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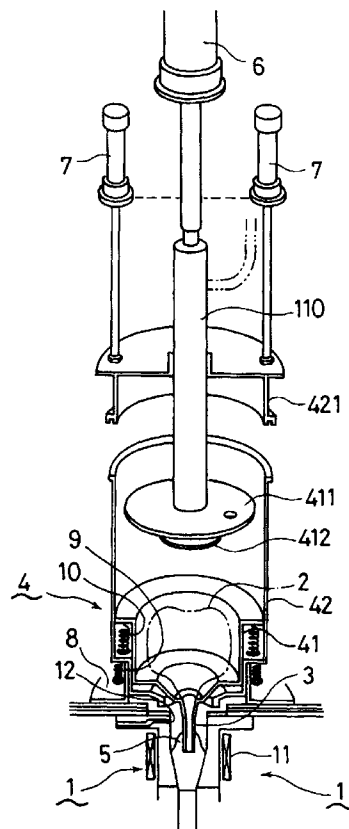
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(57) In an apparatus for casting a metal, particularly an active metal such as Ti, a gas-permeable mould (2) is provided above a levitation melting furnace (1) in a mould chamber, preferably comprising an inner and an outer mould chamber (41,42). Once the metal (5) in the furnace has become molten, the pressure within the apparatus is reduced and a suction pipe (3) connected to the mould (2) is lowered into the molten metal. The pressure in a space (A) above the furnace is then raised by a blown inert gas, thereby causing the molten metal to rise up the suction pipe (3) and be cast in the mould. Atmospheric pressure is then returned to separate the mould chamber from the furnace.

Fig. 1**EP 0 739 667 A1**

Description

The present invention relates to a method of casting a metal and an apparatus therefor. More particularly, the present invention relates to a novel method of casting metal and an apparatus for the application of such method, which permits achievement of a high-quality casting free from entrapment of impurities, gas contamination or gas defects, and is particularly, but not exclusively, useful for casting active metals such as titanium.

Various methods and apparatus for casting a metal have conventionally been known. For these casting methods and apparatus, diverse and various means for obtaining high-quality products free from entrapment of impurities, gas contamination or gas defects have been examined and industrialized.

The present inventors carried out extensive studies on means for obtaining such high-quality casting products, and have established a method permitting casting of an active metal, in particular for active and high-melting-point metals such as titanium and alloys thereof, which allows casting at a high efficiency with a high productivity.

The method thus established is essentially characterized by the combination of semi-levitation melting a metal, which involves melting a metal while partially magnetic-floating the metal, and reduced-pressure suction casting. This permits melting and casting of an active metal such as titanium by the semi-levitation melting process which is different from conventional processes using a refractory crucible, thereby inhibiting deterioration of quality caused by refractory contamination. It also makes it possible to conduct continuous melting and casting, and to carry out casting of highly uniform castings and ones with complicated shapes by the application of the reduced-pressure casting process. The semi-levitation melting process forming a feature of this method will be described in further detail below. This process is a kind of levitation (magnetic floating) melting process which comprises induction-heating a material charged in a melting crucible, and holding the resultant molten material without causing contact with the inner wall of the melting crucible.

More specifically, the levitation melting process is one of the melting processes which allow, when melting a metallic material charged in a melting crucible, the prevention of contamination of the molten metal from chemical reactions caused by contact of the metal with the inner wall of the crucible, thereby achieving an improvement in quality.

The process of levitation melting can be further divided into two processes: full-levitation melting process, which comprises fully floating a molten metal within the furnace by the action of electromagnetic force; and semi-levitation melting which comprises using a water-cooled copper crucible, and causing the molten metal to float by electromagnetic force while keeping the bottom of the material in a solidified state.

In the full-levitation melting process, although contamination from the melting crucible can be fully prevented because the molten metal is fully floated, it is difficult to keep the molten metal in that floating state. Also the quantity of molten metal capable of being floated is too small to be applied industrially. For industrial purposes, therefore, the semi-levitation melting process is commonly applied.

An outline of the semi-levitation melting process is as follows. In the water-cooled copper crucible used in this melting process, a peripheral wall of the main body, which is formed into a cylindrical shape and has a bottom, is circumferentially divided to form a plurality of segments into which cooling water is supplied in circulation. The individual segments are insulated from each other with an insulating material. Doughnut-shaped high-frequency induction coil turns are arranged at prescribed annular intervals on the outside of the water-cooled copper crucible. The material is induction-heated upon charging the material into the crucible by supplying high-frequency current to the induction coil. Upon heating the material to a prescribed temperature, the material partially melts, while the lower material in contact with the bottom of the water-cooled copper crucible is kept in its solidified state. The molten material is kept floating in the non-contact state relative to the inner wall of the crucible under the effect of electromagnetic force generated by the penetration of the molten material into the crucible.

