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(54) METHOD AND APPARATUS FOR THE CONTINUOUS CASTING OF ALUMINIUM ALLOYS

(57) The invention relates to metallurgy and concerns the continuous and semicontinuous casting of metal, in particular aluminium. The apparatus comprises a crystallizer which is open at both ends in the casting direction, means for feeding a melt into the crystallizer, and two electromagnetic inductors. The inductors are mounted primarily symmetrically to each other relative to the vertical plane of symmetry of a billet. In order to induce a mixing motion in the melt, the inductors generate two electromagnetic fields running in opposite directions along the billet extraction direction. The area of action of the electromagnetic fields encloses the entire liquid core. This makes it possible to flexibly control the mixing speed, the flow structure and turbulization capacity along the entire liquid core of the crystallizing aluminium slab.

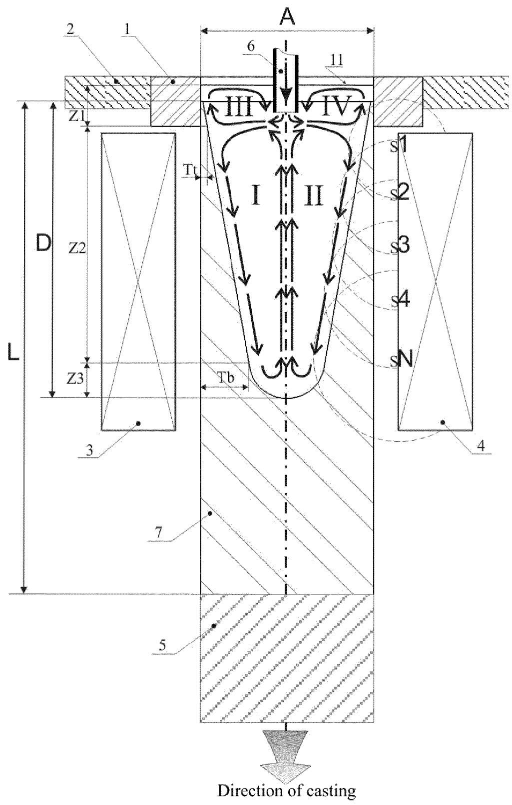

Fig. 1

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Description

Field of the Invention

[0001] The invention relates to continuous casting of metals, in particular aluminium.

Background of the Invention

[0002] It is known an invention "A method and apparatus for electromagnetic stirring of molten metals at an advanced stage of solidification" (Patent WO2009117803, publication date: 2009.10.01), wherein an apparatus comprises one or more multiphase inductors arranged along a billet and providing the stirring of a liquid core about the axis of the billet and, generating at least a first and a second rotating magnetic fields differing in frequency about an axis of solidifying molten metal. The rotating magnetic fields from different inductors superpose providing, in addition to the main stirring, an increased turbulent motion that provides efficient heat and mass exchange at the border of crystallization and obtaining equi-axial dendrites and a more uniform structure over the cross-section of the cast product.

[0003] The main shortcoming of such method and apparatus as applied to aluminium slabs is impossibility to generate stirring action coinciding in character with the directions of flows in natural convection in a liquid core of an aluminium slab. According to said method within the creation of rotating stirring in a billet about its axis it is created a circular motion of metal which due to elongated profile of the slab results substantially different conditions of cooling of wide and narrow sides. Besides, taking into account that the depth of the liquid core D is comparable with the dimensions of the cross sections A and B, a rotation along the whole height of the liquid core will be created, resulting a flow similar to a funnel breaking the meniscus form, and an intensive burling in the meniscus area.

[0004] It is known an invention "A method and apparatus for flow control in a crystallizer for continuous casting of slabs" (Patent RU 2325245, publication date: 27.05.2008), wherein the molten metal is fed into crystallizer through immersed pouring nozzle provided with lateral outlet holes turned towards the smaller faces of the crystallizer. Configuration of the molten metal in the crystallizer may be naturally set into single loop, double loop or unstable loop modes. Sliding magnetic fields are generated along the whole cast product to induce, or stabilize a permanent configuration of flow in the double loop mode. Or the magnetic fields are induced only in case the configuration of flows hasn't naturally set into the double loop mode. At that, the used inductors generate electromagnetic field at a single frequency.

[0005] The principal shortcoming of such method and apparatus as applied to aluminium slabs is non-optimal use of inductor that generates electromagnetic field at a single frequency from the point of control of flows in liquid core making it impossible to flexibly control the flow structure in the liquid core.

[0006] It is known an invention "A method of electromagnetic stirring for continuous casting of metal products of elongated cross-section" (Patent RU 2357833, publication date: 10.06.2009) wherein in order to promote liquid metal exchange at the solidification well between the secondary cooling zone and the crystallizer, a longitudinal metal flow localized in the central region of the cast product is forcibly created by two opposed collinear currents providing four-foil liquid metal circulation in a form of two upper and two lower flows forming the foils, wherein two upper ones reach in the crystallizer the currents exiting through the outlet ports of the immersed pouring nozzle. The invention makes it possible to provide general stirring of metal along the whole metallurgical length providing thermal and chemical uniformity between the upper and lower parts of the liquid well without detriment to positive effects characteristic to stirring in a crystallizer and secondary cooling zone, without disturbing and even improving the mode of local flow in the crystallizer.

[0007] The principal shortcomings of such method and apparatus as applied to aluminium slabs are non-optimal use of inductor generating the electromagnetic field at a single frequency from the point of control of flows in the liquid core, impossibility to flexibly control the structure of flows in the liquid core. In addition to the shortcoming of limited control over the structure and turbulization of flows, the alternating magnetic field of a single frequency is commonly generated with a view to efficiently create main streams in the liquid core and doesn't take into account a possibility of mechanical resonance of liquid oscillations.

[0008] Said invention is the closest to the claimed one, i.e. is the prior art.

Description of the Invention

[0009] The object of the present invention is to provide flexible control over the rate of stirring, the flow structure and turbulization capacity along the entire liquid core of the crystallizing aluminium slab.

[0010] The steel continuous casting operations commonly use a practice of melted steel stirring in the area of crystallizer of the apparatus for continuous steel casting and in the area of liquid core of a steel ingot by a low-frequency electromagnetic field of alternating current applied from outside. At present, according to patents FR 03 12555 (RU2357833) and FR 02 12706 (RU 2325245), for steel slabs casting it is used one or more pairs of inductors arranged in various zones along the whole length of liquid core of a steel ingot with a length of up to several meters, wherein each inductor may induce an alternating electromagnetic field at different frequencies according to the desired action on the metal. That provides levelling of chemical composition along the entire melted metal and increases heat exchange in the area of crystallization providing more qualitative and uniform structure of the produced ingot. To provide stability to the free surface of the melt commonly called meniscus, inductors that generate permanent or alternating magnetic fields in the area of pouring nozzle are used. However, in case of continuous steel casting the depth of the liquid core D is much greater than the width of the ingot A and may constitute more than 10 meters for the ingot with the section of 2000 mm x 600 mm. Besides, while creating a stirring action in the liquid core of the steel ingot, they generally try to create a rotational motion of the melted metal about the direction of ingot extraction or in the plane being perpendicular to the direction of extraction mainly due to the fact that the depth of the liquid core D exceeds the width of the ingot A, and due to the radiussed form of the ingot, making it difficult to create symmetric circulation of metal according to the double loop model.

[0011] While designing the inductors intended for the steel ingot liquid core stirring arranged along the ingot, they proceed from the fact that the thickness of the skin of the ingot on one end of the inductor Tb changes slightly and practically corresponds to the thickness of the skin on the other end of the inductor Tt, i.e. Tb - Tb. Taking that into account, for the liquid core stirring in a particular location they use an inductor (mainly a linear induction machine) that generates travelling or rotating field of a single frequency, and disregard the difference in magnetic field attenuation due to different thickness of the ingot skin along the length of the inductor. To determine the thickness of the layer from the wall of the ingot where the main effective area of induced electromagnetic forces is concentrated, it is used a commonly used term "electromagnetic field penetration depth» or "skin-layer" where 86 % of power released in the melt is concentrated, which skin thickness in the simplest case for pulsating field is determined as

$$\Delta = \sqrt{\frac{2}{\gamma \mu_a \omega}}, \qquad (1)$$

where γ - is a specific conductivity (Ohm·m) $)^{-1}$; μ_a - is an absolute permeability, (Henry/m); ω - an angular frequency (rad/sec) being related to the cyclic frequency f by the relation $\omega = 2 \cdot \pi \cdot f$.

