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(54) **VERTICAL ELECTROMAGNETIC BRAKING DEVICE FOR CONTROLLING FLOW OF MOLTEN STEEL IN CONTINUOUS CASTING CRYSTALLIZER**

(57) The invention relates to a vertical electromagnetic braking device for controlling molten steel flow in a continuous casting mold. The vertical electromagnetic braking device comprises one or two pairs of horizontal magnetic poles, exciting coils, two pairs of vertical magnetic poles and a magnet yoke. When one pair of the horizontal magnetic poles is set up, the horizontal magnetic poles are located below a submerged nozzle and arranged along the whole width sides of the mold. When the two pairs of the horizontal magnetic poles are set up, the two horizontal magnetic poles are marked as upper horizontal magnetic poles and lower horizontal magnetic poles respectively, wherein the lower horizontal magnetic poles are located below the submerged nozzle and set up along the whole width side of the mold, and the upper horizontal magnetic poles are located near a molten steel surface of the mold and set up along the whole width of

the mold. The two pairs of the vertical magnetic poles are respectively set up near the two side areas of the mold and the two pairs of the vertical magnetic poles intersect with one or two pairs of the horizontal magnetic poles. The exciting coils and the magnet yoke are mounted to match with the horizontal magnetic poles. As the current is applied through the exciting coils, a steady magnetic field is formed between the horizontal magnetic poles and the vertical magnetic poles. The molten steel which flows in the mold is suppressed by the electromagnetic force as the molten steel passes through the steady magnetic field, wherein the direction of the electromagnetic force is opposite to the molten steel flowing direction, so that the molten steel flow in the mold is controlled through the electromagnetic force.

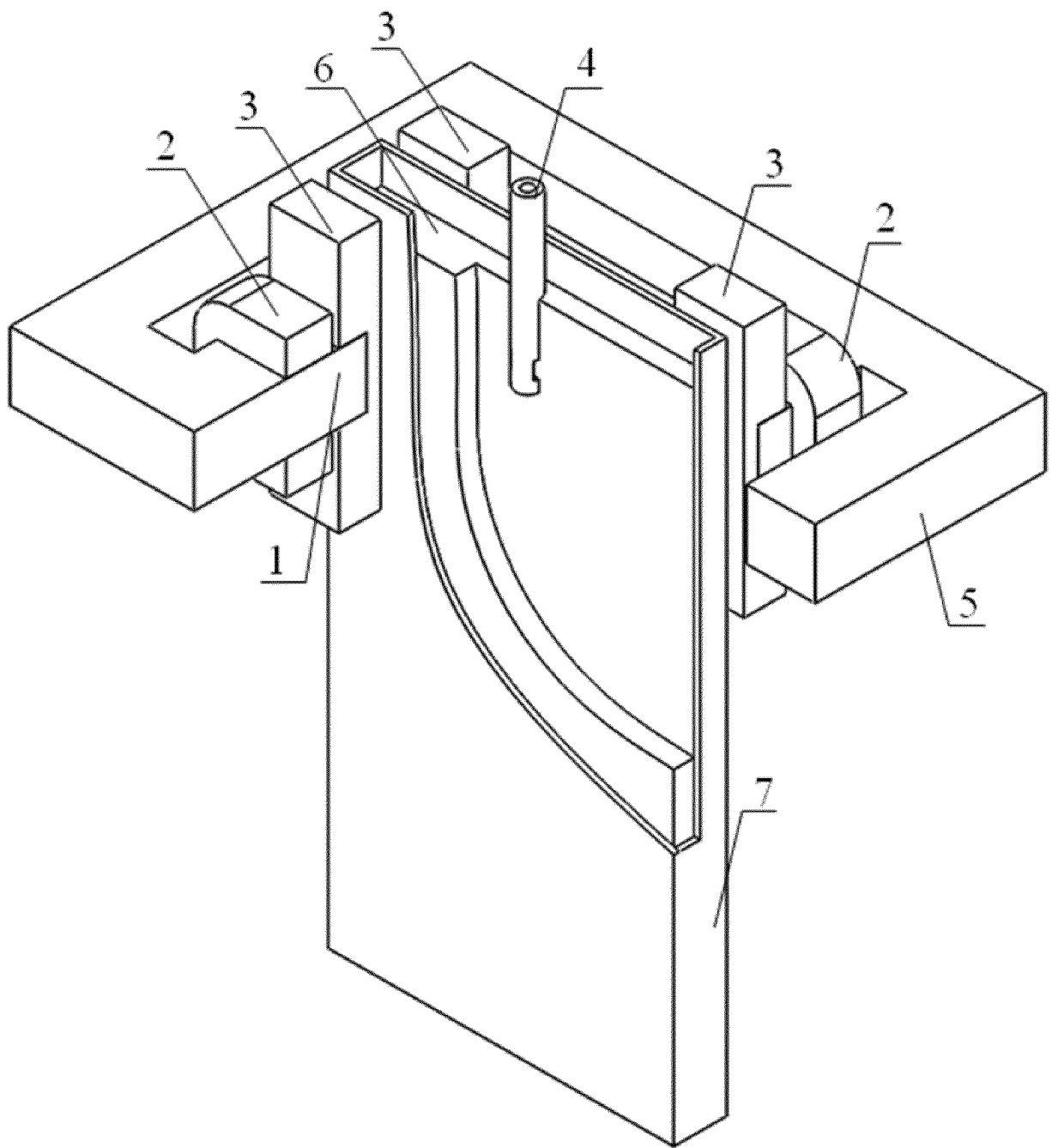


Fig.1

Description

Technical Field

[0001] The invention belongs to the technical field of continuous casting, and particularly relates to a Vertical Electromagnetic Braking (V-EMBr) device for controlling molten steel flow in a continuous casting mold.

Background Art

[0002] In the continuous casting process, molten steel flows into a mold through a submerged nozzle at a certain jet angle, and the molten steel can impact the side area of the mold in a certain velocity so as to form an upward reflux and a downward reflux, wherein the molten steel flows out of the submerged nozzle.

[0003] The upward reflux can impact the molten steel surface in the mold to cause level fluctuation, and especially the level fluctuation of the molten steel near the meniscus can be aggravated to cause slag entrapment easily.

[0004] The downward reflux has great penetration depth and can bring heterogeneous substances such as inclusions and bubbles in the molten steel to deep positions of the mold. The heterogeneous substances are not liable to float upward and can be captured by the front edge of an initial solidification shell of the molten steel so as to cause surface or subsurface defects in continuous casting billet.

[0005] In addition, the molten steel impacts the initial solidification shell in the mold and can also cause the initial solidification shell to be thin or uneven, wherein the molten steel flows out of the submerged nozzle, so that steel breakout accidents can be easily caused.

[0006] In order to solve the problems, technicians usually set an electromagnetic brake (EMBr) on the width of the mold in horizontal direction. A steady magnetic field is formed in the mold through the electromagnetic brake. When passing through the steady magnetic field, the molten steel flowing in the mold can be suppressed by the electromagnetic force, wherein the direction of the electromagnetic force is opposite to the flowing direction of the molten steel, so that the purpose of controlling molten steel flow in the mold is realized.

[0007] At the present time, electromagnetic brakes for generating steady magnetic fields mainly include the Local Magnetic Field, the LMF (Level Magnetic Field) and the FC (Flow Control) Mold.

[0008] The Local Magnetic Field EMBr device can produce a steady magnetic field so as to further achieve the effect of controlling the molten steel flow out of a submerged nozzle, wherein the steady magnetic field acts on the outflow area of the side hole of a mold nozzle. However, the steady magnetic field produced by the local electromagnetic braking device has limited acting area. The steady magnetic field cannot effectively control the molten steel flow in the entire mold and may easily cause

other defects such as ditches.

[0009] The LMF EMBr device (for example Chinese patent application No.98810685.X) produces a steady magnetic field through one pair of horizontal magnetic poles so as to further control the impact depth of downward reflux molten steel in the whole width side of the mold, wherein the horizontal magnetic poles are set up below a submerged nozzle and cover the whole width of a mold. However, the LMF EMBr cannot effectively control the level fluctuations of molten steel and slag entrapment caused by upward reflux molten steel in the mold.

[0010] The FC Mold EMBr device (for example Chinese patent application No.98801009.7) produces a steady magnetic field via two pairs of horizontal magnetic poles in the width of mold, one is set up in the molten steel surface and another is located below a submerged nozzle so as to further achieve the effect of controlling the level fluctuations and impact depth of molten steel in the mold. However, the higher magnetic flux intensity for the purpose of effectively controlling the level fluctuation in the molten steel surface area of mold always brings too lower velocity of molten steel in the most surface area of mold. That is easy to obviously reduce the heat exchange between the molten steel and covering slags, so that the melting of covering slags and adsorption of inclusions are not facilitated.

[0011] In addition, for the LMF and the FC Mold EMBr device, the positions of the horizontal magnetic poles are non-adjustable in height direction. In the continuous casting process, when the operating parameters such as nozzle immersion depth, nozzle outflow angle, molten steel level height and casting speed have some changes, the matching relation between the horizontal magnetic poles and the operating parameters can be changed, and the reasonable and optimal matching relation cannot be always kept. Thus the metallurgical effect of electromagnetic braking can be seriously affected, and even the floating of heterogeneous substances such as inclusions and bubbles can be inhibited.

[0012] The Chinese patent No.200810011104.7 further discloses an electromagnetic braking device. Two pairs of vertical magnetic poles are set up near two sides of a mold and along the height direction of the mold. The vertical magnetic poles cover the molten steel surface area which is close to the narrow face of the mold. The impact area of the nozzle outflow can be controlled very well and can also produce a steady magnetic field. The level fluctuations and the flow in the nozzle outflow impact area are controlled by the steady magnetic field, wherein the steady magnetic field is produced by two pairs of the vertical magnetic poles. The braking effect of the V-EMBr device on the area which is close to the mold sides is little affected by the changes of operating parameters. However, the electromagnetic braking device consists of two half rings of magnetic poles and exciting coils wound around the sides of the mold, and the width of the vertical magnetic poles in the width direction of the mold is limited. As the mold has a large width, the steady magnetic field

in the central area of the mold has weak magnetic flux intensity and cannot effectively control the impact depth of the downward reflux molten steel, so that the floating of heterogeneous substances such as inclusions and bubbles is not facilitated.

Summary of the Invention

[0013] Aiming at the problems existing in the prior art, the invention provides a brand-new improved vertical electromagnetic braking device for controlling molten steel flow in a continuous casting mold. When the vertical electromagnetic braking (V-EMBr) device preferably inhibits the impact of nozzle outflow molten steel on the sides of a mold and the molten steel surface flow at meniscus, it can also control the molten steel flow in the central area of the mold and avoid lower molten steel surface velocity in the central area of the mold and larger impact depth of downward reflux molten steel, in order to inhibit level fluctuations and slag entrapment on the molten steel surface and also promote the floating of heterogeneous substances such as inclusions and bubbles. Moreover, the metallurgical effect of V-EMBr is little affected by the change in operating parameters of the continuous casting process.

[0014] In order to realize the purpose, the technical scheme adopted by the invention lies in that a V-EMBr device, which controls the molten steel flow in a continuous casting mold, comprises one pair of horizontal magnetic poles, exciting coils, two pairs of vertical magnetic poles and a magnet yoke. In addition, one pair of the horizontal magnetic poles is located below a submerged nozzle and set up along the whole width side of mold, and the two pairs of vertical magnetic poles are set up near the two side areas of the mold respectively, which intersect with one pair of the horizontal magnetic poles. The exciting coils and the magnet yoke are mounted to match with the horizontal magnetic poles. As a current is applied through the exciting coils, a steady magnetic field is formed between the horizontal magnetic poles and the vertical magnetic poles. The molten steel which flows in the mold is suppressed by the electromagnetic force as the molten steel passes through the steady magnetic field, wherein the direction of the electromagnetic force is opposite to the flowing direction of the molten steel, so that the molten steel flow in the mold is controlled through the electromagnetic force.

