APPARATUS FOR CONTROLLING THE FLOW OF MOLTEN METAL

Filed April 20, 1953 2 Sheets-Sheet 1

Fig.1.

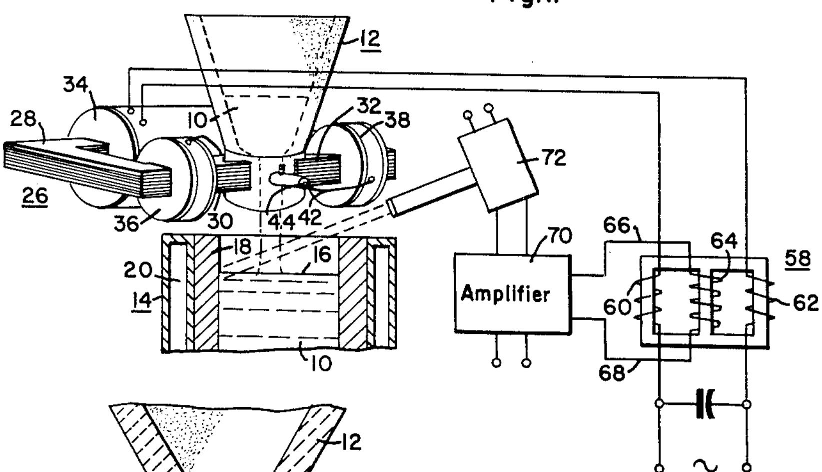


Fig.2.

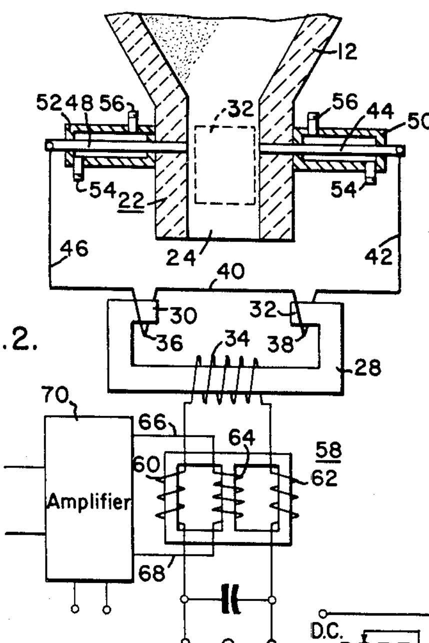


Fig.3.

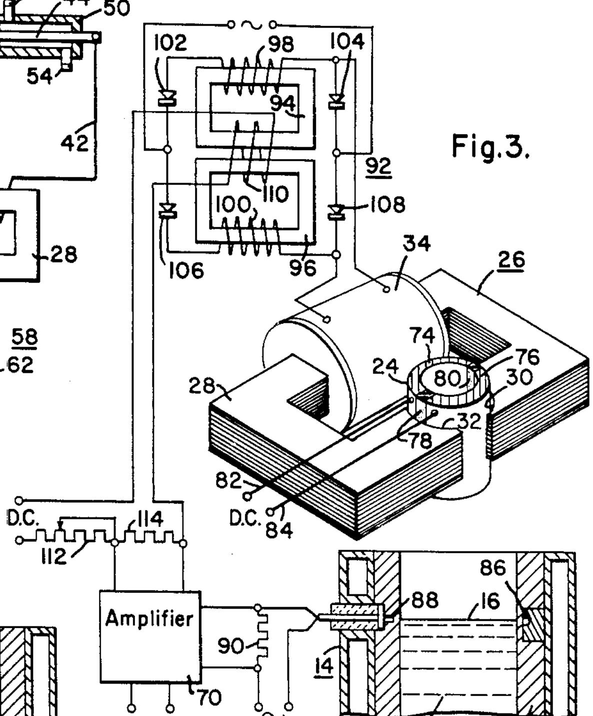
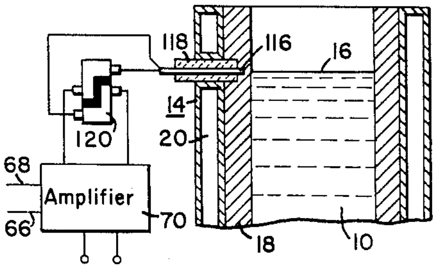


Fig.4.