[0012] However, in the casting of aluminium slabs of rectangular section in the direct chill crystallizer by a method of semicontinuous casting, for example, with the use of vertical molding machine by Wagstaff, the process conditions considerably differ from the steel ingot casting. That is, for an aluminium slab having section A x B - 0,6 x 2,3 m, the depth of the liquid core constitutes D - 1,2 m with the length of the slab L - 11 m, thus D is comparable with A, i.e. D - A. That is mainly conditioned by the fact that aluminium possesses considerably greater heat conductivity as compared to iron. Besides, the thickness of the aluminium slab skin considerably differs on the portions at the outlet of the crystallizer - Tt and at the area of the bottom of the liquid core - Tb. Thus for an aluminium slab having section of 2,3 m x 0,6 m, corresponding Tt - 3 cm, Tb - 20 cm, and their relation Tb/Tt - 6,6. According to formulae (1), the frequency f to which the depth of electromagnetic field penetration into the solid aluminium corresponds, for aluminium thickness Tt - 3 constitutes f - 6 Hz, for aluminium thickness Tb - 20 cm constitutes f - 0,17 Hz. Taking into account high electro-conductivity of solid aluminium, it's obvious that the use of an inductor that generates electromagnetic field at a single frequency is not optimal from the point of control over the flows in the liquid core. Thus, in case of use of sliding electromagnetic field acting on the entire liquid core along the length D under the condition that this field provides effective stirring in the area of the bottom of the liquid core, the development of excessive stirring in the area of meniscus is obvious, being a far undesirable phenomenon. On the contrary, in case of applying a similar sliding magnetic field which value doesn't create excessive stirring in the area of the meniscus, the efficiency of stirring in the area of the bottom of the liquid core will be insufficient due to a high screening effect of the solid skin of the billet having thickness Tb.

[0013] In addition to the shortcoming said afore, the use of alternating magnetic field of a single frequency does not provide a possibility to flexibly control the structure of flows in the liquid core. Of course, it is possible to control the direction of rotation of vortices by reversing the direction of magnetic field motion, or shifting the location of main vortices due to magnetic strength and its frequency, however, in whole, at present there are no methods and apparatuses for slabs which make it possible to organize flexible control over the structure of hydrodynamic fields such that the sliding magnetic field of a single frequency acting along the entire area of the liquid core D would create essentially different flows in the liquid core, for example, would create a flow not only in the form of a single or double loop or one vortex, but also a large array of highly perturbed flows with flexible control over the number of vortices and the location thereof.

[0014] In addition to the shortcoming of limited control over the flow structure and turbulization, an alternating magnetic field of a single frequency is usually created in order to efficiently create main flows in the melt of the liquid core and doesn't take into account a possibility of mechanical resonance of liquid oscillations. Nonetheless, it is known that in case of application to a body or a liquid volume of forces at the frequency of natural oscillation, then the oscillations in the body or in the liquid volume greatly increase and the mechanical system becomes especially sensitive to force application at such frequency. At that, the liquid volume under the force acting with the resonance frequency is characterized not only by the fact that the rate of flows in the liquid volume increases with the minimum energy consumption, but also by the fact that the pulsation constituent of oscillation increases resulting an increase of oscillations of turbulent fluctuations and as consequence an increase of the share of turbulent motion.

[0015] However, in case of use of multi-frequency electromagnetic field it becomes possible to organize efficient stirring in all liquid cores of all layers of the billet. A major problem in the casting of oversized aluminium billets is the problem of difference of the billet structure at the start portion and at the end portion of the billet, arising mainly because of the conditions of crystallization at the beginning of the casting process when the casting bottom is in the crystallizer and begins to move downwards, and at the end of the casting process when the casting process is deemed to be steady, are too much different.

[0016] Indeed, at the beginning of the casting process the thickness of the metal solid skin on the billet side face is small and, the liquid core is separated from the casting bottom by a short thickness of metal predetermining special thermal conditions of crystallization at that stage where the heat removal through the casting bottom may prevail or be comparable with the heat transfer through the billet side faces. On the contrary, within further casting process the form of the liquid core elongates, the thickness of solid aluminium between the liquid core and the casting bottom increases resulting the prevalence of the heat removal through the billet side faces over the heat removal through the billet bottom portion.

[0017] The object of the claimed technical solution is to provide a possibility to flexibly control the rate of stirring, the flow structure and turbulization along the entire volume of the liquid core of crystallizing aluminium slab.

[0018] The posed technical problem is solved by an apparatus for continuous or semicontinuous casting of aluminium slabs comprising a crystallizer that is open at both ends in the casting direction, means for feeding the melt into the crystallizer, at least two electromagnetic inductors adapted to induce stirring motion in the crystallizer, wherein said inductors are arranged symmetrically to each other relative to the vertical plane of symmetry of the billet, wherein each inductor is adapted to generate at least two electromagnetic fields travelling in opposite directions along the billet extraction direction, the area of action of the fields covers the entire liquid core.

[0019] Besides, the inductor is adapted to generate at least a frequency of one of said travelling electromagnetic fields that is close or coincides with the natural resonance frequency of mechanical oscillations of the volume of the liquid core.

[0020] Besides, the inductor is adapted to create at least a travelling electromagnetic field increasing over the depth of the liquid core D with distance from the crystallizer to the bottom of the core, wherein the relation between the strength of electromagnetic field in the areas of utmost upper and lower portions of the inductor exceeds 2.

[0021] Besides, the increase of the value of electromagnetic field along the inductor over the depth of the liquid core D proceeds according to linear, power or exponential dependencies.

[0022] Besides, the inductor is adapted to generate at least one electromagnetic field with a frequency decreasing over the depth of the liquid core D with distance from the crystallizer to the bottom of the core.

[0023] Besides, the frequency of the electromagnetic fields induced by inductors does not exceed 6 Hz.

[0024] Besides, at least one inductor arranged within the space between at least two billets is adapted to provide liquid core stirring in at least two slabs, between which it is arranged.

[0025] Besides, at least one inductor arranged along the outer edge that covers at least two billets is adapted to provide liquid core stirring in such billets.

[0026] Besides, the directions of motion of travelling electromagnetic fields induced by one inductor coincide.

[0027] Besides, said inductors generate travelling electromagnetic fields being symmetric relative to the billet axis.

[0028] The posed technical problem is solved by a method for continuous or semicontinuous casting of aluminium alloys comprising exposure the liquid metal to electromagnetic field via at least two electromagnetic inductors providing electromagnetic stirring of the liquid core of the billet by at least two electromagnetic fields travelling along the billet extraction direction, wherein each said electromagnetic field is generated at different frequencies which directions of motion are opposite, and which area of action on the liquid core covers the entire depth of the liquid core.

[0029] Besides, at least the frequency of one of said travelling electromagnetic fields is selected to be close to or coinciding with the natural resonance frequency of mechanical oscillations of the volume of the liquid core.

[0030] Besides, it is created a travelling electromagnetic field increasing over the depth of the liquid core D with distance from the crystallizer to the bottom of the core, wherein the relation between the value of electromagnetic field in the area of utmost upper and lower portions exceeds 2.

[0031] Besides, the increase of the value of electromagnetic field along the inductor over the depth of the liquid core D proceeds according to linear, power or exponential relations.

[0032] Besides, the electromagnetic fields are selected with a frequency decreasing over the depth of the liquid core D with distance from the crystallizer to the bottom of the core.

[0033] Besides, the frequency of the electromagnetic fields generated by inductors is selected as not exceeding 6 Hz.

[0034] Besides, the directions of motion of travelling electromagnetic fields induced by one inductor are selected as coinciding.

[0035] Besides, said travelling electromagnetic fields are symmetric relative to the vertical axis of the billet.

Brief Description of the Drawings

[0036]

Fig. 1 - schematically shows the arrangement of inductors relative to the billet in section. It also shows the increase of the value of magnetic field of the sources from s1 to sN with distance from top to down, and the main dimensions are given.

Fig. 2 - shows the arrangement of inductors in three-dimensional space and the main dimensions defining the section are given.

Fig. 3 - shows the action of the inductor arranged in the casting bottom on the liquid core within the casting process at the initial stage of a billet shaping. The travelling electromagnetic field is generated by serial connection of the magnetic field sources s1 ... sn. It also shows zonal connection of side inductors, beginning from zone 1 to zone N, with increase of the billet.

Fig. 4 - shows the main flows arising upon the action of the travelling electromagnetic fields induced by the inductor arranged in the casting bottom, wherein: Fig. 4A) shows the character of flows arising in case of two counter travelling fields; Fig. 4B) shows the character of flows arising in case of two reversed fields; Fig 4C shows the character of flows in case of only one travelling field which penetration depth provides the coverage of layers of the liquid only in the proximity of the casting bottom; Fig. 4D shows the character of flows in case of only one travelling field which penetration depth provides the coverage of the layers of the liquid in the major portion of the liquid volume.

Fig. 5 - shows as an example a scheme of an installation of two tree-phase linear induction machines symmetrically arranged about the axis of the billet.

Fig. 6 - shows the principle of creation of rotative moment and as consequence a vortex in the melt in case of imposition of two travelling electromagnetic fields at different frequencies, wherein Fig. 6A) shows the creation of vortex E in case of imposition of counter travelling fields; Fig. 6B) shows the creation of vortex E in case of imposition of consonant travelling fields, one of which produces greater power in the melt in absolute magnitude than the other one.

Fig. 7 shows as an example a possible scheme of arrangement of inductors relative to several billets casted simultaneously.

Fig. 8 - schematically shows the arrangement of integrated forces F_1 and F_2 in the liquid core that generate at different frequencies the travelling electromagnetic fields Field_1 and Field_2 respectively.

Fig. 9 - schematically shows the controlled splitting of the main four-loop flow into several loops, wherein: Fig. 9A) shows vertical splitting of the loops; Fig. 9B) shows horizontal splitting of the loops.

