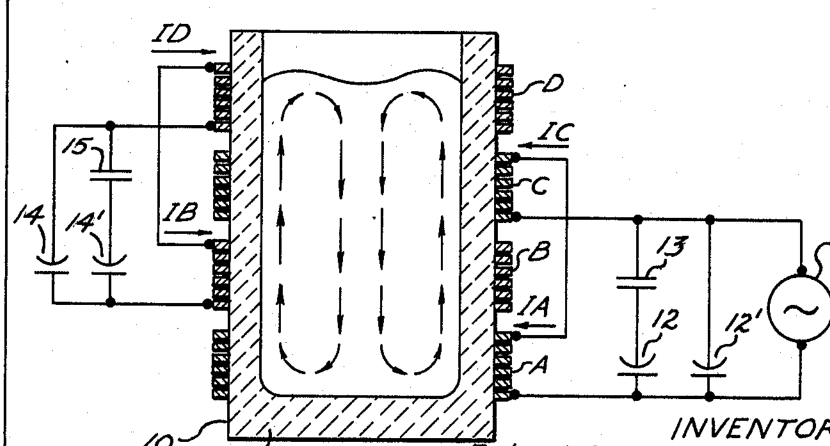

Fig. 3

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POLYPHASE STIRRING OF MOLTEN METAL

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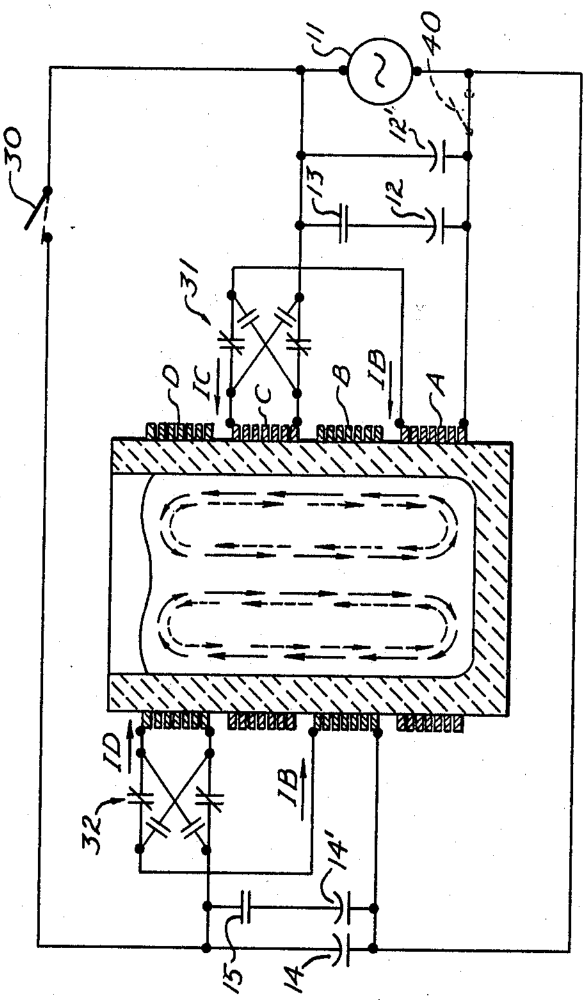

Fig. 4

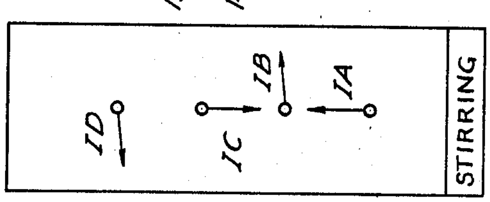

Fig. 4a

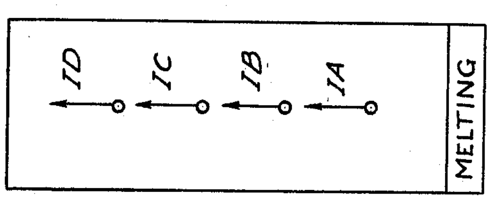

Fig. 4b

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POLYPHASE STIRRING OF MOLTEN METAL

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Int. Cl. H05b 5/12, 5/00, 9/06
U.S. Cl. 13—27 9 Claims

ABSTRACT OF THE DISCLOSURE

Resonant polyphase stirring of molten metal from a single-phase source comprising the combination of a plural-section coil surrounding a molten metal container, each of said coil sections surrounding different portions of said container and being coaxial and axially adjacent each other, a single phase power supply being connected to and energizing a first of said sections and a second of said sections being serially connected to capacitance and unconnected to said power supply, the current in said second unconnected section displaced in phase from the current in said first section.

