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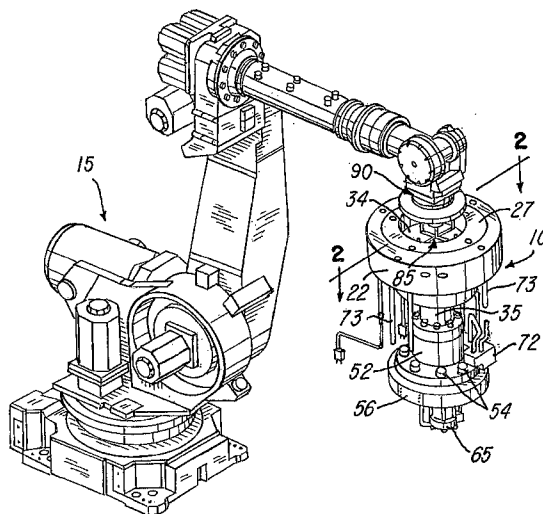
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Declarations under Rule 4.17:

- as to the identity of the inventor (Rule 4.17(i))
- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

[Continued on next page]

(54) **Title:** SEMI-SOLID MOLDING METHOD AND APPARATUS



(57) **Abstract:** A metal alloy is heated to a molten state and then poured into a shallow shot chamber defined by a shot sleeve and a shot piston of a vertical die cast press. A homogenizing member having L-shape arms projecting outwardly from a vertical shaft is inserted into the molten metal, and the shaft and arms are simultaneously rotated and orbited by a six axes robot for moving more solidified semi-solid metal cooled by the shot sleeve and shot piston into a more liquified semi-solid metal within a central portion of the shot chamber to form a homogenizing slurry. The force required to move the homogenizing member is used to determine the solid fraction of the slurry and to stop the homogenizing process after a predetermined force is detected. A hydraulic cylinder actuates the piston to transfer the semi-solid slurry upwardly from the shot chamber into a die cavity.

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SEMI-SOLID MOLDING METHOD AND APPARATUS

Background of the Invention

[0001] This invention relates to semi-solid molding method and apparatus of the type disclosed in U.S. Patents No. 6,808,004 and No. 6,901,991 which issued to the assignee of the present invention and the disclosures of which are herein incorporated by reference. The vertical die cast press and the method of using the press for semi-solid molding of metal alloys, as disclosed in these patents, utilizes a shallow shot chamber defined by a water cooled sleeve and a water cooled piston moveable vertically within the sleeve. The '991 patent also discloses the use of an extendable and retractable cooling pin within a central portion of the shot piston which is actuated or moved on its vertical axis by a hydraulic cylinder.

[0002] When the vertical die cast press is used for developing a semi-solid slurry within the shot chamber, it is desirable for the slurry to have a uniform consistency or percentage of solids throughout the shot chamber before the slurry is injected or transferred upwardly into the cavity defined by the die set supported above the shot chamber. It is also desirable to minimize the time required to develop the uniform semi-solid slurry within the shot chamber in order to minimize the total cycle time required for molding the slurry into a high strength metal part such as an aluminum vehicle wheel.

[0003] As the molten metal within the shot chamber is cooled by the water cooled shot sleeve and the water cooled piston, the more solidified portion of the slurry adjacent the inner surface of the cooling shot sleeve produces a liner or "can" of more solidified metal adjacent the shot sleeve. As disclosed in the above-mentioned patents, this can is trapped by an annular entrapment recess above the shot chamber and opposing the can so that the can collapses and is prevented from flowing inwardly into the more liquid semi-solid metal as it is transferred into the die cavity. However, it has been found desirable to circulate at least some of the cooled pre-solidified metal adjacent the shot sleeve wall and adjacent the top surface of the piston with the more liquified metal so that the uniform slurry is produced more quickly and a greater percentage of the semi-solid metal within the shot chamber is transferred from the shot chamber into the die cavity. A thinner metal can also requires a lesser force to move the shot piston upwardly since there is less pre-solidified can metal to crush into the entrapment recess.

