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(54) **Rheocasting method and apparatus**

(57) A rheocasting method and apparatus are disclosed for die-casting metal alloy pieces. A metal alloy in semi-solid state is injected into a mould (3) by a vertical die-casting system comprising a mixing device (10) and a rotating table (4) provided with injection units (5), each provided with a container (8) for preparing the metal alloy in semi-solid state and injecting the metal alloy in semi-solid state into the mould (3); the injection units (5) are transferred in sequence, with step forward movement, between a loading station (6), where each injection container (8) is filled with a liquid metal alloy which is then stirred mechanically and simultaneously cooled to a semi-solid state by the mixing device (10), an injection station (7) where the semi-solid alloy is injected into the cavity of a mould (3), and a station (6') for removing cast pieces.

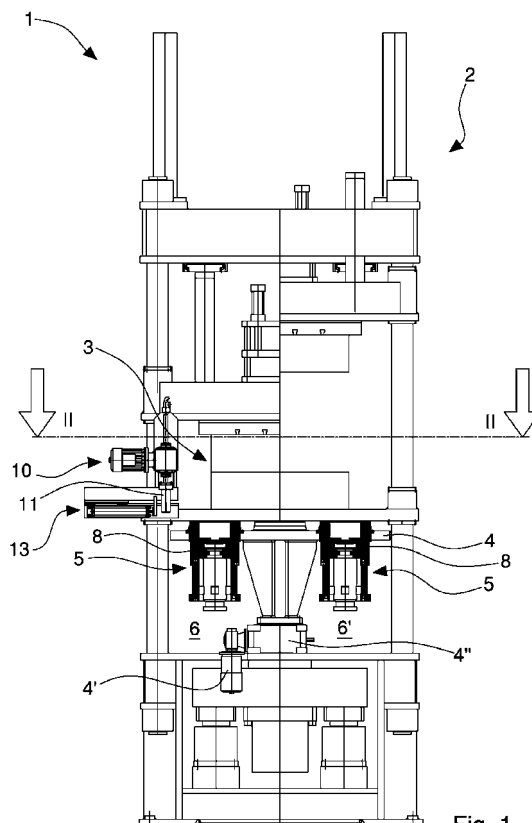


Fig. 1

DescriptionBACKGROUND OF THE INVENTION

5 **[0001]** The invention relates to a method and an apparatus for die-casting pieces of a metal alloy, for example an aluminium alloy, which is injected in semi-solid state into the cavity of a mould; in particular the invention refers to a rheocasting method and apparatus.

[0002] Specifically, but not exclusively, the invention can be advantageously applied to forming pieces of complex shape, of non-uniform thickness, with elevated mechanical features, made of aluminium alloys (for example Al-Si alloys), as required in particular for automobile industry.

10 **[0003]** Rheocasting is one of the known semi-solid processes (also known as SSM, "semi-solid metallurgy", processes). In an SSM process, a light alloy, generally of aluminium, is stirred mechanically, obtaining a structure with a globular solid phase (phase α -Al globules in the case of aluminium alloys) inside a liquid matrix. In these conditions, viscosity depends on the fraction of solid present, which in turn depends on the temperature and percentage of silicon in the alloy, and on the cutting speed applied during the stirring process. In particular, viscosity falls as cutting speed increases. The semi-solid alloy, cooled to a defined intermediate temperature between a "liquid" state and a "solid" state, takes on rheological features that make it suitable, despite the large number of solid particles, for being injected into a mould.

15 **[0004]** The SSM rheocasting process comprises casting an alloy, mechanically stirring the alloy with consequent formation of a globular structure and then the immediate injection into a forming mould. On the other hand, the thixocasting SSM process comprises an intermediate production of billets having the special globular structure, which is always obtained by alloy-casting and mechanical stirring; when necessary, the billets, possibly after cutting to size to make them the required length, are partially melted again and injected into a mould.

20 **[0005]** Patent US-A-6,901,991 shows an SSM process conducted in a vertical press having a loading station and an injection station. The molten alloy is poured into an injection chamber arranged in the loading station, then the injection chamber, with a respective piston, is transferred to the injection station, where the semi-solid alloy is injected into a mould. A cooling fluid flows in a movable plug, the upper end of which protrudes from the piston, penetrating into the semi-solid alloy in the centre of the injection chamber. The cooling plug is connected to a cooling fluid circulating circuit arranged outside the injection chamber.

25 **[0006]** In US-A-6,901,991 no means is provided for stirring the metal alloy and this is not made possible because of the protrusion of the cooling plug into the injection chamber; the use of a grain refining product is therefore envisaged to obtain the desired microglobular or spheroid structure. Further, in order to compensate for the rapid clearing of the alloy in contact with the walls of the injection chamber and in order to ensure the necessary quantity of material with the features required for the process, an injection chamber of large diameter must be used, which entails the formation of feedhead (casting waste) of large dimensions, with corresponding costs of its remelting and/or treating the waste material; the absence of any stirring means entails a relatively low percentage of solid in the mixture.

30 **[0007]** US-A-6,478,075 in turn shows a forming apparatus in which a quantity of molten aluminium is introduced into an injection chamber and subjected to electromagnetic stirring by a coil that surrounds the peripheral wall of the injection chamber, subjecting the wall to cooling by a fluid circulating inside the peripheral wall of the injection chamber. When the aluminium alloy has reached the desired semi-solid state a piston injects the semi-solid alloy into the cavity of a mould.

35 **[0008]** The apparatus shown by US-A-6,478,075 is improvable in many aspects.

40 **[0009]** First, it is desirable to reduce the percentage of solidified material that remains in the injection chamber; further, using an electromagnetic stirring system in combination with a cooling system of the injection chamber does not enable semi-solid alloys to be obtained having a particularly fine and uniform microglobular structure, and injectable mixture (slurry) having a high solid percentage finely dispersed in the liquid matrix.

OBJECTS OF THE INVENTION

45 **[0010]** The technical problem underlying the present invention consists of providing a rheocasting method and apparatus for die-cast pieces by means of which it is made possible to obtain a mixture (slurry) of a semi-solid metal alloy comprising a high percentage of solid particles, having a finely globular structure that is able to maintain a high degree of fluidity for injection also into moulds of complex design, or with extremely restricted passages, in the production of die-cast pieces of high quality.

50 **[0011]** Thus, one object of the invention is to provide a rheocasting method and apparatus for metal alloys that allows mechanical mixing and cooling simultaneously and to obtain a suitable semi-solid mixture to be easily injected into a mould.

55 **[0012]** A further object is to devise a rheocasting apparatus that is suitable for preparing a semi-solid mixture of a metal alloy to be injected into a cavity of a mould, having a high degree of homogeneity and a fine globular structure, thus reducing the percentage of material that, through the effect of cooling, remains solidified against the walls of the injection container.

[0013] A further object is to provide a constructionally simple and economic rheocasting apparatus.

[0014] Another object of the invention is to provide a rheocasting apparatus for a vertical press, with which it will be possible to treat a metal alloy in semi-solid state, thermally and mechanically simultaneously, in particular cooling and mixing, without requiring the installation of further apparatuses dedicated to this purpose.

[0015] A further object of the invention is to provide a vertical type of die-casting press, provided with a rheocasting apparatus, by means of which it is made possible to increase the maximum solid fraction that is obtainable before injection of the material into the mould, with the consequent possibility of reducing work-cycle time.

[0016] One advantage of the invention is to provide a rheocasting apparatus that is able to permit the formation of a great number of solidification cores, thus creating a fine and uniform microglobular structure that is translated into great mechanical properties of the die-cast piece.

[0017] Another advantage is to provide a rheocasting apparatus that is able to cast pieces with the desired micro-structural properties and mechanical features, such as, for example, reduced porosity and great ultimate elongation.

[0018] Yet another advantage is to devise a rheocasting apparatus that is able to subject a molten metal alloy to mechanical stirring and to suitable cooling methods that permit uniform distribution of the temperatures and greater homogeneity in the distribution of the solid fraction.

BRIEF DESCRIPTION OF THE INVENTION

[0019] Such objects and advantages, and still others, are achieved by the rheocasting method according to claim 1, and by a rheocasting apparatus according to claim 7.

[0020] According to a first aspect of the invention, a rheocasting method is provided in which a metered quantity of a molten metal alloy is loaded into an injection container, where it is subjected to stirring and cooling action until it assumes a semi-solid state and is then injected into a cavity of a mould;

characterised by the steps of:

setting up a mixing device comprising a stirring impeller supported in a movable manner to be dipped in the molten metal alloy, inside the injection container;

subjecting the molten metal alloy to simultaneous stirring and cooling by circulating a cooling fluid in the stirring impeller dipped into the molten metal alloy in the injection container; and

maintaining stirring of the semi-solid metal alloy in a controlled manner whilst it is cooled in the injection container, for a preset interval of time.

[0021] According to another aspect of the of the invention, the rheocasting apparatus comprises a vertical die-casting system that integrates a mixing device and a transferring device (for example of the rotating table type) that has at least two injection units for preparing a metal alloy in semi-solid state, in which each injection unit comprises an injection container that is suitable for receiving a quantity of molten metal alloy, and a movable element (piston) to inject the semi-solid alloy into a cavity of a mould, and in which the transferring device transfers in sequence, with step forward movement, the injection units between a loading station, where each injection unit is supplied with the molten alloy, an injection station, where each injection unit injects the semi-solid alloy into the mould cavity, and a station for removing the cast pieces from the mould.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The invention can be better understood with reference to the attached drawings that illustrate an example thereof by way of non-limiting example.