The levitation melting process as a melting process having the features as described above is simply called "levitation melting" hereafter.

The casting method established by the present inventors, using levitation melting as described above, and an apparatus for the application thereof are characterized in that, as shown in Fig. 5 for example, a suction pipe (d) connecting with a mould (c) arranged above a melting furnace (a) is immersed in a molten metal (b) in said furnace (a), and the molten metal (b) is sucked up for casting into the mould (c) through the suction pipe (d) under conditions including reducing pressure in the mould (c) and a mould chamber (e) to below atmospheric pressure.

In the conventional method and apparatus, however, there were left points to be improved in terms of improvement of casting efficiency along with reduced-pressure suction and uniform casting into the mould. More specifically, it would be desirable to improve productivity of levitation melting and reduced-pressure suction casting and to permit more uniform casting into the mould while avoiding occurrence of defects resulting from casting.

The present invention provides a method for casting a molten metal comprising the steps of:

(A) levitation-melting a metal in an inert atmosphere in a levitation melting furnace under atmospheric pressure;

(B) bringing a mould chamber which houses a gas-permeable mould into proximity with the levitation melting furnace;

(C) reducing the pressure in the mould chamber and a space above the levitation melting furnace to below atmospheric pressure;

(D) immersing one end of a suction pipe into the molten metal, the other end of the suction pipe being in communication with the mould;

(E) casting the molten metal into the mould under an increased pressure by blowing an inert gas into the space above the levitation melting furnace;

(F) withdrawing the suction pipe from the molten metal; and

(G) returning the pressure in the space above the levitation melting furnace and the mould chamber to atmospheric pressure, and raising the mould chamber from the levitation melting furnace.

Preferably the pressure within the mould chamber and the space above the levitation melting furnace is reduced to below 26.7 kPa (200 torr), most preferably below 13.3 kPa (100 torr). Preferably, in order to cast the molten metal into the mould, the pressure is increased by between 6.67-66.7 kPa (50 to 500 torr) in the space above the levitation melting furnace by an atmosphere control mechanism.

The present invention also provides an apparatus for casting a metal comprising a levitation melting furnace, a mould chamber arranged above the levitation melting furnace housing a gas-permeable mould, a suction pipe having one end in communication with the mould and the other end arranged to be lowered into the levitation melting furnace, wherein an atmosphere control mechanism is provided to blow an inert gas into a space above the levitation melting furnace.

In a preferred embodiment, a sliding mechanism is provided to lower the mould chamber toward the levitation melting furnace. Preferably the mould chamber comprises an inner and an outer mould chamber which are slidably coupled together.

Preferably a mould keeper is arranged to press and keep the mould in the inner mould chamber.

Preferably the sliding mechanism has an elastic body, of which compression causes descent and of which repulsive force causes ascent.

Preferably the atmosphere control mechanism is provided with exhaust pressure reducing means and inert gas supply means.

As described above, the interior of the mould is kept under a reduced pressure or under vacuum, the reduced pressure or vacuum being retained preferably due to a double structure of the mould chamber, and the molten metal being cast by pressurising. Using such a system, defects resulting from entrapment by the atmosphere gas do not occur, thus permitting the casting of a uniform structure. In addition, the entire operations of casting including stabilization and fine adjustment of

the casting speed are very efficiently accomplished by the generation of a difference in pressure caused by blowing of inert gas.

The present invention, furthermore, based on levitation melting, is suitable for casting an active metal such as titanium, and because of the absence of inclusions caused by crucible refractories, is effective for ferrous castings.

Thus, according to one preferred embodiment, there is provided a method for casting a molten metal melted in a levitation melting furnace through a suction pipe immersed therein from above into a mould having a gas permeability in a double-structure mould chamber arranged directly above the melting furnace, said method comprising the steps of:

(A) levitation-melting a metal in an inert atmosphere under atmospheric pressure;

(B) contacting an outer mould chamber of the double-structure mould chamber to the levitation melting furnace;

(C) reducing pressure in the outer mould chamber and in an inner mould chamber of the double-structure mould chamber and in an upper space in the levitation melting furnace to below the atmospheric pressure;

(D) immersing the suction pipe arranged in the inner mould chamber and connecting with the mould therein into the molten metal;

(F) casting the molten metal into the mould under an increased pressure by blowing an inert gas into the upper space in the melting furnace;

(F) lifting up the inner mould chamber, thereby pulling out the suction pipe from the molten metal; and

(G) lifting up the outer mould chamber, after returning to the atmospheric pressure to separate same from the melting furnace.

