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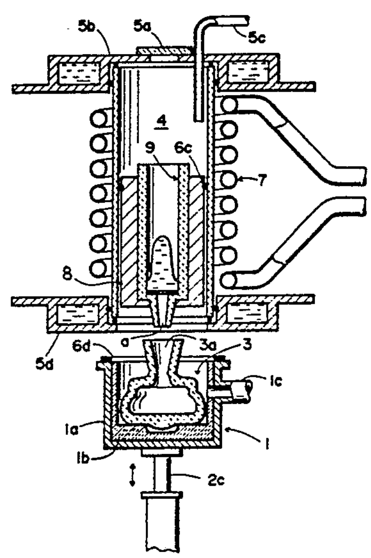
## (54) Method and apparatus for casting a metal.

(57) A method and apparatus for casting a metal, particularly a chemically active metal such as a Ti-Al alloy. The metal is in a heated melting cell (9) in a chamber (4) filled with a non-reactive gas. The heating is effected quickly by means of an induction coil (7). When the metal is molten it flows rapidly into a mould (3) below the melting cell (9) which is sealed to the mould. The mould is made by the lost wax process and is supported in a chamber (1).

FIG. I




EP 0 387 107 A2

# Method And Apparatus For Casting A Metal

The present invention relates to a method and apparatus for casting a metal, and particularly but not exclusively a chemically active metal such as Ti-Al alloy.

Since Ti-Al is lightweight and has a high specific strength, i.e. strength per unit weight, its application fields have been increasing recently. One of the applications is high-speed turbine wheels. Components of this type are generally manufactured by investment casting in which the lost wax process is a typical method.

In the lost wax process, a plurality of wax models, which are similar in shape to the desired finished piece, are made, and these wax models are assembled into a tree. The wax model tree is then dipped into a refractory powder slurry so as to attach the slurry powder to the surface of the wax models. While the slurry is still wet, refractory particles are stuccoed to the slurry. The stuccoed layer is then dried. A cyclic operation consisting of dipping, stuccoing and drying is repeated a plurality of times to form stuccoed layers having a certain thickness on the surface of the wax models. Thereafter, the wax model tree is heated to melt out the wax, and this provides gas-permeable moulds having a predetermined strength. Casting is performed by pouring molten metal obtained by melting a master material having a predetermined alloy composition, into the mould, where the molten metal solidifies in the desired shape. After pouring and cooling, the mould is broken and the cast product is taken out.

Casting of chemically active metals, such as Ti, A1l, Mg., Li or alloys of these metals, by the lost wax process raises certain problems.

These active metals are contaminated to a large degree by the containers which accommodate the molten metals during the melting and pouring processes, resulting in deterioration in the quality of the produced castings. Such containers are made of various types of ceramics which are heat-resistant and corrosion-resistant. In a case where a Ti-Al alloy whose oxygen content is about several hundred ppm is held in and poured from a container made of, for example, alumina, the obtained casting can have an oxygen concentration of several thousand ppm to 1%.

Viewed from one aspect, the present invention provides a method of casting metal in which the metal is melted and poured into a mould, characterised in that the metal is melted in a melting cell whilst exposed to an atmosphere of a relatively inactive gas, the melting being effected rapidly by means of a high frequency induction coil surrounding the cell, and once melted the metal is poured without delay into a mould below the melting cell through a passage effecting a sealed communication between the melting cell and and the mould.

Viewed from another aspect, the present invention provides apparatus for casting a metal including a container for the metal, means for heating the metal in the container, so as to melt the metal and a mould into which the molten metal is poured, characterised in that the container is a melting cell of a refractory material, means are provided for exposing the cell to an atmosphere of a relatively inactive gas, the heating means comprises a high frequency induction coil surrounding the cell, the mould is of a refractory material, and means are provided which establish or which can establish a passage effecting a sealed communication between the melting cell and the mould, the arrangement being such that when metal in the melting cell is molten it can flow rapidly down into the mould which is positioned directly below the cell.

Viewed from a further aspect, the present invention provides apparatus for casting an active metal, characterised in that it comprises a casting chamber in which a mould is disposed, a melting chamber in which an active metal melting cell is disposed, and a high-frequency induction heating coil surrounding said melting chamber; that the casting chamber and the melting chamber are connected with each other in the vertical direction and are hermetically sealed; and that the mould and the melting cell are made of a refractory material, either separately so that they are disposed in the casting chamber and the melting chamber separately, or as connected units or as one unit so that they form an integral member disposed in the casting chamber and the melting chamber.

Viewed from a still further aspect the present invention provides a method of casting an active metal, characterised in that it comprises the steps of: placing a material of the active metal in a melting cell disposed in a melting chamber filled with an inactive gas; melting the active metal rapidly by supplying power of 10 KW or above per 1 kg of the active metal to a high-frequency induction heating coil surrounding the melting chamber; and rapidly pouring thus obtained molten metal into a mould disposed below the melting cell.