Figure 1 is a partially sectioned raised vertical view of a rheocasting apparatus according to the invention;

Figure 2 is section II-II in figure 1;

Figure 3 is section III-III in figure 4 of an injection unit of the apparatus in figure 1;

Figure 4 is section IV-IV in figure 3;

Figure 5 is a top plan view of a part of the mixing device;

Figure 6 is section VI-VI in figure 5;

Figure 7 is a diagram of the control system of the mixing device;

Figure 8 is a diagram of the cooling circuit of the molten metal in the injection container;

Figures 9, 10 and 11 show, in a raised elevation, three steps in the operating sequence of the apparatus in figure 1, at the loading station of the injection unit;

Figures 12, 13 and 14 respectively show three top views of figures 9, 10 and 11.

DETAILED DESCRIPTION OF THE INVENTION

[0023] With reference to the aforesaid figures, 1 indicates overall a rheocasting apparatus for rheocasting light alloy pieces, in particular an aluminium alloy, which is injected into a mould in semi-solid state, comprising a globular solid fraction (phase α -Al) and a liquid matrix of a eutectic composition.

[0024] The apparatus 1 is configured for receiving a dosed quantity of molten metal, sequentially in suitable containers of respective injection units, and for taking the molten metal to a semi-solid state by cooling to a desired temperature, in an intermediate position between "liquid" state and "solid" state, whilst it is subjected to simultaneous mechanical stirring in the same injection container, the metal in a semi-solid state then being injected into a die-casting mould.

[0025] The apparatus 1 comprises a press 2, in particular a vertical press, for forming metal pieces by rheocasting. The press 2 is provided with at least one mould 3, for example formed by two half-moulds; it can also be provided with operating means normally found in an injection press for rheocasting, for example a mould-closing system and a system for extracting the moulded piece. The press can be, for example, hydraulically driven, or electrically driven, or of still another type. In figure 1 the mould 3 is shown in an open position (on the right) and in a closed position (on the left).

[0026] The rheocasting apparatus 1 comprises a transferring device of the injection units 5, consisting of a movable support 4, in particular a rotating table according to a vertical rotation axis, rotated in steps by a reduction gear 4' and an intermitter 4". The movable support 4 has a plurality of injection units 5, in the case in point three units 5, and is configured for transferring the injection units 5 in sequence, with step forward movement, between at least one loading station 6, figures 2, 9 and 12, where each injection unit 5 receives a metered quantity of molten metal (aluminium alloy) and in which the molten metal is suitably processed to a semi-solid state; a station 7 for injecting and removing the cast pieces, where each injection unit 5 is driven to inject into the mould 3 the molten metal that has been processed directly in the injection unit 5 to a semi-solid state; and a station 6' for removing the feedhead and lubricating the container 8 of each injection unit 5.

[0027] The transferring device 4 may correspond, for example, to the device with a rotating table disclosed in WO-A-01/05537, of the same applicant, which is included here for reference.

[0028] As shown in figure 3, each injection unit 5 comprises an injection container 8 configured for receiving the molten metal, and a piston 9 that is axially slidable for injecting into the mould 3 the molten metal contained in the injection container 8.

[0029] The injection container 8 is open above and the piston 9 is axially slidable, in a vertical direction, inside the injection container 8, to supply the mould 3 from bottom to top.

[0030] The rheocasting apparatus 1 further comprises a mechanical mixing and cooling device 10 provided with an impeller 11 having the possibility of adopting at least one active position (figure 11), in which the impeller 11 protrudes inside the injection container 8 to mix the molten metal contained therein, and at least one inactive position (figures 9 and 10), in which the impeller 11 of the mixing device is outside the injection container 8. The mixing device 10 operates in an active position in the loading station 6.

[0031] As shown in figures 5, 6 and 7, the mixing device 10 comprises an impeller 11 having one or more mixing blades 12, for example two mixing blades 12 as in the example illustrated here.

[0032] The impeller 11 is oriented downwards with a vertical rotation axis and is movably supported vertically and horizontally, and in active position (figure 11) it is dipped into the molten metal in the injection container 8 in such a manner as to generate an intense mixing and simultaneous cooling action, whilst in inactive position (figures 9 and 10) it is outside the injection container 8.

[0033] In the example shown, the apparatus 1 thus comprises control means 13 for moving the impeller 11 of the mixing device 10 vertically and horizontally, between the active and inactive positions. The control means 13, as shown in figures 9 to 14, comprises a first, vertically oriented, extendible guide 13', to which the mixing device 10 is fixed; the first extendible guide 13' is in turn supported by a second, horizontally oriented, extendible guide 13" fixed to a side of the frame of the vertical press. The control means 13 is thus able to move the impeller 11 of the mixing device 10 along two orthogonal axes lying on a vertical plane. The mixing device 10 can thus be driven to move the impeller 11 both in a horizontal position to approach the loading station 6, and in a vertical direction to be dipped into at least a part of the molten metal to be subjected to stirring inside the injection container 8; alternatively to the arrangement fixed to the frame of the press, the mixing device 10 can constitute part of a suitable robot.

[0034] The mixing device 10 comprises motor means for activating the mixing action. The motor means will be configured, in particular, for rotating the mixing impeller 11. The driving means comprises, in the case in point, an electric motor 14 driven by a speed regulator (inverter). As shown in figures 6 and 7, the impeller 11 is connected to a hollow shaft 15, which is in turn connected to the electric motor 14 by a right-angle head 14". The group formed by the impeller 11, hollow shaft 15 and electric motor 14, is mounted on the extendible guide 13', as indicated previously.

[0035] The mixing device 10, figure 7, is further provided with sensor means, for example a drive torque transducer T, configured for issuing a control signal FB indicating the energy used by the motor 14 to drive the mixing device 10, which is fed back to a axes controller CA that is operationally connected to a process unit CPU to send a torque or

current signal SC that is respectively connected to send a motor reference signal RM to an inverter IN for a command SD of the motor 14. The sensor means is able, for example, to detect the torque and/or the electric current absorbed by the motor 14, as function of the signal SM emitted by the motor 14; the process unit CPU sends to the axes controller CA a motor speed reference signal SV and on the basis of a specific calculation algorithm it is able to provide an indication of impeller speed and the percentage of solid globular metal in the liquid matrix of the molten metal in the injection container 8 with a constant impeller speed 11. The control unit (CPU) is thus configured for receiving the signal SC emitted by the axes controller CA and for controlling the speed of the electric motor 14 that rotates the mixing impeller 11, in response to the signal received. Figure 7 shows schematically the feedback control mode of the driving motor 14 of the mixing and mechanical stirring impeller 11.

[0036] As shown in figure 8, the rheocasting apparatus 1 further comprises a cooling circuit 16 of the molten metal in the injection container 8, that extends at least partially inside the mixing device 10 in such a manner that a thermal fluid that flows into the cooling circuit 16 can remove heat from the molten metal directly in the injection container 8, whilst the mixing device 10 is in the active position of figures 8 and 11, and regulate the temperature of the injection container 8' and the respective piston 9.

[0037] In this regard, as shown in figure 6, the bottom end of the rotor 11 near the blades 12 comprises a cavity 19' for the circulation of a thermoregulating or cooling fluid. The cavity 19', in the example shown, consists of a blind hole that extends longitudinally into the body of the impeller 11, in continuation of a longitudinal hole of the hollow control shaft 15. A conduit 18 extends coaxially to the hollow shaft 15 in the blind hole or cavity 19' of the impeller 11, ending at a certain distance from the bottom of the blind hole 19'. The conduit 18 has a lower outer diameter less than the inner diameter of the hole of the hollow shaft 15, in such a manner that between the conduit 18 and the peripheral wall 17 of the hollow shaft 15 an annular gap 19 is formed. The annular gap 19 and the conduit 18 form two distinct portions of the cooling or thermoregulating circuit 16, respectively a supply portion and a recirculating portion inside the impeller 11.

[0038] The hollow shaft 15 and the conduit 18 are operationally connected to the external part of the cooling circuit by a rotating joint 20 having an inlet 20' and an outlet 20" for the fluid.

[0039] More in detail, with reference to the diagram in figure 8, the inlet 20' of the joint 20 communicates, by a manifold unit CL, with the delivery 21 of a supply source 24 of the thermoregulating and/or cooling fluid, whereas the outlet 20" of the joint 20 communicates, again via the manifold unit CL, with the return 22 of the thermoregulating fluid.

[0040] As shown in figures 3, 4 and 8, the thermoregulating and cooling circuit 16 extends, at least partially, inside the side walls of the injection container 8, inside the piston 9 and the impeller 11 as disclosed above. In the case in point, the cooling circuit 16 comprises three secondary circuits that are parallel to one another, connected to the source 24 of the cooling fluid by the manifold unit CL; precisely it comprises a first secondary circuit connected to the impeller 11 of the mixing device 10, a second secondary circuit connected to the delivery conduits 9' and 9" that open in a cavity 9'" of the piston 9 and a third secondary circuit connected to circulation conduits 8' and 8" obtained in the side wall of the injection container 8.

[0041] In the operation of the rheocasting apparatus 1, the control of the rheological properties of the molten metal in the injection container 8 is achieved by adjusting the cooling speed and the cutting speed of the impeller 11 in the step of preparing the semi-solid alloy. The cutting speed is adjusted by the feedback control signal FB, correlated to the signal SM of the driving motor 14 of the mixing device 10. As already mentioned, the feedback signal FB to the axes controller CA is sent to the CPU as a torque or current signal SC; in turn, the CPU sends to the axes controller CA a speed reference signal SV. The axes controller CA sends to the inverter IN a motor reference signal RM that the inverter IN transforms into a motor control signal SD.