[0015] A V-EMBr device, which controls the molten steel flow in a continuous casting mold, comprises two pairs of horizontal magnetic poles, exciting coils, two pairs of vertical magnetic poles and a magnet yoke. In addition, one pair of the horizontal magnetic poles is located below a submerged nozzle, which is set up along the whole width side of a mold and marked as lower horizontal magnetic poles. Another pair of the horizontal magnetic poles is located near a molten steel surface in the mold, which is set up along the width side of the mold and marked as upper horizontal magnetic poles. The two

pairs of the vertical magnetic poles are set up near the two side areas of the mold respectively, and intersect with two pairs of the horizontal magnetic poles. The exciting coils and the magnet yoke are mounted to match with the horizontal magnetic poles. As a current is applied through the exciting coils, a steady magnetic field is formed between the horizontal magnetic poles and the vertical magnetic poles. The molten steel which flows in the mold is suppressed by the electromagnetic force as the molten steel passes through the steady magnetic field, wherein the direction of the electromagnetic force is opposite to the flowing direction of the molten steel, so that the molten steel in the mold is controlled through the electromagnetic force. The connection manner for two pairs of the vertical magnetic poles and one pair of the horizontal magnetic poles at the intersection is as follows:

- (1) The vertical magnetic poles are vertically inlaid on the horizontal magnetic poles.
- (2) The vertical magnetic poles are vertically connected with the horizontal magnetic poles on the upper surfaces and the lower surfaces of the horizontal magnetic poles respectively.
- (3) The vertical magnetic poles are vertically connected with the horizontal magnetic poles only on the upper surfaces of the horizontal magnetic poles.
- (4) The vertical magnetic poles are vertically connected with the horizontal magnetic poles only on the lower surfaces of the horizontal magnetic poles.

[0016] The connection manner for two pairs of the vertical magnetic poles and two pairs of the horizontal magnetic poles at the intersection is as follows:

- (1) The vertical magnetic poles are vertically inlaid on the upper horizontal magnetic poles and the lower horizontal magnetic poles respectively.
- (2) The vertical magnetic poles are vertically inlaid only on the lower horizontal magnetic poles.
- (3) The vertical magnetic poles are vertically inlaid only on the upper horizontal magnetic poles.
- (4) The vertical magnetic poles are vertically inlaid on the upper horizontal magnetic poles, and the vertical magnetic poles are vertically connected with the horizontal magnetic poles on the lower surfaces of the lower horizontal magnetic poles.
- (5) The vertical magnetic poles are vertically connected with the horizontal magnetic poles on the upper surfaces and the lower surfaces of the lower horizontal magnetic poles respectively.
- (6) The vertical magnetic poles are vertically connected with the horizontal magnetic poles only on the upper surfaces of the lower horizontal magnetic poles.
- (7) The vertical magnetic poles are vertically connected with the horizontal magnetic poles on the lower surfaces of the upper horizontal magnetic poles, and are vertically connected with the horizontal mag-

netic poles on the lower surfaces of the lower horizontal magnetic poles 1.

(8) The vertical magnetic poles are vertically connected with the horizontal magnetic poles on the lower surfaces of the upper horizontal magnetic poles.

[0017] The height of the vertical magnetic poles is required to cover the area from 100 mm above the molten steel surface in the mold to 1000 mm below.

[0018] The width range of the vertical magnetic poles is 50-400 mm.

[0019] The magnetic induction intensity of the steady magnetic field between the horizontal magnetic poles and the vertical magnetic poles is 0.01T-3 T.

[0020] The combination position of the vertical magnetic poles and the horizontal magnetic poles is freely selected in the width direction of the mold according to the width adjustment change of the mold and actual requirements for controlling the molten steel flow.

[0021] The V-EMBr device has the following beneficial effects:

The vertical magnetic poles without exciting coils can be combined with horizontal magnetic poles in different connection manners, and a steady magnetic field is formed between the horizontal magnetic poles and the vertical magnetic poles only by using the exciting coils on the horizontal magnetic poles.

[0022] A steady magnetic field is produced by intersecting two pairs of vertical magnetic poles with one pair or two pairs of horizontal magnetic poles. The two pairs of the vertical magnetic poles can cover the molten steel surface near two sides of the mold and the front edge area of an initial solidification shell, and can control the area from the molten steel surface to the nozzle outflow impact area which is close to the sides of the mold and the molten steel flow area below the horizontal magnetic poles. Thus, the nozzle outflow molten steel can be inhibited by the magnetic field before the nozzle outflow molten steels impacts the sides of the mold, and the impact of the nozzle outflow molten steel to the sides of the mold and the disturbance of the molten steel surface are weakened. Therefore, the molten steel fluctuations and slag entrapment in the mold side meniscus area are controlled, the capture of inclusions and bubbles by the initial solidification shell can be reduced, and further, the quality of continuous casting billets can be improved.

[0023] The height of the vertical magnetic poles is required to cover the area from 100 mm above the molten steel surface in the mold to 1000 mm below, i.e. the area from the above of the molten steel surface near the sides of the mold to a certain depth below the submerged nozzle. In the continuous casting process, even when the operating parameters such as nozzle immersion depth, nozzle outflow angle, molten steel level height and casting speed have some changes, the molten steel flow which is close to the sides of the mold is always within the area covered by the vertical magnetic poles. Therefore, the level fluctuations and the impact depth of molten

steel in the mold can be controlled effectively, and the braking effect is little affected by changes in the operating parameters.

[0024] In the invention, as a steady magnetic field is formed by intersecting two pairs of vertical magnetic poles with one pair of horizontal magnetic poles, the horizontal magnetic poles set up along the width side of the mold are used for controlling the downward molten steel flow in the central area of the mold, lowering the impact depth of molten steel and promoting the floating of inclusions and bubbles.

[0025] In the invention, as a steady magnetic field is formed by intersecting two pairs of vertical magnetic poles with two pairs of horizontal magnetic poles, the vertical magnetic poles can be used together with one pair of horizontal magnetic poles which are close to the molten steel surface of the mold. After one connection manner for the vertical magnetic poles and the horizontal magnetic poles is selected, the flow at the meniscus on the sides of the mold can be controlled in order to increase the magnetic field intensity of the vertical magnetic poles and the fluctuations and slag entrapment on the molten steel surface at the meniscus. Besides, when the level fluctuations of molten steel in the central area of the mold are properly controlled, the molten steel surface can still keep a certain velocity and heat exchange capability by relatively weakening the magnetic field intensity of upper horizontal magnetic poles or not applying current to the upper horizontal magnetic poles. Thus, the melting of covering slags and the adsorption of inclusions are facilitated, and good electromagnetic braking effect can be obtained.

Description of the Drawings

[0026]

Fig.1 is structure diagram of a V-EMBr device (one pair of horizontal magnetic poles) for controlling molten steel flow in a continuous casting mold.

Fig.2 is the schematic of molten steel flow and magnetic pole arrangement in the mold of the V-EMBr device of Fig.1.

Fig.3 (a) is the schematic of the connection manner for two pairs of the vertical magnetic poles and one pair of the horizontal magnetic poles of the V-EMBr device at the intersection in Fig.1 (the vertical magnetic poles are vertically inlaid on the horizontal magnetic poles).

Fig.3 (b) is the schematic of the connection manner for two pairs of the vertical magnetic poles and one pair of the horizontal magnetic poles of the V-EMBr device at the intersection in Fig.1 (the vertical magnetic poles are vertically connected with the horizontal magnetic poles only on the upper surfaces and the lower surfaces of the horizontal magnetic poles).

Fig.3 (c) is the schematic of the connection manner for two pairs of the vertical magnetic poles and one

pair of the horizontal magnetic poles of the V-EMBr device at the intersection in Fig. 1 (the vertical magnetic poles are vertically connected with the horizontal magnetic poles only on the upper surfaces of the horizontal magnetic poles).

Fig. 3 (d) is the schematic of the connection manner for two pairs of the vertical magnetic poles and one pair of the horizontal magnetic poles of the V-EMBr device at the intersection in Fig. 1 (the vertical magnetic poles are vertically connected with the horizontal magnetic poles only on the lower surfaces of the horizontal magnetic poles).

Fig. 4 is structure diagram of a V-EMBr device (two pairs of horizontal magnetic poles) for controlling molten steel flow in a continuous casting mold.

Fig. 5(a) is the schematic of molten steel flow and magnetic pole arrangement in the mold of the V-EMBr device in Fig. 4 (width side direction of mold).

Fig. 5(b) is the schematic of molten steel flow and magnetic pole arrangement in the mold of the V-EMBr device in Fig. 4 (narrow side direction of mold).

Fig. 6(a-h) is the schematic of the connection manner for two pairs of the vertical magnetic poles and two pairs of the horizontal magnetic poles of the V-EMBr device at the intersection in Fig. 4 (the vertical magnetic poles are vertically inlaid on the upper horizontal magnetic poles and the lower horizontal magnetic poles respectively); (the vertical magnetic poles are vertically inlaid only on the lower horizontal magnetic poles); (the vertical magnetic poles are vertically inlaid only on the upper horizontal magnetic poles); (the vertical magnetic poles are vertically inlaid on the upper horizontal magnetic poles, and the vertical magnetic poles are vertically connected with the horizontal magnetic poles on the lower surfaces of the lower horizontal magnetic poles); (the vertical magnetic poles are vertically connected with the horizontal magnetic poles on the upper surfaces and lower surfaces of the lower horizontal magnetic poles respectively); (the vertical magnetic poles are vertically connected with the horizontal magnetic poles only on the upper surfaces of the lower horizontal magnetic poles); (the vertical magnetic poles are vertically connected with the horizontal magnetic poles on the lower surfaces of the upper horizontal magnetic poles, and the vertical magnetic poles are vertically connected with the horizontal magnetic poles on the lower surfaces of the lower horizontal magnetic poles); (the vertical magnetic poles are vertically connected with the horizontal magnetic poles on the lower surfaces of the upper horizontal magnetic poles).

Fig. 6(b) is the schematic of the connection manner for two pairs of the vertical magnetic poles and two pairs of the horizontal magnetic poles of the V-EMBr device at the intersection in Fig. 4 (the vertical magnetic poles are vertically inlaid on the lower horizontal magnetic poles).

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Fig. 6 (c) is the schematic of the connection manner for two pairs of the vertical magnetic poles and two pairs of the horizontal magnetic poles of the V-EMBr device at the intersection in Fig. 4 (the vertical magnetic poles are vertically inlaid on the upper horizontal magnetic poles).

Fig. 6(d) is the schematic of the connection manner for two pairs of the vertical magnetic poles and two pairs of the horizontal magnetic poles of the V-EMBr device at the intersection in Fig. 4 (the vertical magnetic poles are vertically inlaid only on the upper horizontal magnetic poles, and are vertically connected with the horizontal magnetic poles only on the lower surfaces of the lower horizontal magnetic poles).

Fig. 6 (e) is the schematic of the connection manner for two pairs of the vertical magnetic poles and two pairs of the horizontal magnetic poles of the V-EMBr device at the intersection in Fig. 4 (the vertical magnetic poles are vertically connected with the horizontal magnetic poles on the upper surfaces and the lower surfaces of the lower horizontal magnetic poles).

Fig. 6 (f) is the schematic of the connection manner for two pairs of the vertical magnetic poles and two pairs of the horizontal magnetic poles of the V-EMBr device at the intersection in Fig. 4 (the vertical magnetic poles are vertically connected with the horizontal magnetic poles only on the upper surfaces of the lower horizontal magnetic poles).

