

[54] **ELECTROMAGNETIC VALVE MEANS FOR TAPPING MOLTEN METAL**  
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[22] Filed: **Sept. 23, 1969**

[21] Appl. No.: **860,253**

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[30] **Foreign Application Priority Data**

Sept. 30, 1968	Sweden .....	13158/68
June 16, 1969	Sweden .....	8512/69

[52] U.S. Cl. .... **137/81.5**  
 [51] Int. Cl. .... **F15c 1/04**  
 [58] Field of Search ..... 137/81.5, 247, 251; 417/50

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[57] **ABSTRACT**

Valve means for ladles or furnaces, preferably of channel type, provided with at least one bottom tap hole. This means comprises a magnetic circuit with an "air gap" in the hole and with a flux direction straight across the flow direction in said hole. Current conductors are also arranged to conduct electric current straight across the stream, perpendicular to the flux, and a force is thus produced in the melt in the hole directed upwards or downwards and depending on the law of magnetic force. The invention also includes an embodiment with similar means in a channel type furnace, but used for circulating molten metal in the channels of the furnace.

**6 Claims, 10 Drawing Figures**

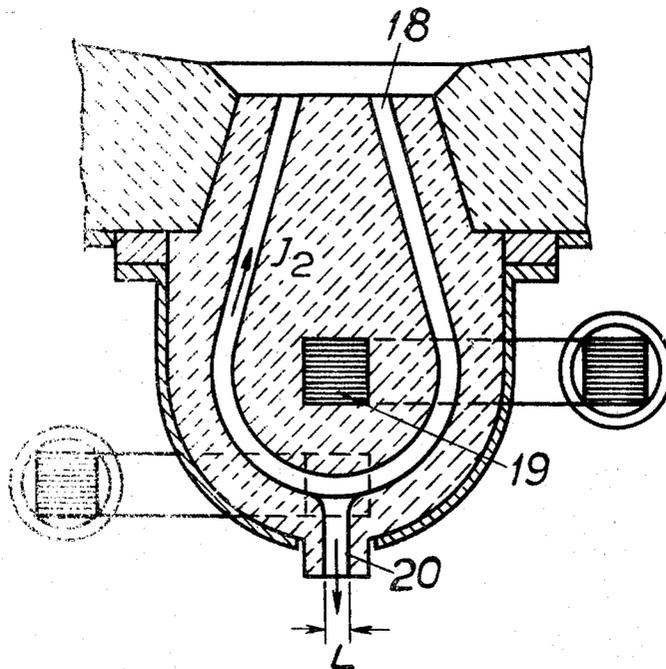


Fig 1

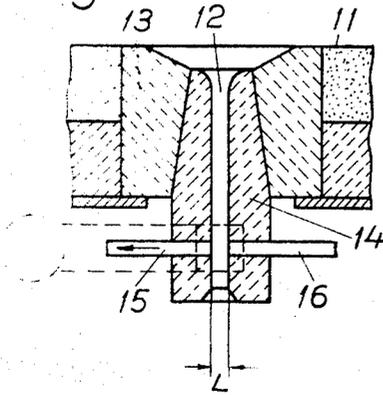


Fig 2

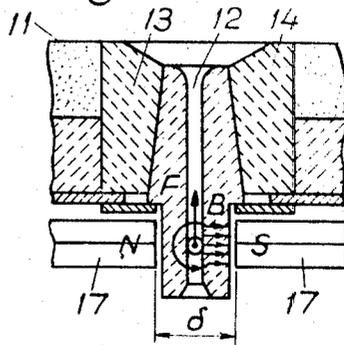


Fig 3

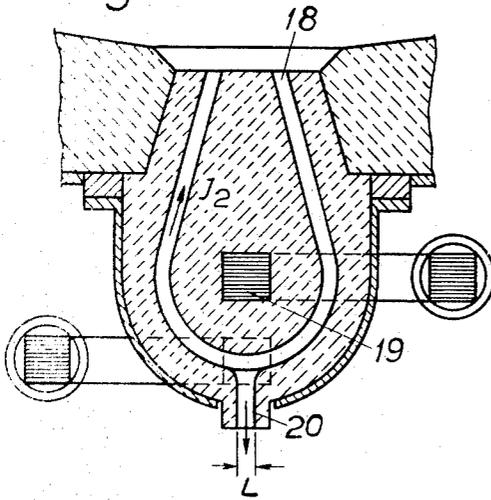


Fig 4

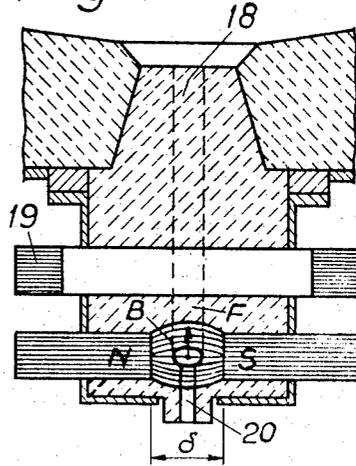
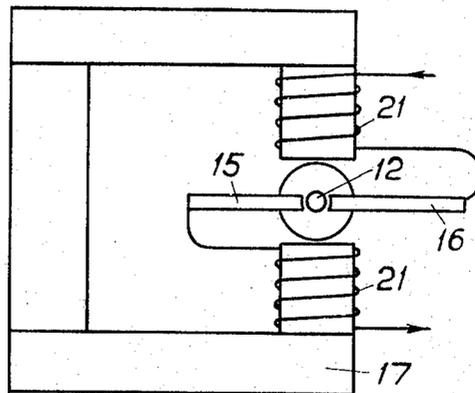


Fig 5



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Fig.6

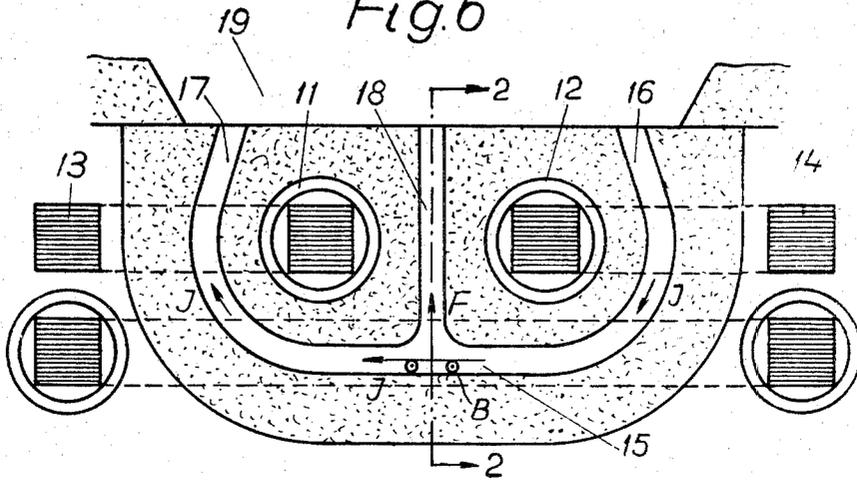


Fig.7

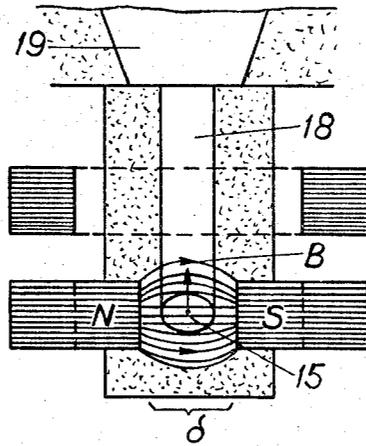
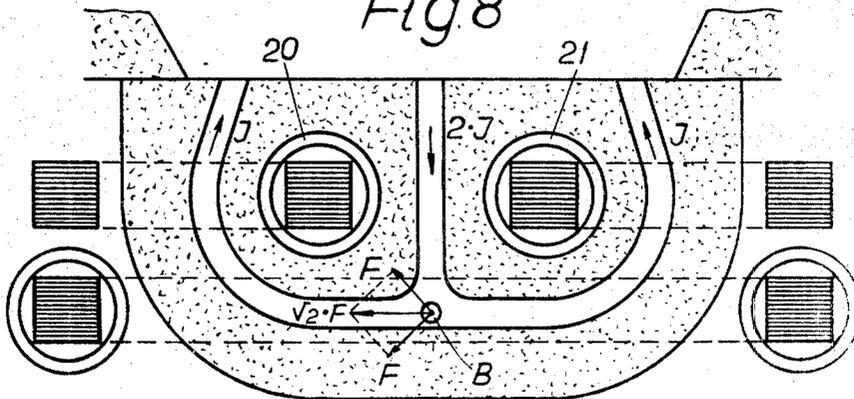


