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(54) Title: SYSTEMS AND METHODS FOR PROCESSING WORKPIECES

(57) Abstract: Workpieces requiring low levels of contamination, such as semiconductor wafers, are loaded into a rotor or a fixed support within a process chamber. The process chamber has a horizontal drain opening in its cylindrical wall. The chamber is closed via a door. A process or rinsing liquid is introduced into the chamber. The liquid rises to a level so that the workpieces are immersed in the liquid. The chamber slowly pivots or rotates to move the drain opening down to the level of the liquid. The liquid drains out through the drain opening. The drain opening is kept near the surface of the liquid to drain off liquid at a uniform rate. An organic solvent vapor is introduced above the liquid to help prevent droplets of liquid from remaining on the workpieces as the liquid drains off. The rotor spins the workpieces to help to remove any remaining droplets by centrifugal force. Multiple process steps are performed within the single process chamber.

DESCRIPTION

Systems And Methods For Processing Workpieces

Field Of Invention

The invention relates to surface preparation, processing and cleaning of workpieces, such as semiconductor wafers, flat panel displays, rigid disk or optical media, thin film heads, or other workpieces formed from a substrate on which microelectronic circuits, data storage elements or layers, or micro-mechanical elements may be formed. These and similar articles are collectively referred to here as a "workpiece".

Background Of The Invention

Surface preparation, such as cleaning, etching, and stripping, is an essential and important element of the manufacturing process for semiconductor wafers and similar workpieces. Surface preparation steps are commonly performed, using liquid corrosive, caustic, or solvent chemicals, or using vapor phase chemicals. Surface preparation of workpieces is performed to prepare or condition the surface for a subsequent process step.

Cleaning is a critical step in manufacturing semiconductors and similar products. Cleaning involves the use of chemical formulations to remove contaminants, such as oxides, particles, metals, or organic material, while maintaining the cleanliness and integrity of the surface of the workpiece. Some liquid, gas or vapor phase chemicals when applied to a workpiece, result in surface characteristics that are more susceptible to contamination than others. For example, application of hydrofluoric acid (HF) to the surface of a workpiece will remove oxide from the silicon surface, resulting in a surface that is active. Workpieces in general, and especially workpieces having an active surface, are constantly susceptible to contamination by airborne microscopic particles. Contamination can also occur in the cleaning process, when the liquid process media is removed from the surface of the workpiece.

Thus, to minimize contamination of the workpiece, it is advantageous to perform a sequence of surface preparation steps within a controlled environment, that preferably occupies a relatively small amount of fabrication facility space, and in which exposure to contamination sources is minimized. Accordingly, it is an object of the invention to provide improved surface processing methods and apparatus.

Cleaning workpieces while avoiding or minimizing contamination has long been an engineering challenge. Workpieces are often cleaned with a spray or bath of de-ionized water. The water is then removed, often in the presence of an organic solvent vapor, such as isopropyl alcohol, which lowers the surface tension of the water. This helps to prevent droplets of water from remaining on and contaminating the workpiece.

Various cleaning methods and systems and various rinsing and drying methods and apparatus have been proposed and used. In a typical system, wafers are immersed in a vessel. A mechanism is provided to hold the wafers. Another mechanism is provided to lift the wafers out of the liquid, by pushing them up from below. While this technique has been used, it can result in trapping of liquid in or around the spaces where the wafers contact the holding mechanism, resulting in increased contamination. It is also complicated by the need for the lifting mechanism. In an alternative system, the wafers are held in a fixed position while the liquid is drained away from below. This technique has less tendency for trapping liquid. However, as the liquid level drops, the solvent vapor above the liquid is absorbed by the liquid. Consequently, the top sections of the wafer are exposed to liquid which is different from the liquid at the bottom sections of the wafers. This potentially results in non-uniform processing. Accordingly, while these and other techniques have been used with varying degrees of success, there is still a great need for improved systems and methods for cleaning workpieces.

It is therefore also an object of the invention to provide an improved system and method for cleaning workpieces.

Brief Statement Of The Invention

In a first aspect, surface preparation processes on workpieces are performed within a single chamber. The workpieces are contacted by process fluids by spraying or immersion. The workpieces may be processed and/or rinsed and dried within the single chamber. This minimizes exposure of the workpiece to contaminants and provides an improved application of process fluids or media to the workpiece.

In a second aspect, workpieces are held in a rotor or within a fixed support in the process chamber. The process chamber around the rotor can pivot to move a drain outlet in the process chamber down to the level of the liquid contained in the chamber. The liquid then drains out of the chamber through the outlet. Rotating the workpieces within the process chamber via the rotor, if used, can allow process fluids to be more uniformly distributed over the work pieces, and also allows for removal of fluids via centrifugal force.

In a third aspect, openings or spray nozzles on or in the process chamber or on the fixed support, supply a fluid onto the workpieces. This allows for versatile processing.

In a fourth aspect, sonic energy, such as ultrasonic or megasonic energy, is applied to the workpiece, preferably through liquid in which the workpiece is immersed.

In a fifth aspect, a door frame is handed off from a door assembly when engaged onto the process chamber, to allow the door frame to pivot or rotate with the process chamber.

In a sixth aspect, the process chamber has a continuous cylindrical side wall including a drain opening or outlet. Liquid within the process chamber drains out through the drain opening, as the chamber is pivoted to bring the drain opening down to the level of the liquid in the chamber. The process chamber encloses the work pieces on all sides, to better control the process environment.

In a seventh aspect, unique methods for cleaning a workpiece is provided. These methods solve the problems of the known methods now used in the semiconductor manufacturing industry. Workpieces are held in a rotor or in a fixed support within a process chamber having a drain outlet. The workpieces are immersed in liquid within the process chamber, with the liquid preferably provided via one or more inlets at the bottom of the chamber. Liquid is preferably continuously supplied into the chamber so that liquid is continuously overflowing and running out of the drain outlet. The process chamber is pivoted to move the drain outlet down in a controlled movement, to lower the level of liquid in the chamber. Liquid supply to the chamber and overflow at the liquid surface preferably continues as the chamber pivots and the liquid level drops. This process continues until the liquid level drops below the workpieces and the chamber is pivoted to drain virtually all liquid out of the chamber.

By maintaining the overflow at the liquid surface, and by maintaining a constant flow towards and out of the drain outlet, impurities at the liquid surface flow away from the workpieces, reducing potential for contamination. The liquid in the chamber remains uniform at all depths, as the surface of the liquid which the solvent vapor dissolves into, is constantly being replaced with fresh liquid. After the liquid is removed from the chamber, the workpieces are advantageously rotated. Liquid droplets remaining on the workpieces or adjacent components of the apparatus are centrifugally removed, in the rotor embodiment. Consequently, cleaning is provided with a uniform liquid bath and with reduced potential for trapped or residual liquid remaining on the workpieces. The disadvantages associated with the machines and methods currently in use, as described above, are overcome.

In an eighth aspect, an inner chamber has a drain opening to allow process fluid to be removed from the inner process chamber. A drive motor pivots the inner process chamber at a controlled rate to bring and then maintain the opening at or below the level of the fluid in the inner chamber. The fluid then drains out from the drain opening. The drive motor may move the inner process chamber by magnetic forces, without an actual physical penetration of or connection into the process environment by a drive shaft. Optionally, the inner process chamber may be connected to the drive motor with a drive shaft, with a shaft seal sealing the shaft opening into the inner process chamber.

In a ninth aspect, the inner process chamber forms a closed chamber, without any drain opening. The workpieces remain stationary, during at least one process step, and a drive motor spins the inner process chamber around the stationary workpieces. Openings or spray nozzles on or in the inner process chamber supply a fluid onto the workpieces. To remove liquid from the chamber, the chamber is turned to or braked to a stop at a position where one or more drain ports are at a bottom position. The drain ports are then opened and the liquid drains out through them via gravity. A gas may be provided into the inner process chamber during draining, to prevent creation of a vacuum slowing or stopping the out flow of liquid. Liquid may alternatively be removed by opening the drain ports and then positioning and maintaining the drain ports at or below the liquid surface by slowly pivoting the inner process chamber, as in the third aspect described above. This allows for controlled removal of liquid, resulting is less potential for contamination of the workpieces.

In a tenth aspect, the inner chamber is closed or sealed and remains stationary and the workpieces spin within the inner chamber. This minimizes exposure of the workpiece to contaminants and provides an improved application of process fluids to the workpiece.

In an eleventh aspect, the outer containment chamber is purged with a gas and/or vapor to maintain a desired environment around the workpiece. The gas or vapor may be nitrogen, or argon, or hydrofluoric acid (HF).

The aspects of the invention described above provide greatly improved processing and cleaning apparatus and methods. These aspects help to provide more reliable and efficient processing.

Further embodiments and modifications, variations and enhancements of the invention will become apparent. The invention resides as well in subcombinations of the features shown and described. Features shown in one embodiment may also be used in other embodiments as well.

Brief Description Of The Drawings

In the drawings, wherein the same reference number indicates the same element, throughout the several views:

Figure 1 is a perspective view of a system for processing workpieces.

Figure 2 is a front view of the system shown in Figure 1.

Figure 3 is a side view of the system shown in Figure 1.

Figure 4 is a side view of the process station shown in Figure 2.

Figure 5 is a front view of the process station shown in Figure 3.

Figure 6 is a section view of a processor unit having a rotor which spins within the process chamber.

Figure 7 is a cut away perspective view of the process chamber shown in Figure 6.

Figure 8 is a partial section view taken along line 8-8 of Figure 6.

Figure 9 is a perspective framework view of the process chamber shown in Figures 6 and 7.

Figure 10 is an enlarged section view of the drain slot in the cylindrical side wall of the process chamber shown in Figures 7 and 9.

Figure 11 is an enlarged partial section view of the back end of the processor unit shown in Figure 6.

Figure 12 is a front view of the door assembly shown in Figure 6.

Figure 13 is a partial section view of features of the door assembly shown in Figure 12.

Figure 14 is a top section view showing the door assembly of Figures 12 and 13 engaged with the process chamber.

Figure 15 is a section view taken along line 15-15 of Figure 12.

Figure 16 is a perspective view of a rotor for holding workpieces directly.

Figure 17 is a perspective view of an alternative rotor for holding workpieces held within a tray, carrier, or cassette.

Figure 18 is a perspective view of an alternative rotor and carrier.

Figure 19 is a perspective view of a carrier for holding workpieces directly, with the workpieces loaded and unloaded through a side wall, and with the carrier held in a rotor such as the rotor shown in Fig. 18.

Fig. 20 is a perspective view of a surface processing apparatus for use in the system shown in Fig. 1, and having an inner process chamber moved to a position to contain fluid for full or partial workpiece immersion processing. The fluid is omitted from this view to more clearly show the components of the apparatus.

Fig. 21 is a perspective cross-sectional view of the surface processing apparatus shown in Fig. 20.

Fig. 22 is a perspective view of the apparatus of Fig. 20, with the inner chamber now moved to a position to drain out fluid, and also showing a removable cover plate for use with the apparatus of Figs. 1-3.

Fig. 23 is a perspective view of the apparatus of Figs. 20-22, with the inner process chamber door and the outer containment chamber door installed and closed.

Figure 24 is a side view of an alternative processor, similar to Fig. 4, but showing a fixed wafer support in place of the rotor.

Figure 25 is a front view of the processor or process station shown in Figure 24.

Figure 26 is a perspective view, in part section, of a processor shown in Figures 24 and 25.

Figure 27 is a partial section view of the processor unit shown in Figure 26.

Figure 28 is a section view of the workpiece support shown in Figures 26 and 27.

Figure 29 is a section view of the process chamber shown in Figures 26 and 27.

Figure 30 is a section view of the chamber or bowl shown in Figures 26 and 27.

Figure 31 is a back end view thereof.

Figure 32 is an enlarged section view of the door assembly shown in Figure 27.

Figure 33 is a front view of the door assembly shown in Figure 32.

Figure 34 is a side view thereof.

Figure 35 is a section view of an alternative embodiment for processing workpieces supported within a carrier, cassette or tray.

Figure 36 is a perspective view, in part section, of the processor unit shown in Figures 26 or 35, with the inner process or sub-chamber in an upright or 0° position, and with various components removed for purposes of illustration.

Figure 37 is a perspective view of the processor unit shown in Figure 36, with the process chamber now pivoted about 30°, to remove liquid.

Figure 38 is a perspective view thereof with the process chamber rotated about 60°.

Figure 39 is a perspective view thereof with the process chamber rotated about 100°, to allow all liquid to flow out.

Figure 40 is a front section view of the processor unit shown in Figure 36.

Figure 41 is another section view thereof, with the process chamber shown in the 0° position in solid lines, and with the process chamber shown in the fully rotated position of Figure 39, in dotted lines.

Detailed Description

A workpiece rotor holds workpieces, either directly, or by holding a carrier containing workpieces. A process chamber is provided around the rotor and is adapted, when closed, to hold a liquid. Liquid is provided into the process chamber, so that the workpieces are at least partially immersed. The process chamber pivots or rotates, causing a drain opening to move down to the level of the liquid. This allows liquid to move out of the process chamber. The process chamber continues to rotate until most or all liquid is removed from the chamber. Other steps and features described below may be advantageous, but are not necessarily essential to the invention.

As shown in Figures 1, 2 and 3, a workpiece processing system 10 preferably has an enclosure 12 to maintain and control clean air flow and reduce contamination of workpieces. An input/output station 14 at the front of the system 10 allows workpieces 60 to be loaded and unloaded from the system 10. An indexer 16, or other temporary workpiece storage is provided adjacent to the input/output station 14.

The system 10 is preferably divided into an interface section 24 and a process section 26. These sections may be separated by a partition having a door opening. The interface section 24 includes the input/output station 14 and the indexer 16 or other temporary workpiece storage. The process section 26 includes one or more process stations 30, with each process station 30 including a processor unit 50. The process station is separately shown in Figures 3B and 3C. The interface section 24 also includes a process robot 22 for moving workpieces to and from the indexer 16 and processor unit 50. A control panel 28 may be provided on the enclosure 12, to allow instructions or programming to be input into a computer controller 32 which controls the system 10.

The workpieces 60 may be provided in open carriers, cassettes, boats or trays. Alternatively, the workpieces 60 may be provided within sealed pods or containers which are unsealed at a docking station.

A processor unit 50 is shown in Figures 4 and 5. The processor unit 50 may be used in the automated system 10 shown in Figures 1-3, or in other automated systems, or as a stand alone unit.

Referring to Figure 6, in an alternative processor unit 300, a rotor 304, or a rotatable workpiece support, is positioned within a process chamber 302. A pivot motor or actuator 306 is linked to the process chamber 302. The pivot motor 306 pivots the process chamber from a first position where the chamber can hold a liquid, to a second position where most or all liquid in the chamber runs out via gravity. The first position may be a 0° or upright position. The second position is generally from 60° up to about 180°, and typically about a 100°, 110° or 120° position from the first position. A spin motor 308 is connected to the rotor 304, to spin the rotor 304 within the process chamber 302. A door assembly 310 is disengaged from the process chamber 302, for loading and unloading workpieces. The door assembly 310 has a door frame engageable to the process chamber 302, to close off or seal off, the open front end of the process chamber 302, during processing. An overflow trough 312 is optionally positioned below the open front end of the process chamber 302, to collect any liquid released outside of the process chamber 302.

As certain process fluids are corrosive, the rotor 304 and process chamber 302 may be made of a corrosion-resistant material, such as Teflon (fluorine-containing resins). Where Teflon is used, the rotor and process chamber may have relatively thick walls and sections to provide adequate strength. In addition, a metal chamber support 360 may be provided around the outside of the process chamber 302, as shown in Figure 6, in a position where it is not exposed to process fluids. The support 360 strengthens the process chamber 302.

Turning to Figure 7, the process chamber 302 has a continuous preferably cylindrical side wall 320 joined to a rear wall 324. Consequently, when the open front end

332 of the process chamber 302 is closed off by a door frame, as described below, the process chamber 302 surrounds and encloses workpieces on all sides, during processing.

Referring to Figures 7-10, a drain opening or slot 326 is provided in the cylindrical side wall 320 of the process chamber 302. The drain opening 326 is preferably horizontal and connects to a drain port 330 at the back end of the process chamber 302. Notches 328 are advantageously formed along the inside edge of the drain slot 326. A flexible drain line 338 runs from the drain port 330 to a system or facility drain or collection point, as shown in Figure 9.

Referring to Figures 8 and 9, one or more lower manifolds 340 are provided near the bottom of the chamber 302. The bottom is the sector generally opposite (e.g., +/- 45°) from the drain opening 326. An array of upper manifolds 342 are provided near the top of the chamber 302, and on the side of the chamber opposite from the drain slot 326. The manifolds 340 and 342 are supplied with liquid, vapor, or gas, by flexible supply lines 346 and 348 extending from the manifolds to supply sources. The manifolds have openings or nozzles 354, to apply or spray gas, vapor or liquid inwardly towards workpieces within the chamber 302. Depending on the processes to be performed, additional supply lines may be used. In addition, some of the manifolds 342 may provide a first fluid, such as water and process chemicals, whereas other manifolds 342 may provide another different fluid, such as nitrogen gas and or IPA vapor. The supply lines have sufficient slack or uptake loops, to allow the chamber 302 to pivot while maintaining fluid connection to the manifolds.

Turning to Figure 11, a rotor shaft 350 extends from the spin motor 308 to the rotor 304. The rotor shaft 350 passes through a shaft opening 322 in the rear wall 324 of the chamber 302. Seals 362 and 364 are provided around the shaft opening 322, to prevent fluid leakage through the shaft opening 322. The rotor 304 is supported on the rotor shaft 350. A chamber collar 352 on the pivot motor 306 is joined to the rear wall 324 of the process chamber 302. The process chamber 302 is supported on, and pivots with, the chamber collar 352, driven by the pivot motor 306.

Turning to Figure 12, the door assembly 310 moves vertically on door rails 370 from the up position, shown in solid lines, to the down position, shown in dotted lines. A door bridge 372 extending between the rails 371 supports the door assembly 310. Turning to Figure 13, the door assembly 310 includes a round plate-like closure frame 374 including an annular door pad 375 attached to an annular door ring 382. A window 376 is secured between the pad 375 and the ring 382. With the door assembly 310 in the closed position, as shown in Figure 27, the door pad 375 is clamped against the front flange plate 334 of the process chamber 302. A seal 336 in the flange plate 334 seals against the door pad 375.

Referring to Figures 12-15, swing actuators 378 are radially spaced apart around the circumference of the flange plate 334. A cam lever 380 on the swing actuator 378 is turned inwardly by the actuator 378 to clamp the door ring 382 and pad 375 against the flange plate 334 of the process chamber 302. The swing actuators 378 are mounted on the chamber support 360, which moves with the chamber 302.

Referring to Figure 13, hand-off actuators 384 supported on the door bridge 372 have pickups 386. The actuators 384 move the pickups 386 to engage and hold the closure frame 374 during loading and unloading of workpieces into the process chamber 302. The pickups 386 are released and separated from the closure frame 374 during processing. Accordingly, the closure frame 374 can freely move with the process chamber 302, during processing. As shown in Figures 14 and 15, the door bridge 372 is connected to lift actuators 371, which move the door frame vertically between the up and down positions shown in Figure 12.

The rotor 304 may have various forms. The rotor 304 may be any device which holds workpieces, and spins within the process chamber 302. Figures 16-19 show examples of rotors which may be used. Referring to Figure 16, a rotor 400 has combs 402 for holding workpieces 60 directly. Retainers 404 are moved into engagement against the edges of the workpieces, to hold them in place within the rotor 400 by the process robot.

As shown in Figure 17, an alternative rotor 410 is adapted to hold workpieces contained in trays, cassettes, or carriers. The trays 416, or cassettes or carriers 418 slide into a slot 412 and are held in place within the rotor, for example, by lips 414.

As shown in Figure 18, an alternative rotor 420 has steps 422 formed on ribs 424. The steps 422 are dimensioned to receive or mate with corresponding lugs 432 on a carrier 426. Figure 19 shows another carrier 440 which may be used with the rotor 420, with or without the lugs 432. The carrier 440 has slots 442 for receiving and holding workpieces 60. The workpieces 60 are loaded into the carrier 440 from an opening 444 in the side of the carrier.

The process chamber 302 described above may also be used with a fixed carrier support, in place of a rotor 304. In this design, the spin motor 308 and drive shaft 350 can be omitted, with the workpiece support supported on a central arm extending through the shaft opening 322 in the process chamber 302 and joined or supported by the chassis 134.

In use, the processor unit 300 operates as follows. Workpieces 60 are loaded into the rotor 304. This may be achieved manually, or via the process robot 22. The workpieces may be loaded directly into combs or slots in the rotor 304. Alternatively, the workpieces may be held in a tray, cassette or carrier, which in turn is loaded into the rotor 304.

Typically, several carriers, cassettes or trays of workpieces 60 will be loaded in, so that several, or all, of the available storage positions in the indexer 16 are occupied. The indexer 16 may have shuttle positions and movements, as shown in Figures 1 and 3. Alternatively, fixed or moving transfer carriages may be used. The workpieces 60 may alternatively be provided into the system 10 within sealed containers or pods. If the workpieces 60 are provided within sealed pods, the pods may be handled, unsealed, and accessed as described in the patent applications referenced above.

The workpieces 60 are picked up by the process robot 22, and moved from the interface section 24 to the process section 26. Process parameters and workpiece movement may be controlled by the computer/controller 32, or by the control panel 28, or by another remote or facility computer/controller.

During loading, the door bridge 372 is in the down position shown in dotted lines in Figure 12. Consequently, the front end 332 of the process chamber 302 is open. The process chamber 302 is preferably in the upright or 0° position, as shown in Figure 7, with the drain slot 326 at or near the top. The axis of rotation R of the rotor 304 is preferably horizontal. The pivot axis P of the process chamber 302, as shown in Figure 6, is also preferably horizontal and may coincide with the axis R. The workpieces are preferably in a vertical or near vertical orientation.