Summary of the Invention

[0004] The present invention is directed to an improved method and apparatus for more efficiently producing high strength metal parts from a semi-solid metal and which provides all of the desirable advantages mentioned above. The method and apparatus especially provides for significantly reducing the cycle time for producing a metal part from a semi-solid metal in addition to providing for more uniformity of the grain structure throughout the part. In accordance with the illustrated embodiment of the invention, a vertical die cast press includes a water cooled shot sleeve surrounding a water cooled shot piston movable axially or vertically within the shot sleeve. The shot sleeve and shot piston cooperate to define a shot chamber, and molten metal, such as a molten aluminum alloy, is poured into the shot chamber. A homogenizing member is supported by a multiple axis robot and is inserted into the molten metal within the shot chamber and moved by the robot along an orbital and rotating path for moving the more solidified semi-solid metal adjacent the shot sleeve and shot piston into a more liquified semi-solid metal within a central portion of the shot chamber for more quickly producing a generally homogeneous semi-solid slurry.

[0005] The homogenizing member is retracted by the robot, and a die set is positioned over the shot chamber. The shot piston is then moved upwardly by a hydraulic cylinder to transfer the slurry from the shot chamber into a die cavity defined by the die set above the shot chamber. In the embodiment illustrated, the homogenizing member may include a vertical shaft supporting a plurality of radially outwardly projecting L-shaped arms. The arms are maintained under the surface of the semi-solid metal and slurry while the shaft and arms are simultaneously rotated and orbited about the shot chamber at a predetermined RPM.

[0006] Other features and advantages of the invention will be apparent from the following description, the accompanying drawings and the appended claims.

Brief Description of the Drawings

[0007] FIG. 1 is a perspective view of the assembled components of a vertical die cast press with a homogenizing member suspended within and orbited by the arm of a multiple axes programmable robot, in accordance with the invention;

[0008] FIG. 2 is a plan view of the vertical die cast press and homogenizing member, taken generally on the line 2-2 of FIG. 1;

[0009] FIG. 3 is fragmentary elevational view of the robot arm and an elevational view of the homogenizing member with a vertical section of the assembled components of the vertical die cast press shown in FIG. 1; and

[0010] FIG. 4 is diagrammatic plan view of the vertical press shot chamber and showing the homogenizing member and its orbital and rotating path within the shot chamber.

Description of the Illustrated Embodiment

[0011] FIGS. 1 & 3 illustrate the components of a vertical die cast press 10 which is constructed generally the same as the presses disclosed in above-mentioned U.S. Patents No. 6,808,004 and No. 6,901,991 issued to the assignee of the present invention, the disclosures of which are herein incorporated by reference. FIG. 1 also illustrates a six axes industrial robot 15, for example, of the type produced by ASEA Brown Boveri AB and generally disclosed in its U.S. patents, for example, Patent No. 5,564,312 and No. 5,931,047, the disclosures of which are herein incorporated by reference. The multiple axes robot 15 may also be of another form, for example, as produced by Fanuc Ltd. and disclosed in its U.S. patents, for example, Patent No. 6,250,174, the disclosure of which is herein incorporated by reference. Such industrial robots commonly have six axes of movement or rotation, and the sixth axis is the axis of rotation of the output head or shaft which usually supports a tool.

[0012] Referring to FIG. 3, the vertical die cast press 10 includes a support ring or an annular support member 22 which supports a tubular or cylindrical shot sleeve 25 having an outwardly projecting upper flange 27 secured to the support member 22 by peripherally spaced screws 29. The shot sleeve 25 has circumferentially spaced and axially extending internal passages 32 through which a cooling fluid or water is circulated for cooling the sleeve. The shot sleeve 25 has an inner surface 33 which may be cylindrical or non-cylindrical and which slidably receives a mating head portion 34 of a shot piston 35, with the head portion being secured by circumferentially spaced screws 37. The top surface of the head portion 34 has a pair of dovetail slots 41, as disclosed in above-mentioned Patent No. 6,901,991, and the bottom surface of the head portion 34 has interconnected concentric grooves 43 which receive a

cooling fluid or water through a set of axially extending passages 44 within the shot piston 35.