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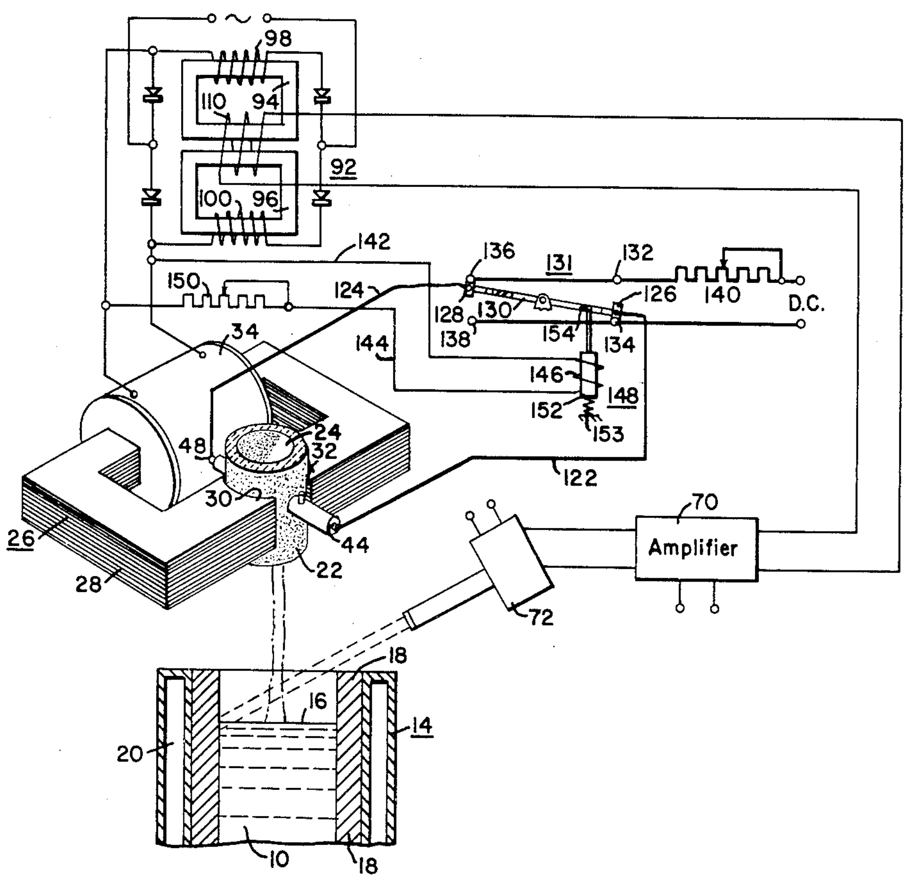
May 1, 1956 R. EASTON 2,743,492

APPARATUS FOR CONTROLLING THE FLOW OF MOLTEN METAL

Filed April 20, 1953 2 Sheets-Sheet 2

Fig.5.



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APPARATUS FOR CONTROLLING THE FLOW OF MOLTEN METAL

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Application April 20, 1953, Serial No. 349,673

5 Claims. (Cl. 22—79)

This invention relates to the casting of molten metal and in particular to apparatus for controlling the flow of molten metal into a mold.

In many commercial applications of the pouring of molten metal, it is desirable to control the flow of such molten metal. Thus in casting ingots of certain types of steel, it is desirable to control the pouring rate of the molten metal so as to provide a substantially constant rate of flow to facilitate a proper and preferred solidification of the metal in the ingot form. Likewise in the making of continuous castings it is desired to control the flow of molten metal into the mold so as to maintain a predetermined level of molten metal in the mold above the solidified casting in order to obtain a sound casting therefrom.

In commercial practice, the molten metal is usually poured from a melting or holding furnace into a tundish of refractory material which is provided with an orifice in the bottom thereof, the molten metal flowing through such orifice into the mold. By visually observing the level of the metal in the tundish and manually controlling the pouring rate of the metal from the furnace to maintain a predetermined level of the metal in the tundish, a rough control of the pouring rate of the molten metal into the mold can be achieved. However, such visual and manual control is not satisfactory as there are too many variables depending upon the constant observation of an operator and the resulting quality of the casting is dependent to a great extent upon the skill of the operator.

An object of this invention is to provide for automatically controlling the flow of molten metal from a tundish into a mold.

Another object of this invention is to provide for electrically developing a positive force applied to a stream of molten metal as it flows from a tundish to control the flow thereof.

A further object of this invention is the provision of apparatus for use in conjunction with a tundish and a mold for the making of continuous castings, of means responsive to a measure of the level of the metal in the mold for electrically developing a positive force applied to the stream of molten metal as the metal flows through the tundish into the mold.

A more specific object of this invention is the provision of magnetic means in conjunction with current conducting means for developing a positive force on a stream of molten metal as the metal flows from a tundish to a mold to thereby control the flow of such stream.

A further specific object of this invention is the provision of means responsive to the level of metal in a mold for electrically controlling a magnetic means disposed to cooperate with current conducting means for developing a positive force on a stream of molten metal as the metal flows through a tundish into the mold to thereby control the flow of such stream to maintain a substantially constant level of the metal in the mold.