According to another preferred embodiment, there is provided a levitation melting furnace, a suction pipe which is arranged directly above said levitation melting furnace, and sucks up a molten metal into a gas-permeable mould retaining a mould into which the molten metal is cast, a double-structure mould chamber having an inner mould chamber allowing said suction pipe to connect with said mould and an outer mould chamber forming the outer periphery thereof, a sliding mechanism causing the inner mould chamber and the outer mould chamber to move independently up and down, and an atmosphere control mechanism, and wherein:

(a) a metal is melted in an inert atmosphere under the atmospheric pressure in said levitation furnace;

(b) said sliding mechanism contacts said outer mould chamber of the double-structure mould chamber to the levitation melting furnace;

(c) said atmosphere control mechanism reduces pressure in the outer mould chamber and the inner

mould chamber in said double-structure mould chamber and in the upper space in said levitation melting furnace to below the atmospheric pressure; (d) said sliding mechanism brings down the inner mould chamber, whereby the suction pipe provided in the inner mould chamber and connecting with the mould therein is immersed into the molten metal; (e) said atmosphere control mechanism blows an inert gas into the upper space of the melting furnace to cast the molten metal into the mould; (f) said sliding mechanism lifts up the inner mould chamber, thereby pulling out the suction pipe from the molten metal; and (g) after returning to the atmospheric pressure, said sliding mechanism lifts up the outer mould chamber which is separated from the levitation melting furnace.

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

Fig. 1 shows a partial perspective sectional view illustrating a preferred embodiment of the casting apparatus of the present invention;

Fig. 2 is a sectional elevation of the outer cover above the outer mould chamber during a descending operation in the apparatus shown in Fig. 1;

Fig. 3 is a sectional elevation of the apparatus of Fig. 1 after the outer mould chamber has descended and been brought into contact with the levitation melting furnace, following the operation shown in Fig. 2;

Fig. 4 is a sectional elevation illustrating descent of the inner mould chamber and casting operation, following the operation shown in Fig. 3; and

Fig. 5 is a sectional elevation illustrating a conventional apparatus and method.

For example, as shown in Figs. 1 to 4, the preferred casting apparatus of the present invention comprises a levitation melting furnace 1, and a mould chamber 4 which holds a gas-permeable mould 2 in the interior thereof into which the molten metal is to be cast. A suction pipe 3 is also provided for sucking up the molten metal into this mould 2. The mould 2 is not limited to a precision-casting mould based on the lost wax process, but may consist of any of various moulds using sand, a metal or the like, which so long as it is permeable may be used.

The mould chamber 4 has a double structure comprising an inner mould chamber 41 having a mould 2 arranged therein which connects a suction pipe 3 to the mould 2, with an outer mould chamber 42 forming the outer periphery thereof. The casting apparatus is provided with a sliding mechanism which moves the inner mould chamber 41 and the outer mould chamber 42 independently up and down, and an atmosphere control

mechanism.

In this embodiment, furthermore, an inner cover 411 for the inner mould chamber 41 and a mould keeper 412 for pressing the mould 2 from above are made vertically slidable, and an outer cover 421 for the outer mould chamber 42 is provided. The inner cover 411 and the outer cover 421 are made vertically slidable by independently operating cylinder mechanisms 6 and 7. Outer springs 9 are provided between the outer mould chamber 42 and a base 8, and inner springs 10 between the flange portion of the inner mould chamber 41 and the staged portion of the outer mould chamber 42.

Casting operations are now described further in detail with reference to Figs. 2 to 4.

I. In the levitation melting furnace 1 in the condition shown in Fig. 2, melting of a metal is started by operating an induction coil 11 while supplying an inert gas such as argon (Ar) or the like through a gas supply port 12, in order to adjust the atmospheric conditions in the upper space A. Molten metal 5 is generated substantially at the center, thereby minimizing possible contact with the furnace wall, a feature of levitation melting.

II. The outer cover 421 is brought down by the cylinder piston mechanism 1 shown in Fig. 1 toward the outer mould chamber 42, to close the outer mould chamber with this outer cover 421. At the same time, as shown in Fig. 3, the outer spring 9 is further compressed to bring the outer mould chamber 42 composing the double-structure mould chamber into close contact with the levitation melting furnace 1. In this state, an inert gas such as argon (Ar) is blown by the atmosphere control mechanism into the inner and the outer mould chambers, 41 and 42. The inner and the outer mould chambers 41 and 42 are thus filled with an inert gas atmosphere.