Some embodiments of the invention will now be described by way of example and with reference to the accompanying drawings, in which:-

Fig. 1 is a vertical cross-sectional view of an embodiment of a casting apparatus according to the present invention;

Fig. 2 is a vertical cross-sectional view of a melting cell and a mould which are formed as one unit;

Fig. 3 is a vertical cross-sectional view of a mould in which another member is set as an internal chill;

Figs. 4 and 5 respectively show a state where a raw material of an active metal is poured into the melting cell which is manufactured separately from the mould and is connected to the mould;

Figs. 6, 7, 8 and 9 respectively show various types of adjustment of the distribution of an induced magnetic field;

Figs. 10 is a horizontal cross-sectional view of a flux collecting body which is employed in the case shown in Fig. 9, showing the directions of eddy currents;

Fig. 11 is a vertical cross-sectional view of a casting chamber accommodating the mould which is preheated;

Fig. 12 is a vertical cross-sectional view of another example of a connection between the melting cell and the mould; and

Figs. 13 and 14 show a casting method conducted using a combination of melting cell and mould which can be turned up-side down.

Fig. 1 shows an embodiment of a casting apparatus according to the present invention. The casting apparatus has at its lower portion a casting chamber 1, which is a casing 1a with a lining 1b, of an thermal insulating refractory material such as alumina, provided on the inner wall thereof. The casting chamber 1 is supported by a jig 2c in such a manner as to be movable up and down. The casting chamber 1 houses a mould 3. The side of the casting chamber 1 is provided with a suction pipe 1c through which air is evacuated from the casting chamber 1.

The casting apparatus also has in its upper region a melting chamber 4 made of a refractory heat-resistant material such as silica. The melting chamber 4 has an upper opening which is covered by an upper disc-shaped magnetic field shielding plate 5b provided with an inspection window 5a and an gas inlet pipe 5c. The melting chamber 4 also has a lower opening which is surrounded by a ring-shaped lower magnetic field shielding plate 5d. Both the upper and lower magnetic shielding plates 5b and 5d are hollow plates which are made of a conductive material such as copper, and through which a cooling water flows to cool them.

The casting apparatus further includes a high-frequency electric induction heating coil 7 which is disposed in such a manner that it surrounds the portion of the melting chamber 4 which is located between the upper and lower magnetic field shielding plates 5b and 5d. In the melting chamber 4 there are accommodated a flux collector 8 and a melting cell 9 at the centre of the flux collector 8.

The melting chamber 4 can be connected to the casting chamber 1 with a seal 6d as a boundary so that the melting chamber 4 and the casting chamber 1 are hermetically sealed together. This is achieved by pushing up the casting chamber 1 by the operation of jig 2c until the opened end of the casting chamber 1 presses against the upper magnetic field shielding plate 5d with the seal 6d interposed therebetween., At that time, a sprue 9a of the melting cell 9 is also connected to an inlet 3a of the mould 3.

It is preferable for the melting cell to be formed of a refractory material which has high heat-resistance and thermal shock resistance and which is chemically stable and does not contaminate the melted material. Suitable examples include BN, ZrO2, graphite, ZrB2. Among these materials, graphite and ZrB2 are particularly preferable to the melting of the active metal because they are conductive and self-heated when induction heated.

The mould 3 is made by stuccoing, like ones conventionally made by the lost wax process. In the present case, since the mould 3 is used in a state where it is placed and supported within the casting chamber 1, the stuccoed layers need not be so strong as the conventional ones. Two to four stuccoed layers are enough.

In the casting apparatus shown in Fig. 1, the melting cell 9 and the mould 3, which are manufactured separately, are connected to each other for use. However, they may also be manufactured as one unit, as shown in Fig. 2.

If desired, a member, such as an intermediate joining member 3b used When the casting is joined to another member, may be set in the mould 3 as an internal chill, as shown in Fig. 3.

When the casting apparatus is to be operated, raw material of an active metal, which assures a predetermined alloy composition, is placed in the melting cell 9, and the atmosphere within the melting chamber 4 is then replaced by an inactive gas such as an inert gas, e.g. Ar or He, or N2. The type of gas employed is dependent on the type of the metal. Thereafter, power is supplied to the high-frequency induction heating coil 7 to melt the active metal rapidly. At that time, a power level of 10 KW or above per 1 kg of the active metal accommodated in the melting cell 9 is necessary, because it takes a long time to melt the metal if the supplied power is less than 10 KW/kg, during which contamination of the molten metal proceeds.

The magnetic field inducted by the coil 7 is distributed between the upper and lower magnetic field shielding plates 5b and 5d, and over-heating of the casting chamber made of a metal is thereby prevented.

When the active metal, e.g., Ti-Al alloy, is to be melted, a Ti plate 9b having a predetermined thickness may be laid at the sprue 3a of the melting cell 9 to close it, as shown in Figs. 4 and 5. Over the Ti plate 9b are placed pellets of Al 9c, pieces of Ti sponges 9d or Ti-Al scraps 9e. The composition of these raw materials is selected so as to provide the molten metal having a predetermined composition when all of them are melted together. During the induction heating of the raw materials accommodated in the above-described manner, melting of the Ti plate 9b which closes the sprue 9a proceeds from its upper surface to its lower surface, and the plate 9b finally breaks, allowing the already prepared molten metal to be poured into the mold 3 rapidly and all at once, immediately full melting has occurred.

The melting time can be shortened or the Ti plate 9b which closes the sprue 9a can be left unmelted until the last minute when the raw material is placed in the melting cell 9 in the manner shown in Figs. 4 and 5, by adjusting the distribution of the induced magnetic field when the molten metal is to be prepared. In order to effect this, the relative position between the melting cell 9 and the coil 7 may be adjusted in the manner shown in Fig. 6 so that the effective magnetic field G does not reach the bottom of the melting cell 9. In this way, the temperature of the bottom of the melting cell 9 is maintained low.