Fig.8



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Fig. 9

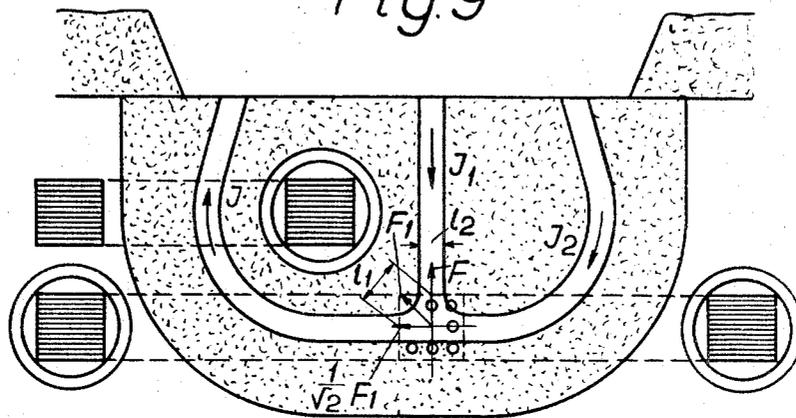
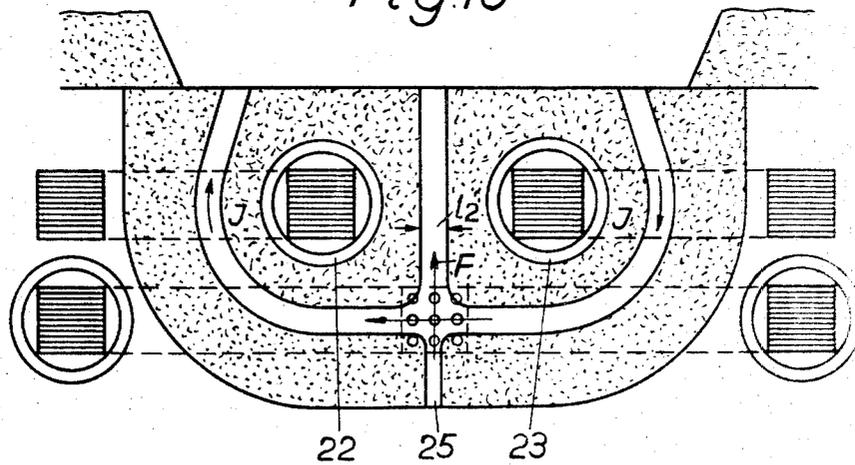


Fig. 10



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## ELECTROMAGNETIC VALVE MEANS FOR TAPPING MOLTEN METAL

### BACKGROUND OF THE INVENTION

The present invention relates, among other things, to an electro-magnetic valve for tapping off molten metal or alloy from the bottom of a ladle or furnace.

Tapping of ladles and furnaces is often carried out through a hole in the bottom which can be closed by a rod operated from above or by a slidable or turnable valve. Certain difficulties arise in controlling the tapping speed near these various valves and there may be considerable wear on the parts.

### STATEMENT OF THE INVENTION

The invention aims at a solution of these and other similar problems and is characterized in that the tapping hole has a magnetic circuit arranged near to it, having a flux direction straight across the flow and an "air gap" in this, and that a current conductor, similarly in contact with (through) the flow, is arranged straight across the flow and substantially perpendicular to the flux direction so that when current is flowing and there is a magnetic field in the flow, a force is produced on the melt in the flow according to the law of magnetic force, directed either with or against the flow.

