Oct. 30, 1956 E. F. W. ALEXANDERSON 2,768,413

SYSTEM FOR CONTROLLING THE FLOW OF MOLTEN METAL

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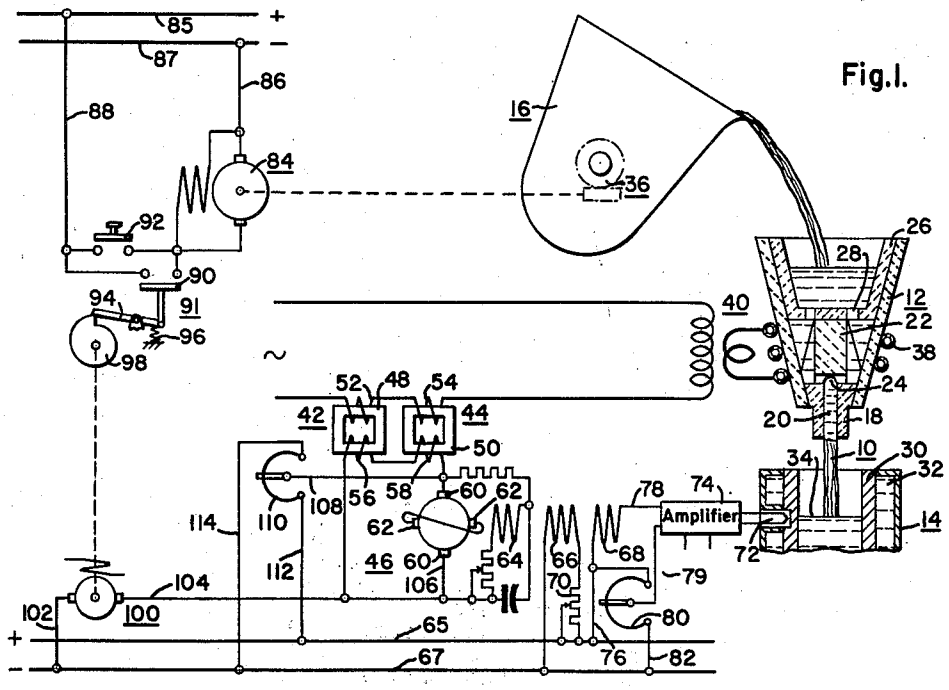
Fig.1.



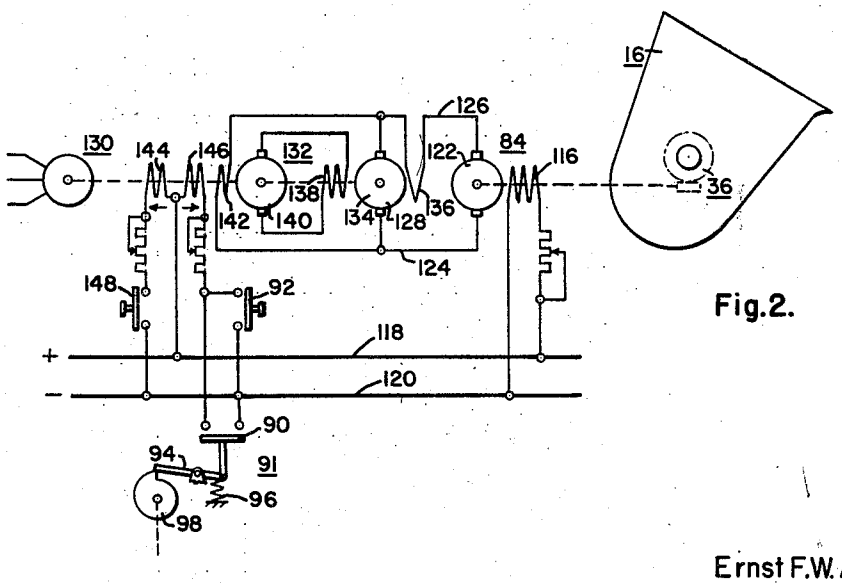


Fig.2.