This invention relates to a method and apparatus for polyphase stirring and/or melting from a single phase source of alternating current.

An object of this invention is to achieve increased stirring in a coreless melting or holding furnace.

A further object of this invention is to provide polyphase stirring in a coreless melting or holding furnace with a single phase source.

A still further object of this invention is to provide said polyphase stirring but eliminating violent agitation of the melt surface.

Another object of this invention is to provide polyphase stirring of molten metal with improved electrical efficiency.

A further object of this invention is to provide a coreless melting or holding furnace wherein transfer from single phase melting to polyphase stirring is accomplished in a relatively simple, economical and expeditious manner.

Another object of this invention is to provide for transfer from polyphase stirring in a coreless melting or holding furnace to single phase melting.

A still further object of this invention is to provide stirring means for a coreless melting or holding furnace wherein the direction of stirring may be readily reversed. A still further object is to provide polyphase stirring of molten metal in pipe lines to move or pump the same.

Other objects of the invention and the invention itself will become more readily apparent by reference to the accompanying drawings, in which:

FIGURE 1 is a longitudinal vertical sectional view of a furnace embodying the invention including electrical circuit connections;

FIGURE 1A is a view showing a phase vector diagram of the coil currents of FIGURE 1;

FIGURE 2 is a view similar to FIGURE 1 showing a switching connection between the two coil sections of FIGURE 1;

FIGURE 2A is a phase vector diagram identical with that of FIGURE 1A showing in dotted lines the phase angle of the current 1B when the switch of FIGURE 2 is closed;

FIGURE 3 is a view similar to FIGURE 1, but showing a modification of the invention wherein four coil sections are used;

FIGURE 3A is a phase vector diagram of the coil currents of FIGURE 3;

FIGURE 4 is a view similar to FIGURE 1 of another modification of the invention disclosing switches for reversing the direction of flow of the metal in a furnace;

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FIGURE 4A is a phase vector diagram of the coil currents of FIGURE 4 during polyphase upward stirring; and

FIGURE 4B is a phase vector diagram of the coil currents of FIGURE 4 during melting.

Referring now more particularly to the drawings, in all of which like parts are designated by like reference characters, a coreless melting or holding furnace **10** and, as shown, with a crucible having a refractory lining **10'**, surrounded by a coil of two or more sections. Sections of said coil are connected to a single phase alternating current power source and other of said sections are unconnected thereto. The said alternating current is applied so that the phase preferably shifts by the same angle from one coil section to the next, as shown in the current vector FIGURES *1a, 2a, 3a* and *4a,* wherefor positive unidirectional motion of the outer portion of the melt in the direction in which the travelling magnetic field moves is achieved. Thus, it is possible to obtain either upward or downward movement (see FIG. 4) in the outer portion of the normally cylindrical melt while a unidirectional return flow in the opposite direction generally prevails in the center portion.

In the embodiment of FIGURE 1, a pair of coaxial spaced coils A and B surround the furnace. The bottom coil A is shown supplied with alternating current from a single phase generator, frequency multiplier, or other alternating current source **11.** A bank of capacitors **12, 12'** connected in parallel in the input line are adapted to be added or subtracted by switching means **13** to improve the power factor.

The coaxial coil section or upper section B is connected to a bank of capacitors **14, 14'**, similar to those designated at **12, 12'**, and said capacitors **14, 14'** are adapted to be switched in and out as required by switch means **15.** The coil section B is not connected to the power source.

It has been found that in this arrangement the amount of capacitors connected to the upper section may be adjusted to produce resonance or near resonance in tune with the circuit of coil section A with the result that a very substantial upward stirring of the melt at the sides of the crucible **10** results with corresponding downward flow in the center section of the melt as shown in FIGURE 1. Under these circumstances the phase angle of the current 1_B through the upper section B lags the current in the lower section 1_A by approximately 90°, as shown in the current vector diagram FIGURE *1a.*

The phase angle shown in FIGURE *1a,* it will be understood, can be adjusted within a wide range from substantially less than 90° to substantially more than 90° without significantly affecting the current itself or the upward stirring effect produced. It is generally found desirable to tune the upper coil close to resonance.

