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CA 2341252 C 2009/09/15

(11)(21) **2 341 252**

(12) **BREVET CANADIEN**
CANADIAN PATENT
(13) **C**

(86) **Date de dépôt PCT/PCT Filing Date:** 2000/06/12
(87) **Date publication PCT/PCT Publication Date:** 2000/12/28
(45) **Date de délivrance/Issue Date:** 2009/09/15
(85) **Entrée phase nationale/National Entry:** 2001/02/20
(86) **N° demande PCT/PCT Application No.:** US 2000/016071
(87) **N° publication PCT/PCT Publication No.:** 2000/078481
(30) **Priorité/Priority:** 1999/06/21 (US09/337,058)

(51) **Cl.Int./Int.Cl.** *B22D 37/00* (2006.01)
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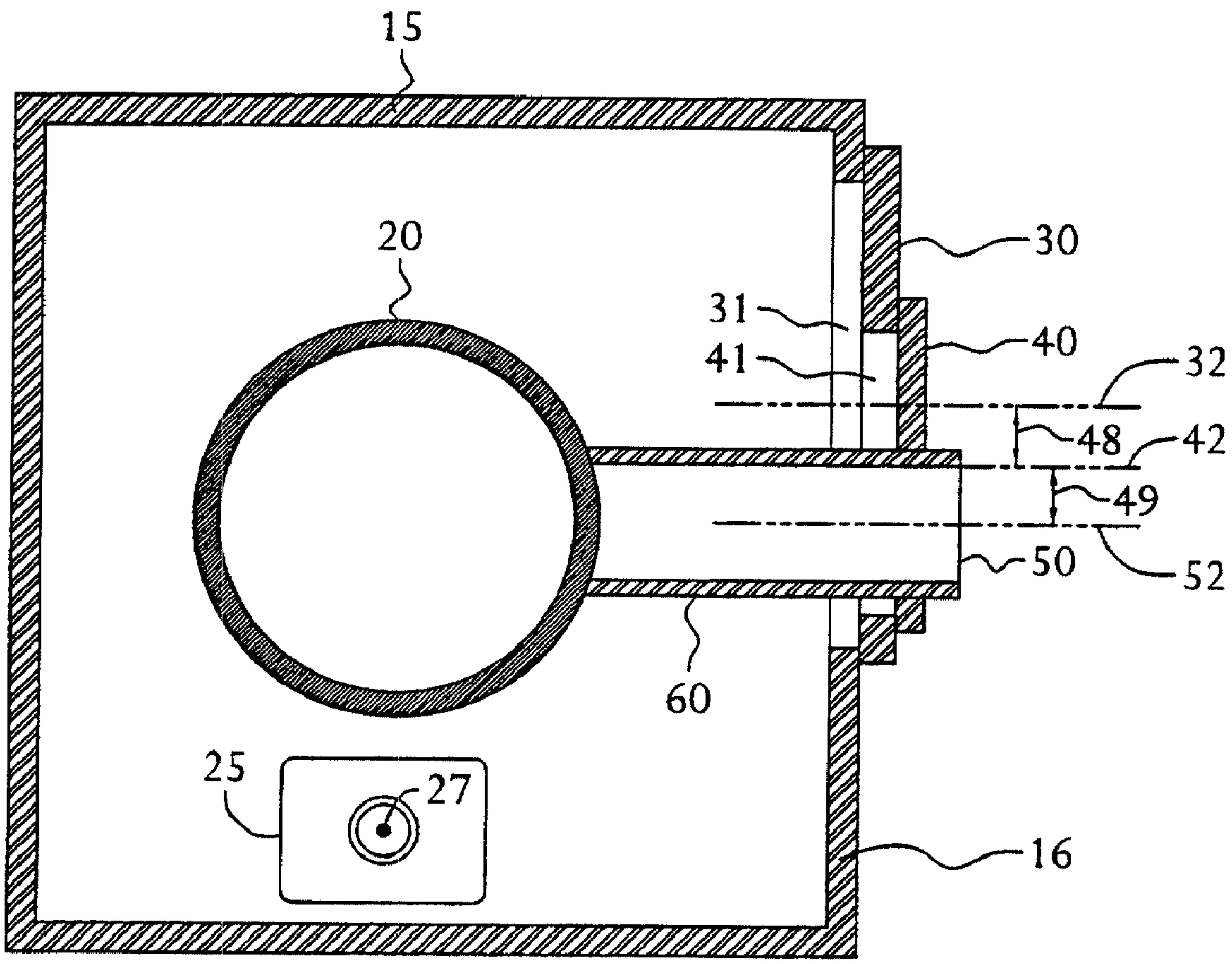
(54) **Titre :** APPAREIL DE POSITIONNEMENT ET PROCEDE PERMETTANT DE VERSER AVEC PRECISION UN LIQUIDE AU MOYEN D'UN RESERVOIR
(54) **Title:** POSITIONING APPARATUS AND METHOD FOR PRECISION POURING OF A LIQUID FROM A VESSEL



(57) **Abrégé/Abstract:**
Apparatus and method accomplishes the precision pouring of a liquid from a vessel (20) to a predetermined position with a controlled rate of flow. Independently controllable horizontal and vertical translation of the vessel (20) is accomplished by using two

(57) Abrégé(suite)/Abstract(continued):
rotational elements (30, 40) lying in substantially parallel planes, with the rotational axis of the second element (40) passing through the first element (30), and having offset first and second axes of rotation. Independently controlled tilting of the vessel (20) about a third axis of rotation that passes through the second element (40) maintains a desired pour rate and aim point of the pour stream. The apparatus is particularly useful when the vessel (20) and the container (25) that receives the liquid are inside of a sealed chamber (15).

Abstract

Apparatus and method accomplishes the precision pouring of a liquid from a vessel (20) to a predetermined position with a controlled rate of flow. Independently controllable horizontal and vertical translation of the vessel (20) is accomplished by using two rotational elements (30, 40) lying in substantially parallel planes, with the rotational axis of the second element (40) passing through the first element (30), and having offset first and second axes of rotation. Independently controlled tilting of the vessel (20) about a third axis of rotation that passes through the second element (40) maintains a desired pour rate and aim point of the pour stream. The apparatus is particularly useful when the vessel (20) and the container (25) that receives the liquid are inside of a sealed chamber (15).

POSITIONING APPARATUS AND METHOD FOR PRECISION POURING OF A LIQUID FROM A VESSEL

Field of the Invention

The present invention relates to precision pouring of a liquid from a vessel into a container, particularly when the vessel and container are located inside a chamber.

Background of the Invention

In vacuum metallurgy and in many other fields, liquids, such as molten metals and alloys, are often processed inside a chamber containing an atmosphere that may be at, above or below ambient atmospheric pressure. Such processing includes the pouring of a liquid at a pre-determined rate from a vessel, such as a melting furnace, into a container such as a mold. A vessel generally having a pour lip and containing a liquid is tilted to establish a pour stream that is targeted at an opening in the container. The desired pour rate may be fixed, or it may be profiled, meaning that the desired rate varies during the course of the pour. Since the targeted opening is usually fixed and the trajectory of the pour stream changes during the pour, the relative positions of the vessel and container must be controllable to allow the pre-determined flow rate and aim point to be maintained. Where the container is not moved, the horizontal (or X-axis) position of the vessel and its tilt angle measured from the Y-axis (orthogonal to the X-axis) must be adjustable. If it is also desired to simultaneously control the vertical distance of the pour lip above the target opening, the vertical position of the vessel must also be controlled.

A known approach to meeting the above requirements is to mount the vessel on a manipulator, located inside the chamber. However, such a manipulator is difficult to access for maintenance or repair. Moreover, any mechanism so located is likely to be exposed to liquid splash, fume, condensation of volatiles evolved from the liquid, etc., so it is likely to need frequent maintenance or repair. Therefore, it is advantageous that essentially all of the mechanism for moving and tilting the vessel be accessibly located outside of the chamber and sealed such that it is not exposed to the atmosphere inside. The seal system must also maintain the integrity of the atmosphere, allowing gases to leak neither out of nor into the chamber.

A prior art approach that achieves some of the above objectives is to mount the vessel eccentrically on a plate which is supported from the chamber wall and which rotates about the center of a circular peripheral seal. Rotary motion about said center is advantageous because sealing surfaces that were covered by the seal, and therefore protected from contamination prior to such rotation, remain covered and protected during and after rotation. Such protection from contamination such as splash, fume and condensates improves seal life. Rotation about this first axis, which is at a relatively large vertical distance below the vessel pour lip, will move the pour lip primarily in the horizontal direction, as long as the amount of angular motion is kept small. Rotation about a second axis, located closer to the vessel's pour lip than the first axis, tilts the vessel to assist the pouring of molten metal from the vessel.

This approach, however, has its own disadvantages. The requirement that the amount of angular motion about the first axis be kept small, means that for a given amount of traverse motion, a relatively large distance must be maintained between the pour lip and the first axis of rotation. This requirement makes the rotary plate relatively large in diameter. Consequently, relatively large forces are exerted on it when there is a significant differential pressure between the outside and the inside of the chamber. In such a case, which happens commonly, the plate must be built to withstand these large forces. This can make the plate relatively heavy and expensive. These large forces also undesirably increase the loads on the bearings that rotatably connect the plate to the chamber, unless additional compensating measures are taken. Another disadvantage of this approach is that, since the vessel's translation movement is an arc, there will also be some accompanying, coupled vertical movement of the vessel as the plate is rotated to obtain the required horizontal translation. Therefore, the height above the target opening of the vessel and its pour lip change as a function of the translation motion. This height change, being a function of the geometry of the apparatus and the motion around the two axes, is not independently controllable. For precision pouring, it is desirable that the pour lip height be independently controllable.

In the present invention, a combination of rotational movements about two offset axes can be used to achieve a truly horizontal translation of a vessel if such is desired, while a coordinated rotational movement about a third axis can be used to control the tilt angle of the vessel. This combination has the capability of pouring at a controlled rate, while simultaneously directing the pour stream at an aim point. This apparatus can be made more compact than the prior art apparatus just described, while providing equivalent or better functionality. Such compactness minimizes the above disadvantageous aspects of the prior art, while also permitting installation of the present invention on smaller chambers.

Alternatively, the rotations about the three axes may be differently coordinated, to further provide an independently controllable vertical component to the motion of the vessel. In this case, not only can the pour rate be maintained at a pre-selected value and the pour stream directed at the aim point as described above, but the vertical position of the pour lip can also be independently controlled.

Summary of the Invention

The present invention, in one aspect, is a method for pouring liquid from a vessel by a fluid stream that flows from the vessel to a predetermined location or aim point. Three rotational elements are established to provide for two-dimensional movement of the vessel simultaneously with independent controllable tilt of the vessel. The first element rotates about a first axis of rotation. The second element rotates about a second axis of rotation. Relative to the first element, the rotational axis of the second element is located within the periphery of the first element, with its axis of rotation offset from and substantially parallel to the axis of rotation for the first element. The third element rotates about a third axis of rotation. Relative to the second element, the rotational axis of the third element is located within the periphery of the second element, with its axis of rotation substantially parallel to and offset from the axis of the second element. The vessel is connected to the third element. Consequently, rotation of the first, second and third elements about the first, second and third axes of rotation, respectively, will translate and rotate the vessel to accomplish pouring of the liquid from the vessel by a fluid stream to a predetermined location. If the offset distance between the axes of rotation for the first and second elements and the offset distance between the axes of rotation for the second and third elements are equal, then equal counter-rotation of the first and second elements will translate the vessel a horizontal distance of up to four times the equal offset distance. With equal offset distances and without equal counter-rotation, the trajectory of the two dimensional translation can be anywhere within a circle centered on the axis of rotation for the first element, and having a diameter equal to four times the equal offset distance.