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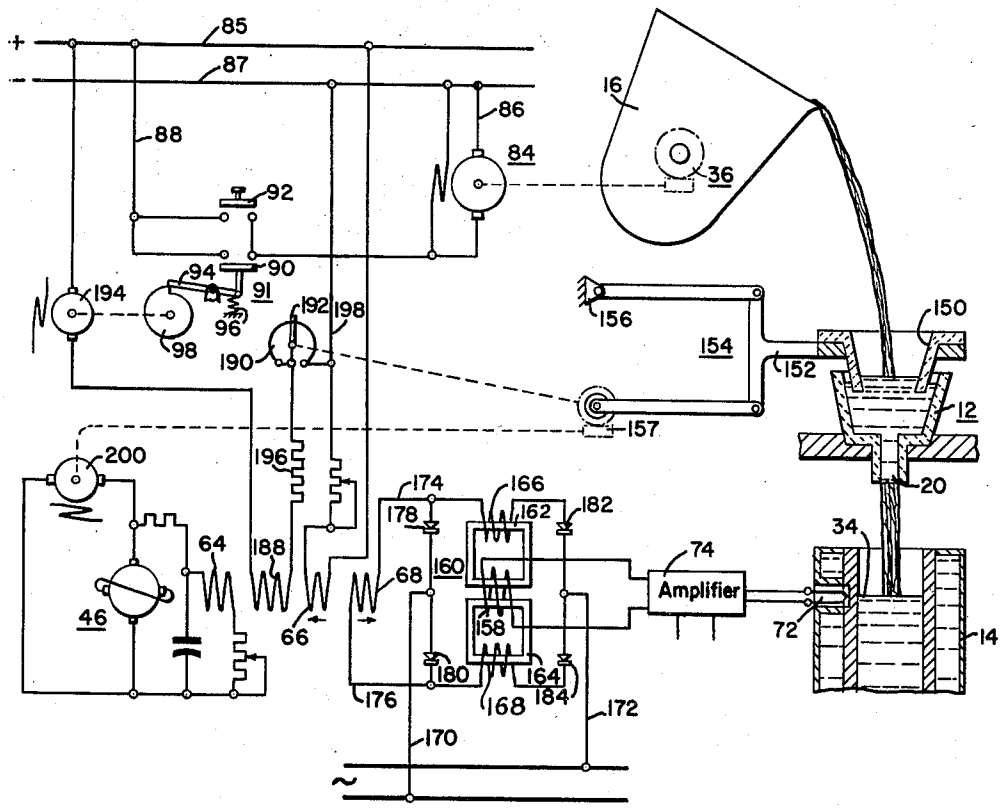
Fig.3.



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2,768,413

SYSTEM FOR CONTROLLING THE FLOW OF MOLTEN METAL

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Application April 20, 1953, Serial No. 349,846
3 Claims. (Cl. 22—57.2)

This invention relates to the pouring of molten metal, and in particular to a system and apparatus for controlling the flow of molten metal in the making of castings.

In casting molten metal, it is desirable to control the flow of such molten metal into a mold so as to obtain a sound homogeneous casting. This is especially true in the casting of stainless steel, and in particular in the making of continuous castings of steel or other metals. In the continuous casting of steel it is desired to maintain a substantially constant level of molten metal above the solidified casting to insure a substantially constant solidification rate and a sound casting.

Heretofore many attempts have been made to control the pouring of such castings, but the known controls have been based primarily on a manually initiated control operation resulting from the actions of an operator dependent upon a visual observation of the pouring action. Such prior art operations have not proven to be satisfactory and have frequently resulted in castings so faulty that they had to be scrapped.

An object of this invention is the provision of an automatic control for controlling the pouring of molten metal from a tundish to a mold.

Another object of this invention is to provide an electrical system responsive to the level of molten metal in a mold for controlling the flow of molten metal from a tundish to the mold.

A further object of this invention is to provide a system for controlling the flow of molten metal from a tundish supplied by a tiltable furnace in response to the level of molten metal in a mold supplied from the tundish, the system including means for controlling the tilting of the furnace simultaneously with controlling the flow from the tundish.

Other objects of this invention will become apparent from the following description when taken in conjunction with the accompanying drawings in which:

Figure 1 is a diagrammatic view of circuits and apparatus embodying the teachings of this invention;

Fig. 2 is a diagrammatic view of a specific control circuit which can be employed as a modification of a part of the system illustrated in Fig. 1; and

Fig. 3 is a diagrammatic view of circuits and apparatus illustrating another embodiment of this invention.

Referring to the drawing, and in particular to Fig. 1, this invention is illustrated by reference to a system for controlling the flow of molten metal 10 from a tundish shown generally at 12 into a mold 14, the molten metal being supplied to the tundish 12 from a tiltale holding furnace or ladle illustrated schematically at 16.

The tundish 12 is formed of refractory material and as illustrated is of a general conical design terminating in a downwardly depending portion 18 having an orifice 20 centrally disposed therethrough. The tundish 12 in this instance is provided with a centrally disposed core member 22 of refractory material, the core member 22 being provided with openings 24 at the lower end thereof for permitting passage of molten metal from about the core portion 22 into the orifice 20. Adjacent the upper end of the tundish 12 is a liner 26 of refractory material of general dish shape having openings 28 in the bottom thereof communicating with the space formed between the core 22 and the side walls of the tundish 12. The

core member 22 and/or the liner 26 may be secured in assembled relation in the tundish 12 in any suitable manner, such as by cementing them in position. The purpose of the core member 22 is to so displace molten metal in the tundish 12 that in practice a ring of molten metal will be formed between the core member 22 and the side wall of the tundish 12, the purpose of which will be explained more fully hereinafter.