[0042] Cooling speed is on the other hand regulated by a system for controlling the flow of cooling and/or heat adjusting fluid, comprising one or more flow sensors, for example the flow meters 23 in figure 8, that measure the flow of the cooling fluid in at least one portion of the cooling circuit, for example in the outer part of the first secondary circuit of the mixing device 10, and/or in the outer part of the second secondary circuit that traverses the punch 9, and/or in the outer part of the third secondary circuit that traverses the walls of the injection container 8, and at least one unit 24 for thermally conditioning the fluid that is controlled by the control unit CPU to regulate and vary the temperature of the cooling fluid in response to signals coming from the flow sensors 23.

[0043] With reference to the figures, the process of preparing the semi-solid metal alloy comprises the following steps in sequence:

a metering element 25 removes from a holding furnace that is in itself known and not illustrated, a metered quantity of liquid molten metal alloy and pours the liquid molten metal alloy into the injection container 8 of the injection unit 5, which at a given moment is found in the loading station 6 (figures 9 and 12). The temperature at which the metal is poured into the injection container can be, for example, about 640 °C ÷ 650 °C; the mixing device 10 is deactivated and in a retracted position.

[0044] After that, the mixing device 10 intended for mechanical stirring treatment of the alloy is positioned above the

injection container 8 containing the liquid metal that has just been poured (figures 10 and 13), by movement along a horizontal movement axis guided by the conveying unit 13.

[0045] Subsequently, the impeller 11 of the mixing device is rotated and dipped into the liquid metal to prepare the alloy for the semi-solid state (figures 11 and 14). At the same time the cooling fluid is made to flow in the cooling circuit at a controlled temperature and/or at a controlled flowrate. In this step, the cooling speed of the material is adjusted by acting on the temperature and/or on the flowrates of the thermoregulating flows that affect the impeller 11 and the container/piston units. The thermoregulating or cooling fluid consists, for example, of pressurised water with temperatures settable in a range from 20 °C to 200 °C.

[0046] The rheocasting apparatus 1 can be provided with means (known and not illustrated) for blowing an inert gas onto the molten metal, in particular onto the surface of the metal being prepared inside the injection container 8. During the mixing step it is thus possible to control direct blowing of an inert gas such as argon or nitrogen onto the metal. This drastically reduces the oxidation of the surface portion of the metal that is otherwise in contact with the ambient air.

[0047] During the mixing step, owing to the cooling and formation of the globular solid part, the density of the mixture consisting of the fraction of liquid metal and of the fraction of globular solidified metal, normally known by the technical term of "slurry", tends to increase gradually; consequently, the energy increases that is necessary for driving the electric motor 14 of the mixing device 10. Thus, by means of the control signal generated by the transducer T, the CPU is at any instant able to know the percentage of solid globular metal, which can be compared with a reference value stored in the CPU.

[0048] Tests conducted have shown that after termination of cooling and stirring a semi-solid mixture is shown with a high percentage of the solid fraction, having a finely globular structure that is comparatively inferior to what is obtainable with currently known systems.

[0049] The high percentage of solid fraction, and the fine globular structure, are extremely advantageous for the reasons indicated above and inasmuch as the semi-solid mixture maintains a high degree of fluidity that enables die-cast pieces of high quality to be obtained even in the case of particularly complex pieces, or with moulds having passages of extremely small dimensions.

[0050] The stirring time can vary and be comprised, for example, between about 10 and 15 seconds for aluminium alloy casts. The injection container can be preheated, by adjusting the temperature of the side walls thereof, in such a manner as to be comprised initially within values comprised between 200 and 250°C, and then subsequently lowered by as much as necessary; heating values, for example up to 300°C or above, can be obtained during an automatic operating cycle, owing to the heat yielded by the metal alloy in semi-solid state, or by providing a configuration with diathermic oil thermoregulation of the conditioning circuit of the injection containers 8.

[0051] Once the process of preparing the semi-solid state alloy has terminated, the injection unit 5 is moved, for example by a step, by the movable support 4, to the injection station 7, where it is below the forming mould 3. Here, the piston 9 is raised to inject the semi-solid material into the mould 3 and form a die-cast piece.

[0052] The semi-solid alloy is thus prepared directly in a rheocasting apparatus 1 constituting part of a vertical press by means of which direct transfer of the metal in a semi-solid state is made possible, the metal in a semi-solid state passing from the preparing station 6 in the injection container 8 to the forming mould 3 in an extremely short time, rheological features being maintained substantially unchanged.

[0053] In the course of experimentation, it was found that it is possible to obtain an injectable semi-solid material having a solid fraction value that is greater by about 60 ÷ 65 %, with an extremely fine globular shape that is less than what is obtainable with currently known systems.

[0054] The rheocasting apparatus 1 disclosed here enables the excessive initial cooling of the alloy in contact with the hot walls of the injection container 8 and of the piston 9 to be limited, it being possible to thermoregulate the walls so as to avoid or significantly reduce the portion of solidified material that adheres to the container. In the rheocasting apparatus 1 disclosed here it is further possible to obtain controlled cooling of the semi-solid metal by combining the mixing action with the action of thermoregulating and cooling of the walls of the injection container 8 and/or of the piston 9, and with the cooling action exerted by the mixing device 10 that stirs the material mechanically.

[0055] It has in fact been ascertained that cooling exercised through the mixing device 10, in particular if combined with the thermoregulating action exerted through the walls that bound the injection container 8, enables a great number of solidification cores to be generated and enables the solidification cores to be spread evenly throughout the entire semi-solid mass of the metal alloy, so that the microglobular structure obtained is finer and more uniform.

[0056] The rheocasting apparatus 1 disclosed here enables relatively high injection container 8 temperatures and relatively short dwell times of the metal inside the container to be obtained.

[0057] The process of forming the globular structure, which can be implemented with the rheocasting apparatus 1 disclosed here, following the synergic action of central cooling and stirring performed directly in the injection container 8 of the mixing device 10, finally enables the temperatures to be distributed evenly over the molten alloy and thus greater evenness thereof to be obtained.

[0058] As said, the rotation speed of the rotor 11 is regulated by controlling in a closed loop the number of revolutions

of the electric motor 14 that drives the impeller. By checking the value of the torque and/or current absorbed by the motor 14 during mixing, the repeatability of the process and of the percentage of solid fraction at the end of the process of preparing the semi-solid material is guaranteed; as previously mentioned, it was in fact ascertained that the same torque and/or current absorbed by the motor corresponds substantially to a set solid fraction in the alloy being prepared. The repeatability of the percentage of solid fraction in the injected alloy is an important requisite that enables the constancy of the mechanical features of the cast pieces to be ensured such as, for example, elongation and tensile strength.

EXAMPLE

[0059] Some data relating to an example of a piece cast using the rheocasting apparatus disclosed above are set out below. The die-casting machine used has a mould closing force of 400 T, an injection force of 250 T, and an injection container diameter of 180 mm.

[0060] A single-cavity mould was used to produce a flange for pylon structures in an aluminium alloy.

[0061] The molten aluminium alloy (AlSi7Mg0.6) was subjected, in a holding furnace, only to degassing and slagging treatment. The pieces, which were cast according to this SSM technology, were produced with the following process parameters: maintenance temperature of the alloy in the holding furnace 650°C; time of treatment of the material inside the container for preparing the semi-solid alloy: 13 seconds; rotation speed of the rotor 90 rpm.

[0062] With regard to the mould temperature, the walls in contact with the injected alloy were thermoregulated with diathermic oil at a temperature of 250°C. A second circuit with water at 25°C was subsequently used to cool the body of the mould. The injection container, the piston and the impeller were thermoregulated with pressurised water at a temperature of 90°C.

[0063] The speed of the injection piston during the filling step was 30 mm/sec. This speed was translated into a speed of the metal in the ingates of 900 mm/sec. The final pressure on the metal was 900 bar. The pieces that were thus obtained were subjected to heat treatment T6, according to SPM standards, which consists of hardening and complete artificial aging. In the case of the alloy in question, the pieces were maintained for 5 hours at 540°C, hardened in water at 20°C and then 6 hours at 165°C.

[0064] The pieces were then sectioned in such a manner as to obtain testpieces on which to conduct tensile stress tests to ascertain the mechanical features obtained. The following table summarises the values obtained, where:

RM = Ultimate tensile stress

RP0,2% = Load at proportionality limit

A% = Elongation percentage

Type of alloy: EN 42200 (AlSi7Mg0.6)			
SSM process rheocasting			
Treatment: T6			
Testpiece	Rm (N/mm ²)	Rp 02% (N/mm ²)	A%
1	324.5	287.1	3.2
2	332.2	278.5	3.5
3	354.1	291.8	5.4
4	347.2	286	6
5	336.9	286.5	3.5
6	327.4	282.5	2.9
7	349.9	283.2	7.2
8	342.8	277.5	6.2
9	337.1	289.4	4.4
10	338	278.4	4.8
average	339.0	284.1	4.7

[0065] The data obtained confirm that the SSM process performed with the rheocasting apparatus according to the invention enables, in an extremely short time, casts to be obtained with mechanical features that are comparable to if not greater than those obtainable with conventional rheocasting methods and with those obtainable with iron-mould

casting technology, with the further advantage of being able to produce pieces with complex geometry and less thickness.