Furthermore, a cylindrical yoke 10 may be provided around the coil 7 in such a manner that the lower end thereof is aligned with the bottom of the melting cell 9, as shown in Fig. 7. At that time, the effective magnetic field G forms a loop, as shown in Fig. 7, and is weakened at the bottom of the melting cell 9. This keeps the temperature of the bottom of the melting cell 9 lower than that of other portions.

Alternatively, a magnetic field shielding plate 11 may be provided on the outer periphery of the bottom of the melting cell 9, as shown in Fig. 8. In that case, the effective magnetic field can also be weakened at the bottom of the melting cell 9, as in the former cases, thereby maintaining the temperature of the bottom lower.

Fig. 9 illustrates the embodiment where a magnetic collector 12 is provided on the outer periphery of the melting cell 9 so as to weaken the magnetic field at the bottom of the melting cell 9 and thereby delay the melting of the Ti plate 9b as well as to separate a prepared molten metal 13 from the inner wall of the melting cell 9.

Fig. 10 shows the cross-section of the flux collector 12. The flux collector 12 includes a portion 12a which is located between the top of the melting cell 9 and the bottom thereof, and a non-heating portion 12d which corresponds to the portion of the melting cell 9 lower than the bottom thereof. The portion 12a consists of a pluality of heating portions 12c and insulating slits 12b which separate the heating portions 12c from each other. As power is supplied to the coil 7, induced currents p flow in the heating portions 12c to heat them. On the other hand, no current is induced inside of the non-heating portion 12d, so heating of the conductive material would not occur even if it is located inside of the non-heating portion 12d. Also, the magnetic field G formed by the flux collector 12 and the magnetic field G′ formed by the eddy current q generated within the molten metal 12 repel each other, thereby separating the molten metal 13 from the inner wall of the melting cell 9. This results in the reduction in contamination of the molten metal 13 by the cell.

The molten metal 13 of the active metal which is prepared in the manner described above is then poured into the mould 3 from the sprue 9a of the melting cell 9.

During the pouring, a difference between the pressure in the melting chamber 4 and that in the casting chamber 1 may preferably be generated so as to improve the running of the molten metal 13 filling the mould 3, by evacuating air from the casting chamber 1 through the suction pipe 1c and by introducing an inert gas into the melting chamber 4 through the inert gas introducing pipe 5c. The pressure difference may preferably be 10 mm Hg or above. Uniform running of the molten metal 13 may be obtained by vibrating the overall apparatus using, for example, an ultrasonic oscillator or a vibrating motor.

Run of the molten metal may also be improved by employing a casting apparatus shown in Fig. 11. In this apparatus, the inner wall of the casing 1a made of a non-conductive ceramic is provided with the lining 1b made of an insulating refractory material and a heating ring 1d formed of $ZrB_2$, graphite or various heat-resistant conductive materials such as heat-resistant steel. The lining 1b and the heating ring 1d are disposed such that the heating ring 1d encloses the mould 3 and such that the lining 1b surrounds the heating ring 1d. A coil 7′ is disposed outside of the casing 1a so as to preheat the heating ring 1d by the induction heating prior to the pouring of the molten metal and thereby achieve further improvement in the running of the molten metal 13.

In a case where the raw metal is not placed in the melting cell 9 in the manner shown in Figs. 4 and 5, a shutter mechanism shown in Fig. 12 may be interposed between the melting cell and the mould. In fig. 12, the lower opening of the melting cell 9 is sealed by the lower magnetic field shielding plate 5d, and rams 17a and 17b pass through the lower magnetic field shielding plate 5d in such a manner as to be movable to the right and left. A shutter member 18, which is made of the same material as that of the melting cell 9 and which has a larger cross-section than the melting cell 9, is accommodated in space 16 in such a manner as to be slidable within the space 16 to the right and left.

When the active metal is to be melted, the lower opening (the sprue) of the melting cell 9 is closed with the shutter member 18 by moving the rams 17a and 17b.

Thereafter, the raw material is placed in the melting cell 9, and is then melted by the induction heating. When the molten metal is to be poured into the mould 3, the shutter member 18 is pushed aside by operating one of the rams. Consequently, the molten metal existing in the melting cell 9 is poured into the mould 3 through a coupling 14 all at once. In a case where this shutter mechanism is used, it is not necessary to strictly adjust distribution of the magnetic field induced by the coil 7, as in the case where the Ti plate is used.

The casting apparatus may also be designed such that it can be rotated about substantially the central portion thereof in the vertical plane and be turned upside down. Fig. 13 shows such an example. The molten metal 13 is prepared in the melting cell 9 having a bottom which is in a state where it is connected to the inlet 3a of the mould 3 through the coupling 14. When the molten metal is to be poured into the mold 3, the entirety of the apparatus is rotated by 180 degrees, whereby the molten metal 13 flows into the mould 3 all at once, as shown in Fig. 14. Since it takes a very short time for the molten metal 13 to be poured into the mould, the time required for melting the pouring can be shortened.

## EXAMPLE

Hot wheels for a turbo charger were manufactured by casting of Ti-Al alloy using the casting apparatus having a configuration shown in Fig. 1.

The moulds employed had three stuccoed layers. It took 2 days to manufacture the moulds. The raw material was placed in the melting cell 9 in the manner shown in Fig. 3, and was melted by supplying power of 200 KW/kg. The molten metal was then poured into the mould. The time required for this 1 cycle of casting was about 1 minute.