The mold 14 may be any suitable type of mold, although in this instance it is illustrated as being the upper end of a continuous casting type of mold. Thus the mold 14 is provided with an inner mold wall 30 of copper or other good thermally conductive metal, the upper end being surrounded by a water cooling jacket 32 for extracting heat from the mold wall 30. Although not illustrated, the downwardly depending portion 18 of the tundish 12 which is in alignment with the mold cavity of the mold 14 and the upper end of the mold 14 may be suitably housed to retain a protective atmosphere therein to prevent oxidation and other contamination of the molten metal as it flows from the tundish 12 into the mold 14. As is well-known, with a continuous casting mold 14 the solidified cast metal is withdrawn from the bottom of the mold 14 at a substantially constant rate and it is desired to maintain the level of the molten metal in the mold 14 at the predetermined level 34 illustrated in order to obtain a substantially constant rate of solidification of the metal as the cast metal is withdrawn from the mold 14.

The tiltable furnace or ladle 16 may be of any suitable type for containing a supply of the molten metal 12 and delivering such molten metal to the tundish 12 at a controlled rate for cooperating with the tundish, as will be explained more fully hereinafter, to control the rate of flow of molten metal from the tundish 12 to the mold 14. In this instance the tiltable furnace 16 is schematically illustrated as having a rack and pinion gear drive 36 disposed for operation to control the tilting of the furnace 16 and thereby control the flow of molten metal supplied to the tundish 12.

In order to apply a force to the molten metal in the tundish 12 to control the flow therefrom, current is induced in the ring of molten metal formed by the core member 22 within the tundish 12. For this purpose a water-cooled induction coil 38 is so disposed about the tundish 12 as to extend along the outer wall thereof a distance substantially equal to the length of the core member 22 and consequently substantially equal to the height of the ring of molten metal in the tundish 12. Energy is supplied to the induction coil 38 from a transformer 40, the primary windings of which are connected to a source of alternating current. Thus as current flows in the induction coil 38, which is illustrated as of the water-cooled type, an electromagnetic repulsion is developed between the current flowing in the coil 38 and the current induced thereby in the ring of molten metal within the tundish 12 to effectively retard the flow of molten metal from the tundish 12 to the mold 14. The degree of such electromagnetic repulsion will of course depend upon the magnitude of the current flow in the induction coil 38.

The current flow in the induction coil 38 is controlled by controlling the saturation of a pair of reactors 42 and 44 connected in circuit relation with the transformer 40, the degree of saturation thereof being controlled by the operation of a dynamo-electric machine 46 in response to a measure of the change in the level of the molten metal from the predetermined level 34 which is to be maintained in the mold 14. The reactors 42 and 44 are formed of rectangular laminated core members 48 and 50, respectively, having a main winding 52 and 54, respec-

tively, and a direct current control winding 56 and 58, respectively, disposed thereon.

In order to control the current flow in the series connected direct current windings 56 and 58 of the saturable reactors 42 and 44, the dynamo-electric machine 46 is connected so that its output current flows through such windings. In this instance the dynamo-electric machine 46 is of the well-known amplidyne type and is driven by any suitable driving means such as an induction motor (not shown). The dynamo-electric machine 46 is provided with two sets of brushes per pair of poles and is illustrated as being a 2-pole machine. One set of the brushes 60 is connected to the load illustrated as being the series connected direct current windings 56 and 58 of the saturable reactors 42 and 44 and the other set of brushes 62 is short circuited. The two mutually perpendicular brush axes are commonly known as the control axis and the short circuit axis, respectively. In this instance the dynamo-electric machine 46 is illustrated as having three field windings 64, 66 and 68, the field winding 64 being a shunt field winding which functions as a delayed negative feedback to render the operation of the dynamo-electric machine responsive to a rate of change to prevent hunting in the operation thereof. The winding 66 is connected through an adjustable resistor 70 to a constant direct current source represented by conductors 65 and 67 to function as a bias winding, the degree of energization of which is controlled by adjusting the resistor 70. On the other hand, the field winding 68 constitutes a control field winding for the dynamo-electric machine 46 and while the winding 68 is illustrated as being connected across the direct current source of supply, the degree of energization of the winding 68 is dependent upon a measure of the level of molten metal in the mold 14. The windings 66 and 68 are disposed in opposition to each other to control the output of the machine 46.

