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**EUROPEAN PATENT APPLICATION**

(21) Application number: **81300093.2**

(51) Int. Cl.<sup>3</sup>: **B 22 D 11/01**  
**B 22 D 11/16**

(22) Date of filing: **09.01.81**

(30) Priority: **10.01.80 US 110893**

(43) Date of publication of application:  
**22.07.81 Bulletin 81/29**

(84) Designated Contracting States:  
**CH DE FR GB IT LI NL SE**

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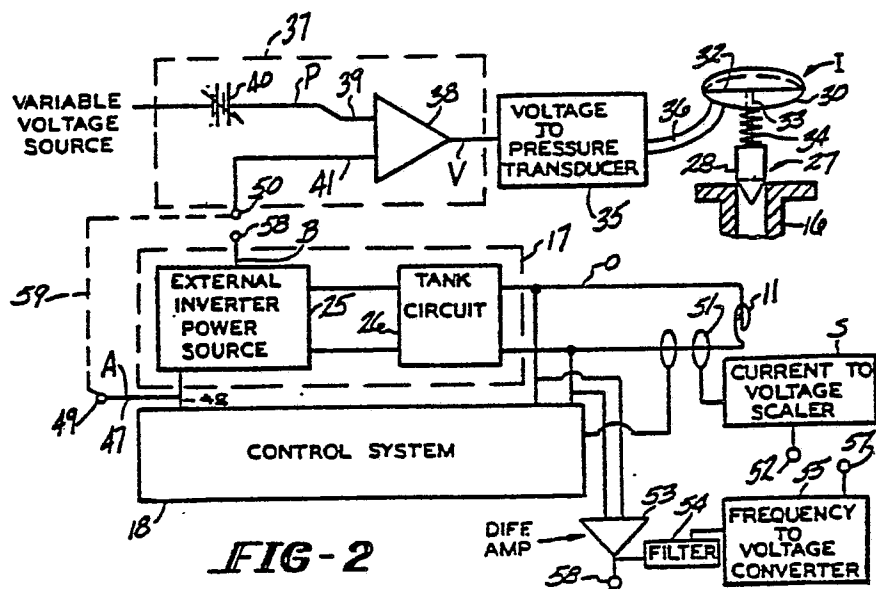
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(54) **Electromagnetic casting apparatus and process.**

(57) An electromagnetic casting apparatus and process is disclosed in which a flow control system (37, 35, 30) is provided to control the flow of molten material to the casting zone. The flow of molten material is controlled in response to sensed variations in the hydrostatic pressure in the head of molten material in the casting zone with the object of keeping those variations to a minimum. Optimum conditions are therefore maintained for the operation of the conventional control system (18) which controls the power source (17) for the inductor (11).

**EP 0 032 442 A1**



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Electromagnetic Casting Apparatus and Process

This invention relates to an improved process and apparatus for electromagnetically casting electromagnetically castable materials, e.g. metals and alloys. The electromagnetic casting process has been known and used for many years for continuously  
5 and semi-continuously casting metals and alloys. The process has been employed commercially for casting aluminum and aluminum alloys.

The electromagnetic casting apparatus comprises a three part mould consisting of an inductor, a non-magnetic screen and a manifold for applying cooling water to the ingot. Such an apparatus is  
10 exemplified in U.S. Patent No. 3,467,166 to Getselev et al. Containment of the molten metal is achieved without direct contact between the molten metal and any component of the mould. Solidification of the molten metal is achieved by direct application of water from the cooling manifold to the ingot shell.

15 A large body of prior art relating to various aspects of the electromagnetic casting process and apparatus is described in the prior art statement of U.S. Patent No. 4,161,206 and, therefore, will not be repeated here.

The present invention is particularly related to the process  
20 and apparatus for controlling the electromagnetic casting system. Various approaches have been described in the prior art for controlling the excitation of the inductor in a manner so as to provide ingots of uniform cross-section. In U.S. Patent No. 4,014,379 to Getselev a control system is described for controlling the current

flowing through the inductor responsive to deviations in the dimensions of the liquid zone (molten metal head) of the ingot from a prescribed value. In Getselev, U.S. Patent No. 4,014,379 the inductor voltage is controlled to regulate the inductor current in response to measured variations in the level of the surface of the liquid zone of the ingot. Control of the inductor voltage is achieved by an amplified error signal applied to the field winding of a frequency changer.

In Russian Patent 537,750 to Getselev an alternative control approach is described wherein the potential on the inductor is regulated to reduce a deviation of the phase angle from a programmed value.

In U.S. Patent No. 4,161,206 to Yarwood et al. a control system for electromagnetic casting is utilized for minimizing variations in the gap between the molten metal and the inductor. In this approach a reactive electrical parameter of the inductor which varies with the magnitude of the gap is determined and compared to reference values to generate an error signal for controlling the inductor excitation.

In Russian Patent 273,226 to Kabakov there is disclosed a control system for controlling the metal level in the electromagnetic casting mould. A metal level measuring coil has a relay connected to the ingot withdrawal mechanism via a regulator. At the start of casting the withdrawal mechanism is in its initial position. The regulator is connected to an actuator which starts the feed of metal into the mould. When the metal level reaches the height of the sensing coil, a signal is transmitted to the regulator which throws the

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relay and operates the withdrawal mechanism to withdraw the ingot from the mould.

In Russian Patent 338,297 to Irkutsk the electromagnetic casting mould is fitted with measuring coils to control the metal level in the mould. The amount of metal flowing into the mould is controlled by a valve compounded with an actuator. No description is given in this patent of any automated feedback of the sensed signal from the coil to the actuator. In fact, the actuator appears to be manually operated.