[0066] It is understood that what has been said and shown with reference to the example of the attached drawings has been given by way of illustration of the general features of the method and of the rheocasting apparatus according to the invention and of a preferred embodiment thereof. Accordingly, other modifications and/or variations can be made to the method and/or to the apparatus; for example, the impeller of the mixing device and the internal circulating circuit of the cooling fluid could be conformed differently from what is shown. The same mixing and cooling that on the other hand constitutes part of a vertical injection press, as shown, could consist of a separate device supported by a suitable robot, without in any manner falling outside the scope of the object of the claims.

Claims

1. A rheocasting method wherein a metered quantity of a metal alloy in a molten state is loaded into an injection container (8), where it is subjected to stirring and cooling actions until to a semi-solid state, whereupon it is injected into a mould cavity (3);

characterised by the steps of:

providing a stirrer device (10) comprising a stirring impeller (11), movably supported to be dipped into the molten metal alloy within the injection container (8);

subjecting the molten metal alloy to simultaneous stirring and cooling actions by causing a cooling fluid to flow within the stirring impeller (11) while the latter is dipped into the molten metal alloy within the injection container (8); and

keeping the semi-solid metal alloy under controlled stirring conditions, while it is being cooled within the injection container (8), for a preset time.

2. The rheocasting method according to claim 1 wherein an aluminium metal alloy in the semi-solid state comprises a globular solid fraction (phase α -Al) in a liquid matrix of a eutectic composition, **characterised by** the step of adjusting a solid fraction percentage, by controlling the cooling rate of the semi-solid metal alloy within the injection container (8), as well as controlling the temperature and/or flow rate of the cooling fluid circulating within the impeller (11) of the stirrer device (10).

3. The rheocasting method according to claim 1 or 2, **characterised by** the step of detecting the flow rate of the cooling fluid, and controlling the cooling rate by adjusting the cooling fluid temperature to a value selected from 20°C to 200°C, as a function of the detected flow rate.

4. The rheocasting method according to any one of claims 1 to 3, further **characterised by** the step of heating the injection container (8) to a temperature lower than the temperature of the molten metal alloy at the pouring into the injection container (8).

5. The rheocasting method according to claim 4, **characterised by** the step of pre-heating the injection container (8) to a temperature equal to, or higher than 200°C-250°C.

6. The rheocasting method according to any one of claims 1 to 5, **characterised by** the step of stirring and cooling the metal alloy in the semi-solid state, for a time ranging between 10 and 15 seconds.

7. An apparatus suitable to carry out a moulding of die-cast metal pieces according to the rheocasting method of any one of claims 1 to 6, **characterised by** comprising:

at least one injection unit (5) having an injection container (8) configured for receiving a metered quantity of a molten metal alloy, and a piston (9) to inject the molten metal alloy, in a semi-solid state, into a mould cavity (3); a stirrer device (10) for the molten metal alloy comprising an impeller (11), said impeller (11) being movably supported between an inactive condition in which the impeller (11) is outside the injection container (8), and an active condition in which the impeller (11) is extending into the injection container (11); and

cooling means for the stirrer device (10), said cooling means comprising a first circuit for circulation of a thermal fluid, having a part (18, 19) thereof extending inside the impeller (11) of the stirrer device (10).

8. The rheocasting apparatus according to claim 7, **characterised in that** said part (18, 19) of the cooling circuit inside the impeller (11) is parallelly extending to the rotational axis of the impeller (11).

9. The rheocasting apparatus according to claim 7 or 8, **characterised by** comprising a second circuit for circulation of a thermal fluid, having a part thereof (8', 8'') extending into walls of the injection container (8).

10. The rheocasting apparatus according to any one of claims 7 to 9, **characterised by** comprising a third circuit for circulation of a thermal fluid, having a part thereof (9', 9'', 9''') extending into the piston (9) of the injection container (8).

11. The rheocasting apparatus according to one or more claims 7 to 10, **characterised in that** each of said thermal fluid circulation circuits comprises means (23) for detecting the temperature and/or the flow rate of the thermal fluid, said detecting means (23) being operatively connected to an electronic control unit (CPU) configured to adjust the cooling rate of the molten metal alloy, as a function of the detected temperature and/or flow rate.

12. The rheocasting apparatus according to any one of claims 7 to 11, wherein the impeller (11) of the stirrer device (10) is operatively connected to a control electric motor (14), **characterised by** comprising means for detecting the current and/or the torque of the electric motor (14) of the impeller (11), and to generate a control signal (FB); and an electronic control unit (CPU) configured to generate a reference signal (SV) for the rotational speed of the impeller (11), as a function of the control signal (FB) received, which is fed as input to an axis controller (CA) operatively connected to an inverter (IN) for generating a motor control signal (SD).

13. A vertical press for die-casting metal alloy pieces, by the method according to any one of claims 1 to 6, wherein said press comprises a rheocasting apparatus according to one or more of claims 7 to 12, **characterised by** comprising:

a plurality of injection units (5), each having an injection container (8) and a piston member (9) axially movable within the injection container (8);

a movable support device (4) for supporting and transferring the injection units (5), and control means (4', 4'') configured to control a step forward movement of the support device (4) to sequentially transfer the individual injection units (5) between a loading station (6) for cooling the molten metal alloy into a semi-solid state into the injection container (8); an injection station (7) for injecting the metal alloy in the semi-solid state into a mould (3); and a removing station (6') for removing a cast piece; and

in that the stirrer device (10) is configured to move the impeller (11) vertically and horizontally in respect to the axis of the injection container (8).

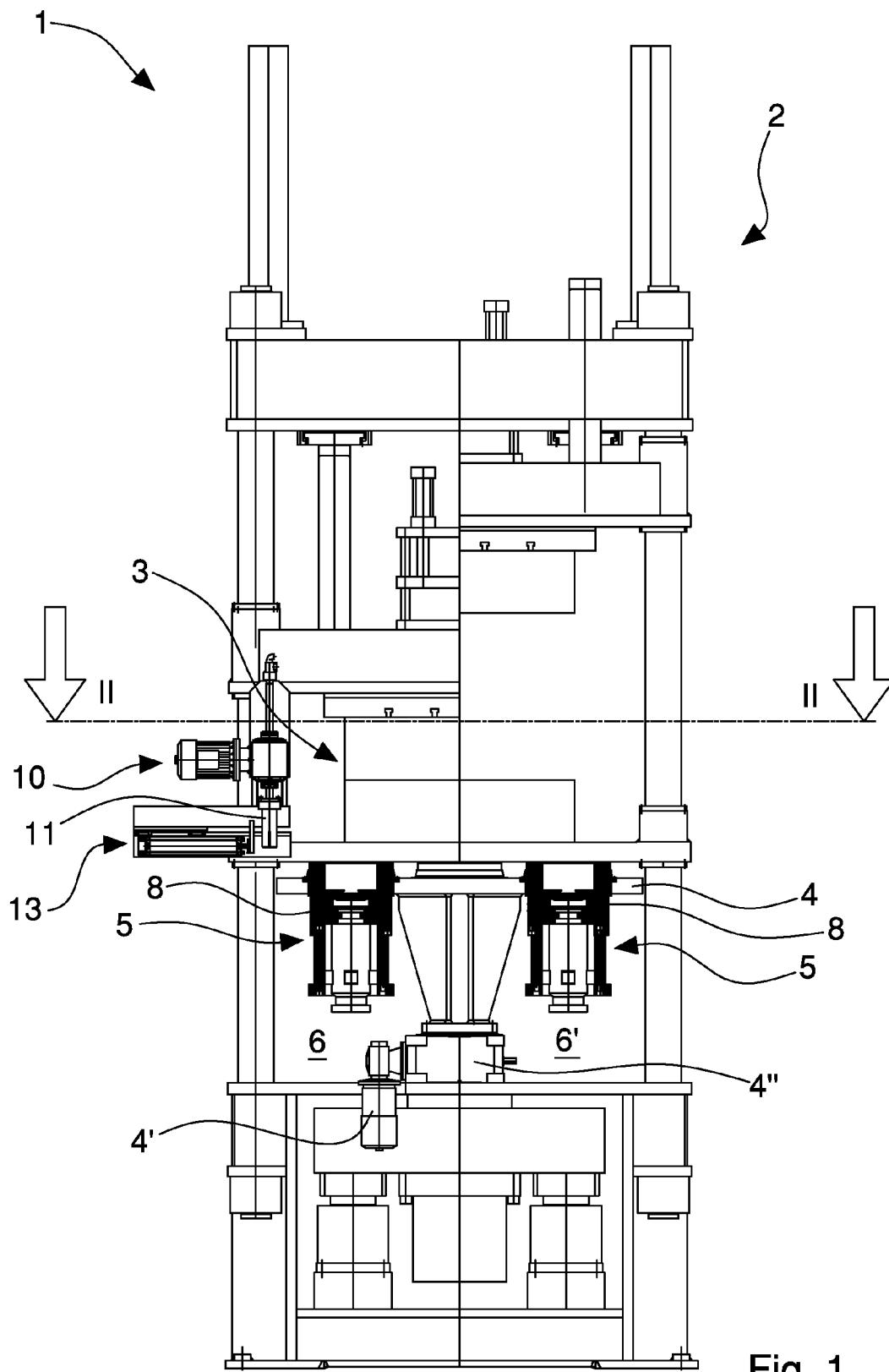
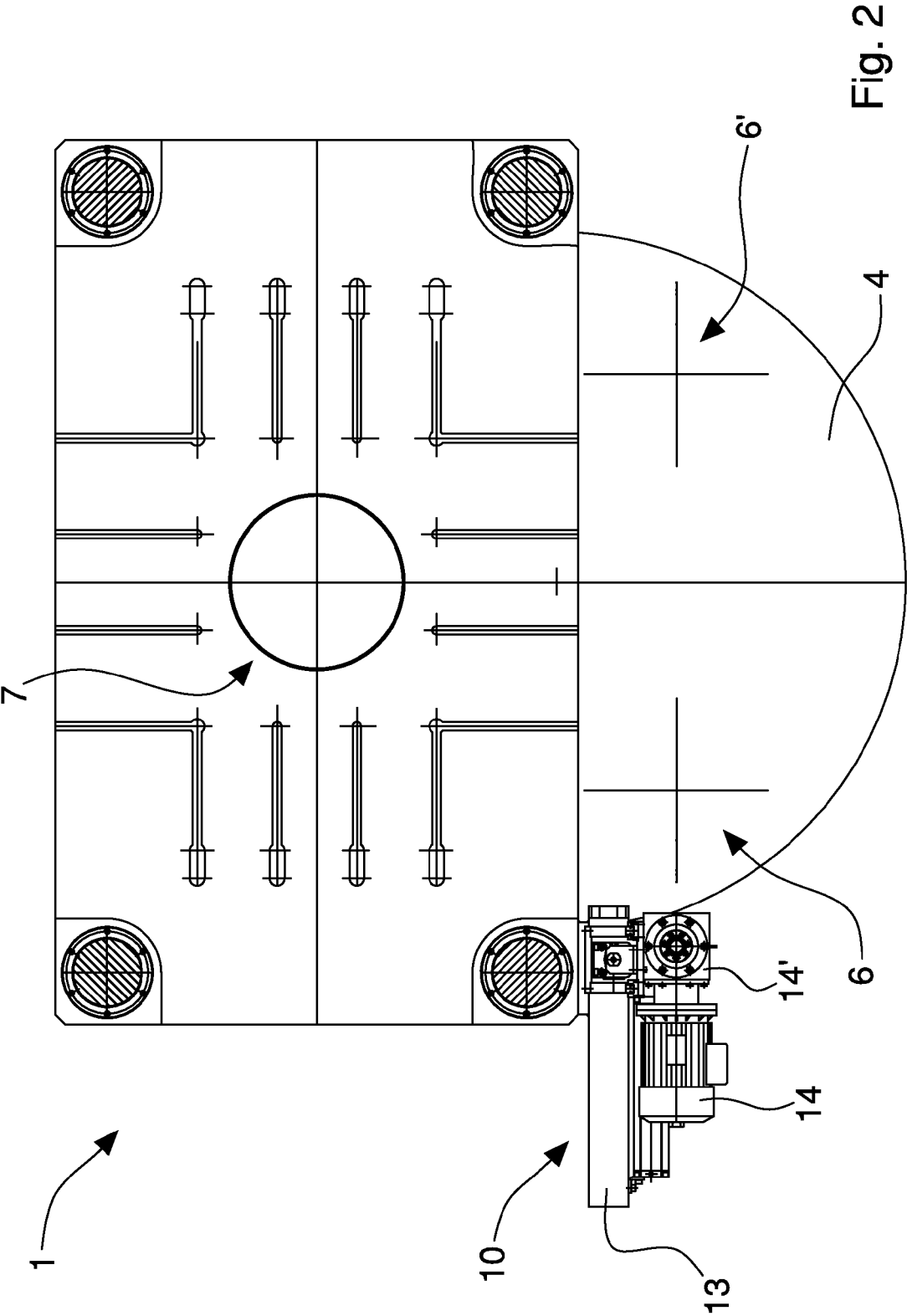