III. Pressure in the outer mould chamber 42 and the inner mould chamber 41 forming the double-structure mould chamber, and the upper space in the levitation melting furnace 1 is reduced to a pressure lower than the atmospheric pressure (preferably to below 26.7 kPa (200 torr), or more preferably to below 13.3 kPa (100 torr)). Gases are withdrawn through a gas guide 130 by an evacuation pump forming part of the atmosphere control mechanism, from an exhaust port 120 provided in the slide for sliding the inner cover 411.

IV. As shown in Fig. 4, the slide 110 is caused to descend by the above-mentioned cylinder piston mechanism 6, and the inner mould chamber 41 is brought down while compressing the inner springs 10 to immerse the suction pipe 3 connecting with the mould 2 into the molten metal 5. The inner sur-

face of the steps of the inner mould chamber 41 and the outer mould chamber 42 are sealed with a packing material 422. The inner mould chamber 41 is closed by the inner cover 411, and the mould 2 is pressed by the mould keeper 412.

V. Simultaneously with immersion as described above, an inert gas such as argon (Ar) is blown into the upper space A in the melting furnace 1, and the molten metal 5 is pushed up by the difference in pressure 6.67-66.7 kPa (50 to 500 torr) between the upper space A and the inner mould chamber 41. The molten metal 5 thus uniformly rises up through the suction pipe 3, and immediately cast into the mould 2.

VI. After blowing argon gas by means of the atmosphere control mechanism into the inner and the outer mould chambers 41 and 42 and the above-mentioned space A, and returning to atmospheric pressure, the outer mould chamber 42 is lifted up by the sliding mechanism as described above to separate the outer mould chamber 42 and the inner mould chamber 41 from the levitation melting furnace 1.

The suction pipe 3 is consequently pulled out from the molten metal.

In the preferred casting method using the preferred apparatus of the present invention, as is clear from these operations I to VI, the mould chamber 4 is more perfectly closed under the effect of the double structure comprising the inner mould chamber 41 and the outer mould chamber 42, and casting of a product free from defect at meniscus, having a uniform structure and containing minimum impurities is made possible by the absence of entanglement by the atmosphere gas and uniform ascent of molten metal, resulting from casting by reduced pressure and inert gas pressurizing. Control of atmosphere is also easier.

The outer springs 9, the inner springs 10 and the cylinder piston mechanisms 6 and 7 for ensuring the close contact and sliding property of the inner mould chamber 41 and the outer mould chamber 42 are not limited to particular ones.

Inert gas is supplied for sealing the furnace during levitation melting, and is continued throughout the entire period of casting except for the period of pressure reduction before casting.

After the completion of a casting operation as described above, wear of the suction pipe 3 is determined, and if the degree of wear is within a tolerable range, the mould 2 is removed and additional materials are charged into the melting furnace 1 to repeat the same operations as above.

By using a suction pipe made from the same metal as the molten metal or base metal of the molten alloy, the wear tolerance of the suction pipe is increased. Thus, it is preferable to use a suction pipe made from Ti

for melting a Ti-Base-alloy.

According to the method and the apparatus described above, it is possible to avoid entanglement of inclusions from crucible refractories resulting from levitation melting, leading to easier casting of an active metal such as titanium. The atmosphere in the mould is controlled by the double structure of the mould chamber and the pressure reduction and casting by pressuring of the inert gas make it possible to cast a product with the least defects and excellent uniformity of structure. Furthermore, the pressure difference achieved by the pressure reducing conditions and inert gas blowing permit efficient casting including stabilization and fine adjustment of the casting speed, with a largely improved productivity.

Claims

1. A method of casting a molten metal comprising the steps of:

(A) levitation-melting a metal in an inert atmosphere in a levitation melting furnace (1) under atmospheric pressure;

(B) bringing a mould chamber (41,42) which houses a gas-permeable mould (2) into proximity with the levitation melting furnace (1);

(C) reducing the pressure in the mould chamber (41,42) and a space (A) above the levitation melting furnace (1) to below atmospheric pressure;

(D) immersing one end of a suction pipe (3) into the molten metal (5), the other end of the suction pipe being in communication with the mould (2);

(E) casting the molten metal (5) into the mould (2) under an increased pressure by blowing an inert gas into the space (A) above the levitation melting furnace (1);

(F) withdrawing the suction pipe from the molten metal (5); and

(G) returning the pressure in the space (A) above the levitation melting furnace (1) and the mould chamber (41,42) to atmospheric pressure, and raising the mould chamber (41,42) from the levitation-melting furnace (1).