[0013] As also disclosed in the above '991 Patent, the central portion of the shot piston 35 supports an axially extendable and retractable cooling pin 46, and the lower flange portion of the shot piston 35 is secured by circumferentially spaced screws 49 to an annular coupling member 52 having a bottom flange secured by circumferentially spaced screws 54 to a circular plate 56 mounted on the upper end of the piston of a hydraulically actuating injection cylinder. The annular coupling member 52 defines an internal cylindrical bore 58, and a bottom flange of the cooling pin 46 is secured by circumferentially spaced screws to a cylindrical bushing 63 which slides vertically within the bore 58. The cooling pin 46 is extended upwardly and retracted downwardly by a fluid actuating cylinder 65 including a piston 67 having a piston rod 68 with an upper end portion secured to the bushing 63. Cooling fluid or water is supplied to and circulated through the cooling passages 44 and through the passages within the cooling pin 46 by lines 71 connected to a fluid manifold block 72 mounted on the coupling member 52 for vertical movement with the shot piston 35. Cooling fluid or water is also circulated through the passages 32 within the shot sleeve 25 by lines 73 (FIG. 1) connected to the passages 32.

[0014] The internal surface 33 of the shot sleeve 25 and the top surface of the shot piston head portion 34 define a shot chamber 80 which preferably has a horizontal width substantially greater than its vertical depth, as shown in FIG. 3. For example, the shot chamber 80 may have a horizontal width of ten inches and a vertical depth of three inches. A molten metal such as an aluminum A356 alloy, is poured into the shot chamber 80 on top of the piston head portion 34 and to a predetermined level forming a surface 82. A homogenizing head or member 85 is supported for rotation by the output shaft 88 on a head member 90 of the robot 15. The homogenizing member 85 includes a vertical shaft 92 (FIG. 4) which is attached to the rotary output shaft 88 of the robot 15. A plurality of four L-shaped arms 94 are secured to the shaft 92 and project radially outwardly with ninety degrees angular spacing between adjacent arms, and each arm 94 has a vertical tip or end portion 96.

[0015] The robot 15 is programmed to insert the homogenizing member 85 quickly into the molten metal or aluminum within the shot chamber 80 and then orbit the homogenizing member in an orbital path 98 shown in FIG. 4 while the homogenizing member 85 is also simultaneously rotated. By programming the rotation of the shaft 92 with the orbital movement of the robot output shaft

88, the end portions 96 of the arms move around the adjacent shot sleeve surface 33 while the molten metal is being cooled by the shot sleeve 25 and by the piston head member 34. As a result, the more solidified semi-solid metal adjacent the shot sleeve surface 33 and on top of the piston head member 34 is moved inwardly and upwardly into the more liquified semi-solid metal within a central portion of the shot chamber 80. The homogenizing member 85 thereby quickly produces a more homogenous semi-slurry within the shot chamber 80. For example, the homogenizing member 85 may be orbited within a range of forty to sixty RPM within a ten inch diameter shot chamber, and an orbital rotation of twenty-six to thirty revolutions is effective to produce a slurry having approximately forty percent solids or solid fraction. While the homogenizing member 85 is rotating and orbiting within the semi-solid metal in the shot chamber 80, the upper ends of the tip portions 96 of the arms 94 are maintained below the level 82 of the semi-solid metal, as shown in FIG. 3.