The door bridge 372 is raised to the up position shown in solid lines in Figure 12 by the door lifters 371. With the closure frame 374 aligned with the open front end 332 of the process chamber 302, the hand-off actuators 384 extend to move the closure frame 374 against the flange plate 334, as shown in Figure 13. The swing actuators 378 then move the cam levers 380 inwardly. The cam levers 380 engage the door ring 382 of the closure frame 374, clamping the closure frame 374 against the flange plate 334. The hand-off actuators 384 then release the pickups 386 from the door ring 382 and retract. The closure frame 374 is now closing off, or sealing, the open front end 332 of the process chamber

302. In addition, the closure frame 374 is released or free from the rest of the door assembly 310, so that it can move with the process chamber 302, as the process chamber pivots.

Referring to Figure 9, process liquids, gases, or vapors (collectively referred to as fluids) are sprayed or otherwise introduced into the process chamber via the supply lines 346 and 348. Referring momentarily to Figures 16-19, the rotor 304 advantageously has an open frame structure. This allows fluids from the manifolds 340 and 342 to be sprayed or otherwise applied through the rotor 304 and onto the workpieces 60. Depending on the specific process to be performed on the workpieces, the fluids used may include corrosives or caustics, solvents, vapor phase chemicals, acids, such as hydrofluoric acid, ozone, water, ozonated water and mixtures of them. As multiple fluids may be provided to different manifolds through multiple supply lines, various sequential processing steps may be carried out within the process chamber 302, without removing the workpieces from the chamber. As the chamber 302 encloses the workpieces, potential for external contamination of the workpieces is reduced. For sequential processing steps, different fluids may be applied to the workpieces by immersion, spraying, or other application. Cleaning may be performed in between the processing steps.

For immersion or rinsing steps, liquid is introduced into the process chamber 302, until the level of liquid rises high enough so that the workpieces are immersed. The workpieces may dwell in the bath of liquid for a predetermined amount of time. To remove the rinsing or immersion liquid, the pivot motor 306 is actuated, optionally via the controller/computer 32. As the chamber 302 pivots, the drain slot or opening 326 moves down to the level of the liquid. Liquid runs into the drain slot 326, via gravity, and out through the drain port 330 and drain line 338. The pivot motor 306 continues to pivot the process chamber 302 until the drain slot 326 moves from position A to position B in Figure 8. This allows all liquid within the process chamber 302 to be drained out through the drain slot and drain port 330, via gravity. As the process chamber 302 pivots, the supply lines 346 and 348 (and others if provided) move with the process chamber 302 via take-up loops provided for this purpose. In addition, the closure frame 374 closing or sealing off the front end 332 of the chamber 302 moves with the chamber. For more rapid liquid removal, or to remove liquid without changing the positions of the manifolds 340 and 342, a bottom switched drain 325 may also be provided in the cylindrical side wall 320 of the process chamber 302.

Preferably, the chamber is turned or pivoted so that the liquid drains out at a rate of about 0.1-30 or 0.1-10 or 0.1-5 or 0.1-2 mm/second, 0.5-10 or 0.5-5 or 0.5-1 or 2 mm/second. The drain or drop rate is selected to be as fast as practical, without having the meniscus separate from the workpiece surface.

For cleaning procedures, water is introduced into the process chamber 302 from the lower manifold 340 and/or the upper manifolds 342. The water may be sprayed onto the workpieces. Alternatively, the water may flow in through outlets without spraying. As the water level within the process chamber 302 rises, the workpieces are immersed and rinsed. Many of the manifolds 342 may be submerged in the liquid as the liquid level rises. Depending on the process, flow or spray from these manifolds may be turned off, or they may continue to deliver a liquid, gas or vapor into the bath of liquid in the chamber 302.

The workpieces are immersed in the cleaning liquid. Preferably, a continuously refreshed bath of liquid is provided into the chamber 302. The liquid is sprayed or pumped in via the lower manifold 340 or another inlet. The liquid preferably continuously drains out through the drain opening 326 through the entire liquid removal sequence, until the workpieces are no longer contacted by the bath of liquid. Sonic energy may be applied to the work pieces 60 via a transducer 333 on the chamber or the rotor. The transducer 333, such as a megasonic or ultrasonic transducer, is positioned to transmit sonic energy through liquid in the chamber 302, to the work pieces immersed in the liquid.

The process chamber 302 is pivoted (counterclockwise in Figures 7 and 8) to allow the rinse liquid to drain out through the drain slot 326, as described above. Before the level of the rinse liquid or water begins to drop, organic solvent vapor, such as IPA vapor, is introduced into the process chamber 302, above the liquid level, through one or more of the manifolds 342. The organic solvent vapor reduces the surface tension of the water at the workpiece surface/water interface. This reduces or prevents water droplets from remaining on the workpiece surfaces, as the water level drops, resulting in less contamination. This vapor assists in removing liquid from the workpiece. A gas such as nitrogen or air, may also be introduced into the process chamber 302, via one or more manifolds 342, or with the vapor. The gas may be heated. Additional solvent vapor and gas (if used) is provided as the process chamber 302 continues to pivot and the liquid level continues to drop. The vapor may be entrained in the gas. After the liquid drops entirely below the level of the workpieces, the vapor supply is shut off. Gas supply preferably continues to purge any remaining vapor from the chamber 302.

After most or all of the liquid has been drained out by pivoting the chamber, the spin motor 308, preferably under the control of the controller/computer 32, turns on, causing the rotor 304 to spin. The spinning movement of the workpieces within the rotor helps to remove any remaining droplets from the workpieces via centrifugal force. Gas may be sprayed onto the workpieces while they are spinning, helping to remove any remaining liquid from the workpieces. The process chamber pivots back to its original upright position, before or after spinning the workpieces.

After processing of the workpieces within the process chamber 302 is complete, the hand-off actuator 384 re-engages the closure frame 374 with the pickups 386. The swing actuators 378 move the cam levers outwardly and off of the door ring 382. The actuators 384 then pull the closure frame 374 away from the front end 332 of the process chamber 302. The door bridge 372 moves back to the down position. The workpieces are then removed from the process chamber 302. While described for use on batches of workpieces, the invention applies as well to single workpiece operations.

In an alternative design, the rotor shaft 350 is extended and may telescope axially outwardly via the motor 308 or another actuator, along the axis R to extend the rotor 304 out of the process chamber 302 to better facilitate loading and unloading.

Ordinarily, during immersion processing, when the process chamber 302 is largely filled with liquid, the rotor 304 will remain in position and not spin. However, for certain processes, the rotor 304 may spin at slow speed while the rotor 304 and workpieces 60 are immersed in liquid to agitate the liquid or improve the flow of liquid over the surfaces of the workpiece. The workpieces may alternatively be held at an inclined angle of e.g., 5-15 degrees from vertical in the rotor, to help avoid contact between workpieces during processing.

Turning now to the first alternative system, as shown in Fig. 20, a surface processing system 511 is provided for processing flat workpieces, such as semiconductor wafers 60. The apparatus or system 511 includes a process chamber 517, optionally within an outer containment chamber 519. The outer chamber 519 contains and disposes of process fluids, and isolates the process environment from the ambient environment, human operators, and adjacent parts and equipment. The process media or fluid may include cleaning liquid such as hydrofluoric acid (HF), a rinsing liquid such as water, a gas, as nitrogen or a mixture of a gas and an organic vapor, or any combination of them. Processing of the workpieces is performed in the process chamber 517.

Referring now to Fig 21, the chamber 517 has a shaft section 525 extending rearwardly through a back section 527 of the outer chamber 519. The shaft section 525 is linked to an inner chamber drive motor or actuator 529, either by a direct mechanical linkage, or via a magnetic linkage. The motor 529 can pivot the inner chamber 517 in a relatively slow continuous and controlled movement. The motor 529 can also spin the inner chamber 517. The motor 529 can also pivot the inner chamber 517 to a desired angular orientation or position, and hold the chamber 517 in that position. The inner chamber 517, as shown in Fig. 22, has a cylindrical sidewall having a drain opening, slot, or window 555 for removing liquid from the chamber. A drain edge 557 defines the lower end of the opening 555. The drain edge 557 is preferably horizontal, and runs substantially over the entire length of the inner chamber 517. A protrusion 559 may extend below the drain edge. Pivoting here means less than 360° movement. In contrast, rotating or spinning here means sustained 360° plus movement.

The inner chamber 517 preferably contains at least one outlet 531 such as a nozzle, for delivering process fluid 521 by spray or other technique to the workpieces 515. The nozzle or outlet 531 may be above or below, or to one side of the workpieces 60, so that the process fluid 521 can travel vertically up or down, or horizontally. At least one channel or pipeline 533 delivers process fluid 521 to the nozzle or outlet 531. One or more manifolds 535, each having an array of outlets or nozzles may be used. In an embodiment where the inner chamber 517 spins, the pipeline or base 533 is connected to a rotary fluid coupling 537 or similar device within or outside of the apparatus as shown in Fig. 21.

Referring now to Figs. 20 and 21, a rotor or workpiece support 539 for holding the workpieces 60 is positioned with the chamber 517. Preferably, the rotor 539 has grooves, typically equally spaced apart, for holding the workpieces 60. A rotor drive motor 541 is linked to a shaft section 543 of the rotor 539 extending through the shaft section 525 of the inner chamber 17. Alternatively, the rotor 539 may be linked to the motor 541 with a magnetic coupling.

The rotor 539 may alternatively have features for holding workpieces 60 within a carrier or cassette. In either case, the rotor 539 has retainers for holding the workpieces in place.

If used, the magnetic couplings connect the rotor 539 and rotor drive 541, and the chamber actuator 529 and the chamber 517, respectively, by magnetic force, without an actual physical connection or penetration of the chamber 517 by a drive shaft. Hence, the space within the chamber 540 may be better closed or sealed against contaminants.

Referring once again to Figs. 21 and 23, the chamber 517 has a door 547, for containment of the process liquid 550 within the chamber 517. The outer chamber 519 similarly has an outer door 549. With the door 549 closed, the outer chamber 519 isolates the workpieces 60 from contaminants in the environment outside of the outer chamber 519. The outer chamber 519 has one or more outlets 551 for removing fluids.

In use, the rotor 539 may be extended out of the inner chamber 517 through the open doors, by hand or with a robot. Workpieces 515 may then be loaded into the rotor 539. With the rotor loaded with one or more workpieces, the doors 547 and then 549 are closed, preferably, but not necessarily, providing fluid tight and/or gas tight seals. With the doors closed, the chamber 517, within the preferably closed or sealed outer chamber 519, provides an entirely closed off space or environment.

Various process steps may then be performed. For immersion processes, process fluid is pumped into the chamber 517 from one or more openings or nozzles 531 via the supply line(s) 533. The inner chamber 517 can pivot about a longitudinal (front to back) axis, via the motor 29. This allows the opening 555 to be moved from a position above the level of the liquid in the chamber 517, to a lower position, where liquid can drain out through the opening 555. In an embodiment where the chamber 517 pivots, but does not spin or rotate, the supply line(s) 533 can be provided with sufficient slack to allow it to follow the pivoting movement of the chamber 517, and no rotary coupling 537 or other fluid delivery techniques are needed.

During an immersion process, fluid is provided into the chamber 517 until the workpieces are preferably completely immersed. The chamber 517 is positioned so that the opening 555 is near the top of the chamber as shown in Fig. 20, preventing liquid from draining out of the chamber 517. The rotor drive motor 541 may then spin the rotor 539 and workpieces 60 within the process fluid. This technique provides mixing and fluid movement over the workpieces 60, via relative movement between the fluid and the workpieces. The spin speed may be low, to avoid excessive splashing and turbulence. For some applications, both the rotor 539 and chamber 517 may remain still, with the workpieces immersed in the still process fluid contained in the chamber 517, for a desired time interval.

At an appropriate time during processing, to remove liquid, the chamber 517 is pivoted by the chamber drive 529, so that the opening 555 is at or below the level of the liquid 521. This allows the fluid to overflow or drain out through the opening 555 in the cylindrical sidewall of the inner process chamber 517, as shown in Fig. 22. The opening 555 is gradually moved down, preferably in a controlled manner, by continuing to pivot the chamber 517, to remove fluid a controlled rate. The liquid removed from the inner chamber flows into the outer chamber 519, where it is temporarily held, or optionally purged through and out of the outer chamber 530 via the port(s) 551.

With the liquid removed (or if no immersion steps are performed), the workpieces 60 are in the clean ambient gas or air environment within the chamber 517. Further process steps may then be performed. For example, the workpieces 515 may be cleaned by spraying them with a cleaning liquid (e.g., water). A gas, which is optionally heated, may then be sprayed onto the workpieces via the nozzles 531, with or without, rotating or pivoting the chamber 517 (and the nozzles 531 on the chamber 517), and with or without spinning the rotor holding workpieces, or both. To provide centrifugal liquid removal, the rotor 531 may be rotated at higher speeds.

For sequential processing steps, different liquid, gas, or vapor (collectively referred to here as "fluids") media may be applied to the workpieces from a fluid supply source 581, by immersion within a liquid gas or vapor, spraying, or other application. Rinsing and/or cleaning may be performed in between processing steps. However, the workpieces can remain within the chamber 517 at all times, reducing the potential for contamination.

The removal of the process fluids 521 from the inner process chamber 517 may alternatively be accomplished by allowing the fluids 521 to escape through a switched drain 561 in the inner process chamber 517, generally at a position opposite from the drain edge 557. The drain 61 may be switched via external magnetic influence, or via a pneumatic or hydraulic or electrical control line on or in the chamber 517, similar to the fluid line 533.

For processing workpieces by immersion, a continuously refreshed bath of liquid may be provided in the inner process chamber 517, while simultaneously and continuously draining out over the drain edge 557 in the sidewall, as the chamber 517 pivots counterclockwise in Figs. 20 and 22. For some applications, the process liquid level in the chamber 517 may only cover a fraction of the workpieces. The workpieces can then be rotated in the rotor 539, so that all surfaces of the workpieces are at least momentarily immersed.

In any of the above embodiments or methods, the workpieces can be rotated in the rotor, to provide uniform distribution of the process fluid.

In a process for removing liquid from workpieces, a surface tension gradient lowering process can be used. A rinsing fluid, such as de-ionized water is introduced into the inner process chamber 517 to remove any remaining process chemicals. A gas, such as nitrogen, and an organic vapor, such as isopropyl alcohol, is then introduced via the manifold 535, or via a second similar manifold, to facilitate surface tension gradient removal of the rinsing fluid from the workpiece surfaces.

Referring back to Fig. 20, the rinsing liquid 521 is removed using the organic vapor which reduces surface tension at the liquid-gas interface 565. Via surface tension effects, the rinsing liquid 521 can be made to move from the interface region 565 down to the bulk of the rinsing liquid 521.

Therefore, through slow, controlled rotation of the inner process chamber 517, the rinsing fluid level can be lowered, removing the rinsing fluid 521 and the contaminants that may reside on the surface of the rinsing fluid. This method removes liquid from the workpieces 60 by allowing the surface tension gradient induced by the organic vapor to be maintained at the surface of the workpieces 60 as the rinsing liquid recedes. A suction manifold 567 may be provided adjacent to the drain edge 557, to draw off the surface of the liquid in the chamber 517.

During the process of removing the rinsing fluid from the inner process chamber 517, fresh rinsing fluid can be introduced into the inner process chamber 540 while the process chamber is pivoting to drain off fluid. The constant inflow of fresh liquid causes overflow, with the surface of the liquid flowing towards the drain slot. This allows for removal of particles and accumulated contaminants which may result from the cleaning and rinsing process, and which tend to be at the fluid surface..

The outer containment chamber 519 can be purged with a gas or vapor via a purge gas source 583 connected to a purge port 587, to maintain a desired environment. Such a gas may be nitrogen, argon, or a vapor such as hydrofluoric acid (HF) or a combination thereof. Similarly, gas or vapor(s) can be introduced in the inner process chamber 517 to provide a controlled environment.

Sonic energy may be applied to the workpieces via a transducer 575 (such as a megasonic or ultrasonic transducer) in or on the inner chamber, as shown in Fig. 20. The transducer 575 is positioned to transmit sonic energy through liquid in the inner chamber, to the workpieces immersed in the liquid. The sonic transducer may also be provided on the rotor, or in contact with the workpieces held by the rotor. Different types of opening, transducers may be used alone or in combination with each other. The sonic transducer 575 is powered via wires running on or through the inner chamber 517, optionally to slip rings at the back end of the system or apparatus 511, or via wires on the rotor 539.

In another embodiment, the apparatus is the same as described above in connection with Figs. 20-22, except that the chamber 517 has no opening 555. Rather, the inner chamber has continuous cylindrical sidewalls, so that it can be closed off and sealed by the door 547. In addition, the fluid supply line 533 connects to the outlets or nozzles in the inner chamber via the rotary fluid coupling 537. The rotary fluid coupling allows the inner chamber to rotate (not just e.g., 100° for draining liquid, but 360° plus, continuously) while it is supplied with fluid. A similar rotary connection (preferably electrical or pneumatic) links the switched drain opening 561 in the inner chamber 517, to a controller. With this design, the inner chamber 517 is closed off, (and preferably sealed off) from even the outer chamber 519. Consequently, contamination is further avoided. The outer chamber 519 can then be omitted. The embodiment having the drain opening 555 may be converted to the closed embodiment by installing a sidewall panel 579 shown in Fig. 22 over the opening 555.

For certain process steps, the workpieces 60 in the holder or rotor 539 can remain stationary, while the chamber 517 spins around them. Alternatively, both the chamber 517 and workpieces 515 in the rotor 539 may rotate or spin. Still further, the rotor 539 may be configured as a holder simply attached to a fixed (non-rotating) rear structure, in a design where the workpieces 60 remain stationary at all times, and the chamber 517 rotates around them (e.g., while draining liquid or spraying or otherwise applying process media onto the workpieces). This closed chamber embodiment may also perform immersion processing. However, as there is no opening 555, liquid removal occurs by opening the drain 561, with the chamber positioned so that the drain 561 is at a low point.

In an alternate processor design, a workpiece support holds workpieces, either directly, or by holding a carrier containing workpieces. A sub-chamber or process chamber is provided around the carrier support and is adapted, when closed, to hold a liquid. Liquid is provided into the process chamber, so that the workpieces are at least partially immersed. The process chamber pivots or rotates, causing a slot, drain opening or overflow edge to move down to the level of the liquid. This allows liquid to move out of the process chamber. The process chamber continues to rotate until most or all liquid is removed from the chamber. Other steps and features described below may be advantageous, but are not necessarily essential to the invention.

An alternate processor unit 650 for use in the system 10 is shown in Figure 26. The processor unit 650 may be used in the automated system 10, shown in Figures 1, 24 and 25 or in other automated systems, or it may be used alone, with workpieces loaded and unloaded from the processor unit 650 manually, or via a dedicated robot. As shown in Figure 26, the processor unit has a workpiece support 656. The workpiece support 656 is fixed in position and does not move. A process chamber or sub-chamber 654 surrounds or encloses the workpiece support 656, generally on three sides. The top of the chamber 654 is open.

The workpiece support 656 is shown as a separate component or subassembly, in Figure 28. A front ring 672 and a rear ring or plate 674 are attached to a support arm 670. Combs 676, or other workpiece edge supports (such as bars or rods) extend between the front ring 672 and the rear ring 674. An attachment hub 678 at the back end of the support arm 670 is attached to the back wall of the outer chamber 652 or other fixed structure. Consequently, the wafer support 656 is fixed in place, relative to chamber 654 and the process robot 22. A front opening 684 in the front ring 672 allows workpieces 60 to be loaded and unloaded from the workpiece support 656.

Referring to Figures 27 and 28, an upper manifold 682 is provided near the top of the workpiece support 656. The upper manifold 682 is connected to a process liquid or vapor supply, preferably isopropyl alcohol vapor (although other liquids and vapors may be used). A lower or second manifold 680 is provided near the bottom of the workpiece support 656. The lower manifold 680 is connected to a supply of process or rinse liquid, preferably, deionized water.

Figure 29 shows the chamber 654 separately. As shown in Fig. 29, the chamber 654 has a cylindrical wall 692 attached to a back wall or plate 690 at the back end of the chamber 654. As shown in Fig. 26, the cylindrical wall 692 is open at the top. One of the upper edges of the cylindrical wall 692 (at the left side in Figure 26) forms a drain edge 696. In use, liquid contained within the chamber or bowl 654 flows out over the drain edge 696. Notches 700 may be provided in the drain edge 696 to improve liquid outflow characteristics.

The chamber 654 is attached to and supported by an axle 698 pivotably supported in the outer chamber 652 (if used) or other fixed structure of the process station 30. Referring to Figures 27 and 29, a drive shaft 702 of a motor or rotary actuator 704 extends through the axle 698 and is joined to the back plate 690 of the chamber 654. The motor or actuator 704 may be electrical, hydraulic, pneumatic, etc. Actuation of the motor 704 causes the chamber 654 to pivot. Where an outer chamber 652 is used, the drive shaft 702 may be replaced with a magnetic coupling, to avoid penetrating into the process environment around the workpieces.

Figures 30 and 31 show the optional outer chamber 652 as a separate assembly, with various components removed for purpose of illustration. Referring to Figure 30, the outer chamber 652 includes a cylindrical wall 720 joined to a back plate 722. A drain trough 726 at the bottom of the outer chamber 652 is provided to collect liquid and direct it to a drain outlet 728. The drain outlet 728 is connected to a facility waste drain or other drain system. A base plate 730 which supports the outer chamber 652 is in turn attached to a chassis 734 shown in Fig. 27, or other structure of the process station 30. The cylindrical wall 720 of the outer chamber 652 extends continuously (360°). The front end 732 of the outer chamber 652 is open.

Referring to Figure 27, a door assembly 738 is provided to close off the open front end or front opening 684 of the chamber 654 during processing. This allows the chamber 654 to hold liquid during processing. As also shown in Figure 27, where an outer chamber 652 is used, the door assembly 738 also closes off the open front end 732 of the outer chamber 652.

Referring to Figures 27 and 32, the door assembly 738 includes a chamber door plate 740 attached to a pivot socket 742. The pivot socket 742 is secured within a retainer 744 by a pivot ball 754. The door plate 740 and pivot socket 742 can pivot on an O-ring 752 relative to the retainer 744. This allows the door plate 740 to pivot with the chamber 654, while the rest of the door assembly 738 remains in place.