2. A method as claimed in claim 1, wherein the pressure in the mould chamber (41,42) and the space (A) above the levitation melting furnace (1) is reduced to below 26.7 kPa (200 torr).

3. A method as claimed in claim 2, wherein the pressure is reduced to below 1.33 kPa (100 torr).

4. A method as claimed in any of claims 1, 2 or 3, wherein the molten metal (5) is cast into the mould

(2) under a pressure increase of between 6.67-66.7 kPa (50 to 500 torr).

5. Apparatus for casting a molten metal comprising a levitation melting furnace (1), a mould chamber (41,42) arranged above the levitation melting furnace housing a gas-permeable mould (2), a suction pipe (3) having one end in communication with the mould and the other end arranged to be lowered into the levitation melting furnace, wherein an atmosphere control mechanism (12, 120) is provided to blow an inert gas into a space (A) above the levitation melting furnace (1). 5 10
6. Apparatus as claimed in claim 5, wherein a sliding mechanism is provided to lower the mould chamber (41,42) toward the levitation melting furnace (1). 15
7. Apparatus as claimed in claim 6, wherein the sliding mechanism is resiliently biased to urge the mould chamber (41,42) away from the levitation melting furnace (1). 20
8. Apparatus as claimed in any of claims 5, 6 or 7, wherein the mould chamber (41,42) comprises an inner and an outer mould chamber which are slidably coupled together. 25
9. Apparatus as claimed in any of claims 5 to 8, wherein a mould keeper (412) is provided to retain the mould (2) in position. 30
10. Apparatus as claimed in any of claims 5 to 9, wherein the atmosphere control mechanism (12, 120) comprises a pump, an exhaust port (120) and an inlet (12). 35