In another aspect, the present invention is apparatus for pouring a liquid from a vessel by using a positioning system that has three rotatable elements. The first element has an opening and is connected to a fixed supporting structure in such manner that it is rotatable about an axis of rotation relative to the fixed supporting structure. The second element has an opening and is connected to the first element in such manner that it is rotatable about a second axis of rotation relative to the first element. The second element is located in a substantially parallel plane relative to the first element, and the second axis of rotation passes through the opening in the first element. The axis of rotation for the second element is offset from and substantially parallel to the axis of rotation for the first element. The third element is connected to the second element in such manner that it is rotatable about a third axis of rotation relative to the second element. The third element is located in a substantially parallel plane relative to the second element, and the third axis of rotation passes through the opening in the second element. The axis of rotation for the third element is offset from and substantially parallel to the axis of rotation for the second element. A supporting structure for the vessel projects from the third element, through the openings in the first and second elements, so that rotation of the third element rotates the vessel. This rotation allows the vessel tilt angle to change and results in fluid flow from the vessel that is independently controlled. Rotation of first and second elements will translate the vessel in a two-dimensional plane parallel to the planar orientation of the first, second and third elements. If the offset distance between the axes of rotation for the first and second elements, and the offset distance between the axes of rotation for the second and third elements are equal, then equal counter-rotation of the first and second elements will translate the vessel a horizontal distance of up to four times the equal offset distance. With equal offset distances and without equal counter-rotation, the trajectory of the two dimensional translation can be any where within a circle centered on the axis of rotation for the first element, and having a diameter equal to four times the equal offset distance.

In still another aspect, the present invention is apparatus and a method for the precision pouring of a liquid from a vessel that provides for motion of the vessel in a two-dimensional plane and an independently controllable tilt motion of the vessel. The precision pouring is accomplished by using a positioning system that has three rotatable elements. A wall has a first opening. The first element is disposed in a plane substantially parallel with said wall and occupies the first opening. The first element is rotatable about a first axis of rotation. The first axis of rotation is perpendicular to the said plane substantially parallel with the wall and passes through said first opening. The first element has a second opening. The second element is disposed in a plane substantially parallel with the wall and occupies the second opening. The second element is rotatable relative to the first element about a second axis of rotation. The second axis of rotation is parallel to and offset from the first axis of rotation, and passes through the first and second openings. The second element has a third opening. The third rotatable element is a structure adapted to support a liquid-containing vessel. The structure occupies the third opening and projects axially away from the wall. The vessel-supporting structure is rotatable relative to the second element about a third axis of rotation. The third axis of rotation is parallel to and offset from the second axis of rotation, and passes through the first, second, and third openings. A liquid-containing vessel is so supported by the vessel-supporting structure that liquid can be poured from the vessel by rotation about the third axis. The first and second elements are rotated about the first and second axes of rotation so as to position said vessel at a desired position. The vessel-supporting structure is rotated about the third axis of rotation so as to pour liquid from the vessel.

The rotation about the third axis allows the vessel tilt angle to change and results in fluid flow from the vessel that is independently controlled. Rotation of the first and second elements will translate the vessel in a two-dimensional plane parallel to the planar orientation of the first, second and third elements. If the offset distance between the axes of rotation for the first and second elements is equal to the offset distance between the axes of rotation for the second and third elements, then equal counter-rotation of the first and second elements will translate the vessel a horizontal distance of up to four times the equal offset distance. With equal offset distances and without equal counter-rotation, the trajectory of the two dimensional translation can be anywhere within a circle centered on the axis of rotation for the first element, and having a diameter equal to four times the equal offset distance. The means for rotatably connecting the first, second and third elements to the wall, first element and second element, respectively, can be ball bearing assemblies. The sealing of the first, second and third elements to the wall, first element and second element, respectively, can be accomplished using circular dynamic seals, such as O-rings. Additionally, drives can be provided to achieve the rotation of the first, second and third elements. With appropriate power and control, the drives can be used to provide manual or automatic bi-directional rotation of first, second and third elements.

A reading of the following description and appended claims will provide a thorough understanding of the invention.

Description of the Drawings

For the purpose of illustrating the invention, there is shown in the drawings a form that is presently preferred; it being understood, however, that this invention is not limited to the precise arrangements and instrumentalities shown.

FIG. 1 is an elevational view of the positioning apparatus of the present invention for pouring a liquid from a vessel, looking at the apparatus from outside a chamber, and showing the rotatable elements of the apparatus in one particular orientation.

FIG. 2 is a cross sectional side view of the apparatus of **Fig. 1**, as indicated by section line AA in **Fig. 1**.

FIG. 3 is a cross sectional planar view of the apparatus of **Fig. 1**, as indicated by section line BB in **FIG. 1**.

FIG. 4(a) through **4(e)** schematically illustrates the full range of horizontal translation of a vessel using the positioning apparatus of the present invention.

FIG. 5(a) is a cross sectional side view showing bearings, seals and rotation means used in one arrangement of the present invention.

FIG. 5(b) is an enlarged cross sectional detail of the bearing and seals arrangement for first, second and third elements used with the positioning apparatus of the present invention.

FIG. 5(c) is an enlarged cross sectional detail of the bearing and seals arrangement for the vessel mounting structure used with the positioning apparatus of the present invention.

FIG. 6 is a schematic diagram showing a preferred control system used with the positioning apparatus of the present invention.

Detailed Description of the Invention

Referring now to the drawings, wherein like numerals indicate like elements, there is shown in **FIG. 1** through **3**, in accordance with the present invention, a positioning apparatus **10** mounted on the wall **16** of a chamber **15** for pouring a liquid from a vessel **20** into a container **25** with a target or aim point **27** for the liquid stream, the vessel, container and pour stream all being inside the chamber. **FIG. 1**. is a view of the positioning apparatus **10** from outside the chamber. Consequently, container **25** and vessel **20** are shown in phantom in **FIG. 1**. In the figures, chamber **15** is shown as an enclosed box for convenience of depicting one type of chamber that could be used, rather than limiting the configuration of the chamber. Container **25** can be any type of receptacle having an opening for receiving the fluid stream. For example, the receptacle may be a mold, with aim point **27** being the center of the mold's pour cup. It should be appreciated that the aim point **27** generally represents the center of a fluid stream since the stream will pass through a defined area, rather than a point. Vessel **20** generally has a pour lip **22** over which the fluid flows when the vessel is tilted. The pour lip can also be a spout or other element that provides a flow path for molten metal out of the vessel when the vessel is tilted. Vessel **20** may be a furnace, ladle, or other apparatus known in the art of processing molten or other liquid materials.

First element **30** is disposed to cover an opening **31** in the wall **16** of chamber **15**. First element **30**, rotatable about a first axis of rotation **32**, is mounted on wall **16** and is peripherally sealed to the wall by a circular, substantially gas-tight dynamic seal such as an elastomeric O-ring, which is substantially concentric with the first axis of rotation **32**. As shown in the figures, first element **30** has an opening **41** to allow for the passage of vessel mounting structure **60** through first element **30**. For clarity, rotational means, bearings and seals for first element **30** are not shown in **FIG. 1** through **3**. Second element **40** is rotatably attached and similarly peripherally sealed to first element **30**, covering the opening **41** in first element **30**. Second element **40** is rotatable about a second axis of rotation **42**, which is substantially parallel to first axis of rotation **32**. As shown in the figures, second element **40** has an opening to allow for the passage of vessel mounting structure **60** through second element **40**. For clarity, rotational means, bearings and seals for second circular element **40** are not shown in **FIG. 1** through **3**. As shown in **FIG. 3**, axes of rotation **32** and **42** are separated by a first offset distance **48**. Without limitation, first and second elements **30** and **40**, respectively, may be circular metal plates, with appropriate openings, supported by peripherally located roller, plain or other bearings.

Vessel mounting structure **60**, as shown in **FIG. 1** through **3**, is a hollow tube in the shape of a circular cylinder. The first open base of the cylindrical mounting structure **60** defines a third element **50**, as shown in the figures. The end of the cylindrical mounting structure **60** opposite the first open base provides a point of connection to vessel **20**. For the purpose of allowing the vessel to be controllably tilted, mounting structure **60** is rotatably disposed in an opening in the second circular plate **40** and peripherally sealed to it. Third element **50** is rotatable about a third axis of rotation **52**, which is substantially parallel to second axis of rotation **42**. As shown in **FIG. 3**, axes of rotation **52** and **42** are separated by second offset distance **49.** Preferably, first and second offset distances **48** and **49** are substantially equal.

While the vessel mounting structure **60** is shown in the drawings as a hollow circular cylinder, other configurations are also satisfactory as long as the structure is used to mount vessel **20** so that the vessel can be rotated about the third axis of rotation **52** located as described above. Consequently, rotation of the mounting structure **60** about the third axis of rotation **52** will also result in corresponding rotation of the connected vessel **20**. As shown in **FIG. 1** through **3**, vessel **20** is in the zero degree tilt position (angle of vertical centerline of the vessel from the vertical Y-axis). An artisan will appreciate that intervening support and mounting structural elements may be incorporated between mounting structure **60** and vessel **20**. A hollow cylinder is not a necessity, but if the vessel **20** is a furnace which requires cables and tubing to supply electrical power and cooling water, the bore of a hollow cylinder provides a convenient path for routing such cables and tubing.

While the bearings, seals and rotational components for first and second elements, **30** and **40**, and for vessel mounting structure **60**, can be made in many ways, particular components are described below.

In the preferred arrangement, in which first and second offset distances **48** and **49** are equal (equal offset distance), rotation of first element **30** and second element **40** through equal angles in opposite directions about their respective axes of rotation **32** and **42**, will result in a horizontal translation of the vessel as shown in **FIG. 4(a)** through **4(e)**. During this translation, a simultaneous coordinated rotation of vessel mounting structure **60** about the third axis of rotation **52** permits the vessel to be positioned at any desired vessel tilt angle for any horizontal position. When first and second elements **30** and **40** have rotated 180 angular degrees, as shown in **FIG. 4(e),** from the position shown in **FIG. 4(a)**, vessel **20**, attached to mounting structure **60** will have translated horizontally by a distance equal to four times the equal offset distance, without accompanying vertical motion. The horizontal translation of first and second elements **30** and **40**, and appropriate coordinated rotation of vessel mounting structure **60**, can be used to establish a selected pour profile of liquid over the pour lip so that the liquid stream has a desired rate of flow and its center is continually directed to the predetermined aim point **27**. In comparison with the prior art approach of using a comparatively large element with restricted arc movement to accomplish mainly horizontal motion of the vessel, the present invention provides for an equivalent range of horizontal movement in less space.

For other pour processes using the preferred arrangement, coordinated varying rotation of first and second elements **30** and **40**, not limited to equal angular counter-rotations, can be used to move the third axis of rotation **52** along a trajectory that lies anywhere within a circle **68** shown in phantom in **FIG. 1**. Circle **68** is concentric with first element **30** and has a diameter equal to four times the equal offset distance. Selection of a trajectory having appropriate vertical, horizontal and vessel tilt components can provide uncoupled, independent control of not only the pour rate and fluid stream aiming, but also the height of the vessel's lip above the aim point. The availability of independent vertical, horizontal and tilting motions can also be useful for other purposes, such as positioning the vessel for filling or maintenance.

In Fig. **4(a)** through **4(e)**, the reference arrow on each of the rotating components of the system, first, second and third elements, **30**, **40** and **50** (and the vessel **20** and mounting structure **60** by connection to third element **50**) is used to indicate angular position of the rotating components, as they move through their complete range of horizontal motion. As indicated by the arrow on mounting structure **60**, the vessel remains at zero tilt angle throughout this sequence, though it should be appreciated that, at any horizontal location, third element **50** and connected mounting structure **60**, may be rotated to tilt the connected vessel, and to thereby obtain a liquid pour stream with a desired flow rate.

Summarizing the general configuration of the first, second and third elements, first element **30** is peripherally connected to a fixed supporting structure, which can be the wall **16** of a chamber **15**. The peripheral connection between the first element **30** and the fixed supporting structure is such that the first element **30** can be rotated about its axis of rotation **32**. Second element **40** is peripherally connected to the first element **30** in a manner such that the second element **40** can rotate about its axis of rotation **42**. The second axis of rotation **42** is located within the periphery of the first element **30**. The third axis of rotation **52** is locate within the periphery of the second element **40**. In general terms, vessel supporting structure **60** is a structure projecting from the perimeter of the third element **50**. The supporting structure passes through openings in the first and second elements. It will be appreciated that environmental seals will not be required between interfacing elements when the positioning system **10** is not used in a sealed chamber. Furthermore, while the preferred embodiment uses peripheral means for connecting the elements to each other, and to the wall of the chamber, other methods of connection are suitable for the present invention.