Other objects of this invention will become apparent

from the following description when taken in conjunction with the accompanying drawing in which:

Figure 1 is a view partly in perspective and partly diagrammatic and in section of apparatus embodying the teachings of this invention;

Fig. 2 is a view partly in section and partly diagrammatic of a part of the apparatus of Fig. 1;

Fig. 3 is a view partly in perspective and partly diagrammatic and in section of apparatus illustrating another embodiment of this invention;

Fig. 4 is a view in section of a portion of the apparatus of Figs. 1 and 3 illustrating another sensing device which can be employed in practicing this invention; and

Fig. 5 is a view partly in perspective and partly diagrammatic and in section of apparatus illustrating an embodiment of this invention.

Referring to Figs. 1 and 2 of the drawing, this invention is illustrated by reference to apparatus for controlling the flow of molten metal **10** from a tundish shown generally at **12** into a mold **14**. The holding furnace or ladle for containing a supply of the molten metal **10** for supplying the tundish **12** may be of any of the well-known types but is not illustrated in order to simplify the drawing. The mold **14** may be any suitable type of mold in which it is desired to control the lever **16** of molten metal **10** therein.

In this instance the mold **14** is only partially illustrated and is of the continuous casting type being formed of an inner mold wall **18** of copper or other highly thermal conducting metal, the upper end of which is surrounded by a water jacket **20**. Where desired, the mold **15** may be reciprocated in the manner similar to that illustrated in the Junghans Patents 2,135,183 and 2,135,184.

The tundish **12** is made of a suitable refractory material being preferably conical and terminating in a lower downwardly depending end portion **22** provided with an orifice **24** therethrough. The orifice **24** is relatively small in diameter and is aligned with the mold **14** which is positioned under the tundish **12** so as to centrally discharge molten metal directly into the mold cavity formed by the mold walls **18**. Where desired, the space between the lower portion **22** of the tundish and the upper end of the mold **14** above the level **16** of molten metal can be enclosed for receiving an inert or protective gas for preventing oxidation of the molten metal as it flows from the tundish **12** to the mold **14**. Such apparatus is well-known and is not illustrated in this embodimhent for purposes of simplification of the drawing.

In order to control the rate of flow of molten metal through the orifice **24** of the tundish **12**, an electromagnetic device **26** is positioned in operative relation with respect to the downwardly depending portion **22** of the tundish **12**. In this instance the electromagnetic device **26** comprises a laminated core member **28** terminating in magnetic poles **30** and **32** which are curved to fit closely adjacent the outer cylindrical wall of the lower portion **22** of the tundish **12**. Although not illustrated, the laminations of the core member **28** may be thermally insulated to protect the laminations from the heat of the molten metal contained in the tundish and the heat radiated from the upper end of the mold **14**. A main energizing winding **34** is disposed on the one leg of the core member **28** for developing a magnetic flux in the core member **28**. As illustrated, a pair of auxiliary windings **36** and **38** are disposed on the legs of the core member **28** which terminate in the pole pieces **30** and **32**, respectively.

The windings **36** and **38** are connected by a conductor **40** in series circuit relation with one another, the winding **38** being connected as by means of conductor **42** to a terminal of an electrode **44** (see Fig. 2) which is disposed to extend through the wall portion of the downwardly depending portion 22 of the tundish 12 so as to be in direct contact engagement with the molten metal 12 as it flows through the orifice 24. Likewise the winding 36 is connected by a conductor 46 to another electrode 48 which extends through the wall portion of the downwardly depending portion 22 of the tundish 12 to be in direct contact with the molten metal 12 flowing through the orifice 24. The electrodes 44 and 48 are preferably of material having a high melting point, such as tungsten, and when positioned as described, will be sealed in position by means of the molten metal flowing about the ends of the electrodes into the space between the electrode and the refractory material of the downwardly depending portion 22. The molten metal solidifies in such spaces and thus firmly holds the electrodes in position. The electrodes 44 and 48 are preferably disposed in aligned relation with one another on opposite sides of the orifice 24. Where desired, the electrodes 44 and 48 may be thermally protected by means of water jackets 50 and 52, respectively, disposed about the electrodes, each of the water jackets 50 and 52 being provided with an inlet 54 and an outlet 56 to facilitate the circulation of cooling water about the electrodes.

As clearly illustrated, the pole pieces 30 and 32 of the laminated core member 28 are also disposed on opposite sides of the orifice 24, but are displaced 90° from the aligned electrodes 44 and 48. The electrodes and pole pieces are, however, disposed in the same horizontal plane through the orifice 24. The magnetic device 26 thus serves not only as a means for developing lines of flux through the molten metal flowing in the orifice 24, but also serves as a source of supply of current flowing between the electrodes 44 and 48 which are displaced 90° from the aligned pole pieces 30 and 32 of the core member 28.

As will be appreciated, the lines of flux flowing between the magnetic pole pieces 30 and 32 will cooperate with the current flowing between the electrodes 44 and 48 for developing a positive force on the stream of molten metal flowing through the orifice 24. Thus, if it is considered that the molten metal disposed between the electrodes 44 and 48 is of a definite length L cm. (in practice ½″ diameter has been found to be satisfactory) and is carrying a current of I amperes perpendicular to a magnetic field of B lines per square cm., then the metal disposed between the electrodes 44 and 48 is acted on by a force of $BLI/10$ dynes in a direction found by Fleming's left-hand rule. The force and direction of the force applied to the stream of molten metal flowing through the orifice 24 can thus be controlled.