Fig. 6 (g) is the schematic of the connection manner for two pairs of the vertical magnetic poles and two pairs of the horizontal magnetic poles of the V-EMBr device at the intersection in Fig. 4 (the vertical magnetic poles are vertically connected with the horizontal magnetic poles only on the lower surfaces of the upper horizontal magnetic poles, and are vertically connected with the horizontal magnetic poles only on the lower surfaces of the lower horizontal magnetic poles).

Fig. 6 (h) is the schematic of the connection manner for two pairs of the vertical magnetic poles and two pairs of the horizontal magnetic poles of the V-EMBr device at the intersection in Fig. 4 (the vertical magnetic poles are vertically connected with the horizontal magnetic poles only on the lower surfaces of the upper horizontal magnetic poles).

Fig. 7 is the magnetic field distribution diagram of the vertical magnetic pole center on the side central section of the mold along the height direction (the V-EMBr device as shown in Fig. 1 is adopted).

Fig. 8(a) is the level fluctuation diagram of molten metal near the sides of the mold without electromagnetic braking (the V-EMBr device as shown in Fig. 1 is adopted).

Fig. 8(b) is the level fluctuation diagram of molten metal near the sides of the mold with electromagnetic braking (the V-EMBr device as shown in Fig. 1 is adopted);

Fig.9 is the internal magnetic field distribution diagram of molten steel in the mold when 850A current is applied (the V-EMBr device in Fig.1 is adopted).

Fig.10(a) is the molten steel flow field distribution diagram in the central section of the sides of the mold without electromagnetic braking (the V-EMBr device in Fig.1 is adopted).

Fig.10(b) is the molten steel flow field distribution diagram in the central section of the sides of the mold with electromagnetic braking (the V-EMBr device in Fig.1 is adopted).

Fig.11 is the molten steel surface velocity distribution diagram in the central section of the sides of the mold with electromagnetic braking (the V-EMBr device in Fig.1 is adopted).

[0027] In the figures, 1 - horizontal magnetic poles, 2 - exciting coils, 3 - vertical magnetic poles, 4 - submerged nozzle, 5 - magnet yoke, 6 - molten steel surface, 7 - mold, 8 - solidification shell.

Embodiments

[0028] Hereinafter, the invention is further described in details in combination with drawings and embodiments.

[0029] As shown in Fig.1 and Fig.2, a V-EMBr device for controlling molten steel flow in a continuous casting mold comprises one pair of horizontal magnetic poles 1, exciting coils 2, two pairs of vertical magnetic poles 3 and a magnet yoke 5, wherein one pair of the horizontal magnetic poles 1 are located below a submerged nozzle 4 and set up along the width side of a mold 7. Two pairs of the vertical magnetic poles 3 are set up near the two side areas of the mold 7 respectively, and intersect with one pair of the horizontal magnetic poles 1. The exciting coils 2 and the magnet yoke 5 are mounted to match with the horizontal magnetic poles 1. As a current is applied through the exciting coils 2, a steady magnetic field is formed between the horizontal magnetic poles 1 and the vertical magnetic poles 3. The molten steel flow in the mold 7 is suppressed by the electromagnetic force as the molten steel passes through the steady magnetic field, wherein the direction of the electromagnetic force is opposite to the flowing direction of the molten steel, so that the molten steel flow in the mold 7 is controlled through the electromagnetic force.

[0030] As shown in Fig.4, Fig.5(a) and Fig.5(b), a V-EMBr device for controlling molten steel flow in a continuous casting mold comprises two pairs of horizontal magnetic poles 1, exciting coils 2, two pairs of vertical magnetic poles 3 and a magnet yoke 5, wherein one pair of the horizontal magnetic poles 1 is located below a submerged nozzle 4, set up along the width side of a mold 7 and marked as lower horizontal magnetic poles 1. Another pair of the horizontal magnetic poles 1 is located near a molten steel surface 6 in the mold 7, set up along the width side of the mold 7 and marked as upper horizontal

magnetic poles 1. Two pairs of the vertical magnetic poles 3 are set up near the two side areas of the mold 7 respectively, and intersect with two pairs of the horizontal magnetic poles 1. The exciting coils 2 and the magnet yoke 5 are mounted to match with the horizontal magnetic poles 1. As a current is applied through the exciting coils 2, a steady magnetic field is formed between the horizontal magnetic poles 1 and the vertical magnetic poles 3. The molten steel flowing in the mold 7 is suppressed by the electromagnetic force as the molten steel passes through the steady magnetic field, wherein the direction of the electromagnetic force is opposite to the flowing direction of the molten steel, so that the molten steel flow in the mold 7 is controlled through the electromagnetic force.

[0031] As shown in Fig.3(a)-3(d), the connection manner for two pairs of the vertical magnetic poles 3 and one pair of the horizontal magnetic poles 1 at the intersection is as follows:

- (1) The vertical magnetic poles 3 are vertically inlaid on the horizontal magnetic poles 1.
- (2) The vertical magnetic poles 3 are vertically connected with the horizontal magnetic poles 1 on the upper surfaces and lower surfaces of the horizontal magnetic poles 1 respectively.
- (3) The vertical magnetic poles 3 are vertically connected with the horizontal magnetic poles 1 only on the upper surfaces of the horizontal magnetic poles 1.
- (4) The vertical magnetic poles 3 are vertically connected with the horizontal magnetic poles 1 only on the lower surfaces of the horizontal magnetic poles 1.

[0032] As shown in Fig.6(a)-6(h), the connection manner for two pairs of the vertical magnetic poles 3 and two pairs of the horizontal magnetic poles 1 at the intersection is as follows:

- (1) The vertical magnetic poles 3 are vertically inlaid on the upper horizontal magnetic poles 1 and the lower horizontal magnetic poles 1 respectively.
- (2) The vertical magnetic poles 3 are vertically inlaid only on the lower horizontal magnetic poles 1.
- (3) The vertical magnetic poles 3 are vertically inlaid only on the upper horizontal magnetic poles 1.
- (4) The vertical magnetic poles 3 are vertically inlaid on the upper horizontal magnetic poles 1, and the vertical magnetic poles 3 are vertically connected with the horizontal magnetic poles 1 on the lower surfaces of the lower horizontal magnetic poles 1.
- (5) The vertical magnetic poles 3 are vertically connected with the horizontal magnetic poles 1 on the upper surfaces and the lower surfaces of the lower horizontal magnetic poles 1 respectively.
- (6) The vertical magnetic poles 3 are vertically connected with the horizontal magnetic poles 1 only on the upper surfaces of the lower horizontal magnetic

poles 1.

(7) The vertical magnetic poles 3 are vertically connected with the horizontal magnetic poles 1 on the lower surfaces of the upper horizontal magnetic poles 1, and the vertical magnetic poles 3 are vertically connected with the horizontal magnetic poles 1 on the lower surfaces of the lower horizontal magnetic poles 1.

(8) The vertical magnetic poles 3 are vertically connected with the horizontal magnetic poles 1 on the lower surfaces of the upper horizontal magnetic poles 1.

[0033] The height of the vertical magnetic poles 3 is required to cover the area from 100 mm above the molten steel surface 6 in the mold 7 to 1000 mm below.

[0034] The width range of the vertical magnetic poles 3 is 50-400 mm.

[0035] The magnetic induction intensity of the steady magnetic field between the horizontal magnetic poles 1 and the vertical magnetic poles 3 is 0.01T-3 T.

[0036] The combination position of the vertical magnetic poles 3 and the horizontal magnetic poles 1 is freely selected in the width direction of the mold 7 according to the width adjustment change of the mold 7 and actual requirements for controlling the molten steel flow.

Embodiment I

[0037] In the embodiment, the V-EMBr device as shown in Fig.1 is adopted, the connection manner shown in Fig.3(a) is adopted for the vertical magnetic poles 3 and the horizontal magnetic poles 1, the height of the vertical magnetic poles 3 can enable the vertical magnetic poles 3 to cover the area from the molten steel surface 6 on the sides of the mold 7 to the impact point of the molten steel flowing out of the submerged nozzle 4 and the area below the horizontal magnetic poles 1, the section size of the mold 7 is 300 mm×50 mm, and the height of the vertical magnetic poles 3 is 240 mm.

[0038] A current of 700A and 1050A is applied to the exciting coils 2 of the horizontal magnetic poles 1, and the magnetic field distribution diagram of the vertical magnetic pole center on the side central section of the mold along the height direction is shown in Fig.7.

[0039] As shown in Fig.7, as the current intensity increases, the magnetic induction intensity gradually increases and reaches the maximum in the center of the area covered by the horizontal magnetic poles 1. When the applied current is increased from 700A to 1050A, the maximum magnetic induction intensity in the center of the horizontal magnetic poles 1 is increased from 0.46T to 0.52T. At the upper ends and lower ends of the vertical magnetic poles 3, i.e. close to the molten steel surface 6 of the mold 7 and below the horizontal magnetic poles 1, the magnetic induction intensity is from 0.21T to 0.25T. Therefore, when the vertical magnetic poles 3 are not provided with exciting coils 2, an intense magnetic field

can be formed in the area covered by the vertical magnetic poles 3 by connecting the vertical magnetic poles 3 with the horizontal magnetic poles and using the exciting coils 2 of the horizontal magnetic poles 1, so that the purpose of controlling molten steel flow in the mold 7 is realized.

Embodiment II

[0040] In the embodiment, the V-EMBr device as shown in Fig.1 is adopted. In order to observe the level fluctuations in the mold 7 more intuitively, molten metal of low-melting-point alloy SnPbBi is selected as the test object. The connection manner as shown in Fig.3(b) is adopted for the vertical magnetic poles 3 and the horizontal magnetic poles 1, the height of the vertical magnetic poles 3 enables the vertical magnetic poles 3 to cover the area from the molten steel surface 6 on the side of the mold 7 to the impact point of the molten steel flowing out of the submerged nozzle 4 and the area below the horizontal magnetic poles 1, the thickness of the mold 7 is 100 mm, the half width size of the mold 7 is 600 mm, the height of the vertical magnetic poles 3 is 440 mm, the side hole inclination of the submerged nozzle 4 is -15 degrees, the immersion depth of the submerged nozzle 4 is 100 mm, and the casting speed is 1.27 m/min.

[0041] A current is applied to the exciting coils 2 of the horizontal magnetic poles 1, so that a magnetic field about 0.28 T is formed in the mold 7 in the middle of one pair of vertical magnetic poles 3. The level fluctuations of molten metal close to the sides of the mold with/without electromagnetic braking are as shown in Fig.8(a) and Fig.8(b).

[0042] As shown in Fig.8(a), without magnetic field, namely without electromagnetic braking, the upward reflux rate of the molten metal is large, the molten metal surface is suppressed by the intense impact and disturbance, and the width of the fluctuation area of the molten metal surface reaches about 2/3 of the entire section. As shown in Fig.8(b), when the magnetic induction intensity reaches about 0.28T, the molten metal surface tends to be stable, the fluctuations are obviously reduced, and the width of the fluctuation area of the molten metal surface is reduced to 1/3 of the entire section. Therefore, the V-EMBr device of the invention can effectively inhibit the level fluctuations close to the sides of the mold and is beneficial for preventing slag entrapment.

Embodiment III

[0043] In the embodiment, the V-EMBr device as shown in Fig.1 is adopted, and the connection manner shown in Fig.3(c) is adopted for the vertical magnetic poles 3 and the horizontal magnetic poles 1. The height of the vertical magnetic poles 3 below the horizontal magnetic poles 1 is 0 mm, the vertical magnetic poles 3 cover the area from the molten steel surface 6 on the sides of the mold 7 to the impact point of the molten steel flowing

out of the submerged nozzle 4 and the area below the horizontal magnetic poles 1 in the height, the section size of the mold 7 is 1400 mm×230 mm, the side hole inclination of the submerged nozzle 4 is -15 degrees, the immersion depth of the submerged nozzle 4 is 170 mm, and the casting speed is 1.6 m/min.