Fig. 5(a) shows in cross sectional view one preferred arrangement of the bearings, seals and drive means of the present invention. In order to display these components most clearly, first element **30** has been rotated 90 degrees clockwise from the position shown in **FIG. 1** through 3. In addition, vessel mounting structure **60** has been rotated 90 degrees counter clockwise, to keep the vessel at zero tilt angle. **Fig. 5(a)** thereby illustrates the vessel at maximum translation in the upwards, or Y direction. The chamber has a circular opening in its wall **16** that is bounded by a chamber structural supporting ring **17.** Chamber structural supporting ring **17** is integrally connected to the wall of the chamber. Adapter ring **82** is connected to chamber structural supporting ring **17**. The interface for the adapter ring and chamber structural supporting ring is environmentally sealed by static O-ring **84**. It should be appreciated that in alternate embodiments of the invention, the chamber structural supporting ring **17** and adapter ring **82** can be integral with the wall **16** of the chamber. Adapter ring **82** supports first peripheral ball bearing assembly **88**, which provides the rotational support for first element **30**. First element **30** is connected to and supported by ball bearing assembly **88** as shown in **FIG. 5(a)**. O-ring seals **86**, are located concentric with ball bearing assembly **88** in adjacent grooves in first element **30** as shown in detail in **FIG. 5(b)**. One or more O-rings can be provided. The preferred embodiment with two O-ring seals **86** is shown in the figures. The space between the two O-rings is preferably filled with an oil or grease to provide lubrication for these O-rings, which dynamically seal first element **30** to the adjacent surface of adapter ring **82**. Ball bearing assembly **88** has radially-oriented gear teeth **89** disposed around its outer periphery. First pinion gear **102**, driven by first hydraulic motor **100**, engages teeth **89**. Motor **100** is attached by conventional mounting means not shown in the drawings to the wall **16** of the chamber **15**. This arrangement allows motor **100** to rotate first element **30** relative to wall **16**.

In like manner first element **30** supports ball bearing assembly **90**, which provides the rotational means for second element **40**. Second element **40** is connected to and supported by ball bearing assembly **90** as best shown in **FIG. 5(b)**. O-ring seals **92** are located concentric with ball bearing assembly **90** in adjacent groves in second element **40** as shown in detail in **FIG. 5(b)**. One or more O-rings can be provided. The preferred embodiment with two O-ring seals **92** is shown in the figures. The space between the two O-rings is preferably filled with an oil or grease to provide lubrication for these O-rings, which dynamically seal second element **40** to the adjacent surface of first element 30. Ball bearing assembly **90** has radially-oriented gear teeth **91** disposed around its outer periphery. Second pinion gear **112**, driven by second hydraulic motor **110**, engages teeth **91**. Motor **110** is attached by conventional mounting means not shown in the drawings to first element **30**. This arrangement allows motor **110** to rotate second element **40** relative to first element **30**.

In the embodiment of the invention shown in **FIG. 5(a)**, vessel mounting structure **60** is supported from a tubular extension **45** of second element **40** by dual co-axial ball bearing assemblies **96a** and **96b**. Dynamic sealing of vessel mounting structure **60** to second element **40** is by dual lubricated O-ring seals **94** between the tubular extension **45** of second element **40** and the vessel supporting structure as best shown in

FIG. 5(c). One or more O-ring seals can be provided, in this embodiment, third element **50** is defined as the first open base of the cylindrical vessel mounting structure **60** adjacent to ball bearing assembly **96b**. Rotation of vessel mounting structure **60** relative to second element **40** is performed by a sprocket drive. Third hydraulic motor **120** has first sprocket **122** attached to its output shaft. Second sprocket **126** is radially attached to the exterior of the first base of vessel mounting structure **60**. The links of chain **124** are engaged by sprockets **122** and **126** to rotate vessel mounting structure **60**. Motor **120** is attached by conventional mounting means not shown in the drawings to second element **40**.

While elastomeric O-rings are used in the preferred embodiment, any type of circular dynamic seals would be suitable for the application. Although hydraulic drives are shown in the drawings for rotation of first and second elements **30** and **40**, and vessel mounting structure 60, an artisan will appreciate that other drives, such as electrical or pneumatic, with appropriate power source, can be used to accomplished powered rotation of these components.

As shown in the embodiment in **FIG. 5(a)**, first and second elements **30** and **40** are circular plates with openings and fastener means for connection to components in the positioning system **10**. Circular packing elements **270** provide closure for the open base of the vessel mounting structure and transit openings for cables **280** that transport electrical power and cooling water to vessel **20**. For a hydraulic-driven power system, hydraulic fluid supply and return lines **128** connect motors **100**, **110** and **120** to a hydraulic power and control system further described below.

A preferred method for controlling the rotational positions of the first and second elements **30** and **40** and vessel mounting structure 60 of the present invention is shown schematically in **Fig. 6**. Hydraulic fluid from a pressurized source **160**, such as a hydraulic pump, flows to first hydraulic motor **100**, which is bi-directional, via first four-way hydraulic valve **130**. The flow of hydraulic fluid through valve **130** is controlled by the output signal from first position error amplifier **200**. This error amplifier, in turn, receives a position command signal from a system controller **230**, and a position feedback signal from first potentiometer **170**, which indicates the angular position of first element **30** relative to the wall **16** of chamber **15**. The wiper arm of potentiometer **170** is connected to first element **30** and the potentiometer's resistive element is attached to the wall of chamber in suitable fashion so that angular rotation of first element **30** will result in a change of the potentiometer's resistance that will be proportional to the degree of angular rotation of first element **30**. Error amplifier **200** is designed such that any difference between the desired position of first element **30**, represented by a command signal from system controller **230**, and the actual angular position of first element **30**, represented by the signal from potentiometer **170**, causes an output signal to be produced. This signal causes valve **130** to open such that the resulting flow of oil from pressurized source **160** to motor **100** causes motor **100** to rotate. Motor **100**, mounted on chamber **15** and having an output shaft that is rotationally coupled to first element **30**, causes first element **30** and the wiper of potentiometer **170** to rotate in a direction which reduces the above difference. When the difference reaches zero, indicating that first element **30** has reached the commanded position, valve **130** closes and motor **100** stops. First element **30** is therefore continuously driven by this hydraulic position control loop to the angular position commanded by system controller **230**. For best control, valve **130** is preferably a servo or proportioning type valve in which the opening of the valve is proportional to the signal received from position error amplifier **200**. System controller **230** preferably comprises a digital storage and computing device, capable of storing a series of values for the desired position of first element **30** and outputting these as command signals in a timed sequence during a pour or other vessel motion.

In like manner, the rotational position of second element **40** relative to first element **30**, as indicated by second potentiometer **180**, is controlled at a second angular position commanded by system controller **230** by a second hydraulic position control loop that includes second four-way hydraulic valve **140**, second position error amplifier **210** and second (bi-directional) hydraulic motor **110**. Also in like manner, the rotational position of vessel mounting structure **60** relative to second element **40**, as indicated by third potentiometer **190**, is controlled at a third angular position commanded by system controller **230** by a third hydraulic position control loop that includes third four-way hydraulic valve **150**, third position error amplifier **220** and third (bi-directional) hydraulic motor **120**.

It will be appreciated by an artisan that the potentiometers used in the preferred embodiment are one type of angular position transducer sensors known in the art. Other position sensors are readily adaptable to the present invention. For non-hydraulic drives, the four-way hydraulic valves **130**, **140** and **150** will be understood to be drive controllers for controlling the speed and direction of the position outputs of the appropriate rotational means that replace the hydraulic motors **100**, **110**, and **120**.

System controller **230** is preferably a digital computer, programmable logic controller or 3-axis digital motion controller. Error amplifiers **200**, **210** and **220** may advantageously be of the Proportional Integral Derivative (PID) type well known to those skilled in the closed-loop-position-control art. Commercially available digital motion controllers often include such amplifiers, implemented partially in software. For reasons that are detailed later, system controller **230** is preferably also programmed with an algorithm that converts any desired position of the vessel, expressed in the form of X and Y coordinates, or components in another coordinate system, plus the vessel's tilt angle relative to the wall **16** of chamber **15**, into the corresponding rotational angles of first, second and third elements, **30**, **40** and **50** (and vessel mounting structure **60** by connection to element **50**). Such an algorithm can be derived from a simple geometric analysis of the system. Preferably, system controller **230** continuously maintains master position values for the desired X and Y coordinates of the vessel, together with its tilt angle. The algorithm described above converts these values to corresponding rotational position commands for the three hydraulic positioning loops, as previously described.

During any automated vessel movement, system controller **230** converts a stored sequence of X, Y and tilt angle positions into a corresponding series of rotational position commands for the three hydraulic position control loops. If the vessel motion is for an automated pour, this causes rotational motion about the three axes such that the pour rate of the fluid from the vessel follows a desired flow rate profile, the position of the terminal end of the pour stream is maintained at the aim point **27** and, optionally, the vertical position of the pour lip of the vessel relative to the aim point is also controlled.

One way to generate the required list of master positions is by a process in which a skilled operator makes a manually controlled vessel movement and the system controller **230** records the resulting master positions at frequent intervals as the vessel motion proceeds. For this purpose, as well as for general re-positioning of the vessel under operator control, the preferred control system includes joysticks **250** and **260**. Other types of input devices are also suitable. Joystick **250** has a spring-centered handle movable in two directions, X and Y. The displacement of joystick **250** in each direction produces a proportional output signal on a corresponding potentiometer. Signals from these potentiometers are read by system controller **230** as representing a desired velocity of vessel **20** in the corresponding X and Y directions. For ease of control, joystick **250** is preferably mounted such that movement of the joystick handle in a particular direction results in vessel motion in the same direction, be it X, Y or any combination of the two. Joystick **260** is similar to **250** but has a single potentiometer representing the desired tilt velocity.

Operation of the system in the manual control mode is as follows. Manual displacement of any joystick handle away from its spring-centered position causes system controller **230** to increment or decrement the corresponding master position value, i.e., X-position, Y-position, tilt angle or any combination of these three values. The rate at which each of the master values is changed is made proportional to the corresponding joystick handle displacement. At frequent intervals, the newly calculated master position values are converted to position values for each of the three hydraulic positioning loops by the algorithm previously mentioned, and outputted as position commands. The hydraulic servo positioning loops cause the vessel **20** to move as directed by system controller **230**. New loop position commands are preferably generated by system controller **230** sufficiently frequently that the resulting vessel motion takes place smoothly.

By depressing a pushbutton that can be integrated with joystick **260**, as shown in **FIG. 6**, any manually controlled movement operation may be recorded. Such pushbutton activation causes the ensuing sequence of master position commands to be stored by system controller **230** as a profile that may be re-called and re-played at any later time. System controller **230** is preferably able to store a number of such profiles. Prior to activating such a pre-recorded movement, the operator would indicate to system controller **230**, by means of a keyboard or other input device not shown in **Fig 6**, which of the pre-stored motion profiles is to be used. The corresponding vessel motion would thereafter commence upon a command, such as activation of pushbutton **240**. Such a pre-recorded vessel motion may be used to perform a pour operation, or to achieve any other vessel re-positioning that may be repetitively required during the course of operation or maintenance.

As an alternative to recording a manually controlled sequence as described above, the list of master vessel positions required for a motion profile may also be obtained by pre-calculation from the geometry and dynamics of the system. Such calculations may be performed by system controller **230**, or by another computing device, the resulting sequence of master vessel positions being communicated to system controller **230**.

Summarizing one embodiment of the process, a pour profile, comprising a manually or automatically generated motion profile resulting from rotational movements of the first and second elements **30** and **40**, either separately or coordinately, and a manually or automatically generated rotation of the third element **50**, with attached vessel **20** and supporting structure **60**, can be executed to pour liquid from the vessel to a predetermined location or aim point **27**.

The pouring apparatus and process disclosed in the present invention is particularly applicable to technologies using chambers that operate under internal vacuum or internal positive pressure. It may also be used for applications that use a controlled atmosphere at ambient atmospheric pressure. Furthermore, two synchronously driven sets of the mechanical parts of the apparatus disclosed in the present invention, can be located on opposite sides of a large vessel to provide two-sided support for such a vessel.