Preferred Embodiment of the Invention

[0037] An apparatus for continuous and semicontinuous casting of aluminium alloys (Fig. 1) comprises a crystallizer 1 that is open at both ends in the direction of casting, means 6 for feeding the melt into the crystallizer, at least two electromagnetic inductors 3, 4 adapted to induce stirring motion in the melt, wherein said inductors 3, 4 are arranged mainly symmetric to each other relative to the vertical plane of symmetry of the billet, the installation is equipped with a device to adjust the position of inductors 3, 4 that makes it possible to move and position the inductors relative to the billet and crystallizer in any direction, each inductor 3 and 4 is adapted to generate at least two electromagnetic fields travelling in opposite directions along the billet extraction direction, the area of action of the fields covers the entire liquid core, the casting bottom 5, the billet 7, the casting table 2.

[0038] Besides, the inductor 3, 4 is adapted to generate at least a frequency of one of said travelling electromagnetic fields that is close to or coinciding with the natural resonance frequency of mechanical oscillations of the liquid core volume.

[0039] Besides, the inductor 3, 4 is adapted to generate at least a travelling electromagnetic field increasing over the depth of the liquid core B with distance from the crystallizer to the bottom of the core, wherein the relation between the value of electromagnetic field in the areas of utmost upper and lower portions of the inductor exceeds 2.

[0040] Besides, the increase of the value of electromagnetic field along the inductor 3, 4 over the depth of the liquid core D proceeds according to linear, power or exponential dependencies.

[0041] Besides, the inductor 3, 4 is adapted to generate at least one electromagnetic field with a frequency decreasing over the depth of the liquid core D with distance from the crystallizer to the bottom of the core.

[0042] Besides, the frequency of the electromagnetic fields generated by the inductors 3, 4 does not exceed 6.

[0043] Besides, at least one inductor arranged within the space between at least two billets is adapted to provide liquid core stirring in at least two billets between which it is arranged.

[0044] Besides, at least one inductor 3, 4 arranged along the outer edge that covers at least two billets is adapted to provide liquid core stirring in such billets.

[0045] Besides, the directions of motion of travelling electromagnetic fields induced by one inductor 3 or 4 coincide.

[0046] Besides, said inductors generate travelling electromagnetic fields being symmetric relative to the axis of the billet 7.

[0047] Fig. 2 - shows additional inductors 8, 9.

Implementation Example of the Method

[0048] According to Fig. 1 and Fig. 2, the molten metal is fed into the zone of liquid melt in at least one crystallizer 1 that is open at both ends in the direction of casting via at least one means 6 immersed into the melt, or at least one jet of metal. Within the process of casting bottom 5 immersion and molten metal cooling by heat transfer through the walls of the crystallizer, side faces of the billet 7 and the material of the casting bottom, the crystallization of the billet occurs with its shaping and formation of its liquid core. The casting bottom 5 is equipped with at least one source of pulsating and travelling magnetic field disposed within or directly below it (not shown) providing the liquid core stirring at the initial stage of casting and billet shaping. The casting bottom 5 is arranged and secured to a platform that moves downwards under the action of lowerator, for example hydraulic cylinder, or is put in downward motion under the action of electromagnetic forces, for example, under the action of travelling electromagnetic field. At least one pair of inductors of alternating magnetic field 3 and 4 (8 and 9) is arranged on the opposite sides of the casted billet 7, that are arranged mainly symmetrically relative to the vertical plane of symmetry on the opposite sides of the billet and stir the liquid core according to the trajectories 10 (Fig. 2). In the context of the present invention, the inductors of alternating electromagnetic field 3 and 4 and the inductor arranged in the casting bottom 5, are an array of elementary sources of alternating magnetic field and functionally may be implemented as linear induction machines or as an array of travelling or rotating permanent magnets.

[0049] According to Fig. 4, within the billet casting process, at the beginning of the process, they use an alternating field generated by the inductor arranged in the casting bottom or under the casting bottom 5. Such alternating field provides efficient metal stirring in the liquid core being formed at the initial stage of casting.

[0050] At that, due to use of varying order of connection of the sources of alternating electromagnetic field in the inductor - S1, S2...Sn, the desired travelling and pulsating magnetic fields are created.

[0051] According to Fig. 4, the most obvious hydrodynamic flows created in case of use of the combination of oppositely directed fields are:

- A scheme of natural circulation of 4 main vortices - I, II, III, IV (Fig. 3). These flows are similar to the steady flows at natural convection and are created by at least two counter travelling electromagnetic fields - Field_1 and Field_2.

- A scheme of abnormal circulation of 4 main vortices - I, II, III, IV (Fig. 3B). These flows are similar to the steady flows at natural convection but are opposite in direction and are created by at least two counter travelling electromagnetic fields - Field_1 and Field_2.

- A scheme of asymmetric circulation of 3 main vortices - I, II, III (Fig. 3C). This flow structure is created by a relatively weak travelling electromagnetic field Field_1, that directly acts on the layers of the melt in the vicinity of the bottom of the liquid core.

- A scheme of asymmetric circulation of 1 main vortex - I (Fig. 4D). This flow structure is created by a relatively intensive travelling electromagnetic field Field_1 that directly acts on the layers of the melt occupying no less than a half of the height of the liquid core from below.

[0052] As the billet forms, at least one pair of inductors 3 and 4 creating alternating travelling (sliding) magnetic field along the direction of the billet extraction is connected. The magnetic field generated by the inductors acts on the liquid core along the entire height D. At that, according to Fig. 3, the inductors 3 and 4 may be connected by zones - zone 1, zone 2 ...zone N, or may be implemented as segments and be connected as the casting advances and the liquid core increases.

[0053] In the result of action of the alternating electromagnetic field the vortex currents arise and consequently the field of Ampere forces, that puts in motion the molten metal.

[0054] The electromagnetic field generated by each inductor possesses the following characteristics (features) that are implemented simultaneously or separately:

1. The magnetic induction of magnetic field increases over the depth of the liquid core D with distance from the crystallizer to the bottom of the core. The dependence of the growth of the magnetic induction on the distance may be proportional, power or exponential;

2. At least one frequency is present in the composition of the field;

3. At least one natural resonance frequency of oscillations of the billet liquid core, or the one close to it is present in the composition of the field;

4. At least one natural resonance frequency of oscillations inherent to the border of crystallization, or the one close to it is present in the composition of the field;

5. At least one natural resonance frequency of oscillations inherent to a solid billet, or the one close to it is present in the composition of the field;

6. The frequency of oscillations of electromagnetic field decreases over the depth of the liquid core D with distance from the crystallizer to the bottom of the core. The dependence of the growth of the magnetic induction on the distance may be linear, power or exponential.

[0055] Said characteristics of the electromagnetic field may be implemented by the following acceptable technical solutions:

1. Use of two- or multiphase induction machine which windings are coupled to two-or multiphase single-frequency power source such that the alternating electromagnetic field generated at one end of the machine is less than the one generated at the other end and, the generated field increases from one end of the machine to the other one. For example, Fig. 5 shows the simplest three-phase inductors 1 and 2, each of which is capable to create electromagnetic field increasing from the upper edge to the lower one in the case the inductor is coupled to asymmetric three-phase voltage or current system. At that the upper coil 3 through which the lowest current flows, generates the lowest magnetic flow as compared to the middle coil 4, where the current is higher than in the coil 3, but lower than in the coil 5, where the highest current flows and that generates the highest magnetic flow.

2. Use of two- or multiphase linear induction machine, which windings are coupled to two- or multiphase multi-frequency power source, such that the father from the crystallizer downwards along the billet the coil is, the lower is the frequency of current or voltage pulsation therein.

3. Use of two- or multiphase linear induction machine, deliberately designed as asymmetric, such that when the coils are coupled to two- or multiphase single-frequency power source an electromagnetic field increasing from one edge to the other one is generated along the machine. The simplest example of such deliberately asymmetric inductor is an inductor wherein the father from the crystallizer downwards along the billet the coil is, the higher is the number of windings or the pole pitch.

4. Rotating the permanent magnets arranged in a row along the billet. At that, the value of the magnetic field of permanent magnets increases from the crystallizer with distance from the crystallizer to the bottom of the core. At the same time or separately, the frequency of rotation of permanent magnets may decrease from the crystallizer with distance from the crystallizer to the bottom of the core.

[0056] The creation of and control over vortex structure of flows due to use of at least two travelling fields are possible with the use of two principles stated below.

[0057] The first principle - a principle of opposite fields, uses the imposition of at least two counter travelling electromagnetic fields generated by one inductor at different frequency providing arising of vortical hydrodynamic flows. Due to different frequency of each field, the depth of penetration of each field differs making it possible to obtain resulting force for each field being arranged at different distance from the crystallization border, but at the same time at the same horizontal level of the liquid core.

[0058] Thus, it is possible to obtain at least one pair of forces from at least two multi-frequency fields making it possible to create a vortex motion in the melt.

[0059] Said principle may be explained in more details in the following way.

[0060] According to Fig. 6, the travelling high frequency electromagnetic field sliding (moving) to the bottom of the billet creates in the horizontal layer of the liquid core t the Ampere force distribution at section ab. In whole, the distribution of forces at that section may be approximated by force F_1 applied in the center of gravity of a figure created by the field of forces at section ab.

[0061] In turn, the low-frequency travelling electromagnetic field being opposite to the high-frequency one creates in the layer 1 the Ampere force distribution at section cd. In whole, the distribution of forces at that section may be approximated by force F_2 applied in the center of gravity of a figure created by the field of forces at section cd.