The conforming article rate of the produced wheels was 98%. Among 2% of the defective articles, the rate of the defective articles resulting from contamination was 0.5% or less. The oxygen content of the conforming articles was actually 200 to 300 ppm, which was rather low.

Conventional casting was also employed to manufacture the hot wheels. In this method, 10 wax models were assembled into 1 tree, and each mould had 9 stuccoed layers. It took 6 days to manufacture the moulds. The cycle of the conventional casting of the hot wheels using this tree was 20 minutes.

As will be understood from the foregoing description, melting of the active metal can be completed in a short period of time by the induction heating obtained by supplying a high level of electric power, and pouring can be performed substantially instantaneously. In consequence, the degree of contamination of the active metal caused during the melting and pouring processes can be greatly reduced. The castings of the active metal which are contaminated less can be manufactured at an excellent productivity.

Furthermore since the moulds are used within a casting chamber, it is not necessary for them to be as strong as conventional ones. Therefore, the thickness of the stuccoed layers can be reduced, and the time and labour required to manufacture the moulds can be thus reduced.

Thus, at least in the preferred embodiments an arrangement is provided in which the metal accommodating containers contaminate active metals as little as possible. Finishing of the metal and pouring processes is also achieved in a very short period of time.

Furthermore, there is provided an apparatus for casting an active metal, which enables a mould whose stuccoed layers are thinner than conventional ones to be employed so as to achieve reduction in the manhours required for manufacturing the mould, which is the active metal material, and which thus allows productivity to be improved.

At least in the preferred embodiments, the present invention provides an apparatus for casting an active metal, which comprises a casting chamber in which a mould is disposed, a melting chamber in which an active metal melting cell is disposed, and a high-frequency induction heating coil surrounding the melting chamber. The casting chamber and the melting chamber are connected in the vertical direction while they are hermetically sealed. The mould and the melting cell may be manufactured from a refractory material separately, the manufactured mould and the melting cell being separately disposed in the casting chamber and the melting chamber. Alternatively, the mould and the melting cell may be manufactured as connected units or as one unit, such mould and melting cell being continuously disposed in the casting chamber and the melting chamber.

There is also provided a method of casting an active metal, which comprises the steps of accommodating an active metal material in a melting cell in a melting chamber filled with an inactive gas, rapidly melting the active metal by supplying power of 10 kw or more per 1 kg of the active metal to a high-frequency induction heating coil surrounding the melting chamber, and rapidly pouring thus obtained molten metal into a mould disposed below the melting cell.

## Claims

1. A method of casting metal in which the metal is melted and poured into a mould, characterised in that the metal is melted in a melting cell (9) whilst exposed to an atmosphere of a relatively inactive gas, the melting being effected rapidly by means of a high frequency induction coil (7) surrounding the cell, and once melted the metal is poured without delay into a mould (3) below the melting cell (9) through a passage (9a) effecting a sealed communication between the melting cell and (9) and the mould (3).

2. A method as claimed in claim 1, characterised in that the induction coil (7) is supplied with power at a level of at least 10 kilowatts per kilogram of metal.

3. A method as claimed in claim 1 or 2 characterised in that the passage (9a) connecting the melting cell (9) and the mould (3) is closed during melting of the main body of the metal by means of a portion (9b) of the metal which is not melted until the main body of the metal has been melted.

4. A method as claimed in claim 3 characterised in that the distribution of the induced magnetic field is adjusted so as to delay melting of the portion (9b) of the metal.

5. A method as claimed in any preceding claim characterised in that the molten metal is separated from the sides of the melting cell (9) by use of a repulsive force generated by the interaction between the magnetic field of the induction coil and a magnetic field formed by eddy currents in the molten metal.

6. A method as claimed in any preceding claim characterised in that whilst the molten metal is poured into the mould (3) the pressure in the mould (3) is kept lower than the pressure in the melting cell (9).

7. A method as claimed in any preceding claim characterised in that the mould (3) is vibrated whilst the molten metal is poured.

8. A method as claimed in any preceding claim characterised in that the metal is a chemically active metal such as Ti, Al, Mg, Li or alloys thereof.

9. A method as claimed in any preceding claim characterised in that the mould (3) is produced by the lost wax process.

10. Apparatus for casting a metal including a container for the metal, means for heating the metal in the container, so as to melt the metal and a mould into which the molten metal is poured, characterised in that the container is a melting cell (9) of a refractory material, means (5c) are provided for exposing the cell (9) to an atmosphere of a relatively inactive gas, the heating means comprises a high frequency induction coil (7) surrounding the cell (9), the mould (3) is of a refractory material, and means (9a,3a) are provided which establish or which can establish a passage effecting a sealed communication between the melting cell (9) and the mould (3), the arrangement being such that when metal in the melting cell (9) is molten it can flow rapidly down into the mould (3) which is positioned directly below the cell (9).

11. Apparatus as claimed in claim 10, characterised in that the melting cell (9) is disposed in a melting chember (4), the induction coil (7) surrounding the chamber, and the means for exposing the melting cell (9) to an atmosphere of a relatively inactive gas comprises an inlet (5c) connected to the melting chamber (4).

12. Apparatus as claimed in claim 10 or 11 characterised in that the mould (3) is supported in a casting chamber (1).

13. Apparatus as claimed in claim 11, characterised in that the mould (3) is supported in a casting chamber (1) and means (6d) are provided for sealing together the melting chamber (4) and casting chamber (1).