The foregoing embodiments do not limit the scope of the disclosed invention. The scope of the disclosed invention is covered in the appended claims.

Claims

What is claimed is:

1. A method for pouring a liquid from a vessel by a fluid stream that flows from the vessel to a predetermined location, comprising the following steps:

establishing a first element with a first axis of rotation;

establishing a second element with a second axis of rotation, said second axis of rotation positioned substantially parallel to the first axis of rotation, and offset from said first axis of rotation by a first offset distance, said second axis of rotation disposed within the periphery of the first element;

establishing a third element with a third axis of rotation, said third axis of rotation positioned substantially parallel to the first and second axes of rotation, and offset from said second axis of rotation by a second offset distance, said third axis of rotation disposed within the periphery of the second element;

supporting the vessel containing the liquid from said third element; and

rotating said first, second and third elements about the first, second and third axes of rotation, respectively, to pour the liquid from said vessel by a fluid stream to the predetermined location.

2. The method of claim 1 wherein said first and second offset distances are equal.

3. The method of claim 2 further comprising rotating said first and second elements coordinately about the first and second axes of rotation, respectively, to translate the third axis of rotation in a horizontal

path through a distance of up to four offset distances.

4. The method of claim 2 further comprising rotating said first and second elements coordinately about the first and second axes of rotation, respectively, to translate the third axis of rotation within a circle centered on said first axis of rotation about the first axis of rotation, the circle having a radius equal to the sum of said first and said second offset distances.

5. Apparatus for precision pouring of a liquid from a vessel comprising:

first element rotatably connected to a fixed supporting structure, said first element having an opening and being rotatable about a first axis of rotation;

second element rotatably connected to said first element, said second element disposed in a plane substantially parallel with the first element, the second element having an opening and being rotatable about a second axis of rotation, said second axis of rotation passing through the opening in the first element and being offset from the first axis of rotation by a first offset distance;

third element rotatably connected to said second element, said third element disposed in a plane substantially parallel with the second element, the third element being rotatable about a third axis of rotation, said third axis of rotation passing through the opening in the second element and being offset from the second axis of rotation by a second offset distance; and

vessel supporting structure rotatably connected to said third element, the vessel supporting structure spatially projecting from the periphery of the third element, through the openings in said first and second elements, the vessel connected to said vessel supporting structure whereby rotation about the first, second and third axes of rotation rotates and positions said vessel to pour liquid from the vessel to the predetermined location.

6. The apparatus of claim 5 wherein said first and second offset distances are equal.

7. The apparatus claim 6, wherein said first element and second elements are coordinately rotatable about the first and second axes of rotation, respectively, whereby the third axis of rotation is translatable in a horizontal path through a distance of up to four offset distances.

8. The apparatus of claim 6 wherein said first element and second elements are coordinately rotatable about the first and second axes of rotation, respectively, whereby the third axis of rotation is translatable within a circle centered on said first axis of rotation about the first axis of rotation, the circle having a radius equal to the sum of said first and said second offset distances.

9. Apparatus for precision pouring of a liquid from a vessel to a predetermined point, comprising:

a wall having a first opening;

a first element disposed in a plane substantially parallel with said wall and occupying said first opening, said first element having a second opening, said first element being rotatable about a first axis of rotation, said first axis of rotation being perpendicular to said plane substantially parallel with said wall and passing through said first opening;

a second element disposed in a plane substantially parallel with said wall and occupying said second opening, said second element having a third opening, said second element being rotatable relative to said first element about a second axis of rotation, said second axis of rotation being parallel to and offset from the first axis of rotation, and passing through said first and second openings; and

a vessel-supporting structure adapted to support a liquid-containing vessel, said structure occupying said third opening and projecting axially away from the wall, said structure being rotatable relative to said second element about a third axis of rotation, said third axis of rotation being parallel to and offset from the second axis of rotation, and said third axis of rotation passing through said first, second, and third openings;

whereby selected rotation of said first and second elements and said vessel-supporting structure about the first, second and third axes of rotation positions and rotates said vessel.

10. Apparatus according to claim 9, wherein said second axis of rotation is offset from the first axis of rotation by a first offset distance, and said third axis of rotation is offset from the second axis of rotation by a second offset distance substantially equal to the first offset distance.

11. Apparatus according to claim 9, wherein said vessel-supporting structure closes said third opening, said second member and said vessel-supporting structure close said second opening, and said first and second members and said vessel-supporting structure close said first opening.

12. Apparatus according to claim 9, wherein each of said first, second, and third openings is generally circular and is centered on said first, second, and third axis, respectively, and each of said first and second elements is generally circular and is centered on said first and second axis, respectively, and a part of said vessel-supporting structure

occupying said third opening is generally circular and is centered on said third axis.

13. Apparatus according to claim 9, wherein said vessel-supporting structure is located within a sealed chamber, and said wall is a wall of said sealed chamber.

14. Apparatus according to claim 9, wherein said first element is sealed to said wall, said second element is sealed to said first element, and said vessel-supporting structure is sealed to said second element, so as to remain sealed as said elements rotate.

15. Apparatus according to claim 14, wherein the first and second elements and said vessel-supporting structure are sealed to the wall of the chamber, first element and second element, respectively, by circular dynamic seals.

16. Apparatus according to claim 9, wherein said first and second elements and said vessel-supporting structure are rotatably connected to the wall of the chamber, first element and second element, respectively, by ball bearing assemblies.

17. Apparatus according to claim 9, further comprising:

a first motor attached to the wall, with its output engaging the first element to rotate said first element;

a second motor attached to the first element, with its output engaging the second element to rotate said second element; and

a third motor attached to the second element, with its output engaging the vessel-supporting structure to rotate the vessel-supporting structure.

18. Apparatus according to claim 17, further comprising:

a power source;

first, second and third drive controllers connected to said power source and the first, second and third motors, respectively, to control the speed and direction of the position outputs of said motors;

a first angular position transducer attached to the wall and driven by the first element whereby the angular position of said first element is indicated by the output of said first angular position transducer;

a second angular position transducer attached to the first element and driven by the second element whereby the angular position of said second element is indicated by the output of said second angular position transducer;

a third angular position transducer attached to the second element and driven by said vessel-supporting structure whereby the angular position of said vessel-supporting structure is indicated by the output of said third angular position transducer;

a system controller;

a first error amplifier having first input from said system controller, second input from the first angular position transducer, and one output to said first drive controller to control the output to said first motor;

a second error amplifier having first input from said system controller, second input from the second angular position transducer, and one output to said second drive controller to control the output to said second motor;

a third error amplifier having first input from said system controller, second input from the third angular position transducer, and one output to said third drive controller to control the output to said third motor; and

input devices to the system controller to manually rotate said first and second elements and said vessel-supporting structure or store pour profiles in said system controller.

19. A method for precision pouring of a liquid from a vessel to a predetermined point, comprising:

providing a wall having a first opening;

providing a first element disposed in a plane substantially parallel with said wall and occupying said first opening, said first element having a second opening, said first element being rotatable about a first axis of rotation, said first axis of rotation passing through said first opening and being perpendicular to said plane substantially parallel with said wall;

providing a second element disposed in a plane substantially parallel with said wall and occupying said second opening, said second element being rotatable relative to said first element about a second axis of rotation, said second axis of rotation being parallel to and offset from the first axis of rotation, and passing through said first and second openings;

providing a vessel-supporting structure adapted to support a liquid-containing vessel, said structure occupying said third opening, said structure being rotatable relative to said second element about a third axis of rotation, said third axis of rotation being parallel to and offset from the second axis of rotation, and said third axis of rotation passing through said first, second, and third openings;

providing a liquid-containing vessel so supported by said vessel-supporting structure that liquid can be poured from said vessel by rotation about said third axis;

rotating said first and second elements about the first and second axes of rotation so as to position said vessel at a desired position; and

rotating said vessel-supporting structure about the third axis of rotation so as to pour liquid from the vessel.

20. A method according to claim 19, wherein said second axis of rotation is offset from the first axis of rotation by a first offset distance, and said third axis of rotation is offset from the second axis of rotation by a second offset distance equal to the first offset distance.

21. A method according to claim 20, further comprising rotating said first and second elements coordinately about the first and second axes of rotation, respectively, to translate the third axis of rotation in a horizontal path through a distance of up to four offset distances.

22. A method according to claim 20, further comprising rotating said first and second elements coordinately about the first and second axes of rotation, respectively, to translate the third axis of rotation within a circle centered on said first axis of rotation about the first axis of rotation, the circle having a radius equal to the sum of said first and said second offset distances.

23. A method according to claim 19, wherein said vessel-supporting structure closes said third opening, said second member and said vessel-supporting structure close said second opening, and said first and second members and said vessel-supporting structure close said first opening.

24. A method according to claim 19, wherein each of said first, second, and third openings is generally circular and is centered on said first, second, and third axis, respectively, and each of said first and second elements is generally circular and is centered on said first and second axis, respectively. and a part of said vessel-supporting structure occupying said third opening is generally circular and is centered on said third axis.

25. A method according to claim 19, which comprises providing said vessel-supporting structure within a sealed chamber, wherein said wall is a wall of said sealed chamber.

26. A method according to claim 19, wherein said first element is sealed to said wall, said second element is sealed to said first element, and said vessel-supporting structure is sealed to said second element, so as to remain sealed as said elements rotate.

27. A method according to claim 19, further comprising:

rotating said first element by way of a first motor attached to the wall, with its output engaging the first element;

rotating said second element by way of a second motor attached to the first element, with its output engaging the second element; and

rotating said vessel-supporting structure by way of a third motor attached to the second element, with its output engaging said vessel-supporting structure.

28. A method according to claim 27, further comprising:

providing a power source;

controlling the speed and direction of the position outputs of said first, second and third motors by way of first, second and third drive controllers connected to said power source and to the first, second and third motors, respectively;

indicating the angular position of said first element by the output of a first angular position transducer attached to the wall and driven by the first element;

indicating the angular position of said second element by the output of a second angular position transducer attached to the first element and driven by the second element;

indicating the angular position of said vessel-supporting structure by the output of a third angular position transducer attached to the second element and driven by said vessel-supporting structure;

comparing an input from a system controller with the output of the first angular position transducer in a first error amplifier and producing one output to said first drive controller to control the output to said first motor;

comparing an input from said system controller with the output of from the second angular position transducer in a second error amplifier and producing one output to said second drive controller to control the output to said second motor; and

comparing an input from said system controller with the output of the third angular position transducer in a third error amplifier and producing one output to said third drive controller to control the output to said third motor.

29. A method according to claim 28, comprising inputting to the system controller to manually rotate said first and second elements and said vessel-supporting structure or to store pour profiles in said system controller.