[0016] Preferably, the torque or forces and moments required to rotate and orbit the homogenizing member 85 are monitored or measured while the homogenizing member 85 is rotated and orbited within the semi-solid slurry. As the slurry thickens, the torque increases so that the torque corresponds to the solid fraction content of the slurry. When the torque reaches and maintains a predetermined level for a predetermined period of time, the homogenizing process is stopped. The homogenizing member 85 is then quickly retracted from the slurry by the robot 15 and moved laterally away from the shot sleeve 25. The shot sleeve 25 and the die set (not shown) may then be quickly brought together either by moving the shot sleeve to the die set or by moving the die set to the shot sleeve. The slurry is then injected upwardly into the die cavity by upward movement of the shot piston 35. The torque or forces and moments required to rotate and orbit the homogenizing member 85 may be monitored by sensing electrical current to the robot motors or by a load cell with strain gauges connected to rotational shafts of the robot. One form of six axis force sensor for a robot is disclosed in U.S. Patent No. 5,490,427, the disclosure of which is herein incorporated by reference.

[0017] The programmed movement of the homogenizing head or member 85 within the molten metal in the shot chamber 80 along the rotational and orbital path shown in FIG. 4 provides desirable features and advantages. For example, the homogenizing member accelerates the development of a semi-solid slurry of substantially uniform consistency by taking advantage of the more rapid cooling at the inner surface 33 of the shot sleeve 25 and the top surface

of the piston head portion 34. That is, the semi-solid metal is circulated from the higher cooling rate area to the lower cooling rate area to produce a more homogenous slurry in a shorter period of time. Minimizing the formation of the pre-solidified metal adjacent the inner surface 33 of the shot sleeve 25 also reduces the thickness of the can of pre-solidified metal at the sleeve wall surface 33, and thereby reduces the force required from the shot piston 35 to crush the pre-solidified metal can adjacent the shot sleeve wall surface.

[0018] A more homogenous slurry and a reduction of the formation of pre-solidified metal adjacent the inner surface of the shot sleeve and on the top surface of the shot piston, also provide for reducing the volume of molten metal that is poured into the shot chamber 80 to cast a part since a greater percentage of the poured volume of molten metal is used to produce the part. The development of the semi-solid slurry entirely within the shot chamber also contributes to minimizing the poured volume of molten metal to produce the part with the semi-solid slurry.

[0019] The use of the six axes programmable robot 15 for moving or simultaneously rotating and orbiting a homogenizing member also provides for adjustably selecting a path and speed which provide the desired semi-solid slurry with a uniform consistency of solids within a minimum time period. As mentioned above, by maintaining the upper ends of the end or tip portions 96 of the homogenizing member 85 below the surface 82 of the molten metal also maintains the metal at the surface more quiescent and minimizes the volume of molten metal that sticks or adheres to the arms 94. This minimizes the metal that must be removed from the homogenizing member between operating cycles. Thus the production efficiency of high strength metal parts, such as aluminum wheels, with the vertical die cast press 10 and the programmable movement of the homogenizing member 85 by the robot 15, is significantly increased. For example, twenty pounds of molten A356 aluminum alloy poured into a ten inch diameter shot chamber 80 to a depth of three inches may be homogenized to the desired percentage of solids in about twenty five seconds.

[0020] While the method and form of apparatus herein described constitutes a preferred embodiment of the invention, it is to be understood that the invention is not limited to the precise method and apparatus described, and that changes may be made therein without departing from the scope and spirit of the invention as defined in the appended claims.

What is claimed is:

1. A method of producing high strength metal parts within a die cavity defined by a die set mounted on a vertical die cast press including a shot sleeve defining a shot chamber having a generally vertical axis and a shot piston movable axially within the shot chamber by a power actuator, the method comprising the steps of heating a solid metal to form a molten metal, directing the molten metal into the shot chamber, cooling the shot sleeve to cool the molten metal within the shot chamber to form a semi-solid metal, positioning a homogenizing member within the molten metal within the shot chamber, moving the homogenizing member along a path effective to move more solidified semi-solid metal adjacent the shot sleeve inwardly into a more liquified semi-solid metal within a central portion of the shot chamber to produce a generally homogeneous semi-solid slurry within the shot chamber, moving the shot piston upwardly to transfer the semi-solid slurry from the shot chamber into the die cavity, and allowing the semi-solid slurry to solidify within the die cavity to form the metal part.
2. A method as defined in claim 1 wherein the homogenizing member includes at least one arm supported by a generally vertical shaft, and including the step of orbiting the shaft and arm within the molten metal confined within the shot chamber.
3. A method as defined in claim 2 including the step of positioning the arm of the homogenizing member below the surface of the molten metal within the shot chamber while orbiting the arm within the molten metal.
4. A method as defined in claim 1 wherein the homogenizing member includes a plurality of arms supported by a generally vertical shaft, and including the step of orbiting the shaft within the molten metal within the shot chamber while simultaneously rotating the shaft to move each arm adjacent the shot sleeve and then inwardly towards a central portion of the shot chamber to form the semi-solid slurry.
5. A method as defined in claim 4 and including the step of maintaining the arms of the homogenizing member below the surface of the molten metal while the shaft and arms are orbiting and rotating.

6. A method as defined in claim 1 and including a step of confining the molten metal within a shot chamber having a horizontal width substantially greater than its vertical depth while moving the homogenizing member along the path within the molten metal.

7. A method as defined in claim 1 and including the step of supporting the homogenizing member with a multiple axes programmable robot for movement of the homogenizing member along a predetermined orbital path within the molten metal in the shot chamber.

8. A method as defined in claim 7 and including the step of providing the homogenizing member with a plurality of arms supported by a generally vertical shaft rotated by the robot, and maintaining the arms of the homogenizing member below the surface of the molten metal within the shot chamber while the shaft and arms are orbiting and rotating.

9. A method as defined in claim 7 and including the steps of measuring the force required by the robot to move the homogenizing member within the semi-solid metal in the shot chamber, and stopping the movement of the homogenizing member after the force has reached a predetermined level.

10. A method as defined in claim 9 wherein the homogenizing member includes a generally vertical shaft, the robot includes a set of electric motors connected to orbit and rotate the shaft simultaneously, and the force is measured by sensing the electrical current required to drive at least one of the motors.

11. A method as defined in claim 1 and including the step of moving the homogenizing member until the semi-solid slurry has a generally uniform consistency of about forty percent solids.

12. A method of producing high strength metal parts within a die cavity defined by a die set mounted on a vertical die cast press including a shot sleeve defining a shot chamber having a generally vertical axis and a shot piston movable axially within the shot chamber by a power actuator, the method comprising the steps of heating a solid metal to form a molten metal, directing the molten metal into the shot chamber, cooling the shot sleeve and the shot

piston to cool the molten metal within the shot chamber to form a semi-solid metal, positioning a homogenizing member within the molten metal within the shot chamber, orbiting the homogenizing member along a path effective to circulate more solidified semi-solid metal adjacent the shot sleeve and shot piston with a more liquified semi-solid metal within a central portion of the shot chamber to produce a generally homogeneous semi-solid slurry within the shot chamber, moving the shot piston upwardly to transfer the semi-solid slurry from the shot chamber into the die cavity, and allowing the semi-solid slurry to solidify within the die cavity to form the metal part.

13. A method as defined in claim 12 wherein the homogenizing member includes a plurality of angularly spaced arms supported by a generally vertical shaft, and including the step of simultaneously orbiting and rotating the shaft and arms within the molten metal confined within the shot chamber.

14. A method as defined in claim 13 including the step of positioning the arms of the homogenizing member below the surface of the molten metal within the shot chamber while orbiting and rotating the arms within the molten metal.

15. A method as defined in claim 12 and including a step of confining the molten metal within a shot chamber having a horizontal width substantially greater than its vertical depth while moving the homogenizing member along the path within the molten metal.

16. A method as defined in claim 12 and including the step of supporting the homogenizing member with a multiple axes programmable robot for movement of the homogenizing member along a predetermined orbital and rotational path within the molten metal in the shot chamber.

17. A method as defined in claim 16 and including the steps of measuring the force required by the robot to move the homogenizing member within the semi-solid metal in the shot chamber, and stopping the movement of the homogenizing member after the force has reached a predetermined level.