In order to control the energization of the winding 34, a saturable reactor 58 is connected between a source of alternating current and the winding 34. The saturable reactor 58 is of a conventional three-legged design having alternating current windings 60 and 62 on its outer legs connected between the source and the winding 34 of the electromagnetic device 26. In order to control the impedance of the reactor 58 a direct current control winding 64 is disposed in the middle leg of the reactor 58, the winding 64 being connected as by means of conductors 66 and 68 across the output of an amplifier unit represented by the rectangle 70.

The amplifier 70 may be of any suitable type, many different types being known to the art, which will be satisfactory when connected in circuit for amplifying a signal to produce a direct current suitable for controlling the saturable reactor 58. In this instance a Leeds and Northrup "Rayotube" or a Brown "Radiamatic" radiation pyrometer 72 is employed as a sensing device for providing a signal which will control the energization of the direct current winding 64 of the reactor 58. The sensing device 72 is positioned relative to the mold 14 so that the level 16 of the metal 10 therein will emit a source of heat radiation energy, the intensity of which depends upon the height of the level 16 to the sensing device 72. The sensing device 72 will provide a signal dependent upon the degree of heat radiation intercepted from the level of the metal which when amplified by the amplifier 70, will control the energization of the direct current winding 64 to so control the output of the reactor 58 as to control the operation of the electromagnetic device 26 to apply a positive force to the stream of molten metal flowing through the orifice 24 to maintain the level substantially constant.

In operation, assuming that the level 16 of molten metal in the mold 14 is at the predetermined level which is to be maintained, the sensing device 72 functions to provide a signal which when amplified by the amplifier 70, will so control the energization of the direct current winding 64 as to control the output of the saturable reactor 58 to energize the winding 34 in a predetermined manner. The energization of the winding 34 causes a flux to be developed between the pole pieces 30 and 32 and current to flow between the electrodes 44 and 48, the current and flux so developed cooperating to develop a positive force on the molten metal flowing through the orifice 24 such as to control the flow so as to maintain a substantially constant level of metal in the mold 14 above the solidified casting.

If, for any reason, the level of the molten metal above the solidified casting should tend to vary, for example, rise, the sensing device 72 functions to provide an increase in the signal output therefrom which when amplified by the amplifier 70, will, in effect, increase the current flow through the control winding 64 to thereby increase the saturation of the saturable reactor 58. The power supplied to the energizing winding 34 of the electromagnetic device 26 is thereby so increased as to simultaneously effect an increase in the flux between the pole pieces 30 and 32 and the current flowing between the electrodes 44 and 48 to effect an increase in the positive force applied to the molten metal flowing through the orifice 24 to effectively retard the flow to permit the level of the molten metal above the solidified casting in the mold 14 to return to the predetermined level 16 which is to be maintained.

On the other hand, if the level 16 of molten metal above the solidified casting in the mold 14 should be lowered, then the sensing device 72 functions to provide a decrease in the signal output therefrom with the result that the current flow through the control winding 64 of the reactor 58 is decreased to decrease the saturation of the saturable reactor 58. Such a change in the saturation of the reactor 58 will effect a decrease in the power supplied to the winding 34 of the electromagnetic device 26 to effect a decrease in the flux between the magnetic pole pieces 30 and 32 and a decrease in the current flow between the electrodes 44 and 48 with the result that the positive force applied to the molten metal flowing through the orifice 24 is decreased and the rate of flow of the molten metal to the mold 14 is increased to return the level of the molten metal in the mold to the predetermined level 16 which is to be maintained.

In the embodiment of the invention illustrated in Fig. 3, the same principle of applying a positive force to the stream of molten metal flowing through the orifice 24 of a tundish 12 to a mold 14 is employed. However, in this embodiment the downwardly depending portion 22 of the tundish forming the orifice 24 is formed of a composite refractory. Thus the depending portion 22 is formed of two semi-circular portions 74 and 76 of a conductive refractory material such as graphite or stabilized zirconium oxide or a semi-conducting metal such as cast iron, depending upon the material which is to be cast, the adjacent meeting edges of the portions 74 and 76 being separated by strips 78 and 80 of non-conductive refractory material. The side wall portions 74 and 76 of the downwardly depending portion 22 of the tundish 12 are disposed to be connected as by conductors 82 and 84, respectively, to a source of direct current power and thus form the electrodes for passing direct current through the stream of molten metal as it flows through the orifice 24.