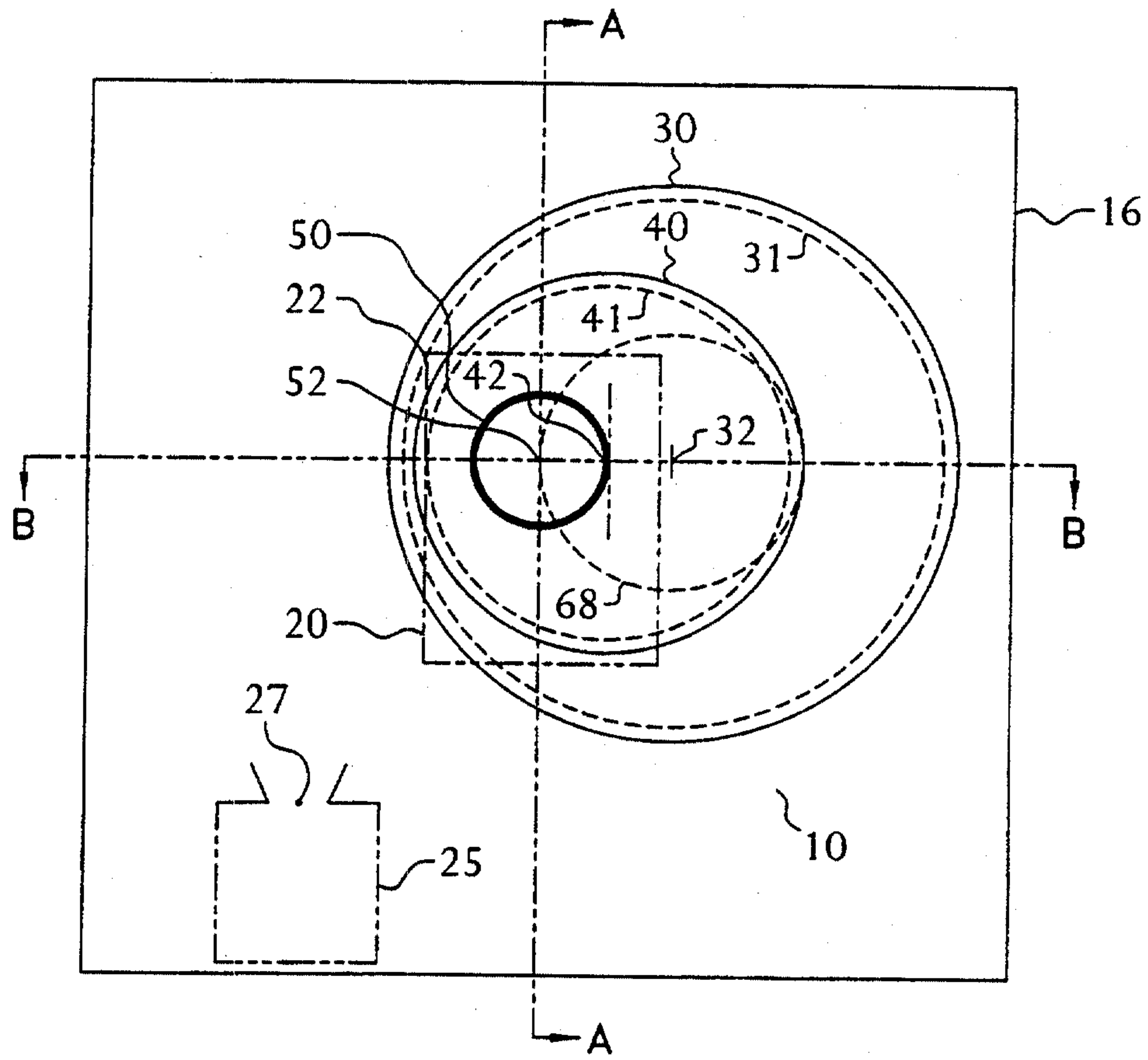


FIG. 1

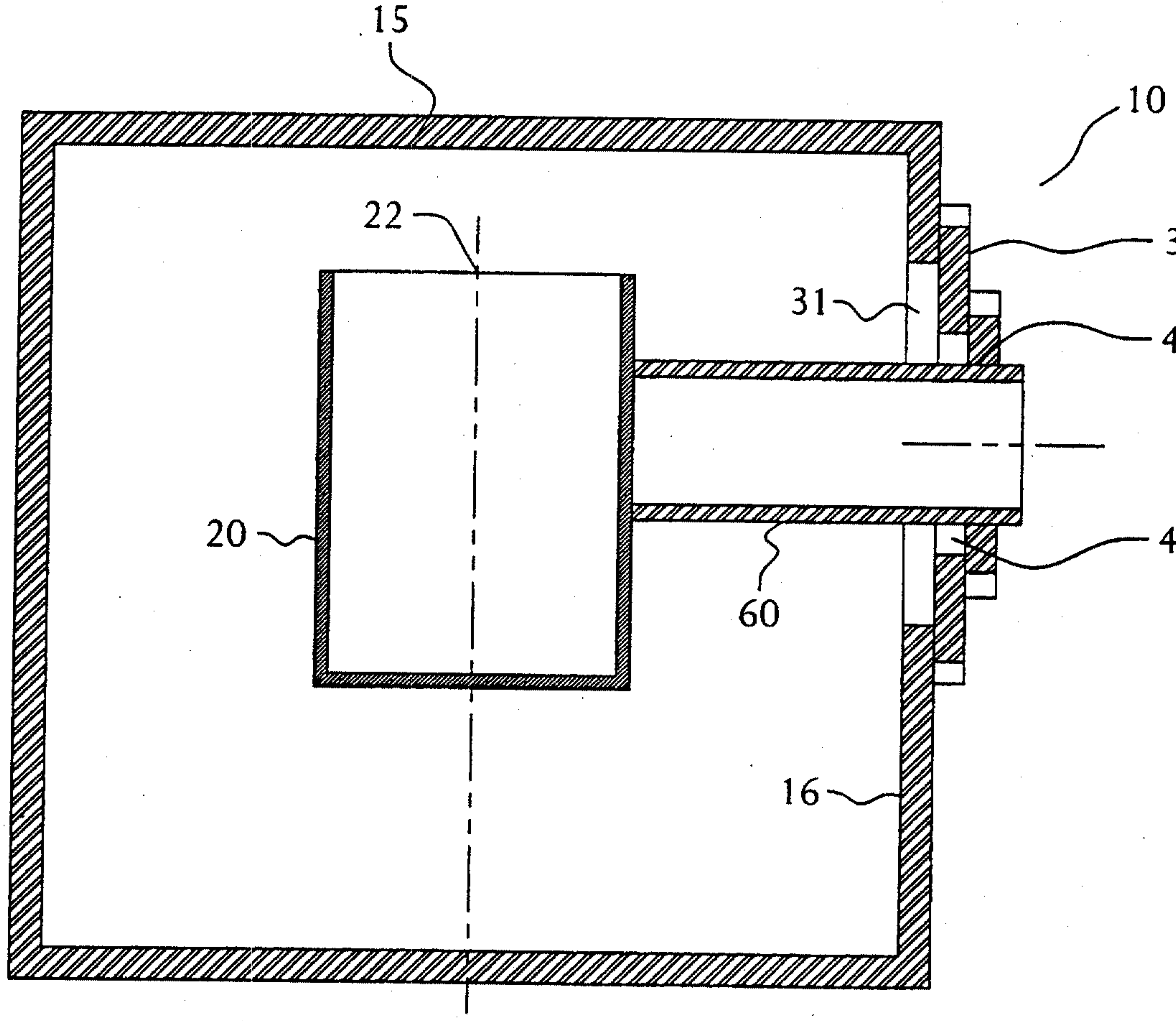


FIG. 2

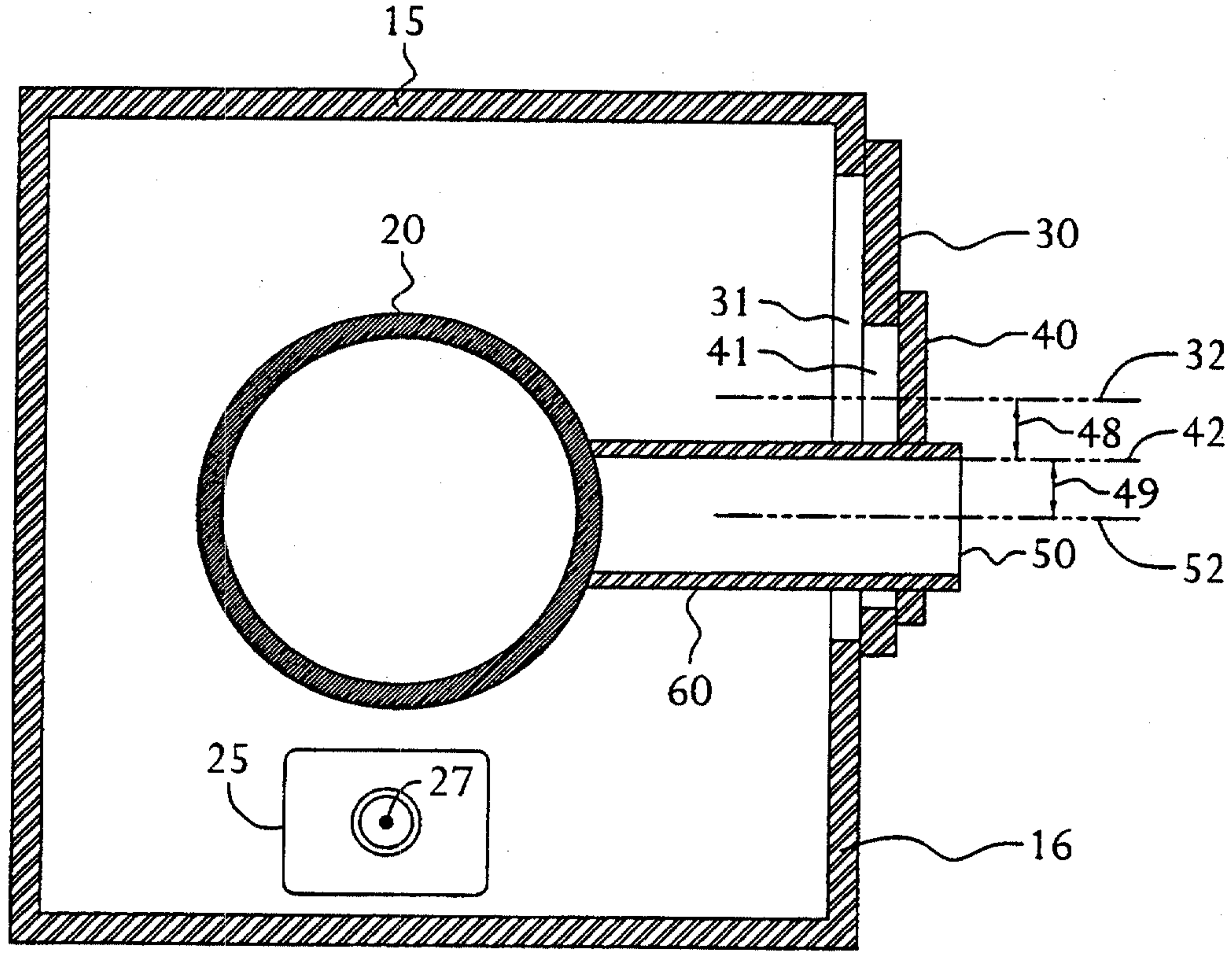


FIG. 3

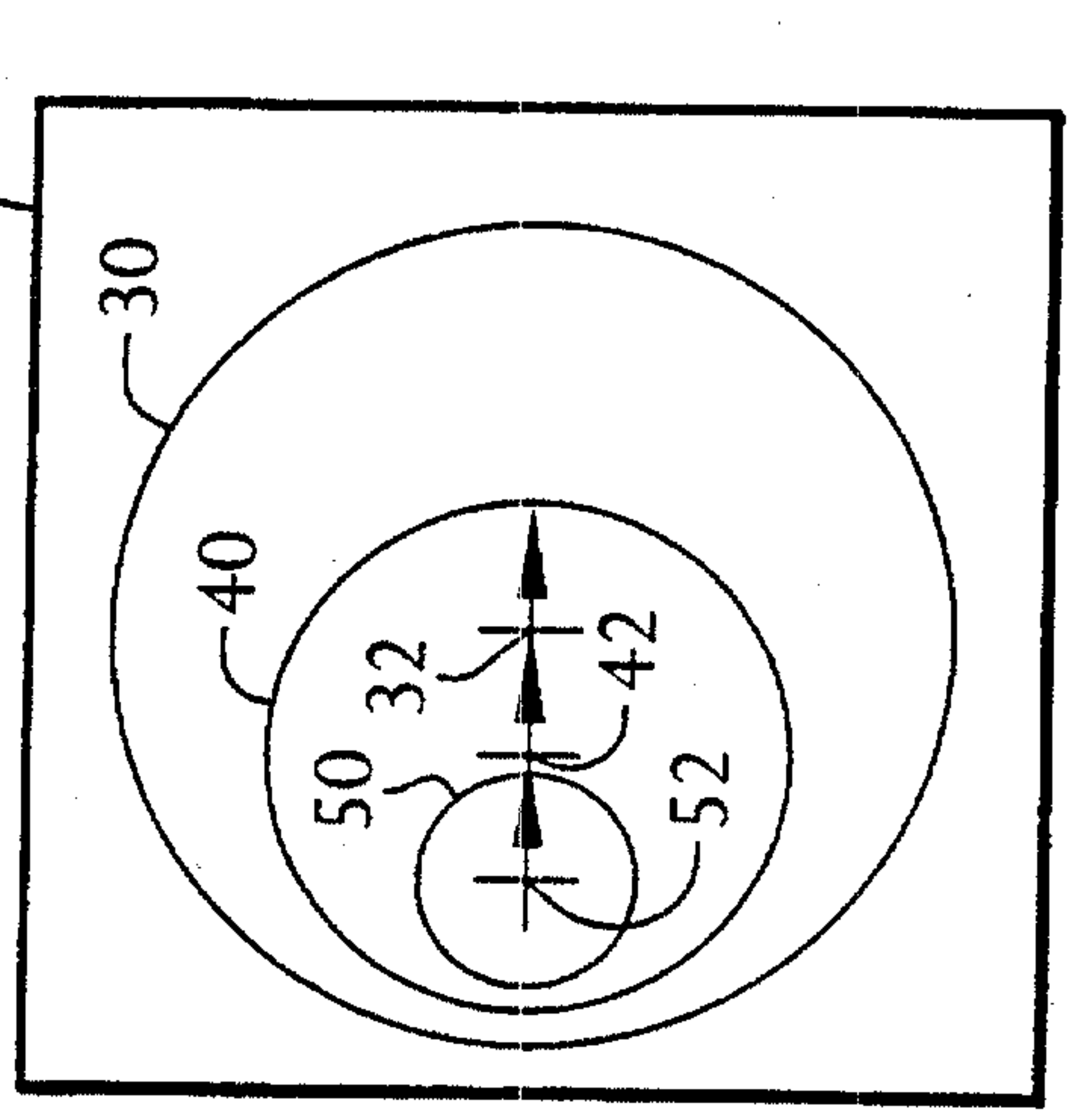