The pivot ball 754 is secured within an inner cylinder 760. The inner cylinder 760 is held within an outer cylinder 762. A sliding pressure seal 764 seals the inner cylinder 760 against the outer cylinder 762, while allowing the inner cylinder to slide (in the left-right direction in Figure 32) within the outer cylinder 762. Compressed air or fluid ports

772 and 774 are provided at the outer and inner ends of the outer cylinder 762, on opposite sides of the sliding pressure seal 764. By introducing air or a liquid under pressure into the port 772 or 774, the inner cylinder 760 is moved in or out, to engage and disengage the plate 740 to the chamber 654. A cap 758 attached to the inside end of the outer cylinder 162 captures the inner cylinder 760 and limits its movement to a prescribed range. An outer chamber door plate 766 is attached to the inner cylinder 760. A seal retainer 748 holds an outer chamber door seal 746 onto the door plate 766.

Referring still to Figures 27 and 32, a door mounting plate 768 supports the outer cylinder 762. A cover 770 is optionally provided over the front surface of the outer cylinder 762.

Referring momentarily to Figures 33 and 34, the entire door assembly 738 is supported on door rails 780 joined to supporting structure of the processor unit 650 or the enclosure 12. Sleeves 782 attached to the door mounting plate 768 slide on the door rails 780. Actuators or motors 776 move the entire door assembly 738 vertically along the door rails.

The workpieces 60 are loaded into the processor unit 650 by the process robot 22, and moved from the interface section 24 to the process section 26. Process parameters and workpiece movement may be controlled by the computer/controller 32, or by the control panel 28, or by another remote or facility computer/controller.

During loading and unloading, the door assembly 738 is in the down position, as shown in double dotted lines in Figure 33. The process robot 22 moves the workpieces through the open front end 732 of the outer chamber 652 (if used), through the open front end 708 of the chamber 654, and through the open front end of the workpiece support 656. The process robot 22 places the workpieces 60 into the combs 676 or other support surface within the workpiece support 660. The process robot 22 then withdraws. The workpieces 60 are held in the workpiece support 656 so that they do not touch each other. Generally, the workpieces are in an upright or near upright position (for example, within +/- 5, 10, 15, 20 or 30° of vertical). The combs 676 may hold the workpieces at a slight angle of e.g., 5-15°, to reduce workpiece movement.

The door assembly 738 moves from the down position, shown in double dotted line in Figure 33, to the up position, as shown in solid lines in Figures 33 and 34.

The door assembly 738 is in the withdrawn or disengaged position, with the inner cylinder 760, pivot ball 754, door plate 766 and chamber door plate 740 shifted forward and away from the outer chamber 652 and the process chamber 654, as shown in dotted lines in Figure 32. A pressurized liquid or gas is provided into the outer cylinder 762 by the outer port 774. This drives the inner cylinder 760 and the door plates 766 and 740 rearwardly and into engagement with the outer chamber 652 and the process chamber 654. Specifically, as the inner cylinder 760 moves inwardly towards the outer chamber 652 and the process chamber 654, the door plate seal 706 around the front edge of the cylindrical wall 692 of the chamber 654 is engaged by the chamber door plate 740. Simultaneously, the outer chamber door plate 766 moves into engagement with the seal 746 on the door plate 766 engaging the front rim of the outer chamber cylindrical wall 720.

With the door assembly 738 in the engaged position, as shown in Figure 27, the chamber 654 can contain liquid, and be filled to a level up to the drain edge 696, so that the work pieces 60 are immersed. The contact at the seal 706 between the front end of the cylindrical wall 692 of the chamber 654, and the chamber door plate 740 may provide a liquid tight seal. However, a small amount of leakage is generally acceptable. Similarly, a small amount of leakage past the seal 746 is also generally acceptable.

With the door assembly 738 engaged, liquid is introduced into the process chamber 654. The liquid may be sprayed from nozzles or it may simply from openings in the lower manifold 680. The liquid is preferably de-ionized water. The lower manifold 680 is supplied via a liquid supply line 686 extending through the support arm 670 and attachment hub 678. This avoids interference between pivoting movement of the chamber 654 and the liquid supply line 686 connecting to the lower manifold 680 on the work piece support 656. The combs 676 preferably provide positions for multiple work pieces, for batch processing, in a batch of, for example, 5-50 workpieces. The lower manifold 680 is preferably at or near the bottom of the workpiece support.

Water or other liquid is supplied via the manifold 680 while the chamber 654 is in the upright or 0° position, as shown in Figures 26 and 36. Water is supplied into the chamber 654 preferably until the work pieces 60 are fully immersed, as shown in Figure 36. Water supply is then stopped. The drain edge 696 is vertically above the top edge of the workpieces The computer/controller 32 determines when the work pieces are immersed, via a volume flow meter measuring flow through the supply line 686, or alternatively, from liquid level detectors 688 on the workpiece support 656.

Upon reaching a predetermined level, or after a predetermined delay interval, the controller 32 energizes the motor or actuator 704, to begin pivoting or turning the chamber

654. The chamber 654 then begins to pivot about the axle 698, so that the drain edge 696 moves down. As this occurs, the water 790 flows over the drain edge 696 and out of the chamber 654. If an outer chamber 652 is provided, the water is collected at the bottom of the outer chamber 654, runs into the drain trough 726, and out of the processor unit 650 via the drain outlet 728. The controller 32 and motor or actuator 704 preferably turn the chamber 654 at an angular rate which causes the level of water or liquid 790 to drop at a substantially uniform linear vertical rate. Preferably, the chamber is turned or pivoted so that the liquid drains out at a rate of about 0.1-30 or 0.1-10 or 0.1-5 or 0.1-2 mm/second, 0.5-10 or 0.5-5 or 0.5-1 or 2 mm/second. The drain or drop rate is selected to be as fast as practical, without having the meniscus separate from the workpiece surface. As the drain edge 696 moves in a circle about the axle 698 as the chamber 654 pivots, a sinusoidal pivot speed profile of the chamber 654 provides a constant or linear decrease in the liquid level 790 within the chamber 654.

Figures 36-39 show the chamber 54 pivoted into four different positions, with Figure 36 showing the starting position, and Figure 39 showing the ending position, wherein all of the liquid has been removed. The movement of the chamber 654 from the position shown in Figure 36 to the position shown in Figure 36 is preferably smooth and continuous.

After all of the liquid has been removed by allowing the liquid to run out over the drain edge 696, the work pieces 60 may be removed from the processor unit 650. This is achieved by reversing the engagement sequence of the door assembly 738. Alternatively, the workpieces 60 may remain within the processor unit 650, and chamber 654 may be returned to its original 0° position, as shown in Figure 36, to repeat the rinsing, spraying or immersion processing, one or more times.

In an alternative process for cleaning the workpieces, the sequence described above is followed. In addition, a vapor of an organic solvent, such as isopropyl alcohol, is introduced into the chamber 654, via nozzles or openings in the upper manifold 682. A gas, such as heated nitrogen, may also be provided, with the organic solvent vapor entrained in the gas, and introduced above the water level 790 in the chamber 654. The chamber 654 is pivoted or rotated, as described above. Water drains out over the drain edge 696. While this occurs, additional organic solvent vapor and gas is supplied into the chamber. The organic solvent vapor reduces the surface tension of the water at the workpiece surface/water interface. This reduces or prevents water droplets from remaining on the workpiece surfaces, as the water level drops, resulting in less contamination. The gas may be provided from a drying gas manifold 710 alongside of the vapor manifold 682, or it may be provided from the vapor manifold, with or without the vapor. After vapor supply is stopped, the drying gas preferably continues, to remove any remaining vapor from the chamber 654.

The outer chamber 652 contains and drains away liquid running over the drain edge 696, or leaking past the seal 706. The outer chamber also helps to isolate the workpieces from the ambient environment, human operators, adjacent parts and equipment. Where an outer chamber 654 is used, it can be purged with a gas or vapor to maintain a desired environment. The gas may be, for example, nitrogen, argon, ozone or a vapor such as HF, or a combination of them. However, the invention may be practiced as described above without any outer chamber. While deionized water is preferred as a rinsing liquid, other liquids or mixtures including hydrofluoric acid (HF) may also be used.

For sequential processing steps, different liquid, gas or vapor (collectively referred to here as "fluids") media may be applied to the workpieces by immersion, spraying, or other application. Cleaning, as described above, may be performed in between the processing steps. The manifolds described above may also be used to introduce other process fluids. Alternatively, additional manifolds may be provided for this purpose.

Especially where an outer chamber 652 is used, this sequential processing allows the workpieces to remain fixed in place, at all times, preferably enclosed within the outer chamber 652, reducing the potential for contamination. Where the workpieces are immersed, a continuously refreshed bath of liquid may be provided into the chamber 654. In this application, the liquid may be pumped in via the lower manifold 680 and continuously drain out over the drain edge 696, with the chamber 654 remaining in the 0° or upright position shown in Figure 36.

Sonic energy may be applied to the work pieces 60 via a transducer 712, preferably positioned on the work piece support 656. The transducer 712, such as a megasonic or ultrasonic transducer, is positioned to transmit sonic energy through liquid in the chamber 654, to the work pieces immersed in the liquid.

As shown in Figures 36-41, the work piece support 656 is supported on the arm 670 which is offset from the work pieces 60 as well as from the axis of rotation or axle 698 of the chamber 654. As shown in Figures 40 and 41, this allows the chamber 654 to pivot by about 100°, to drain all liquid from the chamber 654. All liquid, gas or vapor supply lines, as well as any electrical connections to any sensors, such as the liquid level sensor 688, are routed through the support arm 670 and attachment hub 678. This allows the chamber 654 to freely pivot around the work piece support 656 without interference, and without the need for special fittings or connections to accommodate movement.

Figure 35 shows an alternative processor unit 800, similar to the processor unit 650 described above. However, the processor unit 800 shown in Figure 35 is adapted to receive work pieces 60 held within a carrier, cassette, or tray 804. Accordingly, the processor unit 800 has an alternative work piece support 802 having a shelf 806 for holding a carrier 804, rather than the combs 676 as shown in Figure 27. The design and operation of the processor unit 800 shown in Figure 35 is otherwise similar to the design and operation of the processor unit 650 as described above.

Claims:

1. A system for processing a workpiece comprising:

an interface section;

a process section;

a process robot moveable to carry a workpiece from the interface section to the process section;

a processor unit in the process section, with the processor unit having a process chamber, a drain opening in the process chamber, and a process chamber driver for pivoting the process chamber to drain liquid out of the process chamber by moving the drain opening down to the level of the liquid in the process chamber.

2. The system of claim 1 where the process chamber has a curved sidewall and the drain opening is in the curved sidewall.

3. The system of claim 2 wherein the drain opening comprises a slot in the curved sidewall connecting to a drain port.

4. The system of claim 2 where the process chamber is generally cylindrical and has a central axis, and the process chamber driver pivots the process chamber about an axis parallel to the central axis of the generally cylindrical process chamber.

5. The system of claim 1 wherein the process chamber pivots about a horizontal axis.

6. The system of claim 1 further comprising at least one manifold in the process chamber for introducing a fluid into the process chamber.

7. The system of claim 1 where the process chamber driver pivots the process chamber from a first position where the drain opening is adjacent to the top of the process chamber, to a second position, where the drain outlet is adjacent to the bottom of the process chamber.

8. The system of claim 1 further comprising a rotor rotatably supported within the process chamber, with the rotor having positions for holding workpieces.

9. The system of claim 1 further comprising a door assembly including a closure frame attachable to the process chamber.

10. A system for processing a workpiece comprising:

an interface section;

a process section;

a process robot moveable to carry a workpiece from the interface section to the process section;

a processor unit in the process section, with the processor unit having a process chamber including:

a drain opening in the process chamber;

a process chamber driver for pivoting the process chamber to drain liquid out of the process chamber; and

a rotor rotatably supported within the process chamber.

11. The system of claim 10 further comprising at least one manifold in the process chamber, and a flexible supply line joined to the manifold, with the flexible supply line moving with the process chamber as the process chamber pivots.

12. The system of claim 10 further comprising a switchable drain in the process chamber at a position spaced apart from the drain opening.

13. The system of claim 10 where the process chamber comprises a backwall joined to a cylindrical sidewall, and with the process chamber having an open front end, and further comprising door means for closing off the open front end of the process chamber.

14. The system of claim 1 further comprising a first manifold in the process chamber connected to a source of an organic solvent vapor, and a second manifold in the process chamber connected to a source of water.

15. The system of claim 1 where the process chamber is supported only by the process chamber driver.

16. The system of claim 10 further comprising a spin motor connected to the rotor.

17. A method for processing a workpiece comprising the steps of:

supporting the workpiece on a support within a process chamber;

closing the process chamber;

filling the process chamber with a rinse liquid to at least partially immerse the workpiece in the liquid; and

removing the liquid from the chamber by moving the chamber so that a drain opening in the chamber moves into a position where the liquid moves through the drain opening via gravity and out of the process chamber.

18. The method of claim 17 where the drain opening is in a sidewall of the chamber and the liquid is removed by pivoting the chamber to bring the drain opening to the level of liquid in the chamber.

19. The method of claim 17 further including the step of spinning the support and the workpiece in the process chamber after removing the liquid.

20. The method of claim 17 further including the step of spraying a process fluid onto the workpiece in the chamber, before filling the process chamber with the rinse liquid.

21. The method of claim 20 wherein the rinse liquid comprises water.

22. A method for processing a workpiece comprising the steps of:

supporting the workpiece in a rotor within a process chamber;

closing the process chamber;

filling the process chamber with a rinse liquid to at least partially immerse the workpiece in the liquid;

removing the liquid from the chamber by moving the chamber so that a drain opening in the chamber moves into a position where the liquid moves through the drain opening via gravity and out of the process chamber; and

spinning the rotor and the workpiece.

23. The method of claim 22 further comprising the step of spraying the workpiece with a gas.

24. A method for cleaning a workpiece, comprising the steps of:

supporting the workpiece within a process chamber;

filling the process chamber with a rinse liquid to a level sufficient to immerse the workpiece in the liquid;

removing the liquid from the chamber by moving the chamber so that a drain opening in the chamber moves into a position where the liquid moves through the drain opening via gravity and out of the process chamber; and

introducing a vapor of an organic solvent into the chamber.

25. The method of claim 24 further comprising the step of spinning the workpiece.

26. The method of claim 24 further comprising the step of introducing a gas into the chamber.

27. The method of claim 24 further comprising the step of introducing sonic energy into the process chamber when the workpiece is immersed.

28. A processor unit for processing a workpiece, comprising:

a process chamber;

a workpiece support in the process chamber;

a drain opening in the process chamber; and

a process chamber driver for pivoting the process chamber to move the drain opening from a first position to a second position relative liquid in the process chamber, to drain liquid out of the process chamber.

29. The processor of claim 28 where the workpiece support comprises a rotor rotatably positioned within the process chamber.

30. A system of processing a workpiece, comprising:

a containment chamber;

a process chamber within the containment chamber and having a drain opening;

a process chamber driver linked to the process chamber, for pivoting the process chamber, to drain liquid out of the process chamber, at a controlled rate; and

a workpiece holder within the process chamber.

31. The system of claim 30 further including a sonic transducer in the process chamber.

32. The system of claim 30 further including a removable door on the process chamber.

33. The system of claim 30 where the process chamber driver is linked to the process chamber with a magnetic coupling.

34. The system of claim 30 wherein the process chamber has a cylindrical side wall, and the drain opening is in the cylindrical sidewall.

35. The system of claim 30 wherein the process chamber is pivotable from a first position, where the process chamber can hold liquid at a level at least partially immersing a workpiece held in the workpiece holder, to a second position where liquid within the process chamber is able to drain out, through the opening, to a level entirely below the workpiece.

36. The system of claim 35 further comprising a fluid supply system including a fluid supply line extending into the process chamber.

37. The system of claim 36 further comprising at least one spray nozzle joined to the fluid supply line.

38. The system of claim 36 further comprising at least one of a process liquid source, a process gas source, and a process vapor source, connected into the fluid supply system.

39. The system of claim 30 further comprising a workpiece holder extender, for moving the workpiece holder out of the process chamber, for loading and unloading workpieces, and moving the workpiece holder into the process chamber, for processing workpieces.

40. The system of claim 30 where the process chamber has cylindrical sidewalls and is pivotable about an axis parallel to the cylindrical sidewalls.

41. The system of claim 30 further comprising a workpiece holder driver for rotating the workpiece holder.

42. The system of claim 41 where the workpiece holder driver is linked to the workpiece holder by a magnetic coupling.

43. The system of claim 36 wherein the fluid supply line pivots with the process chamber.

44. The system of claim 30 further comprising combs on the workpiece holder.

45. A system for processing a workpiece, comprising;
an outer chamber;
an inner chamber rotatably supported within the outer chamber;
an inner chamber driver for rotating the inner chamber;
a rotor within the inner chamber; and
a rotor driver for rotating the rotor.

46. The system of claim 44 further including a fluid delivery system having a fluid delivery line extending into the inner chamber.

47. The system of claim 46 further comprising at least opening in the inner chamber joined to the fluid delivery line.

48. The system of claim 47 where the at least one opening comprises at least one spray nozzle.

49. The system of claim 45 further including an inner door on the inner chamber, and an outer door on the outer chamber.

50. The system of claim 45 further including a drain opening in the inner chamber leading out to the outer chamber.

51. The system of claim 45 further including a removable sidewall panel in the inner chamber.

52. The system of claim 45 where the inner chamber and the outer chamber are cylindrical.

53. The system of claim 52 where the rotor is cylindrical and concentric with the inner chamber and the outer chamber.

54. The system of claim 45 further comprising a purge gas system connected into at least one of the outer chamber and the inner chamber.

55. A method for processing a workpiece, comprising the steps of:
placing the workpiece into a workpiece support;
enclosing the workpiece support holding the workpiece within a process chamber;
providing a process liquid into the process chamber;
pivoting the process chamber to allow process liquid to drain out; and
rotating the workpiece support.

56. The method of claim 55 where the workpiece is at least partially immersed in the process liquid.

57. The method of claim 55 further comprising the step of rotating the workpiece support while the workpiece support is at least partially immersed in the process liquid.

58. The method of claim 55 further comprising the step of introducing a process gas or vapor into the process chamber.

59. The method of claim 55 further comprising the step of enclosing the process chamber within an outer containment chamber.

60. The method of claim 55 where the process chamber is pivoted at a controlled rate to remove liquid from the process chamber.

61. The method of claim 55 further comprising the step of drawing off a surface layer of the liquid within the inner chamber via vacuum.

62. The method of claim 58 where the gas comprises nitrogen, air, argon or HF.

63. The method of claim 55 further comprising the step of providing sonic energy to the workpiece.

64. The method of claim 59 further comprising the step of sealing the process chamber with a process chamber door.

65. The method of claim 55 further comprising the steps of introducing a rinsing liquid into the process chamber, and then introducing a drying gas and an organic vapor into the process chamber, to facilitate removal of the rinsing liquid from the workpiece.

66. A method for processing a workpiece, comprising the steps of:

placing the workpiece into a workpiece support;

enclosing the workpiece support holding the workpiece into a chamber;

rotating the first chamber about the workpiece support; and providing a process fluid into the first chamber from at least one fluid supply opening on the first chamber.

67. A system of processing a workpiece, comprising:

an enclosure;

a process chamber having a drain opening;

a workpiece holder within the process chamber and fixed in position relative to the enclosure;

a process chamber driver linked to the process chamber, for pivoting the process chamber, to drain liquid out of the process chamber, at a controlled rate.

68. The system of claim 67 further including a sonic transducer on the workpiece holder.

69. The system of claim 67 further including a door engageable to the process chamber.

70. The system of claim 67 where the process chamber driver is linked to the process chamber with a magnetic coupling.

71. The system of claim 67 wherein the process chamber has a cylindrical side wall, and the drain opening is in the cylindrical sidewall.

72. The system of claim 67 wherein the process chamber is pivotable from a first position, where the process chamber can hold liquid at a level at least partially immersing a workpiece held in the workpiece holder, to a second position where liquid within the process chamber is able to drain out, through the opening, to a level entirely below the workpiece.

73. The system of claim 72 further comprising a fluid supply system including a fluid supply line extending into the process chamber.

74. The system of claim 73 further comprising at least one spray nozzle joined to the fluid supply line.

75. The system of claim 74 further comprising at least one of a process liquid source, a process gas source, and a process vapor source, connected into the fluid supply system.

76. The system of claim 67 where the workpiece holder includes combs having slots for holding workpieces.

77. The system of claim 76 where the workpiece holder is supported on a support arm offset from the center of the process chamber.

78. The system of claim 67 where the process chamber has cylindrical sidewalls and is pivotable about an axis parallel to the cylindrical sidewalls.

79. The system of claim 67 further comprising an outer chamber around the process chamber, with the workpiece holder fixed in position relative to the outer chamber.

80. A system for processing a workpiece, comprising;

an outer chamber;

a process chamber pivotably supported within the outer chamber;

a drain opening in the process chamber;

a process chamber driver for pivoting the process chamber; and

a workpiece support within the process chamber, and with the workpiece support and the outer chamber fixed in position relative to each other.

81. The system of claim 80 where the drain opening comprises a slot through a cylindrical sidewall of the process chamber.

82. The system of claim 80 further including a door assembly having a first door engageable on the process chamber, and a second door engageable on the outer chamber.

83. The system of claim 80 where the process chamber and the outer chamber are cylindrical.

84. A method for processing a workpiece, comprising the steps of:
placing the workpiece into a workpiece support;
maintaining the workpiece in a stationary position;
enclosing the workpiece support holding the workpiece within a process chamber;
providing a process liquid into the process chamber; and
pivoting the process chamber to allow process liquid to drain out.

85. The method of claim 84 where the workpiece is immersed in the process liquid.

86. The method of claim 84 further comprising the step of introducing a process gas or vapor into the process chamber.

87. The method of claim 84 further comprising the step of enclosing the process chamber within an outer chamber.

88. The method of claim 84 further comprising the step of pivoting the process chamber at a controlled rate to remove liquid from the process chamber at a controlled rate.

89. The method of claim 84 further comprising the step of providing sonic energy to the workpiece.

90. The method of claim 84 further comprising the step of closing off an open front end of the process chamber with a process chamber door.

91. The method of claim 84 further comprising the steps of introducing a rinsing liquid into the process chamber, and then introducing an organic vapor into the process chamber, to facilitate removal of the rinsing liquid from the workpiece.