Instead of the sensing device 72 employed in the embodiment of Fig. 1, this embodiment illustrates the use of a sensing device formed of a small piece of artificial radioactive material 86, such as radioactive cobalt Co^{60}, which emits gamma rays, the radioactive material 86 being suitably embedded in the mold wall 18 so that only a very thin portion of the material of the mold wall is disposed between the radioactive material and the casting cavity of the mold 14. Disposed on the opposite side of the mold cavity is a small crystal 88 of cadmium sulphide or other suitable radioactive sensitive material which is in alignment with the artificial radioactive material 86. The cadmium sulphide has the characteristic of being normally non-conducting, but becoming conducting when gamma rays fall on it. As illustrated, the cadmium sulphide is connected to a source of voltage so that the current through a resistor 90 to a source of voltage is a measure of the amount of gamma radiation falling on the cadmium sulphide so that the output from the sensing device is a measure of the level 16 of the molten metal contained in the mold 14, it being apparent that as the level rises to intercept the gamma rays, the signal from the sensing device will be decreased.

As in the previous embodiment, the signal from the sensing device is supplied to a suitable amplifier 70 for amplifying such signal. In this instance the amplifier is connected across the resistor 90 so that in effect the amplifier is functioning to measure variations in the potential drop across the resistor 90, which potential drop is a measure of the level of the metal in the mold.

In the embodiment of Fig. 3, a magnetic amplifier 92 of conventional form is employed for supplying power to the energizing winding 34 of the electromagnetic device 26. In this instance the magnetic amplifier 92 is formed of two rectangular core members 94 and 96, each being provided with a winding 98 and 100, respectively, connected between the source of alternating current voltage and the energizing winding 34 of the electromagnetic winding 36. Rectifiers 102, 104, 106 and 108 are connected in circuit relation with the windings 98 and 100 for controlling the direction of flow of current therein and to provide the flow of a unidirectional current therefrom through the energizing winding 34. In order to control the saturation of the magnetic amplifier 92, a direct current control winding 110 is disposed about the adjacent legs of the core members 94 and 96 to be supplied from a direct current source and to have the flow of current therein controlled in accordance with the output of the amplifier 70. Thus an adjustable rheostat 112 is connected in circuit relation with the control winding 110 and the direct current source for adjusting the initial energization of the winding 110, another resistor 114 being connected in series circuit relation with the rheostat 112 and being connected across the output of the amplifier 70. The amplifier 70 is disposed to impress a potential across the resistor 114 in opposition to the potential drop of the current flow from the direct current source so that as the output of the amplifier 70 varies, the flow of direct current in the winding 110 changes in the opposite sense and the energization of the winding 110 will thus vary in direct proportion to a change in the level 16 as measured by the signal supplied to the amplifier 70 from the sensing device comprising the radioactive material 86 and the cadmium sulphide detector 88.

In operation, it is assumed that the rheostat 112 of the embodiment of Fig. 3 has been adjusted so that with the level 16 of metal in the mold 14 at the predetermined level which is to be maintained, the amplifier 70 will impress a potential across the resistor 114 which will cooperate with the direct current from the source to so control the energization of the winding 110 as to maintain the degree of saturation of the magnetic amplifier 92 at a point suitable for effecting an energization of the winding 34 which will cooperate with the current flowing between the conducting side wall portions 74 and 76 across the orifice 24 to develop a positive retarding force of a magnitude to maintain the flow of metal therethrough at a rate sufficient to maintain the level 16 at the predetermined level which is to be maintained. If, for any reason, the level of the metal in the mold 14 should vary, as for example, raise from the predetermined level 16 which is to be maintained, the radiation of the gamma rays from the radioactive material 86 is intercepted in direct proportion to the increase in the height of the molten metal in the mold 14 so that the signal supplied to the amplifier 70 is decreased. As the signal is thus decreased, the potential impressed across the resistor 114 in opposition to the potential drop of the current from the direct current source is decreased with the result that an increase is effected in the flow of direct current in the winding 110 to so increase the saturation of the magnetic amplifier 92 as to effect an increase in the output therefrom to thereby increase the energization of the winding 34. Assuming that the direct current supply to the side walls 74 and 76 forming the orifice 24 is substantially constant, it is apparent that the increase in the flux between the magnetic pole pieces 30 and 32 occasioned by the increase in the energization of the winding 34 of the electromagnetic device 26 will be effective for increasing the positive retarding force applied to the stream of molten metal flowing through the orifice 24 to effectively decrease the rate of flow thereof and thereby effect a lowering of the level of the molten metal in the mold 14 to the initial predetermined level 16 which is to be maintained.