14. Apparatus as claimed in claim 12 or 13 characterised in that a heating ring (1d) of conductive material is provided in the casting chamber (1) around the mould (3) and a further induction coil (7′) is provided around the casting chamber.

15. Apparatus as claimed in any of claims 10 to 14, characterised in that the melting cell (9) and mould (3) are separate and a shutter mechanism (17a,17b,18) is provided for selectively connecting or disconnecting the cell (1) and mould (3).

16. Apparatus as claimed in any of claims 10 to 15, characterised in that a ring-shaped magnetic field shielding plate (5d) is provided adjacent the portion thereof which is, or is to be, connected to the mould (3).

17. Apparatus as claimed in any of claims 10 to 16, characterised in that a flux collecting member (8) is provided between the melting cell (9) and the induction coil (7), said collecting member (8) extending to the vicinity of the portion of the melting cell (9) which is, or is to be, connected to the mould (3).

18. Apparatus as claimed in any of claims 10 to 17, characterised in that a yoke (10) is provided outside of the induction coil (7′) for the melting cell (9), to serve as a flux collecting member, and extends to the portion of the melting cell (9) which is, or is to be, connected to the mould (3).

19. Apparatus as claimed in any of claims 10 to 18 characterised in that the melting cell (9) is manufactured from a refractory material seleoted

from the group consisting of BN, $ZrO_2$, $ZrB_2$ and graphite.

20. Apparatus as claimed in any of claims 10 to 19 characterised in that the positions of the melting cell (9) and the mould (3) can be inverted so that the melting cell (9) is below the mould (3) during melting of the metal and is above the mould (3) when the metal is poured from the melting cell into the mould.