92. A method for processing a workpiece, comprising the steps of:
placing the workpiece into a workpiece support;
enclosing the workpiece support holding the workpiece into a chamber;
maintaining the workpiece support in a fixed position;

pivoting the chamber about the workpiece support; and

providing a process fluid into the chamber from at least one fluid supply opening on the first chamber.

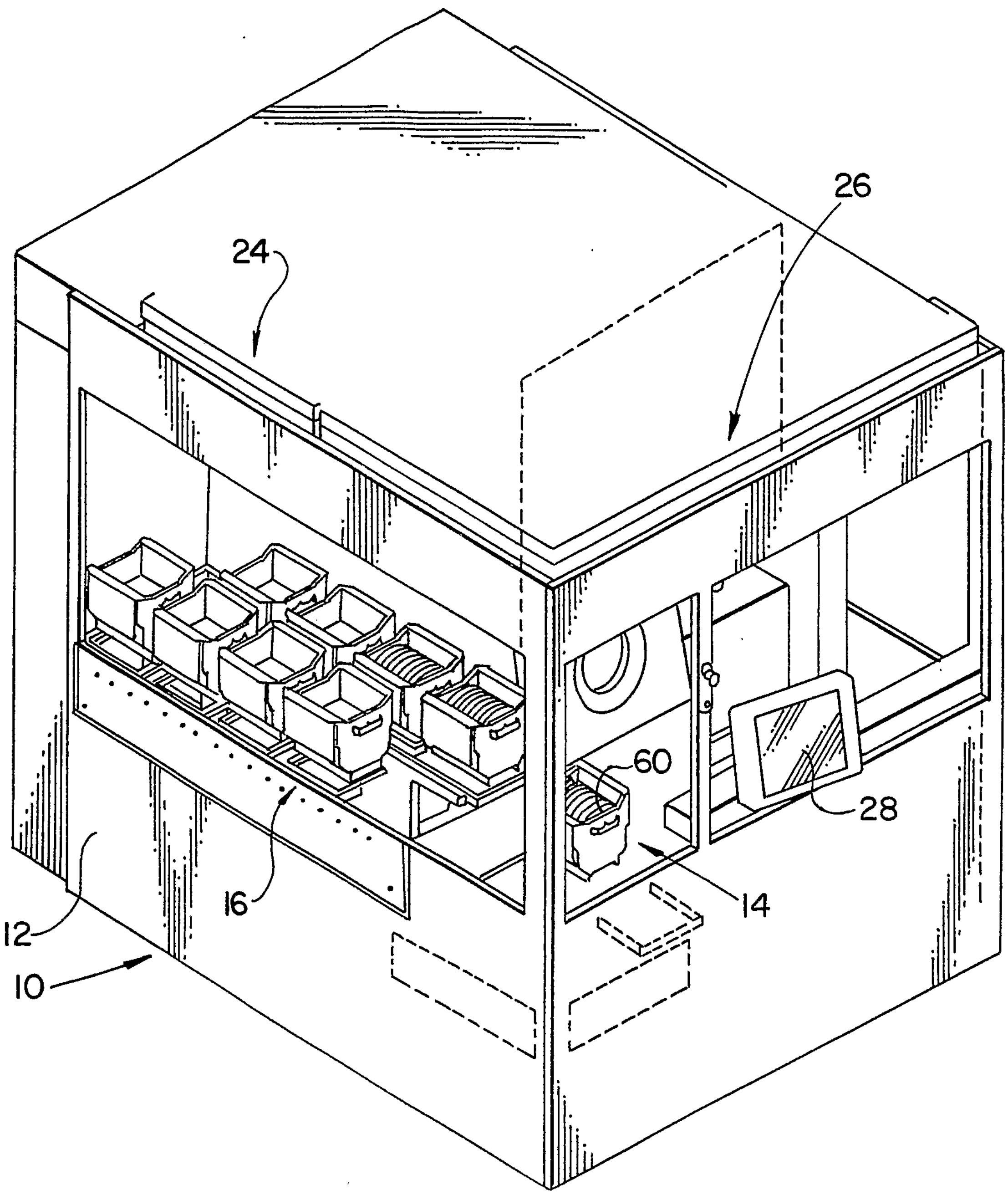

Fig. 1

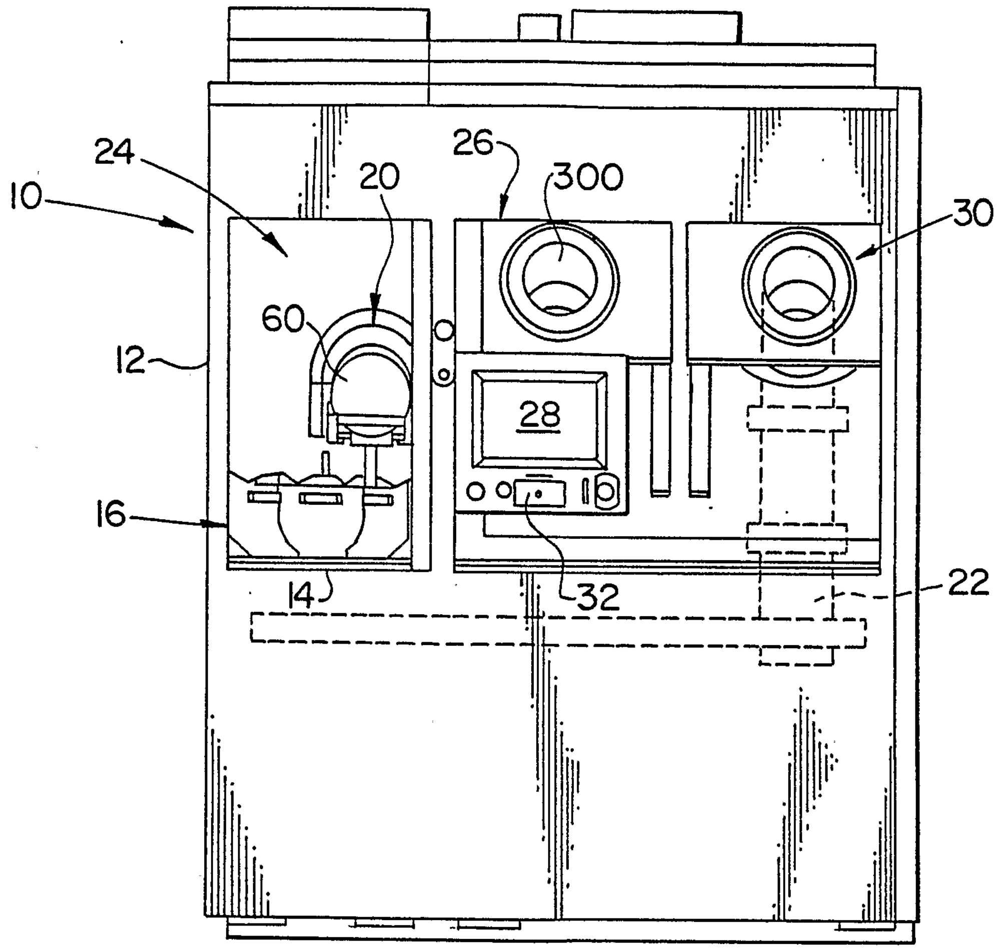

Fig. 2

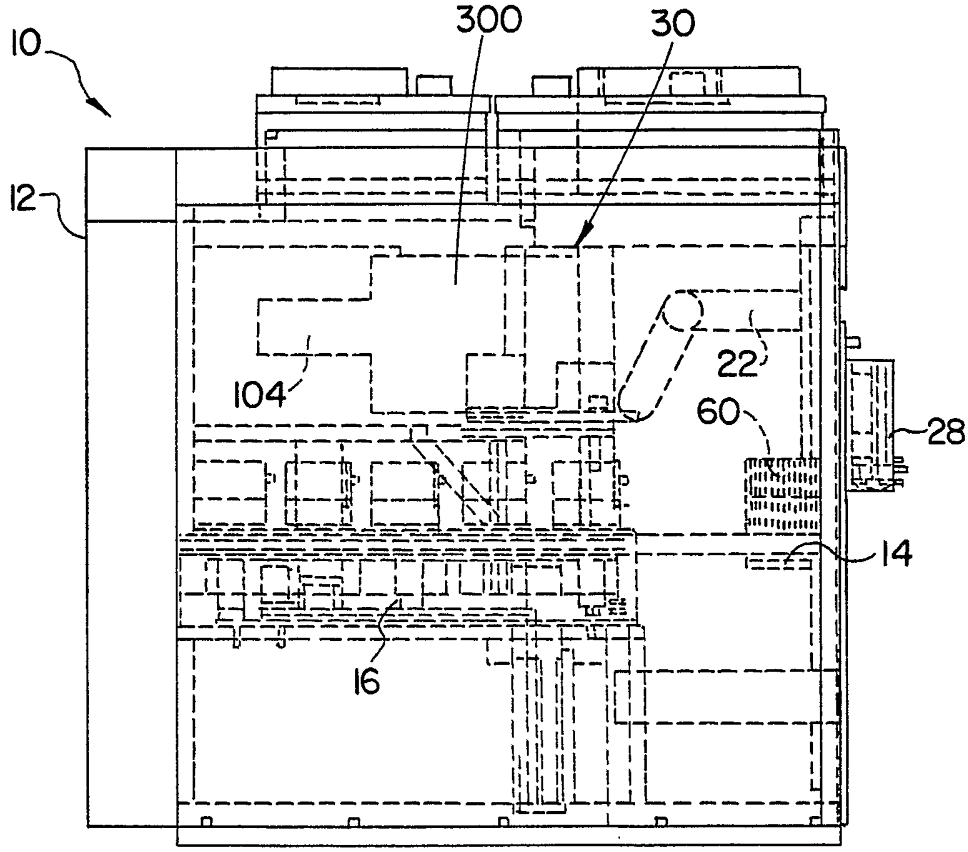

Fig. 3

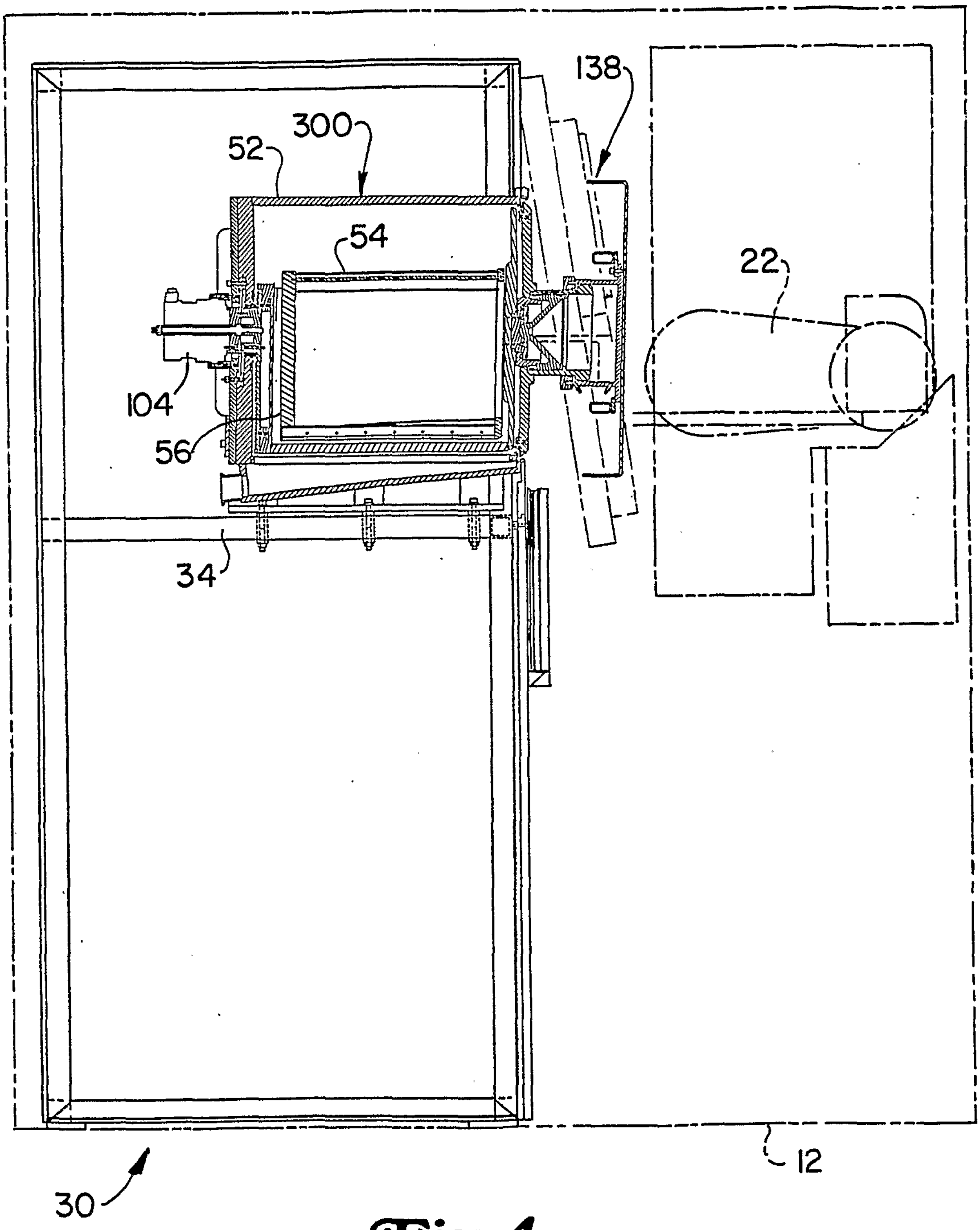

Fig. 4

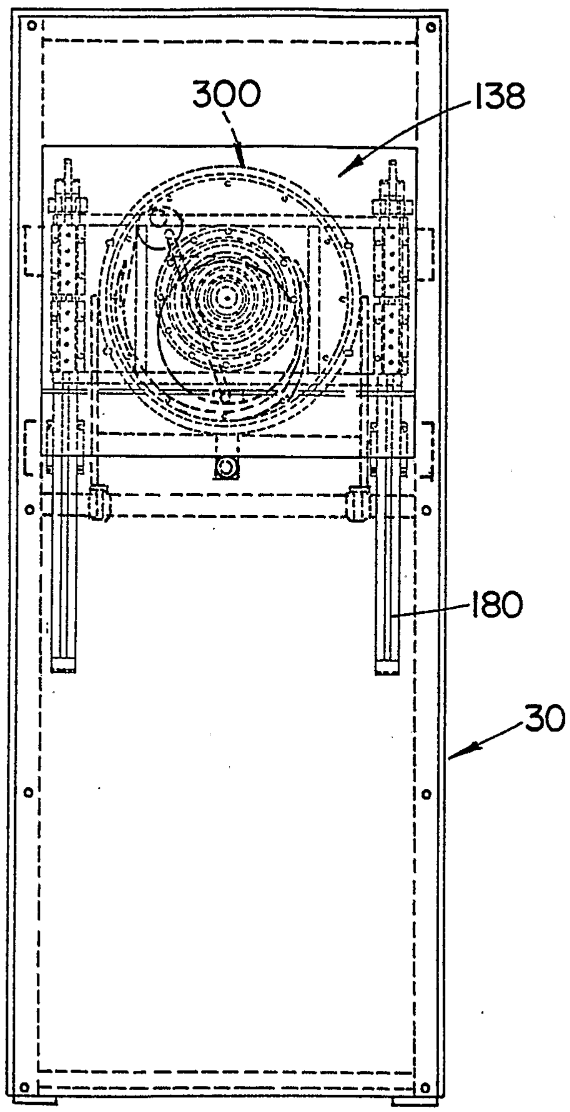

Fig. 5

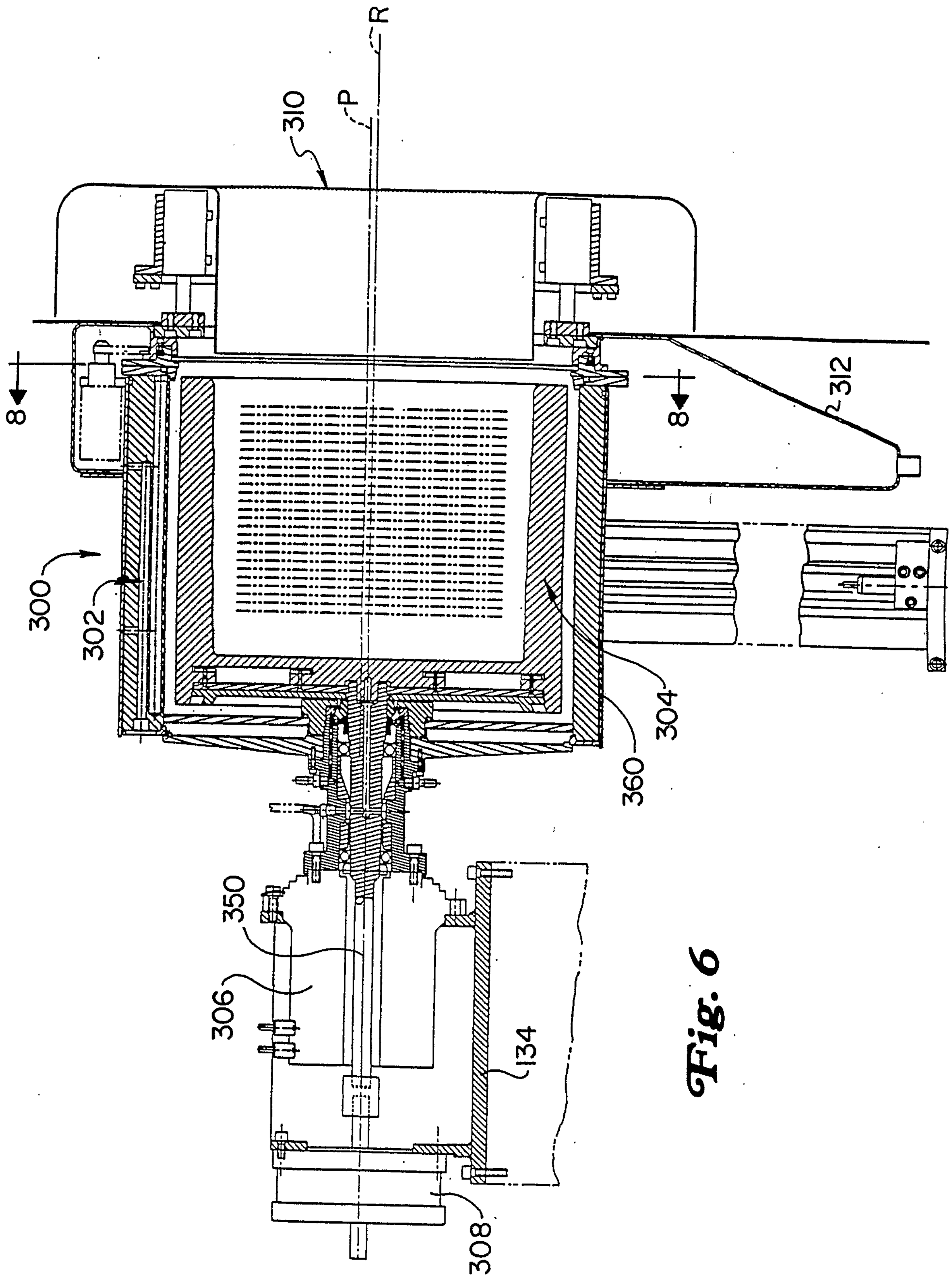

Fig. 6

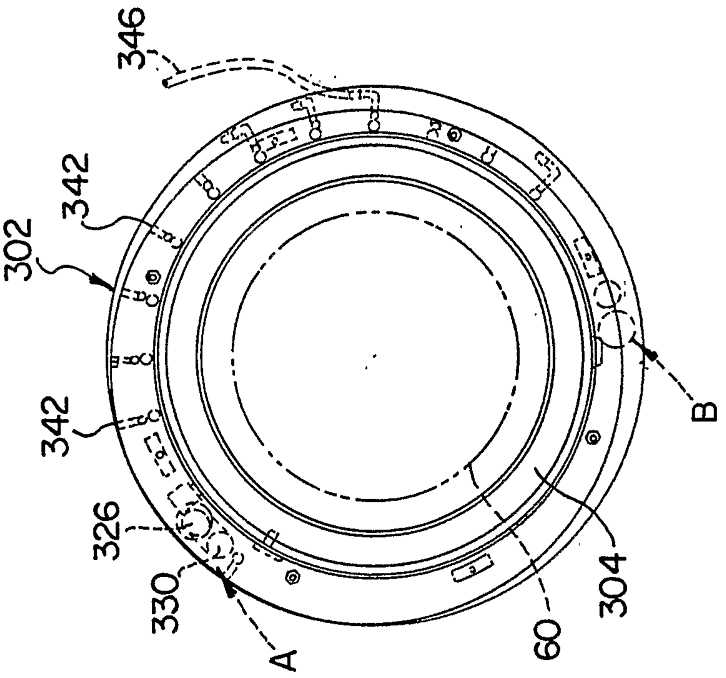
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Fig. 8

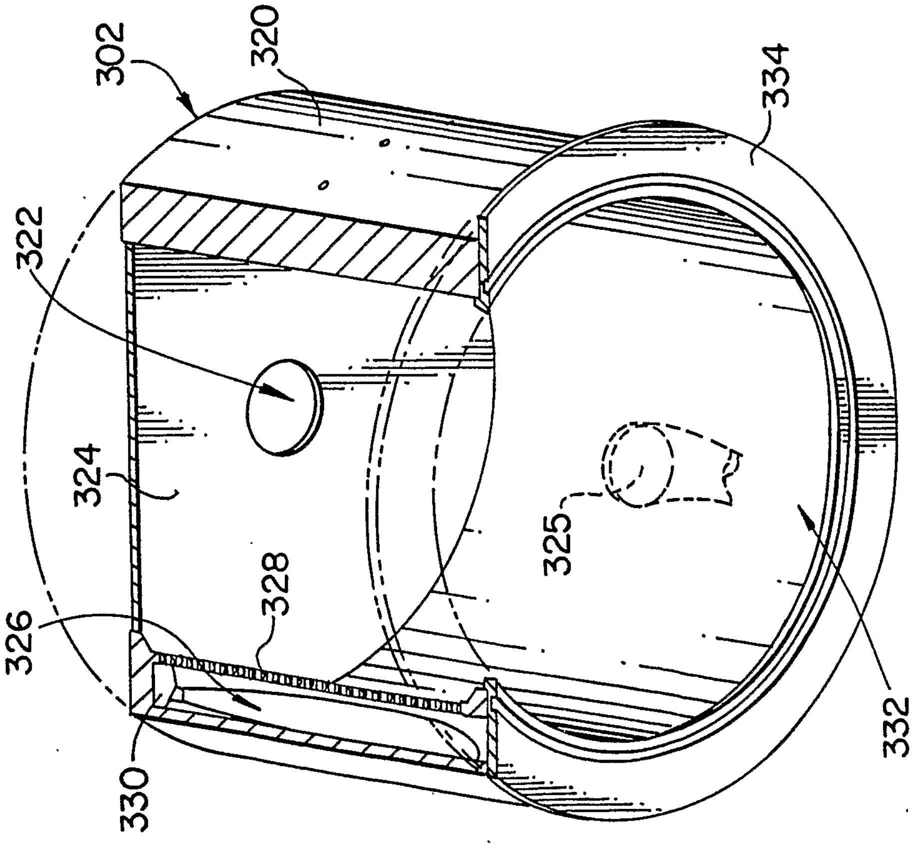
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Fig. 7