[0044] As a current of 850A is applied to the exciting coils 2 of the horizontal magnetic poles 1, the internal magnetic field distribution diagram of molten steel in the mold 7 is as shown in Fig.9, the molten steel flow field distribution diagram in the central section of the sides of the mold with/without electromagnetic braking is shown in Fig.10(a) and Fig.10(b), and the molten steel surface velocity distribution diagram in the central section of the sides of the mold with/without electromagnetic braking is shown in Fig.11.

[0045] As shown in Fig.9, the magnetic induction intensity in the molten steel is mainly concentrated in the area covered by the horizontal magnetic poles 1 and the vertical magnetic poles 3, the magnetic induction intensity in the area covered by the horizontal magnetic poles 1 with the exciting coils 2 is the strongest and reaches 0.356T to maximum, and the magnetic induction intensity in the area covered by the vertical magnetic poles 3 is about 0.2-0.3T. Therefore, when the vertical magnetic poles 3 are not provided with exciting coils 2, an intense magnetic field can be produced in the area covered by the vertical magnetic poles 3 by connecting the vertical magnetic poles 3 with the horizontal magnetic poles 1 and using the exciting coils 2 of the horizontal magnetic poles 1, so that the purpose of controlling molten steel flow in the mold 7 is realized.

[0046] As shown in Fig.11, under the condition of electromagnetic braking, the maximum velocity of molten steel surface in the mold 7 is reduced from 0.5 m/s to about 0.38 m/s. Besides, as shown in Fig.10(b), the molten steel flow in the entire width side of the mold 7 below the horizontal magnetic poles 1 forms a plug flow, which obviously reduces the impact depth of downward reflux molten steel. The downward reflux vortex formed without electromagnetic braking would disappear (the downward reflux vortex is obviously shown in Fig.10(a), which is good for the floating of inclusions and bubbles. Therefore, the vertical electromagnetic braking device of the invention can effectively control the level fluctuations on the sides of the mold and the molten steel surface velocity, and can also control the downward flow of molten steel in the central area of the mold 7.

[0047] The scheme in the embodiments is not intended to limit the patent protection scope of the invention, and any equivalent embodiment or change which is made without deviating from the invention shall belong to the patent scope of the invention.

Claims

1. A vertical electromagnetic braking device for control-

ling molten steel flow in a continuous casting mold, **characterized by** comprising one pair of horizontal magnetic poles, exciting coils, two pairs of vertical magnetic poles and a magnet yoke. Additionally, one pair of the horizontal magnetic poles is located below a submerged nozzle and set up along the whole width side of a mold. Two pairs of the vertical magnetic poles are set up near the two side areas of the mold respectively, and the two pairs of the vertical magnetic poles intersect with one pair of the horizontal magnetic poles. The exciting coils and the magnet yoke are mounted to match with the horizontal magnetic poles. As a current is applied through the exciting coils, a steady magnetic field is formed between the horizontal magnetic poles and the vertical magnetic poles. The molten steel which flows in the mold is suppressed by the electromagnetic force as the molten steel flows through the steady magnetic field, wherein the direction of the electromagnetic force is opposite to the flowing direction of the molten steel, so that the molten steel in the mold is controlled through the electromagnetic force.

2. The vertical electromagnetic braking device for controlling molten steel flow in a continuous casting mold, **characterized by** comprising two pairs of horizontal magnetic poles, exciting coils, two pairs of vertical magnetic poles and a magnet yoke, wherein one pair of the horizontal magnetic poles is located below a submerged nozzle, which is set up along the whole width side of mold and marked as lower horizontal magnetic poles. Another pair of the horizontal magnetic poles is located near a molten steel surface of the mold, which is set up along the whole width side of the mold and marked as upper horizontal magnetic poles. Two pairs of the vertical magnetic poles are set up near the two side areas of the mold respectively, and intersect with two pairs of the horizontal magnetic poles. The exciting coils and the magnet yoke are mounted to match with the horizontal magnetic poles. As a current is applied via the exciting coils, a steady magnetic field is formed between the horizontal magnetic poles and the vertical magnetic poles. The molten steel which flows in the mold is suppressed by the electromagnetic force as the molten steel passes through the steady magnetic field, wherein the direction of the electromagnetic force is opposite to the flowing direction of the molten steel, so that the molten steel in the mold is controlled through the electromagnetic force.

3. The vertical electromagnetic braking device for controlling molten steel flow in a continuous casting mold, according to claim 1, **characterized in that** the connection manner of two pairs of the vertical magnetic poles and one pair of horizontal magnetic poles is as below:

- (1) The vertical magnetic poles are vertically in-laid on the horizontal magnetic poles.
- (2) The vertical magnetic poles are vertically connected with the horizontal magnetic poles on the upper surfaces and the lower surfaces of the horizontal magnetic poles respectively.
- (3) The vertical magnetic poles are vertically connected with the horizontal magnetic poles only on the upper surfaces of the horizontal magnetic poles.
- (4) The vertical magnetic poles are vertically connected with the horizontal magnetic poles only on the lower surfaces of the horizontal magnetic poles.
4. The vertical electromagnetic braking device for controlling molten steel flow in a continuous casting mold, according to claim 2, **characterized in that** the connection manner of two pairs of the vertical magnetic poles and two pairs of the horizontal magnetic poles is as below:
- (1) The vertical magnetic poles are vertically in-laid on the upper horizontal magnetic poles and the lower horizontal magnetic poles respectively.
- (2) The vertical magnetic poles are vertically in-laid only on the lower horizontal magnetic poles.
- (3) The vertical magnetic poles are vertically in-laid only on the upper horizontal magnetic poles.
- (4) The vertical magnetic poles are vertically in-laid on the upper horizontal magnetic poles, and the vertical magnetic poles are vertically connected with the horizontal magnetic poles on the lower surfaces of the lower horizontal magnetic poles.
- (5) The vertical magnetic poles are vertically connected with the horizontal magnetic poles on the upper surfaces and the lower surfaces of the lower horizontal magnetic poles respectively.
- (6) The vertical magnetic poles are vertically connected with the horizontal magnetic poles only on the upper surfaces of the lower horizontal magnetic poles.
- (7) The vertical magnetic poles are vertically connected with the horizontal magnetic poles on the lower surfaces of the upper horizontal magnetic poles, and are vertically connected with the horizontal magnetic poles on the lower surfaces of the lower horizontal magnetic poles 1.
- (8) The vertical magnetic poles are vertically connected with the horizontal magnetic poles on the lower surfaces of the upper horizontal magnetic poles.
5. The vertical electromagnetic braking device for controlling molten steel flow in a continuous casting mold, according to claim 3 or 4, **characterized in that** the height of the vertical magnetic poles is required to cover the area from 100 mm above the molten steel surface in the mold to 1000 mm below.
6. The vertical electromagnetic braking device for controlling molten steel flow in a continuous casting mold, according to claim 3 or 4, **characterized in that** the width range of the vertical magnetic poles is 50 mm-400 mm.
7. The vertical electromagnetic braking device for controlling molten steel flow in a continuous casting mold, according to claim 3 or 4, **characterized in that** the magnetic induction intensity of the steady magnetic field between the horizontal magnetic poles and the vertical magnetic poles is 0.01T-3T.
8. The vertical electromagnetic braking device for controlling molten steel flow in a continuous casting mold, according to claim 3 or 4, **characterized in that** according to the width adjustment change of the mold and actual requirements for controlling the molten steel flow, the combination position of the vertical magnetic poles and the horizontal magnetic poles is freely selected in the width direction of the mold.