Fig. 1



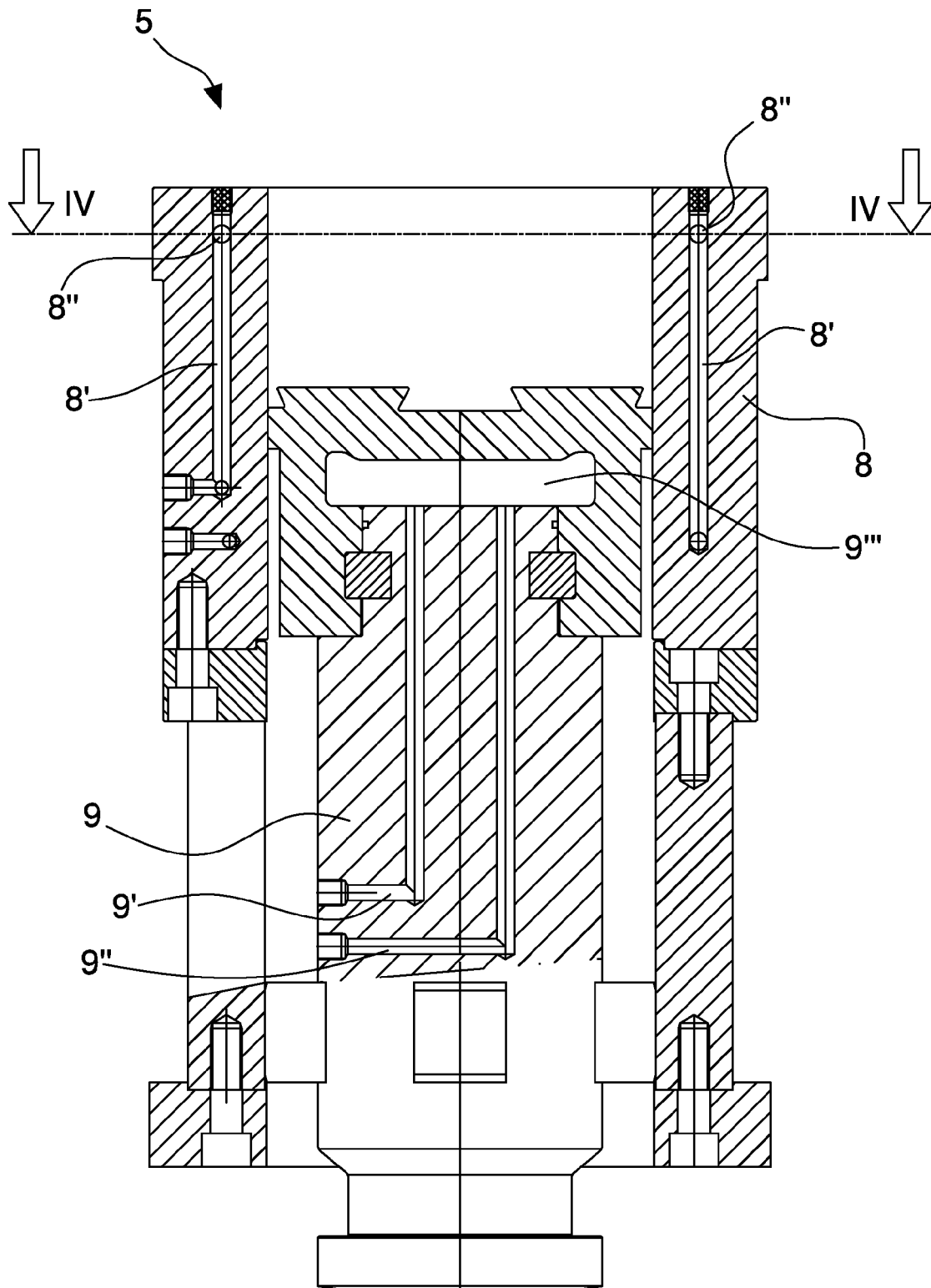


Fig. 3

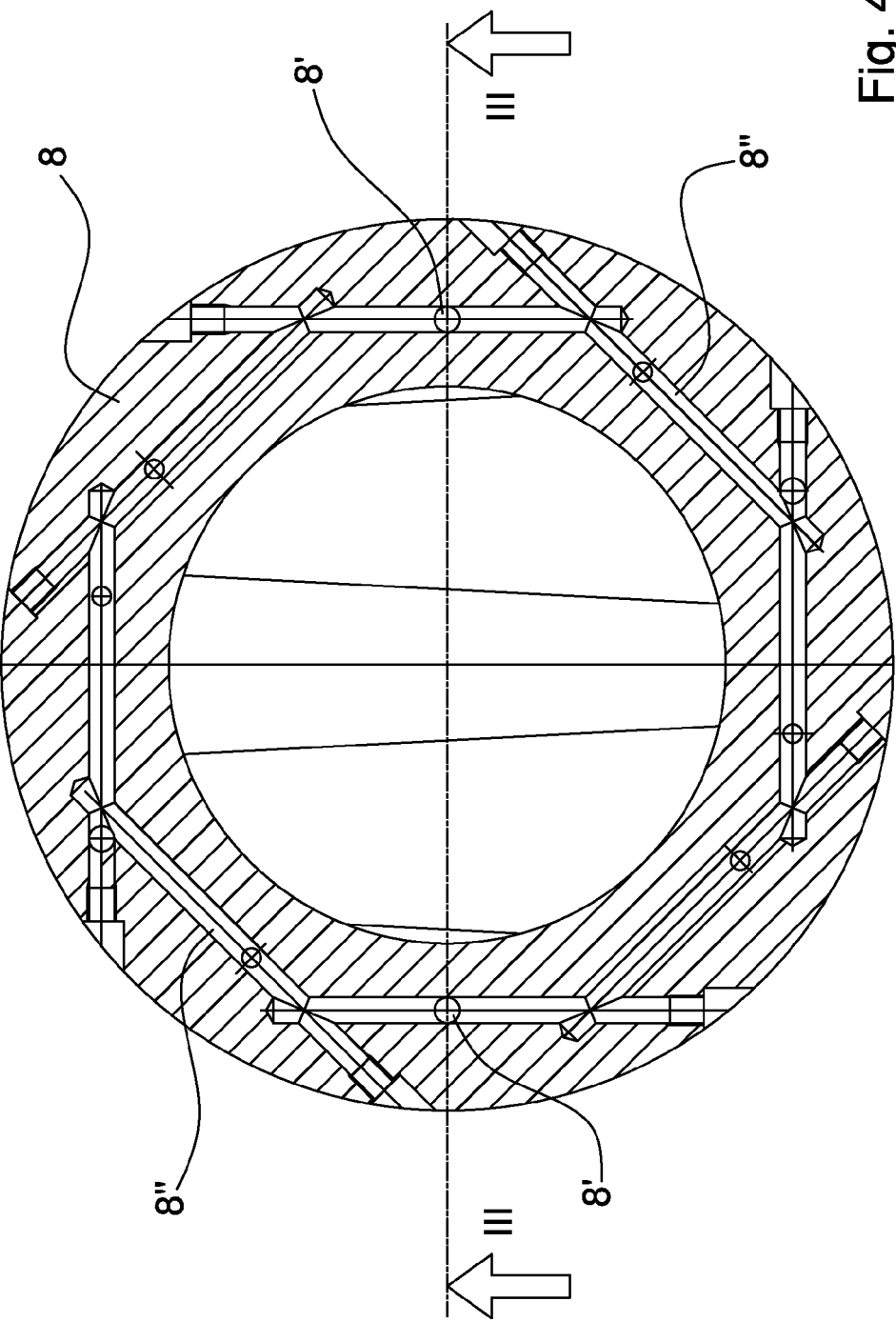


Fig. 4