### DESCRIPTION OF PREFERRED EMBODIMENT

The law of magnetic force (Biot-Savart's law) states that the force  $d\vec{F}$ , operating on a piece of a small current path ( $d\vec{s}_1$ ) in a foreign induction field  $\vec{B}$  is equal to  $I \cdot d\vec{s}_1 \times \vec{B}$  where  $I$  is the current strength in the conductor. In simplified form it may be said that  $\vec{F}_1 = I_1 \cdot d\vec{s}_1 \times \vec{B}$ , where  $\vec{F}_1$  is the operating force in vector form,  $d\vec{s}_1$  is the vector form of the current path in the flow of melt and  $\vec{B}$  is the magnetic field. The force  $F_1 (= B \cdot I \cdot L$ , where  $L$  is the length of the flow in the current conductor) will thus be perpendicular to both the current conductor (in the flow) and the flux and thus directed upwards or downwards along a flow of melt in a tapping hole in a ladle or furnace. By giving the current and the field such direction that the force is directed upwards it is possible by varying the field or the current strength (with alternating current the phase angle between current in the winding and current in the current conductor) to vary the flow in the tapping hole without using metallic or ceramic parts to throttle the flow of metal, etc., and in this way also the valve according to the invention may have a very long life. The invention can also be used for furnaces, for example crucible furnaces with tapping holes in the bottom or channel-type induction furnaces, where the channel in the inductor is provided with a tapping hole for the melt where an electro-magnetic valve can be placed to restrict the flow of the melt.

The invention is exemplified in the accompanying drawings in which FIGS. 1 and 2 show a bottom valve with electrodes for a ladle and FIGS. 3 and 4 a bottom valve with a channel, whereas FIG. 5 shows a principle diagram for coils and current conductors for a valve according to the invention.

The present invention also relates to a modification of this device and is intended for circulation of molten metal in the induction channels of a channel-type induction furnace, which channels consist of at least two

side channels leading from a furnace hearth and at least one bottom channel connecting the bottom parts of these.

In order to prevent local over-heating in channel-type furnace inductors, with consequent damage to the inductor, reduced power output, etc., it is desirable to obtain a so-called unidirectional bath movement in the channels near these inductors. Efforts have been made to achieve this by means of various designs for the channels but these have proved ineffective. Electromagnetic stirrers of multiphase type have also been tried outside the inductor, but it is often difficult to find room for them close to the inductor.

The modification according to the above aims at a solution of these problems in channel-type furnaces. The invention is characterized in that near the junction between the bottom channel and one side channel or near the bottom channel and a vertical channel leading from the middle of this to the hearth, a magnetic circuit is arranged with a flux direction straight across the bottom channel separated from the ordinary heating circuit and having an "air gap"  $\delta$  in the metal melt, and that the side channel or the vertical, central channel is substantially perpendicular to the flux direction so that when current is flowing and there is a magnetic field in the flow of melt a force  $F$  is produced on the melt either in the direction of the bottom channel or in the side or the vertical, central channel, directed upwardly or downwardly along this channel.

According to the law of magnetic force stated previously the force  $F_1$  will thus be perpendicular both to the current conductor (here in the bottom channel) and to the flux and thus directed upwards or downwards along the side or central channel so that a force is obtained which can achieve unidirectional bath movement in the single or double channel system of the channel-type furnace. The ability to alter stirring direction (for example alter field direction) and/or vary its strength makes it possible to vary the flow rate and thus the circulation in the melt, so preventing local over-heating in the melt channels and irregularities in the whole melt. Possibly this bath movement can be combined with vacuum degassing of the melt at its surface in the hearth by in turn subjecting all parts of the melt to the degassing effect.

The present invention also relates to an additional embodiment of the electro-magnetic valve according to the above and relates to tapping off molten metal or alloy from the inductor to a channel-type furnace having at least two side channels and one central channel leading from the bottom channel to the hearth in the channel-type furnace. The valve according to this modification is characterized in that close to the bottom channel near the central channel, near a tapping hole for the melt, a magnetic circuit is arranged with a flux direction straight across the tapping hole and an "air gap"  $\delta$  in the melt, and that when a current is flowing in the melt across the flux direction, a force ( $F$ ) is produced close to the tapping hole on the melt in the central channel and metal flow, directed upwardly or downwardly. Thus the law of magnetic force used in connection with the invention can also be applied to double channel-type furnaces.

FIG. 1 shows the bottom part of a ladle 11 with nozzle 14. A through-hole 12 with conical inlet is located

in a nozzle stone 13. The nozzle 14 and nozzle stone 13 are made of refractory material when necessary.

Current conductors 15, 16 are drawn to the hole 12 which, together with the melt in the tapping hole, form a continuous current conductor which is fed with a certain current strength  $I$ . Perpendicular to this current conductor a magnetic circuit is arranged horizontally with an iron core 17 forming an "air gap" at the tapping flow.