[0062] In the result of interaction of a pair of forces F_1 and F_2 a hydrodynamic vortex E is created (Fig. 6A).

[0063] The second principle - a principle of coinciding fields uses the imposition of at least two travelling coinciding in the direction of motion electromagnetic fields generated by one inductor at different frequency, providing creation of vortical hydrodynamic flows.

[0064] According to Fig. 6B, as opposed to the method mentioned above, the resulting forces are codirectional, but differ by the value providing creation of a pair of forces and rotative moment that creates hydrodynamic vortex E (Fig. 6.B).

[0065] For the majority of casted aluminium rectangular billets the configuration of melted metal flows in the liquid core at natural convection is commonly set into the single loop mode or double loop mode with two main vortices I and II (Fig. 1) in the vertical plane of the billet symmetry that form the main single loop and two secondary upper vortices - III and IV (Fig. 1) which in combination with the single loop create the melt circulation according to the double loop scheme. Depending on the depth of immersion of the means for metal pouring and its delivery rate it is possible to set the metal circulation mode both while in the double loop mode as well as in the single loop mode.

[0066] However, despite different number of vortices in both circulation schemes two lower vortices that create the single loop play the primary role.

[0067] Due to imposition of at least two mutually opposing travelling fields Field_1 and Field_2 generated by one inductor at different frequencies (Fig. 8), different forces F_1 and F_2 are created in different vertical layers that create rotative moment and provide vertical splitting of at least two main vortices I and II (Fig. 1) and increase of the number of vortices throughout the billet width. At that, a flow structure similar to the one shown at Fig. 9A is created. In case of increase of the number of multi-frequency travelling fields, the number of vortices increases respectively. The increase of pulsating constituent of the Ampere force acting in perpendicular to the billet axis results horizontal splitting of vortices and increase of the number of vortices over the depth of the liquid core as shown at Fig. 9B. Such action may be created by the inductor in different manner, for example by generating a standing wave along the height of the core D, or by creating local zones throughout the height D, where the normal component of Lorentz force generated in the melt and directed to the billet axis considerably exceeds the tangential component resulting vortex splitting in that zone. The creation of said zones is implemented by the sources that generate pulsating electromagnetic field and which are arranged in the inductor in the place of arrangement of such zones. Such sources of pulsating field may be separate windings connected when appropriate.

[0068] The created horizontal and vertical splitting of the main vortices may be intermittent, but may be permanent. According to Fig. 7, in order to use the space in the installation for continuous casting to the maximum extent possible the inductors may be arranged according to the following configurations:

1. At least one inductor 4 arranged within the space between at least two billets 7 provides liquid core stirring in at least two billets between which it is arranged.

2. At least one inductor 9 arranged along the outer edge covering at least two billets provides liquid core stirring in such billets.

[0069] The suggested apparatus has the following advantages over the known ones:

- stirring the melt throughout the entire volume of the liquid core by symmetrical flow structure relative to the vertical plane of the billet symmetry providing symmetric conditions of crystallization and lack of mechanical deformations of the billet caused by asymmetry of temperature-induced stresses in the billet;

- a possibility to create circulating flows in the liquid core being different in the number of loops and structure by multi-frequency electromagnetic field and use of resonance frequencies, making it possible to flexibly control the stirring motion in the liquid core.

- simple design solution providing the possibility of liquid core stirring at various thicknesses of the billets by increasing or decreasing the distance between the inductors arranged at both sides of the plane of the billet symmetry.

- decrease of stirring power consumption due to use of resonance frequencies.

Industrial Applicability

[0070] A method for continuous and semicontinuous casting of aluminium alloys and an apparatus for implementation of such method may be used to improve the functional specifications of obtained aluminium billet and to accelerate the process of solidification of the melt by intensive stirring of the melt throughout the entire volume of the liquid core and continuous and semicontinuous casting of aluminium alloys.

Claims

1. An apparatus for continuous or semicontinuous casting of aluminium alloys comprising a crystallizer that is open at both ends in casting direction, means for feeding the melt into the crystallizer, at least two electromagnetic inductors adapted to induce stirring motion in the melt, wherein said inductors are mainly arranged symmetrically to each other relative to the vertical plane of symmetry of the billet, **characterized by** each inductor is adapted to create at least two electromagnetic fields of different frequencies travelling in opposite directions along the direction of billet extraction, and the area of action of the fields covers the entire liquid core.

2. The apparatus of Claim 1 **characterized by** the inductor adapted to generate at least a frequency of one of said travelling electromagnetic fields being close to or coinciding with the natural resonance frequency of mechanical oscillations of the liquid core volume.

3. The apparatus of Claim 1 **characterized by** the inductor is adapted to create at least a travelling electromagnetic field with a magnetic induction increasing over the depth of the liquid core D with distance from the crystallizer to the bottom of the core, wherein the relation between the value of the magnetic induction of magnetic field in the areas of utmost upper and lower portions of the inductor exceeds 2.

4. The apparatus of Claim 3 **characterized by** the increase of the value of the magnetic induction of electromagnetic field along the inductor over the depth of the liquid core D proceeds according to linear, power or exponential dependency.

5. The apparatus of Claim 1 **characterized by** the inductor is adapted with a possibility of generation of at least electromagnetic field with a frequency decreasing over the depth of the liquid core D with distance from the crystallizer to the bottom of the core.

6. The apparatus of Claim 1, wherein the frequency of the electromagnetic fields generated by the inductors does not exceed 6 Hz.

7. The apparatus of Claim 1, wherein at least one inductor arranged within the space between at least two billets is adapted to provide stirring of the liquid core in at least two billets between which it is arranged.

8. The apparatus of Claim 1 wherein at least one inductor arranged along the outer edge covering at least two billets is adapted to provide stirring of the liquid core in such billets.

9. The apparatus of Claim 1, wherein the directions of motion of travelling electromagnetic fields induced by one inductor coincide.

10. The apparatus of Claim 1 **characterized by** said inductors generating travelling electromagnetic fields that are advantageously symmetric relative to the billet axis.

11. A method for continuous or semicontinuous casting of metals comprising exposure molten metal to electromagnetic field via at least two electromagnetic inductors that provide electromagnetic stirring of the liquid billet core by at least two electromagnetic fields travelling along the direction of the billet extraction, wherein each of said fields is generated at different frequencies which motion directions are opposite and which area of action on the liquid core covers the entire depth of the liquid core.

12. The method of Claim 11 wherein at least a frequency of one of said travelling electromagnetic fields is selected to be close to or coinciding with the natural resonance frequency of mechanical oscillations of the volume of the liquid core.

13. The method of Claim 11 **characterized by** an electromagnetic field is generated which magnetic induction increases over the liquid core D with distance from the crystallizer to the bottom of the core, wherein the relation between the value of the magnetic induction of electromagnetic field in the area of utmost upper and lower portions of the inductor exceeds 2.

14. The method of Claim 13 **characterized by** the increase of the value of the magnetic induction of electromagnetic field along the inductor over the depth of the liquid core D proceeds according to linear, power or exponential dependency.

15. The method of Claim 11 **characterized by** electromagnetic fields are selected with a frequency decreasing over the depth of the core D with distance from the crystallizer to the bottom of the core.

16. The method of Claim 11 wherein the frequency of electromagnetic fields generated by inductors is selected as not exceeding 6 Hz.

17. The method of Claim 11 wherein the directions of the motion of the travelling electromagnetic fields induced by one inductor are selected as coinciding.

18. The method of Claim 11 **characterized by** said travelling electromagnetic fields being advantageously symmetric relative to the vertical axis of the billet.

Amended claims under Art. 19.1 PCT

1. An apparatus for continuous or semicontinuous casting of aluminum alloys comprising a crystallizer that is open at both ends in casting direction, means for feeding the melt into the crystallizer, at least two electromagnetic inductors adapted to induce stirring motion in the melt, wherein said inductors are mainly arranged symmetrically to each other relative to the vertical plane of symmetry of the billet, **characterized by** each inductor is adapted to create at least two electromagnetic fields of different frequencies travelling in opposite directions along the direction of billet extraction, and the area of action of the fields covers the entire liquid core, wherein the inductor is adapted to create at least a travelling electromagnetic field with a magnetic induction increasing over the depth of the liquid core D with distance from the crystallizer to the bottom of the core, wherein the relation between the value of the magnetic induction of magnetic field in the areas of utmost upper and lower portions of the inductor exceeds 2, or the increase of the value of the magnetic induction of electromagnetic field along the inductor over the depth of the liquid core D proceeds according to linear, power or exponential dependency, or with a possibility of generation of at least electromagnetic field with a frequency decreasing over the depth of the liquid core D with distance from the crystallizer to the bottom of the core.

2. The apparatus of Claim 1 **characterized by** the inductor adapted to generate at least a frequency of one of said travelling electromagnetic fields being close to or coinciding with the natural resonance frequency of mechanical oscillations of the liquid core volume.

6. The apparatus of Claim 1, wherein the frequency of the electromagnetic fields generated by the inductors does not exceed 6 Hz.

7. The apparatus of Claim 1, wherein at least one inductor arranged within the space between at least two billets is adapted to provide stirring of the liquid core in at least two billets between which it is arranged.