FIG. 1

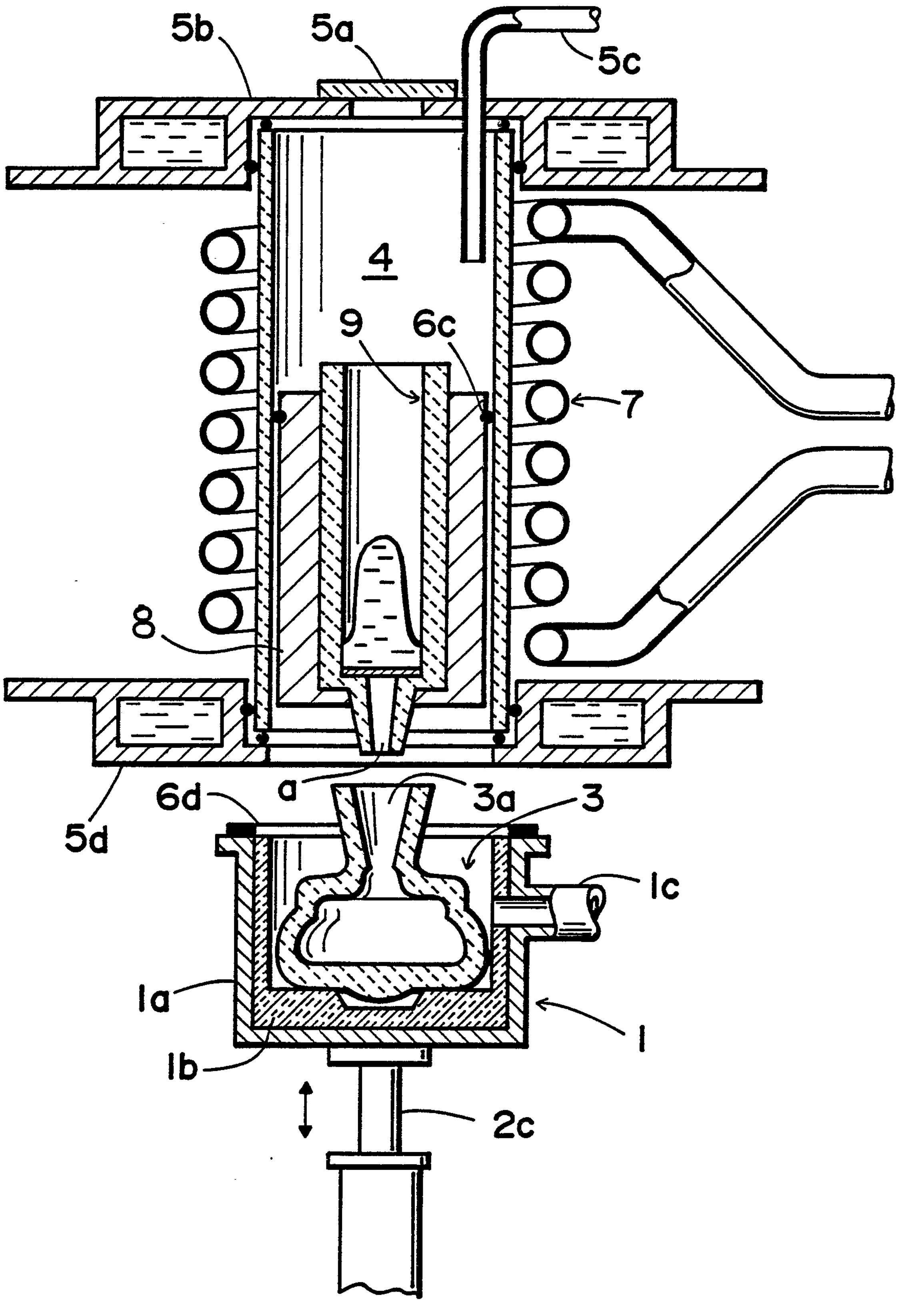


FIG. 2

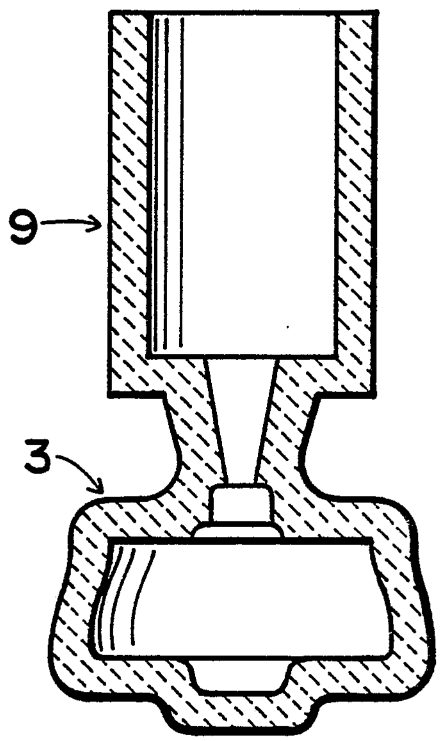



FIG. 3

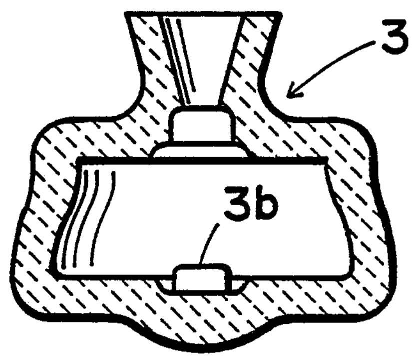



FIG. 4

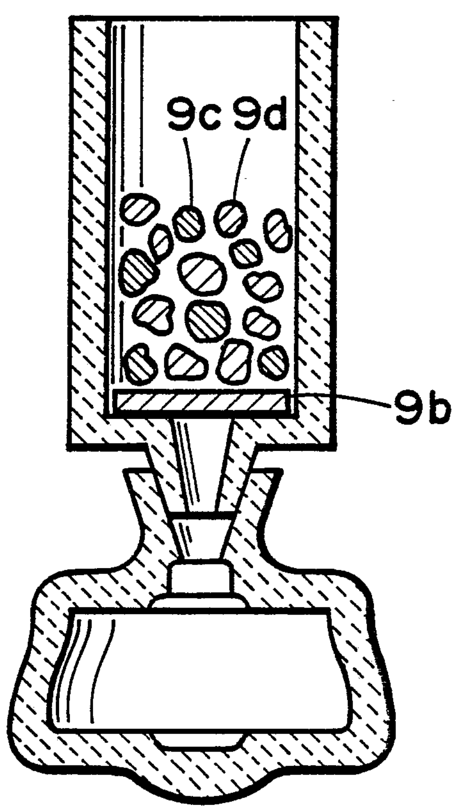



FIG. 5