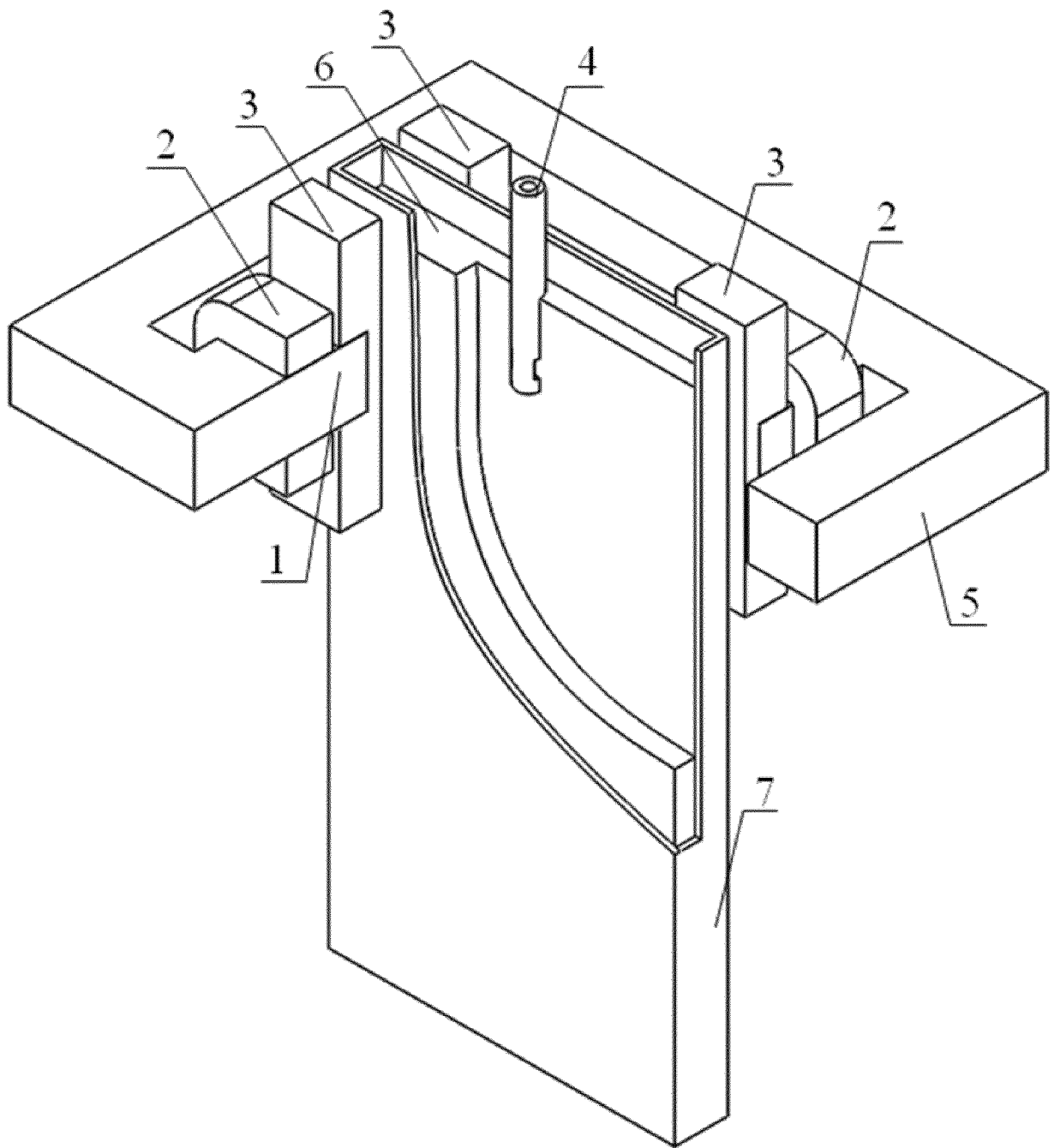


Fig.1

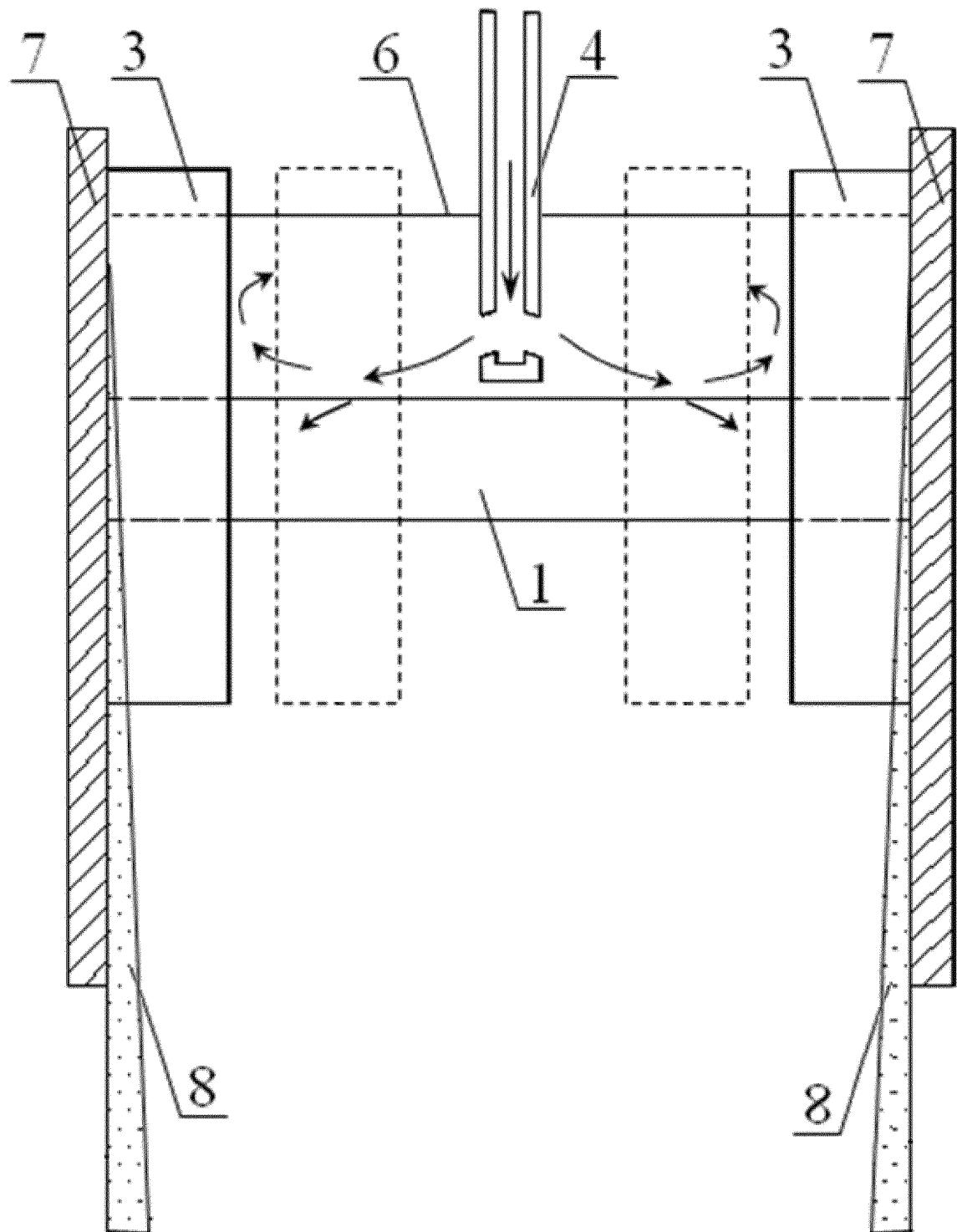


Fig.2

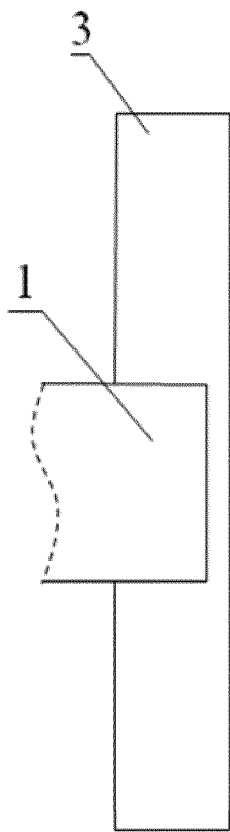


Fig.3(a)

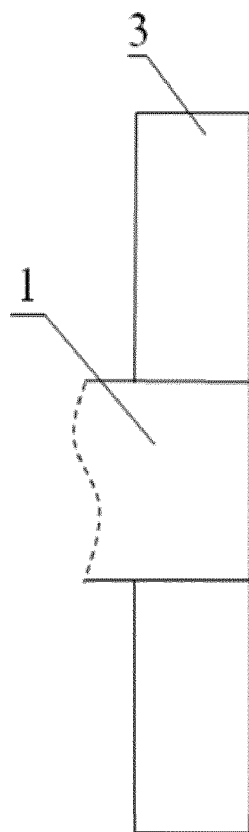


Fig.3(b)

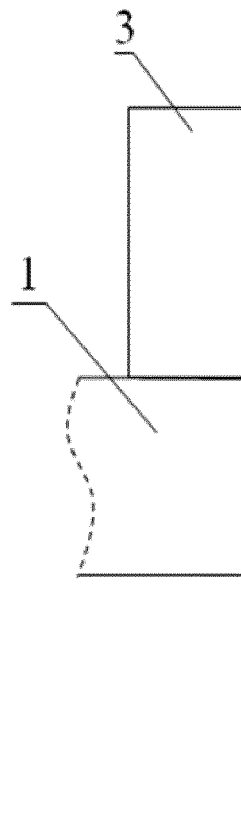


Fig.3(c)

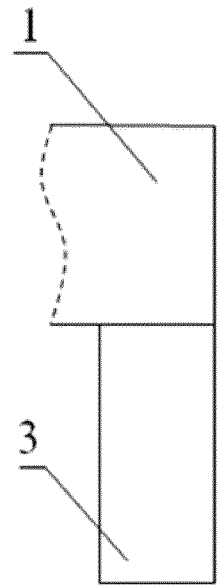


Fig.3(d)

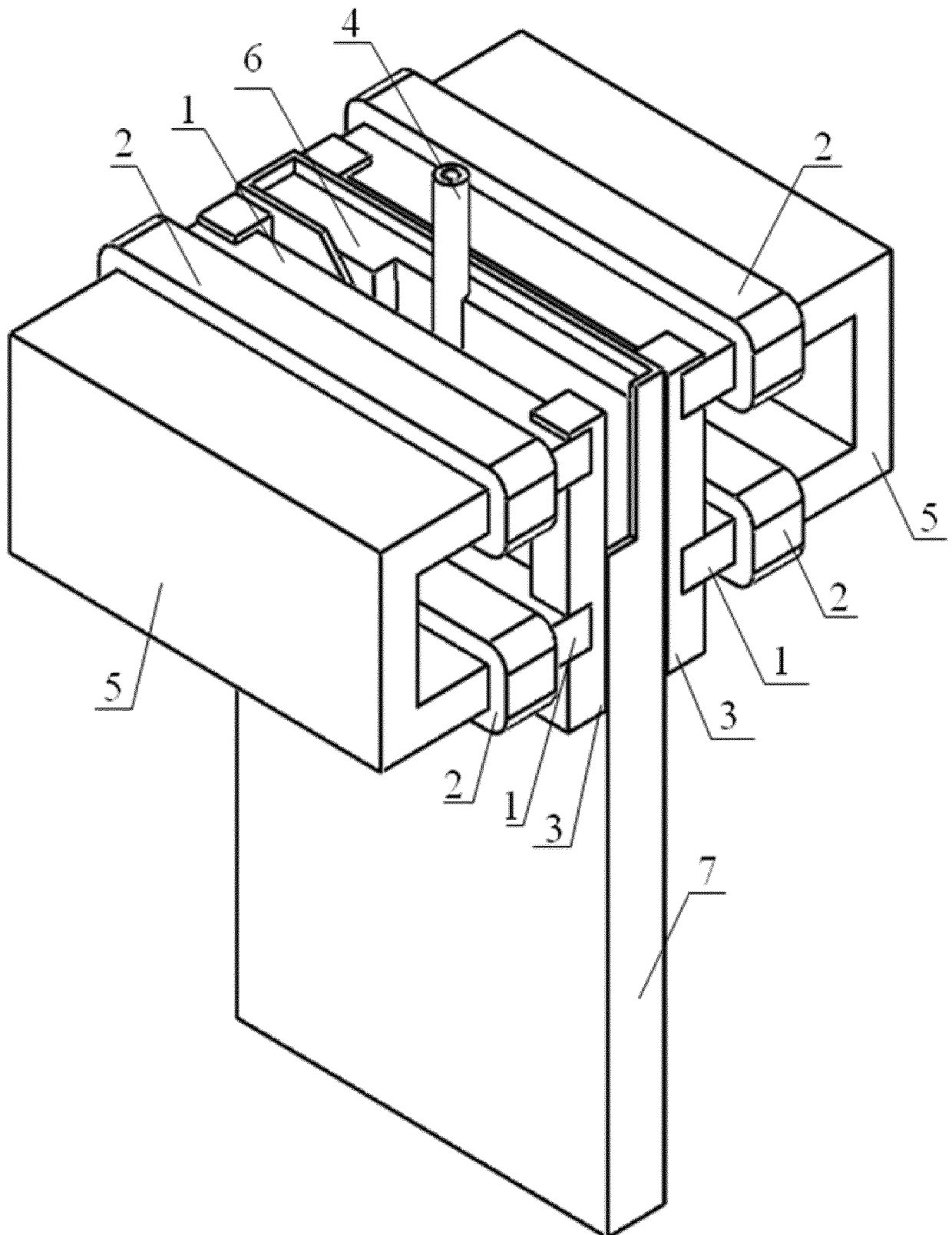


Fig.4

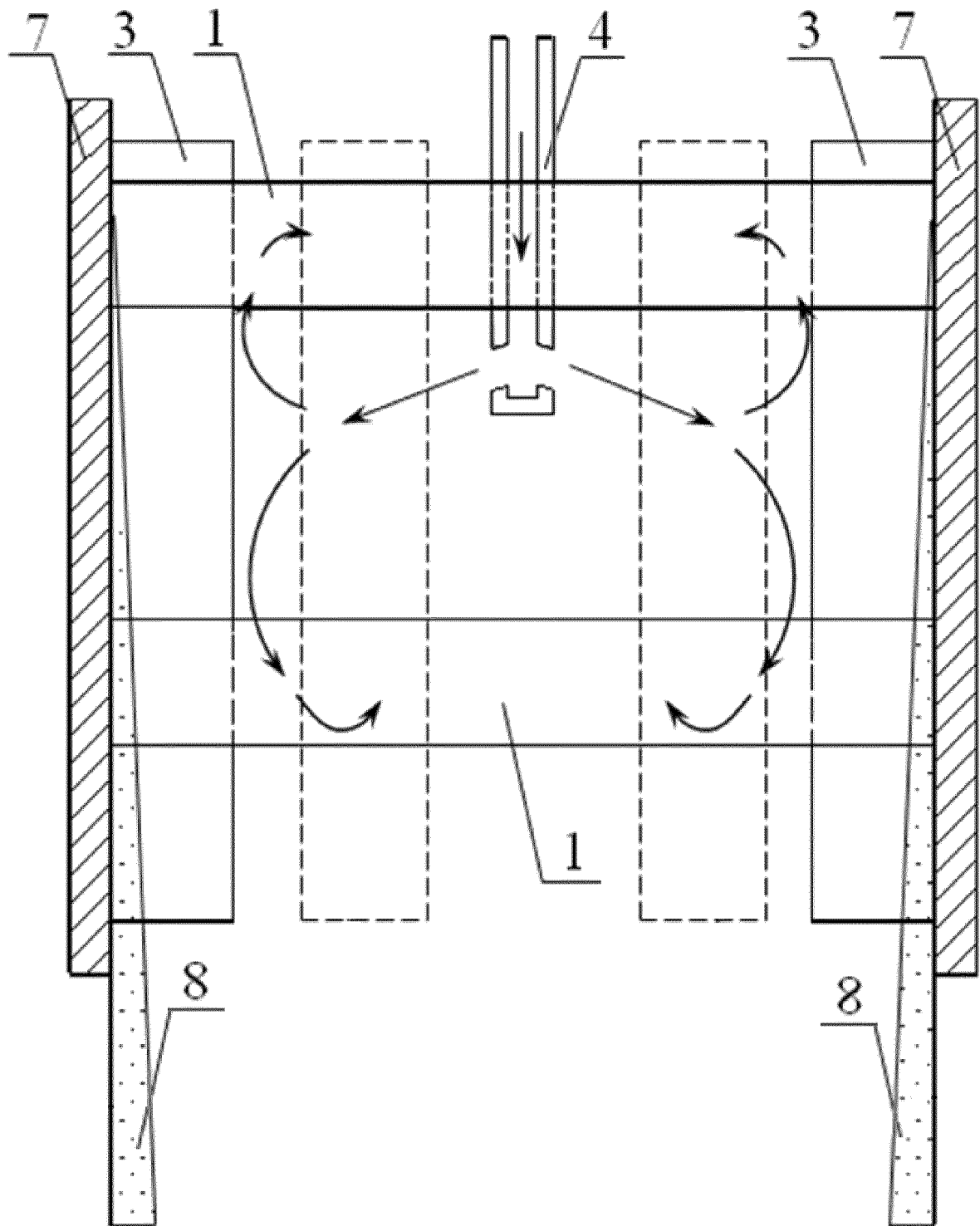


Fig.5(a)