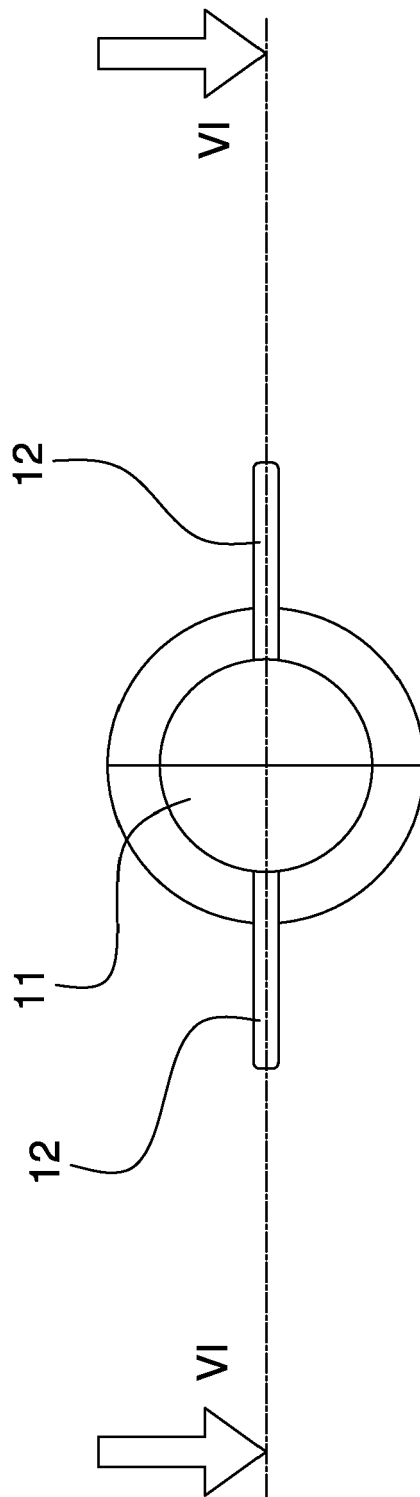


Fig. 5

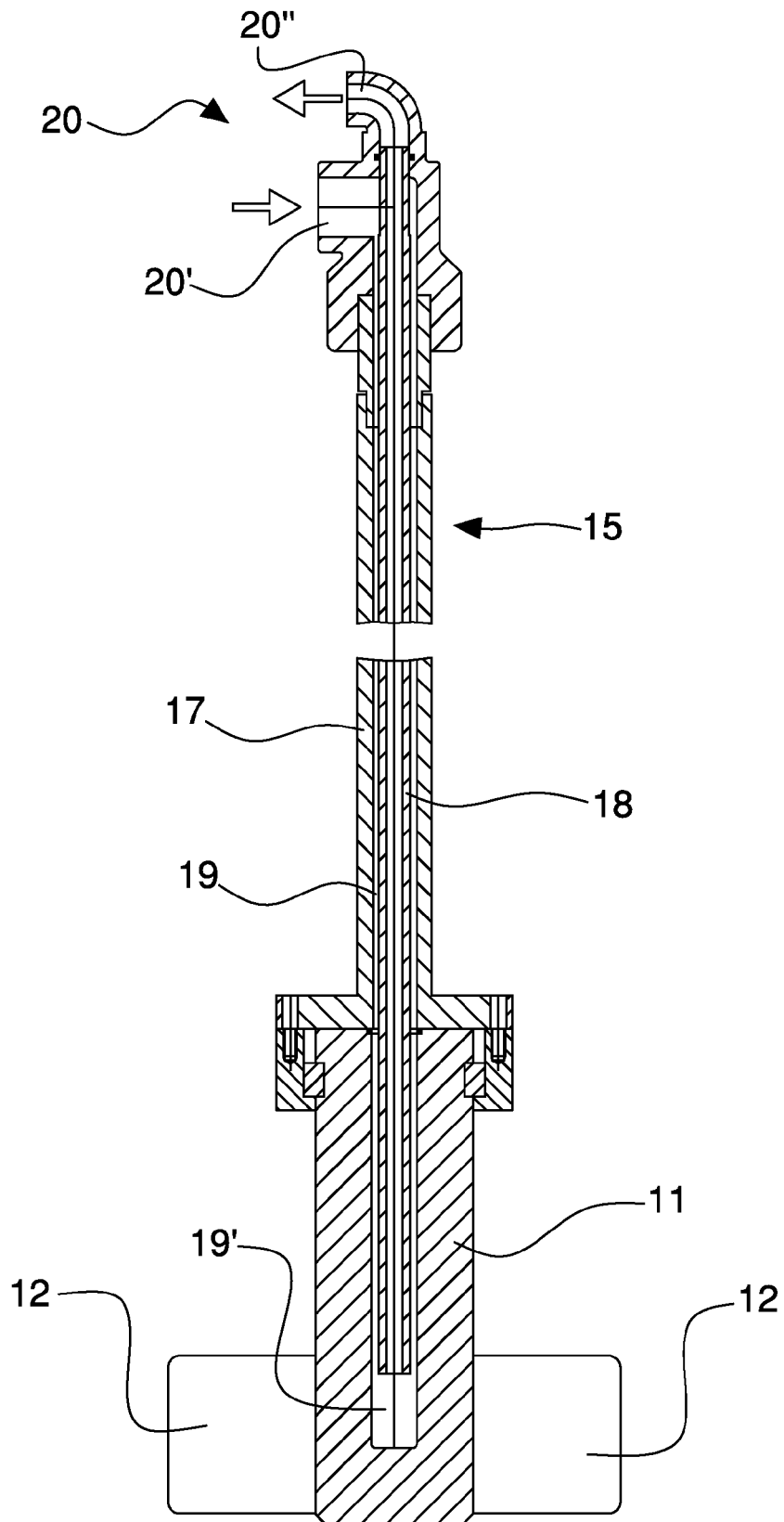


Fig. 6

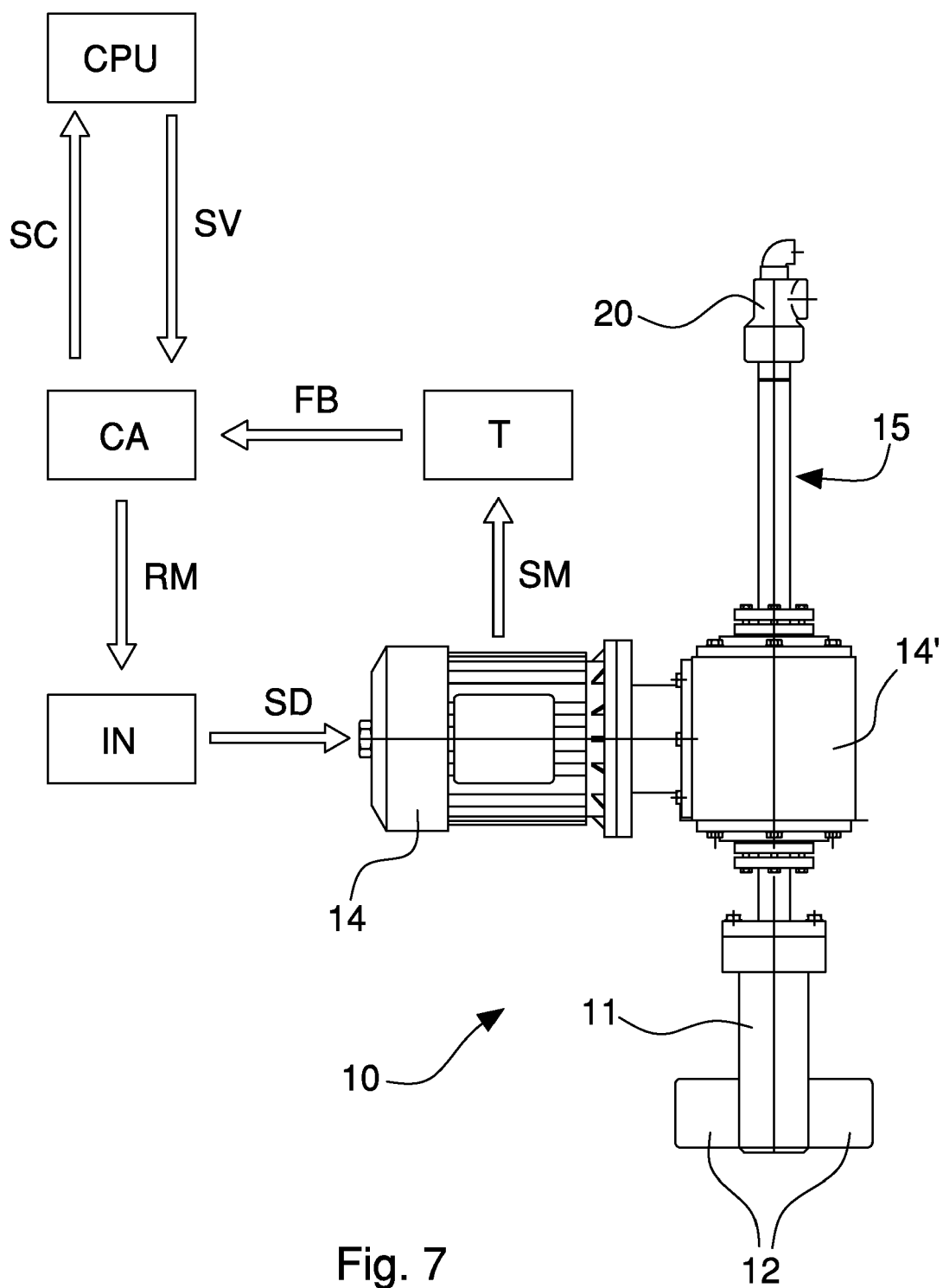