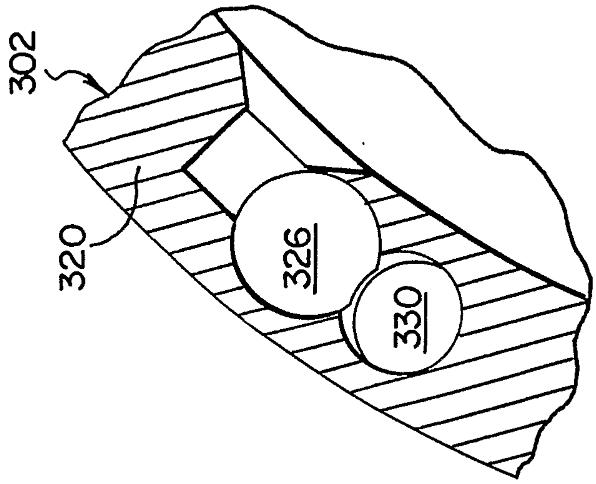
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Fig. 10

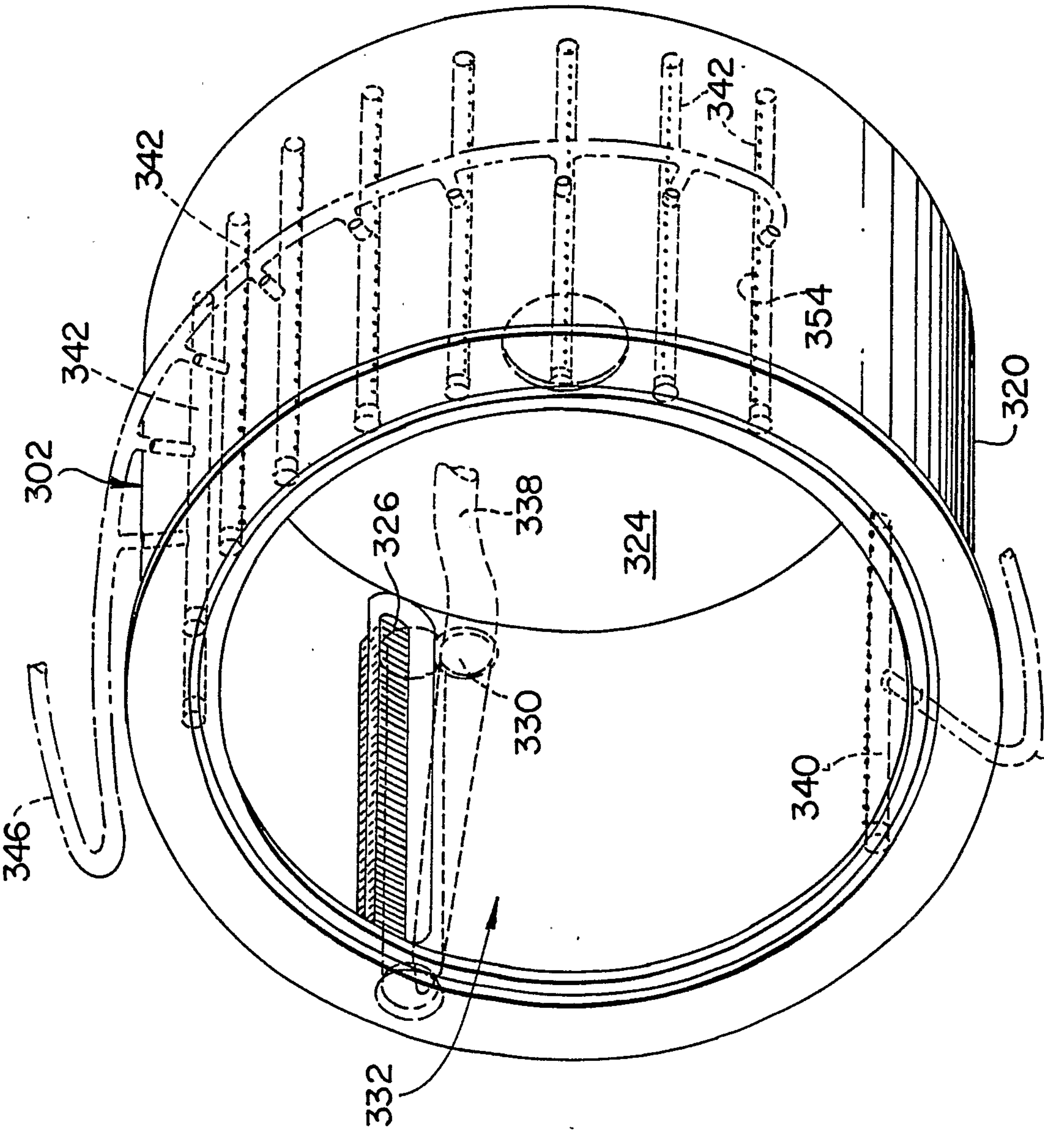
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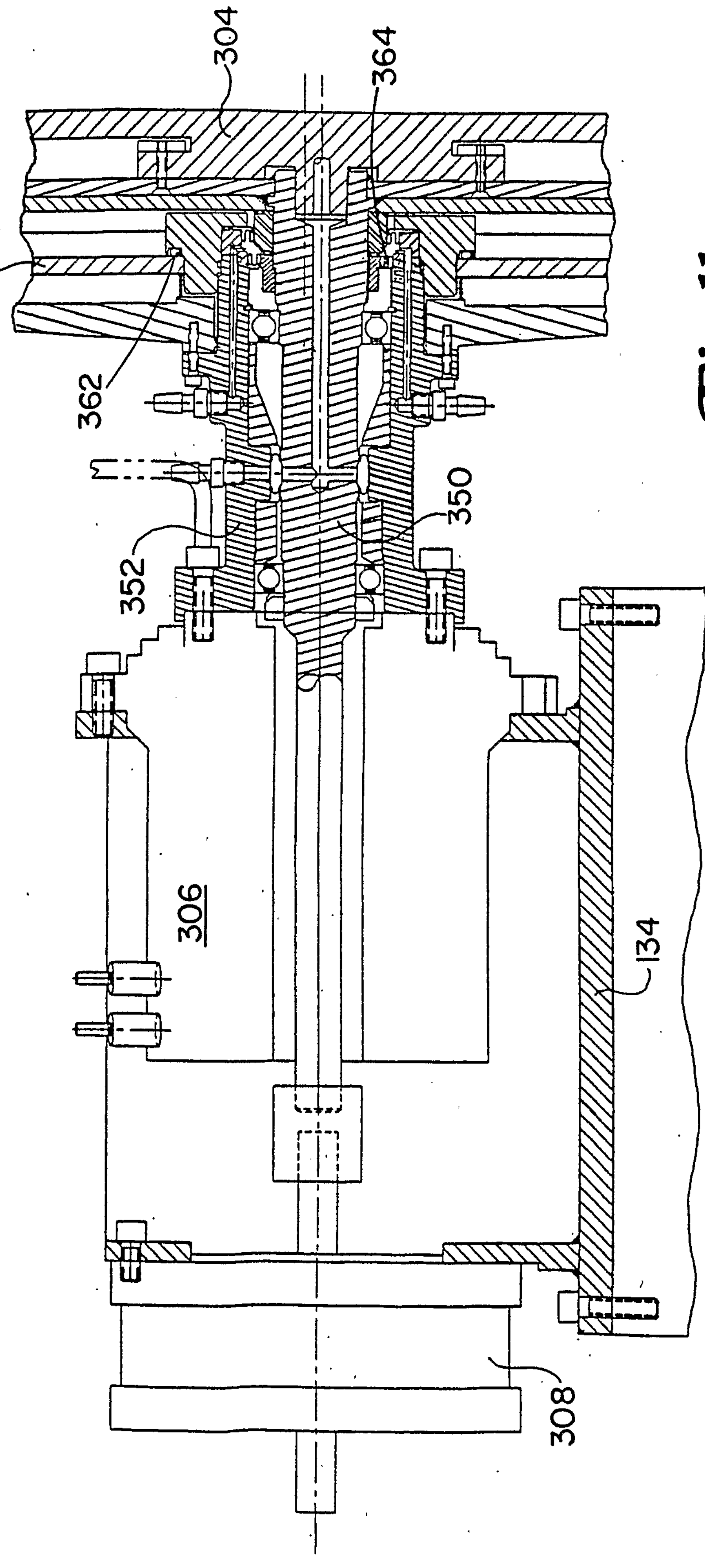
Fig. 9



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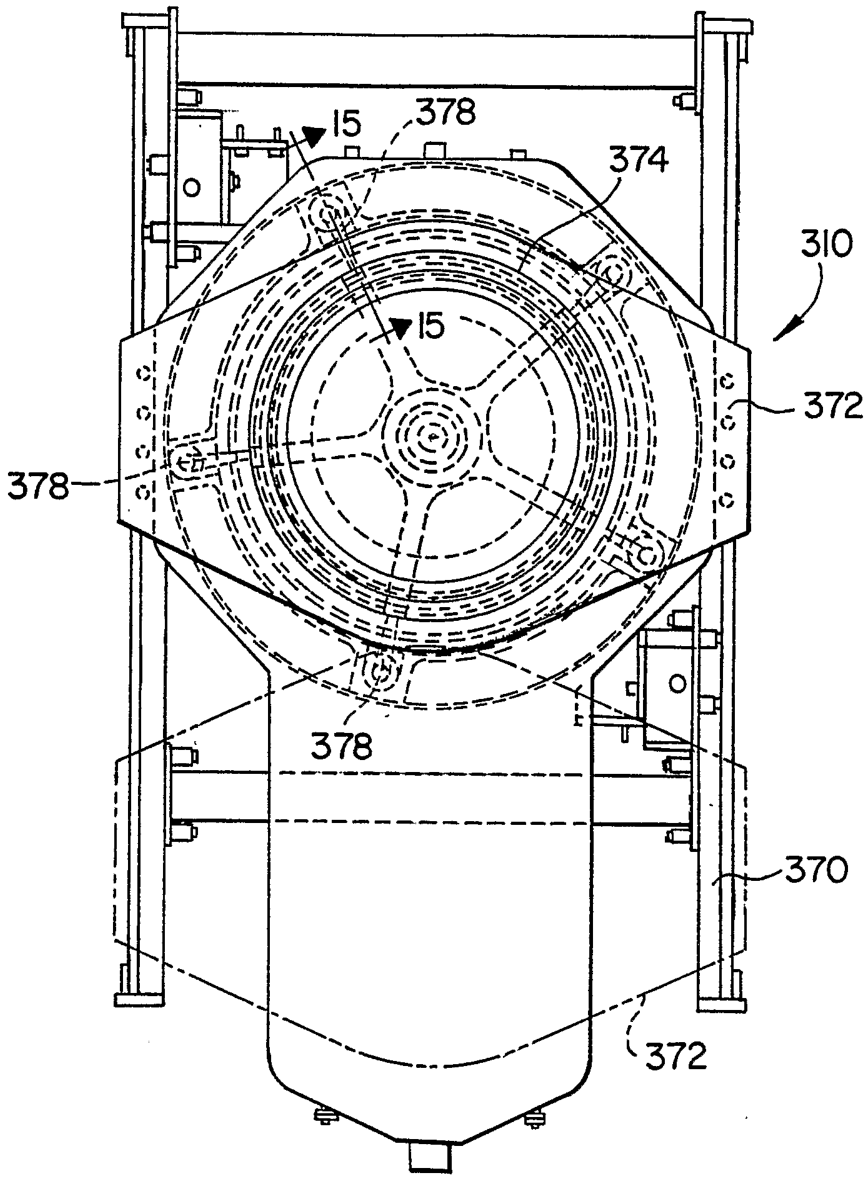

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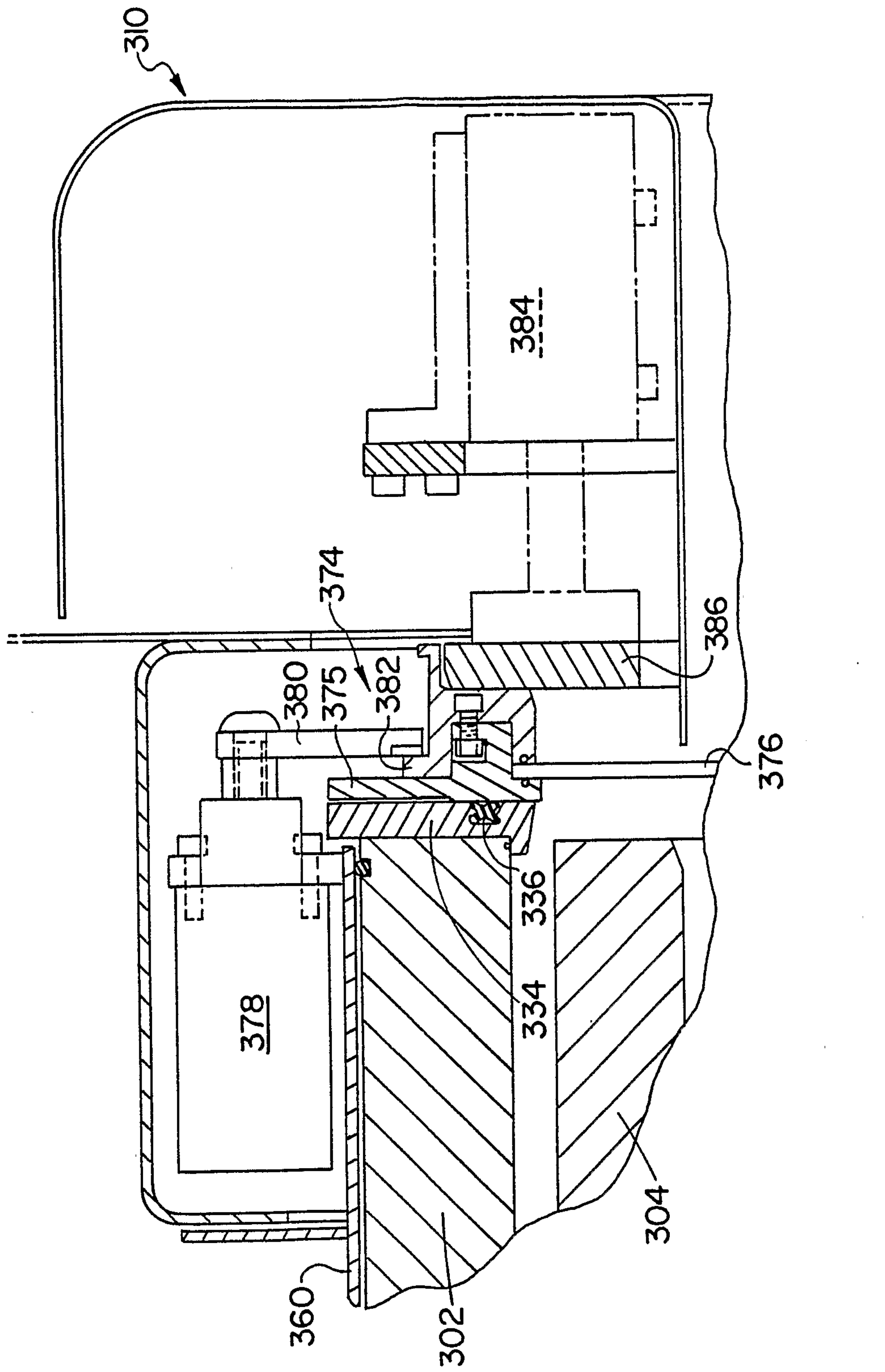
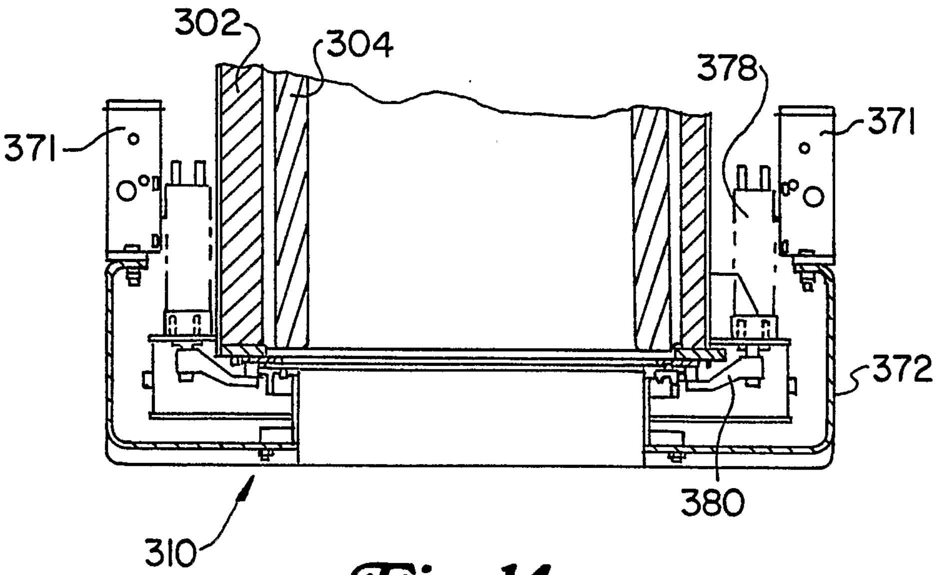


Fig. 13



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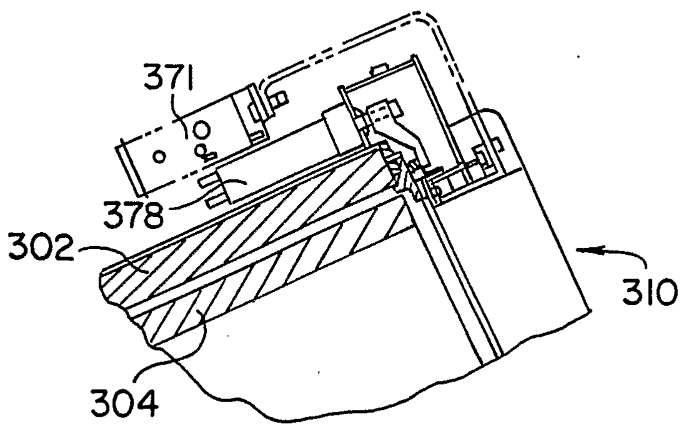

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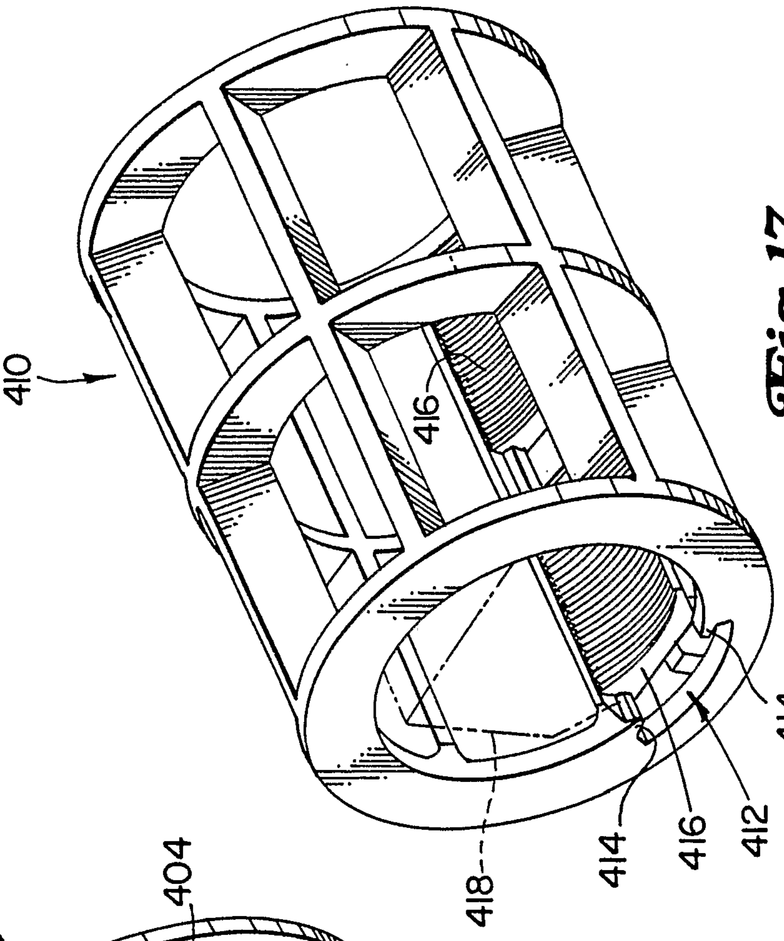