In order to control the energization of the control field winding 68, a sensing means 72 is utilized for giving a signal which is a measure of the level of the molten metal in the mold 14. In this instance the sensing device 72 is illustrated as being a thermostat sensing device of the type known to the trade as a thermosaul which is embedded in the mold wall 30 of the mold 14 at substantially the height of the level of molten metal which is to be maintained in the mold 14. As the mass of molten metal in the mold 14 rises, the thermosaul will give an increased signal in response to the increase in temperature occasioned by increasing such mass, or the signal will be diminished as the level of molten metal lowers from the level which is to be maintained in direct proportion to the decrease in the mass. Since the signal from the sensing device 72 is normally too small for control purposes, such signal is supplied to an amplifier illustrated generally at 74, the output of the amplifier 74 being connected in circuit relation with the control field winding 68 of the dynamo-electric machine 46. Since many different types of amplifiers are well-known and can be employed in this system, the details of the amplifier are not illustrated, the amplifier being represented by the rectangle 74. The output of the amplifier 74 is connected in opposition to the polarity of the normal supply of energy for the control winding 68 so that as the output of the amplifier 74 increases in response to a measure of the rise of the level of the molten metal in the mold 14, the net energizing effect of the control field winding 68 is decreased insofar as the operation of the dynamo-electric machine 46 is concerned. This is apparent when it is considered that the control field winding 68 is normally connected as by conductor 76 to the positive conductor 65 of the source of direct current energy and by conductor 78 through the amplifier 74, a portion of an adjustable rheostat 80 and conductor 82 to the negative conductor 67 of the source of direct current supply whereas the amplifier 74 is connected through a circuit

which extends from the amplifier 74 through conductor 78, the field winding 68, conductor 76 and another portion of the adjustable rheostat 80 and conductor 79 back to the amplifier 74.

The tiltable furnace or ladle 16 is disposed to be driven in a direction to tilt the furnace to supply the molten metal to the tundish 12 as the molten metal flows from the tundish to the mold 14. For this purpose, the rack and pinion drive 36 of the furnace 16 is connected to be driven by a motor 84 disposed to be connected as by conductors 86 and 88 to a source of direct current supply represented by conductors 85 and 87. In order to automatically control the energization of the motor 84, a contact member 90 of a toggle switch 91 is disposed to be intermittently actuated into circuit closing position to establish the energizing circuit for the motor 84. Another contact member 92 is disposed to be manually operated to also establish such energizing circuit for the motor 84 where it is desired to increase the tilting of the furnace 16 at a faster rate than the intermittent operation of the contact member 90 permits. As illustrated, the contact member 90 of the switch 91 is carried at one end of a pivotally mounted arm 94 which is normally biased as by means of a spring 96 to actuate the contact member 90 towards the circuit closing position. However, the operation of the contact member 90 is controlled as by means of a cam 98, the cam surface of which is disposed to engage the free end of the pivotal arm 94 to effect the intermittent operation of the contact member 90 as the cam 98 is driven.

In order to control the operation of the cam 98 and consequently control the intermittent operation of the contact member 90, the cam 98 is connected to be driven by a motor 100 which is connected to be supplied from the constant direct current source of supply represented by conductors 65 and 67. However, in order to control the operation of the motor 100, the motor 100 is also connected across the output of the dynamo-electric machine 46, such output being in opposition or bucking relation to the normal energization of the motor 100. Thus the motor 100 is connected as by conductor 102 to the conductor 67 of negative polarity of the direct current source of supply and is connected as by conductors 104 and 106 through the dynamo-electric machine 46, conductor 108, a portion of an adjustable rheostat 110 and conductor 112 to the conductor 65 of positive polarity of the direct current source. At the same time the dynamo-electric machine 46 is connected by a circuit extending from one of its terminals through conductors 106 and 104, the armature of the motor 100, conductor 102, the negative conductor 67 of the source of supply, conductor 114, another portion of the adjustable rheostat 110 and conductor 108 to the other terminal of the dynamo-electric machine 46 to oppose the normal energization of the motor 100.

In operation, assuming that the level of the molten metal in the mold 14 is at the predetermined level 34 which is to be maintained, then the motor 84 functions to drive the tiltable furnace 16 at a rate sufficient to merely supply metal to the tundish 12 at a rate to offset the flow of molten metal from the tundish to the mold 14. At the same time the dynamo-electric machine 46 is energized to control the saturation of the saturable reactors 42 and 44 so that the current flow in the induction coil 38 is at a value that the retardation action on the ring of molten metal in the tundish 12 is sufficient to cooperate with the supply of molten metal from the furnace 16 to the tundish 12 to normally control the flow of molten metal from the tundish 12 to the mold 14 to maintain the level of molten metal therein at the predetermined level 34.