18. A method as defined in claim 12 and including the step of moving the homogenizing member until the semi-solid slurry has a generally uniform consistency of about forty percent solids.

19. A method of producing high strength metal parts within a die cavity defined by a die set positioned above a vertical die cast press including a shot sleeve defining a shot chamber having a generally vertical axis and a shot piston movable axially within the shot chamber by a power actuator, the method comprising the steps of heating a solid metal to form a molten metal, directing the molten metal into the shot chamber, cooling the shot sleeve to cool the molten metal within the shot chamber to form a semi-solid metal, positioning a homogenizing member within the molten metal within the shot chamber, moving the homogenizing member along a path effective to move more solidified semi-solid metal adjacent the shot sleeve inwardly into a more liquified semi-solid metal within a central portion of the shot chamber to produce a generally homogeneous semi-solid slurry within the shot chamber, measuring a force required to move the homogenizing member within the semi-solid metal in the shot chamber, stopping the movement of the homogenizing member after the force reaches a predetermined level, moving the shot piston upwardly to transfer the semi-solid slurry from the shot chamber into the die cavity, and allowing the semi-solid slurry to solidify within the die cavity to form the metal part.

20. Apparatus adapted for producing a high strength metal part within a die cavity defined by a die set, said apparatus comprising a vertical die cast press including a liquid cooled shot sleeve enclosing a shot piston defining a shot chamber having a generally vertical axis, a power actuator connected to move said shot piston movable axially within said shot sleeve, a multiple axes programmable robot positioned adjacent said press, a homogenizing member having a shaft supported by said robot for movement within molten metal within said shot chamber, said homogenizing member having a path of movement effective to move more solidified semi-solid metal adjacent said shot sleeve inwardly into a more liquified semi-solid metal within a central portion of said shot chamber to produce a generally homogeneous semi-solid slurry within said shot chamber, and said power actuator being effective to move said shot piston upwardly to transfer the semi-solid slurry from said shot chamber into the cavity within the die set.

21. Apparatus as defined in claim 20 wherein said homogenizing member includes at least one arm supported by said shaft, and said robot is programmed to orbit said shaft and said arm within the molten metal confined within said shot chamber.

22. Apparatus as defined in claim 21 wherein said robot positions said arm of said homogenizing member below the surface of the molten metal within said shot chamber while orbiting said arm within the molten metal.
23. Apparatus as defined in claim 20 wherein said homogenizing member includes a plurality of arms supported by said shaft, and said robot is programmed to orbit said shaft within the molten metal within said shot chamber while simultaneously rotating said shaft to move each said arm adjacent the shot sleeve and then inwardly towards a central portion of said shot chamber to form the semi-solid slurry.
24. Apparatus as defined in claim 23 wherein said robot maintains said arms of said homogenizing member below the surface of the molten metal while said shaft and said arms are orbiting and rotating.
25. Apparatus as defined in claim 20 and including means for sensing the force required by said robot to move said homogenizing member within the semi-solid metal in said shot chamber to control the movement of said homogenizing member.