8. The apparatus of Claim 1 wherein at least one inductor arranged along the outer edge covering at least two billets is adapted to provide stirring of the liquid core in such billets.

9. The apparatus of Claim 1, wherein the directions of motion of travelling electromagnetic fields induced by one inductor coincide.

10. The apparatus of Claim 1 **characterized by** said inductors generating travelling electromagnetic fields that are advantageously symmetric relative to the billet axis.

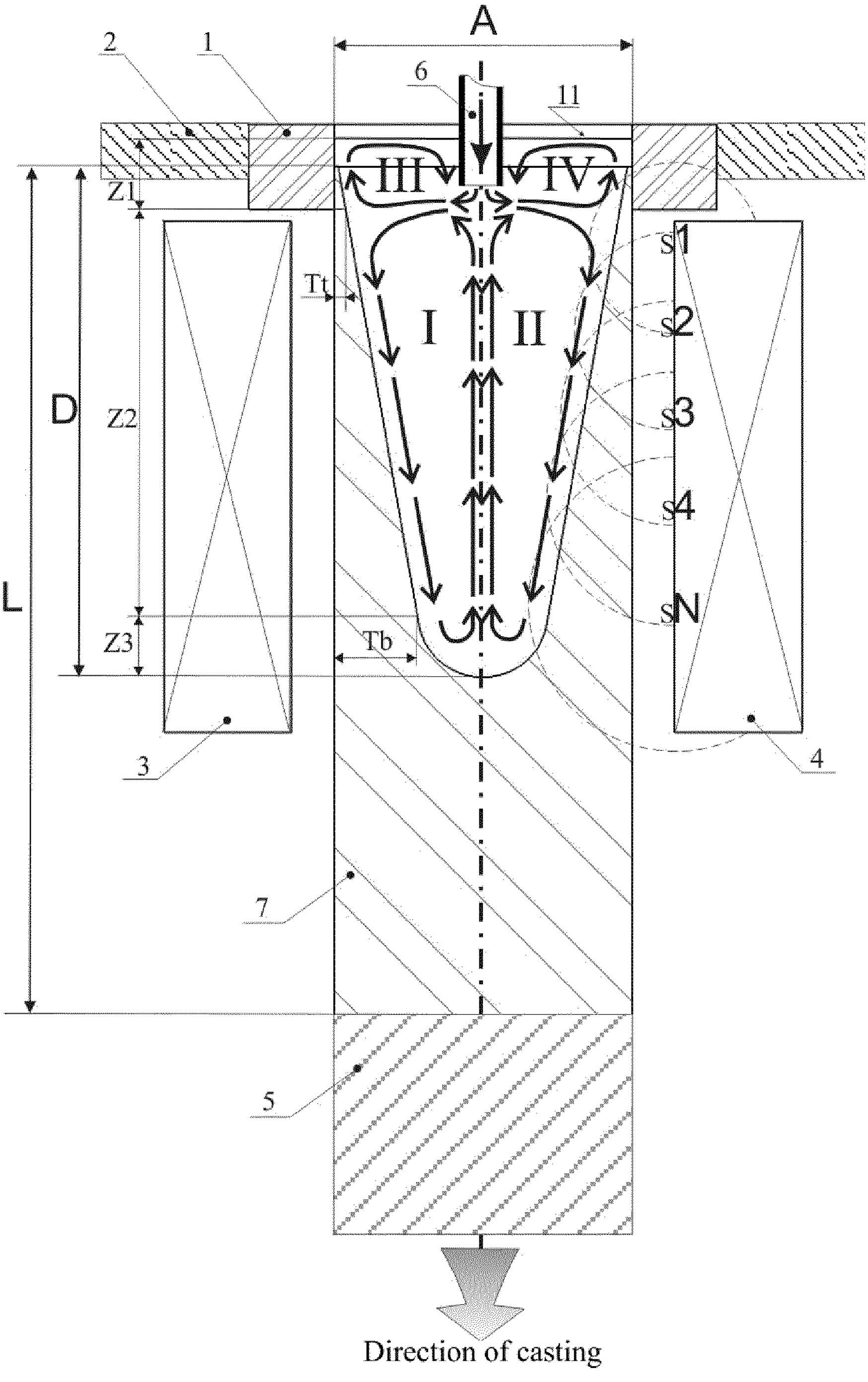
11. A method for continuous or semicontinuous casting of metals comprising exposure molten metal to electromagnetic field via at least two electromagnetic inductors that provide electromagnetic stirring of the liquid billet core by at least two electromagnetic fields travelling along the direction of the billet extraction, wherein each of said fields is generated at different frequencies which motion directions are opposite and which area of action on the liquid core covers the entire depth of the liquid core, wherein an electromagnetic field is generated which magnetic induction increases over the liquid core D with distance from the crystallizer to the bottom of the core, wherein the relation between the value of the magnetic induction of electromagnetic field in the area of utmost upper and lower portions of the inductor exceeds 2, or the increase of the value of the magnetic induction of electromagnetic field along the inductor over the depth of the liquid core D proceeds according to linear, power or exponential dependency, or electromagnetic fields are selected with a frequency decreasing over the depth of the core D with distance from the crystallizer to the bottom of the core.

12. The method of Claim 11 wherein at least a frequency of one of said travelling electromagnetic fields is selected to be close to or coinciding with the natural resonance frequency of mechanical oscillations of the volume of the liquid core.

16. The method of Claim 11 wherein the frequency of electromagnetic fields generated by inductors is selected as not exceeding 6 Hz.

17. The method of Claim 11 wherein the directions of the motion of the travelling electromagnetic fields induced by one inductor are selected as coinciding.

18. The method of Claim 11 **characterized by** said travelling electromagnetic fields being advantageously symmetric relative to the vertical axis of the billet.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S4
SN
Z3
Tb
3
4
7
5
Direction of casting