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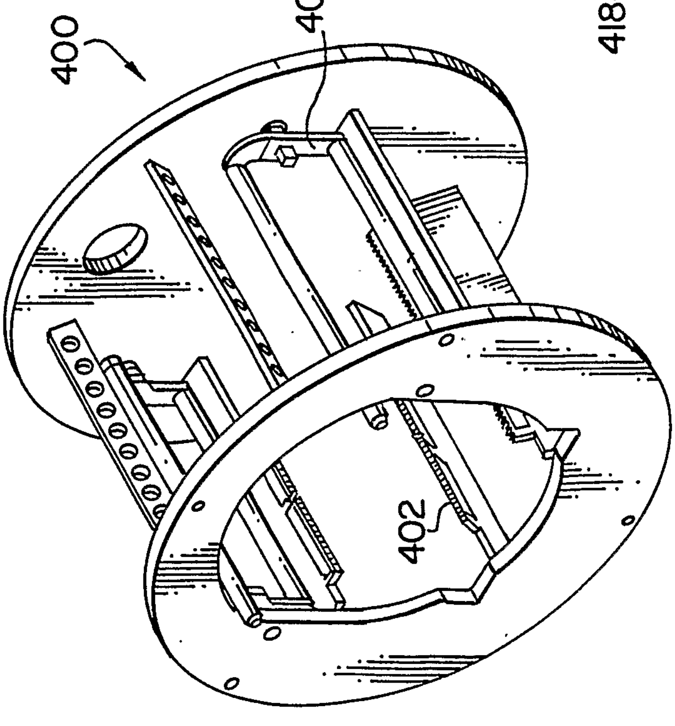
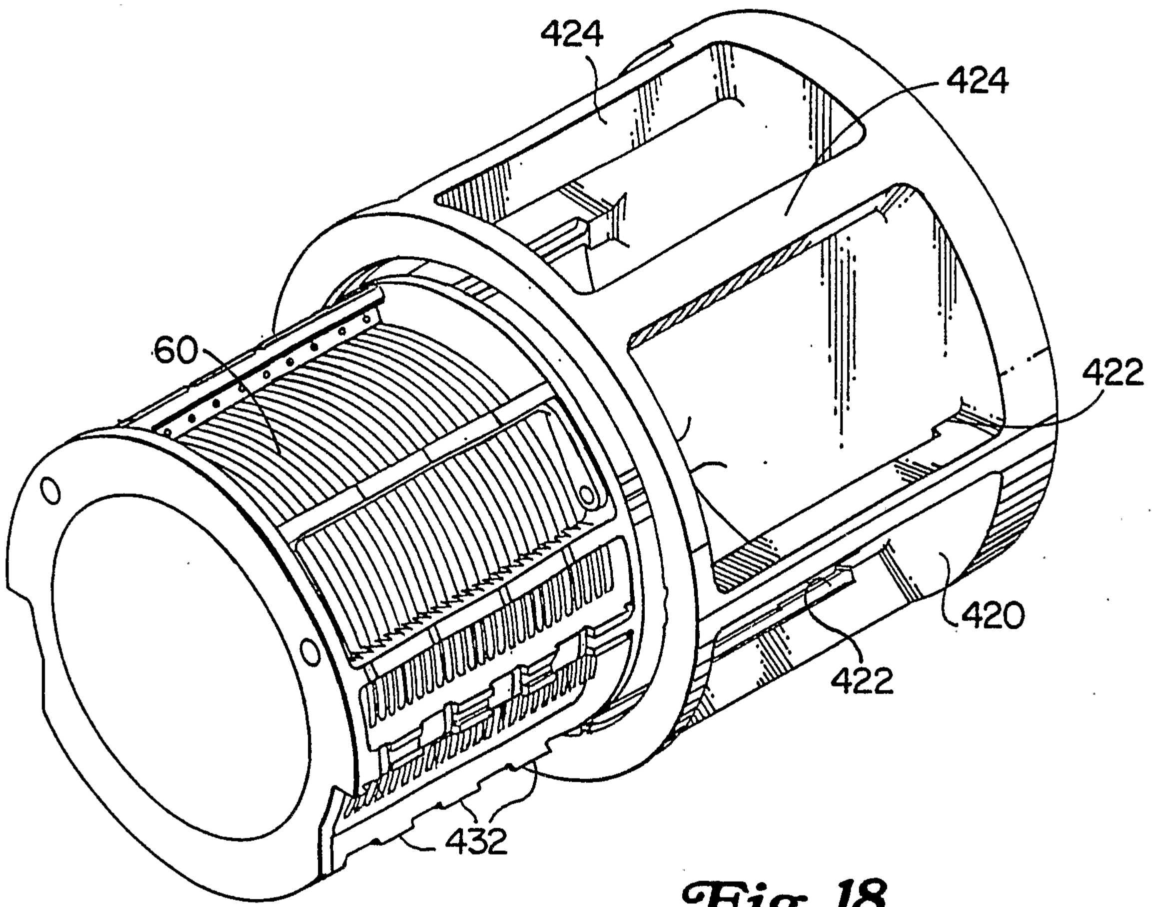


Fig. 16



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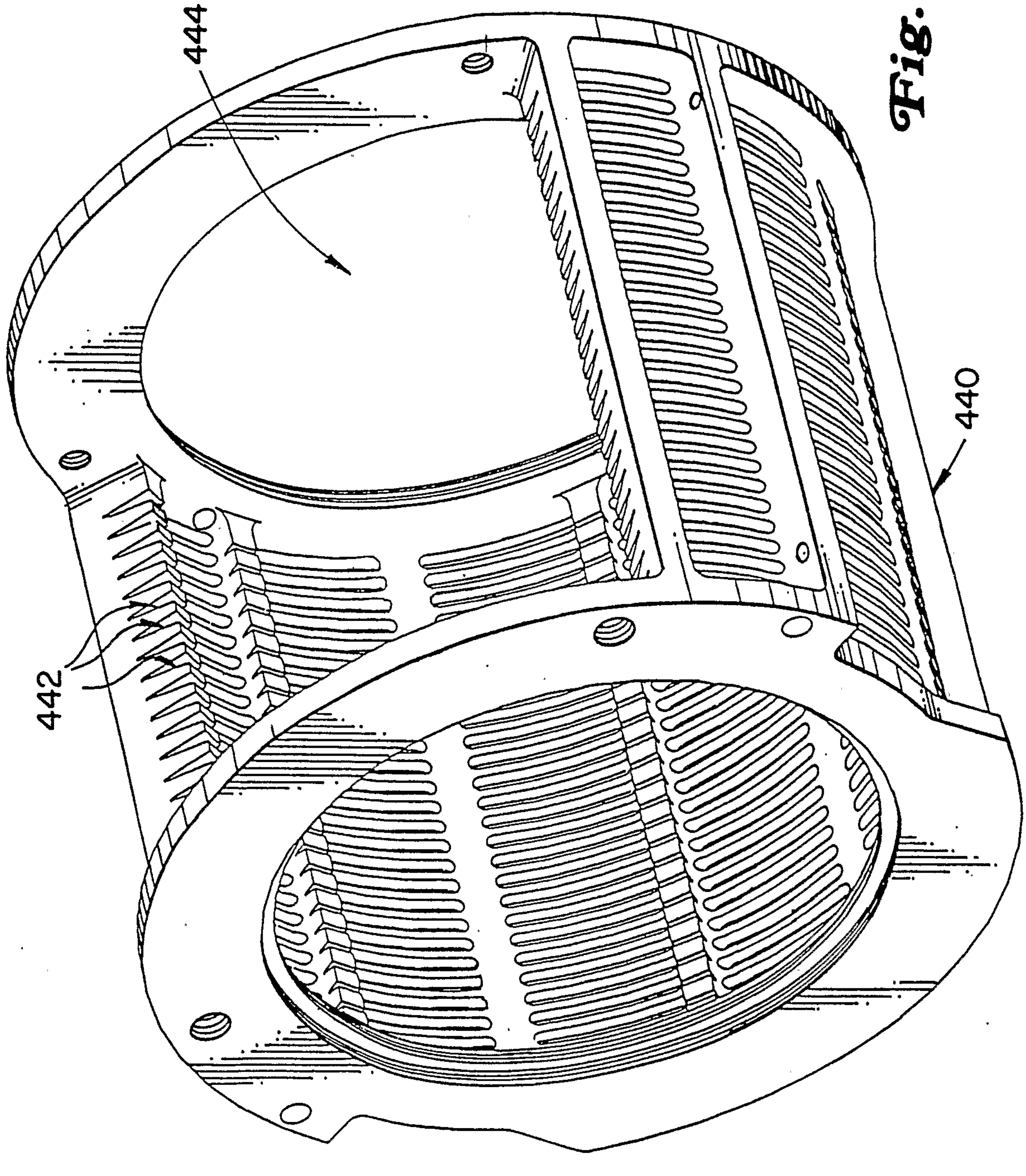

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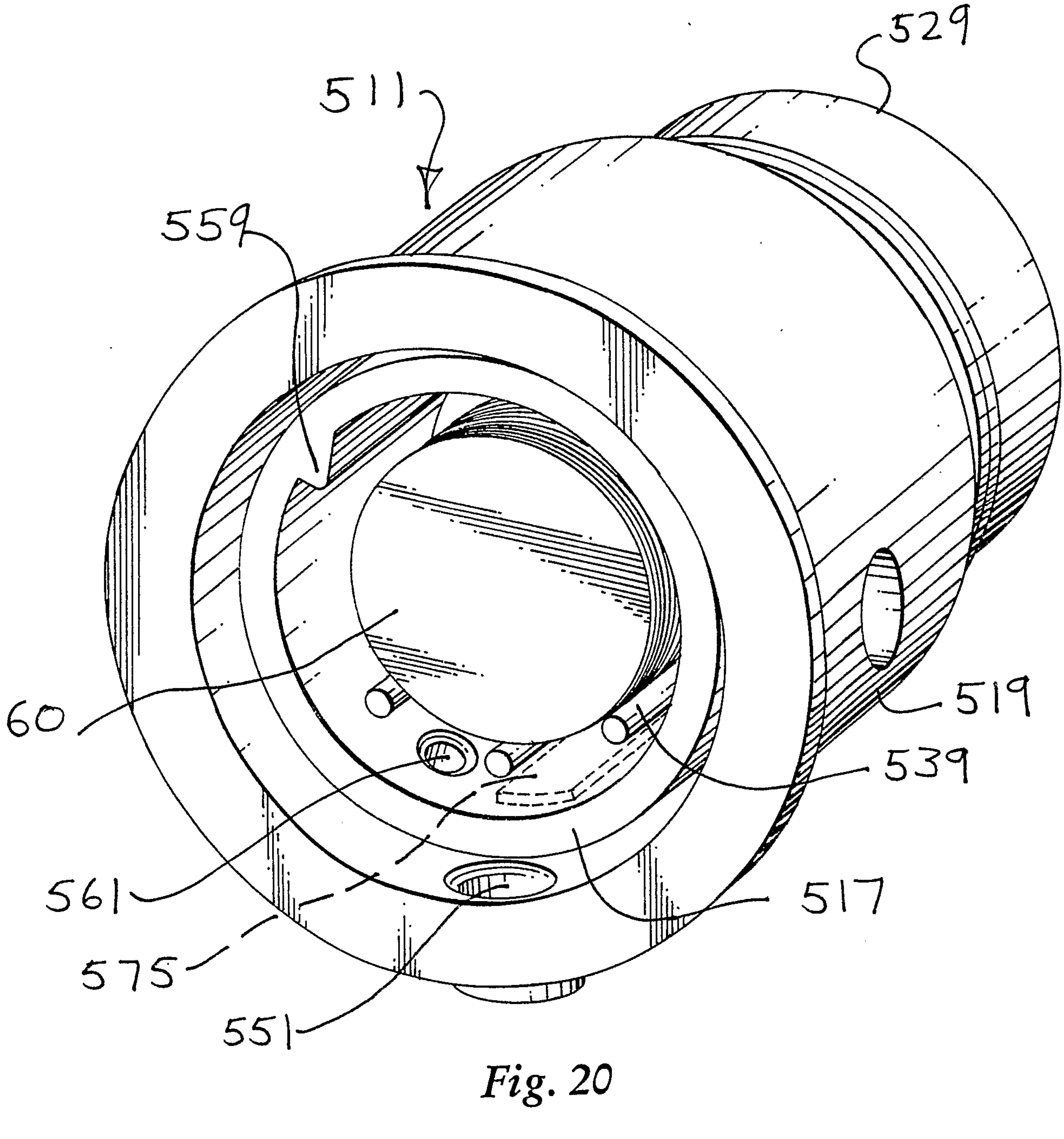

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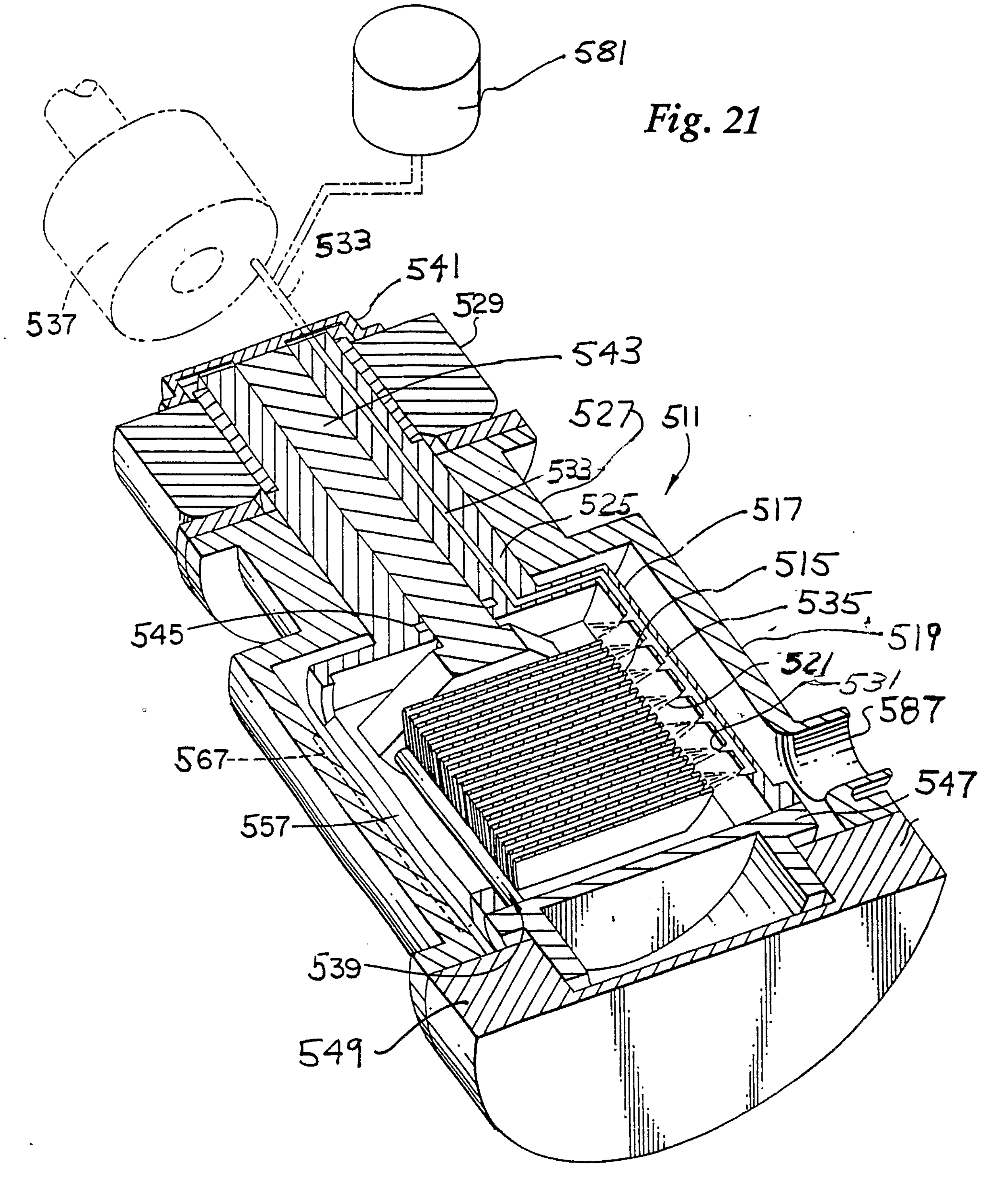
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Fig. 21

