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(54) APPARATUS FOR MOLDING UNDER HIGH PRESSURE.

(57) This invention provides an apparatus usable for molding under high pressure, in which, when slip casting is applied to super-fine powder for porcelains and fine ceramics, no clogging occurs and high efficiency as well as high accuracy is exhibited in molding. The apparatus is a high pressure casting molding apparatus for slip casting provided with an air-permeable mold composed of 10 to 50 % by weight of BN and ceramics, and with a pressure intensifier for pressurizing, press having mold release function, defoaming and stirring vacuum unit, pressure intensifier, ultrasonic cleaning unit, high pressure cleaning and drying unit, and microwave generator, whereby molding, release of mold, cleaning, and drying are performed in succession and excellent mass-production capability is exhibited.

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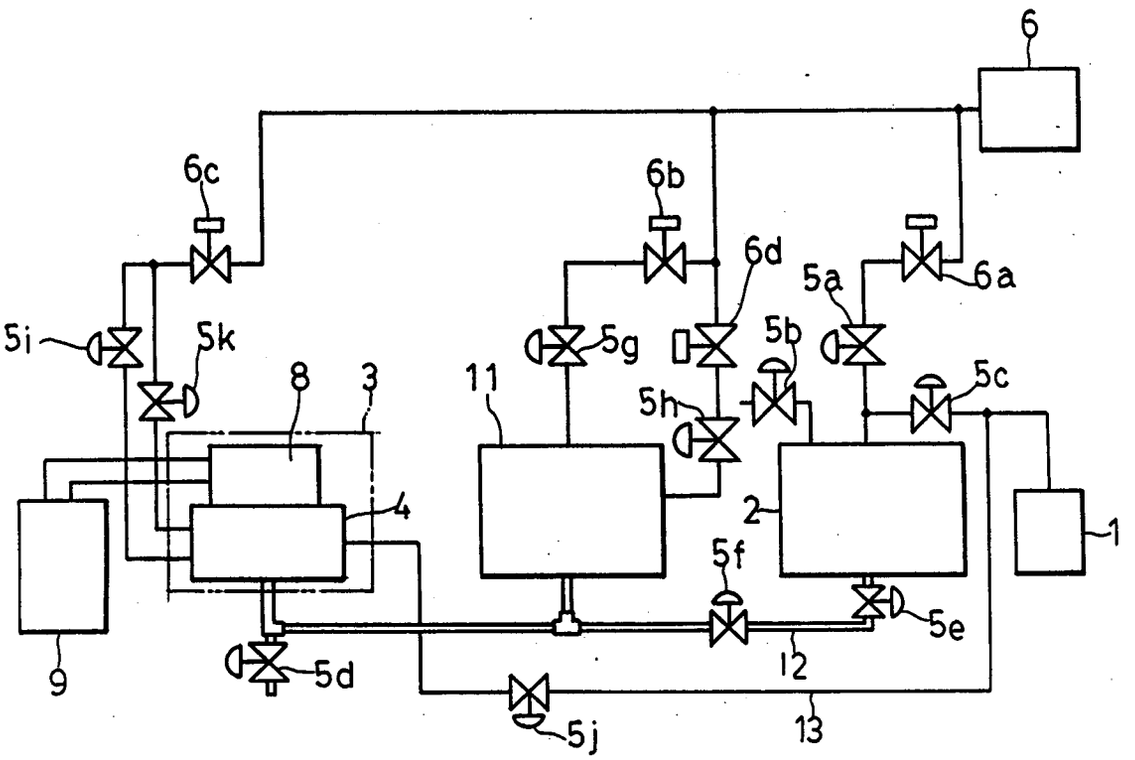

FIG. 1

TECHNICAL FIELD

The present invention relates to a high-pressure slip casting apparatus and, more specifically, to a high-pressure slip casting apparatus employing a special slip-casting mold having minute pores, high durability, high strength and good product disengageability, and capable of slip-casting a high-quality molding in a short process time.

BACKGROUND ART

Slip casting, which is one of powder molding techniques, is applied particularly to manufacturing ceramics, tableware, an electrical insulator and such. Recently, slip casting has been applied to manufacturing fine ceramics of alumina, silicon nitride and zirconia and is regarded as a prospective molding technique for producing parts for industrial usages.

Fig. 11 shows a conventional slip casting apparatus. A prepared slip is stirred and deaerated by a vacuum deaerating stirrer 2 evacuated by a vacuum pump 1. After the slip has completely been deaerated, the internal pressure of the vacuum deaerating stirrer 2 is increased to the atmospheric pressure. Subsequently, the vacuum deaerating stirrer 2 is pressurized to feed the slip by pressure to a casting table 3. A casting mold 4 previously set on the casting table 3 is filled with the slip for molding. The slip casting apparatus is provided also with valves 5a to 5e, a compressed gas source 6 and a pressure reducing valve 6a.

The casting mold 4 is a plaster mold. The plaster mold has advantages including excellent water absorbency, good product disengageability, high dimensional accuracy, and capability of being formed in a large size at a low cost. On the other hand the plaster mold has disadvantages including inferior water resistance, low pressure durability, poor abrasion resistance, and possibility of contaminating the slip by Ca^{2+} ions eluted from the plaster mold. Since a molding is formed by the sedimentation of the slip through the absorption of the water contained in the slip by the capillary action of the pores in the plaster mold, a process time in the range of 10 to 20 minutes is necessary for molding a molding having a wall thickness in the range of 5 to 7 mm. Furthermore, a process time required for sedimentation in the second molding cycle is longer than that in the first molding cycle, and the process time increases with the number of molding cycles. Accordingly, a plurality of plaster molds must be prepared.

Under such circumstances, casting molds of materials other than plaster, such as resin molds, resin-ceramic molds, metal-ceramic molds and metal molds, have been developed to overcome disadvantages attributable to the use of plaster molds. However, those casting molds of materials other than plaster have been used only for molding porcelain and pottery due to their intrinsic disadvantages. For example, a casting mold disclosed in Japanese Patent Laid-open (Kokai) No. 63-21105 has the following disadvantages.

(1) The casting mold has pores of diameters greater than 3 μm and the pores are choked with particles to deteriorate product disengageability.

(2) Cast products are contaminated by iron contained in the casting mold.

(3) Since it is difficult to finish the casting mold, a cast product having a complicated shape, very thin walls and/or very fine portions needs to be machined after casting to finish the product in satisfactory dimensional accuracy and in satisfactory surface accuracy.

DISCLOSURE OF THE INVENTION

The present invention provides a slip casting apparatus capable of solving problems in the conventional slip casting techniques and of casting a product of high quality in a short process time. The slip casting apparatus employs a casting mold having the following characteristics.

(1) The casting mold has very small pores in diameters which are not choked with small particles for fine ceramics as well as particles for porcelain and pottery.

(2) The surface of the casting mold is neither deteriorated nor abraded even if the casting mold is used for many casting cycles, and the casting mold is durable and has excellent water resistance and pressure durability.

(3) The casting mold may achieve high pressure molding at a maximum pressure of 1000 kg/cm^2 which enables quick slip casting.

(4) The casting mold has good product disengageability.

(5) The casting mold forms a product in a high accuracy.

To achieve the foregoing objects in a slip casting apparatus, the present invention provides a high-pressure slip casting apparatus comprising: a porous casting mold formed of a material containing 10 to

50% by weight boron nitride and at least one of other ceramic materials; a casting table for holding the casting mold, provided with a product disengaging device; a vacuum deaerating stirrer for deaerating and stirring a casting slip; a pressure intensifier provided between the casting table and the vacuum deaerating stirrer to pressurize the casting slip; and a pressure regulating piping system interconnecting the casting table, the vacuum deaerating stirrer and the pressure intensifier. Further the apparatus is provided preferably with an ultrasonic cleaner and/or a drier, in order to be able to mold a slip of very fine particles efficiently without choking porosity with the slip.