If, for any reason, the level of the molten metal rises above the predetermined level 34 which is to be maintained in the mold 14, the temperature of the sensing device 72 increases with the result that the signal which is a measure of such a rise in the level, is increased, where-

by the output of the amplifier 74 is increased. Since the output of the amplifier 74 is in opposition to the normal energization of the control field winding 68, the increase in the output of the amplifier 74 functions to effect a net decrease in the energization of the control field winding 68 with the result that the effect of the biasing winding 66, which is normally in opposition to the effect of the field winding 68, increases to effect an increase in the output of the dynamo-electric machine 46. As the output of the dynamo-electric machine increases, more direct current flows through the control windings 56 and 58 of the saturable reactors 42 and 44, respectively, to increase the saturation thereof whereby an increase in the current flow in the induction coil 38 is effected to increase the electromagnetic repulsion developed in the ring of molten metal within the tundish 12 to effectively retard the flow of molten metal from the tundish 12 to the mold 14. At the same time that the output of the dynamo-electric machine 46 is so increased, the field winding 64 senses such a change to effect a rate of change in the energization of the dynamo-electric machine 46 in direct proportion to the rate of such an increase in the output thereof to adjust the net excitation of the dynamo-electric machine 46 in accordance with the rate of change effected in the change of the flow of the molten metal to thereby prevent overshooting in the control of the energization of the induction coil 38.

Simultaneously with the change in the flow of current in the induction coil 38, the dynamo-electric machine 46 functions to buck the normal energization of the motor 100 to effect a decrease in the speed of operation of the cam 98 and thereby effect a decrease in the intermittent operation of the contact member 90 of toggle switch 91 to decrease the speed of the operation of the motor 84. Such a decrease in the speed of operation of the motor 84 effectively decreases the tilting speed of the furnace 16 to decrease the flow of molten metal therefrom to the tundish 12. The decrease in the flow of molten metal caused by a slowing of the tilting operation of the furnace 16 cooperates with the electromagnetic repulsion retardation developed in the ring of metal in the tundish 12 to effectively decrease the flow of molten metal from the tundish 12 to the mold 14 to cause the level of the molten metal in the mold 14 to return to the predetermined level 34 which is to be maintained.

If, on the other hand, the level of molten metal in the mold 14 falls below the level 34 which is to be maintained, then the sensing device 72 provides a decrease in the signal therefrom in response to the decrease in the mass of the metal in the mold 14 with the result that the output of the amplifier 74 is decreased. Such a decrease in the output of the amplifier 74 causes an increase in the energization of the control field winding 68 in opposition to the effect of the bias field winding 66 with the result that the output of the dynamo-electric machine 46 decreases to effect a decrease in the current flow in the control windings 46 and 58 of the saturable reactors 42 and 44, respectively. Such a decrease in the current flow in the control windings 56 and 58 of the reactors 42 and 44, respectively, decreases the saturation thereof with the result that less current flows in the induction coil 38 and less of a retarding action is applied to the ring of molten metal within the tundish 12 with the result that the flow of molten metal from the tundish 12 to the mold 14 is increased to tend to raise the level of molten metal therein to the predetermined level 34 which is to be maintained. At the same time the shunt field winding 64 senses the rate of change in the output of the dynamo-electric machine 46 to prevent an operation thereof to effect an overshooting in the corrective action applied to the induction coil 38.

Simultaneously with the change in the energization of the induction coil 38, the decreased output of the dynamo-electric machine 46 in opposition to the constant source of supply to the cam motor 100 causes an increase in the speed of operation of the cam motor 100 with the result that there is an increase in the intermittent operation of the contact member 90 to effect an increase in the speed of operation of the furnace motor 84. Such an increase in the speed of operation of the motor 84 increases the speed of operation of the rack and pinion drive 36 with the result that the furnace 16 is tilted at a faster rate to increase the supply of molten metal to the tundish 12 simultaneously with the decrease in the retarding force applied by the induction coil 38. The control of the tilting furnace 16 thus cooperates with the change in the energization of the induction coil 38 to effectively increase the rate of flow of the molten metal from the tundish 12 to the mold 14 to return the level of the molten metal therein to the predetermined level 34 which is to be maintained.

If, during the operation just described, it is desired to effect an increase in the supply of the molten metal to the tundish 12 at a faster rate than that obtained through the automatic control of the operation of the furnace tilting motor 84, then the contact member 92 can be manually operated to a circuit establishing position to continuously energize the furnace motor 84 to effectively tilt the furnace 16 at a faster rate than the tilting rate obtained through the operation of the cam motor 100 and toggle switch 91.