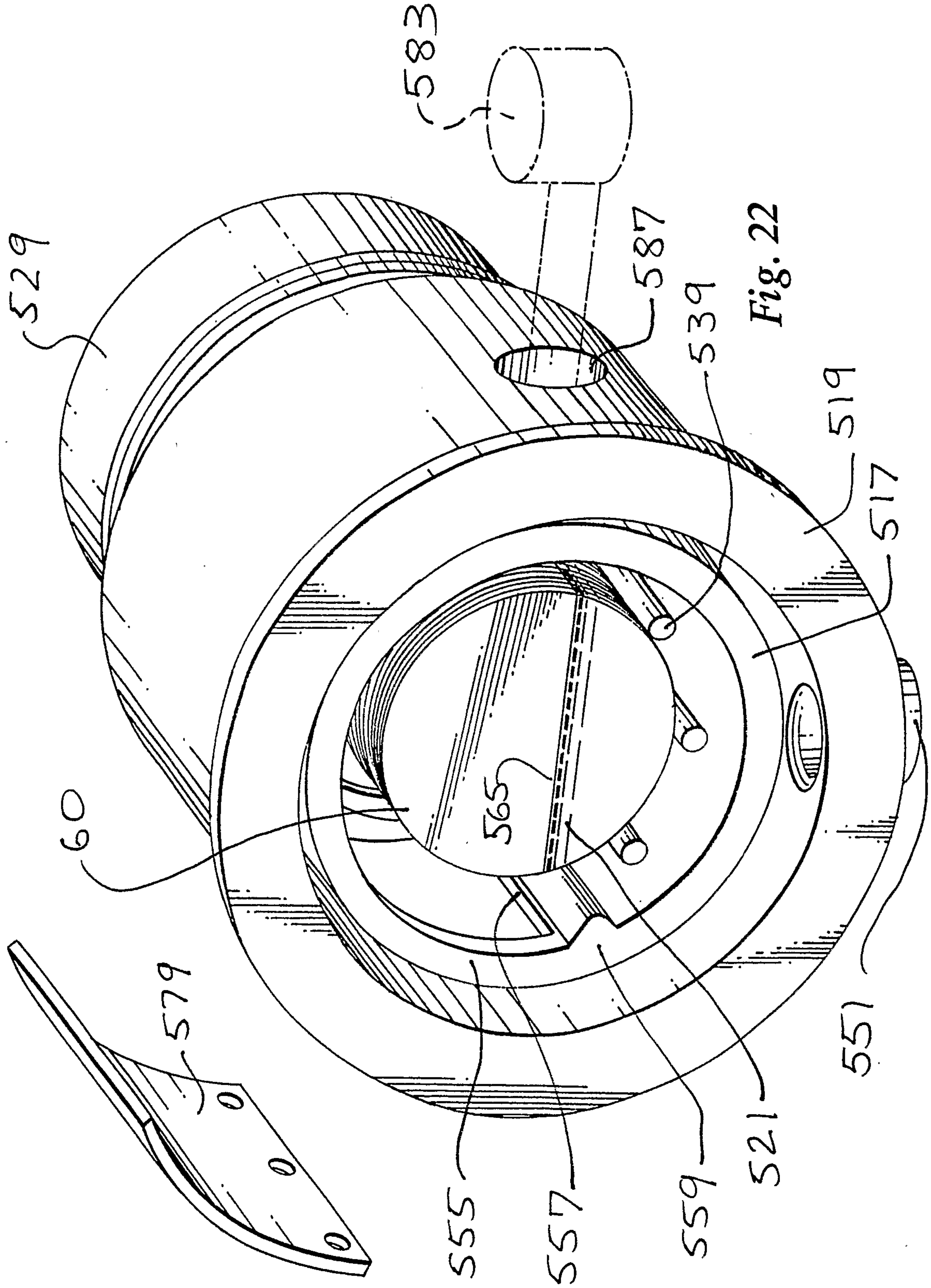


Fig. 22

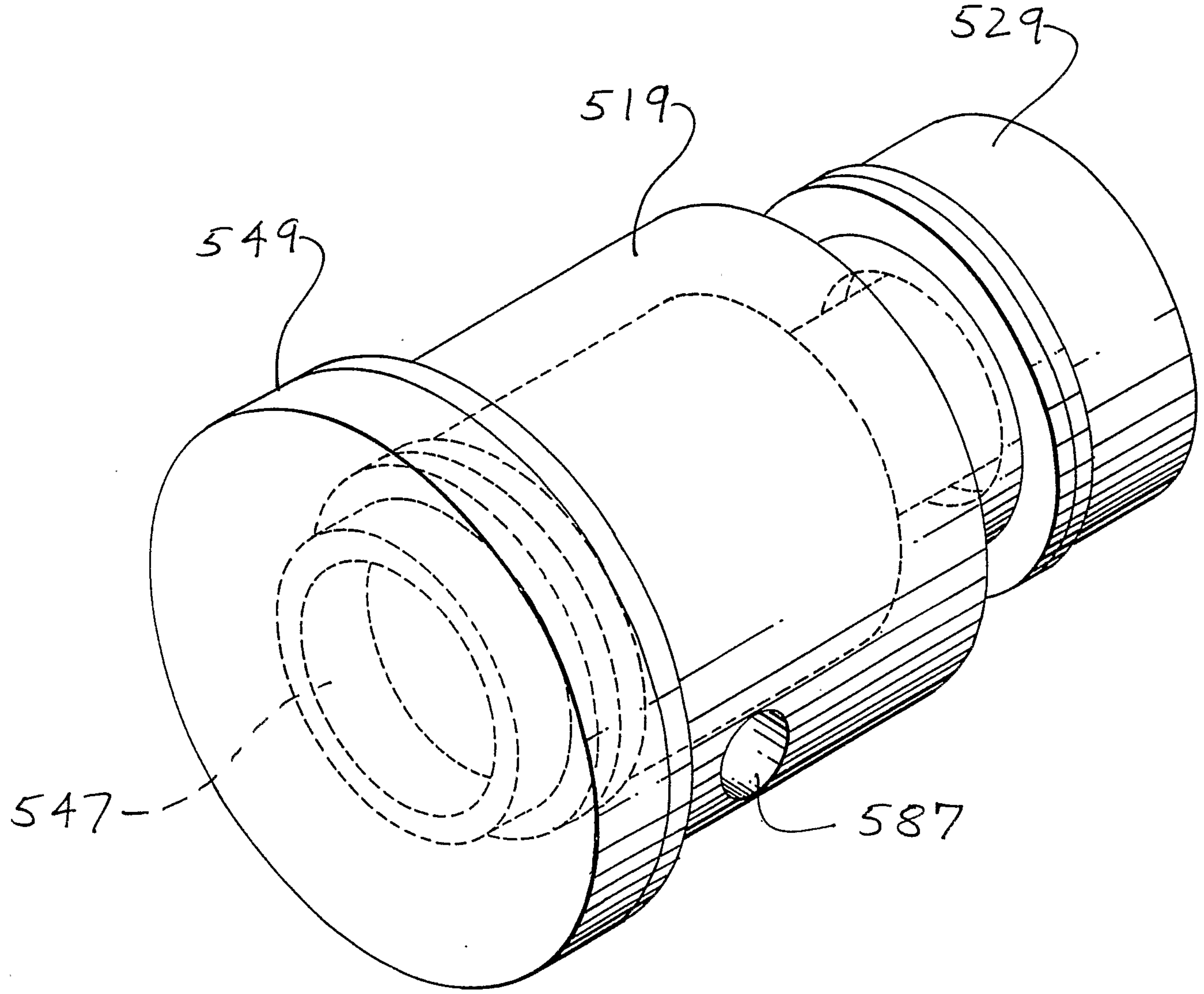


Fig. 23

Fig. 24

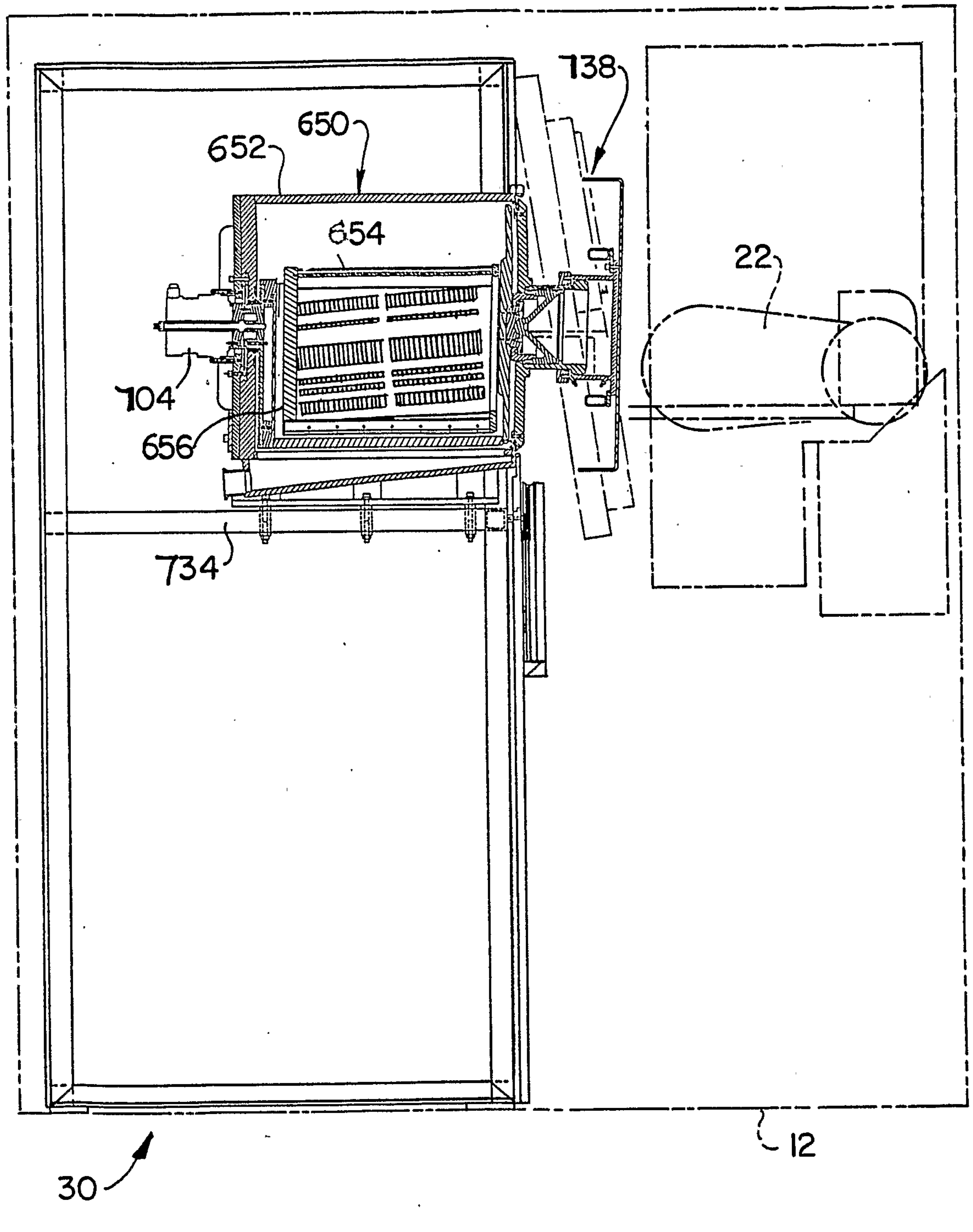
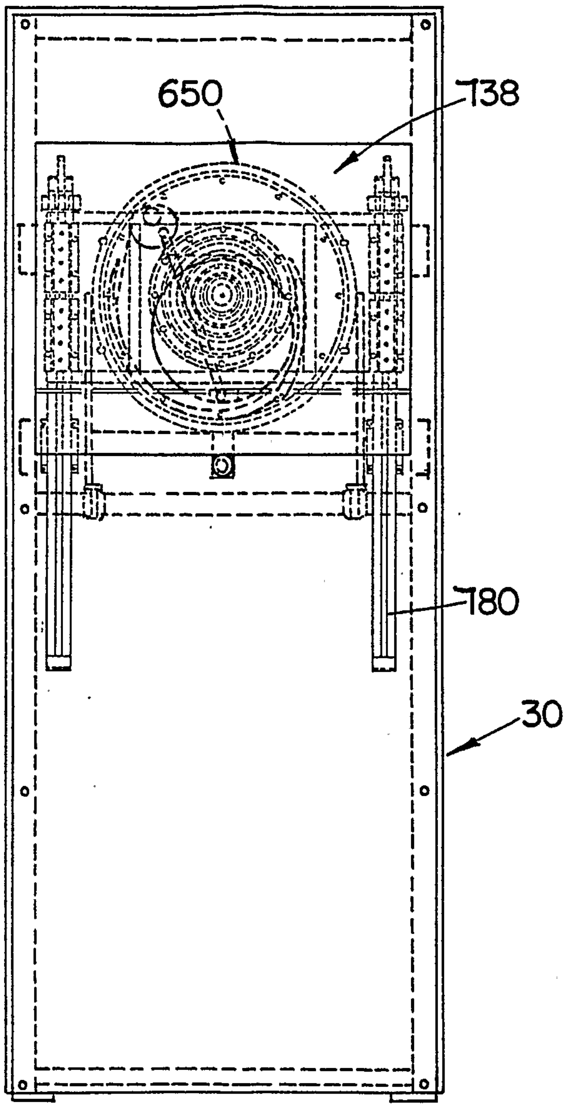
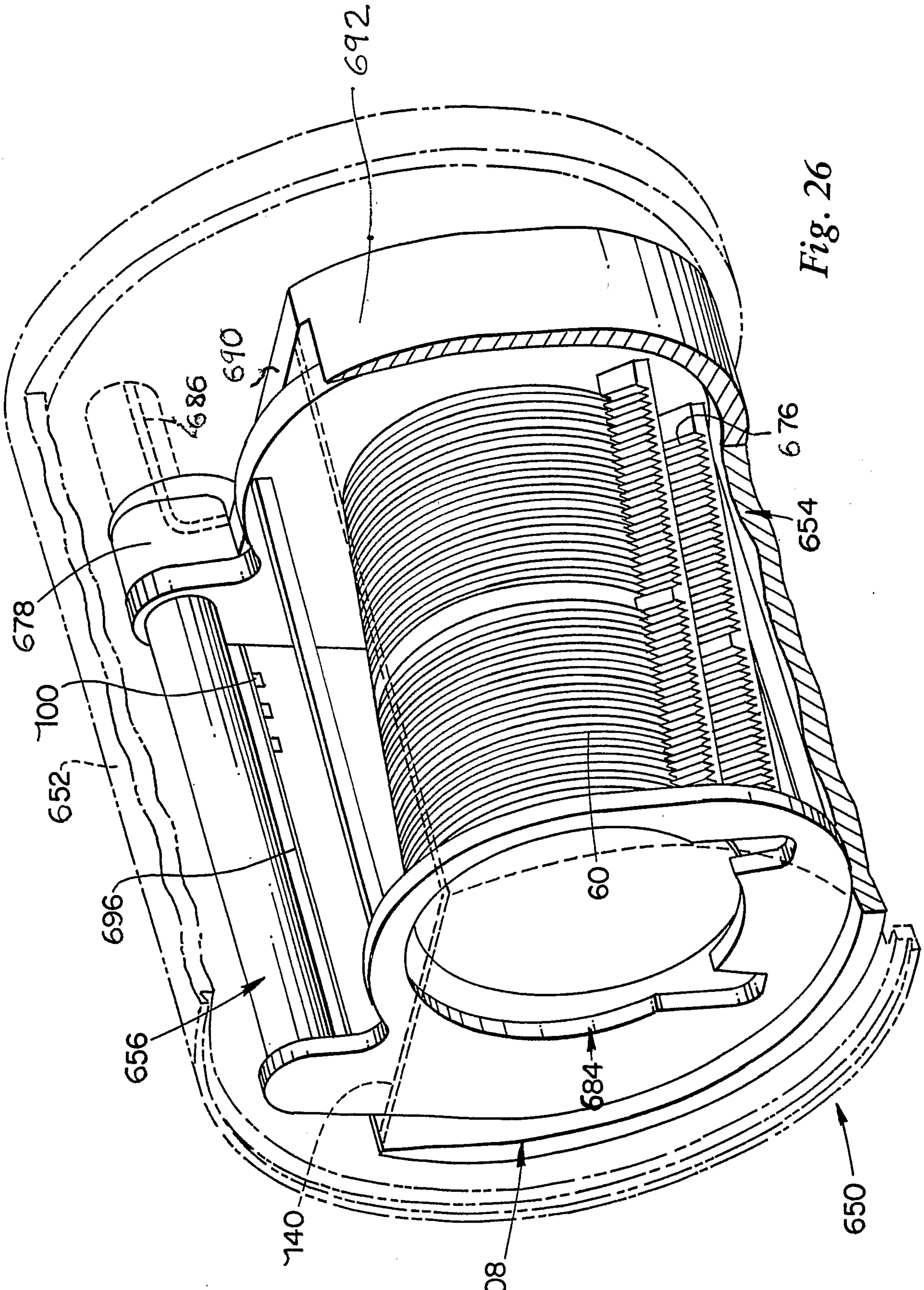


Fig. 25





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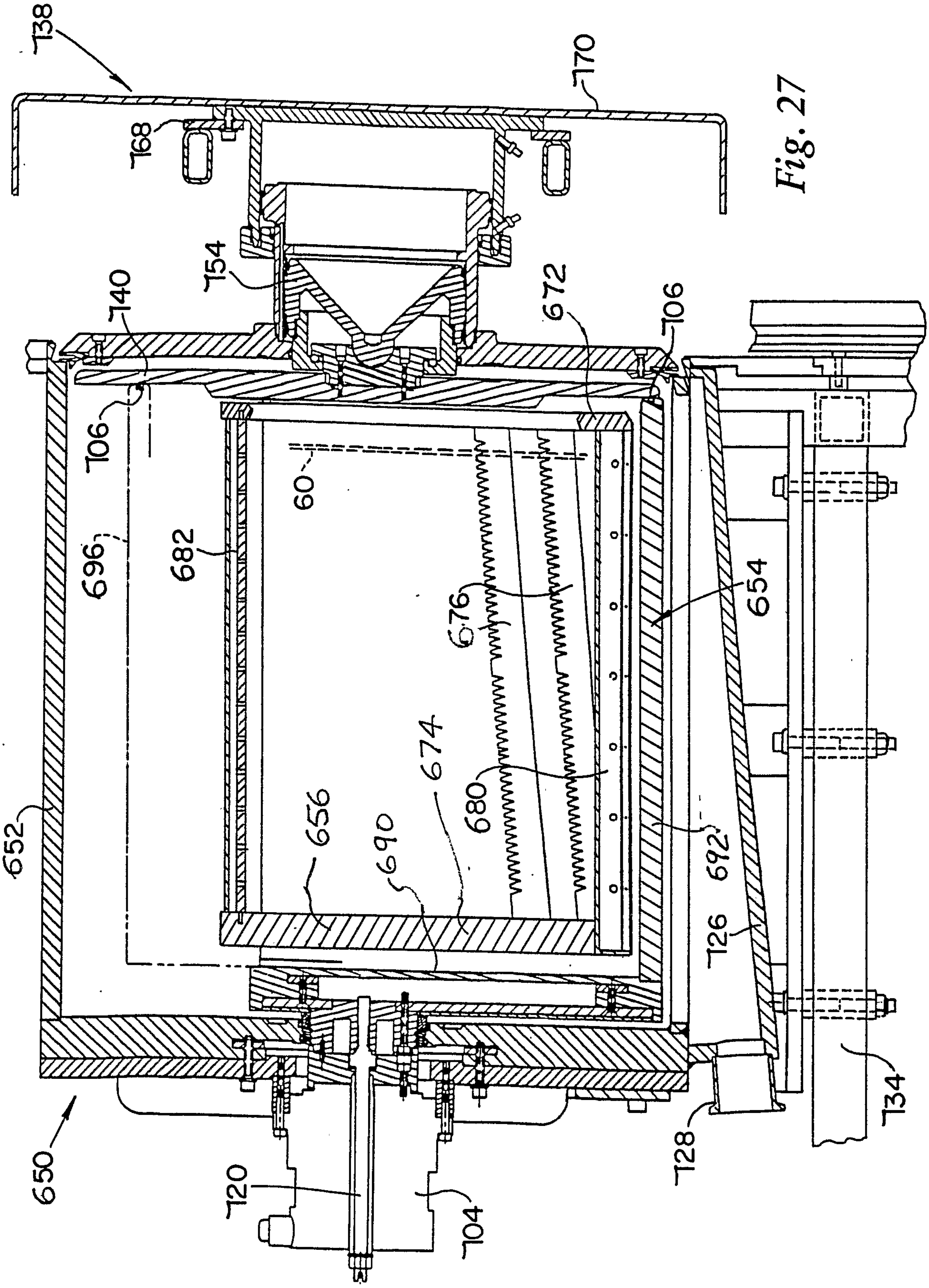
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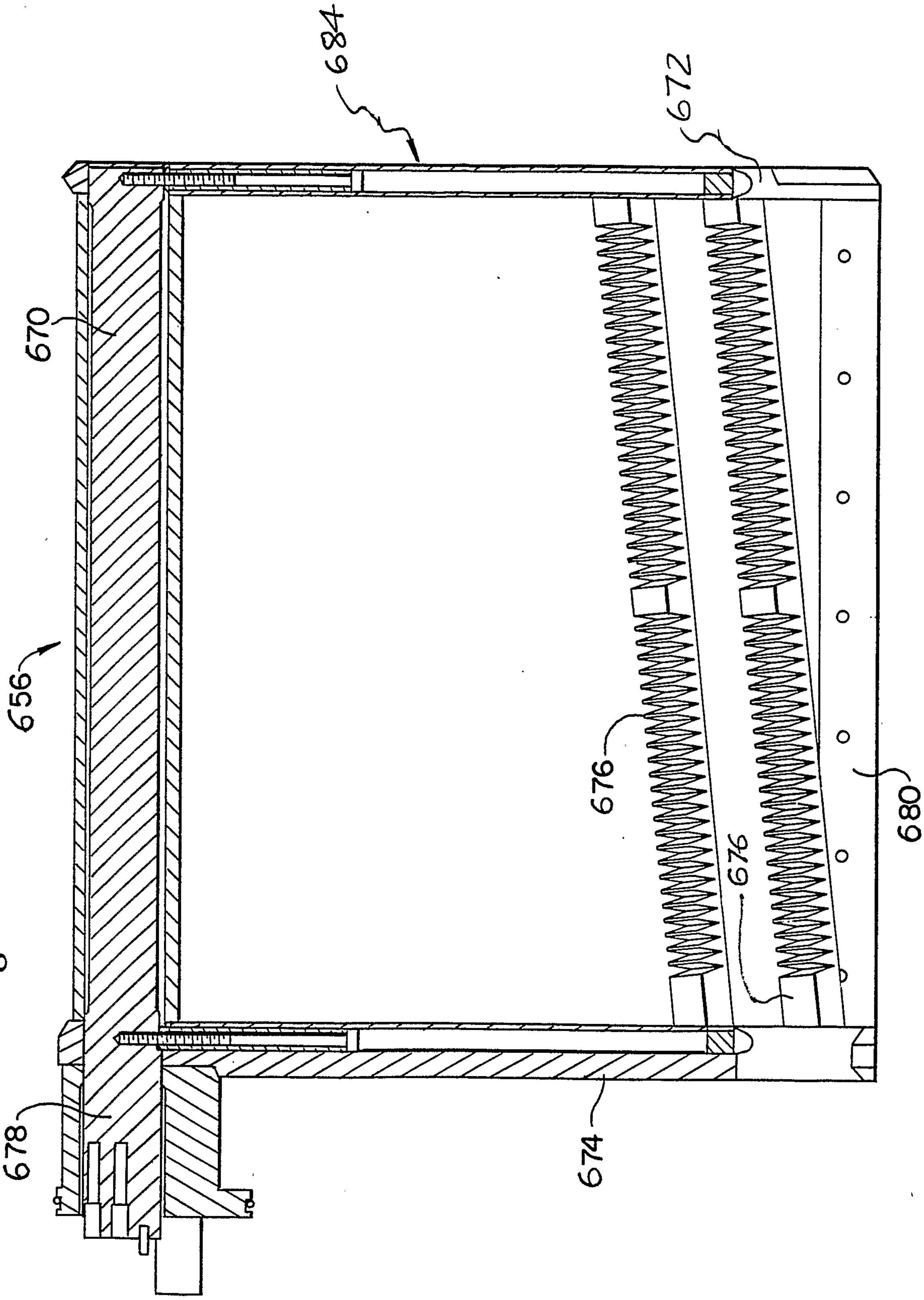
Fig. 27



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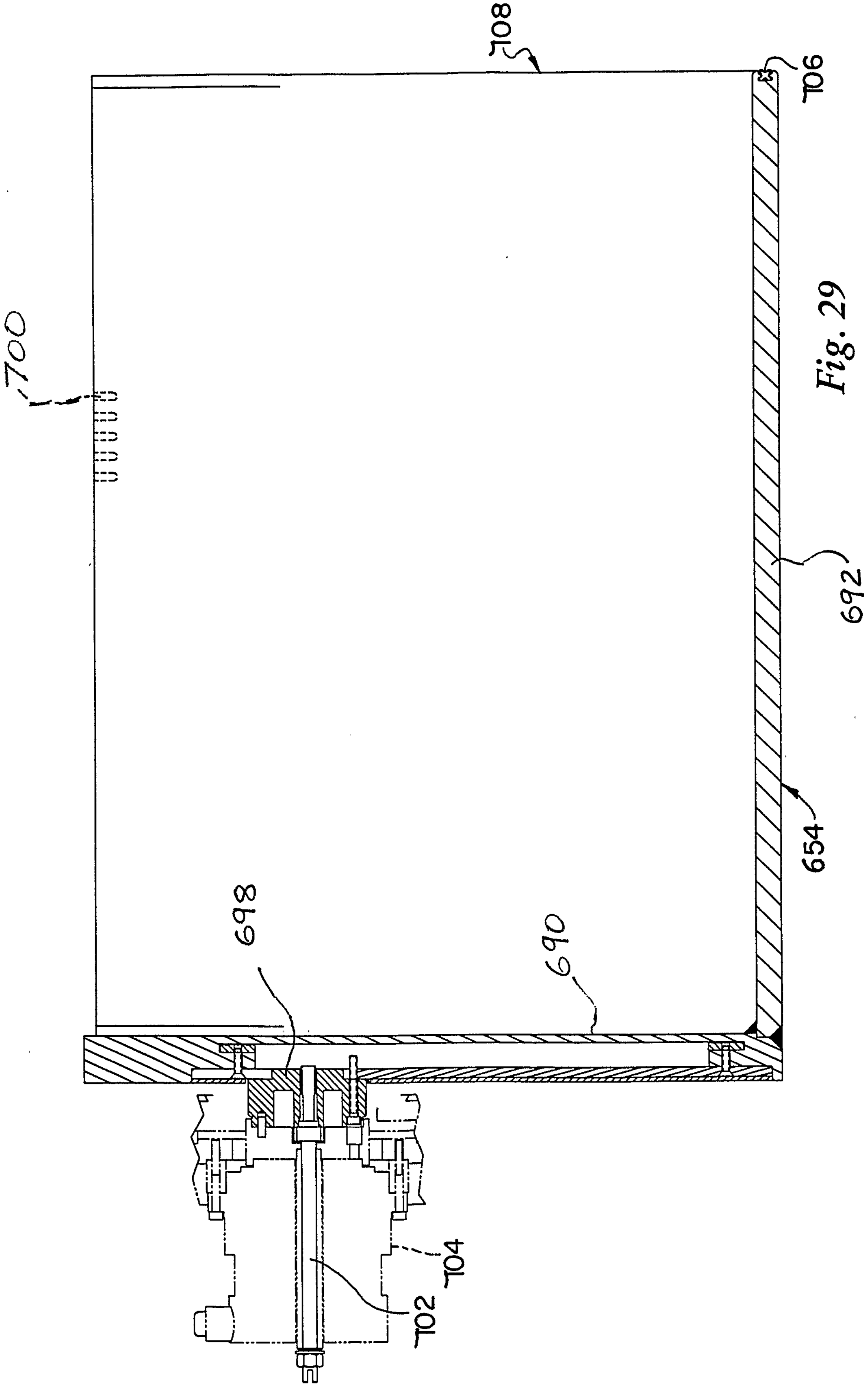