FIG-1

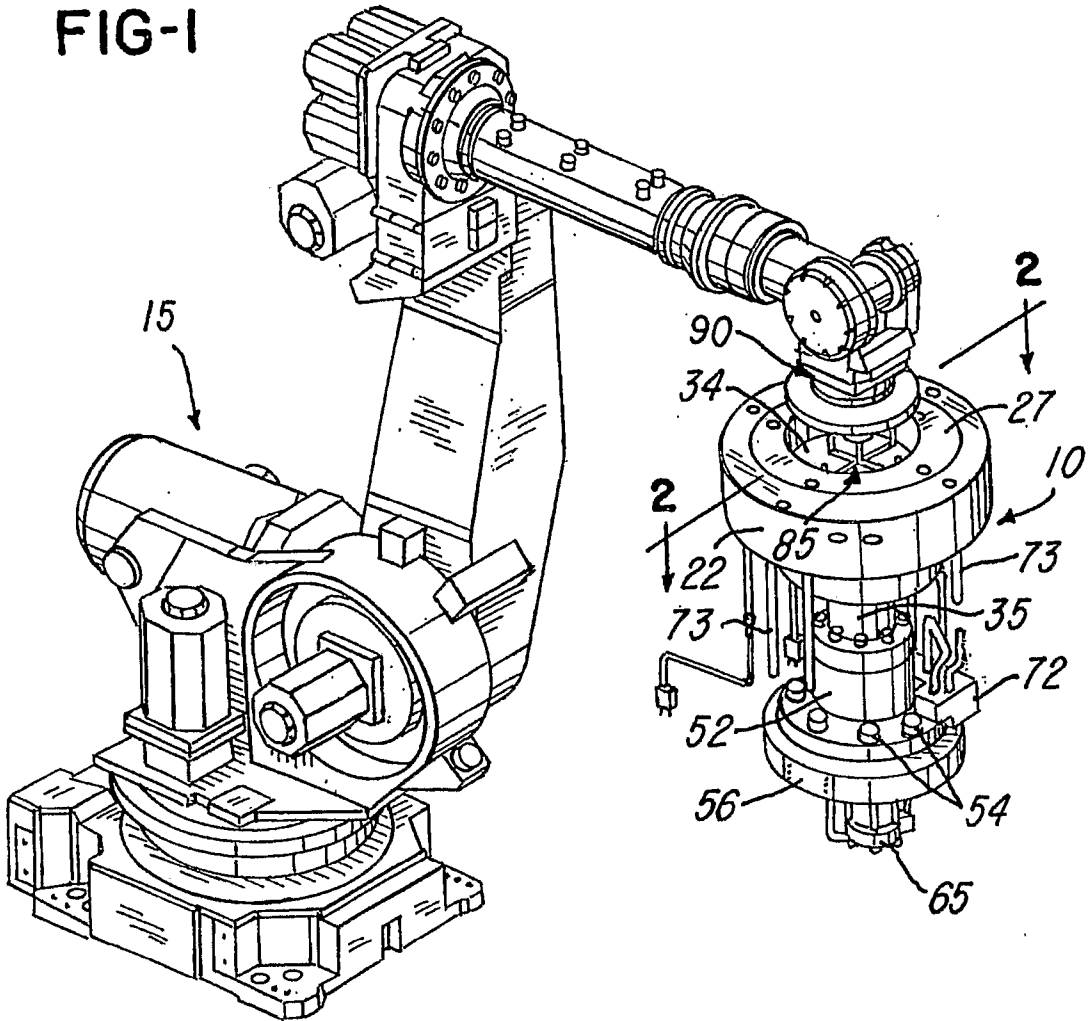


FIG-2

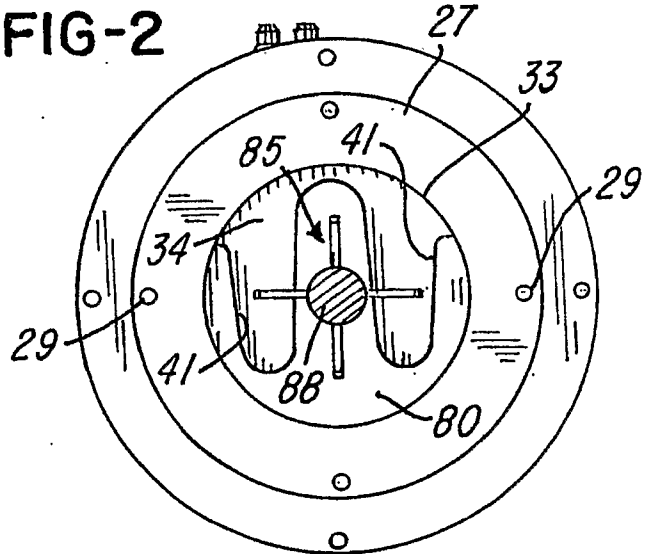