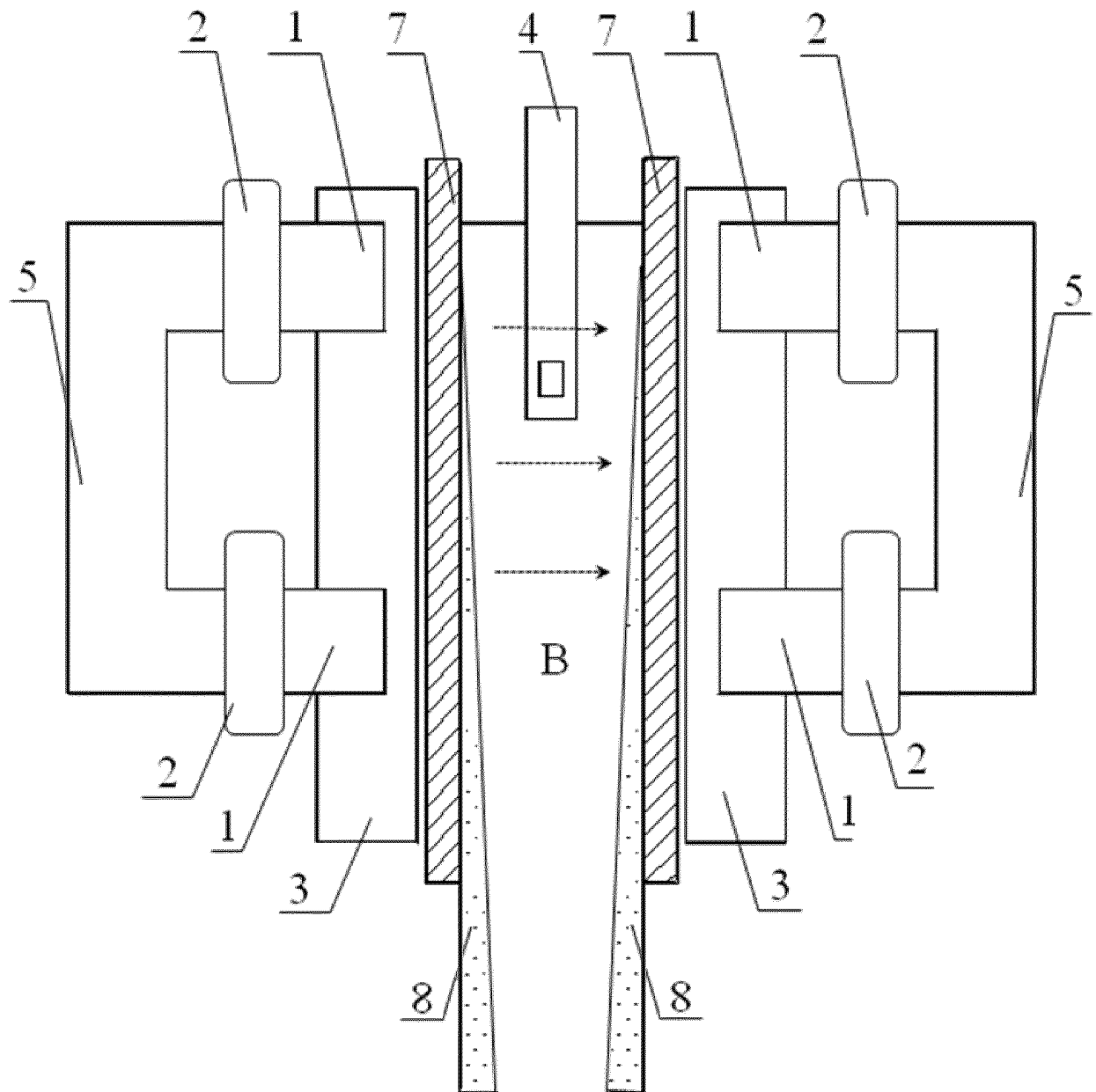


Fig.5(b)

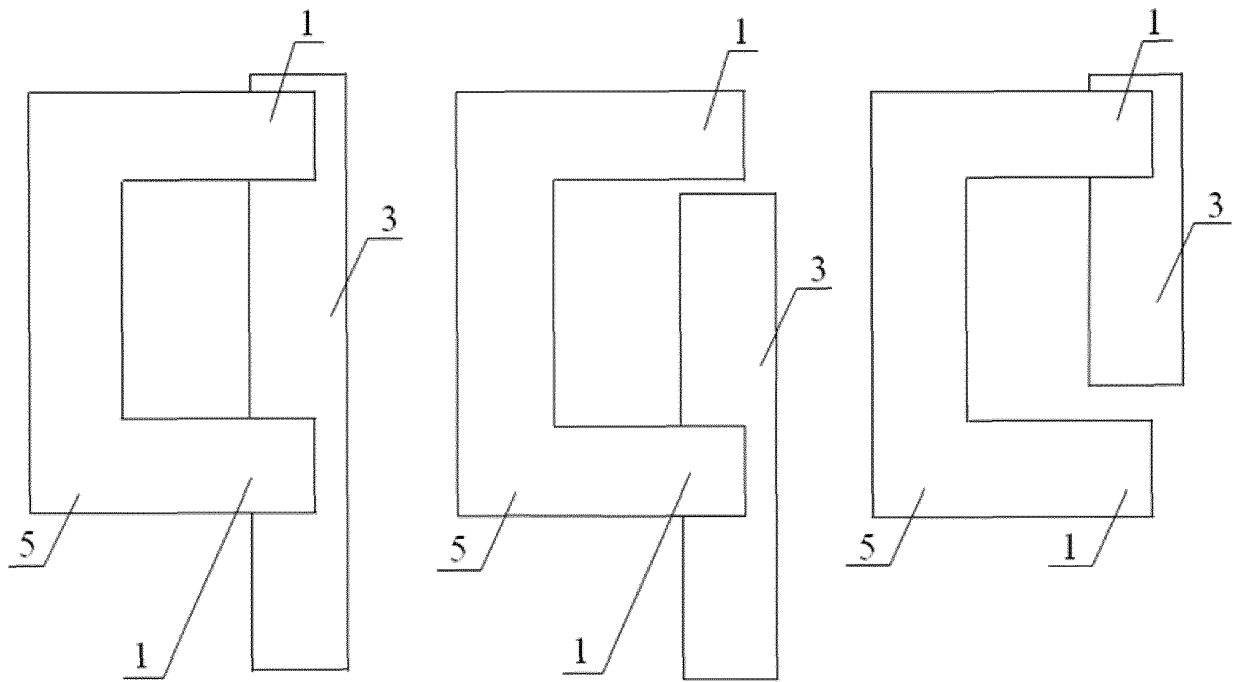


Fig.6(a) Fig.6(b) Fig.6(c)

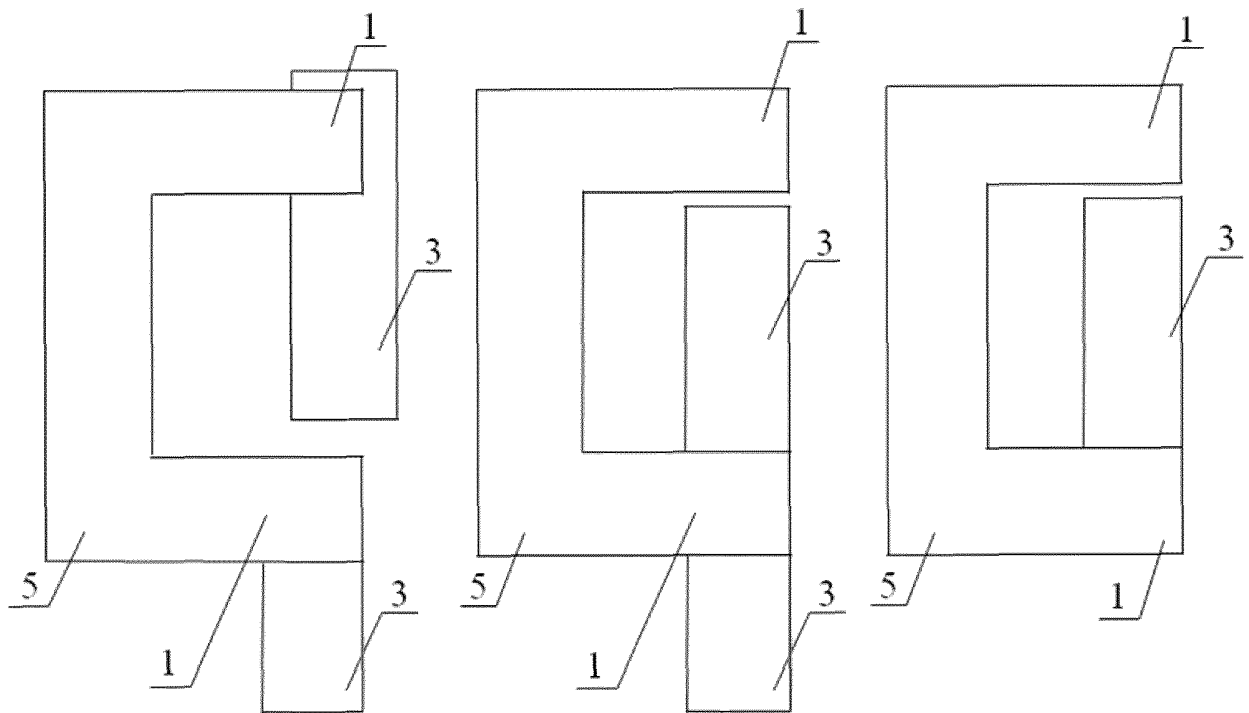


Fig.6(d)

Fig.6(e)

Fig.6(f)