FIG. 2 shows two pole shoes N, S of an electro-magnet fed with direct current, and the flux ( $B$ ) through the air gap  $\delta$  is also shown in this Figure. The current direction in the conductor is shown towards the observer and because of the above-mentioned law of magnetic force a vertical, upwardly directed force  $F$  is obtained on the flow of metal, the strength of which can be varied by varying  $I$  or  $B$ . Thus, by a correct choice of the variants it is possible to completely throttle the flow. In order to prevent the flow of metal becoming frozen one or more special coils may be arranged near it to heat the metal flow. This is specially necessary when there is little or no tapping going on.

By altering the current direction in the current conductor (or the field direction) the direction of  $F$  can be altered and it is possible to accelerate or retard the flow in the tapping hole 12.

As can be seen and is clear from the above, the restriction of the flow of metal is done without the use of mechanical parts. The valve according to FIGS. 1 and 2 can also be used at the bottom of a furnace, for example in a crucible or arc furnace, and in certain cases more than one hole can be used for tapping. It is also possible to combine the valve with known, conventional types of valves.

In FIGS. 3 and 4 an electro-magnetic valve is shown having a channel 18 for the melt, which forms the secondary circuit in a transformer with a primary circuit formed by a coil with iron core 19. A tapping hole 20 is arranged in the lowermost part of the channel. Close to this tapping hole 20 is a magnetic circuit N, S (see FIGS. 3 and 4) and by cooperation of the current  $I_2$  in the channel 18 and the magnetic field  $B$  a force  $F = B \cdot I \cdot L$  is obtained as above, directed upwardly or downwardly depending on the current direction. In this case also the force can be regulated by means of  $I$  or  $B$ . The valve may be included in a channel-type furnace.

Instead of using DC-fed electro-magnets (or permanent magnets), it is also possible to use AC-fed electro-magnets and conductors, in which case the current in the coil or conductor, respectively, should be in phase. This is most easily arranged as shown in FIG. 5, that is by series-connecting the coils 21 for the electro-magnets to the current conductors 15, 16, 12 (12 is the tapping flow). However, by effecting a certain phase angle it is also possible to regulate  $F$ .

$F$  can also be regulated automatically, for example by control from a scales near a lower ladle or intermediate box, from a lower level indicate, etc., so that this is most easily done by means of the current strength ( $I_1, I_2$ ) in the current conductor or through the phase angle (at AC feeding). In certain special cases the control may be done by deflecting the field and current in the current conductor with respect to each other, both horizontally and vertically.

FIG. 6 shows an inductor of double channel-type with either one or two phase fed primary coils electrically connected so that the resultant secondary current is obtained in principle according to FIG. 5. FIG. 7 shows a section along the line 2 — 2 in FIG. 6. FIG. 8 shows an inductor of the same type with either one or two phase fed primary coils being electrically and magnetically so connected that the secondary current in the channel is obtained in principle according to FIG. 8. FIG. 9 shows an alternative embodiment of the inductor according to FIG. 3, one phase fed. FIGS. 6 — 9 refer to the modification of the invention just described above.

FIG. 10 shows an inductor of the double channel type with either one or two phase feeding as before. FIG. 10 refers to the latter modification of the invention.

FIGS. 6 and 7 show an inductor for a channel-type furnace having two primary coils 11, 12 with iron cores so that, in known manner when feeding the primary coils according to the transformer principle, secondary circuits are formed in the inductor channel and thus electric current ( $I$ ) is obtained in these so that the melt is heated. The channels consist of a bottom channel 15 and two side channels 16, 17 leading from the bottom channel to the furnace hearth 19 and a central channel 18 leading between the central part of the bottom channel and the hearth 19. By placing a magnetic flux  $B$  across the bottom channel 15 at the lower opening of the central channel 18 (or at the lower opening of a side channel into the bottom channel, either in single or double channel-type inductors) an air gap  $\delta$  is developed to an AC fed magnet (NS), the flux  $B$  being situated perpendicular to the bottom channel 15 and substantially in phase with the secondary current  $I$  in the channel a force  $F = B \cdot I \cdot L$ , where  $L$  is the length of the part of the melt which is affected by the Flux  $B$ . By varying the flux  $B$  or the second current  $I$  in the channel the force  $F$  can be altered in strength and by altering the direction of  $B$  and  $I$  with respect to each other, the direction of  $F$  can also be changed from downwards to upwards in the central channel (see FIGS. 6 and 7). The force  $F$  can be made sufficiently strong to obtain a unidirectional bath movement upwards in the central channel 18 and thus downwards in the side channels 16, 17, or vice versa.