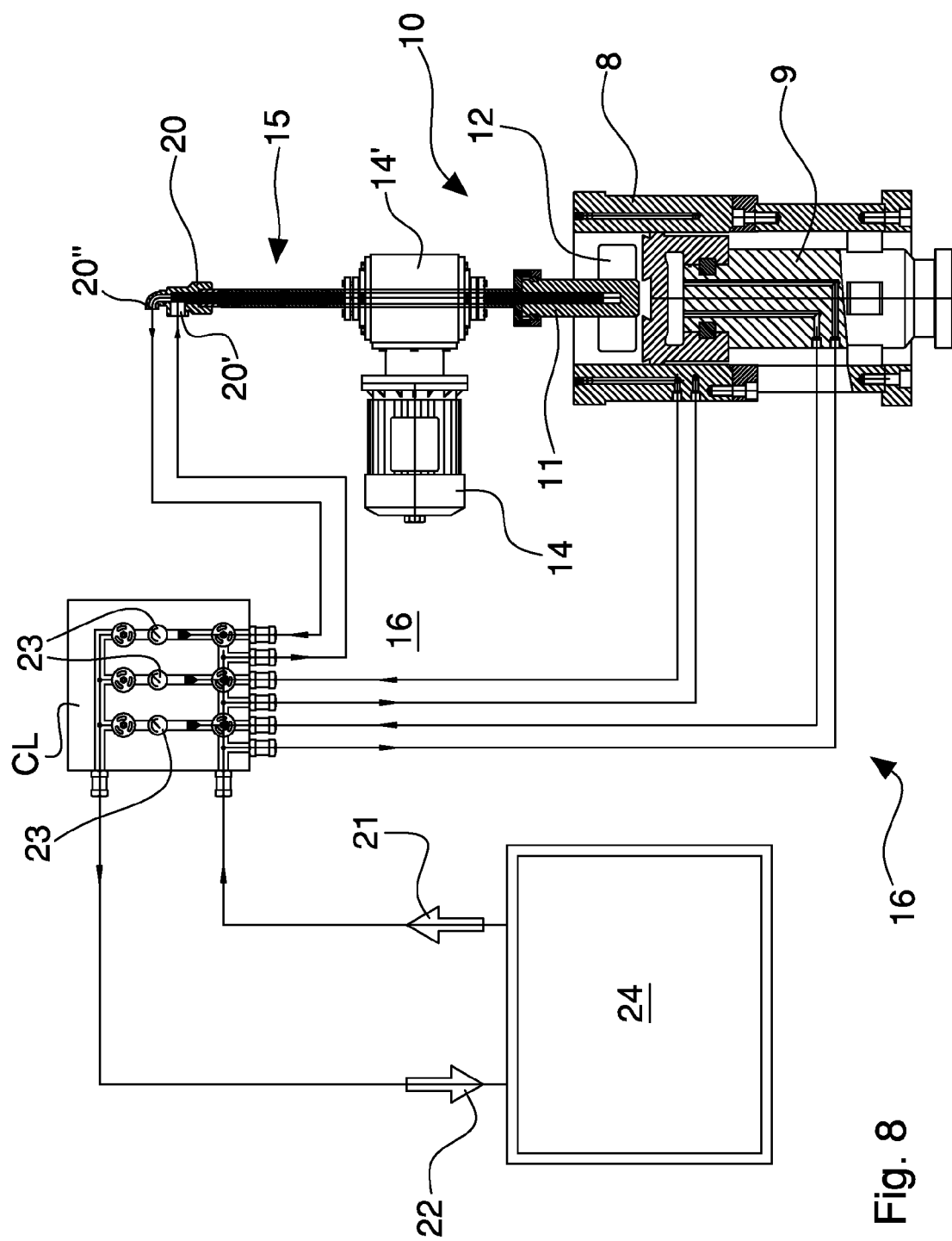
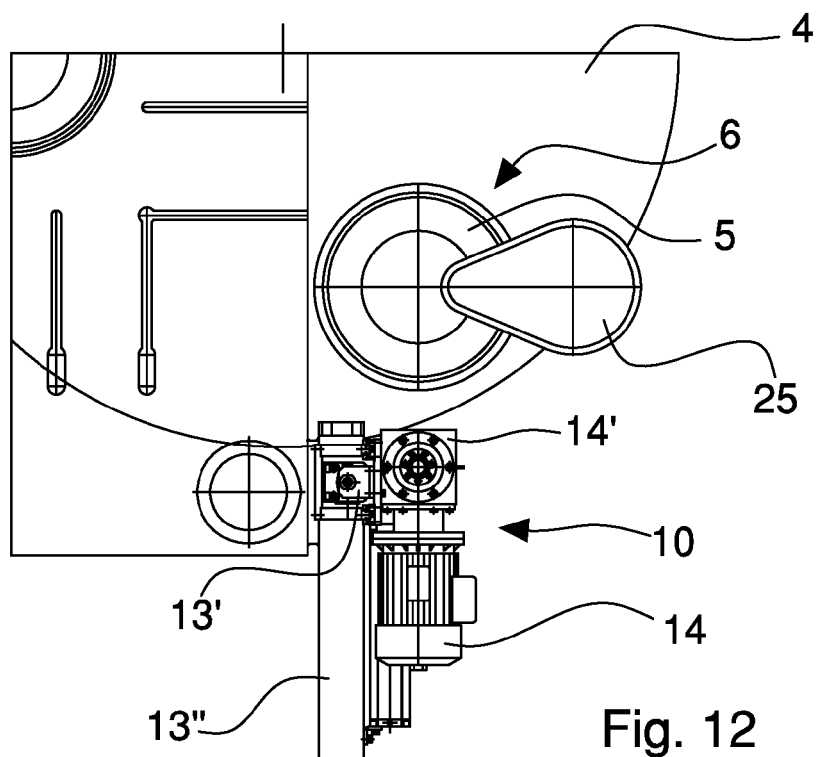
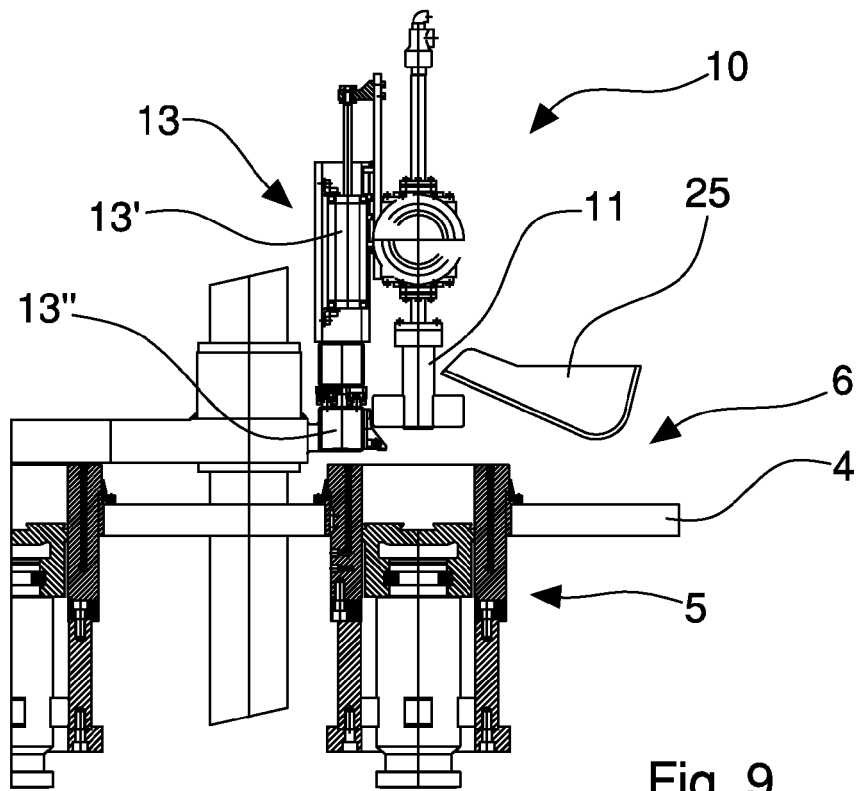