Fig. 1

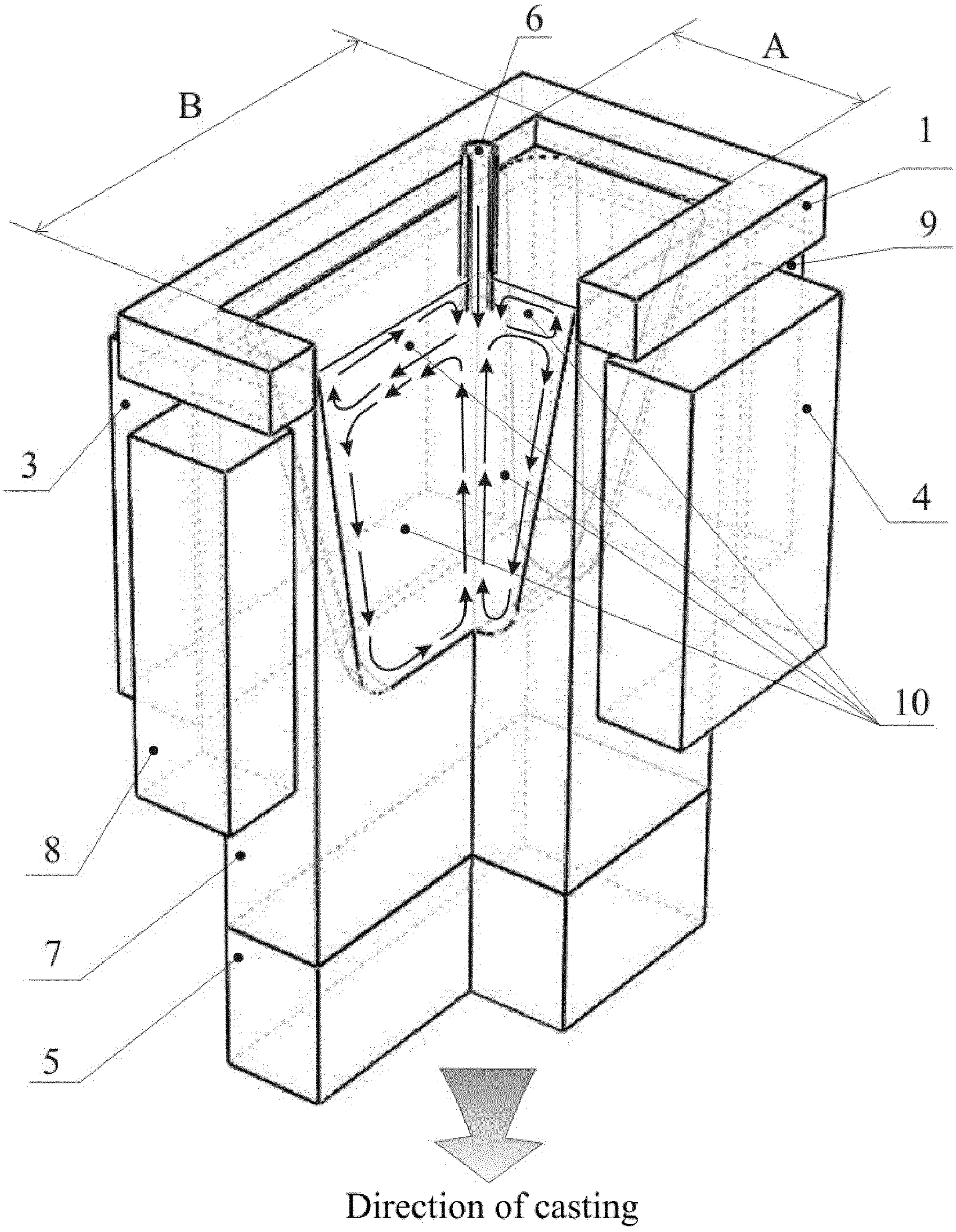
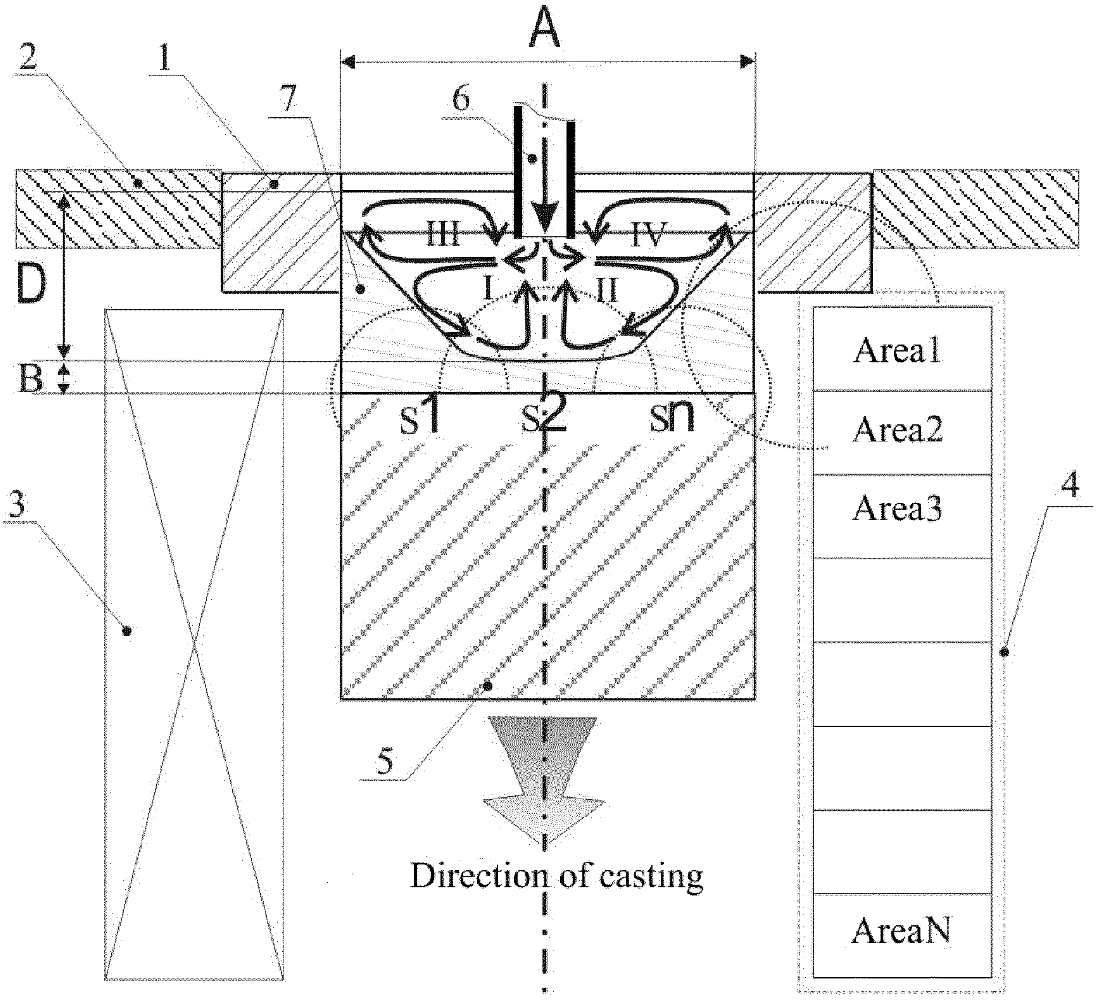


Fig. 2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6
III
IV
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D
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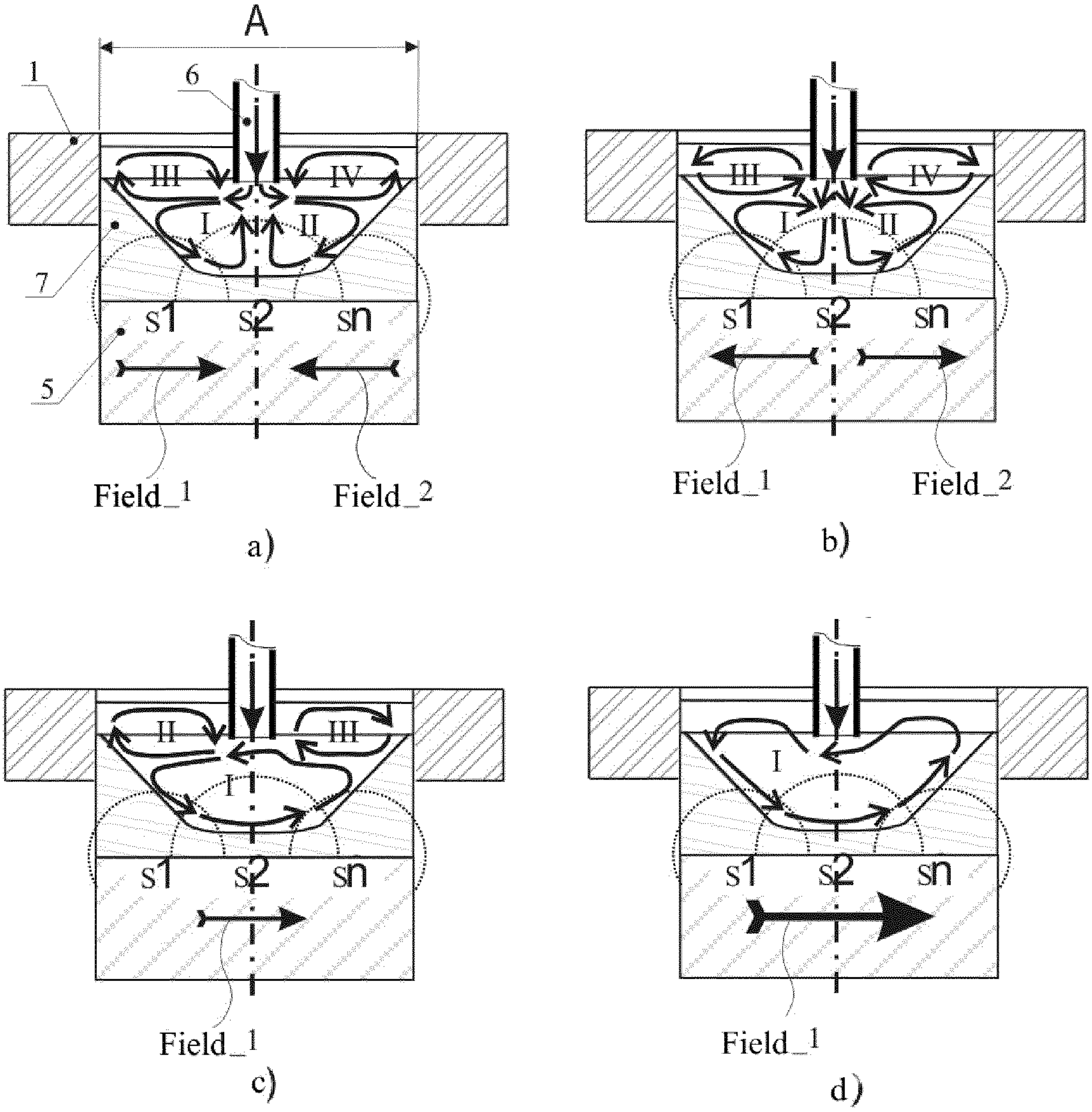
Sn
Area1
Area2
Area3
AreaN
3
4
5
Direction of casting

Fig. 3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6
III
IV
I
II
7
s1
s2
sn
5
Field_1
Field_2
a)
III
IV
I
II
s1
s2
sn
Field_1
Field_2
b)
II
III
I
s1
s2
sn
Field_1
c)
I
s1
s2
sn
Field_1
d)