In another aspect of the present invention, a high-pressure slip casting apparatus comprises: a casting mold cleaning device; a casting mold drying device; a casting device; a product disengaging device; and a casting mold conveying device for sequentially conveying a casting mold to the casting mold cleaning device, the casting mold drying device, the casting device and the product disengageing device. The high-pressure slip casting apparatus is capable of sequentially repeating a casting cycle for slip casting at a high efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of a high-pressure slip casting apparatus in a first embodiment according to the present invention;

Figure 2 is a diagrammatic view of a vacuum deaerating stirrer employed in the high-pressure slip casting apparatus of Fig. 1;

Figure 3 is a diagrammatic view of a pressure intensifier for pressurizing a slip;

Figure 4 is a diagrammatic view of a casting table;

Figure 5 is a diagrammatic view of assistance in explaining the operation of the pressure intensifier;

Figure 6 is a side view of a casting table employed in a high-pressure slip casting apparatus in a second embodiment according to the present invention, in a state after the completion of casting operation;

Figure 7 is a side view of the casting table of Fig. 6, in a state for a cleaning process;

Figure 8 is plan view of a high-pressure slip casting apparatus in a third embodiment according to the present invention;

Figure 9 is a side view of the high-pressure slip casting apparatus of Fig. 8;

Figure 10 is a front view of the high-pressure slip casting apparatus of Fig. 8; and

Figure 11 is a diagrammatic view of assistance in explaining the arrangement and operation of a conventional high-pressure slip casting apparatus.

BEST MODE FOR CARRYING OUT THE INVENTION

The inventors of the present invention have found through comparative studies of casting molds of different materials for slip casting that a casting mold formed of a composite sintered material containing boron nitride (BN) and one or a plurality of other ceramic materials has excellent characteristics, and have invented a slip casting apparatus on the basis of such knowledge.

First, a casting mold will be described. In view of non-wettability with a slip and ease of fabrication, materials based on BN were examined. BN is poor in sinterability, requires high-pressure pressing for sintering, and has a comparatively low abrasion resistance. The inventors of the present invention intended to use, in combination with BN, ceramic materials capable of being densely sintered together with BN by low-pressure pressing or under pressurized atmosphere and having high abrasion resistance and high pressure durability in anticipation of the following composite effects.

(1) Formation of pores in a casting mold by the obstruction of BN to the sintering of ceramic materials

(2) Supplementation of abrasion resistance of a casting mold by ceramic materials and making most of the advantages of BN

The pores must penetrate the wall of the casting mold so that the casting mold is gas-permeable to secure sufficient moisture absorbency for the casting mold.

Ceramic materials having high abrasion resistance, such as Si_3N_4, SiC, SIALON, ZrO_2, Al_2O_3, AlN and mullite, are suitable for forming a casting material employed in the present invention. These ceramic materials may be used either individually or in combination according to the purpose.

The product disengageability and workability of the casting mold are improved and the pressure durability and hardness of the same are reduced with the increase of the BN content of the casting mold. Accordingly, the BN content may be determined according to the material to be molded. The diameter of the pores and the porosity of the casting mold can optionally be determined by selectively determining the particle size of the materials and the respective contents of the materials. Preferably, the BN content of the

material for forming the casting mold is in the range of 10 to 50% by weight, the average diameter of the pores of the casting mold is in the range of 0.1 to 2 μm, and the porosity of the casting mold is in the range of 10 to 40%.

The casting mold meeting such conditions may keep permeability without porosity choking even with a particulate material, ensures good product disengageability, withstands high-pressure casting under a considerably high pressure and improves the ability of mass production. The excellent abrasion resistance of the casting mold ensures cast products in a constant surface accuracy, and hence the casting mold is applicable to casting articles required to meet severe quality standards, such as automotive parts. A fired blank for the casting mold can be finished by machining, similarly to dies for pressing and injection molding, in a very high accuracy, and hence cast products can be cast by using the casting mold in a very high accuracy.

A slip casting apparatus employing the foregoing casting mold will be described hereinafter. The conventional casting mold has a low pressure durability or if it has a high pressure durability then it is subjected to poor product disengageablity and porosity choking inherence. The casting mold in accordance with the present invention has a high pressure durability and good product disengageability, and keeps good permeability even in use for super-high-pressure slip casting.

The conventional slip casting apparatus shown in Fig. 11 which pressurizes a slip by a compressed gas has a complicated construction, is expensive and has the danger from bursting. Accordingly, a safe, highly productive slip casting apparatus must be used in combination with the casting mold to achieve high-pressure slip casting. The present invention provides a high-pressure slip casting apparatus meeting such requirements and also capable of feeding a slip by a compressed gas of a pressure below 10 kg/cm^2.

High-pressure slip casting apparatus in preferred embodiments according to the present invention will be described hereinafter with reference to Figs. 1 to 10. Referring to Fig. 1 showing the general construction of a high-pressure slip casting apparatus in a first embodiment according to the present invention, a vacuum deaerating stirrer 2 is connected to a casting mold 4 provided on a casting table 3 by a pipe line 12. A slip pressure intensifier 11 is connected to the pipe line 12. A vacuum pump 1 and a compressed gas source 6 are connected to the vacuum deaerating stirrer 2 and the casting mold 4 provided on the casting table 3. A clamping cylinder actuator 8 is connected to the casting mold 4. The clamping cylinder actuator 8 is operated by a hydraulic unit 9.

Fig. 2 is a diagrammatic view showing the vacuum deaerating stirrer 2 shown in Fig. 1, Fig. 3 is a diagrammatic view of the slip pressure intensifier 11 shown in Fig. 1, Fig. 4 is a diagrammatic view of the casting table 3, and Fig 5 is a diagramtic view of assistance in explaining the operation of the slip pressure intensifier 11. The operation of the high-pressure slip casting apparatus will be described hereinafter with reference to Figs. 1 to 5. A slip prepared beforehand is poured into the vacuum deaerating stirrer 2, and after the vacuum deaerating stirrer 2 is sealed, the slip is stirred in the vacuum deaeating stirrer 2 at a reduced pressure of 700 mmHg or higher evacuated by the vacuum pump 1. After the completion of stirring and deaerating the slip, a valve 5c is closed and a valve 5b is opened to raise the internal pressure of the vacuum deaerating stirrer 2 to the atmospheric pressure. Then, the casting mold 4 is set on the casting table 3.

Next, gas pressure to be supplied to the slip is reduced in the range of 0.1 to 2 kg/cm^2 adjusted by a pressure reducing valve 6a. Subsequently, valves 5a, 5e and 5f are opened and the valve 5b is closed to supply compressed air to the vacuum deaerating stirrer 2, so that the slip is discharged from the vacuum deaerating stirrer 2 by the compressed air to fill up the lower chamber 11c (Fig. 5) of the pressure intensifier 11, and the casting mold 4 with the slip. The lower piston 11a of the pressure intensifier 11 is lowered beforehand to its lowest position by operating a pressure reducing valve 6b and a valve 5g before supplying the slip into the lower chamber 11c to prevent making air bubbles in the slip. Since the ratio of the area of the lower piston 11a to that of the upper piston 11b of the pressure intensifier 11 is very large, for example, 1 : 125, the sealing ring of the upper piston 11b exerts a large resistance against the upward movement of the pistons 11a and 11b in filling up the lower chamber 11c with the slip. Therefore, a valve 5h is opened to supply the compressed air of a pressure in the range of 4 to 8 kg/cm^2 adjusted by a pressure reducing valve 6d to a chamber under the upper piston 11b in order to apply pressure to the lower surface of the upper piston 11b to balance the resistance of the sealing member of the upper piston 11b, so that the lower chamber 11c can readily be filled up with the slip.

Then, the valve 5f is closed, the pressure reducing valve 6b is operated to adjust the pressure of the compressed air to a pressure in the range of 5 to 9.9 kg/cm^2, and then the valve 5g is opened to apply the pressure to the upper piston 11b. Consequently, the slip filling up the lower chamber 11c is pressurized by the lower piston 11c and the pressure prevailing in the lower chamber 11c is transmitted to the slip supplied to the casting mold 4 to accelerate the casting speed. After the completion of casting, the valve 5g is

opened, and then the valves 5f and 5b are opened. Subsequently, a valve 5i is opened to supply the compressed air through the pressure reducing valve 6c to the bottom half mold of the casting mold 4 to press the molding to the upper half mold of the casting mold 4, and then the top half mold is raised. Then, the valve 5i is closed, a pallet is placed under the molding, and then a valve 5k is opened to mount the molding on the pallet. The residual slip is discharged through a valve 5d. Indicated at 8 is a mold clamping cylinder actuator, and at 9 is a hydraulic unit for controlling the mold clamping cylinder actuator 8. It is possible to construct a mass production system by additionally providing the high-pressure slip casting apparatus with a molding removing device, an electric circuit, solenoid valves and sensors.

A high-pressure slip casting apparatus embodying the present invention capable of continuous casting operation will be described hereinafter with reference to Figs. 6 and 7.