FIG. 4(a)

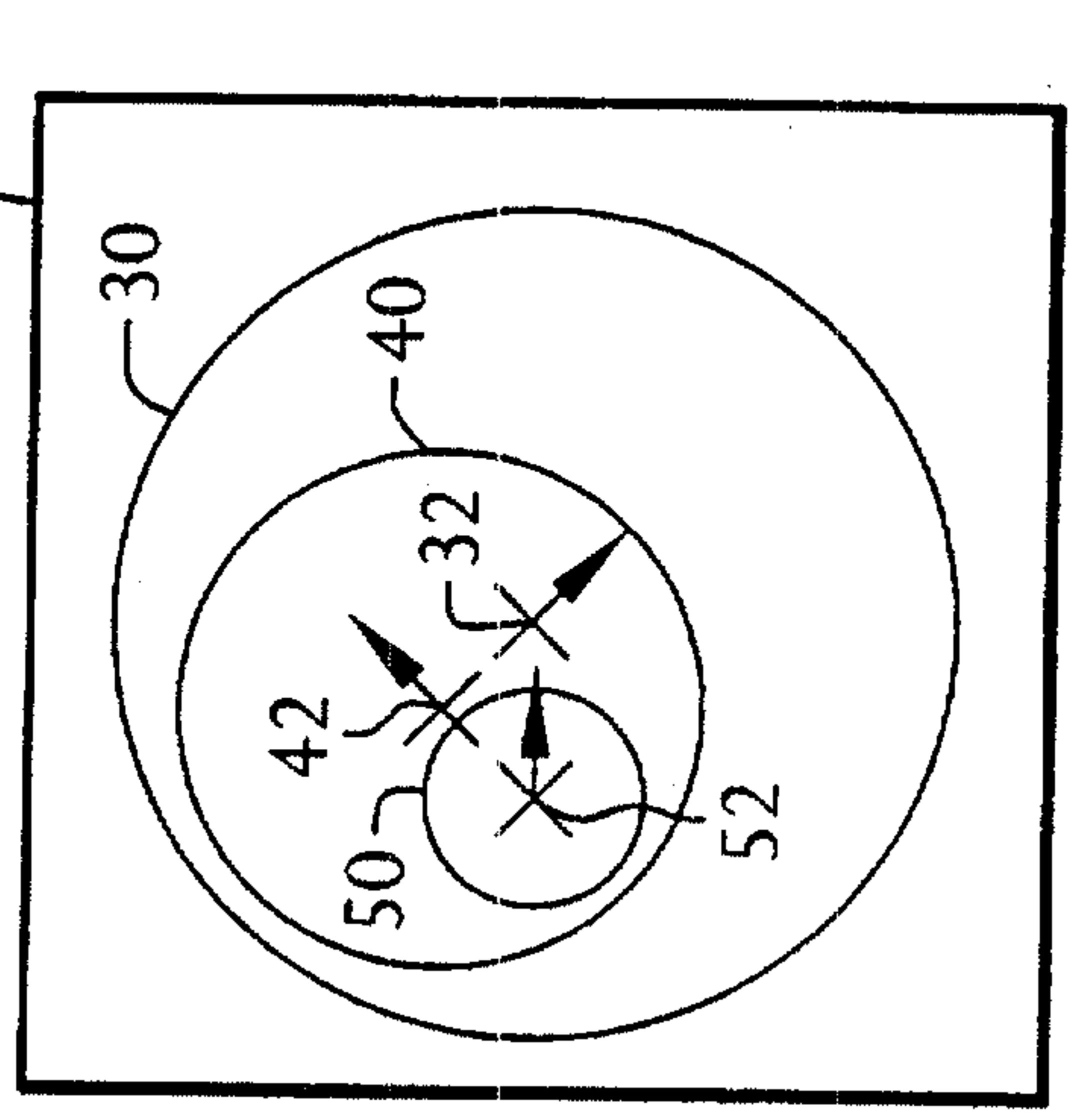


FIG. 4(b)

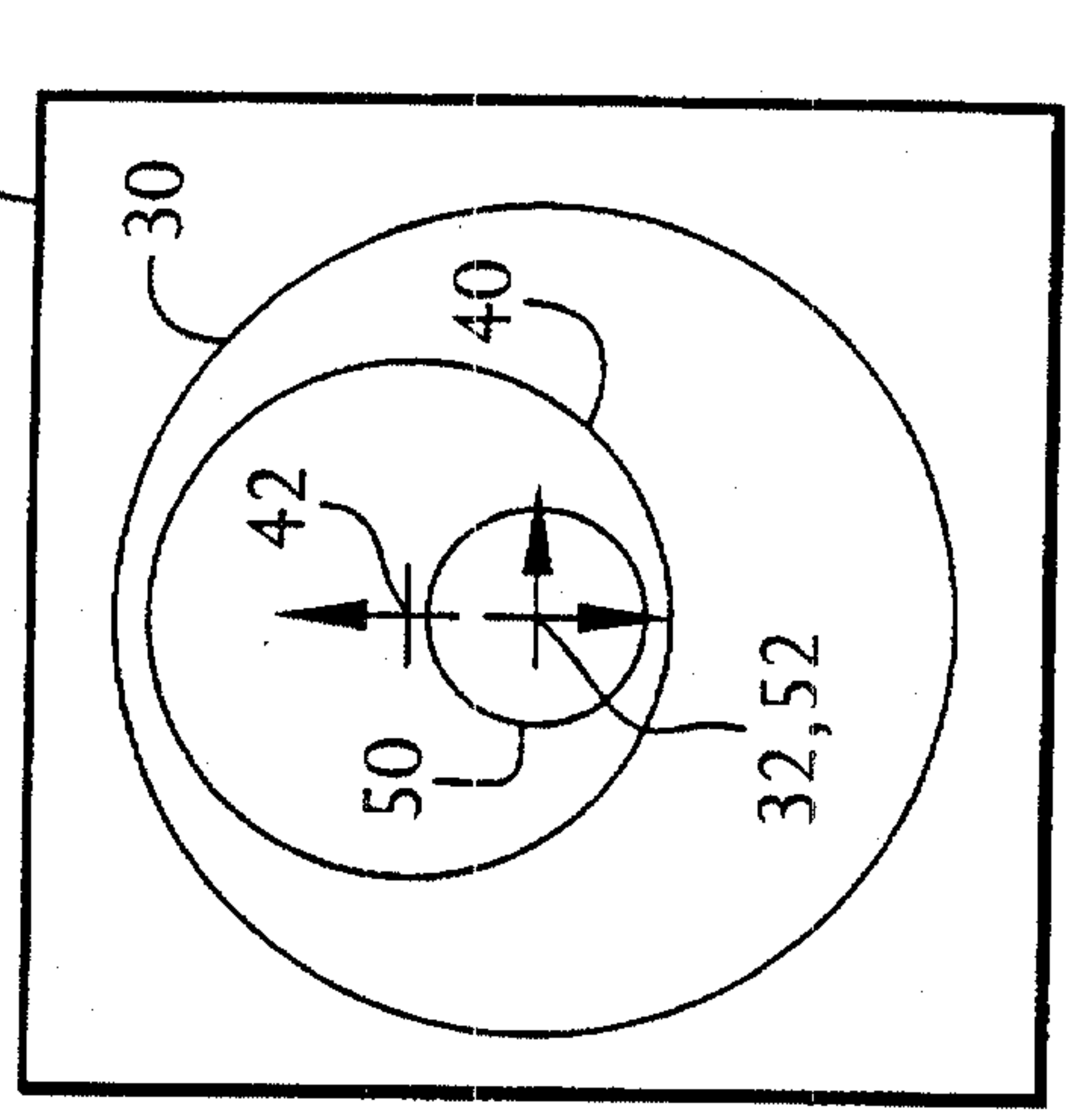


FIG. 4(c)

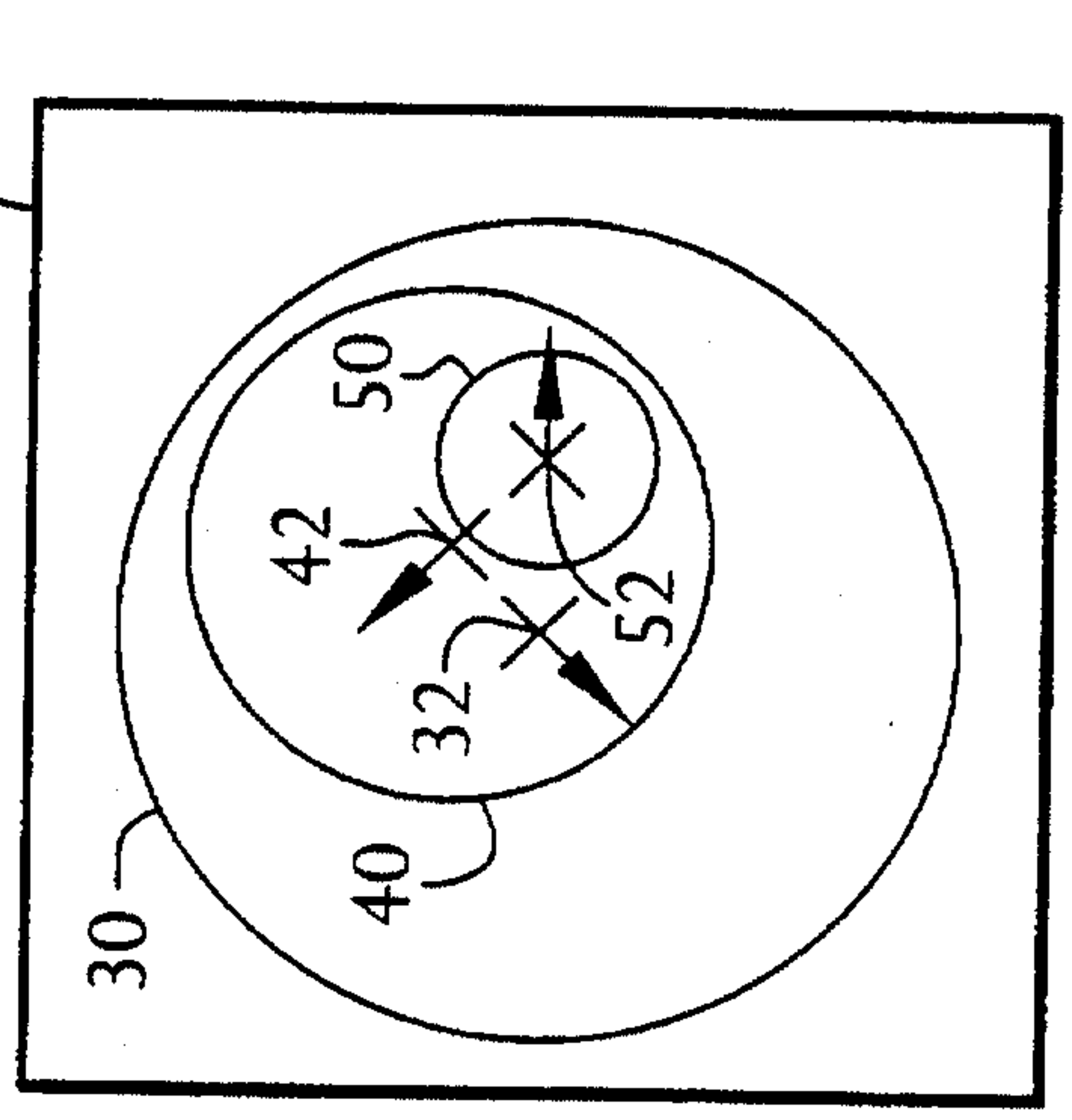


FIG. 4(d)