If, in addition to controlling the rate at which the furnace 16 tilts, it is desired to provide for returning the furnace 16 to a vertical or non-pouring position or to definitely stop the pouring of the molten metal from the furnace 16 at any point during the operations previously described, a circuit as illustrated in Fig. 2 can be employed for controlling the tilting of the furnace 16. In this embodiment the furnace motor 84 comprises a field winding 116 disposed to be energized from a suitable direct current source represented by conductors 118 and 120 and an armature winding 122 connected by conductors 124 and 126 to be supplied with energy from a generator 128 that is driven by an alternating current motor 130 and excited by an excitor generator 132. The main generator 128 comprises an armature winding 134, one terminal of which is connected to the conductor 124 and the other terminal of which is connected through a self energizing field winding 136 to the conductor 126 for supplying the motor 84, and a field winding 138 disposed to be supplied with energy from the armature winding 140 of the excitor generator 132. The excitor generator 132 illustrated is provided with a field winding 142, connected across the main generator 128 to be energized in accordance with the output thereof and two control field windings 144 and 146 which are disposed to be energized in opposition to each other and will function to control the excitation of the excitor generator 140. The control field winding 144 is disposed to be connected through a manually operated contact member 148 to the source of direct current energy represented by the conductors 118 and 120 whereas the field winding 146 is disposed to be connected by the intermittently operated contact member 90 of toggle switch 91 across the direct current source of supply or by a manually operated contact member 92 across the direct current source of supply.

If the cam 98 is driven in the manner described with reference to the control circuit of the embodiment of Fig. 1, then the contact member 90 is intermittently operated to a circuit closing position to effect the intermittent energization of the control field winding 146 to so control the excitation of the excitor generator 122 as to control the excitation of the main generator to effectively energize the motor 84 to drive the rack and pinion drive 36 in a direction to tilt the furnace 16 at a rate depending upon the rate of intermittent operation of the contact member 90 of toggle switch 91. Again, as in the previous embodi-

ment, if it is desired to tilt the furnace **16** at a faster rate than is obtained through the intermittent operation of the contact member **90**, the contact member **92** can be manually operated to establish the energizing circuit for the control field winding **146** to effectively increase the energization thereof in a direction to cause the operation of the motor **84** in a direction to tilt the furnace **16** at a faster rate.

If, at any time during the operation, it is desired to stop the flow of molten metal from the furnace **16** to the tundish **12**, or upon completion of the pouring operation, it is desired to return the furnace **16** to a vertical position, then the contact member **148** can be manually operated to a circuit closing position to effect the energization of the control field winding **144**. If such energization of the control field winding **144** is effected during the intermittent operation of the contact member **90**, the continuous energization of the field winding **144** during the manual operation of contact member **148** will predominate over the intermittent energization of the control field winding **146** occasioned by the operation of contact member **90** to so control the excitation of the excitor generator **132** as to effect an operation thereof in a direction to control the excitation of the main generator **128** to cause a reversal of the direction of operation of the motor **84**. Such reversal of the motor **84** stops the tilting operation of the furnace **16** and if maintained, will operate the rack and pinion drive **36** in a direction to effect a reversal in the tilting operation of the furnace **16** to return the furnace **16** to a vertical position. Thus a fast decrease in the flow of molten metal from the furnace **16** to the tundish **12** can be obtained during any normal operation of the cam **98** in response to an operation of the dynamo-electric machine **46**. As will be appreciated, upon the completion of a pouring operation from the furnace **16**, the furnace **16** can be returned to its vertical position by maintaining the contact member **148** in its circuit closing position to maintain the energization of the control field winding **144** to effectively drive the motor **84** in a direction to return the furnace **16** to a vertical position.

Instead of the electromagnetic control as described with reference to Fig. 1 of the drawing, an electromechanical control can be utilized for controlling the flow of molten metal from the tundish **12** to the mold **14**. Such a system is illustrated in Fig. 3 of the drawing, like numerals of Figs. 1 and 2 being employed for designating like pieces of apparatus and parts of the circuits. In the embodiment of Fig. 3 the tundish **12** can be of any suitable construction and is provided with a plunger member **150** disposed to be actuated into the molten metal **10** in the tundish **12** to displace metal therein to thereby raise the static head of molten metal above the orifice **20** to control the flow of the molten metal therefrom to the mold **14**. The plunger **150** in this instance is formed of refractory material and is of general conical shape to conform to the inner shape of the side walls of the tundish **12**. As illustrated, the plunger **150** is carried by an arm **152** which is secured to a mechanical linkage **154**, one end of which is pivotally secured to a fixed bracket **156**, the other end of the linkage **154** being secured to the pinion of the rack and pinion drive **157** whereby an operation of the drive **157** will effect a vertical movement of the plunger **150** into or out of the tundish **12**.

In the embodiment of Fig. 3, the same type of sensing device **72** is employed for providing a signal that is a measure of the level **34** of molten metal in the mold **14**, the signal being amplified as by means of the amplifier **74**. In this case, however, the output of the amplifier is supplied to the control winding **158** of a magnetic amplifier **160**, the output of which is disposed to control the energization of the control field winding **68** of the dynamo-electric machine **46**. The magnetic amplifier **160** is of usual construction being formed of two rectangular laminated core members **162** and **164** each of which is provided with a main winding **166** and **168**, respectively, the control winding **158** being common to both of the laminated core members **162** and **164**. The main windings **166** and **168** are connected in parallel circuit relation with each other and are disposed to be connected as by conductors **170** and **172** across an alternating current source of supply and by conductors **174** and **176** to the control field winding **68**. Rectifiers **178, 180, 182** and **184** are connected in circuit relation with the main windings **166** and **168** and between such windings and the control field winding **68** as illustrated for supplying a unidirectional current to the control field winding **68**.