10       The approaches for controlling molten metal head described in the Russian patents to Kabakov and Irkutsk are deficient in that control is based solely on the sensed upper level of the molten metal head. Therefore, these control systems do not take into account changes in the molten metal head due to fluctuations in the position of the solid liquid interface between the molten metal and the solidified casting. These changes in the interface position occur because of instabilities in the withdrawal mechanism, instabilities in the coolant application system, etc. The result of increasing or reducing the height of the molten metal head whether due to a repositioning of the solid liquid interface or the upper surface of the molten metal or both is to increase or decrease, respectively, the hydrostatic pressure exerted by the molten metal head. These changes in hydrostatic pressure must be offset by the control system for controlling the excitation of the inductor.

25       The system described in Yarwood et al. has been shown to be effective for providing solidified castings of more uniform cross-

section by overcoming the instabilities associated with changes in hydrostatic pressure of the molten metal head. It is, of course, desirable that any control system for controlling the inductor excitation operate over its most preferred range of control. Therefore, it is highly undesirable to have any long term changes in hydrostatic pressure due to changes in the height of the molten metal head. Consequently, it has been found desirable to provide some control in addition to the electrical control of the inductor excitation which could reduce the variation in molten material head height during a casting run.

In accordance with the present invention, a process and apparatus is provided for controlling the molten material head height during a casting run. The system of this invention does not require actual measurement of the position of the liquid-solid interface or the top surface of the molten material. Rather, it relies upon the sensing of an electrical parameter or signal from the inductor excitation and control system which changes as the hydrostatic pressure of the molten material head changes. The electrical signal which is sensed as above is applied to a controller which adjusts the flow of molten material into the mould in response thereto.

In particular, the present invention is directed to a process and apparatus for casting electromagnetically castable materials, e.g. metals and alloys, by electromagnetically forming the molten material into a desired casting shape. The electromagnetic forming is accomplished by means of an inductor which applies a magnetic field to the molten material. The magnetic field serves to define a

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containment or casting zone for the molten material. A system is provided for controlling and applying an alternating current to the inductor to generate the magnetic field.

In accordance with this invention, the aforementioned apparatus  
5 is improved by providing a system for controlling the hydrostatic pressure exerted by the molten material in the containment zone. This is accomplished by sensing an electrical signal derived from the system for controlling and applying the alternating current to the inductor. The electrical signal which is sensed is one which  
10 changes in correspondence to changes in the hydrostatic pressure of the molten material in the containment zone. In response to the sensed electrical signal, the flow rate of molten material into the containment zone is controlled.

The electrical signal which is sensed may comprise any of a  
15 number of possible signals including but not limited to: the error signal which is applied to the power supply to control the inductor excitation; or any of the voltage frequency or current signals applied to the inductor; or internal signals applied within the power supply such as bus voltage control signals. The sole criteria  
20 for selecting the appropriate signal is that it be one which varies in correspondence with a variation in the hydrostatic pressure of the molten material head.

The process and apparatus of the present invention will be further described with reference to the accompanying drawings, in  
25 which:-

Figure 1 is a schematic representation of an electromagnetic casting apparatus in accordance with the present invention; and

Figure 2 is a partial schematic representation of an electromagnetic casting apparatus showing further details of the molten metal hydrostatic pressure control system.

Figure 3 is a partial schematic representation of an electromagnetic casting apparatus showing an alternative hydrostatic pressure control system.

In the description which follows reference is made to a metal as the material being cast. This is used generically to cover both substantially pure metals and metal alloys. It is to be understood however that the invention is applicable to other electromagnetically castable materials.

Referring now to Figure 1, there is shown by way of example an electromagnetic casting apparatus of this invention.

The electromagnetic casting mould 10 is comprised of an inductor 11 which is water cooled; a cooling manifold 12 for applying cooling water to the peripheral surface 13 of the material being cast C; and a non-magnetic screen 14. Molten metal, or other electromagnetically castable material, is continuously introduced into the mould 10 during a casting run using a trough 15 and down spout 16 and molten metal head control I in accordance with this invention. The inductor 11 is excited by an alternating current from a power source 17 and control system 18 which preferably is of the type described in the aforementioned Yarwood et al. U.S. Patent No. 4,161,206.



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The alternating current in the inductor 11 produces a magnetic field which interacts with the molten metal head 19 to produce eddy currents therein. These eddy currents in turn interact with the magnetic field and produce forces which apply a magnetic pressure to the molten metal head 19 to contain it in the zone defined by the magnetic field so that it solidifies in a desired ingot C cross-section.

An air gap d exists during casting, between the molten metal head 19 and the inductor 11. The molten metal head 19 is formed or moulded into the same general shape as the inductor 11 thereby providing the desired ingot cross-section. The inductor may have any desired shape including circular or rectangular as required to obtain the desired ingot C cross-section.

The purpose of the non-magnetic screen 14 is to fine tune and balance the magnetic pressure with the hydrostatic pressure of the molten metal head 19. The non-magnetic screen 14 may comprise a separate element as shown or may, if desired, be incorporated as a unitary part of the manifold for applying the coolant.

Initially, a conventional ram 21 and bottom block 22 is held in the magnetic containment zone of the mould 10 to allow the molten metal to be poured into the mould at the start of the casting run. The ram 21 and bottom block 22 are then uniformly withdrawn at a desired casting rate.

Solidification of the molten metal which is magnetically contained in the mould 10 is achieved by direct application of water

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from the cooling manifold 12 to the ingot surface 13. In the embodiment which is shown in Figure 1 the water is applied to the ingot surface 13 within the confines of the inductor 11. The water may be applied to the ingot surface 13 above, within or below the inductor 11 as desired.

If desired any of the prior art mould constructions or other known arrangements of the electromagnetic casting apparatus as hereinbefore described could be employed.

The present invention is concerned with the control of the casting process and apparatus in order to provide cast ingots C, which have a substantially uniform cross-section over the length of the ingot and which are formed of metals and alloys such as copper and copper base alloys. This is accomplished in accordance with the present invention by controlling the molten metal head in the casting zone so as to maintain a substantially uniform hydrostatic pressure. The molten metal head 19 corresponds to the pool of molten metal arranged above the solidifying ingot C which exerts the aforementioned hydrostatic pressure in the magnetic containment zone. In a vertical casting apparatus 10 as in Figure 1, the molten metal head 19 extends from the top surface 23 of the molten metal pool to the solid/liquid interface or solidification front 24 and further includes a limited contribution associated with the molten metal in and above the down spout 16.

In the prior art as noted in the background of this application, various systems have been described with the aim of providing cast ingots by the electromagnetic casting process which have substantially

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uniform cross-sections. In these approaches the excitation of the inductor 11 is controlled in a way so as to compensate for any variations in the molten metal head 19 in order to maintain uniform dimensions in the cast ingot. The approach suggested in U.S. Patent  
5 No. 4,161,206 to Yarwood et al is particularly preferred in accordance with the present invention and has been found to provide ingots of substantially uniform cross-section.

With any of these approaches some parameter of the casting process or system 10 is sensed in order to generate an error signal  
10 which is applied to the power supply 17 which excites the inductor 11 in order to control the inductor current in a way so as to overcome variations in the hydrostatic pressure of the molten metal head 19. Any such control system will optimally operate at peak efficiency over a given range of such a sensed parameter. In any  
15 casting apparatus, however, there can be trends or changes which can shift the range of the sensed parameter over a period of time adversely with respect to its optimum control range.

Therefore, in accordance with this invention longer term changes in the molten metal head 19, and more particularly the hydro-  
20 static pressure exerted by the molten metal head, are overcome by controlling the flow of the molten metal into the containment zone so as to maintain the hydrostatic pressure within desired limits. This should enable the control system 18 for the excitation of the inductor 11 to operate within its optimum ranges of control and should also reduce  
25 the instabilities associated with changes in hydrostatic pressure of the system, particularly long term instabilities.

The prior art control systems for controlling the excitation

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of the inductor 11 even if effective for their purposes are not effective for preventing long term changes in hydrostatic pressure associated with the molten metal head 19. The two Russian patents to Getselev described in the background of this application utilize  
5 sensing coils for sensing metal head height and attempt to control the flow of molten metal into the containment zone. These approaches take into account only changes in the hydrostatic pressure associated with changes in the top surface 23 of the molten metal head 19.

In contrast to the approaches adopted by Getselev, the present  
10 invention is directed to an integrated approach. Instead of sensing head height of the molten metal head 19, an electrical parameter is sensed which is derived from the control and/or current application system 17, 18 of the apparatus 10. The means for controlling and exciting the inductor 11 can comprise a separate power supply 17 and  
15 electrical control system 18 as shown, or they could be combined in a single unit. For purposes of the present invention, the signal which is sensed can be derived from either the control portion 18 or the power source portion 17 of the control and current application means. The electrical signal which is sensed is one which varies generally  
20 proportionally with changes in hydrostatic pressure of the molten metal head 19. Therefore, changes in the signal correspond to changes in the hydrostatic pressure. By determining or sensing a parameter indicative of hydrostatic pressure as opposed to head height alone, it is an advantage of the present invention that changes in the position  
25 of the liquid-solid interface 24 between the solidifying casting C and the molten metal pool 19 are also taken into account. This is something that the prior art systems have not provided for.

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In accordance with this invention, it is presumed that the control system 18 is effective for providing a cast ingot of substantially uniform diameter. Most control systems 18 operate in one way or another by generating an error signal which is applied to the power supply 17 in order to change its output in a direction which will counteract the effect of changing hydrostatic pressure of the molten metal head 19. The flow rate of molten metal into the containment zone cannot be controlled so precisely so as to avoid instability or other variations in the molten metal head 19 and its resultant hydrostatic pressure.

Referring now to Figures 1 and 2, control system 18 operates with relatively short control cycles so that the ingot C diameter never changes substantially. Therefore, the error signal A as in Figure 2, which is generated by the control system 18 for application to the power supply 17, is one signal which corresponds to changes in hydrostatic pressure of the molten metal head 19. The error signal A may take any desired form, for example, it could be a current, voltage, frequency, etc. Preferably, in accordance with this invention, the error signal A is a voltage signal which is applied to an appropriate control input of the power supply 17 to control the output thereof.

Preferably, in accordance with this invention the power supply 17 comprises a solid state power supply as is known in the art, although a motor generator could be utilized if desired. In such a solid state power supply 17 various internal signals B result from the application of the error signal A to the control input of the supply. For example, in a solid state power supply 17 where an

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incoming AC voltage is rectified to a DC voltage which is then chopped to regulate the voltage and then inverted to provide an AC output of the desired frequency and voltage, a bus voltage which is used to control the voltage output of the supply 17 is a signal B which corresponds to the error signal A and, therefore, to changes in hydrostatic pressure. Similarly, various other signals B could be extracted from the power supply 17 at any point from the error signal A input to the output of the supply so long as they correspond to changes associated with the error signal and, therefore, changes in hydrostatic pressure. Finally, the output signals Q of the power supply 17 which are applied to the inductor 11 and which correspond to changes in hydrostatic pressure can be used. This applies, of course, only to those output signals Q which are varied in response to changes in the error signal A. In the apparatus of this invention one such output signal Q would be the current in the inductor 11. Alternatively, the voltage applied to the inductor 11 or in a variable frequency supply 17 the frequency could be sensed.

The present apparatus 10 is preferably directed to an arrangement wherein the frequency is fixed and only the voltage and current on the inductor 11 is varied. However, if desired, power supplies wherein the frequency is not fixed could be employed and thereby changes in frequency could be utilized as a signal Q. It is apparent from the foregoing that the signal which is sensed A, B, or Q as desired in accordance with this invention to determine changes in hydrostatic pressure can be derived from either the control system 18 or the power supply 17 for exciting the inductor 11.

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Referring again to the apparatus of Figures 1 and 2, the inductor 11 is connected to an electrical power source or supply 17 which provides the necessary controlled current and voltage at a desired frequency. A typical power supply circuit may be considered  
5 as two subcircuits 25 and 26. An external circuit 25 consists essentially of a solid state generator providing an electrical potential across the load or tank circuit 26 which includes the inductor 11. This latter circuit 26 except for the inductor 11 is sometimes referred to as a heat station and includes elements such  
10 as capacitors and transformers.

In accordance with this invention, the generator circuit 25 is preferably a solid state inverter. A solid state inverter is preferred because it is possible to provide a selectable frequency output over a range of frequencies. This in turn makes it possible  
15 to control the penetration depth of the current in the load. Both the solid state inverter 25 and the tank circuit or heat station 26 may be of conventional design. Preferably, the power supply is provided with front end DC voltage control in order to separate the voltage and frequency functions of the supply.

20 The control system 18 may be of any desired design including any of these described in the background of this application. However, preferably it is a system in accordance with the U.S. 4,161,206, Yarwood et al patent. In that system a reactive parameter of the inductor is sensed which is a function of the gap 'd' between the  
25 molten metal 19 and the inductor 11. The sensed parameter is compared with a preset value thereof and an error signal A is generated which is a function of the difference between the magnitude of the sensed

parameter and a preset value thereof. As the sensed parameter changes, so does the error signal A in correspondence thereto. If the sensed parameter corresponds about to inductance, as in the preferred approach of the Yarwood et al patent, then the control  
5 system 18 is adapted to control the power supply 17 in a way so as to maintain a substantially constant inductance and thereby a substantially uniform ingot cross-section.

The changes in the value of the error signal are a function of changes in the hydrostatic pressure of the molten metal head 19. As  
10 the molten metal head 19 increases in height either due to an increase in the height of the upper surface 23 or to a lowering of the solidification front 24 or both, there is an increase in hydrostatic pressure. This hydrostatic pressure increase would normally increase the diameter of the resultant ingot C. However, the control  
15 system 18 is effective to counteract this increase in hydrostatic pressure by increasing the current applied to the inductor 11. These changes occur very rapidly, in fractions of a second, so that the inductance and cross-section of the ingot appear substantially constant throughout.

20 Normally, the molten metal flowing into the containment zone is controlled manually by a suitable valve which in copper alloy casting practice is located at the top of the down spout 15. For other types of metals the valve may be located in any desired location. For example, for aluminum casting the valve is normally  
25 located toward the bottom of the down spout. The particular position of the flow control valve may be selected as desired. Conventionally



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manual control of flow rate is performed in response to sensing the height of the molten metal in the containment zone either visually or through electrical or electroptical means as are known in the art.

It is desired in accordance with this invention, however, that  
5 the control of the flow rate be fully automated and integrated into the control of the casting system 10. Referring now to Figures 1 and 2, this is accomplished by providing a flow control valve 27 somewhere in the molten metal distribution system which leads to the mould. Preferably, it is in the down spout 16. The flow control  
10 valve 27 shown comprises a pin 28 having a conical end 29 which is arranged to control the flow rate of metal from the trough 15 into the down spout 16. The pin 28 is arranged coaxially above the down spout 16. Raising the pin 28 increases the flow rate. Lowering the pin 28 decreases the flow rate. Lowering the pin 28 into contact with  
15 the end corners of the down spout 16 cuts off flow entirely.

Movement of the valve pin 28 up or down in accordance with this invention is fully automated by means of a suitable actuator 30 which can be controlled electrically. The actuator 30 shown in Figures 1 and 2 comprises a pneumatic actuator. The pneumatic  
20 actuator 30 includes a housing 31 internally of which is supported a flexible diaphragm 32. The diaphragm 32 in turn is connected to the valve pin 28 by means of a rod 33. The valve pin 28 is normally biased to its closed position by means of a spring 34 extending between the pin 28 and the housing 31 of the pneumatic actuator 30.  
25 Air is introduced or withdrawn from the housing 31 by a valve to pressure transducer 35. The magnitude of the air pressure applied by

the transducer 35 to the housing 31 via conduit 36 is directly proportional to the magnitude of the control voltage signal V input to the transducer 35. Variations in the signal V cause corresponding variation in the output pressure of the transducer 35. A suitable  
5 transducer 35 comprises a Model T5100 series manufactured by Fairchild, Inc. of North Carolina.

The air pressure from the transducer 35 deflects the diaphragm 32 as shown in phantom in proportion to the magnitude of the air pressure. This causes the pin 28 to be raised from its fully-closed  
10 position. The position of the pin 28 is, therefore, a function of the pressure on the lower side of the diaphragm 32. As the pressure increases, the deflection of the diaphragm 32 increases and, therefore, the flow opening into the casting zone is increased. Similarly, as the pressure decreases, the flow opening is decreased.

15 The transducer 35 receives the input control signal from the flow control system 37 which is connected to the power source 17 and control system 18 of the casting apparatus 10. The flow control system 37 is best shown in Figure 2. It comprises a set point control amplifier 38, one input 39 of which is connected to a  
20 variable voltage source 40 which is utilized to set the control point of the amplifier 38. The other input 41 to the amplifier is connected to receive the desired signal A, B, or 0 as described above, which is sensed from within the control and excitation system 17, 18 of the inductor 11. The sensed signal A, B, or 0, which is applied to the  
25 control input 41 of the amplifier is compared by the amplifier to the variable voltage source set point signal P to generate the output signal V which is proportional to the difference therebetween. The output

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signal V from the amplifier 38 causes the transducer 35 to increase or decrease the deflection of the diaphragm 32 to correspondingly increase or decrease the flow rate of metal from the trough 15 into the down spout 16.

5           The flow control system 37 preferably is of the proportional type wherein the differential between the set point signal P and the input signal A, B, or Q from the control system and power source 17 and 18 is measured and amplified by a desired factor. The controller 37 preferably includes a reset function which serves to  
10 long term average the sensed signal A, B, or Q. In this way, the flow control system 37 will comprise an integrating control arrangement wherein the flow rate change cycles are from 2 to 10 times the cycle time associated with the power supply control system 18. For example, the flow rate change cycles will range in time in seconds  
15 rather than in fractions of a second, preferably 2 to 10 seconds.

          If the casting apparatus 10 is to be one which may be subject to drastic changes in flow rate, then the controller 37 preferably also includes a rate function which is particularly useful at start-up. The rate function of the controller 37 adds a factor to the  
20 control output signal V which would be a function of the rate of change in the input error signal A, B, or Q.

          The specific details of the controller 37 do not form part of the present invention, and any desired set point controller 37 which is adapted to receive the sensed hydrostatic pressure error  
25 signal A, B, or Q and compare it with a predetermined value thereof to generate an error signal for controlling the transducer 35 could be used.

It is not necessary in accordance with this invention to utilize a pneumatic actuator 30. It would be fully appropriate to use in place thereof either a stepping motor or a servo control motor 42 as in Figure 3 and in place of the transducer 35, an appropriate servo amplifier 43 which would receive the error signal V from the set point amplifier 38. The pin type flow control valve 27 is arranged for movement in a frame not shown vertically and axially of the down spout 16. A rack 44 is connected to the pin 28 and is associated with a pinion gear 45 which is driven by the servo motor 42 which in accordance with this embodiment could be either a servo motor or a stepping motor. The servo motor 42 is actuated by the output signal V' from the servo amplifier 43 in response to the error signal V from the set point amplifier which is applied at the input 46 to the servo amplifier.

Accordingly, it is a unique aspect of this invention that a hydrostatic pressure change signal A, B, or Q from the control and excitation system 17 and 18 for the inductor 11 is utilized to control the flow rate of the molten metal into the containment zone of the casting machine 10. The signals A, B, or Q which are sensed in accordance with this invention can be sensed in any desired conventional fashion. For example, as shown in Figure 2, the error signal A from the control system 18 can be sensed by a parallel connection 47 to the output 48 of the control system 18 so that the output 48 thereof is applied to both the power supply 17 and the flow rate controller by suitably connecting terminal 49 to terminal 50 as by a wire 59 shown in phantom.

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If the current in the inductor 11 is to be sensed, this can be accomplished through the use of a current transformer 51 whose output is current to voltage scaled at S to provide a corresponding voltage signal at terminal 52 which is connected to terminal 50.

5       The voltage or frequency across the inductor could be sensed by means of a differential amplifier 53, filter 54 and frequency to voltage converter 55 as described in U.S. Patent 4,161,206. In this approach the differential amplifier 53 is utilized to provide a voltage across the inductor 11 signal at terminal 56. The output of  
10 the differential amplifier 53 alternatively is fed to a filter circuit 54 for extracting the fundamental frequency. The output of the filter 54 is fed to a frequency to voltage converter 55. The output signal of the frequency to voltage converter 55 at terminal 57 comprises a signal proportional to the frequency of the applied  
15 current. Hydrostatic pressure control signals B from within the power source 17 such as the control bus voltage are provided at terminal 58. In practice selectively only one of the control signals A, B, or Q is connected to terminal 50 as by a wire connecting that terminal to any of the signal terminals 49, 56, 57, and 58. A suitable wire  
20 connection 59 is shown in phantom connecting terminals 49 and 50 as an example.

The means for sensing the signals A, B, or Q referred to above can be any desired means including a volt meter, a current meter or any other suitable instrument.

25       In operation the apparatus 10 of the present invention will sense changes in the hydrostatic pressure of the molten metal head 19.

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If the magnitude of the hydrostatic pressure change signal A, B, or Q increases or decreases with time, depending on whether the hydrostatic pressure is increasing or decreasing, then the set point control amplifier 38 will provide an appropriate control signal V for controlling the actuator 30 of the flow control valve 27. If for example there is an increase in hydrostatic pressure associated with an increased flow of molten metal into the containment zone, the effect on the control system 18 for the inductor 11 would be to increase the current to overcome the higher hydrostatic pressure.

10 This current increase would be sensed at any of the points as described above, either as the current output signal Q itself or some other corresponding signal which could be traced all the way back to the change signal A which caused the increased current. The change signal A, B, or Q is applied to the set point control amplifier

15 38 to generate an output signal V from the amplifier which would cause the flow control valve 37 to reduce the flow of molten metal into the mould. This in turn would reduce the hydrostatic pressure and cause the control system 18 for the power supply 17 to reduce the current in the inductor. This would result in a change signal A,

20 B, or Q which would be fed back to the flow control system 37 and the two systems 18 and 37 will interact until a quiescent or near quiescent condition is obtained. If some change in the flow of molten metal into the mould destroys this quiescence, then the same control interaction will occur again until a more quiescent condition

25 is achieved.

Of course, it is recognized that the control system 18 for the power supply 17 is reacting or cycling in fractions of a second whereas the control system 37 for the molten metal flow rate is reacting or cycling in seconds. In this way it is possible to  
5 control the flow rate into the casting zone in such a manner as to have the control system for the power supply operate within its optimum range of control. The net result of the dual control of both the output of the power supply 17 and the flow rate of molten metal into the mould fully automatically as described should be to  
10 provide cast ingots of even more uniform cross-section than would be obtained by the use of a control system 18 of the Yarwood et al patent or other system alone.

In the figures common elements have the same reference numbers.

15 The flow control 37 could be similar to the Model 7355 three mode proportioning controllers manufactured by Honeywell, Inc., Minneapolis, Minnesota.

While the casting as described above has been described as an ingot, it could comprise any desired type of continuously or  
20 semi-continuously cast shape, such as rods, bars, etc. While the invention has been described by reference to copper and copper base alloys, it is believed that the apparatus and process described above can be applied to a wide range of metals and alloys including nickel and nickel alloys, steel and steel alloys, aluminum and aluminum  
25 alloys, etc. While the control circuitry has been described in an analog format, it should be apparent that digital circuitry could be substituted including the use of appropriate micro-processing as desired.

Instead of controlling the flow of molten metal into the mould by means of a valve 27 in the down spout 16 the valve 27 could be located in the trough 15 though this is deemed less desirable. Further, in place of a valve 27 the pour rate of the

5 furnace which provides the molten metal can be controlled by any desired means. For example, if a conventional tilt type furnace is utilized the rate at which the furnace is tilted could be controlled in a manner similar to the way the valve 27 in the embodiments described above is controlled. This approach again is not preferred

10 because it is too far upstream of the mould. Ideally, the valve should be located as far downstream in the distribution system as possible in order to reduce the time interval necessary to change the rate of flow of molten metal into the mould.

The terms molten metal flow or flow rate as used herein refer

15 to the volumetric flow rate of the molten metal.



Claims

1. An electromagnetic casting apparatus comprising means (15, 16) for supplying a material to be cast to a casting zone, an inductor (11), a power source (17) for supplying power to the inductor to form a magnetic field within said zone and effective to form the cast material therein into a desired shape, means (12) for supplying coolant to the surface of the cast material, means (22) for withdrawing the cast material from the casting zone, and means (18) for controlling the power source in response to changes in the hydrostatic pressure in the column of molten material in the casting zone, characterised in that the apparatus further comprises means for automatically controlling the amount of molten material in the casting zone in response to said changes in said hydrostatic pressure and thereby to minimize said changes.

2. An apparatus according to claim 1, characterised in that the apparatus comprises means (49, 51, 53) for sensing an electrical signal supplied to or derived from said control means (18) and/or said power source (17) and which signal varies in proportion to changes in said hydrostatic pressure, and means (37) responsive to said sensing means for operating the automatic control means to control the amount of molten material in the casting zone.

3. An apparatus according to claim 2, characterised in that said sensing means (49) operate to sense an error signal from the control means to the power source for the purpose of regulating the

output from the power source to the inductor.

4. An apparatus according to claim 2, characterised in that said sensing means operate to sense the frequency, voltage or current supplied to the inductor from the power source.

5. An apparatus according to claim 2, 3 or 4, characterised in that the means responsive to said sensing means comprise a control circuit for receiving the sensed electrical signal, comparing that signal with a reference signal and generating an output signal, said automatic control means being responsive to said output signal to increase or decrease the amount of molten material in said casting zone.

6. An apparatus according to any one of claims 1-5, characterised in that said automatic control means operate to control the flow of molten material from the supply to the casting zone.

7. An apparatus according to claim 6, characterised in that said automatic control means comprise a valve (27) positioned in the flow path of the molten material from the supply to the casting zone.

8. An electromagnetic casting process which comprises feeding a molten material to be cast to a casting zone, containing that molten material within the casting zone by application of an electromagnetic field, applying a coolant to the surface of the cast material, and

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withdrawing the solidified cast material from the casting zone, characterised in that changes of hydrostatic pressure within the molten material in the casting zone are minimized by sensing changes of hydrostatic pressure in the molten material in the casting zone, and automatically adjusting the amount of molten material in said zone in response to said changes, thereby to keep said changes to a minimum.

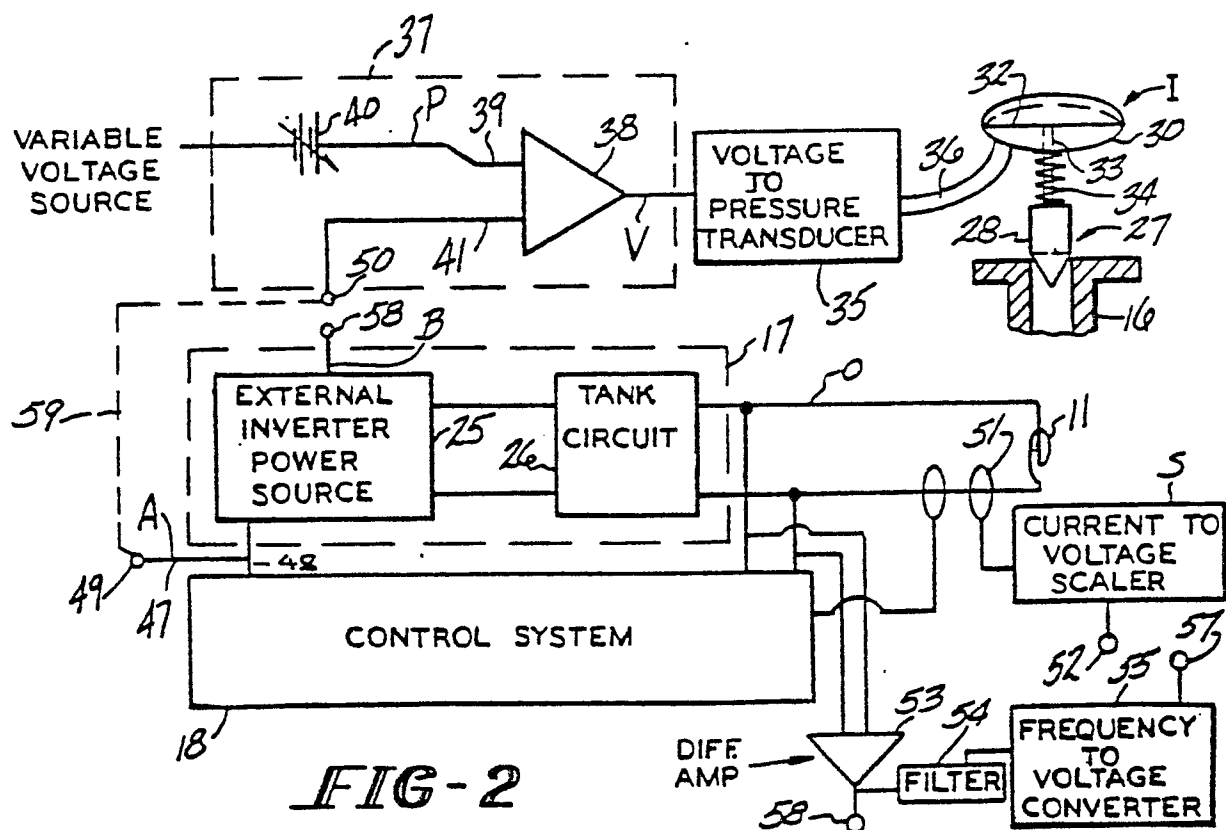
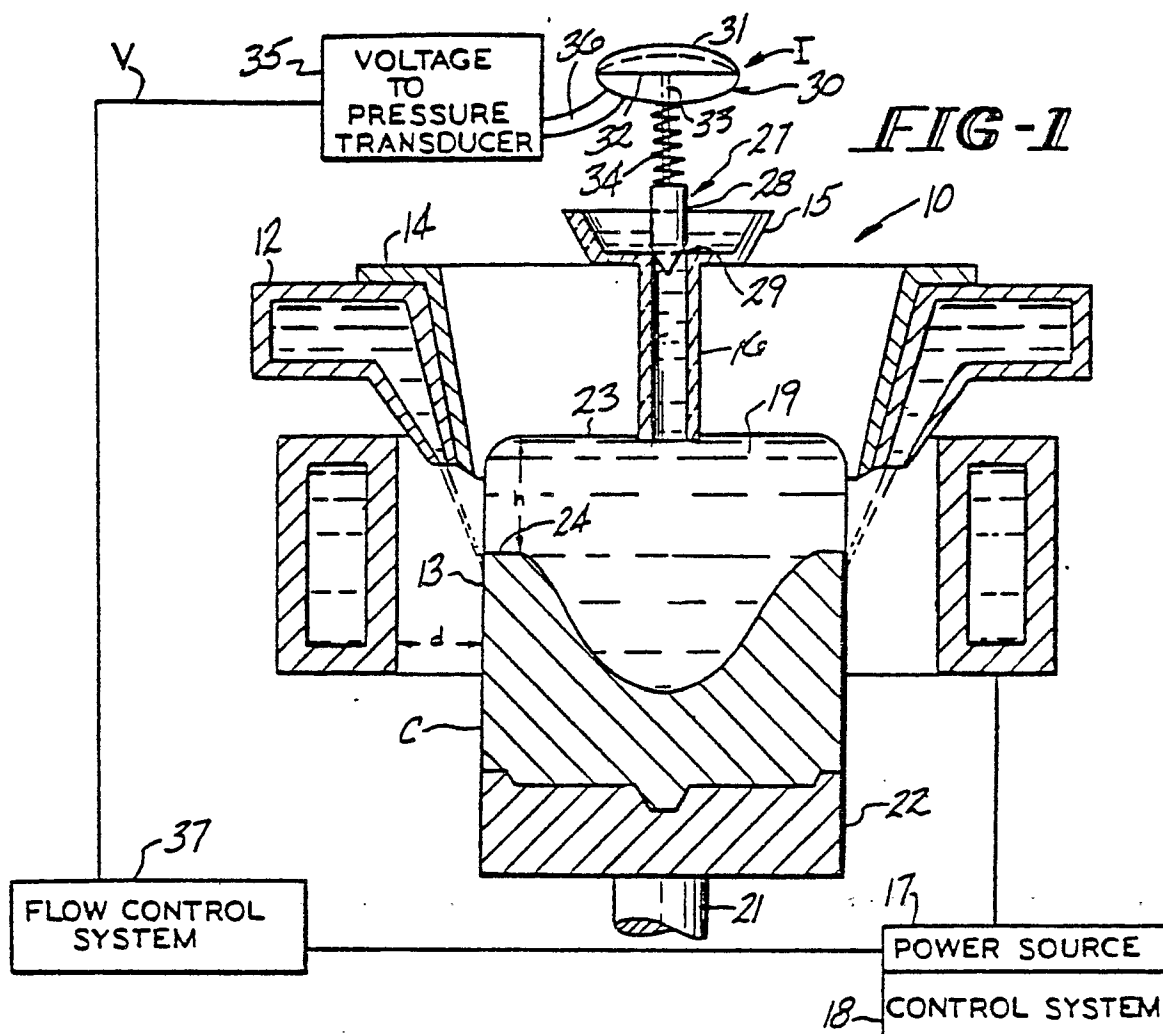
9. A process according to claim 8 which comprises feeding a molten material to a casting zone surrounded by an inductor, supplying current to the inductor to generate an electromagnetic field within said zone effective to contain the molten material in a desired shape, applying a coolant to the surface of the shaped material, sensing changes of hydrostatic pressure in the molten material contained in the casting zone, generating an electrical signal proportional to said changes and controlling the current to the inductor in response to that signal thereby to maintain the desired shape, characterised by sensing that signal and automatically adjusting the amount of molten material in the casting zone in response to that signal thereby to minimize those changes.

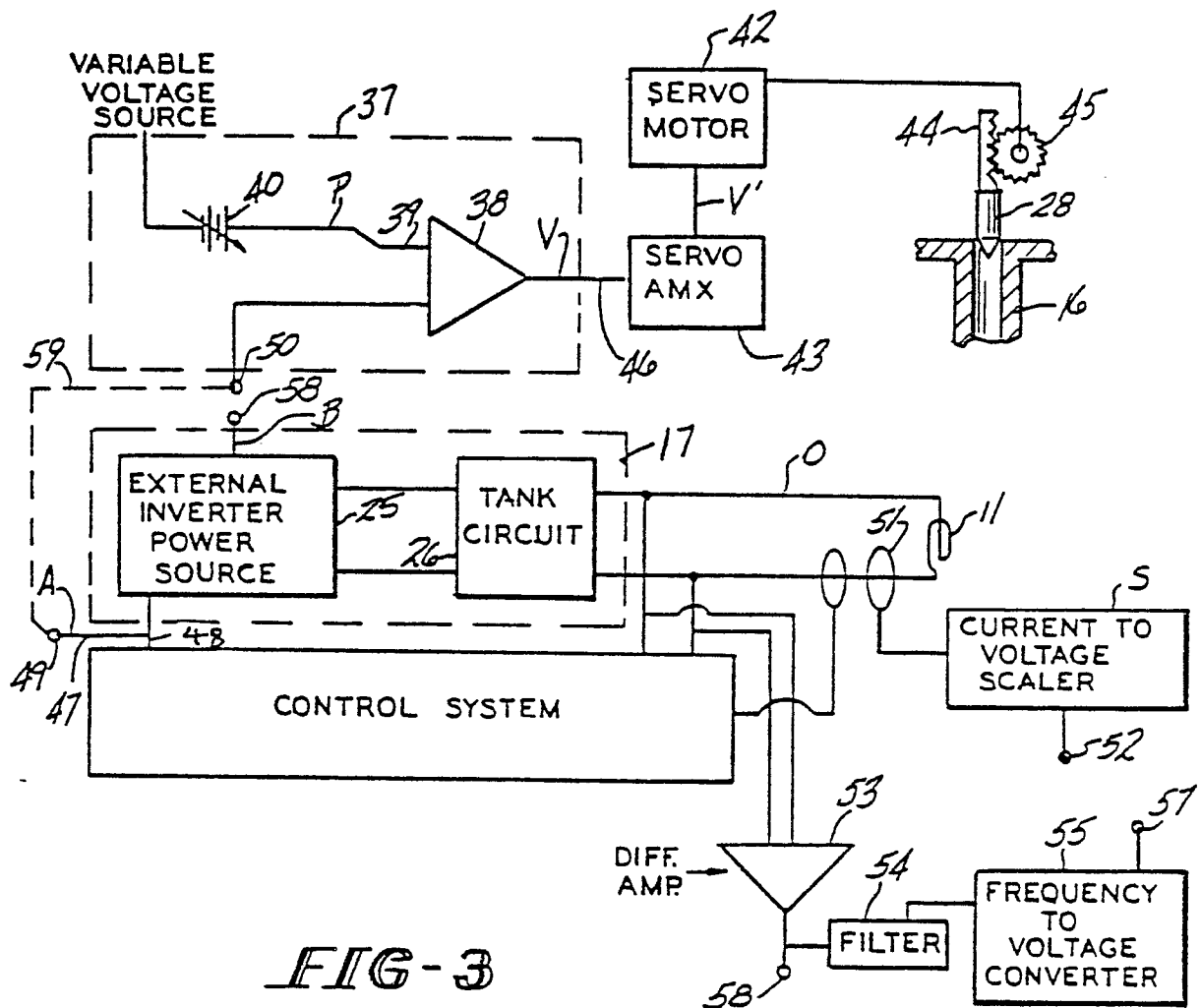
10. A process according to claim 9, characterised in that the sensed signal is an error signal used to control the current flow to the inductor.

11. A process according to claim 9, characterised in that the sensed signal comprises the current, frequency or voltage of the supply to the inductor.

12. A process according to any one of claims 8-11, characterised in that the amount of molten material in the casting zone is controlled by automatically adjusting the rate of flow of the molten material into the casting zone.

13. A process according to any one of claims 8-12, wherein the material being cast is a metal or alloy.







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# EUROPEAN SEARCH REPORT

0032442

Application number

EP 81 30 0093.2

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl. <sup>3</sup> )
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
A	DE - A1 - 2 757 785 (R. THEILER) * claim 1 * --	1	B 22 D 11/01 B 22 D 11/16
	US - A - 4 161 978 (BROOKS et al.) * abstract * --	1	
	A,D	US - A - 3 467 166 (GETSELEV et al.) * fig. * ----	
			TECHNICAL FIELDS SEARCHED (Int. Cl. <sup>3</sup> )
			B 22 D 11/00
			CATEGORY OF CITED DOCUMENTS
			X: particularly relevant A: technological background O: non-written disclosure P: intermediate document T: theory or principle underlying the invention E: conflicting application D: document cited in the application L: citation for other reasons
<input checked="" type="checkbox"/> The present search report has been drawn up for all claims			&: member of the same patent family, corresponding document
Place of search		Date of completion of the search	Examiner
Berlin		03-04-1981	GOLDSCHMIDT