The magnets (NS) may also be made DC-fed.

FIG. 8 shows a double channel-type inductor with two primary coils 20, 21 which are either one or two phase fed as before. In this case a slightly different force is obtained where a resulting force  $\sqrt{2} \cdot F$  is obtained from the two part-components  $F$  from each current circuit.

If one of the primary coils is omitted an inductor according to FIG. 9 is obtained. The current  $I_1$  is obtained in the central channel and the current  $I_2$  in the right-hand side channel ( $I = I_1 + I_2$ ).  $F_2 = B \cdot I_2 \cdot l_2$  ( $l_2$  width of the central channel)  $F_1 = B \cdot I_1 \cdot l_1$ .  $F_1$  forms about  $45^\circ$  to  $F_2$ . If  $F_1$  and  $F_2$  are added vectorally  $F = \sqrt{2} \cdot F_1 + F_2$  ( $l_1$  is the width of the channel in one plane,  $45^\circ$  to the horizontal plane).

FIG. 10 shows how in a double channel and with feeding as previously by primary coils 22, 23, a force  $F = B \cdot I \cdot L$  is obtained.  $F$  can be directed upwards or downwards and varied from 0 to maximum, thus

enabling tapping through a hole 25 to be varied or stopped.

If the electric current for the electro-magnetic valve (*I* or *B*) should be cut off and thus its restrictive effect cease, the device may be completed by an automatically operating blocking valve or a reserve aggregate for electric current can be automatically connected. (For example a spring-loaded valve, a stop-rod with automatic release, etc.)

The field *B* may also be obtained by means of DC-fed magnets.

The means described above may be varied in many ways within the scope of the following claims. They may be used whenever controlled tapping is required, for example during continuous casting.

We claim:

1. In a furnace of the submerged resistor type having a hearth and one or more channels for the circulation of molten metal between the hearth and channels, where melt in the channel or channels, together with melt in the hearth, forms secondary circuits in which currents may circulate between the hearth and channels induced as a result of transformer action from one or more AC-fed primary coils, an electromagnetic valve for regulating the circulation of molten metal between the hearth and the channels comprising:

means for establishing a magnetic flux through the molten metal in the channel, the flux direction being perpendicular to the direction of the channel,

whereby a force is produced by cooperation between current in the channel and flux in either direction of the channel in dependence of the direction of current and flux in accordance with Biot-Savart's law.

2. A furnace according to claim 1, in which the means is energized with alternating current substantially in phase with the current in the coils, the coils and the means being series-connected.

3. A furnace according to claim 1 intended to circulate molten metal in the inductor channels of a channel-type induction furnace, the channels consisting of at least two side channels leading from a furnace hearth

and at least one bottom channel joining the lower parts of the side channels, characterized in that near the junction between the bottom channel and one side channel or near the bottom channel and a vertical channel leading from the middle of the bottom channel to the hearth, the means is arranged with a flux direction straight across the bottom channel, separated from the ordinary heating circuit and having an "air gap" ( $\delta$ ) in the metal melt, and that the side channel or the vertical, central channel is substantially perpendicular to the flux direction so that when current is flowing and there is a magnetic field in the flow of melt, a force (*F*) is produced on the melt either in the direction of the bottom channel or in the side or the vertical, central channel, directed upwardly or downwardly along this channel.

4. In a furnace as claimed in claim 1, where the channel or channels have a circulation portion and a teeming tap hole and a portion of the channel or channels directed from and towards and the tap hole, said magnetic flux being arranged at the last-mentioned portions of the channel near the circulation portion, thus together with the current in said portion producing a force from or towards said tap hole.

5. A furnace according to claim 4 in which the channel with molten metal comprises the secondary circuit of a transformer, the lowest part containing the tap hole with the magnetic flux perpendicular to the current near the tap hole.

6. An electro-magnetic valve for tapping off molten metal or alloy from the bottom of a furnace of the submerged resistor type according to claim 4, comprising at least one bottom channel and at least two side channels and a central channel leading from the bottom channel to the hearth, characterized in that close to the bottom channel near the central channel, near one or more tapping holes for the melt, one or more magnetic circuits are arranged with a flux direction straight across the tapping holes and having an "air gap" in the melt, and that when a current is flowing in the melt across the flux direction, a force is produced close to the tapping hole on the melt in the central channel and metal flow, directed upwardly or downwardly.

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