On the other hand, if the level of the molten metal in the mold 14 should be lowered from the predetermined level 16 which is to be maintained, more of the gamma rays from the radioactive material 86 will impinge upon the cadmium sulphide detector 88 with the result that the signal supplied to the amplifier 70 is so increased as to effect an increase in the potential impressed thereby across the resistor 114. Since the potential impressed upon the resistor 114 is in opposition to the direct current source, such an increase in the signal will effect a decrease in the current flow through the control winding 110 to decrease the saturation of the magnetic amplifier 92. As the saturation of the magnetic amplifier 92 is decreased, the output therefrom is decreased with the result that the energization of the winding 34 is decreased to effect a decrease in the flux between the magnetic pole pieces 30 and 32. Such a decrease in the magnetic flux between pole pieces 30 and 32 is effective for decreasing the positive retarding force applied to the stream of molten metal in the orifice 24 whereby the flow of molten metal into the mold 14 is increased to raise the level of the molten metal to the predetermined level 16 which is to be maintained.

Instead of the sensing device illustrated with respect to the embodiment of Figs. 1 and 2, a thermocouple 116 may be employed as illustrated in Fig. 4 of the drawing. Where the thermocouple 116 is employed, it is embedded in the mold wall 18 of the mold 14 as close as possible to the inner wall at the level at which it is desired to maintain the level 16 of molten metal in the mold. The thermocouple is preferably insulated as at 118 from the water cooled jacket 20 and the side walls 18 except at its terminus where it is desired to measure the temperature. Since the changes in the thermal E. M. F. produced by a thermocouple are too small to be amplified directly, it is preferred to utilize a rotating commutator 120 connected between the thermocouple 116 and an amplifier 70 for amplifying the output of the commutator 120. Where such a sensing device is employed, the output of the amplifier 70 can be connected as by conductors 66 and 68 to the control winding 64 of the saturable reactor 58 of the control of Fig. 1. Thus as the level of metal in the mold 14 rises, the thermocouple 116 senses the change by reason of the increase in the temperature of the larger mass of molten metal and provides a signal for controlling the saturation of the reactor 58 to control the positive force applied to the metal flowing through the orifice 24 in the same manner as the embodiment of Fig. 1.

Instead of applying a positive force to retard the flow of molten metal through the orifice 24 of the tundish 12 as described hereinbefore with reference to the embodiment of the invention illustrated by Figs. 1 and 3, it may be desirable to reverse the direction of the positive force thus applied to, in effect, produce "pumping" of the molten metal as it flows through the orifice 24. With the apparatus illustrated in Fig. 5, not only can a control of the degree of positive force applied to the molten metal in the orifice be effected, but also a reversal of the direction of the positive force can be obtained to produce a pumping action applied to the metal flowing through the orifice 24 of the tundish 12.

As in the previous embodiments, an electromagnetic device 26 formed of an energizing winding 34 disposed on the laminated core member 28 is provided for developing a flux between pole pieces 30 and 32 disposed on opposite sides of the orifice 24 in the downwardly depending portion 22 of a tundish. Independent electrodes 44 and 48 are disposed 90° apart from the magnetic pole pieces 30 and 32 and in alignment with one another for passing a direct current through the molten metal in the orifice 24. In this embodiment of the electrodes 44 and 48 are connected as by means of conductors 122 and 124 to contact members 126 and 128 carried on the opposite ends of a pivotal arm member 130 of a reversible switch 131, the contact members 126 and 128 being disposed to be actuated into contact engagement with fixed contact members 132—134 and 136—138, respectively, which are connected to a source of direct current supply. An adjustable rheostat 140 is connected in circuit relation between the contact member 132 and the source of direct current. As in the embodiment of Fig. 1, a "Rayotube" or "Radiamatic" radiation pyrometer 72 is employed as a sensing device for providing a signal indicative of the level of molten metal 10 in the mold 14, the output of the sensing device 72 being amplified as by means of an amplifier 70 for controlling the output of a magnetic amplifier 92 of the type employed in the embodiment of Fig. 3. In this embodiment, the output of the magnetic amplifier is connected to supply the energization of the winding 34 of electromagnetic device 26 whereby the flux between the magnetic pole pieces 30 and 32 is in direct relation with the level of the molten metal 10 in the mold 14.

In addition to supplying the energization of the winding 34, the magnetic amplifier 92 is connected as by means of conductors 142 and 144 to the energizing winding 146 of an electromagnetic device 148. An adjustable rheostat 150 is connected in circuit relation with the winding 146 to initially adjust the energization thereof. The electromagnetic device 148 is provided with an armature member 152 about which the winding 146 is disposed, the armature member 152 being pivotally connected as at 154 to the pivotal arm 130 of the reversing switch 131. A spring member 153 is disposed to bias the armature member 152 in an upward direction in opposition to the force developed by the energizing winding 146.