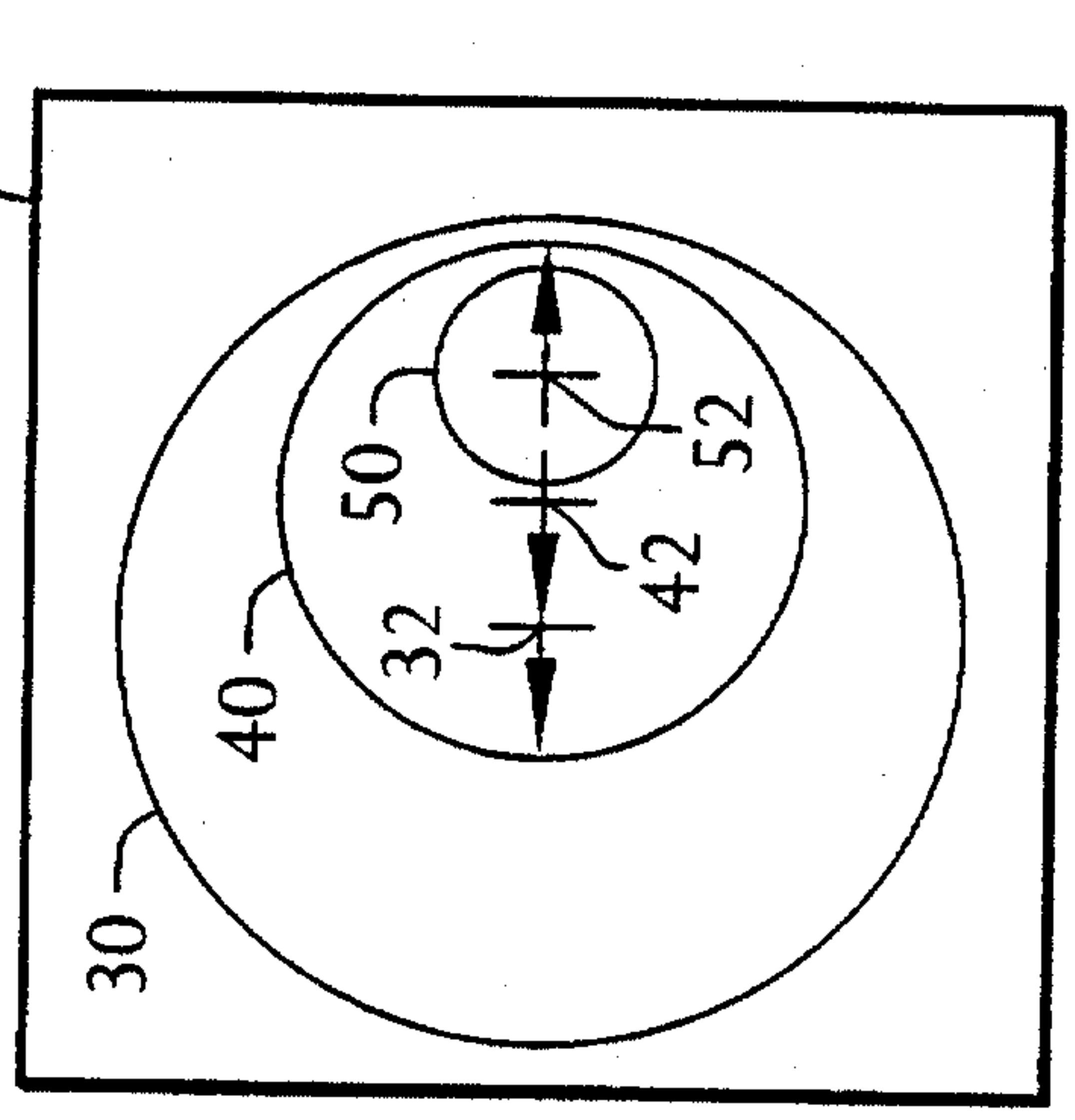


FIG. 4(e)

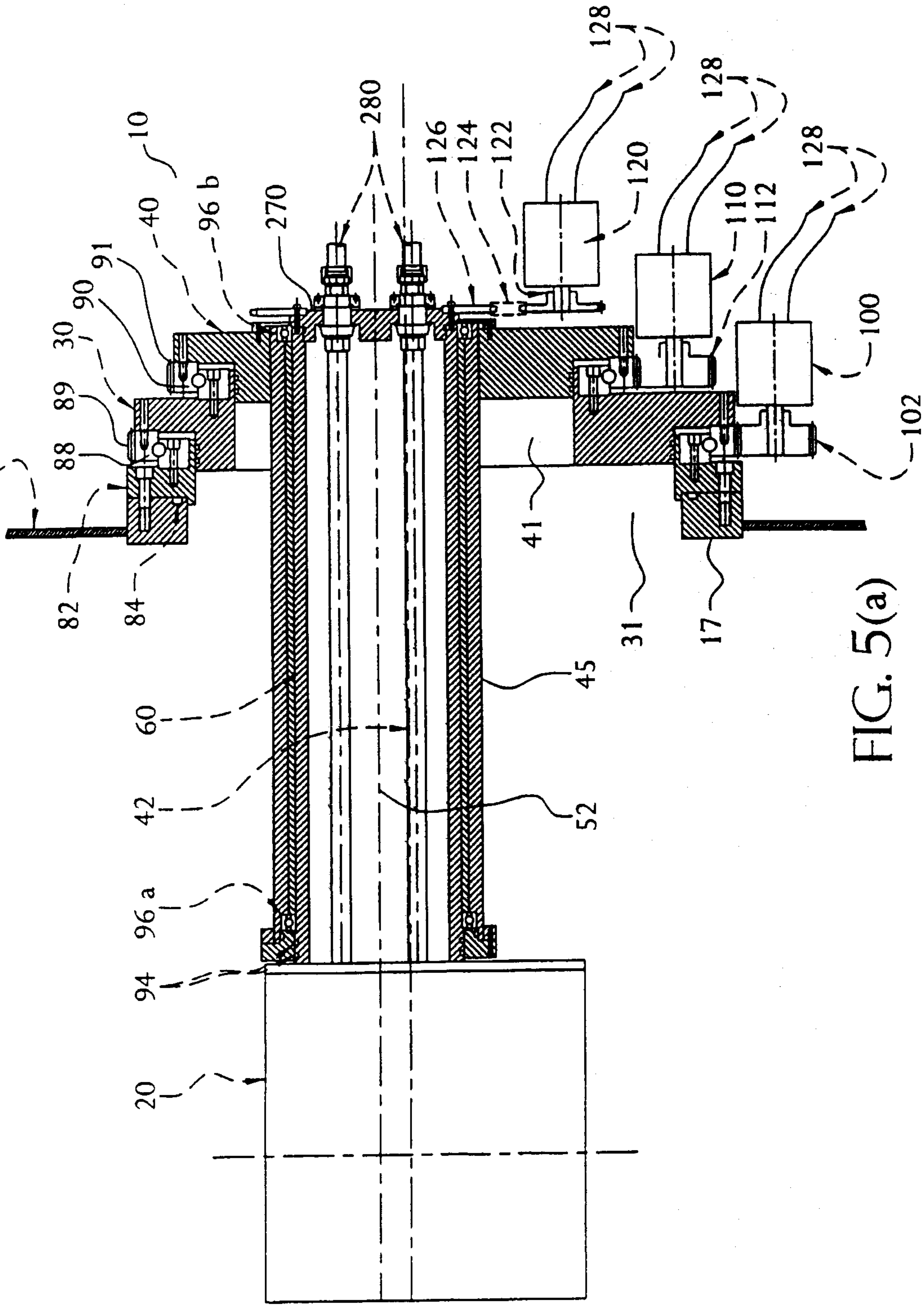

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FIG. 5(a)

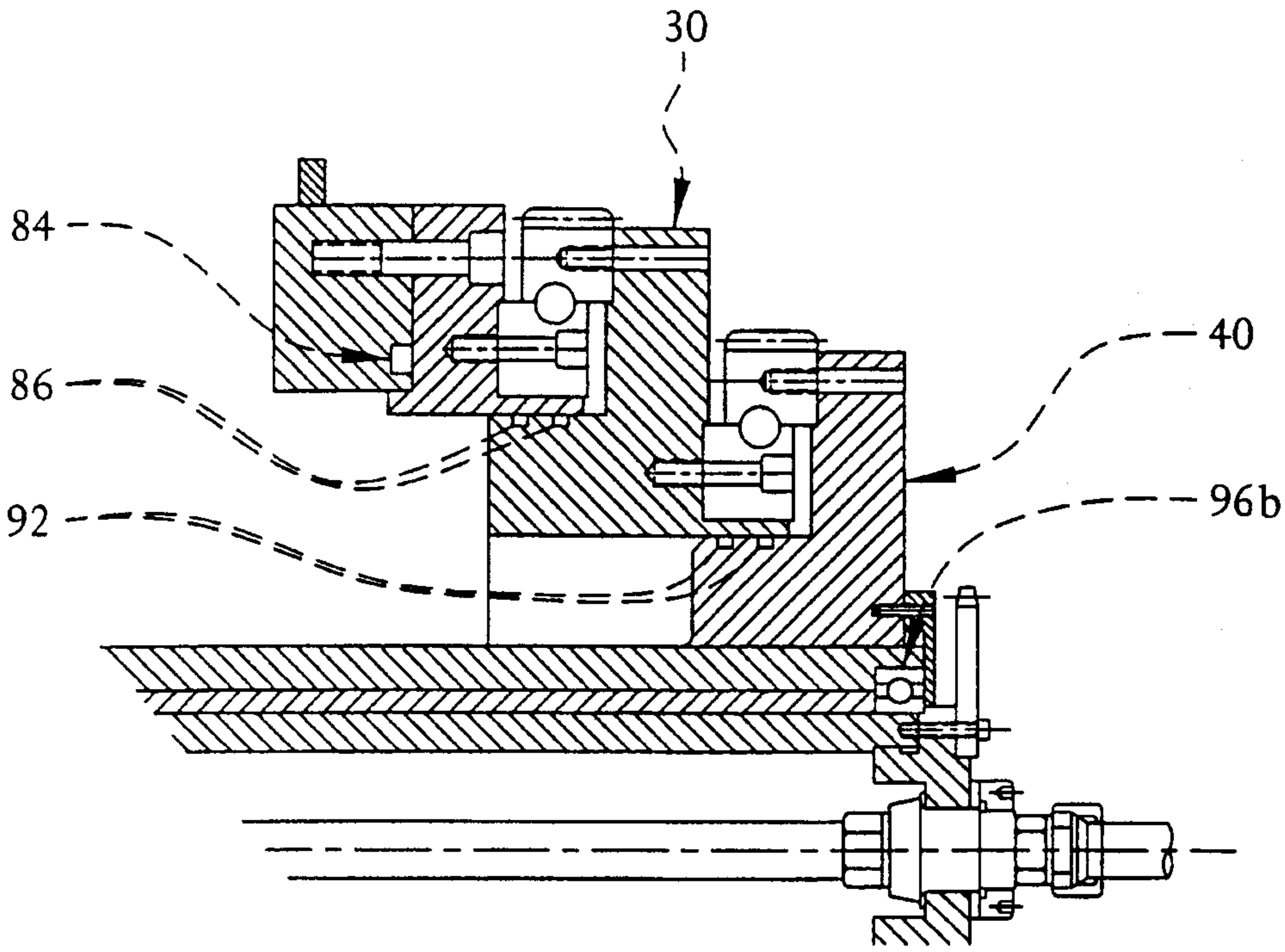


FIG. 5(b)