Coreless furnace installations of the prior art provide at least two separate sources of voltage with a substantial phase angle between them to accomplish polyphase stirring and are usually designed to operate at maximum power for melting from a single-phase high power supply and at a reduced power level for polyphase stirring by transferring each coil section from such single phase high power supply to one phase of a polyphase supply, since it is normally not desirable to melt in the polyphase mode since a significant loss of electrical efficiency would take place and a strong agitation of the melt surface which could be deleterious and detrimetal to the metallurgy. A large number of switches and at least partial duplication of voltage regulating facilities is required therefor, hence the transfer is costly and complicated in such installations.

In FIGURE 2, an arrangement for transferring the system of FIGURE 1 from melting to stirring is illustrated. It will be noted that a fixed electrical connection **16** between the bottom terminals of the two coil sections B and A and a tie-line **18** with a single switch means **17** between the upper terminals of coil sections B and A has been added to the showing of FIGURE 1. Conversion from stirring to melting is accomplished, in this form of the invention, by closing the switch **17** as indicated by dotted lines so that both sections B and A now operate as parallel sections of a single-phase coil in a conventional manner. The capacitors **12, 12′, 14, 14′** can then be readjusted manually or automatically, act jointly and are fully utilized to correct the power factor of the single phase furnace.

It is proposed that taps may be provided on the induction coil or a transformer interposed between the induction coil and the capacitors, or a transformer interposed between said coil and the capacitors and that in such event the tap or transformer setting may be adjusted when transferring from stirring to melting operation. It is believed that such tap or transformer setting adjustments are of the type readily understood by those skilled in the art to which the present invention appertains.

The effectiveness of polyphase stirring, it has been found, generally improves with the number of separately phased coil sections used, hence, in the form of the invention shown in FIGURE 3, the furnace is disclosed with four sections designated as A, B, C and D in sequence from the bottom coil upward to the top coil section.

If upward stirring is desired as shown by arrows in the form of FIGURE 3, the generator or other single-phase power source is connected to coils A and C and this connection may be in series or in parallel. However, such coils must be connected in a way, as shown, that their electro-magnetic fields "buck" or oppose each other. In other words, I_A and I_C, as shown in FIGURE 3, are substantially 180° out of phase.

A battery of capacitors, as shown, with fixed and variable capacity, is connected, in the form of FIGURE 3, to sections B and D in series, but again in such a manner that the current in these two sections will "magnetically buck" each other or be 180° out of phase with each other.

It will be apparent that parallel "bucking" may be used in this form of the invention, but the series connection which is shown in FIGURE 3 is preferably used for the enenergized B and D sections. As shown, if the battery of capacitors **14, 14′** is tuned to resonance or near resonance, the current I_B lags the current I_A by approximately 90°; the current I_C as hereinbefore described is 180° out of phase with the current I_A and, hence, lags the current I_B by 90°. Finally, the current I_D lags I_B by 180° and, therefore, lags the current in section C by approximately 90°. The four currents referred to hereinabove, viz. I_A, I_B, I_C and I_D are illustrated in FIGURE 3*a* by vectors opposite the separate coil sections illustrated in FIGURE 3. The current in each section, it will be noted, lags behind that in the section below it by approximately 90°. The resulting "full wave" travelling field produces upward flow as shown by arrows in FIGURE 3 in the outer layers of the melt in an improved manner over that of FIGURE 1.

It has sometimes been found desirable to provide a furnace that can be provided with upward stirring or downward stirring at the operator's option and a furnace that can melt in a normal single-phase operation and in addition be capable of stirring either upwardly or downwardly at the operator's option.

In FIGURE 4, a switching arrangement is disclosed wherefore transfer may be made from polyphase stirring to single-phase melting with the basic four phase stirring connection shown in FIGURE 3. A switch **30** is provided to connect sections B and D to the generator or other single phase source so that all four sections A, B, C and D, respectively, may be placed in phase for

melting rather than 180° apart, as required in stirring. The circuit of FIGURE 4 provides that in the melting operation, sections A and C and B and D are connected in series and both groups then connection in parallel to the single phase source or generator. Each section then operates at approximately ½ the generator voltage and all four sections, A, B, C and D contribute approximately the same power.

It will be obvious that coil taps or transformers, as previously described in connection with FIGURE 2, may be employed in the form of the invention as shown in FIGURE 4.