Fig. 7





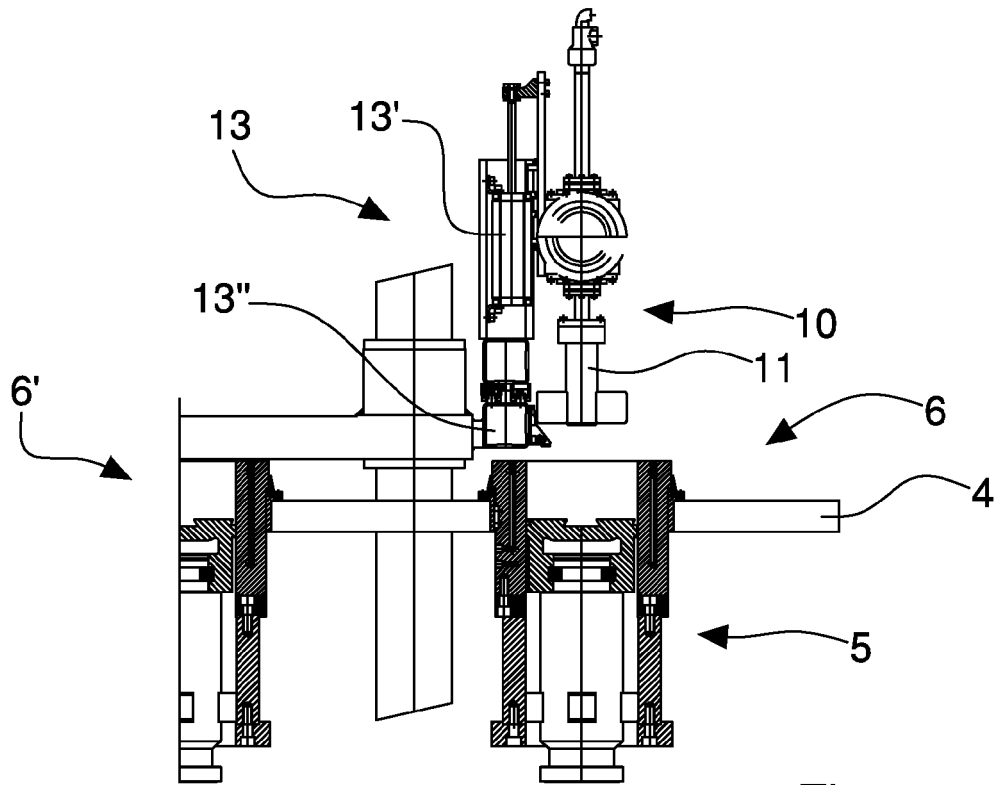


Fig. 10

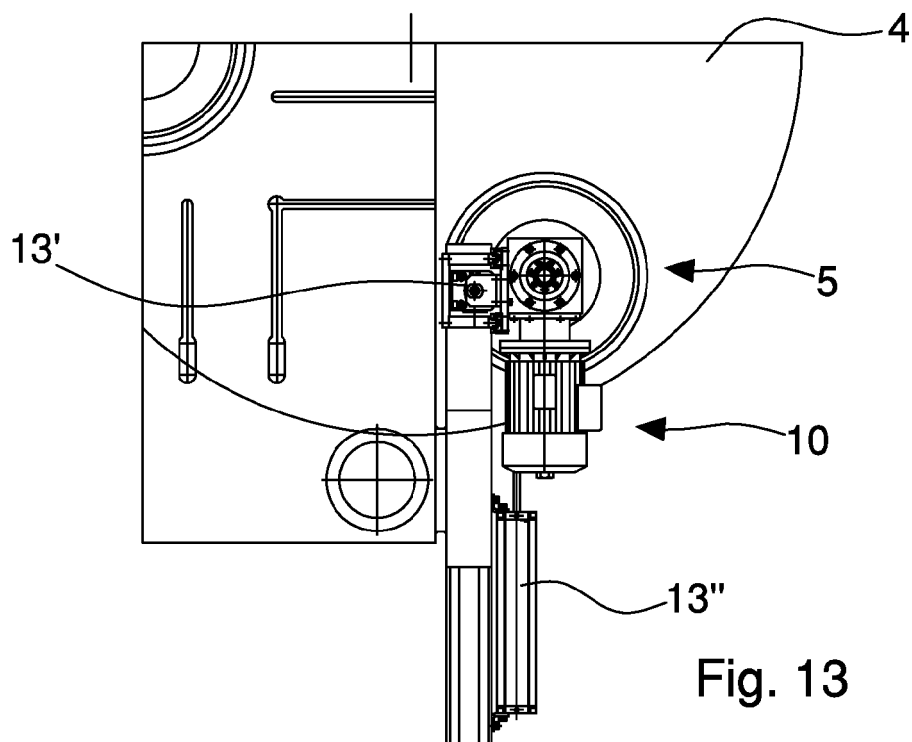
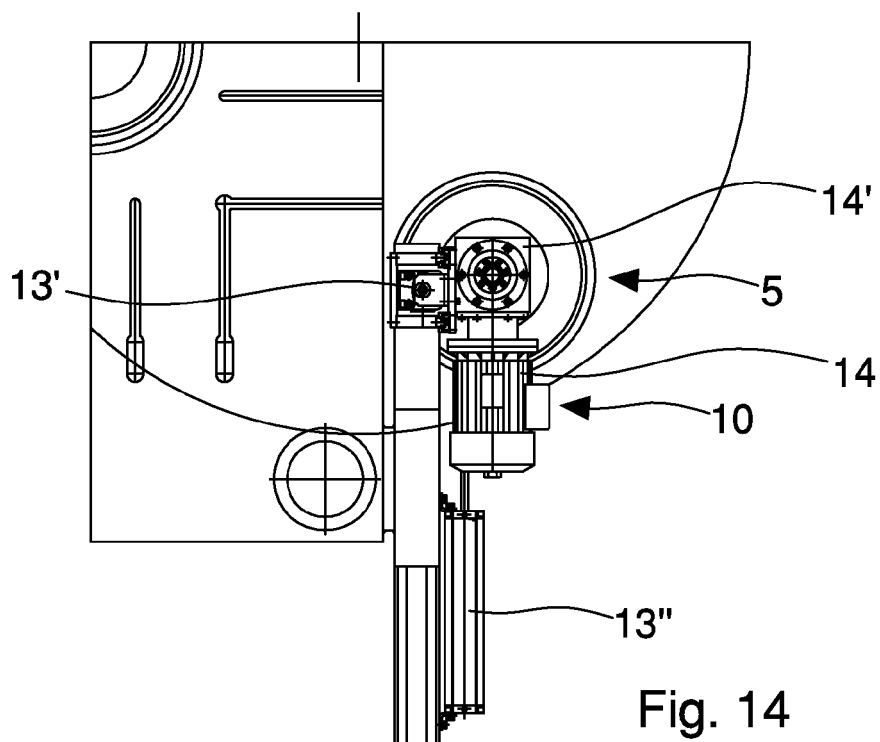
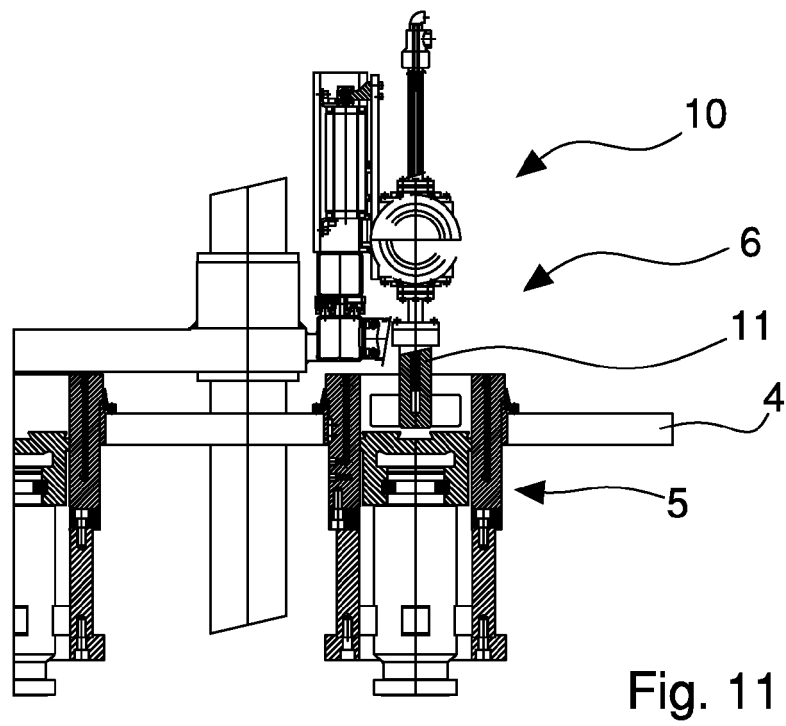


Fig. 13



REFERENCES CITED IN THE DESCRIPTION

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