A system shown in Fig. 6 has a casting table 3 provided with a single casting mold 4 and is capable of cleaning and drying the casting mold 4. Shown also in Fig. 6 are a cold force feed device 21, a hot force feed device 22, a cleaning liquid supply device 23, an ultrasonic cleaning device 24, and an operating device 26 for operating the ultrasonic cleaning device 24. After a cast product 15 has been formed in the casting mold 4, compressed air is supplied to the bottom half mold 4a of the casting mold 4, and vacuum suction is applied to the top half mold 4b of the casting mold 4 so that the molding 15 is attracted to the top half mold 4b, the top half mold 4b is raised, and then compressed air is supplied to the top half mold 4b to disengage the cast product 15 from the top half mold 4b.

Fig. 7 shows the system in a state for cleaning operation subsequent to the state shown in Fig. 6. ultrasonic cleaning device 24, which is held on one side of the casting. The cleaning water tank 24 held on one side of the casting mold 4 in the state shown in Fig. 6, is moved by a cylinder actuator 26 and is guided by a horizontal guide 25 and a vertical guide 27 to enclose the bottom half mold 4a as shown in Fig. 7, and then the top half mold 4b is lowered into the ultrasonic cleaning device 24. Then, the cleaning liquid supply device 23 supplies a cleaning liquid into the ultrasonic cleaning device 24. Then, ultrasonic waves are applied to the cleaning liquid and compressed air of a pressure in the range of 1 to 5 kgf/cm^2 or high-temperature, high-pressure steam is blown from the backside of the casting mold against the casting mold to clean the casting mold 4. After the casting mold 4 has thus been cleaned, the cleaning liquid supply device 23 drains the cleaning liquid to dry the casting mold 4. The use of a microwave oscillator for drying the casting mold 4 removes moisture from the casting mold 4 in a short process time. Very fine ceramic particles adhere to the inner surface of the porous casting mold to reduce the casting speed of the casting apparatus. The casting mold is cleaned by ultrasonic cleaning to remove the fine ceramic particles completely from the casting mold and to reduce the cleaning time required for cleaning the casting mold by compressed air. Although it is impossible to clean the conventional plaster mold by ultrasonic cleaning, the BN-based casting mold can be cleaned by ultrasonic cleaning without any trouble.

A continuous slip casting apparatus in another embodiment according to the present invention will be described hereinafter with reference to Figs. 8, 9 and 10. The high-pressure slip casting apparatus is equipped with a casting mold conveying device of a turntable type. A casting mold cleaning device 30, a casting mold drying device 40, a high-pressure slip casting device 50 and a product disengaging device 60 are arranged around a turntable 70. The turntable 70 locates a casting mold sequentially at positions corresponding respectively to those devices.

The casting mold cleaning device 30 has an arm 32 which holds the top half mold of the casting mold and moves the same vertically, and a cylinder actuator 31 which moves a tank 33 for containing a cleaning liquid vertically. The tank 33 may be provided with an ultrasonic cleaning device. A cleaning liquid supply/drain device 34 supplies a cleaning liquid through a tube 35 to the tank 33.

The drying device 40 is provided with pipes for blowing high-temperature drying gas against the casting mold. The pipes are extended through the rotary shaft of the turntable 70 and are connected to a drying gas supply device provided in a base 90.

The high-pressure slip casting device has a pressing cylinder actuator 51, holds the casting mold between upper and lower die sets 53, feeds a slurry by force through a slurry feed pipe into the casting mold for casting in a manner similar to that described previously with reference to Fig. 1. The slurry feed pipe is extended through the rotary shaft of the turntable 70. After the completion of the casting operation, the product disengaging device is actuated for operation similar to that described with reference to Fig. 1.

The product disengaging device 60 comprises an arm 62 for holding the top half mold of the casting mold, a cylinder actuator 61 for raising the arm 62, a swing arm 63 for supporting a product removed from the casting mold, and a simple robot 64 for turning the swing arm 63 to transfer the product from the swing arm 63 to a conveyor 64.

A driving unit 80 for driving the turntable 70 turns the turntable 70 intermittently in the direction of an arrow 71 to transfer the casting mold in synchronism with the actions of the casting mold cleaning device

30, the casting mold drying device 40, the high-pressure slip casting device 50 and the product disengaging device 60.

This high-pressure slip casting apparatus carries out the slip casting operation, the product disengaging operation, the casting mold cleaning operation and the casting mold drying operation by the separate devices, so that the process time is reduced and the mass production of cast products is possible. There is not any restriction on the number of casting molds to be arranged on the turntable 70. The number of casting molds to be arranged on the turntable 70 is determined taking into consideration a process time required for casting and a process time required for removing the products from the casting mold, cleaning the casting mold and drying the casting mold so that the slip casting process can most efficiently be completed.

The high-pressure slip casting apparatus shown in Fig. 1 was operated for casting a pottery molding slip under different casting conditions. Process times respectively for the different casting conditions needed for the completion of casting a cast product molding and removing the product are tabulated in Table 1. As is obvious from Table 1, the casting cycle needs a comparatively short process time, while the casting mold cleaning and drying cycle needs a comparatively long time. Accordingly, the curtailment of the process time needed for the casting mold cleaning and drying cycle improves the productivity of the apparatus, which can be achieved by the use of the BN-based casting mold having satisfactory spelling resistance and heat resistance. The porosity choking of the casting mold with the fine particles of the slip can be eliminated by the curtailment of the process time needed for cleaning and drying the casting mold.

As is apparent from the results of the slip casting operation of the high-pressure slip casting apparatus, a sufficiently high pressure can be applied to the slip and hence high-speed casting is possible.

When a conventional plaster mold is used for casting a cast product having a wall thickness substantially equal to that cast by using the BN-based casting mold and a pressure of 2 kg/cm^2 is applied to the slip, the casting cycle needs a process time in the range of 10 to 20 min. On the other hand, the high-pressure slip casting apparatus of the present invention is able to cast a product having a wall thickness on the order of 5 mm when the slip is pressurized at 200 kg/cm^2 by the pressure intensifier in a casting time in the range of 10 to 20 sec for a pottery slip, in the range of 5 to 10 sec for an Al_2O_3 slip, and in the range of 5 to 8 sec for a Si_3N_4 slip. The casting time can further be reduced by increasing the pressure applied to the slip.

When the slip is pressurized to a pressure not lower than 100 kg/cm^2 by the pressure intensifier, bubbles made in the surface of the product in feeding the slip by pressure are removed completely from the product during dewatering, so that the-fraction defective is reduced.

Table

Pressure (Kg/cm^2)	Pressurizing time (sec)										
	10	15	20	25	30	35	40	45	50	55	60
50	19.8	19.0	18.4	17.7	17.4	16.9	16.6	16.4	16.2	16.1	16.0
100	19.0	18.3	17.5	16.9	16.3	16.0	15.7	15.3	15.2	15.1	15.0
150	18.0	17.2	16.4	15.7	15.3	15.0	14.9	14.9	14.9	14.9	14.9
200	17.5	16.6	15.7	14.8	14.3	14.2	14.2	14.2	14.2	14.2	14.2

Molding:	Diameter: 50 mm, Thickness: 5mm
Slip :	Class: Stoneware slip
	Viscosity: 50,000 cps
	Water content: 24%
Water content of cast product:	16.5 to 17.5%

Claims

1. A high-pressure slip casting apparatus comprising:
a porous casting mold which comprises boron nitride of 10 to 50% by weight and at least one of other ceramic materials;
a casting table provided with holding means for holding the casting mold, and a product disengaging device;
a vacuum deaerating stirrer for deaerating and stirring a slip;
a pressure intensifier for pressurizing the slip; and
a piping system provided with pressure regulating means and interconnecting the casting table, the vacuum aerating stirrer and the pressure intensifier.

2. A high-pressure slip casting apparatus according to claim 1, further comprising an ultrasonic cleaning device and/or a drying device.

3. A high-pressure slip casting apparatus according to Claim 1, wherein the other ceramic materials are Si_3N_4, SiC, SIALON, ZrO_2, Al_2O_3, AlN and mullite.

4. A high-pressure slip casting apparatus comprising: a sequential arrangement of a casting mold cleaning device, a casting mold drying device, a high-pressure slip casting device and a product disengaging device; and a casting mold conveying device for conveying a casting mold sequentially to the casting mold cleaning device, the casting mold drying device, the high-pressure slip casting device and the product disengaging device.