Fig. 4

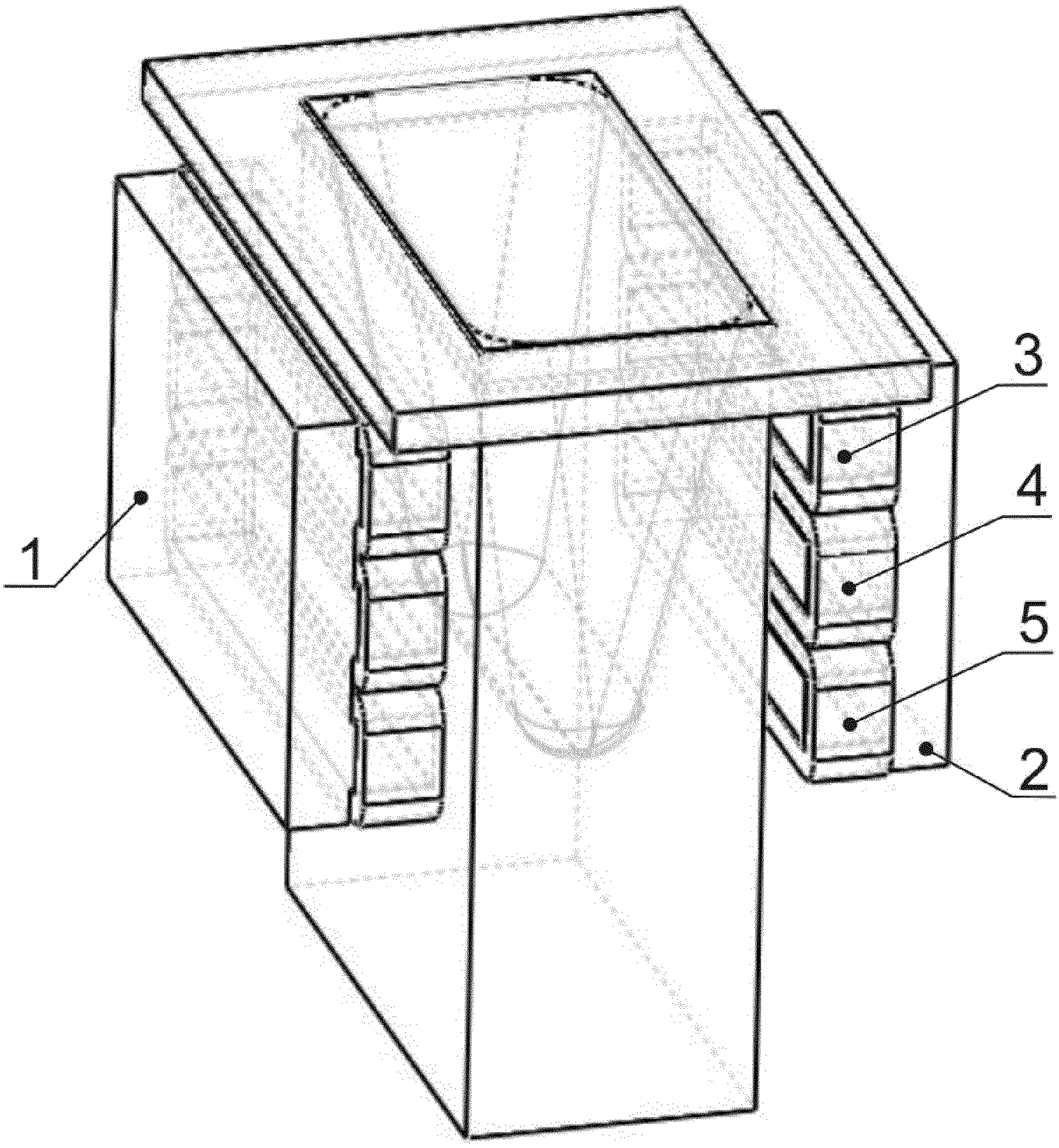
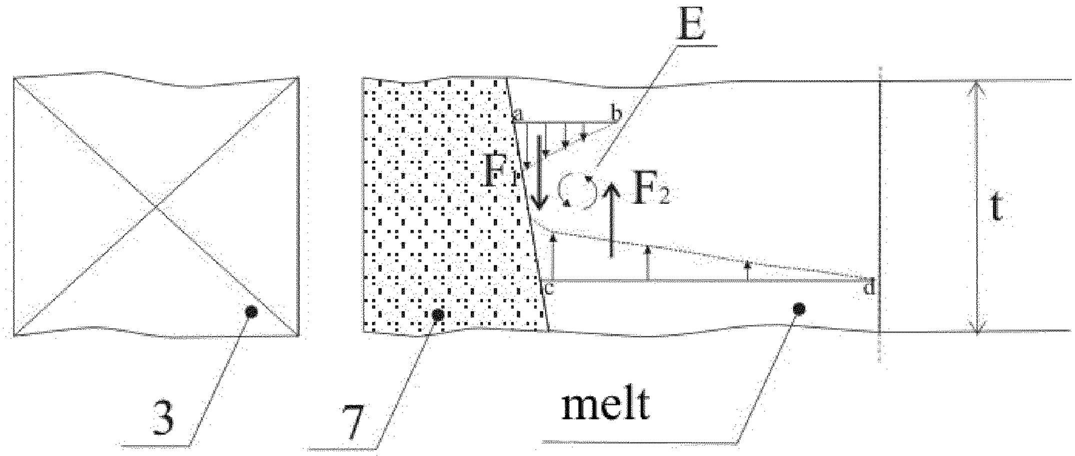


Fig. 5



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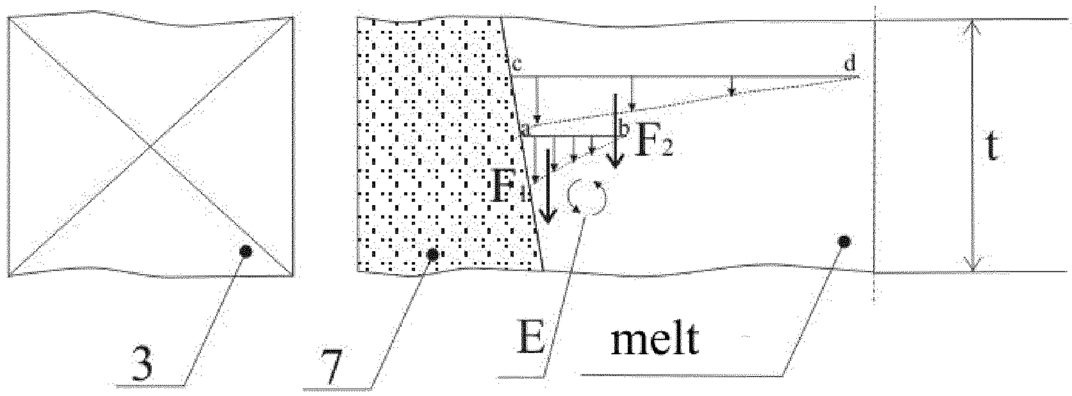


b)