In operation, with the level of the metal in the mold 14 at the predetermined level 16, the sensing device 72 produces a signal which when amplified by the amplifier 70, is sufficient to so energize the control winding 110 of the magnetic amplifier 92 that the output therefrom to the energizing winding 34 of the electromagnetic device 26 is sufficient to develop a magnetic flux between the magnetic pole members 30 and 32 to cooperate with the current flow at right angles thereto between the electrodes 44 and 48 as to apply a retarding force to the stream of molten metal flowing through the orifice 24 to so control the rate of flow thereof as to maintain the level of molten metal in the mold 14 at the predetermined level which is to be maintained. During such an operation, the rheostat 150 is adjusted so that the energizing winding 146 of the electromagnet 148 is sufficient to overcome the force of the spring 153 so as to maintain the contact member 128 in engagement with the fixed contact member 136 and the contact member 126 in engagement with the fixed contact member 134. With the pivotal arm 130 of the reversing switch 131 actuated as indicated, current flows from the positive terminal of the direct current source through the adjustable resistor 140, contact members 132, 136 and 128, conductor 124, the electrode 48, the metal flowing through the orifice 24, electrode 44, conductor 122 and contact members 126 and 134 to the negative terminal of the direct current source. The measure of current flowing between the electrodes 44 and 48 can be adjusted by adjusting the adjustable rheostat 140.

If, for some reason, the level of the metal in the mold 14 should tend to rise, the sensing device 72 will detect such a rise in the level and increase the signal output therefrom with the result that the output from the amplifier 70 is increased. As the output of the amplifier 70 increases, the energization of the control winding 110 is increased to effect an increase in the output of the amplifier 92 to the energizing winding 34 of the electromagnetic device 26. Such an increase in the output of the magnetic amplifier 92 has no effect on the operation of the electromagnet 148 referred to hereinbefore. As the energization of the winding 34 is thus increased, the flux between the magnetic pole pieces 30 and 32 is increased for cooperating with the current flow between the electrodes 48 and 44 to increase the positive retarding force applied to the metal flowing through the orifice 24 to decrease the rate of flow of metal to the mold 14. Such a decrease in the rate of flow of metal through the orifice 24 will effectively return the level of molten metal 10 in the mold 14 to the predetermined level 16 which is to be maintained.

On the other hand, if the level of the metal 10 in the mold 14 should tend to decrease from the predetermined level 16 which it is desired to maintain, the sensing device 72 will provide a decreased signal so that the amplified output of the amplifier 70 is effectively decreased to decrease the energization of the control winding 110 of the magnetic amplifier 92. Under such circumstances the output of the magnetic amplifier 92 is decreased to effectively decrease the energization of the winding 34 of the electromagnetic device 26. At the same time the current flow through the winding 146 of the electromagnet 148 is so decreased that the spring 153 overcomes the magnetic pull of the winding 146 with respect to the armature 152 to actuate the pivotally mounted arm 130 in a counterclockwise direction to interrupt the engagement between contact members 136 and 128, and 134 and 126 and to actuate the contact member 128 into engagement with the fixed contact member 138 and the contact member 126 into engagement with the fixed contact member 132. Such an operation of the reversing switch 131 causes current to flow from the positive terminal of the direct current source through the adjustable rheostat 40, contact members 132 and 126, conductor 122, electrode 44, through the metal in the orifice 24, electrode 48, conductor 124, and contact members 128, and 138 and 134 to the negative terminal of the direct current source to effectively reverse the flow of current through the metal flowing in the orifice 24. By reversing the current flow between the electrodes 44 and 48 in this manner, the positive force developed through the cooperation of the flux developed between the magnetic pole pieces 30 and 32 by the energization of the winding 34 and the current flow between the electrodes 44 and 48 is actually reversed so that instead of applying a retarded force, a positive force is applied to the metal in the orifice 24 in a direction to accelerate the flow of metal therein. In effect, such an acceleration constitutes a "pumping" action to force the metal through the orifice **24** at a faster rate than would be obtained by the force of gravity. Such accelerated rate of flow of the metal is maintained until the level of metal in the mold **14** rises to the predetermined level **16** which is to be maintained. When this occurs, the energization of the winding **146** of the electromagnet **148** is increased to the point where the force of the spring **153** is overcome and the pivotal arm **130** of the reversing switch **131** is actuated to establish the circuits which maintain the flow of current between the electrodes **44** and **48** in a direction to cooperate with the flux between the magnetic pole pieces **30** and **32** to develop a positive force which will, in effect, actually retard the flow of molten metal through the orifice **24**.

It will of course be appreciated that only the reversal of current flow can be employed for effecting the pumping action where it is desired to maintain a substantially constant magnetic flux between the pole pieces **30** and **32**. The throttling and pumping effect occasioned by reversing the current flow between the electrodes **44** and **48** which are disposed 90° from the pole pieces **30** and **32** is quite strong, in practice it being found that where a magnetic field of 12,000 gausses is developed between the pole pieces across a ½ inch diameter orifice, that a reversal of the direct current supply to the electrodes **44** and **48** from 150 amperes in one direction to 150 amperes in the other direction will actually apply such a positive force to the metal in the orifice **24** as to raise the level of metal in the tundish 3 inches.