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Fig. 1

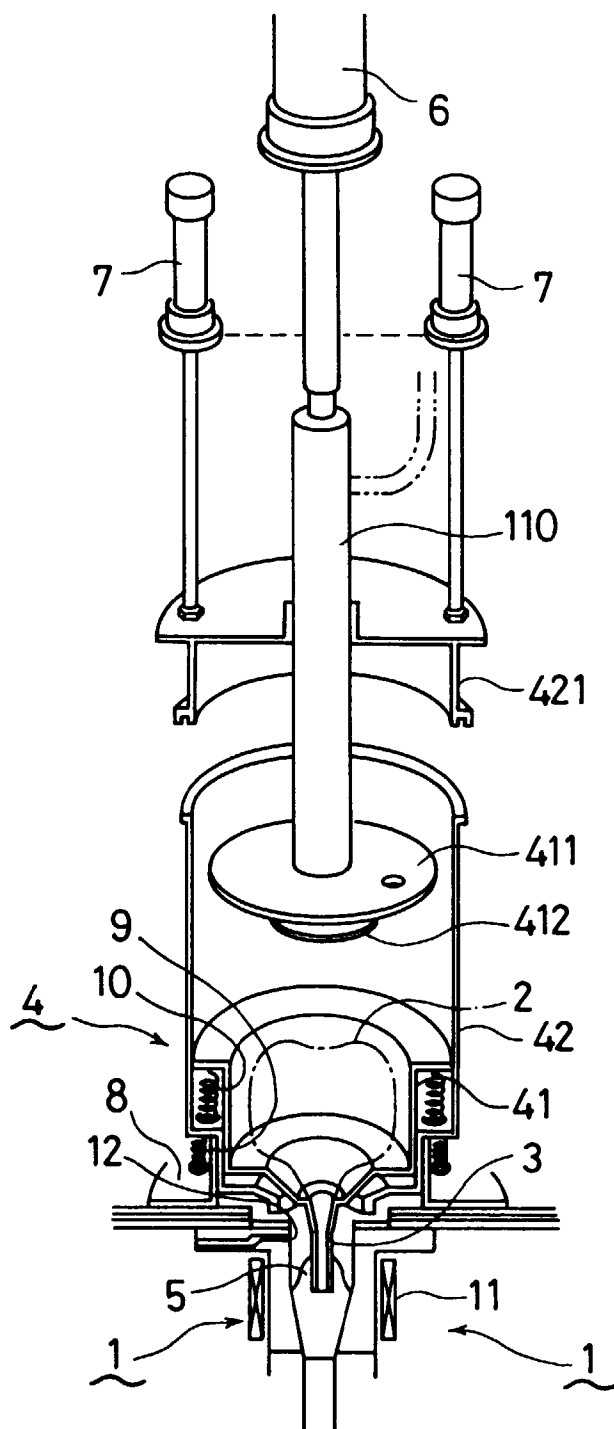


Fig. 2

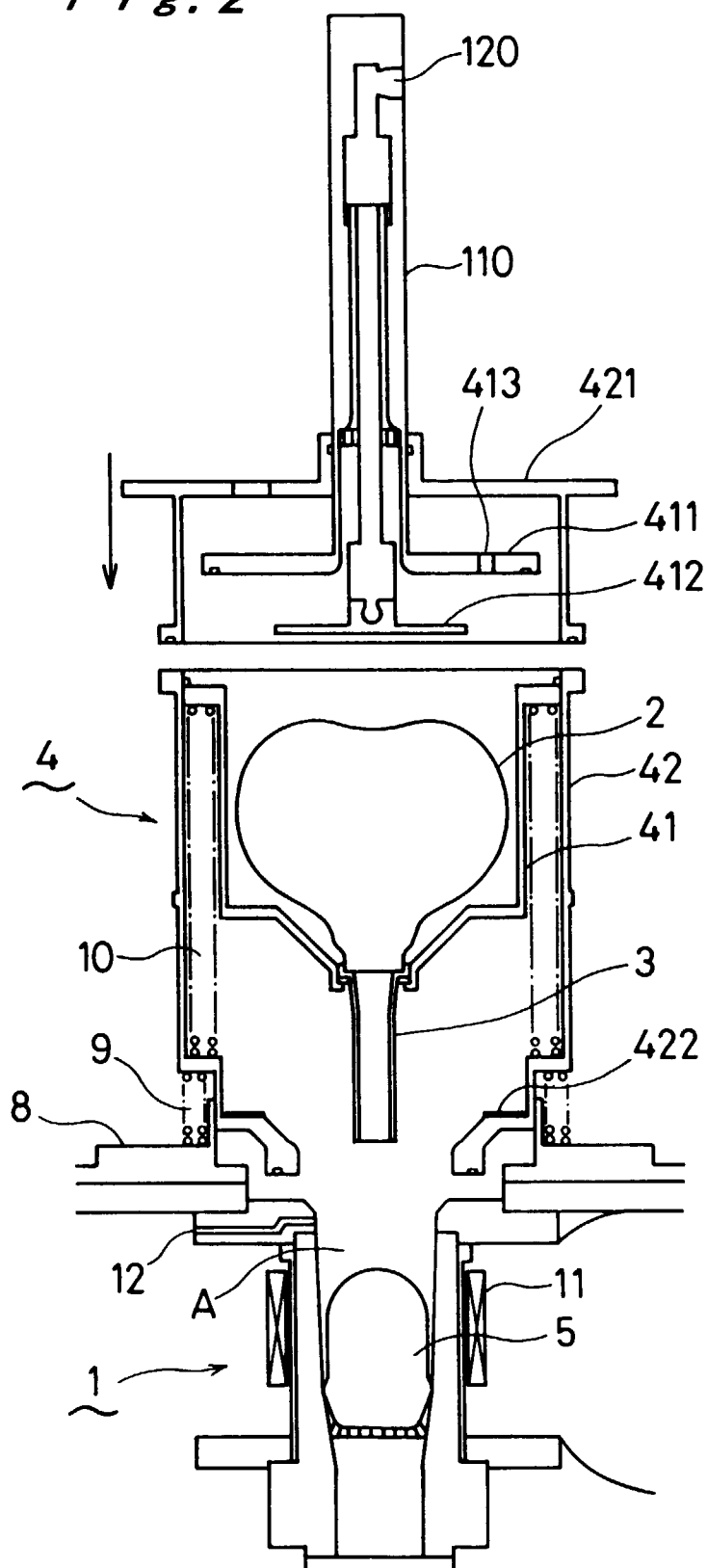


Fig. 3

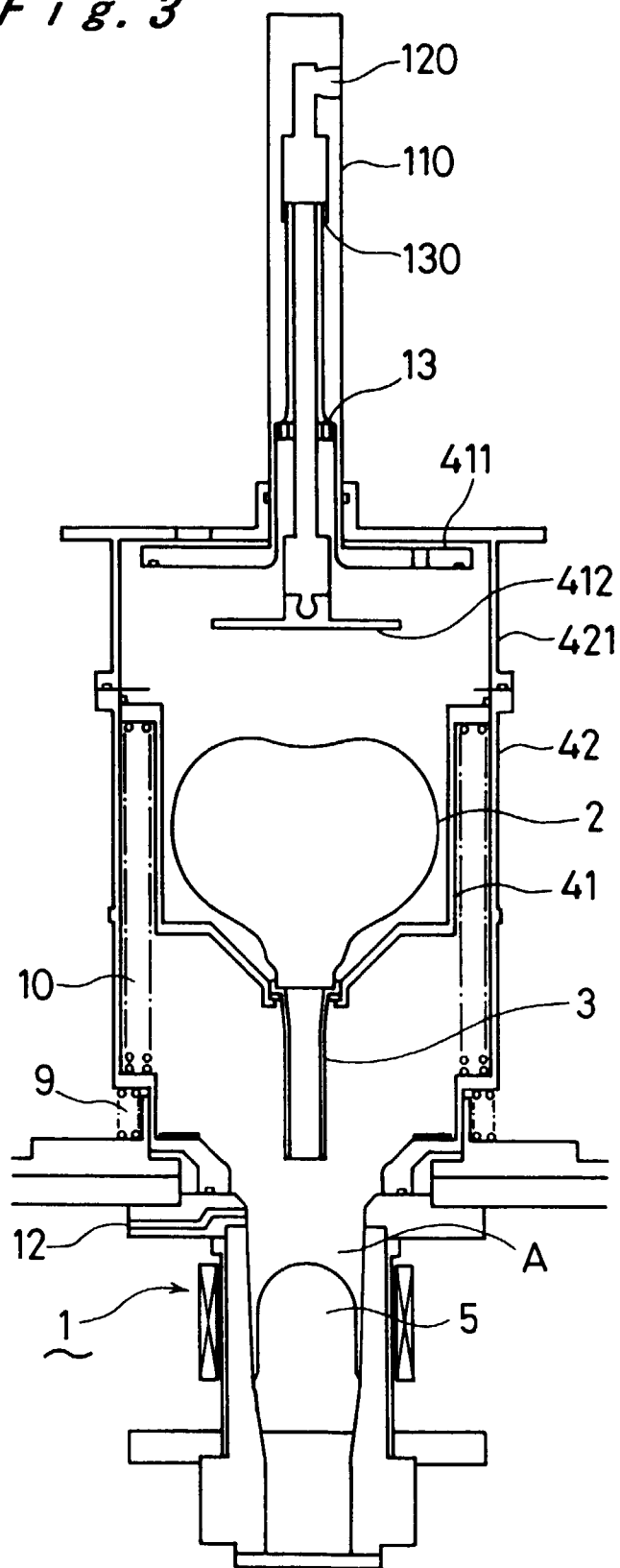


Fig. 4

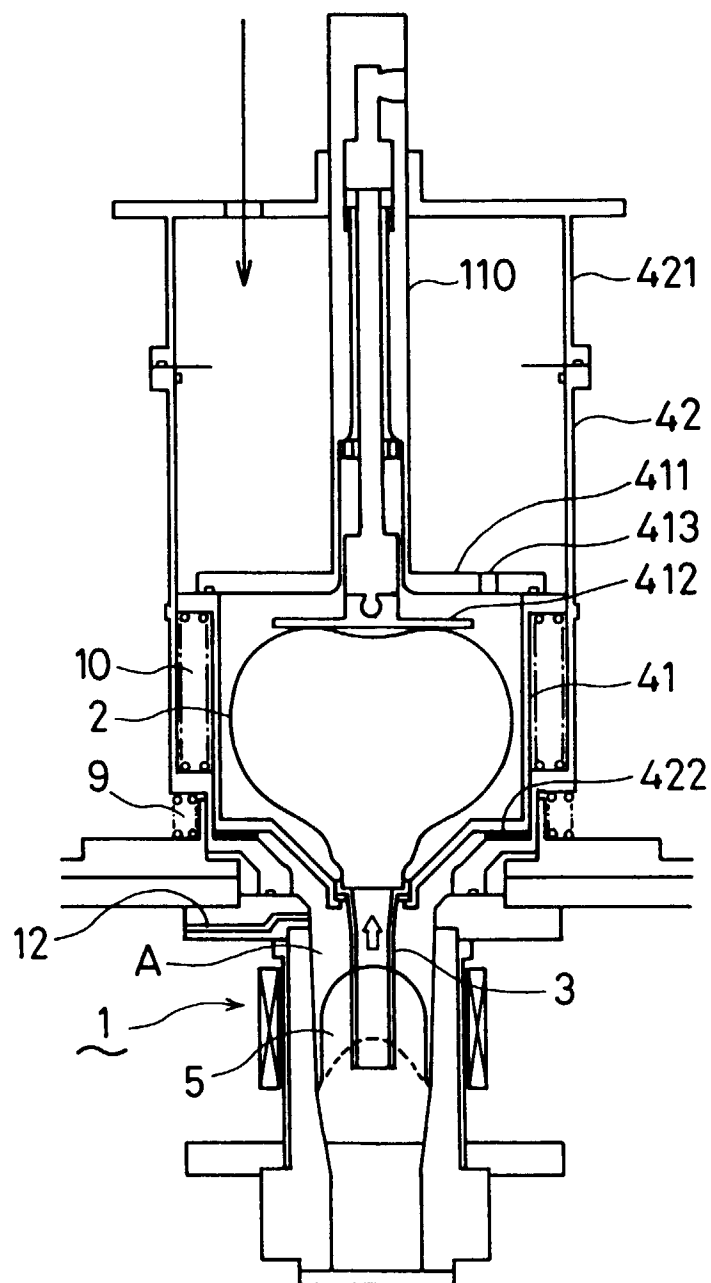
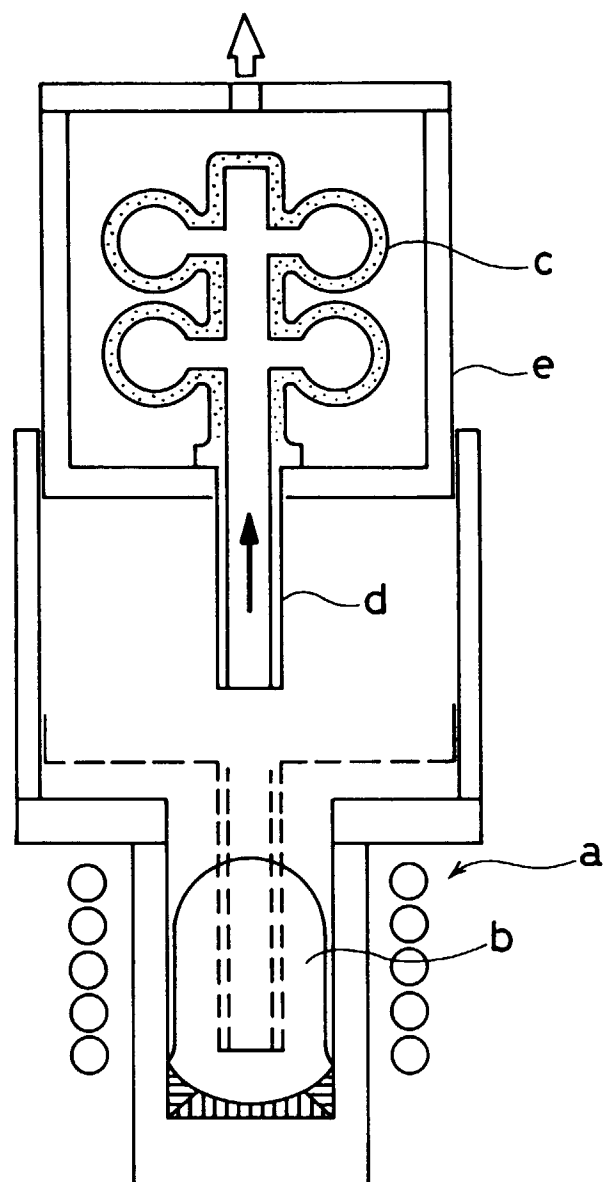


Fig. 5





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EUROPEAN SEARCH REPORT

Application Number
EP 96 30 2915