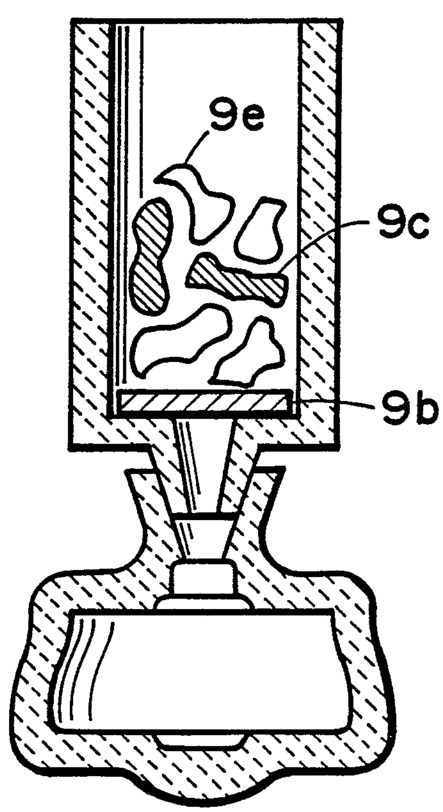


FIG. 6

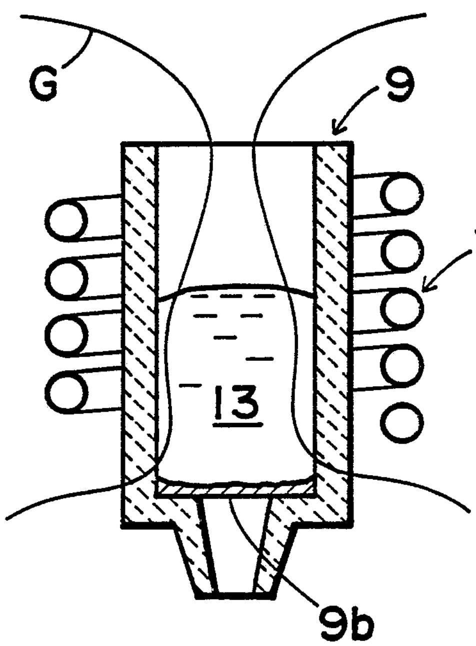



FIG. 7

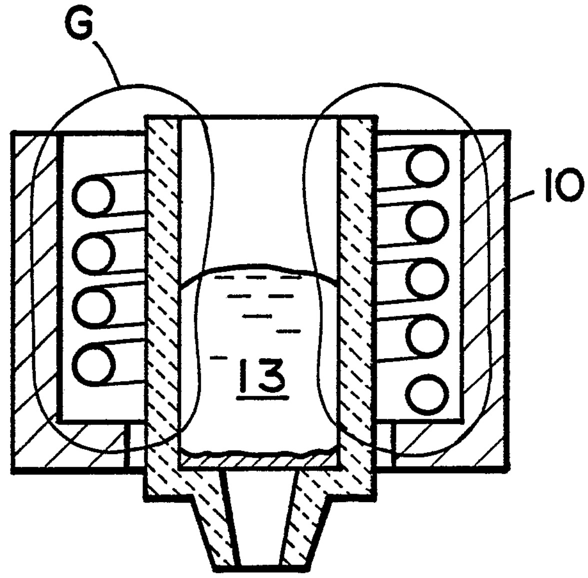



FIG. 8

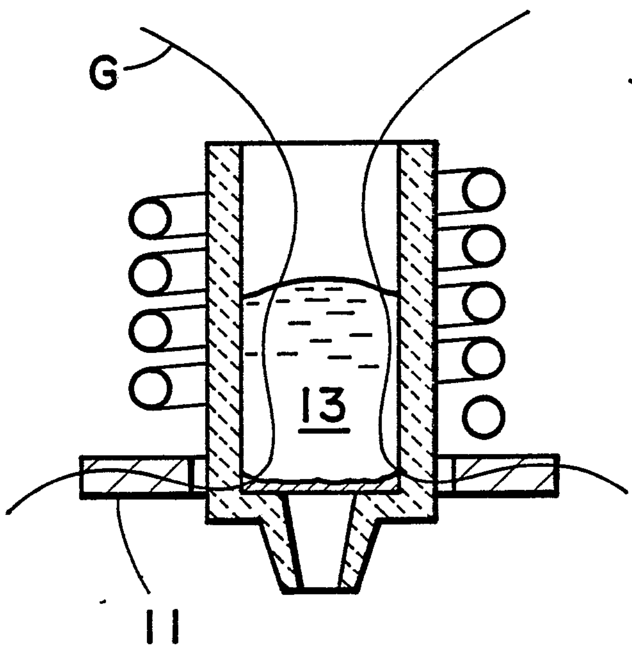



FIG. 9

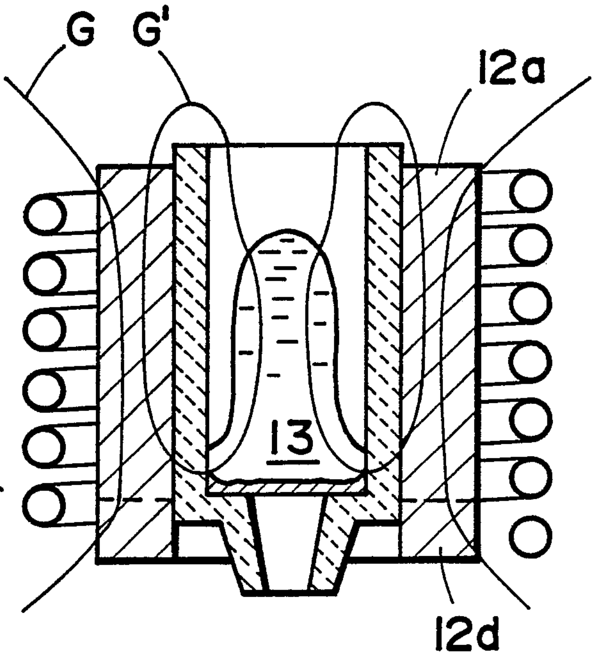