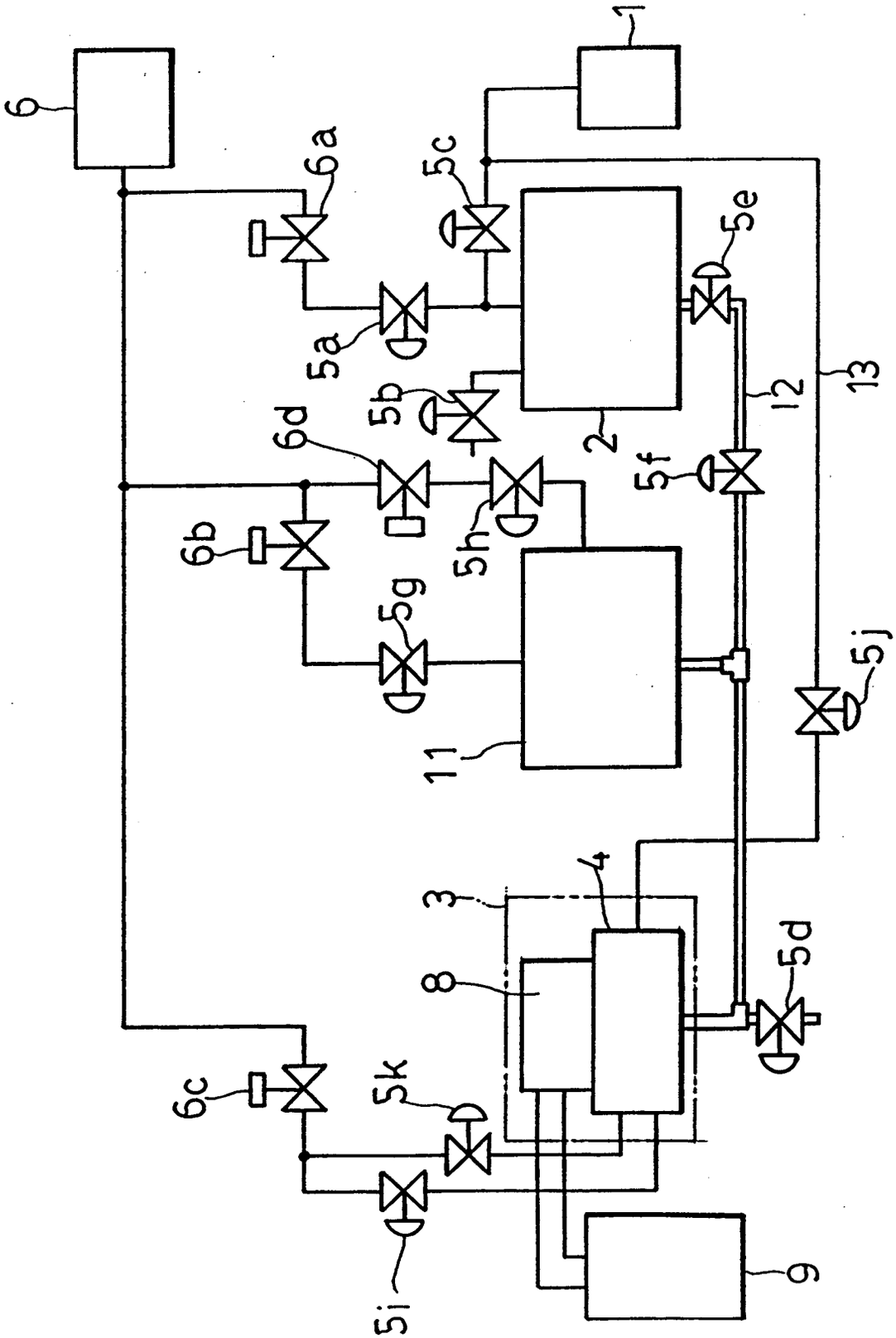

FIG. 1

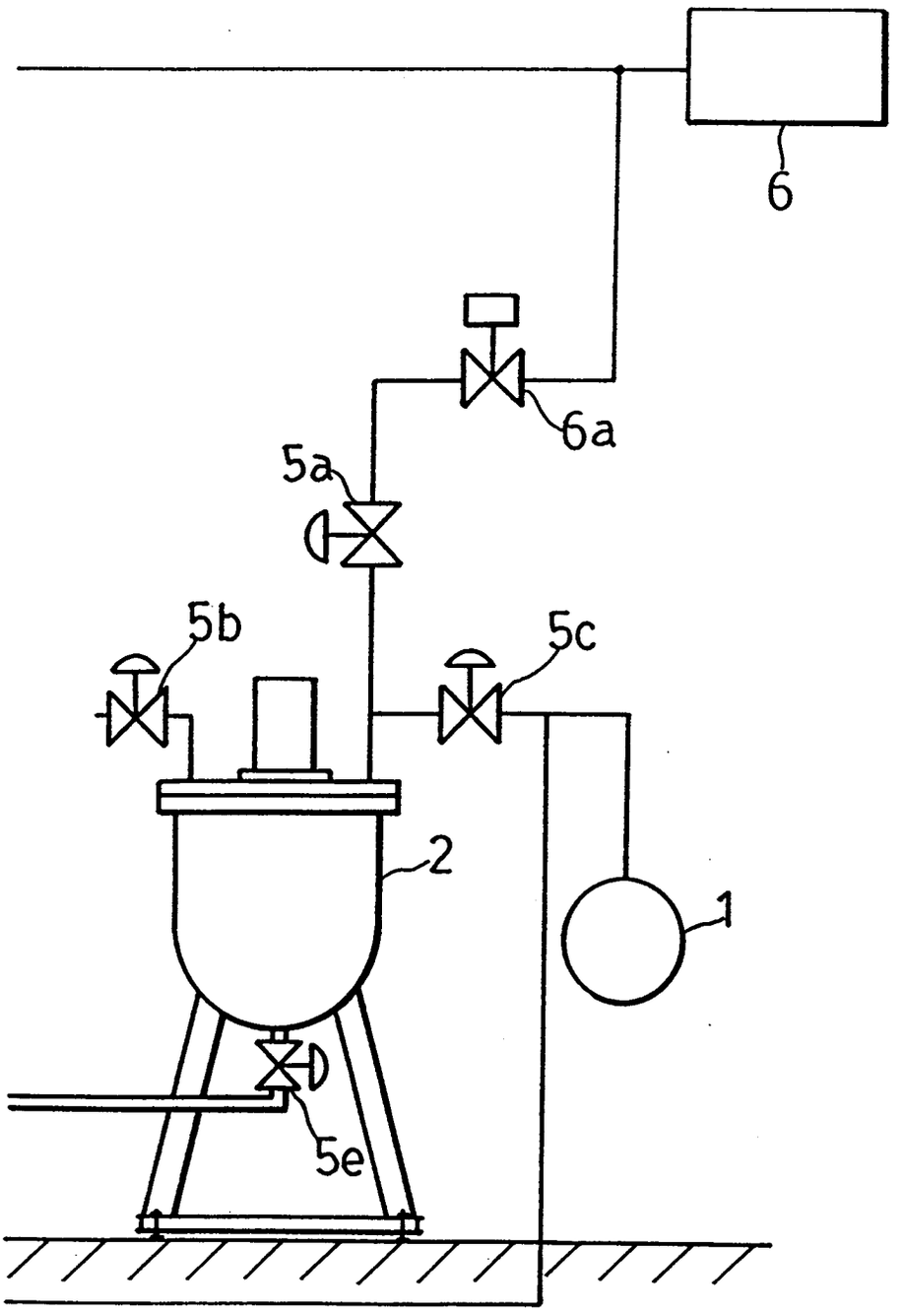

FIG. 2

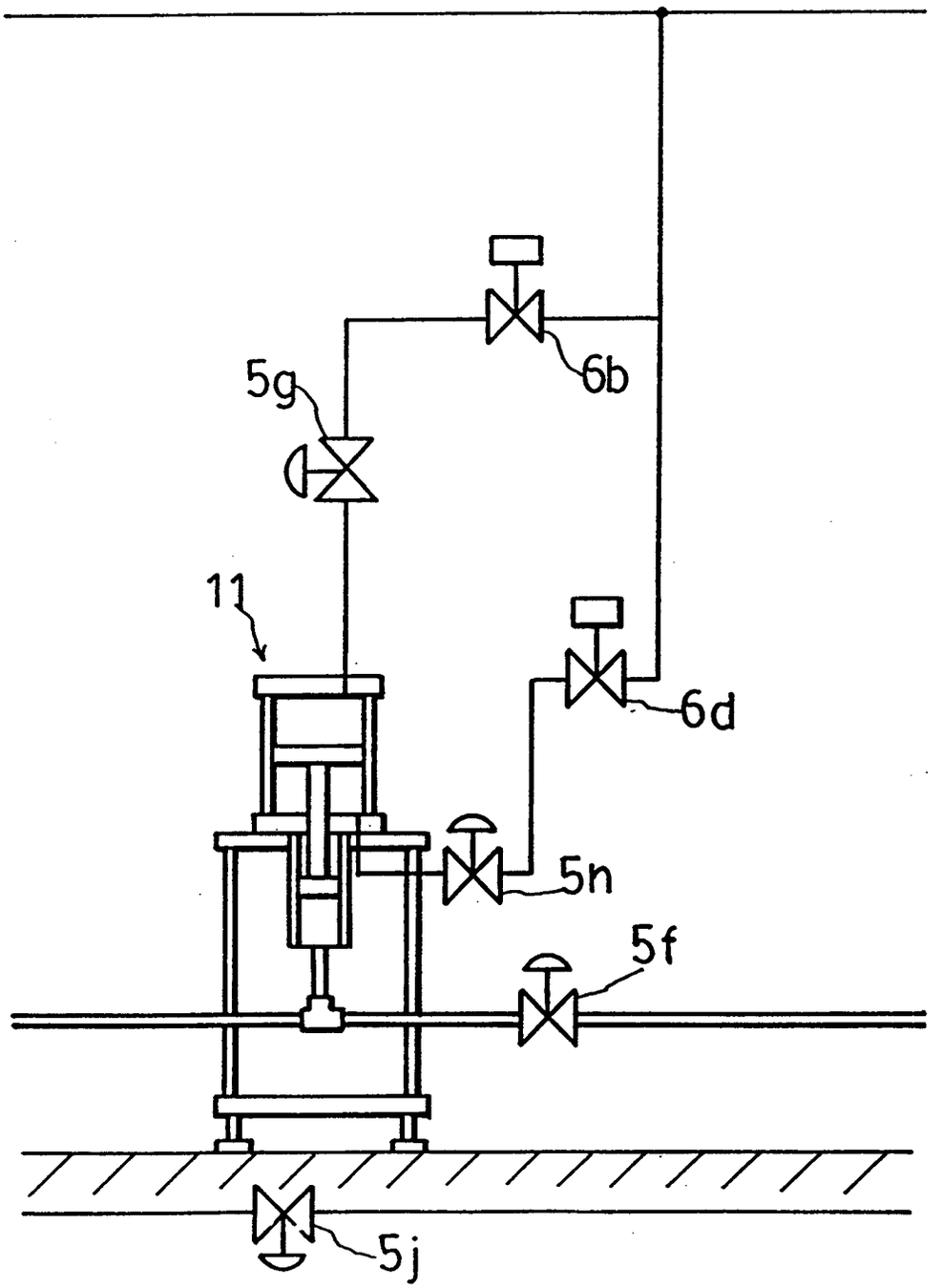

FIG. 3

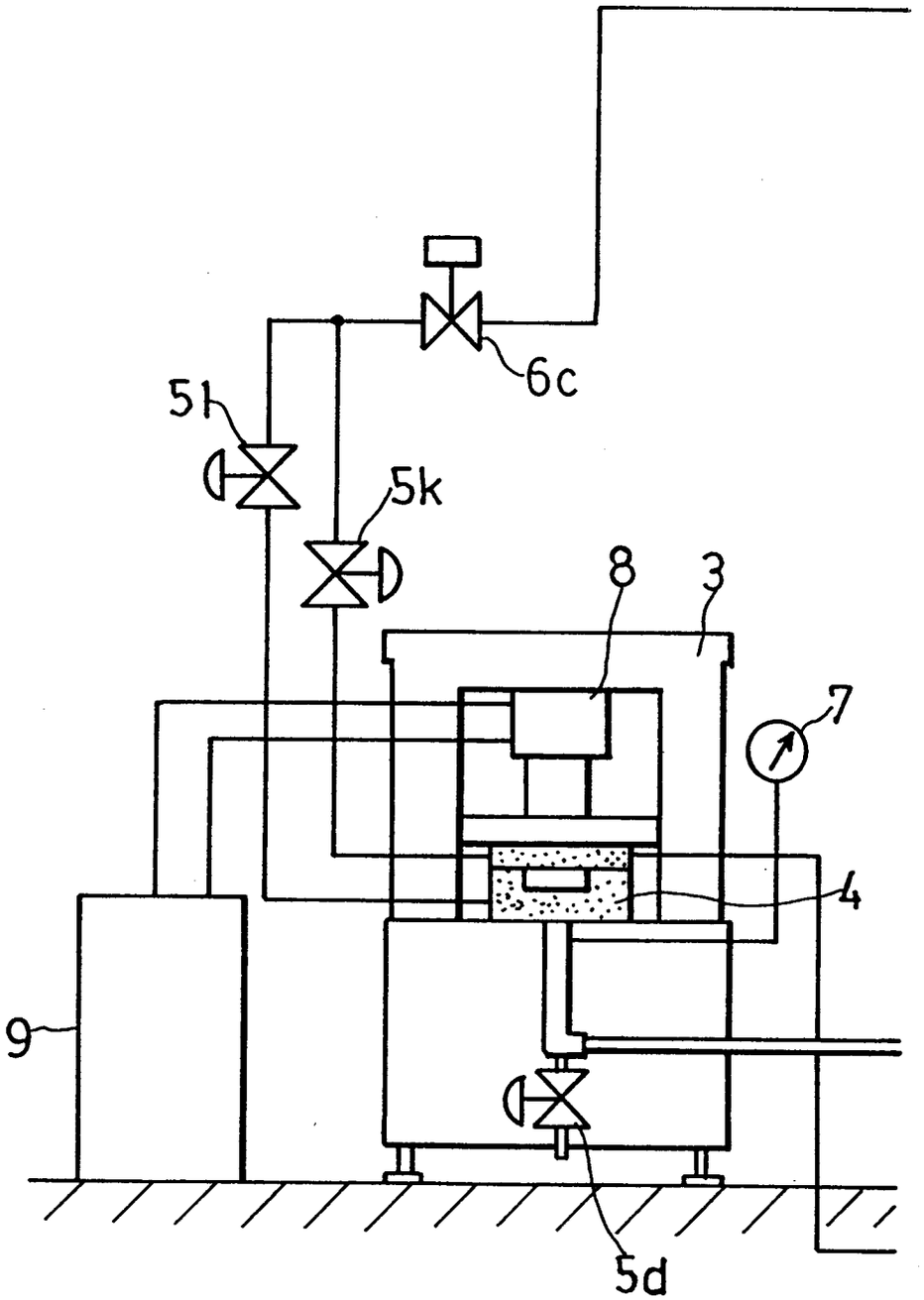

FIG. 4

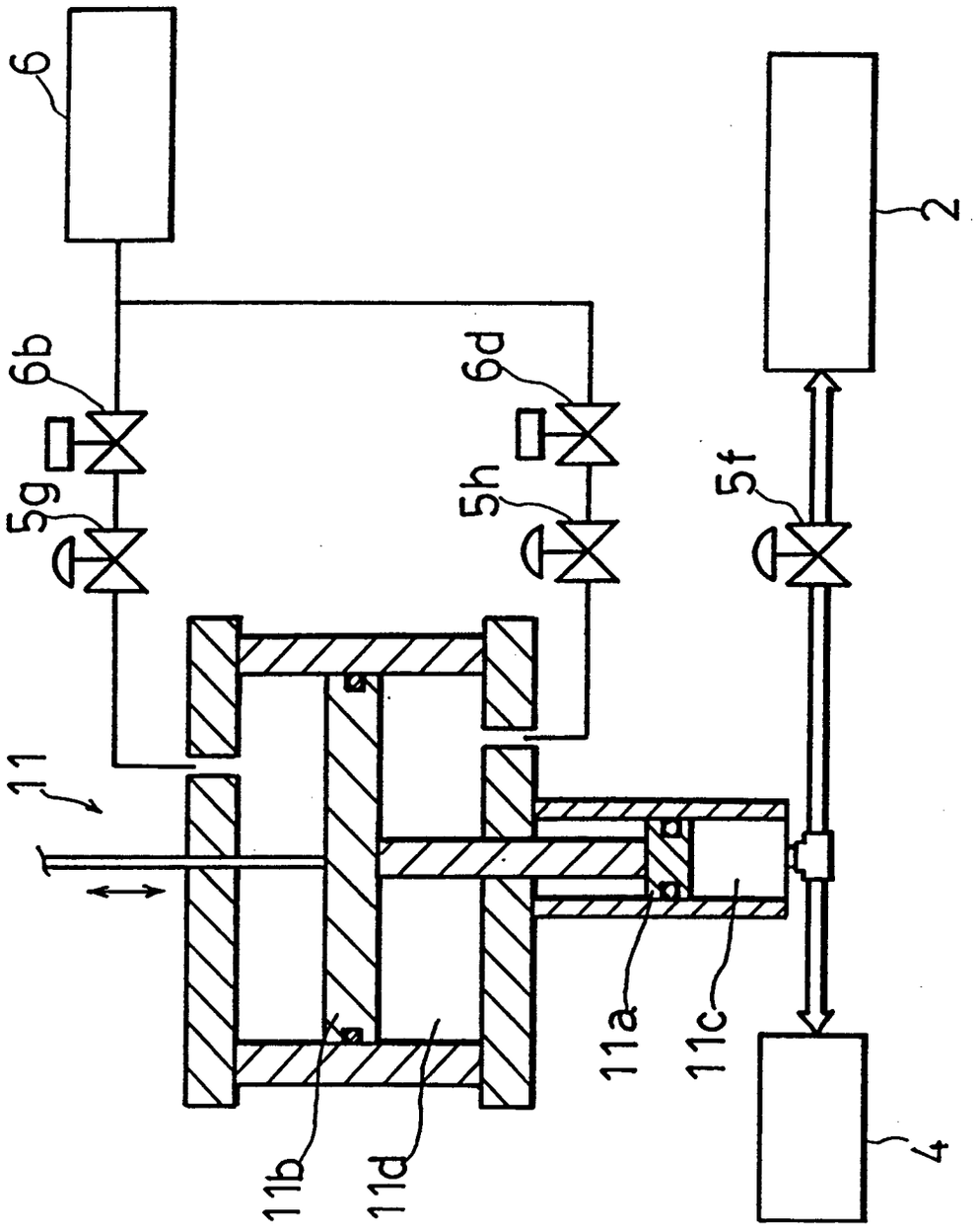

FIG.5

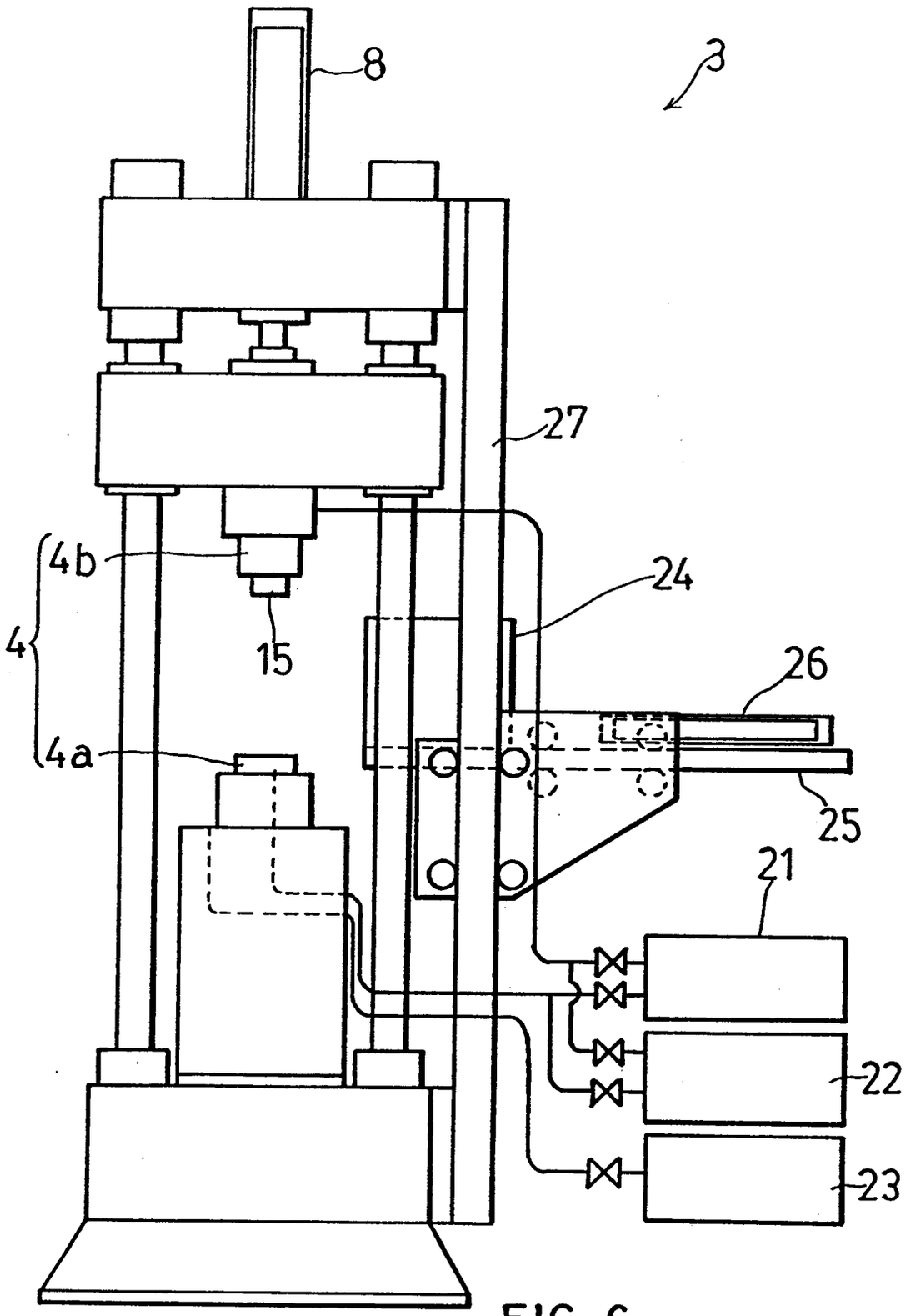