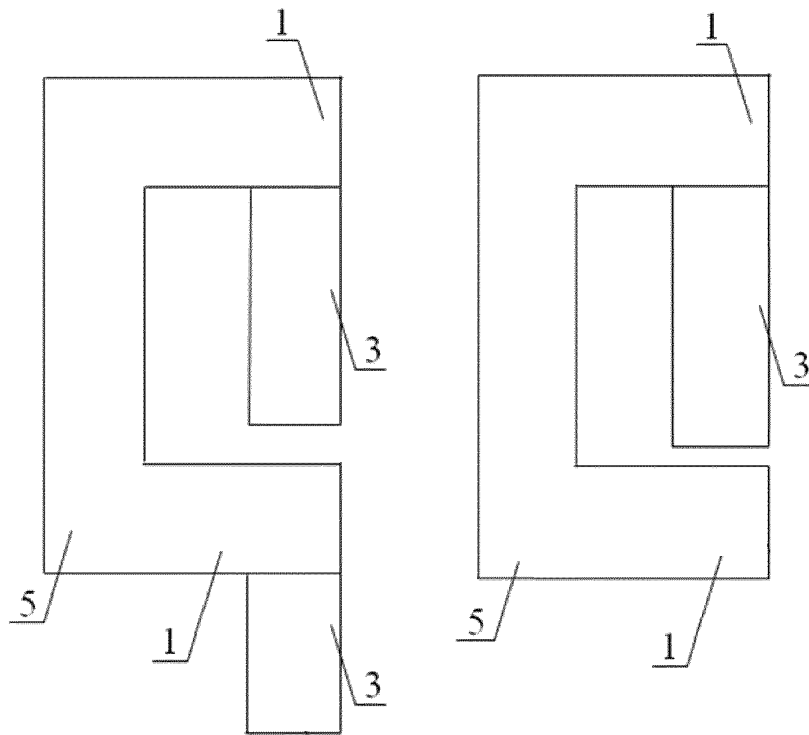


Fig. 6(g)

Fig. 6(h)

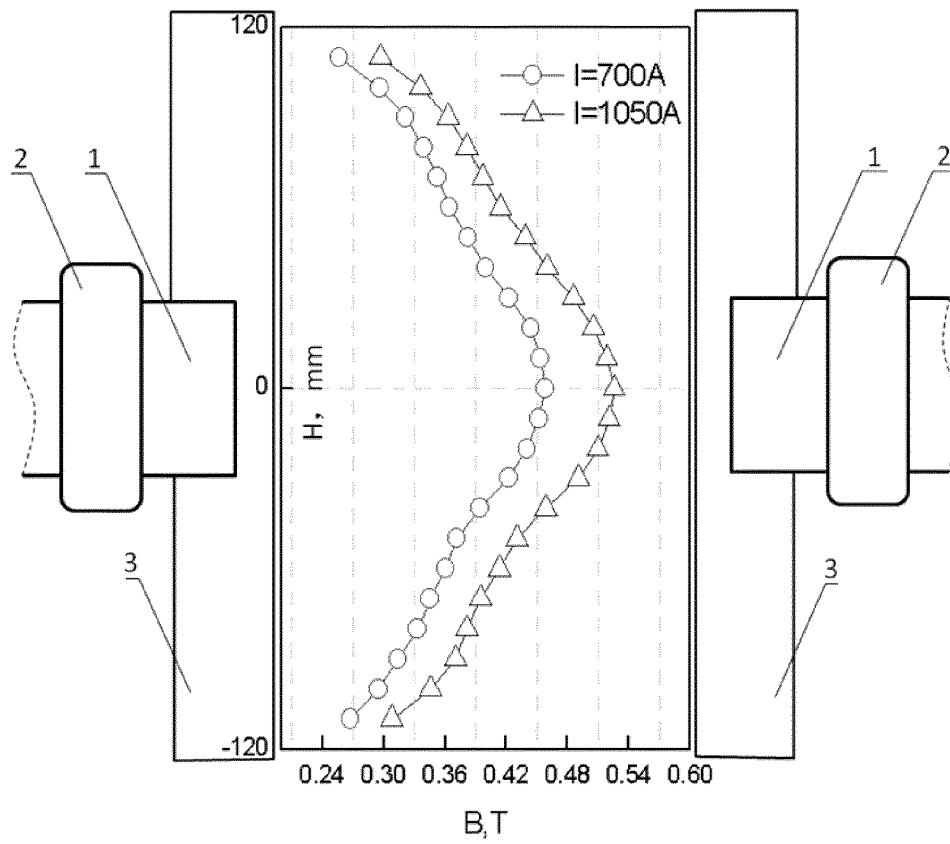


Fig. 7

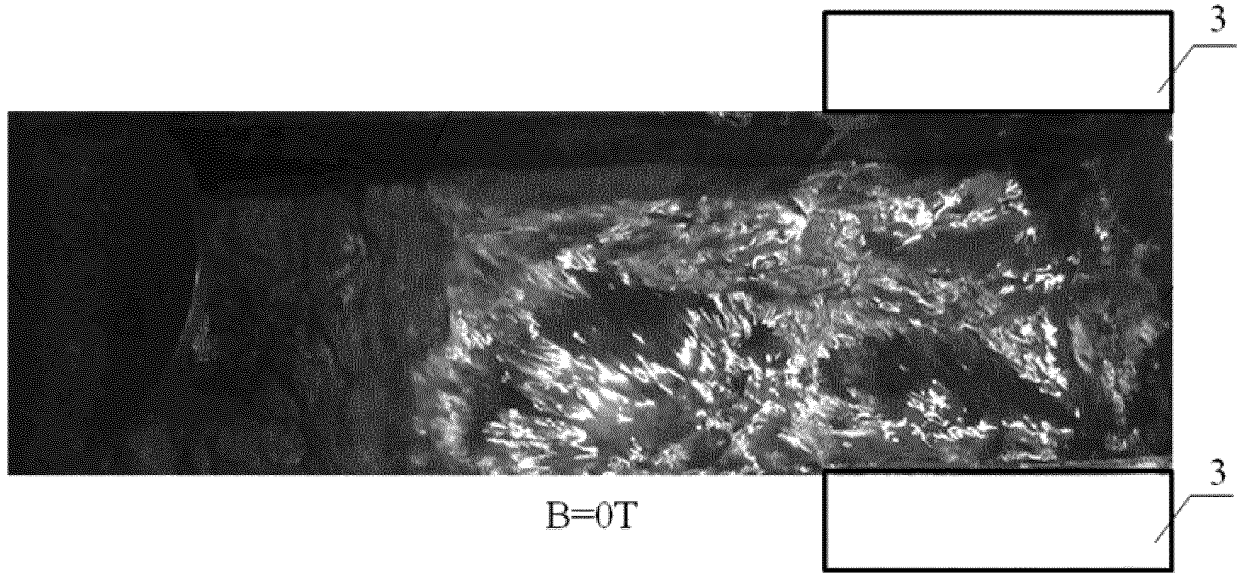


Fig.8(a)

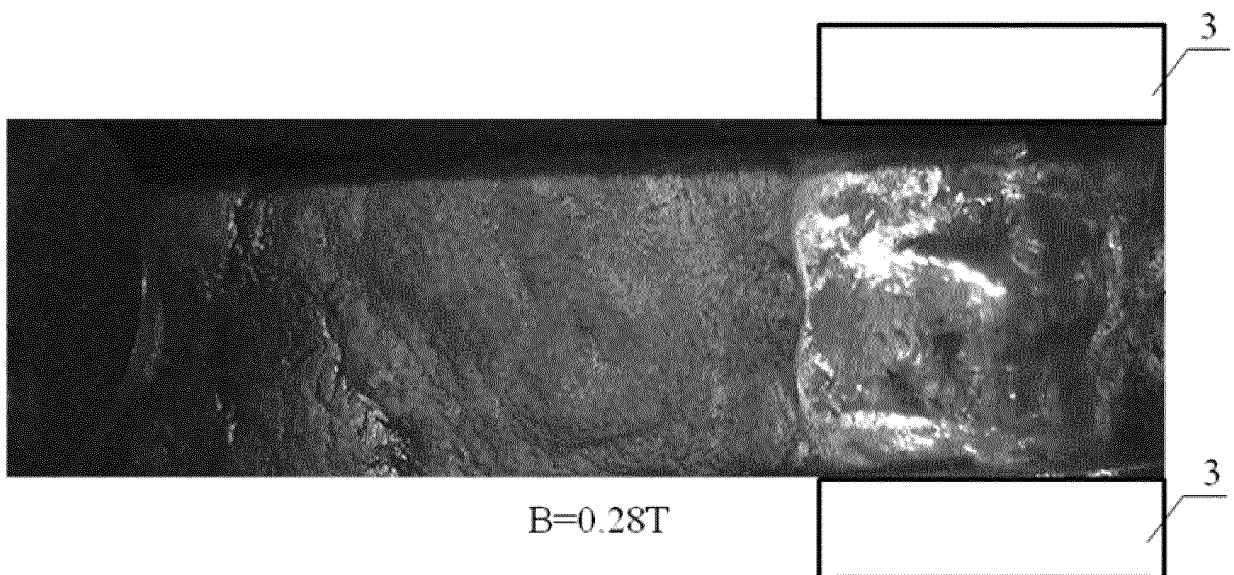


Fig.8(b)