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	PATENT ABSTRACTS OF JAPAN vol. 016, no. 494 (M-1324), 13 October 1992 & JP-A-04 182056 (DAIDO STEEL CO LTD), 29 June 1992, * abstract *	1,5	B22D18/06
A	--- PATENT ABSTRACTS OF JAPAN vol. 017, no. 503 (M-1478), 10 September 1993 & JP-A-05 131265 (DAIDO STEEL CO LTD), 28 May 1993, * abstract *	1,5	
A	--- EP-A-0 457 502 (DAIDO TOKUSHUKO) * claims 1,5; figures 1,2 *	1,5	
A	--- PATENT ABSTRACTS OF JAPAN vol. 008, no. 158 (M-311), 21 July 1984 & JP-A-59 054458 (HITACHI SEISAKUSHO KK), 29 March 1984, * abstract *	1,5	
A	--- EP-A-0 388 235 (PCAST EQUIPMENT)		TECHNICAL FIELDS SEARCHED (Int.Cl.6)
A	--- US-A-3 544 757 (R. E. CHRISTIAN ET AL.)		B22D
A	--- US-A-4 738 713 (D. R. STICKLE ET AL.)		
The present search report has been drawn up for all claims			
Place of search BERLIN		Date of completion of the search 6 August 1996	Examiner Sutor, W
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