FIG. 6

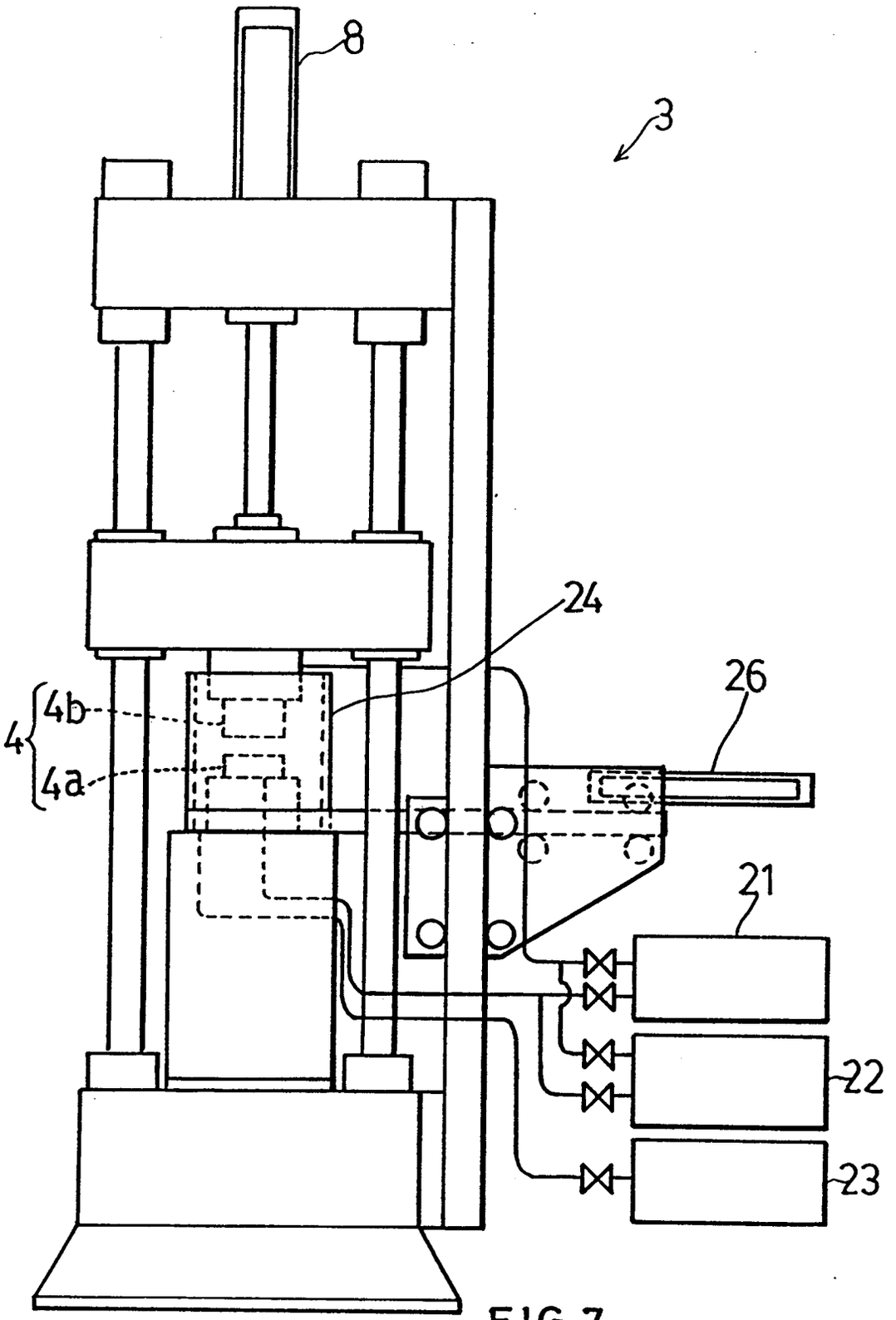

FIG.7

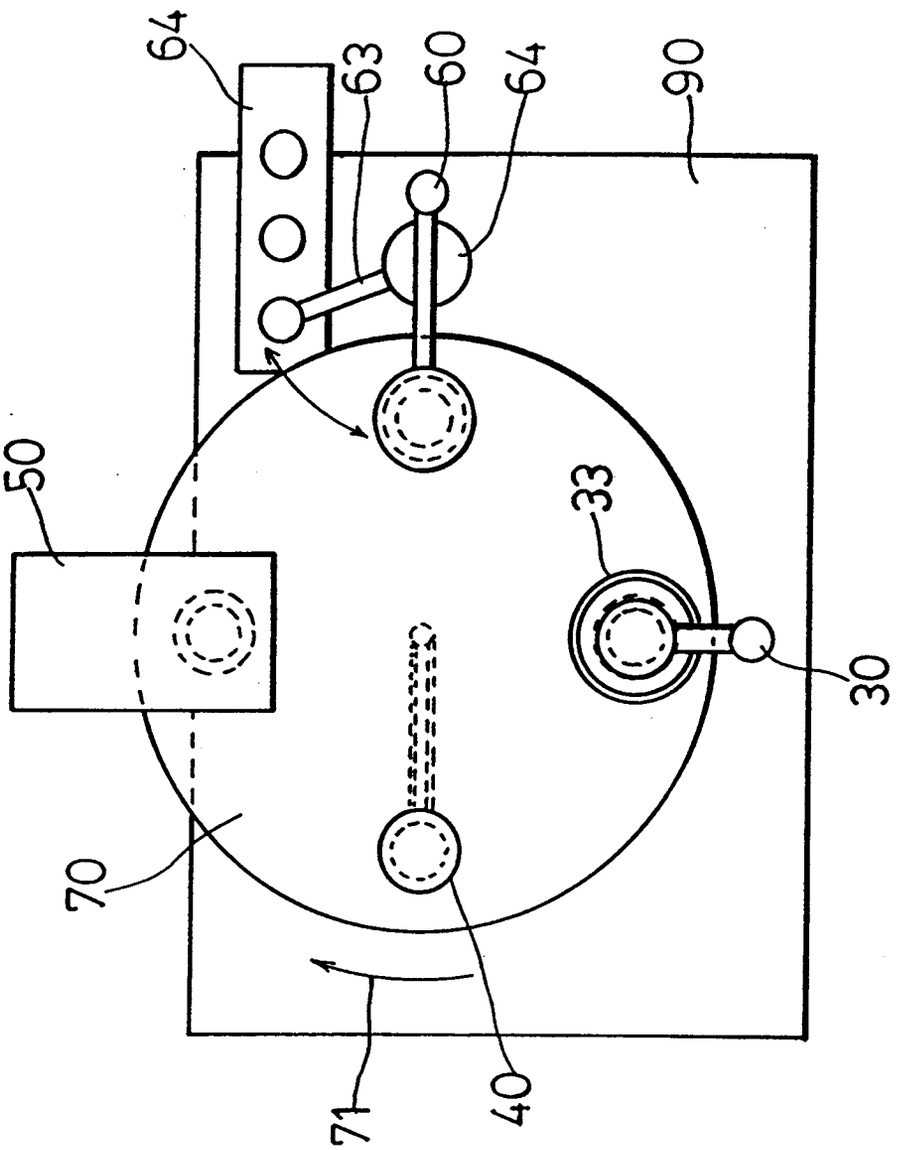

FIG.8

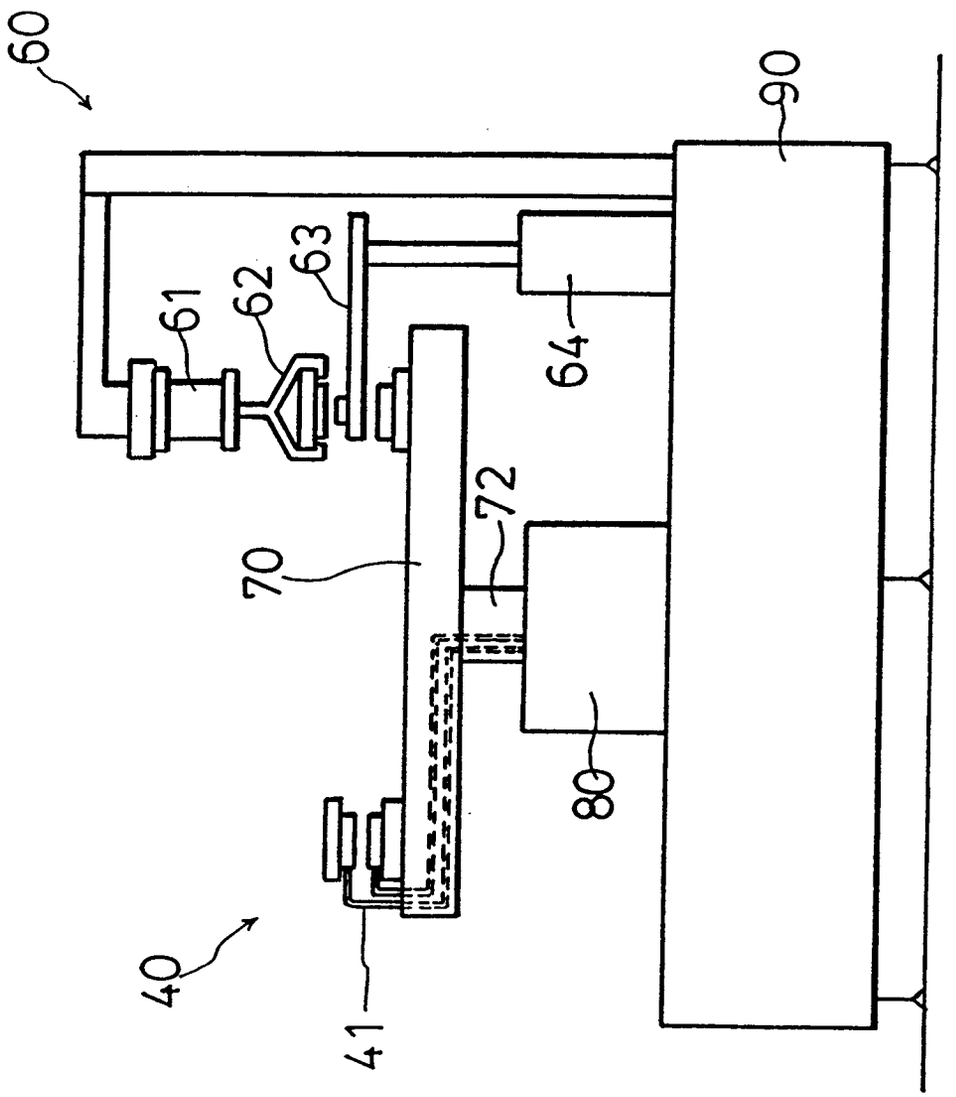

FIG.9

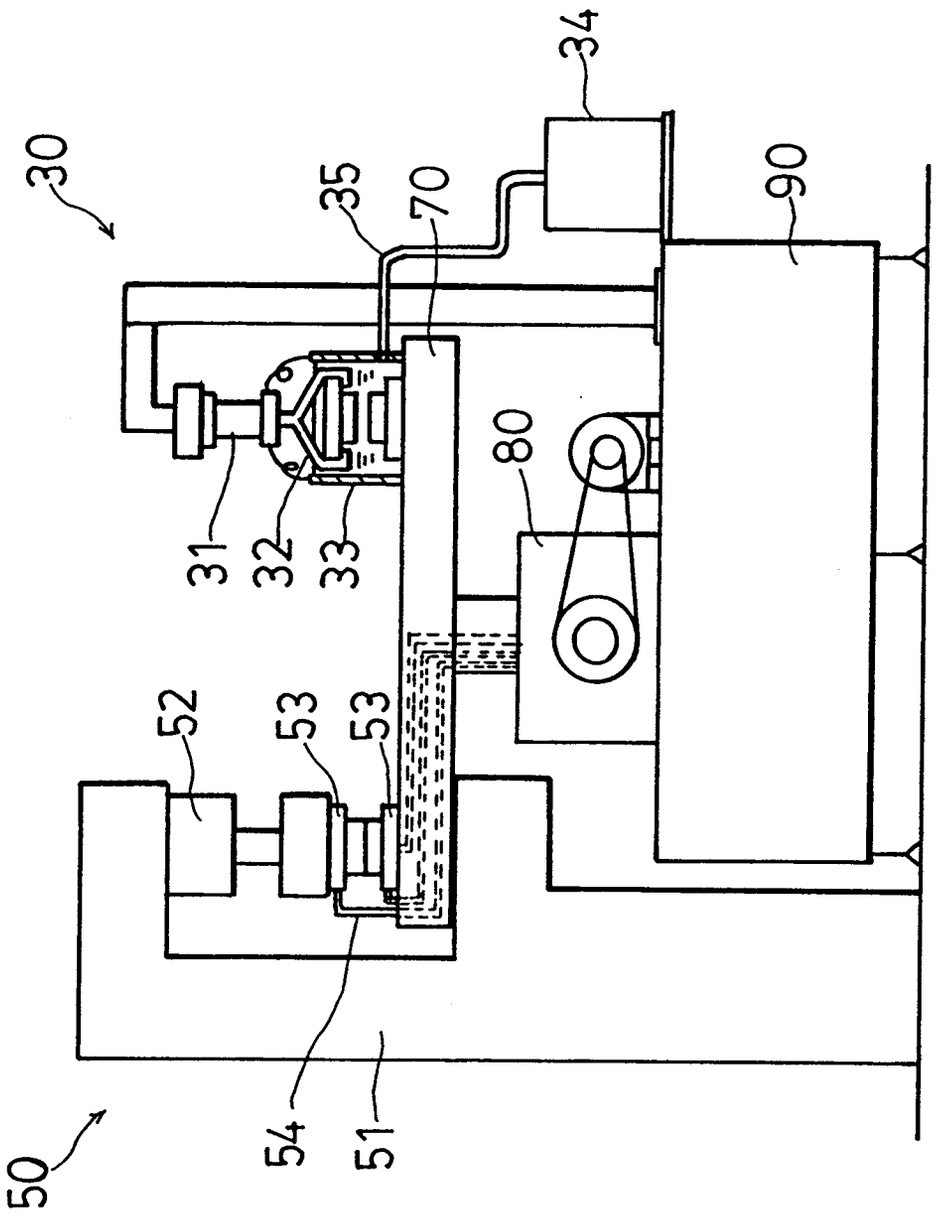

FIG.10

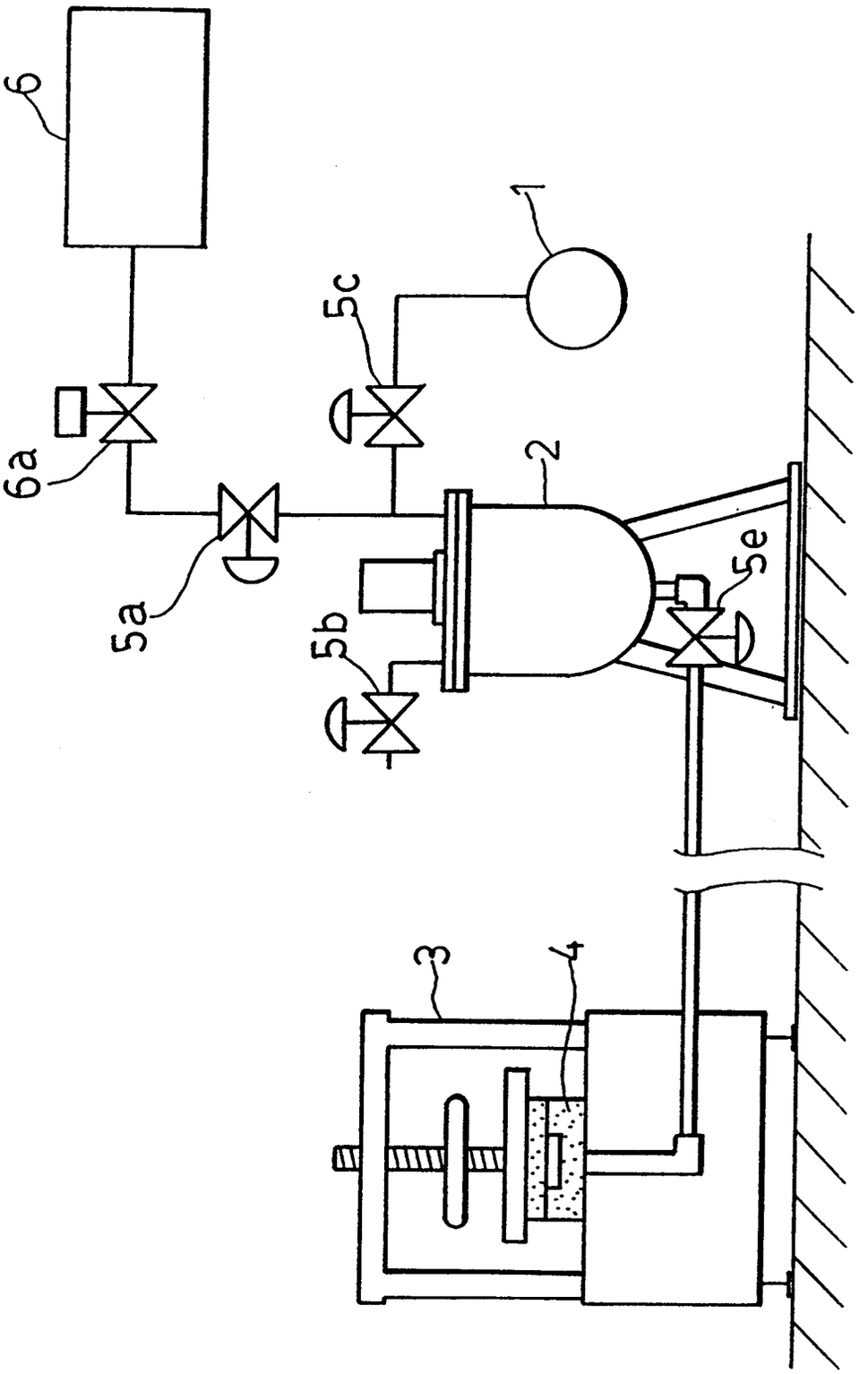

FIG.11

INTERNATIONAL SEARCH REPORT

International Application No PCT/JP91/00041

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl[5] B28B1/26

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC	B28B1/26, B28B7/34

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
Y	JP, A, 59-1207 (Hitachi Metals, Ltd.), January 6, 1984 (06. 01. 84), (Family: none)	1-4
Y	JP, A, 62-244603 (Catalar Kogyo K.K.), October 26, 1987 (26. 10. 87), (Family: none)	1-4

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"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)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

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

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
April 12, 1991 (12. 04. 91)	April 30, 1991 (30. 04. 91)
International Searching Authority	**Signature of Authorized Officer**
Japanese Patent Office	