FIG-3

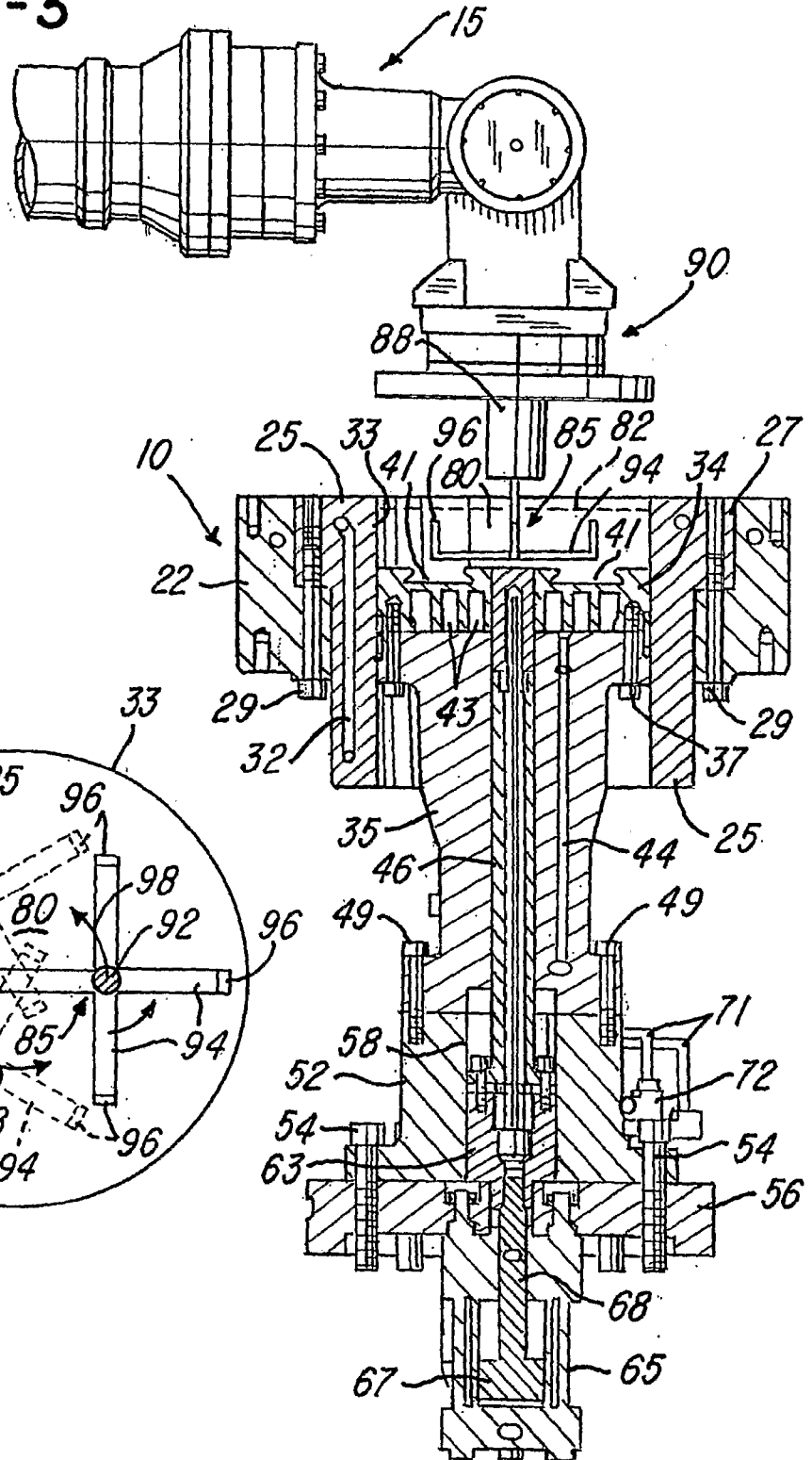


FIG-4