FIG. 10

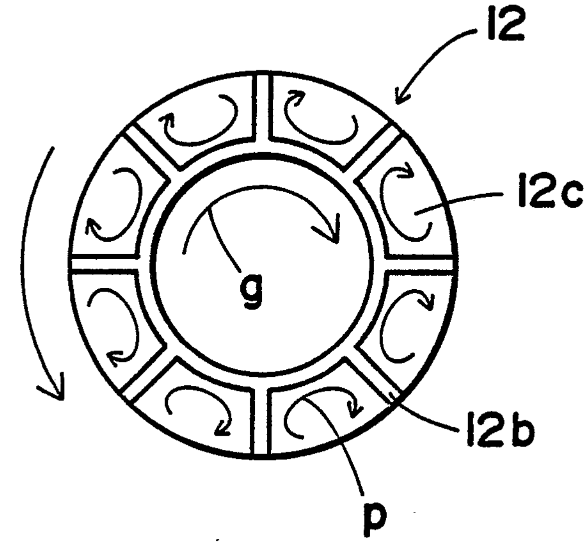



FIG. 11

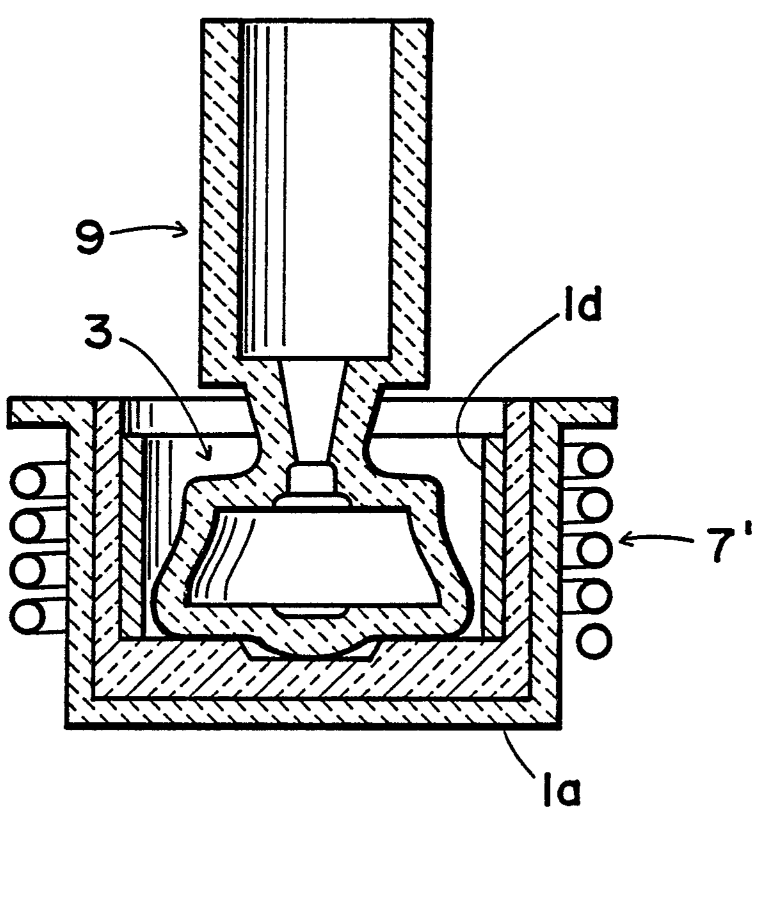


FIG. 12

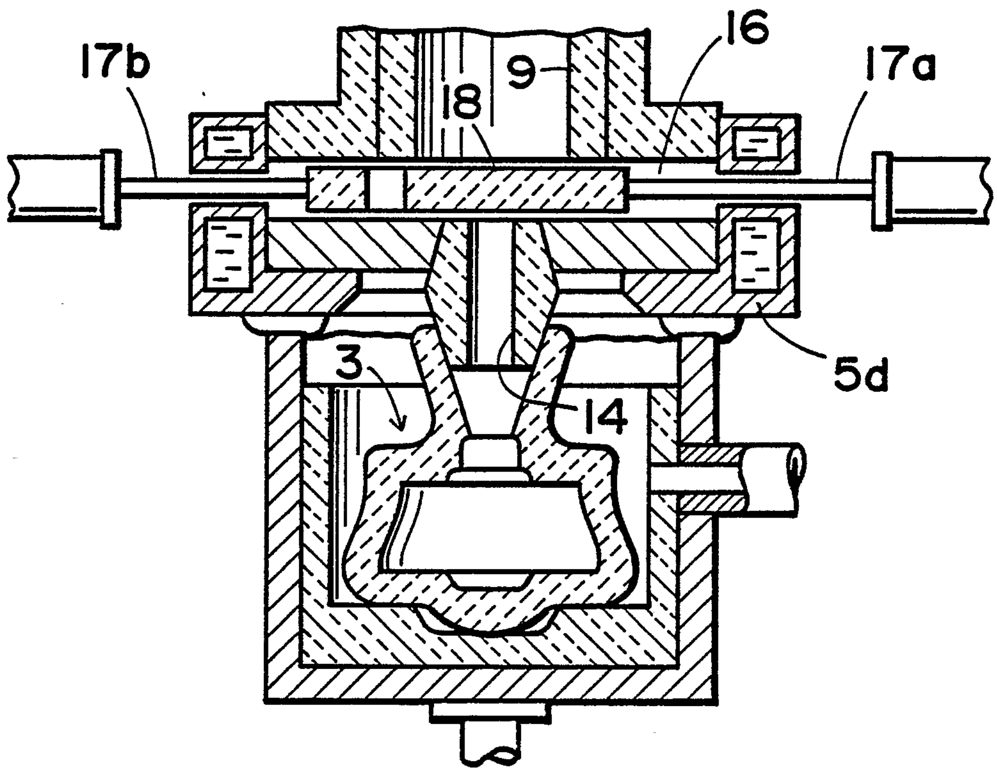



FIG.13

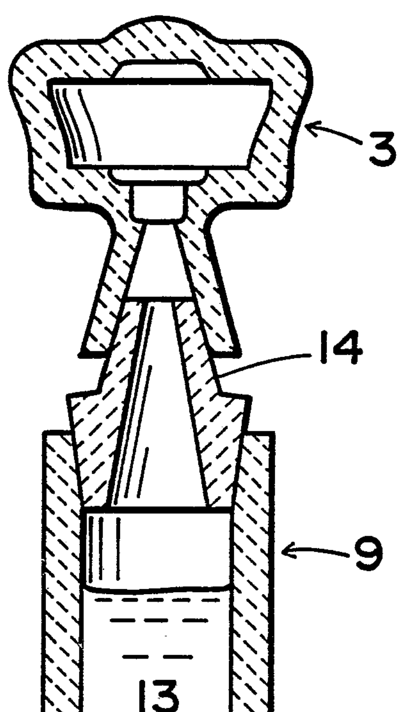



FIG.14