The dynamo-electric machine **46** is similar to that illustrated in the embodiment of Fig. 1, except that in this instance another field winding **188** is added which functions to provide a position signal indicator for reflecting a change in the energization of the dynamo-electric machine **46** in response to an adjustment of the position of the plunger **150** within the tundish **12**. In order that such a measure of the change of the position of the plunger **150** will be reflected by the control winding **188**, the control winding **188** is connected in circuit relation with a potentiometer **190**, the contact arm **192** of which is disposed to be positioned in accordance with the operation of the rack and pinion drive **157**. Thus the position signal control winding **188** is connected in a circuit which extends from the conductor **85** of the direct current source of supply through the armature windings of a motor **194** which is connected to drive the cam **98**, field winding **188**, a resistor **196**, contact arm **192** of the potentiometer **190**, a portion of the potentiometer **190** and conductor **198** to the conductor **87** of the direct current source of supply. Since the motor **194** is connected in series circuit relation with the field winding **188**, the energization of which is controlled by the operation of the potentiometer **190**, it is apparent that the operation of the motor **194** and consequently the cam actuated contact member **90** of toggle switch **91** is directly controlled by the drive **157** which positions the plunger **150** and adjusts the position of the contact member **192** of the potentiometer **190**.

In the embodiment of Fig. 3, the dynamo-electric machine **46** is connected directly across the armature of a motor **200** which is connected to drive the rack and pinion drive **157**, it being understood that such operation will be affected by the energization of the rate of change excitation of the field winding **64** and the position signal of the field winding **188** of the dynamo-electric machine **46** to prevent an overshooting in the control operation of the system.

In operation, assuming that the system is operating with the level of the molten metal in the mold **14** at the predetermined level **34** which is to be maintained so that the signal from the sensing device **72** is adequate to provide a predetermined saturation of the magnetic amplifier **160** to give a predetermined energization of the control field winding **68** to balance the effect of the opposing bias winding **66**, then the dynamo-electric machine **46** has been operated to effect a positioning of the plunger **150** to maintain a static head of the molten metal in the tundish **12** and the potentiometer **190** has been automatically adjusted to regulate the speed of the motor **194** and consequently the tilting operation of the furnace **16** so that the flow of molten metal from the furnace **16** is just sufficient to replace the metal flowing from the tundish **12**. The furnace **16** and the plunger **150** thus cooperate to so control the flow of molten metal from the tundish **12** as to maintain the level of the molten metal in the mold **14** at the predetermined level **34** which is to be maintained.

If, for any reason, the level of metal in the mold **14** should rise above the predetermined level **34** which is to be maintained, an increased signal is supplied by the sensing device **72** to the amplifier **74** and the amplified output thereof is impressed on the control winding **158** of the magnetic amplifier **160**. This increase in the current flow in the control winding **158** of the magnetic

amplifier 160 so increases the saturation of the magnetic amplifier as to effect an increase in the energization of the field winding 68 whereby the field winding 68 cooperates with the opposing bias winding 66 as to give a net effective excitation of the dynamo-electric machine 46 to cause it to operate so that the output thereof effects an operation of the motor 200 in a direction to drive the rack and gear drive 157 in a direction to actuate the linkage 154 to raise the plunger 150 thereby lowering the static head of molten metal contained in the tundish 12. At the same time the operation of the rack and pinion drive 157 effects an operation of the contact arm 192 of the potentiometer 190 to drive the arm in a counterclockwise direction to connect more of the potentiometer 190 in circuit relation with the position signal field winding 188 and the cam motor 194. Such an adjustment of the potentiometer 190 provides a change in the energization of the dynamo-electric machine 46 reflecting the adjustment in the position of the plunger 150 and at the same time decreases the speed of operation of the motor 194 to slow the operation of the cam 98 and consequently to effect a decrease in the number of the intermittent operations of the contact member 90 of the toggle switch 91 to decrease the excitation of the motor 84. As the motor 84 is thus operated a slower speed, or less frequent number of operations, the rack and pinion drive 36 of the furnace 16 is operated at a slower rate so that the tilting of the furnace 16 is effected at a slower rate to decrease the flow of molten metal from the furnace 16 to the tundish 12. Thus as the static head of metal in the tundish 12 is lowered by raising the plunger 150 and as the flow of metal supplied to the tundish 12 is decreased, they cooperate to effect a decrease in the flow of metal to the mold 14 whereby the level of the molten metal returns to the predetermined level 34 which is to be maintained.