Fig. 6

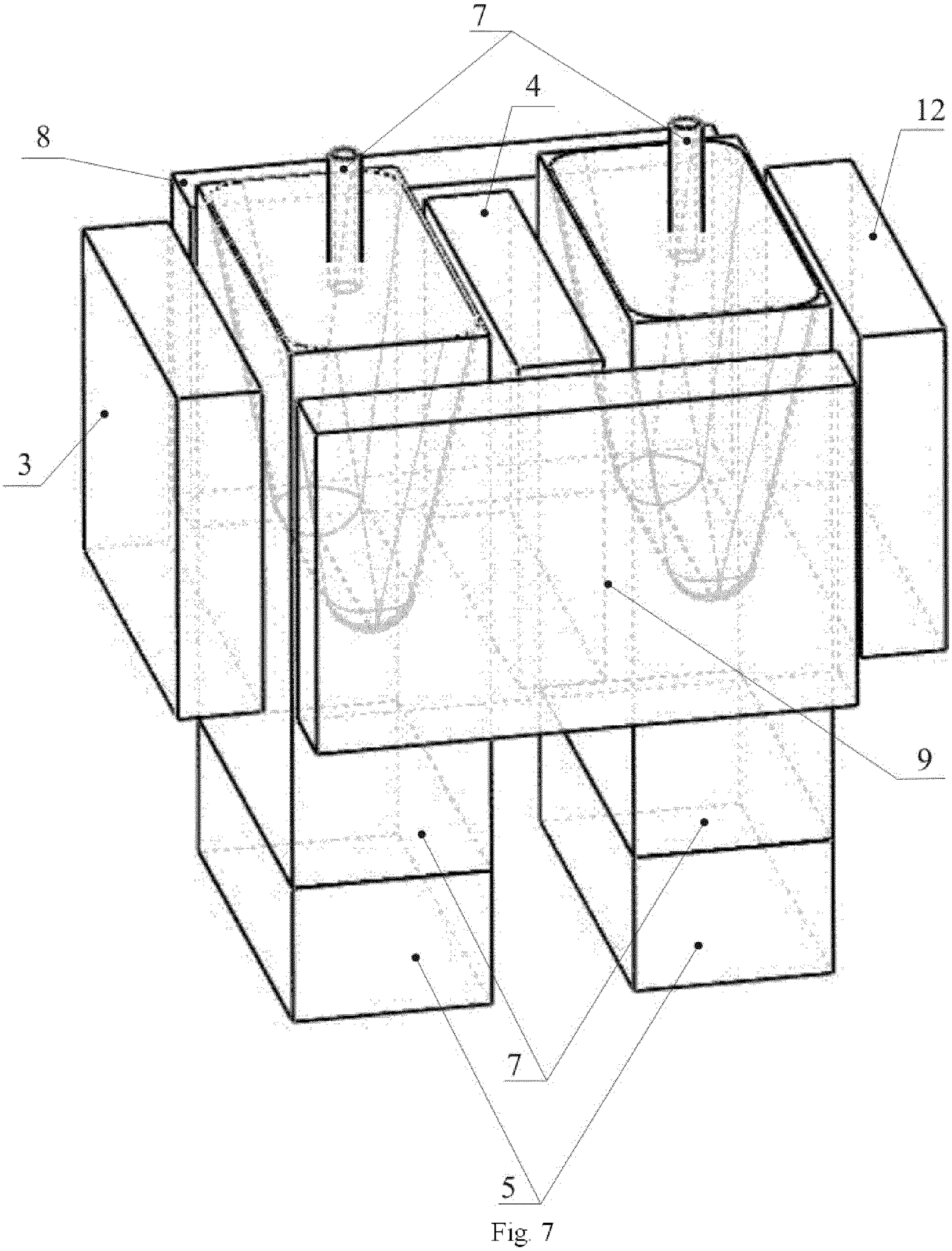
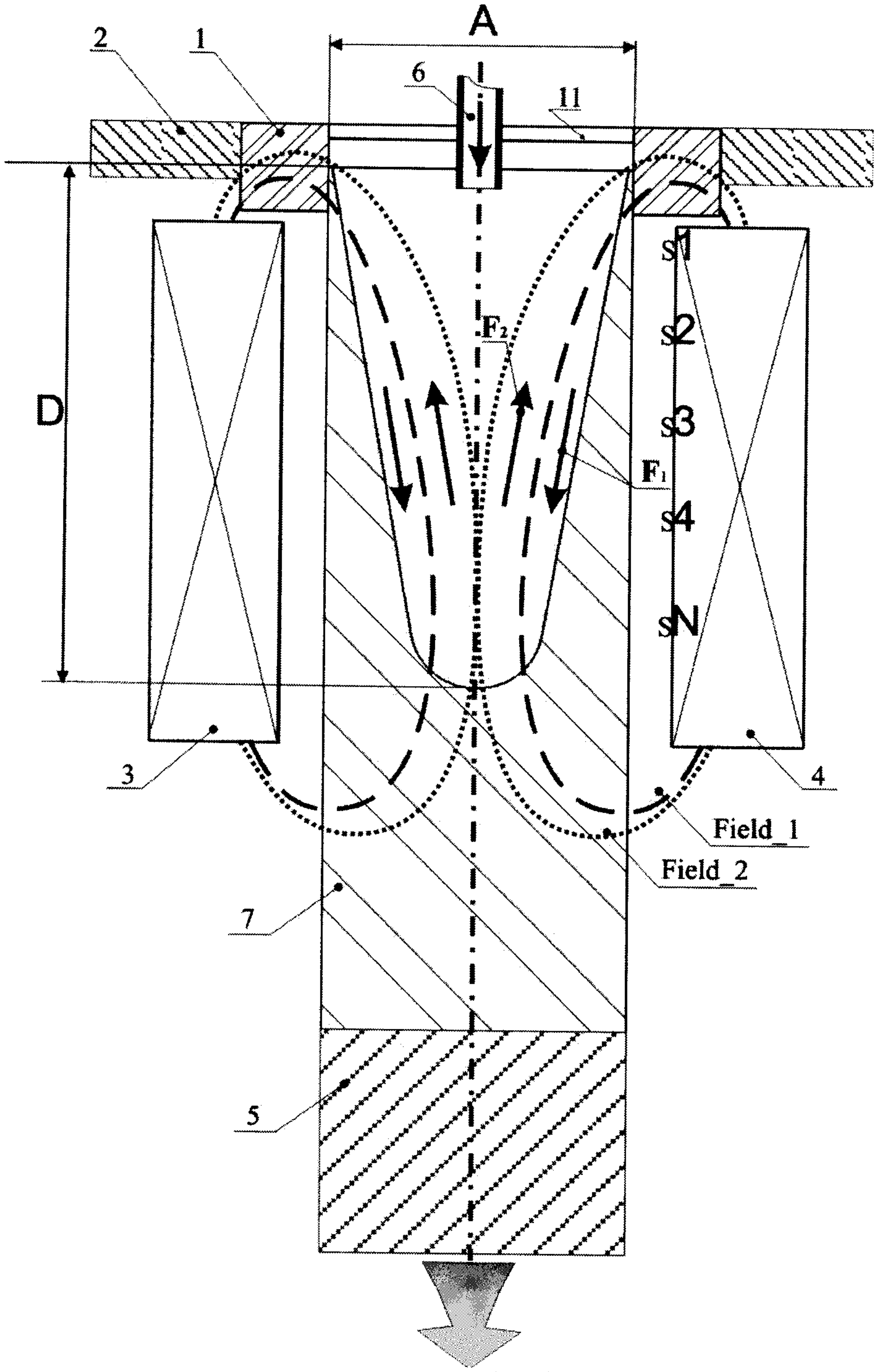


Fig. 7



Direction of casting

Fig. 8

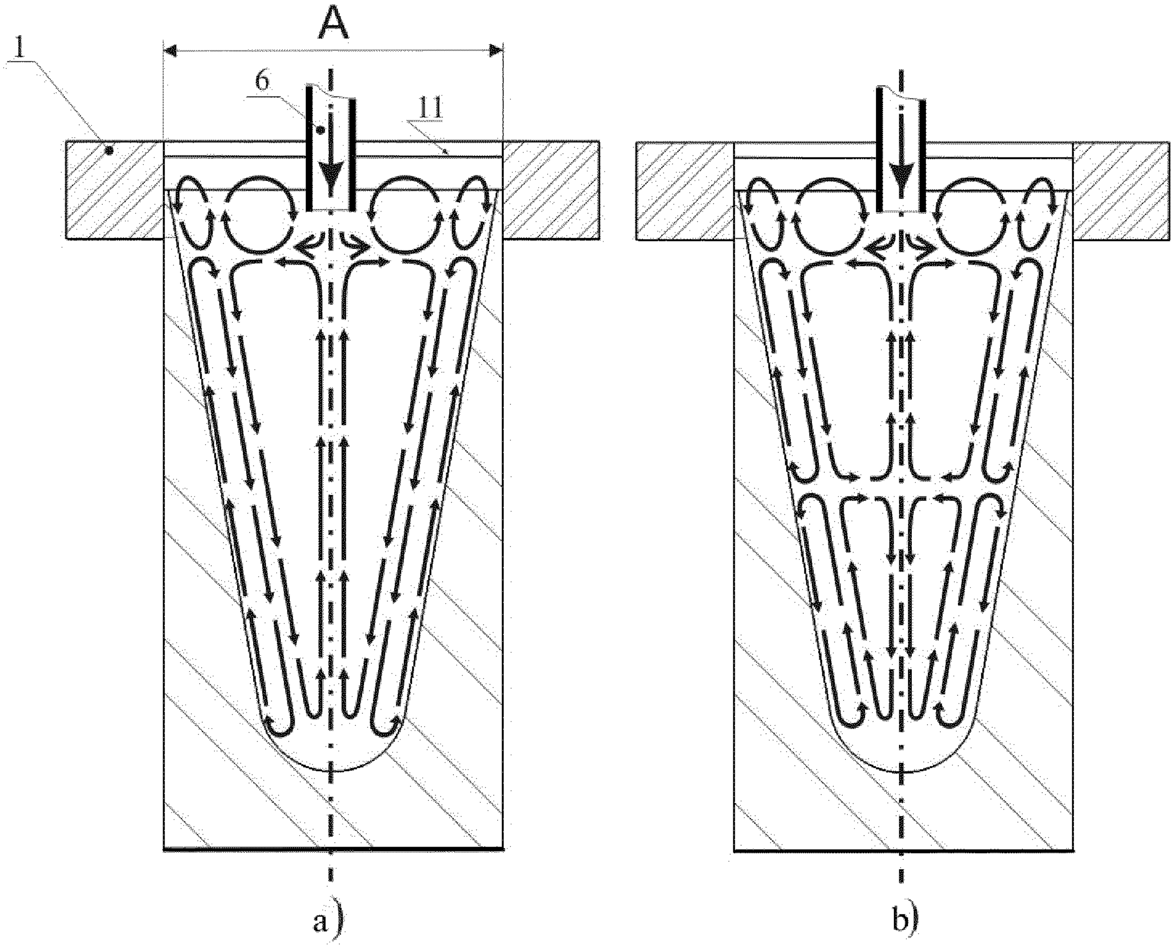


Fig. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/RU 2011/000238

A. CLASSIFICATION OF SUBJECT MATTER *B22D 11/049 (2006.01)*
B22D 27/02 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B22D 11/049, 11/00, 11/10, 11/11, 11/114, 11/115, 27/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Esp@senet, RUPAT, USPTO, WIPO, PAJ, PatSearch

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	RU 2228817 C1 (KRASNOYARSKY GOSUDARSTVENNY TEKHNICHESKY UNIVERSITET) 20.05.2004, p. 3, col. 1, lines 1-5 col. 2, lines 9-49, fig. 1-3	1, 2, 6-12, 16-18
Y	WO 2009/117803 A1 (ABB INC. et al) 01.10.2009, p. 3-4, par. [0011], p. 8, par. [0037], p. 9-10, [0041], p. 10, par. [0042], [0043], p. 14, par. [0052]	1, 2, 6-12, 16-18
Y	US 5222545 A (ALUMINIUM COMPANY OF AMERICA) 29.06.1993, col. 3, line 44-, col. 4, line 2	7, 8
A	US 5219018 A (ALUMINIUM PECHINEY) 15.06.1993	1-18

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 October 2011 (27.10.2011)	**02 November 2011 (02.11.2011)**
Name and mailing address of the ISA/ **RU**	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

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- RU 2325245 **[0004] [0010]**
- RU 2357833 **[0006] [0010]**
- FR 0312555 **[0010]**
- FR 0212706 **[0010]**