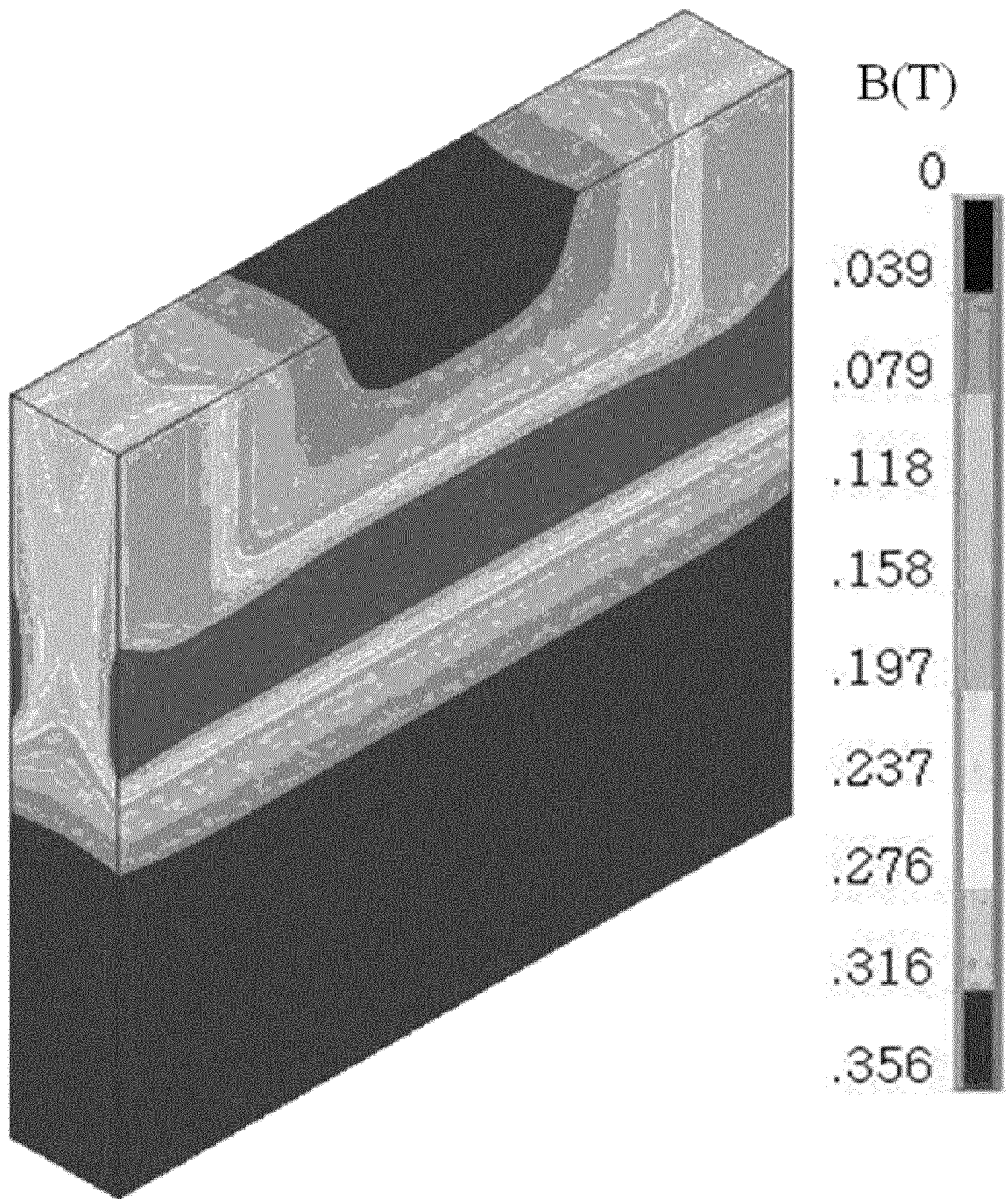
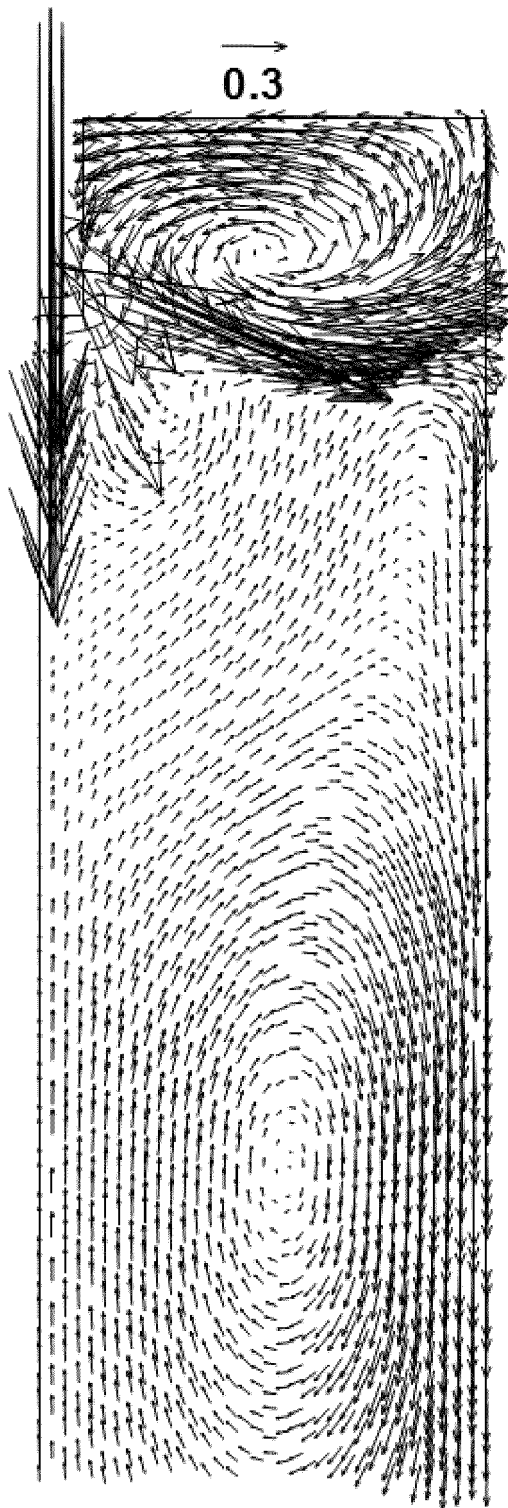
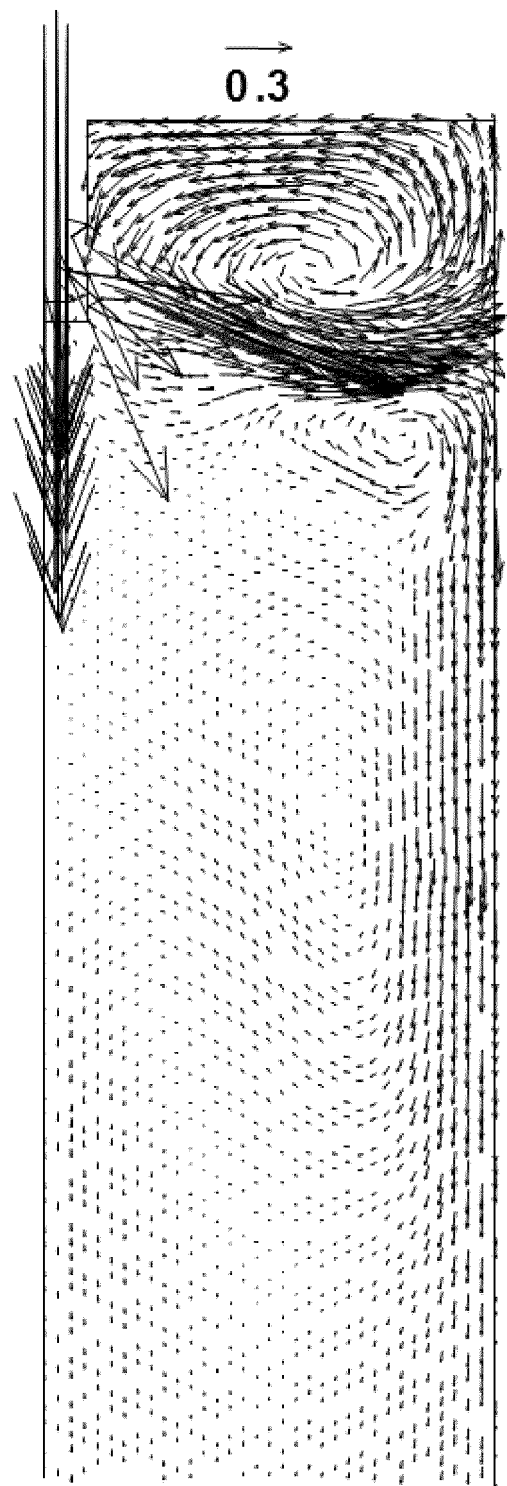


Fig.9



$I=0A$

Fig.10(a)



$I=850A$

Fig.10(b)

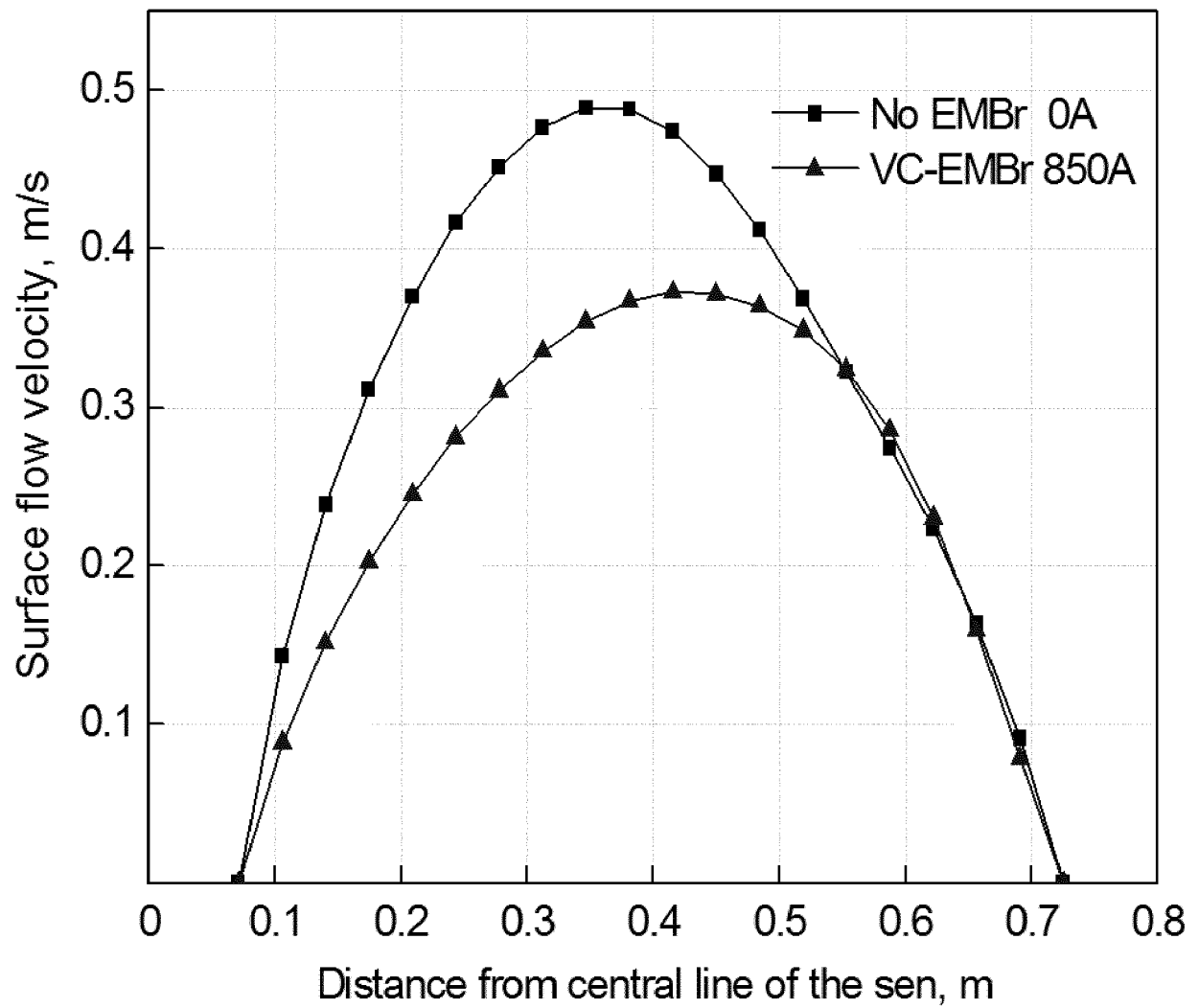


Fig.11

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2017/087116

A. CLASSIFICATION OF SUBJECT MATTER

B22D 11/16 (2006.01) i; B22D 11/11 (2006.01) i

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/+

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)

CNPAT, CNKI, WPI, EPODOC: crystallizer, magnet yoke, perpendicular, vertical, upright, horizontal, magnetic pole, magnet core, steel liquid, molten metal; WANG, Engang; LI, Zhuang; XU, Lin; LI, Fei; DENG, Anyuan; ZHANG, Xingwu; melt, flow+, dur+, magnet+, induct+, core+, coil+, pole

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PX	CN 106041009 A (NORTHEASTERN UNIVERSITY), 26 October 2016 (26.10.2016), the whole document	1-8
X	CN 203621423 U (UNIVERSITY OF SCIENCE & TECHNOLOGY BEIJING), 04 June 2014 (04.06.2014) description, particular embodiments, and figures 1-2	1-8
A	CN 102436900 A (SUN, Zutong), 02 May 2012 (02.05.2012), the whole document	1-8
A	US 2016052050 A1 (PAVLOV, E.), 25 February 2016 (25.02.2016), the whole document	1-8
A	CN 1234756 A (KAWASAKI STEEL CORPORATION), 10 November 1999 (10.11.1999), the whole document	1-8
A	WO 9626029 A1 (ASEA BROWN BOVERI AB), 29 August 1996 (29.08.1996), the whole document	1-8

☐ Further documents are listed in the continuation of Box C.
 ☒ See patent family annex.

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"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"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
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 14 August 2017 (14.08.2017)	Date of mailing of the international search report 25 August 2017 (25.08.2017)
Name and mailing address of the ISA/CN: State Intellectual Property Office of the P. R. China No. 6, Xitucheng Road, Jimenqiao Haidian District, Beijing 100088, China Facsimile No.: (86-10) 62019451	Authorized officer GUO, Lei Telephone No.: (86-10) 010-61648082

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

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/CN2017/087116

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