On the other hand, if the change in the level of the molten metal in the mold 14 is such as to effect a lowering of the level from the predetermined level 34 which is to be maintained, the signal from the sensing device 72 and consequently the output of the amplifier 74 is decreased in a direct measure with respect to the change in the level of the molten metal in the mold 14. As the output from the amplifier 74 is decreased, the output from the magnetic amplifier 160 is correspondingly decreased to effect a decrease in the energization of the control field winding 68. With such a decrease in the energization of control field winding 68, the bias field winding 66 will predominate to effect an excitation of the dynamo-electric machine 46 in a direction to cause the output therefrom to reverse and effect a reverse operation of the motor 200. Such an operation of the motor 200 effects an operation of the rack and pinion drive 157 of the linkage 154 to cause a movement thereof to effectively lower the plunger 150 into the tundish 12 to raise the static head of molten metal in the tundish 12 above its orifice 20. At the same time the rack and pinion drive 157 of the linkage 154 actuates the contact arm 192 of the potentiometer 190 in a clockwise direction to decrease the amount of resistance in circuit relation with the position field winding 188 and the motor 194. It is thus seen that a change in the position of the plunger 150 is directly reflected in the excitation of the dynamo-electric machine 46 and that such change also effects an increase in the speed of operation of the motor 194 to drive the cam 198 to increase the frequency of the intermittent operation of the contact member 90 of the toggle switch 91 to effectively increase the rate of operation of the furnace motor 84. Such an operation of the motor 84 effects an operation of the rack and pinion drive 36 of the furnace 16 to increase the tilting rate of the furnace 16 and thereby increase the flow of molten metal from the furnace 16 to the tundish 12. By simultaneously lowering the plunger 150 to raise the static head of molten metal in the tundish 12 and increasing the flow of molten metal from the furnace 16 to the tundish 12, there is obtained an increase in the rate of flow of the molten metal from the tundish 12 to the mold 14 to return the level of molten metal therein to the predetermined level 34 which is to be maintained.

The systems for controlling the flow of molten metal described hereinbefore as representative of this invention are of relatively simple design being formed of standard components. Such systems can be readily reproduced by anyone skilled in the art. They are very efficient in operation giving a very close control of the rate of flow of metal for maintaining a predetermined level of molten metal in a mold.

I claim:

1. In a system for controlling the flow of molten metal from a tundish supplied by a tiltable furnace to a mold disposed to receive the metal, the combination therewith of, a plunger disposed to be actuated to displace molten metal in the tundish, drive means disposed for directional operation to directionally actuate the plunger, a dynamo-electric machine connected to control the directional operation of the drive means, another drive means disposed to be operated for tilting the furnace, means responsive to the operation of the plunger drive means for controlling the operation of the tilting drive means, the tilting drive means and the plunger drive means cooperating to control the level of the molten metal in the tundish, and means responsive to the level of molten metal in the mold for controlling the operation of the dynamo-electric machine.

2. In a system for controlling the flow of metal from a tundish supplied by a tiltable furnace to a mold disposed to receive the metal, the combination therewith of, means disposed in operative relation with the tundish for acting directly on the molten metal contained therein independently of the operation of the tiltable furnace for changing the level of molten metal in the tundish, a dynamo-electric machine connected to control the operation of the direct acting means, drive means disposed to be operated for tilting the furnace, means responsive to the operation of the direct acting means for controlling the operation of the tilting drive means, the tilting drive means and the direct acting means cooperating to control the level of the molten metal in the tundish, and means responsive to the level of molten metal in the mold for controlling the operation of the dynamo-electric machine.

3. In a system for controlling the flow of metal from a tundish supplied by a tiltable furnace to a mold disposed to receive the metal, the combination therewith of, means disposed in operative relation with the tundish for acting directly on the molten metal contained therein independently of the operation of the tiltable furnace for changing the level of molten metal in the tundish, a dynamo-electric machine connected to control the operation of the direct acting means, means disposed to be operated for tilting the furnace in a predetermined direction, means responsive to the operation of the direct acting means for controlling the operation of the tilting means in said predetermined direction, the tilting means and the direct acting means cooperating to control the level of the molten metal in the tundish, means disposed to be actuated to control the operation of the tilting means in a direction opposite to said predetermined direction irrespective of the operation of the direct acting means, and means responsive to the level of molten metal in the mold for controlling the operation of the dynamo-electric machine.

References Cited in the file of this patent

UNITED STATES PATENTS

1,139,888	Mellen	May 18, 1915
2,246,907	Webster	June 24, 1941
2,536,325	Tama	Jan. 2, 1951
2,683,294	Ennor et al.	July 13, 1954
2,707,720	Tama	May 3, 1955