The apparatus employed in practicing this invention is formed of substantially standard components and is very efficient in operation. With the teaching made hereinbefore, the apparatus can be readily reproduced by anyone skilled in the art thereby providing a very close control of the flow of metal for maintaining the level of molten metal in the mold at a predetermined level. As will be appreciated, the apparatus can be readily adapted to the simple control of the flow of molten metal from a tundish into any type of a mold and is of particular use in connection with the continuous casting of metals.

I claim:

1. Apparatus for controlling the flow of a stream of molten metal from a tundish of refractory material having an orifice therein into a mold disposed to receive such metal, the combination therewith of a pair of electrodes disposed in substantial alignment on opposite sides of the orifice for passing an electrical current through the stream of molten metal flowing therethrough, magnetic poles disposed on opposite sides of the orifice displaced 90° from the pair of electrodes for developing a magnetic flux through the stream of molten metal for cooperating with the flow of current between the electrodes to produce a positive force on the stream, reactive means connected to control the magnetic flux between the magnetic poles, means responsive to the level of the molten metal in the mold for providing a direct current signal indicative of said level, and means for impressing a measure of the direct current signal on the reactive means to thereby provide a positive control of the magnetic flux to control the positive force applied to the stream of molten metal as the metal flows through the orifice.

2. Apparatus for controlling the flow of a stream of molten metal from a tundish of refractory material having an orifice therein into a mold disposed to receive such metal, the combination therewith of a pair of electrodes disposed in substantial alignment on opposite sides of the orifice for passing an electrical current through the stream of molten metal flowing therethrough, an electromagnetic device having a winding disposed to be energized and a core member terminating in a pair of magnetic poles, the core member being disposed with the poles thereof on opposite sides of the orifice displaced 90° from the pair of electrodes for developing a magnetic

flux through the stream of molten metal when the winding is energized for cooperating with the flow of current between the electrodes to produce a positive force on the stream, reactive means connected in circuit relation with the winding of the electromagnetic device, means responsive to the level of the molten metal in the mold for providing a direct current signal indicative of said level, and means for impressing a measure of the direct current signal on the reactive means to thereby control the energization of the winding of the electromagnetic device and the magnetic flux between the poles thereof to control the positive force applied to the stream of molten metal as the metal flows through the orifice.

3. Apparatus for controlling the flow of a stream of molten metal from a tundish of refractory material having an orifice therein into a mold disposed to receive such metal, the combination therewith of a pair of electrodes disposed in substantial alignment on opposite sides of the orifice for passing an electrical current through the stream of molten metal flowing therethrough, an electromagnetic device having a winding disposed to be energized and a core member terminating in a pair of magnetic poles, the core member being disposed with the poles thereof on opposite sides of the orifice displaced 90° from the pair of electrodes for developing a magnetic flux through the stream of molten metal when the winding is energized for cooperating with the flow of current between the electrodes to produce a positive force on the stream, sensing means responsive to the level of the molten metal in the mold for providing an electrical signal indicative of said level, and means responsive to a predetermined change in said electrical signal for reversing the flow of current through the stream of molten metal between the electrodes and thereby reverse the positive force applied to the stream of molten metal.

4. Apparatus for controlling the flow of a stream of molten metal from a tundish of refractory material having an orifice therein into a mold disposed to receive such metal, the combination therewith of a pair of electrodes disposed in substantial alignment on opposite sides of the orifice for passing an electrical current through the stream of molten metal flowing therethrough, a reversing switch disposed to be operated to effect a reversal of the flow of current through the electrodes, an electromagnetic device having a winding disposed to be energized and a core member terminating in a pair of magnetic poles, the core member being disposed with the poles thereof on opposite sides of the orifice displaced 90° from the pair of electrodes for developing a magnetic flux through the stream of molten metal when the winding is energized for cooperating with the flow of current between the electrodes to produce a positive force on the stream, sensing means responsive to the level of the molten metal in the mold for providing an electrical signal indicative of said level, and means responsive to a predetermined change in said electrical signal for operating the reversal switch to effect the reversal of the flow of current through the stream of molten metal to thereby reverse the positive force applied to the stream of molten metal.

5. Apparatus for controlling the flow of a stream of molten metal from a tundish of refractory material having a downwardly depending orifice therein into a mold disposed to receive such metal, the combination therewith of a composite refractory cylinder forming the downwardly depending orifice, the cylinder having two semicircular portions of conductive refractory material forming electrodes for passing an electrical current through the stream of molten metal flowing through the orifice and two sections of non-conductive refractory material disposed between said conductive portions, magnetic poles disposed about the cylinder displaced 90° from the conductive portions thereof for developing a magnetic flux through the stream of molten metal in the orifice for cooperating with the flow of current between the electrode conductive portions to produce a positive force on the

stream, reactive means connected to control the magnetic flux between the magnetic poles, means responsive to the level of the molten metal in the mold for providing a direct current signal indicative of said level, and means for impressing a measure of the direct current signal on the reactive means to thereby provide a positive control of the magnetic flux to control the positive force applied to the stream of molten metal as the metal flows through the orifice.

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