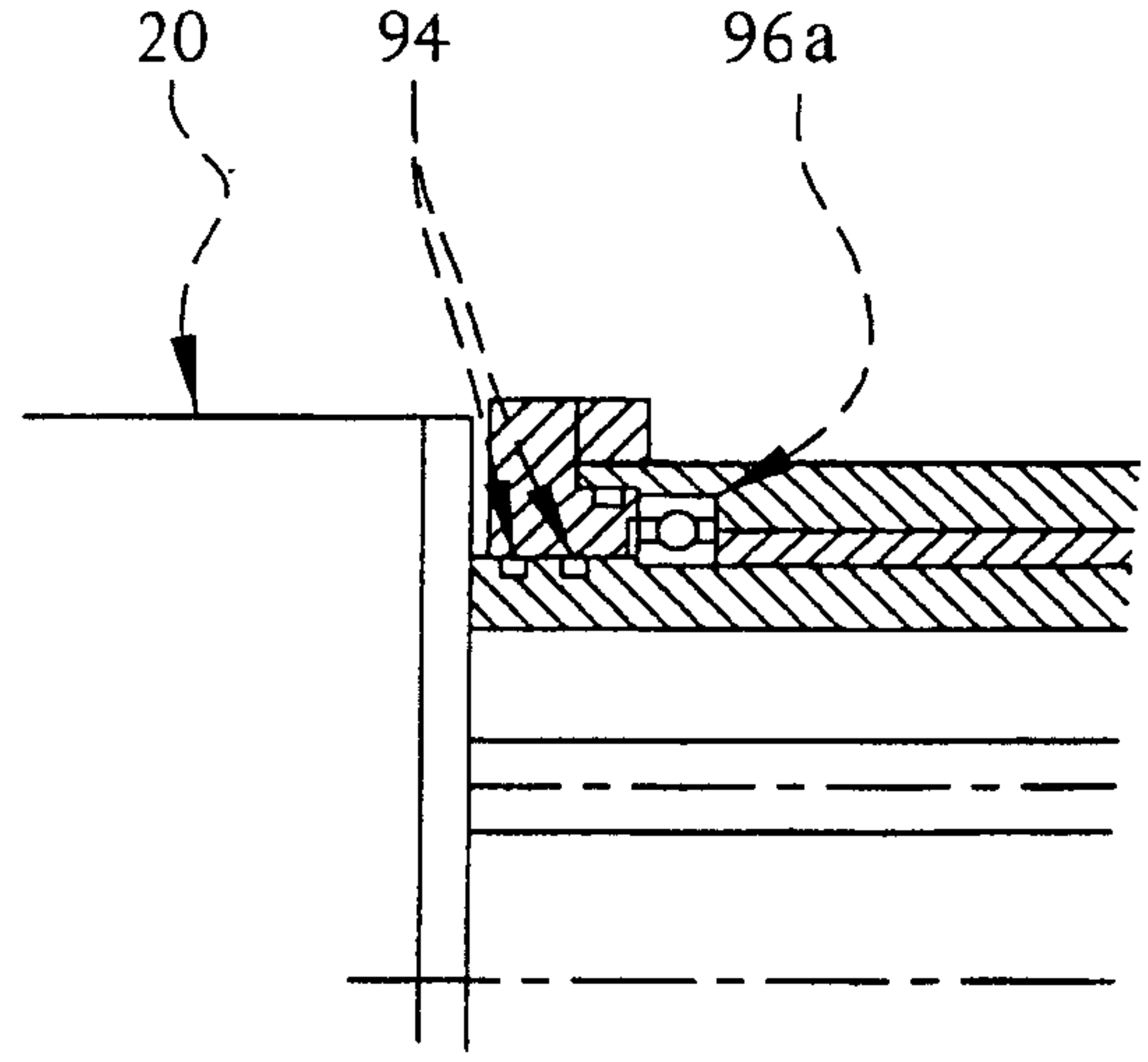
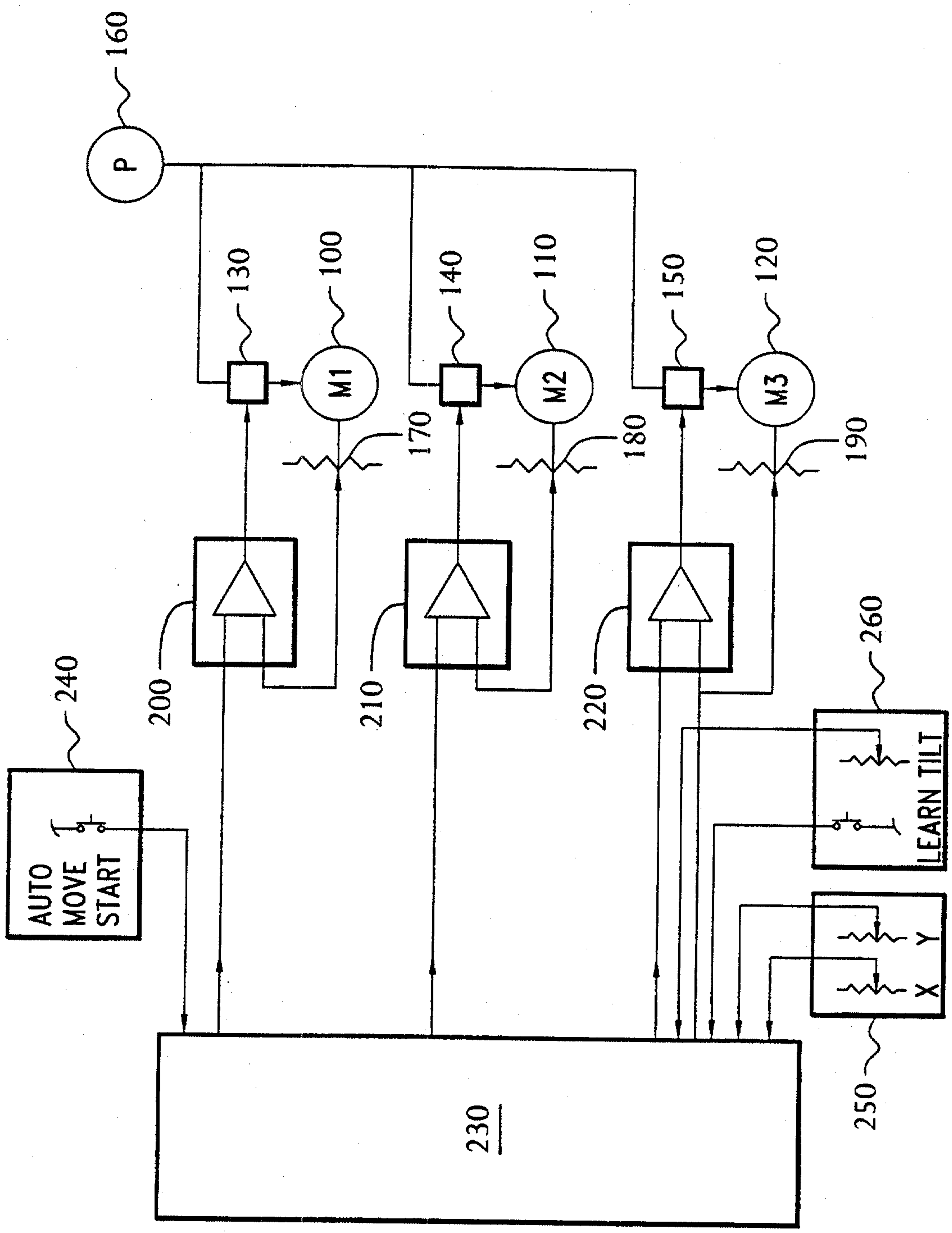


FIG. 5(c)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M2
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M3
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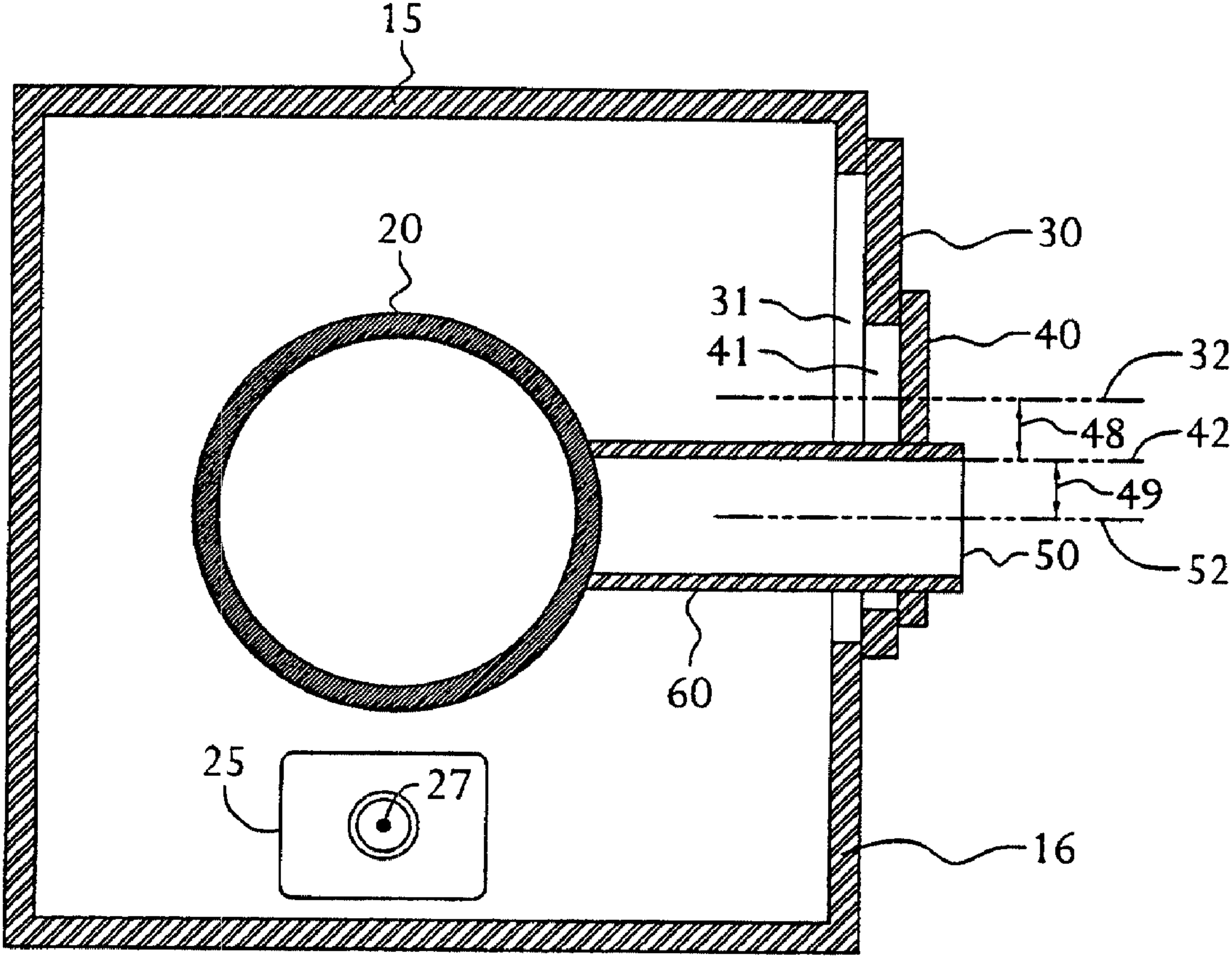
FIG. 6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