FIGURE 4*b* is a vector diagram of the currents of sections A, B, C and D during the melting operation and FIGURE 4*a* is a vector diagram of the currents I_A, I_B, I_C, and I_D during the stirring operation and in said operation the current in each section, similarly to that shown in FIGURE 3*a*, lags behind that in the section below it by approximately 90° and also produces a full-wave upward travelling field producing upward flow in the outer layers of the melt.

To reverse the stirring action shown in solid line arrows in FIGURE 4, the power source may be connected to the upper sections D and B and capacitance only to the lower sections C and A so that the current in the lower section will lag the upper section and thus producing downward flow, as indicated in dotted line arrows, in the outer portion of the melt and upward flow in the center of the melt. This may be effected, for example, by closing switch **30** and opening switch **40** shown in dotted lines.

The polarity of coil sections C and D is reversed as by switch means **21, 32** so that the currents in sections A and C, and in B and D, respectively, will be in phase for melting rather than 180° apart, as required for stirring. The switch **30**, shown in FIGURE 4, is similar to the switch **17** in FIGURE 2, employed to provide a tie-line connection to the upper sections, wherefore sections A, B, C and D are all energized from the same single-phase power source and maximum power is obtained for melting.

Although the invention has been described in connection with coreless melting or holding furnaces, it will be obvious that the same may be employed for moving or pumping molten metal in pipe lines by creating a travelling electro-magnetic field and in such application, since the liquid is free to travel, it should be noted that the flow will be unidirectional throughout the body of molten metal, the center being carried along by the peripheral flow.

It will further be obvious that an increased number of sections for example, either or more coil sections may be used in the furnaces and that the effectiveness of the polyphase stirring will increase as the frequency is lowered and improves with the number of separately phased coil sections used.

Further, it will be understood that the invention may be opearted at the normal line frequency of 60 cycles, or preferably at other frequencies such as a 180 cycle, 960 cycle, 30 cycles, etc. Such frequencies are normally available in single-phase form, whereas, three-phase supply is generally available from 60 cycle.

Although I have described my invention in connection with certain preferred embodiments, I am aware that numerous and extensive departures may be made therefrom without, however, departing from the spirit of my invention or the scope of the appended claims.

What I claim is:

1. In combination, a plural-section coil, a molten metal container, said plural-section coil comprising separate coil sections surrounding different portions of said container, a single phase power supply, said coil sections being coaxial and axially adjacent each other, a first of said sections being connected and energized by said power supply, a second of said sections being connected to capacitance and unconnected to said power supply, the current in said second unconnected section being substantially displaced in phase from the current in such first section thereby producing polyphase unidirectional stirring movement in the molten metal.

2. A coil as claimed in claim 1 wherein said second of said sections is tuned substantially to the frequency of said power supply.

3. In the combination of claim 1, means for adjusting said capacitance to substantially achieve resonance at the frequency of said single phase power supply.

4. In the combination of claim 1, said separate sections having currents of different phase applied to the same during stirring and means whereby currents of the same phase may be applied to all of the said sections for melting.

5. In the combination of claim 1, a lower section being connected to said single phase power supply and an upper section being connected to said capacitance but unconnected to said power supply producing polyphase stirring, said sections having currents of different phase applied to the same during stirring and means whereby currents of the said phase may be applied to the said sections for melting.

6. In the combination of claim 1, means for adjustment of the phase angle between the coil sections.

7. In the combination of claim 1, means for transferring from polyphase stirring of the molten metal in the furnace to single phase melting.

8. In the combination of claim 1, means for reversing the connections of said sections whereby said one section connected to said supply is disconnected therefrom being connected solely to said capacitance and said other section is connected to said supply.

9. In combination, a four-section coil, a molten metal container, said four-section coil comprising four separate coil sections surrounding different portions of said container, a single phase power supply, said coil sections being coaxial and axially adjacent each other, a first of said sections being connected and energized by said power supply, a second of said sections being serially connected to capacitance and unconnected to said power supply, a third of said sections being connected and energized by said power supply, a fourth of said sections being serially connected to capacitance and unconnected to said power supply, the phase angle of current in each of said sections lagging that of the current in the preceding section by substantially 90°, thereby producing polyphase unidirectional stirring movement in the molten metal.

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L. H. BENDER, Assistant Examiner

U.S. Cl. X.R.

219—10.75

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,478,156 November 11, 1969

Robert Sidney Segsworth

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, line 47, "energized" should read -- unenergized --; line 59, after "full wave" insert -- upward --. Column 4, line 33, "21" should read -- 31 --.

Signed and sealed this 10th day of November 1970.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents