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(54) A.C. MAGNETIC STIRRING MODIFIER FOR CONTINUOUS CASTING OF METALS

MAGNETISCHES RÜHREN MITTELS WECHSELSTROM FÜR DAS KONTINUIERLICHE GIESSEN VOM METALLEN

MODIFICATEUR DE BRASSAGE MAGNETIQUE C.A. POUR LA COULEE CONTINUE DE METAUX

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(73) Proprietor: **ABB Inc.**
St.-Laurent, Québec H4S 1Z6 (CA)

(72) Inventors:
- **BEITELMAN, Leonid**
Thornhill, Ontario L3T 6X1 (CA)
- **MULCAHY, Joseph A.**
Brooklin, Ontario L0B 1C0 (CA)

(74) Representative:
Beresford, Keith Denis Lewis et al
BERESFORD & Co.
16 High Holborn
London WC1V 6BX (GB)

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- **PATENT ABSTRACTS OF JAPAN, unexamined applications, M section, vol. 7, no. 102, issued 1983, April 30 THE PATENT OFFICE JAPANESE GOVERNMENT, page 102 M 211; & JP,A,58,23 554 (GOUDOU) (cited in the application).**

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Description

FIELD OF INVENTION

[0001] The present invention relates to the continuous casting of metals and alloys, for example, steel.

BACKGROUND OF INVENTION

[0002] In continuous steel casting by pouring liquid metal into an open-end mold, stability of the free surface of the metal in the mold, often called the meniscus, plays a significant role in both process control and the quality of as-cast product.

[0003] Electromagnetic stirring of liquid steel within the mold, commonly known as M-EMS or simply EMS, is broadly employed in continuous casting mainly to improve quality of the strand surface/sub-surface and solidification structure (i.e., structure refinement, soundness and chemical homogeneity).

[0004] The two most common practices of continuous steel casting impose entirely opposite requirements to the stirring conditions within the region of molten metal near its free surface at the mold top, i.e. the meniscus region.

[0005] Accordingly, casting mainly Al-killed steel grades via a submerged entry nozzle under mold powder requires meniscus stability in order to prevent disruption of mold lubrication and powder entrapment into the cast body. A rotary stirring motion at the meniscus causes meniscus depression in the centre, waves, and excessive erosion of the casting nozzle when stirring intensity exceeds a certain level. On the other hand, casting of Si-Mn deoxidized steel with an open stream is often accompanied by the defects of cast product surface. Pinholes, blowholes, surface slag entrapment and subsurface inclusions are examples of those surface defects. In order to minimize or eliminate the surface defects, an intensive stirring motion of the molten metal is required in the meniscus region. The same requirement applies for casting low deoxidized, or so-called rimming substitute steel. However, overly intensive stirring motion of the meniscus may cause undesirable deterioration of the surface by producing deep oscillation marks and lappings.

[0006] Maximizing stirring intensity within the portion of metal confined by the mold is beneficial for obtaining improvements of the internal quality of cast material. Improvements in the solidification structure refinement and soundness, especially in high-carbon and certain alloy steels, strongly respond to the intensity of stirring. Having a rather limited operating space determined by the mold length, it is difficult to satisfy, with a single system, varying stirring requirements without significantly compromising some of them. For example, the limitation imposed by an acceptable level of meniscus disturbances with casting under mold powder restricts maximizing stirring intensity induced by EMS within the bulk of liquid pool.

[0007] Attainment of different stirring conditions in the mold is difficult, if possible at all, when more than one of the casting techniques mentioned above are being practised at the same casting facility.

[0008] There are some known methods in prior art with the objective to change or control the stirring motion in the meniscus area. Japanese Patent Publication No. 58-23554 describes a method of decreasing the intensity of stirring in the meniscus region by means of an induction coil arranged on the mold adjacent to that region and providing rotating stirring motion opposite to that induced by the main EMS coil arranged below.

[0009] The main drawback of this method is that the induction coil adjacent to the meniscus region provides only a deceleration of the stirring velocity produced by EMS. In the case when an intensive stirring action within the meniscus region is required, this method would need to relinquish its decelerating action by de-energizing the coil. The coil is not intended to enhance stirring action if the need of such enhancement arises, for the reasons discussed above.

[0010] In addition, the range and criterion of stirring deceleration are not disclosed in the publication. For example, a complete or near to it deceleration of stirring velocity can be related to meniscus flatness. The meniscus depression caused by rotational motion is proportional to angular stirring velocity, as seen from the expression:

$$h = \frac{W^2R^2}{2g} \qquad (1)$$

where,

- h is the depth of meniscus depression
- W is the angular stirring velocity
- R is the radius of the stirred pool
- g is the acceleration due to gravity

[0011] The depth of meniscus depression h approaches zero when the angular stirring velocity at the meniscus caused by EMS is equalized by counter-stirring angular velocity produced by a braking induction coil.

[0012] Without such equalizing, the merits of that method for application to the casting under the mold powder will be limited.

[0013] Another possible way of alleviating the problem of meniscus instability and decreasing stirring motion at the surface in on application of a strong horizontal D.C. magnetic field to the meniscus region. Such a field produces an electromagnetic (Lorentz) force directed opposite to the liquid metal motion and thereby reduces that motion velocity, providing a quiescent surface. An application of this concept is described in the U.S. Patent No. 4,933,005 of June 12, 1990, assigned to the assignee hereof.

[0014] AT-PS 189751 discloses electromagnetic stirring in an open stream process using two electromagnetic coil arrangements are above the other operated in unison.

[0015] EP-A-0 096 077 discloses a plurality of electromagnetic agitations arranged in a horizontal direction along a wall of a mold to accelerate or decelerate the circulatory flow along the flow direction but does not provide a second magnetic field at a location upstream of the stirring by a first rotating magnetic field. DE-A-3 819 492 discloses two stirrers, one upon the other, and discloses operating one or both of the stirrers in a casting method. EP-A-0 080326 discloses one rotational field only together with an axial field. JP-A-59 89649 discloses a submerged nozzle process in which an upper coil produces a field rotating in the opposite direction to that produced by a lower coil to provide a braking effect at the surface of the molder metal.

[0016] An electromagnetic volume force will be produced in either of two situations, firstly, when an A.C. rotating magnetic field interacts with liquid metal which is in the state of complete rest, the metal will be set into a motion with a velocity lower than that of the A.C. field; and, secondly, when a stationary, i.e. D.C. magnetic field, interacts with liquid metal already in motion. The volumetric magnetic force is proportional to velocity slip, i.e., the difference between the velocities of magnetic field and liquid metal, in accordance with the relationship:

$$F_r = 0.5\ \sigma\ B^2\ (W_f - W_m).R \qquad (2)$$

[0017] In this expression describing a tangential component of the electromagnetic force produced by a two-pole induction stirrer, the parameters are:

σ is the electrical conductivity of liquid metal
B is the magnetic flux density
W_f is the angular velocity of magnetic field
W_m is the angular velocity of liquid metal
R is the radius of liquid metal pool

[0018] In the case of electromagnetic stirring with an A.C. magnetic field, $W_f >> W_m$, while $W_f = 0$ for a D.C. magnetic field and W_m is comparatively low in both cases. Thus, the velocity slip between an A.C. magnetic field and moving liquid metal is much greater than that between the moving metal and a stationary field. Therefore, in order to attain magnetic force of the same value, a much greater value of magnetic flux density B is employed for a D.C. magnetic field than would be required for an A.C. magnetic field. This demand for magnetic flux increases with the requirement to reduce metal velocity to a lower level.

[0019] Laboratory experiments have shown that a magnetic flux density of the order of 300 mT was required to reduce a stirring velocity in a pool of mercury by 70 to 90 percent. Considering a scaling-up effect of industrial application, it is difficult to attain both the level of magnetic field intensity and the degree of stirring velocity reduction.

SUMMARY OF INVENTION

[0020] The process according to the invention is defined in claim 1.

[0021] The present invention thus provides an improved method of controlling electromagnetic stirring intensity within a continuous casting mold. This method provides both the flexibility of adaptation of stirring conditions to the casting processes and the accuracy of stirring control which were lacking by prior art.

[0022] The present invention may be performed using an apparatus which includes an electromagnetic A.C. coil similar to but smaller than that of a main electromagnetic stirrer installed downstream and arranged around the mold in the meniscus area. This device is in essence another induction stirrer, similar to the main stirrer which is arranged axially symmetrical around the mold and farther down from the meniscus. However, the coil in the upper part of the mold is suitable for counterbalancing and equalizing, or enhancing, depending on specific objectives, the stirring motion in the adjacent volume of liquid metal, whose motion is originated by the main stirrer. Therefore, the working function of this stirrer is to modify the pattern and/or intensity of the stirring induced by the main stirrer and henceforth the device performing that function will be called A.C. magnetic stirring modifier or A.C. MSM. The action of the A.C. MSM is typically contained within the upper portion of molten metal pool, comprising approximately 10 to 15 percent of its volume confined by the mold.

[0023] The stirring motion within that portion of the metal pool is caused and maintained by the inertia forces, i.e. velocity drag, which transmit the momentum from the part of the pool where the motion has been commenced by M-EMS. Therefore, the stirring velocity at the meniscus area is less than that in the area of maximum value of M-EMS magnetic flux density, i.e. the area corresponding to the middle of EMS coil. Consequently less magnetic energy is required to counterbalance the kinetic energy of molten metal motion in the meniscus area than is provided by the M-EMS coil. Being a part of a single magnetohydrodynamic system, both the A.C. MSM and M-EMS operate at a common frequency determined by the parameters of the mold. The current supplied to both sets of the coils can be of the same variable value or it can be controlled separately. These operating features conveniently allow for a single power source for both sets of coils.

[0024] The invention is broadly applicable to all electroconductive materials, i.e. metals and alloys, which can be electromagnetically stirred and where control of stirring intensity is required within some region or regions without interference with stirring within other regions of the liquid pool. The invention is applicable to a wide variety of spacial orientation of a vessel containing the molten method. For example, a casting mold may be arranged vertically, inclined or horizontally.

BRIEF DESCRIPTION OF DRAWINGS

[0025]

Figure 1 is a schematic of an arrangement of an A. C. magnetic stirring modifier and an electromagnetic stirrer (EMS), with respect to a casting mold ;
Figure 2 is a schematic representation of the magnetic flux density axial profiles for the A.C. magnetic stirring modifier and the EMS of Figure 1 and the axial profile of rotational stirring velocity produced thereby;
Figure 3 is a graphical representation of the relationship of meniscus depression without and with an A.C. magnetic stirring modifier at varying current of an EMS;
Figure 4 is a single-line diagram of possible electrical connections for the induction coils of the A.C. magnetic stirrer modifier and the EMS of Figure 1; and
Figure 5 is an elevational sectional view of the mechanical arrangement of the A.C. MSM and the EMS within the mold housing and corresponding to the schematic arrangement of Figure 1.

[0026] Referring to the drawings, Figure 1 is a schematic depiction of an arrangement of an A.C. MSM and an EMS within a mold housing assembly of a continuous casting machine 10 . Figure 5 is a more detailed depiction of the mechanical elements of the mold assembly.

[0027] A series of induction coils 12, is arranged equally spaced around the periphery of a vertical casting mold 14, at its lower portion to comprise an A.C. electromagnetic stirrer (EMS). The EMS coils 12, when energized, induce rotary motion of a strand of molten metal 16 within the mold 14 about its longitudinal axis.

[0028] A casting ceramic tube 18 is axially located with respect to the strand of molten metal 16, if the apparatus is to be used for casting with a submerged entrance nozzle instead of the open pouring method. A.C. MSM induction coils 20, are equally spaced around the vertical mold 14, adjacent to a free upper surface or meniscus 22 of the strand of molten metal 16. The EMS coils 12 are designed to induce a strong rotational flow of molten metal in the strand of molten metal 16 within the mold 14. The intensity of this rotational flow is characterized by its rotational velocity U_R which, in turn, depends on the parameters comprising the expression:

$$U_R = K \sqrt{\frac{T}{L}} \qquad (3)$$

wherein,

K is a proportionality coefficient
T is the magnetic torque applied to the molten metal
L is a characteristic length of stirrer

[0029] The magnetic torque T is defined by other parameters of the electromagnetic system:

$$T = 0.5\,\pi^2 \bullet f \bullet \sigma \bullet B^2 \bullet R^4 \qquad (4)$$

where,

f is the current frequency
σ is the liquid metal electrical conductivity
B is the magnetic flux density
R is the stirred pool radius

[0030] A maximum value of rotational velocity is attained within and about the region of molten metal defined by a characteristic length of stirrer L which corresponds to a magnetic flux density B distribution along stirring axis. A typical magnetic flux density distribution for the two sets of induction coils 12 and 20 are shown in Figure 2.

[0031] The axial distribution of rotational stirring velocity, U_R, also is presented in Figure 2. As seen from this schematic, the rotational velocity U_R extends well beyond the active stirring zone L of the EMS coils 12 within the molten metal pool 16. This effect is due to the fact that angular momentum originated by the stirring coils 12 is transported by secondary poloidal flow within the metal strand 16. The secondary flow is originated at the stirring symmetry area, i.e., the stirrer neutral horizontal axis, and is directed from the active stirring zone L along the solidification front, making a return loop towards the stirrer at the stirred pool centre.

[0032] The value of the maximum stirring velocity within and about the active stirring zone L and the rate of its axial attenuation within the metal 16 determine the stirring velocity at the meniscus area 22 in the absence of other effects.

[0033] Along with the value of magnetic flux density and the frequency, the stirring velocity value and its lengthwise axial range depend on the stirrer length L, the radius of the stirred pool R, and the roughness of the solidification interface with liquid metal. Accordingly, it is difficult to quantitatively and accurately predict the stirring velocity at the meniscus, based upon the design and operating parameters of the EMS coils 12 and the distance from EMS neutral axis to the meniscus.

[0034] For a typical EMS arrangement within a steel billet/bloom continuous caster mold housing, the stirring velocity at the meniscus generally is about 0.5 to 0.7 (about 50 to 70 percent) of maximum stirring velocity value while the EMS coils 12 are located at a lowest position with respect to the meniscus. Therefore, a substantial stirring action can be expected at the meniscus area produced by the EMS coils even if the latter is located at the farthest possible distance from the meniscus. Meniscus depression and, more generally, turbulence at this location manifest themselves as a result of this stirring action.

[0035] The meniscus depression depth, as was shown earlier in the expression (1), is strongly correlated to the angular stirring velocity at the meniscus. At given EMS design parameters, for example, active stirring length, power input, frequency and distance from the meniscus, the meniscus stirring velocity and depression are proportional to the current supplied to the EMS coils 12, as shown schematically in Figure 3.

[0036] Depending on the factors mentioned above, the meniscus depression for industrial systems can range from approximately 6 to 27 mm, for example.

[0037] In order to counterbalance the stirring velocity at the meniscus area produced by the EMS coils 12, the induction coils 20 of A.C. MSM are energized, to induce a stirring action within the liquid metal at the meniscus opposite to that caused by the EMS coils 12. All the previous considerations with respect to a rotary movement of liquid metal are applicable to the stirring produced by the A.C. MSM coils 20.

[0038] The A.C. MSM coils 20 are substantially smaller and require less power for their operation than the EMS coils 12 due to a much less stirring velocity expected for them to produce to counteract the rotational motion at the meniscus induced by the EMS coils 12.

[0039] The A.C. MSM coils 20 are energized from a power supply common with the EMS coils 12, as shown by single line diagrams in Figure 4. Schemes I and II appearing in Figure 4 show the A.C. MSM and EMS coils 20 and 12 respectively connected in series and, therefore, operating at the time same current and frequency supplied from a common power source. The coil connections presented in Scheme I provide for unidirectional rotating magnetic fields produced by both the EMS and A.C. MSM coils. This mode of operation is employed for enhancing the stirring motion at the meniscus area by the A.C. MSM coils 20 when performing the process of the present invention with the illustrated apparatus. The coil connections presented in Scheme II provide for counter-rotating magnetic fields and cause counter-rotating liquid metal motions in the areas corresponding to the EMS and A.C. MSM coils. In order to provide fine control over stirring action at the meniscus which is determined by the variables of EMS (for example, B-flux), the current level supplied to the A.C. MSM coils 20 may have an independent control from that of the EMS coils 12, as shown by Scheme III in Figure 4. This arrangement allows for independent control of stirring actions of either of the EMS or the A.C. MSM coils regardless of the directional pattem of stirring, namely unirotational or counter-rotational.

[0040] The independent control of stirring motion at the meniscus provided by the use of the A.C. MSM coils 20 enables a greater flexibility of the stirring process control with a possibility of achieving equalization of the opposite stirring motions at the meniscus, and minimization of its depression, as illustrated in Figure 3.

[0041] As seen therein, the line OA corresponds to the meniscus depression caused by the stirring induced by EMS coils 12 without being opposed or added by A.C. MSM stirring. Similarly, the line OD represents meniscus depression associated with isolated stirring action induced by the A.C. MSM coils 20. In order to equalize the stirring velocities caused by the EMS and A.C. MSM coils, the meniscus depression must be of the same value in either of the situations. For example, if the meniscus depression caused by EMS stirring corresponds to the level A, then counter-rotational stirring provided by A.C. MSM stirring should have corresponding meniscus depression, i.e. level D.

[0042] The line OC is the resultant of two opposite stirring actions produced respectively by the EMS and AC MSM coils and equalized at the meniscus.

[0043] The line AB represents the resultant of two unidirectional stirring actions. In this case, the range of stirring enhancement expressed through the meniscus depression can be adjusted in accordance with the casting practice requirements, so that the stirring intensity of EMS is fully utilized.

<u>SUMMARY OF DISCLOSURE</u>

[0044] In summery of this disclosure, there is provided an improved method of controlling disturbance of the free surface of molten steel or other metal or alloy being cast through a mold and caused by electromagnetic stirring applied to the liquid metal, to minimize such disturbance or achieve an enhanced, within a single casting unit stirring motion at the meniscus, by employing an induction modifier in the form of an electromagnetic stirrer adjacent to the location of the meniscus.

Claims

1. A process for continuously casting billets and blooms from molten metal utilising apparatus which comprises a casting mold into which the molten metal is introduced by a process of open pouring of the molten metal, and performing an induction stirring method on the molten metal in the mold, the induction stirring method comprising:

   electromagnetically inducing stirring of molten metal with such intensity as normally to result in turbulence in the molten metal including its

free surface, by applying a first rotating magnetic field to said molten metal, and
applying a second rotating magnetic field produced by a source separate from that providing said first magnetic field and at a location upstream of said stirring, wherein:

the second rotating magnetic field is rotated in the same direction as the direction of rotation of the first field to enhance stirring motion in said free surface area but applies a torque to the molten metal which is lower than that applied by the first field.

2. The process claimed in claim 1, wherein said second rotating magnetic field is provided by a set of induction coils located adjacent the free surface area of said molten metal.

3. The process claimed in claim 1 or 2, wherein the second rotating magnetic field is provided by a set of induction coils controlled by an A.C. current supplied from a power source independent from a power source for a set of induction coils producing said first rotating magnetic field.

4. The process claimed in claim 3 , wherein the sets of induction coils are coils of multi-phase and multipole arrangement spaced peripherally around the mold in order to provide the respective rotating magnetic fields.

5. The process claimed in any one of claims 1 to 4, wherein the second rotating magnetic field is employed to effect stirring motion in the meniscus area sufficient to enhance the stirring motion in the meniscus area effected by the first rotating magnetic field to a level at or near the level of the stirring motion produced by the first rotating magnetic field adjacent its downstream location of application.

6. A process according to any of claims 1 to 5 wherein the molten metal is steel.

Patentansprüche

1. Verfahren zum kontinuierlichen Gießen von Knüppeln und Vorblöcken aus Metallschmelze mittels einer Vorrichtung, die eine Gießform aufweist, in die Metallschmelze durch einen Vorgang des offenen Gießens der Metallschmelze eingeführt wird, und Durchführung eines Induktionsrührens in der Metallschmelze in der Form, wobei das Induktionsrührverfahren umfasst:

elektromagnetisches Induzieren des Rührens von geschmolzenem Metall mit einer Intensität, die normalerweise zu einer Turbulenz in dem geschmolzenen Metall einschließlich seiner freien Oberfläche führt, durch Anlegen eines ersten rotierenden Magnetfeldes an das geschmolzene Metall, und
Anlegen eines zweiten rotierenden Magnetfeldes, das von einer von der das erste Magnetfeld liefernden Quelle getrennten Quelle und an einer Stelle stromaufwärts des Rührens erzeugt wird, wobei das zweite rotierende Magnetfeld in derselben Richtung rotiert wie die Rotationsrichtung des ersten Feldes, um die Rührbewegung im Bereich der freien Oberfläche zu verstärken, aber ein Drehmoment auf das geschmolzene Metall ausübt, welches niedriger ist als das von dem ersten Feld ausgeübte Drehmoment.

2. Verfahren nach Anspruch 1, bei dem das zweite rotierende Magnetfeld durch einen Satz von Induktionsspulen geliefert wird, die nahe der freien Oberfläche der Metallschmelze angeordnet sind.

3. Verfahren nach Anspruch 1 oder 2, bei dem das zweite rotierende Magnetfeld von einem Satz von Induktionsspulen erzeugt wird, die von einem Wechselstrom beaufschlagt sind, der von einer Stromquelle geliefert wird, die unabhängig ist von einer Stromquelle für einen das erste rotierende Magnetfeld erzeugenden Satz von Induktionsspulen.

4. Verfahren nach Anspruch 3, bei dem die Sätze von Induktionsspulen Spulen mit Multiphasen- und Multipol-Anordnung sind, die in Umfangsrichtung beabstandet um die Form herum angeordnet sind, um die jeweiligen rotierenden Magnetfelder zu erzeugen.

5. Verfahren nach einem der Ansprüche 1 bis 4, bei dem das zweite rotierende Magnetfeld dazu dient, eine Rührbewegung in dem Meniskusbereich zu bewirken, die ausreicht, um die von dem ersten rotierenden Magnetfeld in dem Meniskusbereich bewirkte Rührbewegung auf ein Niveau anzuheben, das bei oder nahe dem Niveau der Rührbewegung liegt, die von dem ersten rotierenden Magnetfeld an seiner stromabwärts liegenden Aufbringungsstelle erzeugt wird.

6. Verfahren nach einem der Ansprüche 1 bis 5, bei dem die Metallschmelze Stahl ist.

Revendications

1. Un procédé pour mouler en continu des billettes et des lingots épais (blooms) à partir de métaux fondus faisant emploi d'un moule de coulée dans lequel le métal fondu est introduit par un procédé d'alimentation ouverte du métal fondu avec mise en oeuvre d'un procédé d'agitation en continu du métal fondu dans le moule, le procédé d'agitation par induction comprenant:

- le brassage par induction électromagnétique du métal fondu avec une intensité telle qu'on obtient normalement une turbulence du métal fondu y compris de sa surface libre par application audit métal fondu d'un premier champ magnétique tournant, et
- l'application d'un second champ magnétique tournant, obtenu par une source distincte de celle qui produit ledit premier champ magnétique et à un endroit en amont de ladite agitation,

dans lequel le second champ magnétique tournant tourne selon la même direction que la direction de rotation du premier champ magnétique tournant, pour augmenter le mouvement d'agitation dans la zone de ladite surface libre mais exerce une action de couple sur le métal fondu qui est inférieure à celle exercée par le premier champ.

2. Le procédé selon la revendication 1, dans lequel ledit second champ magnétique tournant est appliqué au moyen d'un jeu de bobines d'induction en un endroit adjacent à la zone de la surface libre dudit métal fondu.

3. Le procédé selon la revendication 1 ou 2, dans lequel le second champ magnétique tournant est produit par un jeu de bobines d'induction contrôlées par un courant alternatif, alimentées par une source de puissance indépendante par rapport à la source de puissance pour le jeu de bobines d'induction produisant ledit premier champ magnétique tournant.

4. Le procédé selon la revendication 3, dans lequel les jeux de bobines d'induction sont des bobines à disposition multiphase et multipôle écartées périphériquement autour de la zone du métal fondu afin de produire les champs magnétiques tournants respectifs.

5. Le procédé selon l'une quelconque des revendications 1 à 4, dans lequel le second champ magnétique tournant est utilisé pour obtenir un mouvement d'agitation dans la zone du ménisque suffisant pour augmenter, dans ladite zone du ménisque, le mouvement d'agitation produit par le premier champ magnétique tournant à un niveau, ou au voisinage dudit niveau, du mouvement d'agitation produit par le premier champ magnétique tournant en un emplacement adjacent à sa position d'application en aval.

6. Le procédé selon l'une quelconque des revendications 1 à 5, dans lequel le métal liquide est l'acier.

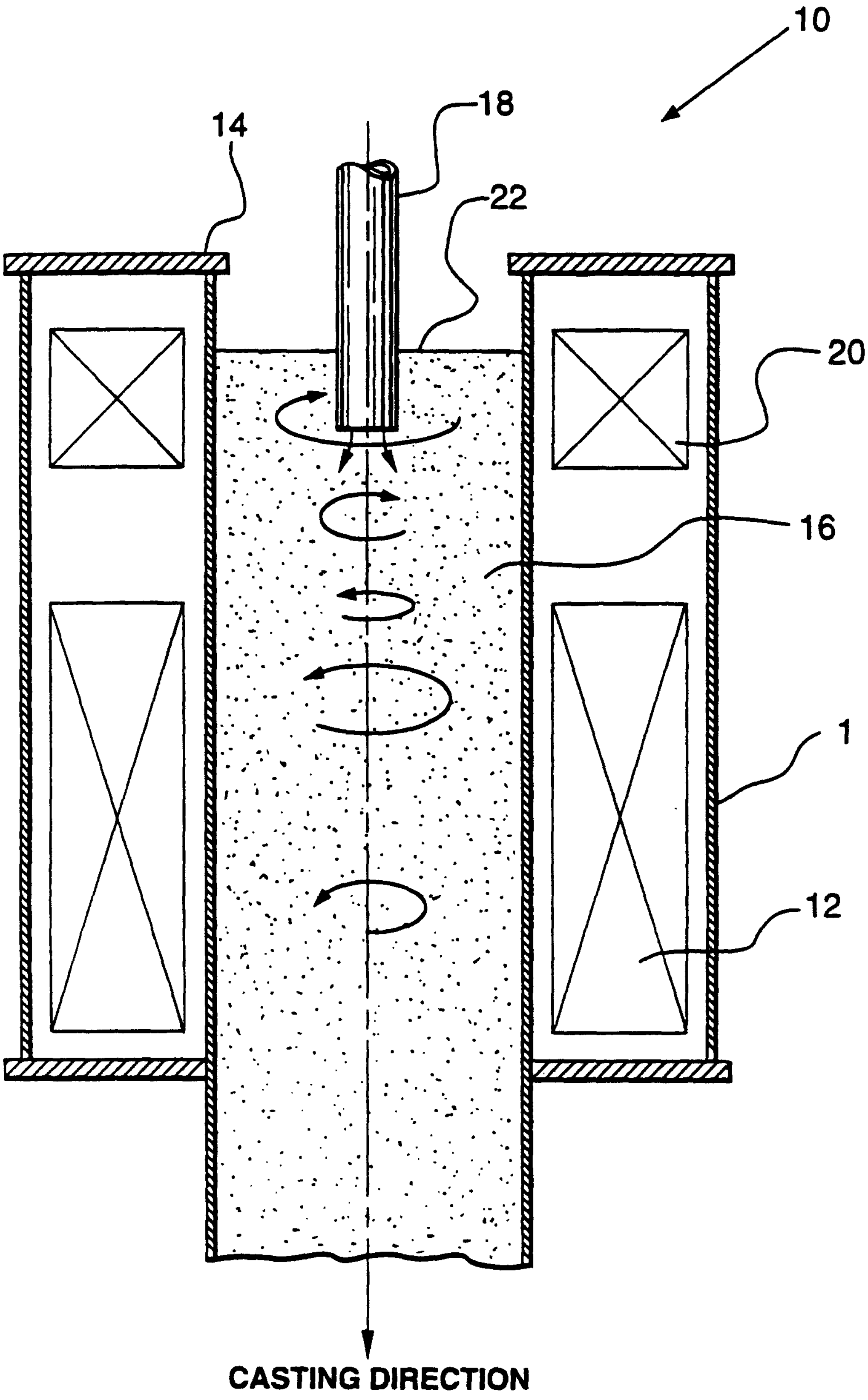

FIG.1.

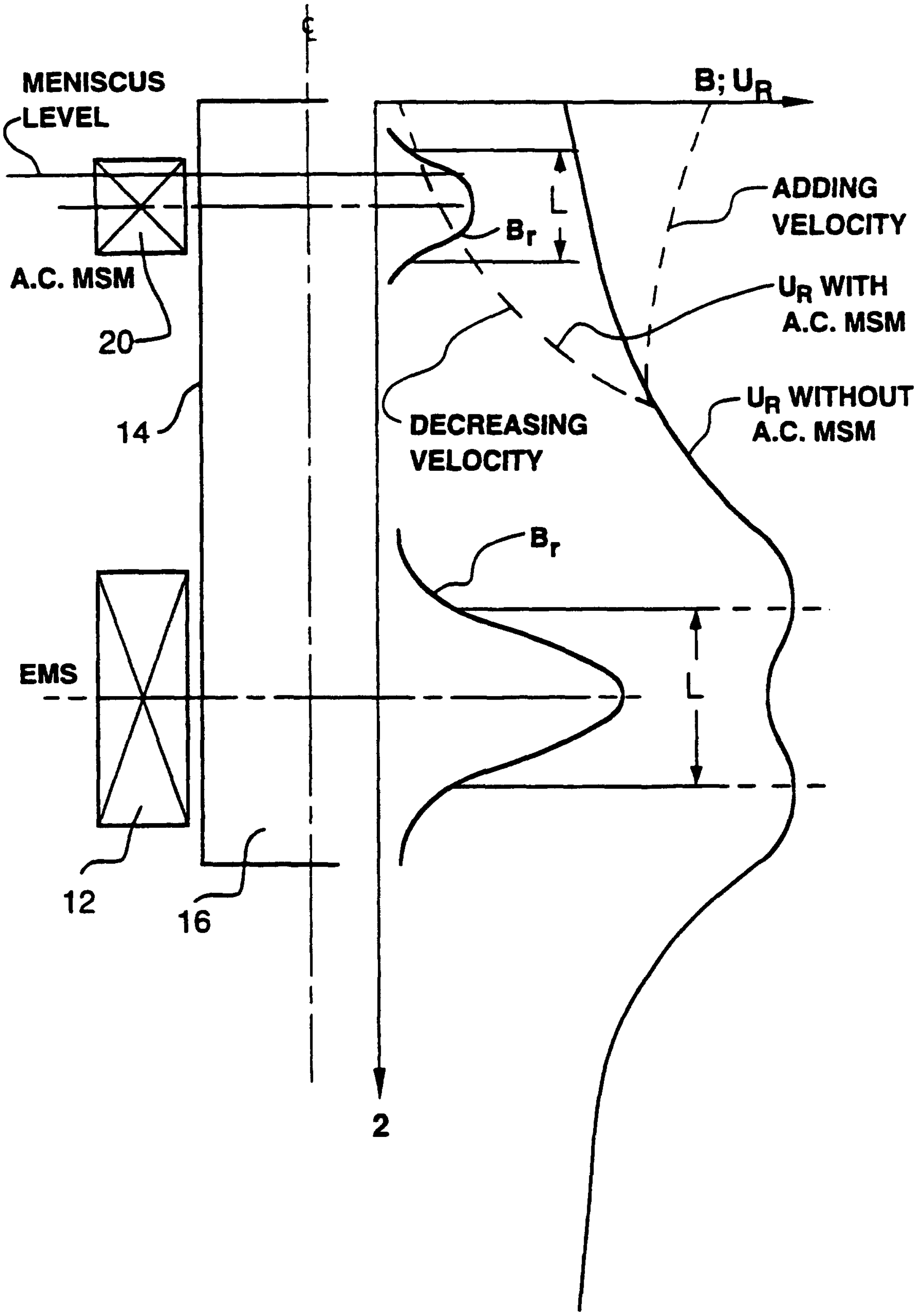
MENISCUS LEVEL
A.C. MSM
20
14
EMS
12
16
B; U_R
L
B_r
ADDING VELOCITY
U_R WITH A.C. MSM
DECREASING VELOCITY
U_R WITHOUT A.C. MSM
B_r
L
2

FIG.2.

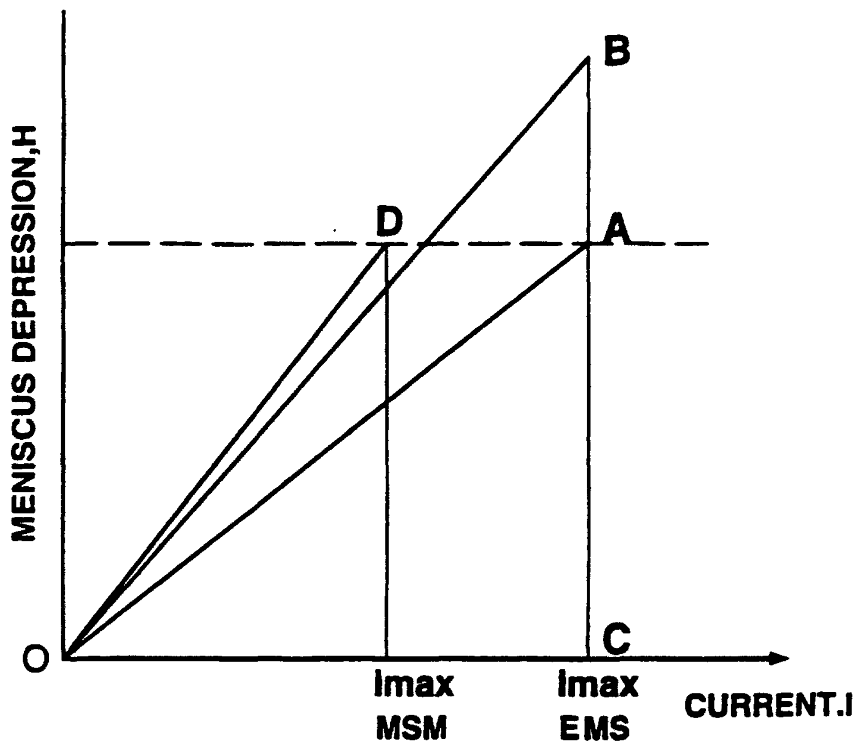
MENISCUS DEPRESSION,H
B
D
A
O
C
Imax
MSM
Imax
EMS
CURRENT.I

FIG.3.

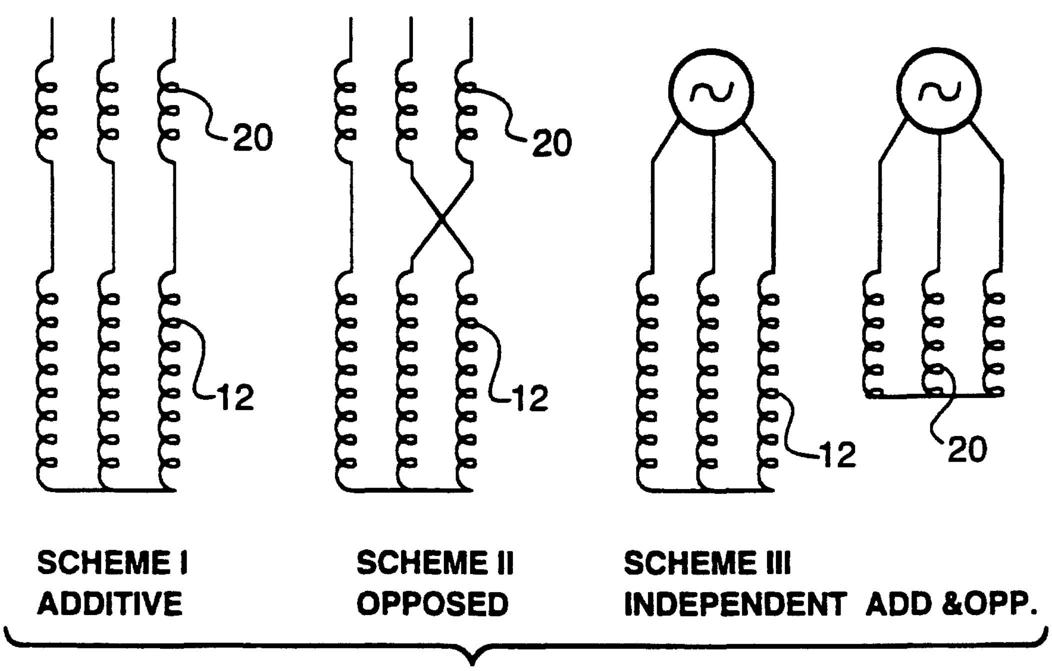
20
12
20
12
12
20
SCHEME I
ADDITIVE
SCHEME II
OPPOSED
SCHEME III
INDEPENDENT
ADD &OPP.

FIG.4.

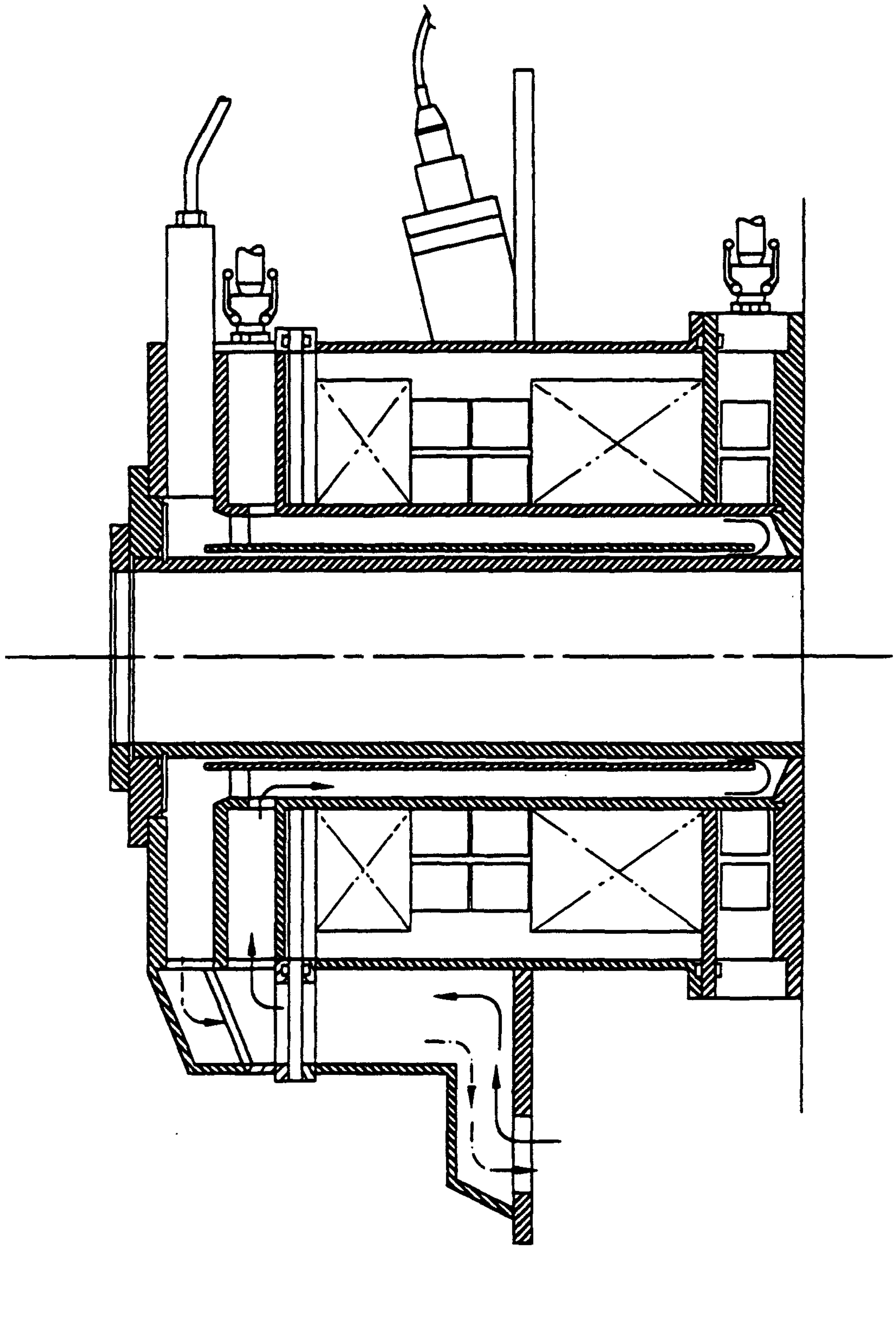

FIG.5.