Fig. 29

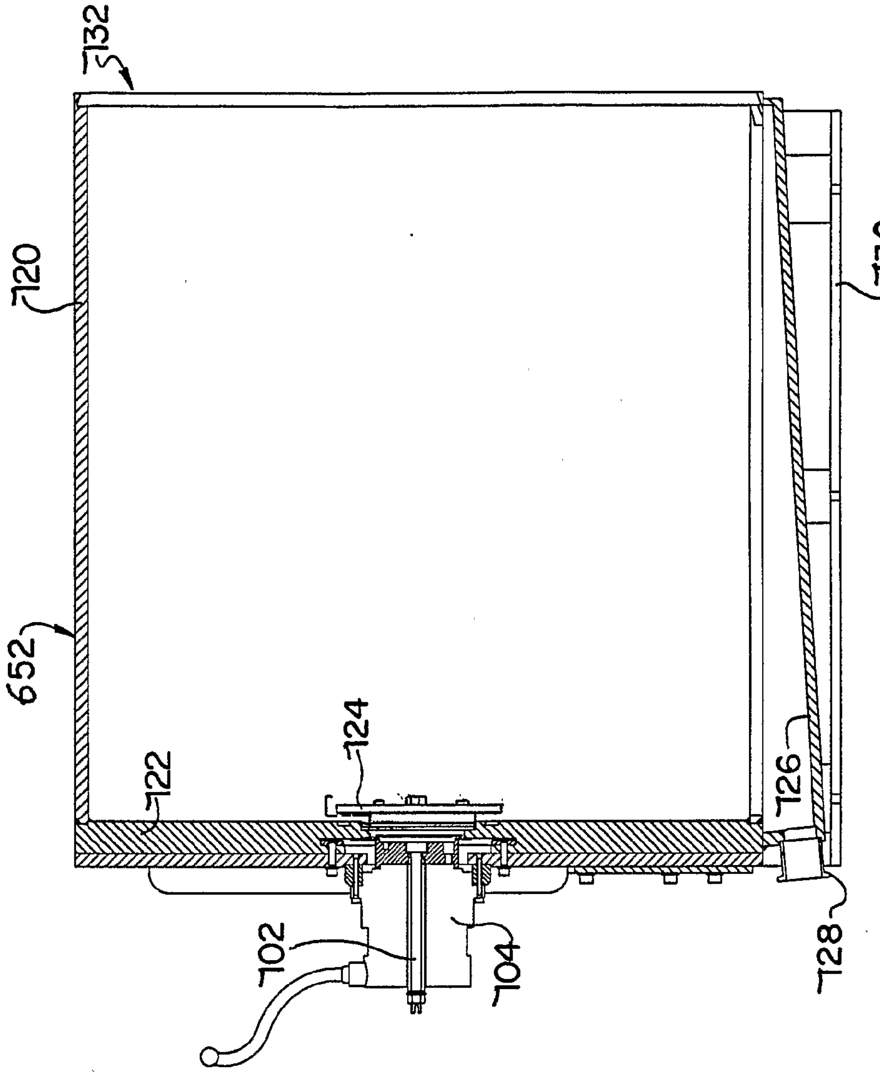

Fig. 30

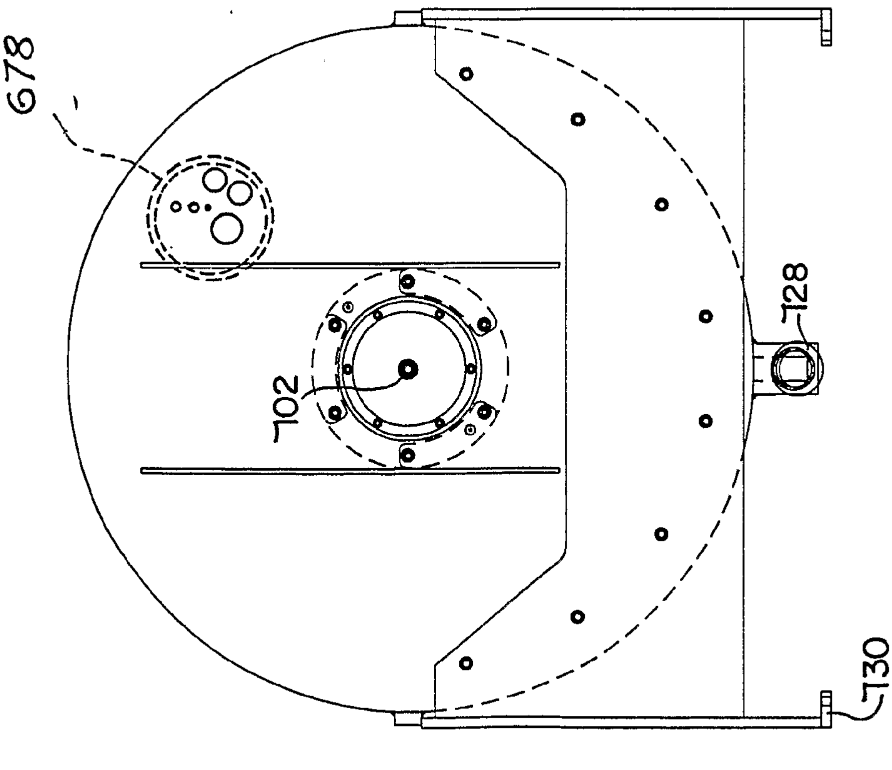

Fig. 31

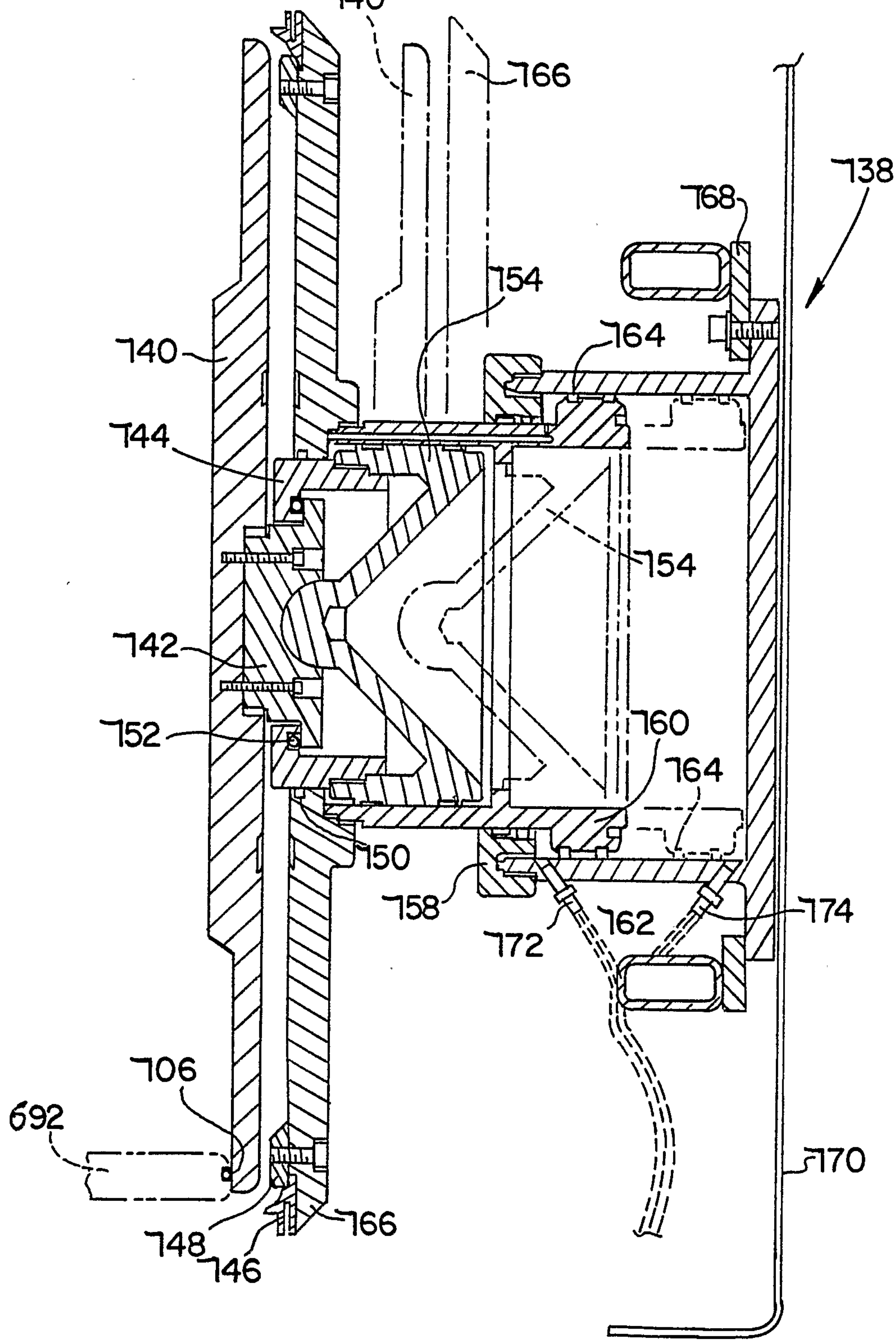
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Fig. 32

Fig. 33

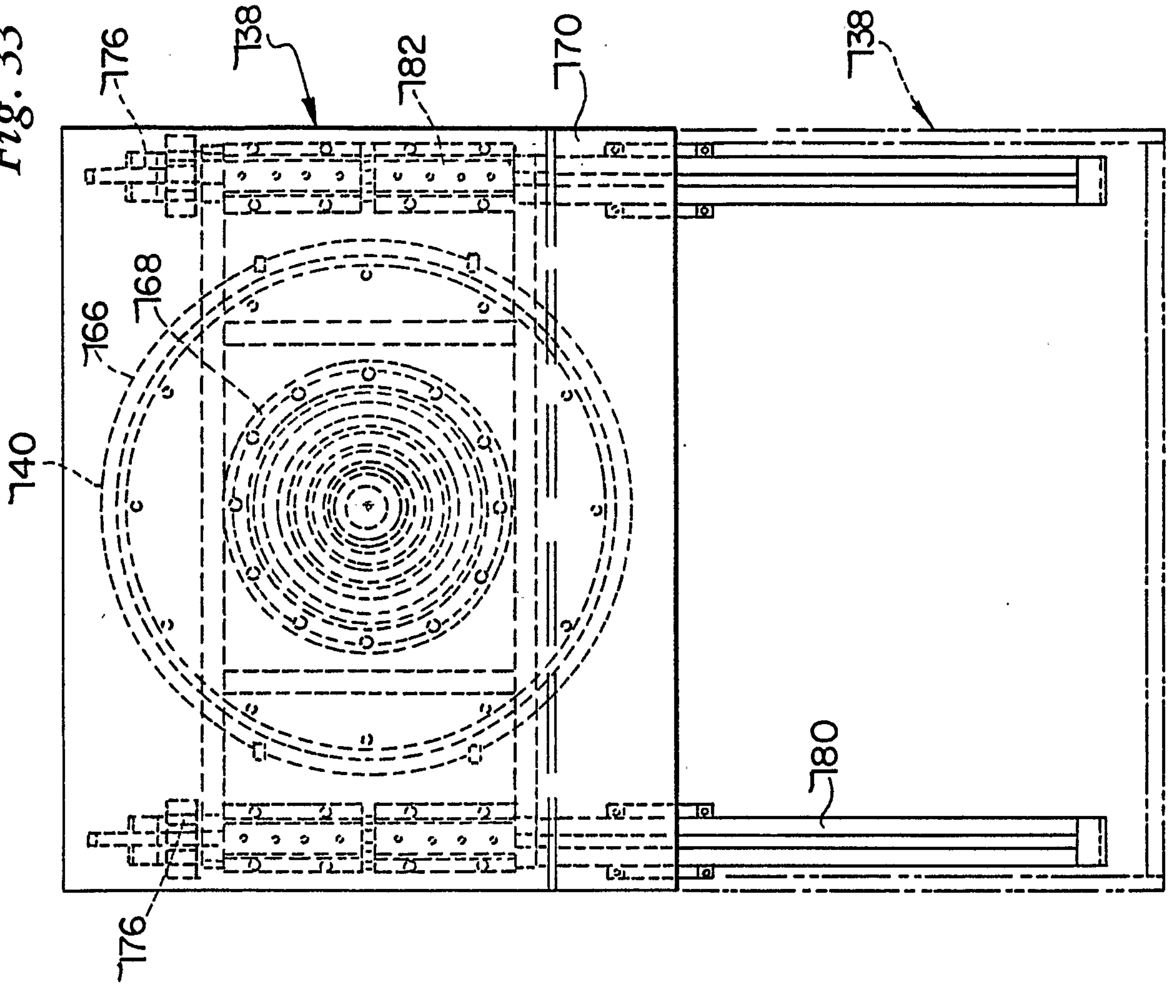
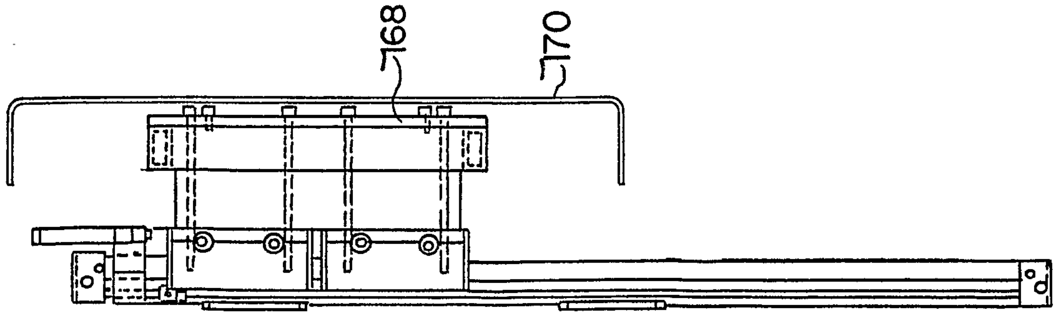


Fig. 34



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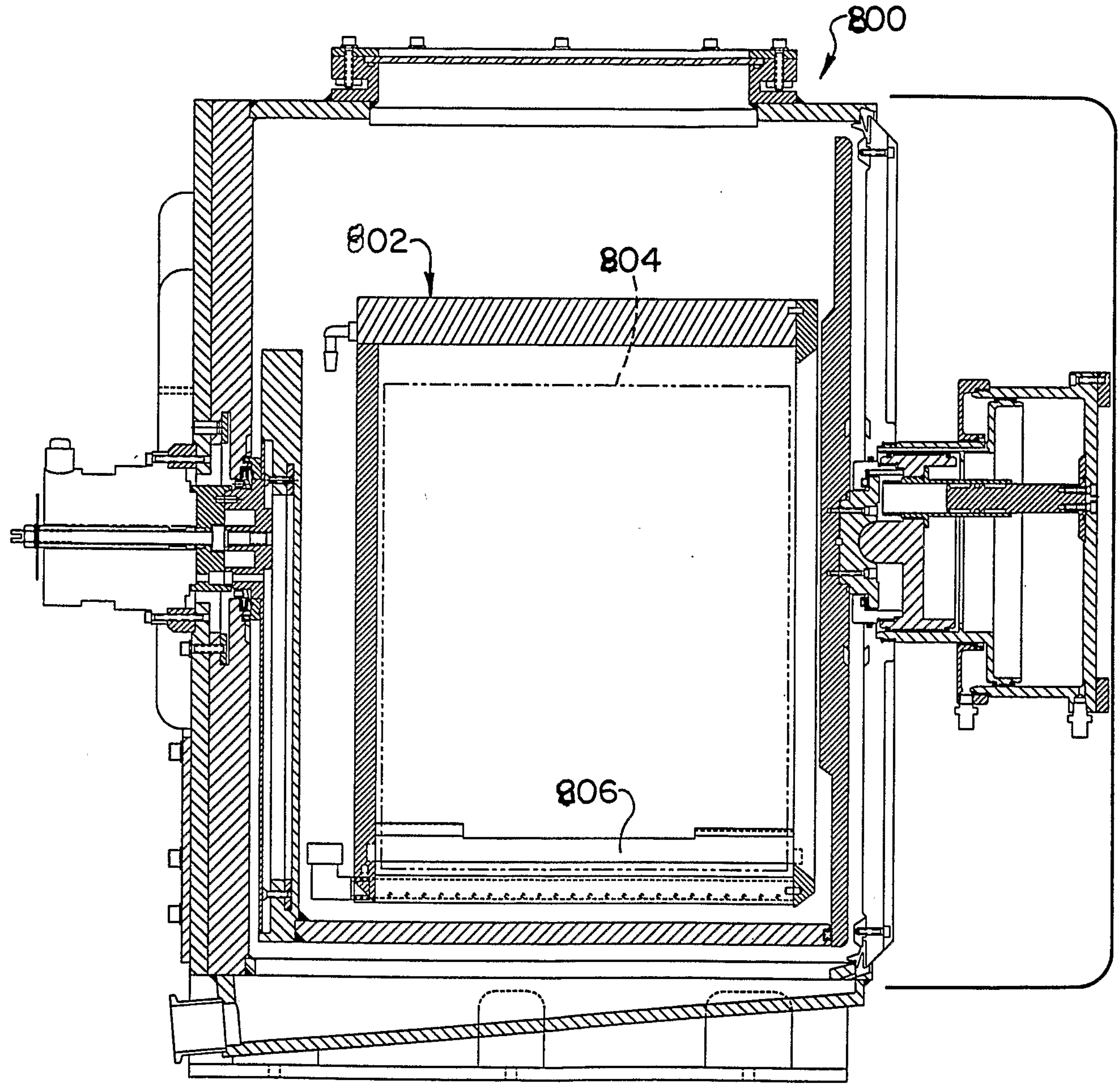

Fig. 36

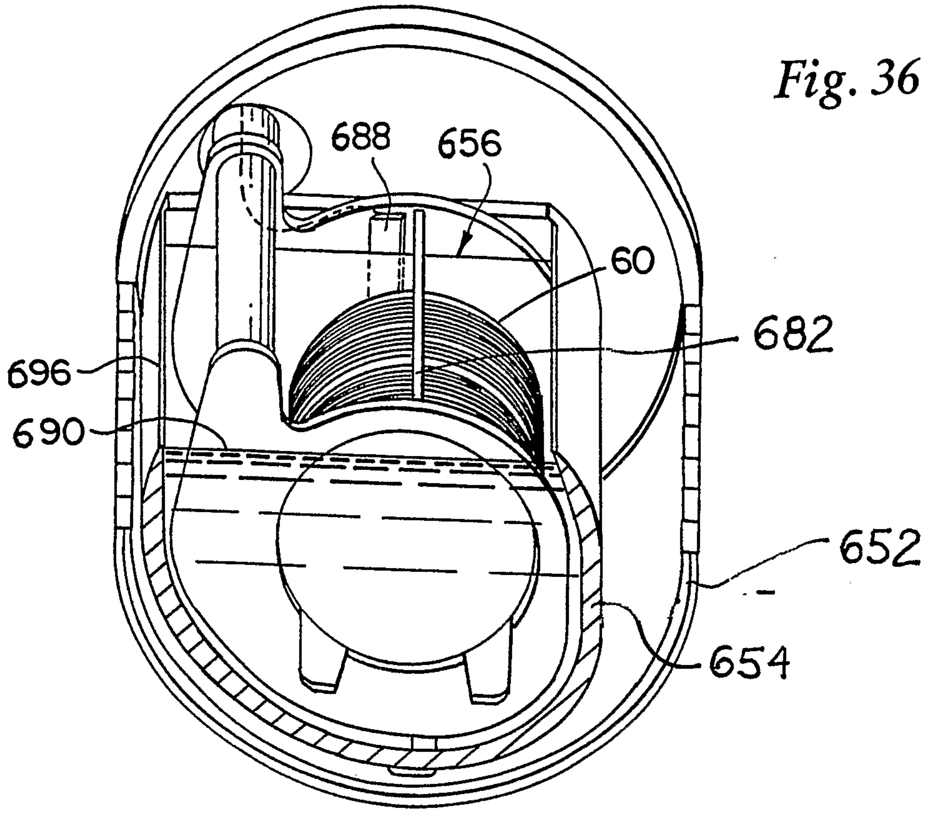
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Fig. 37

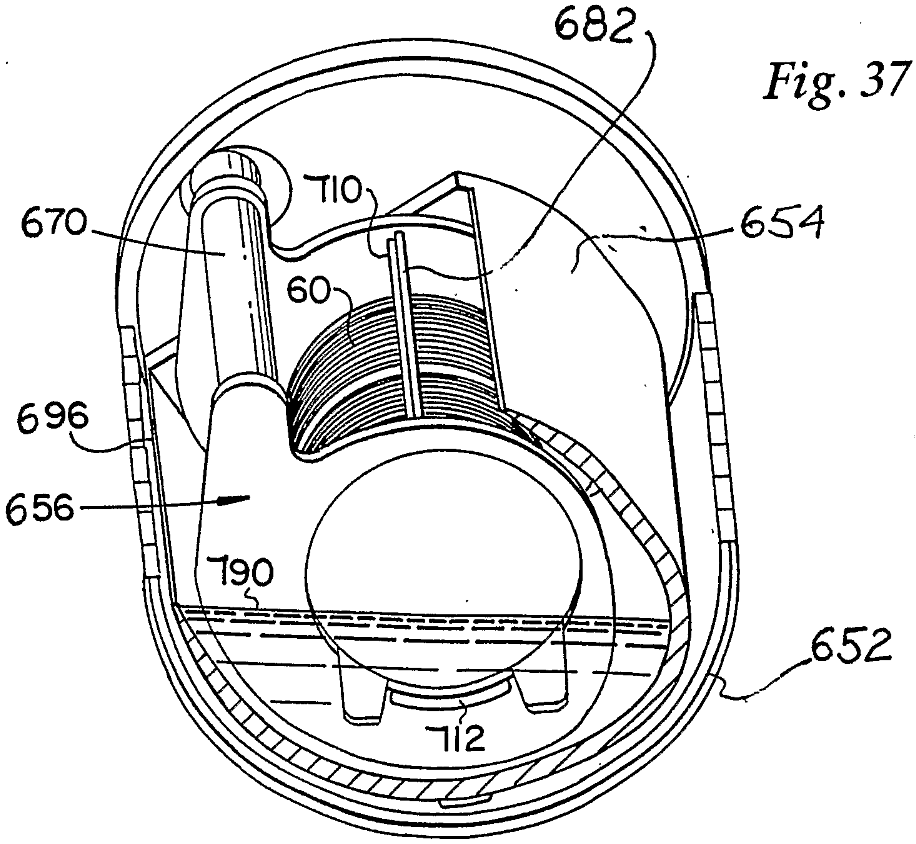
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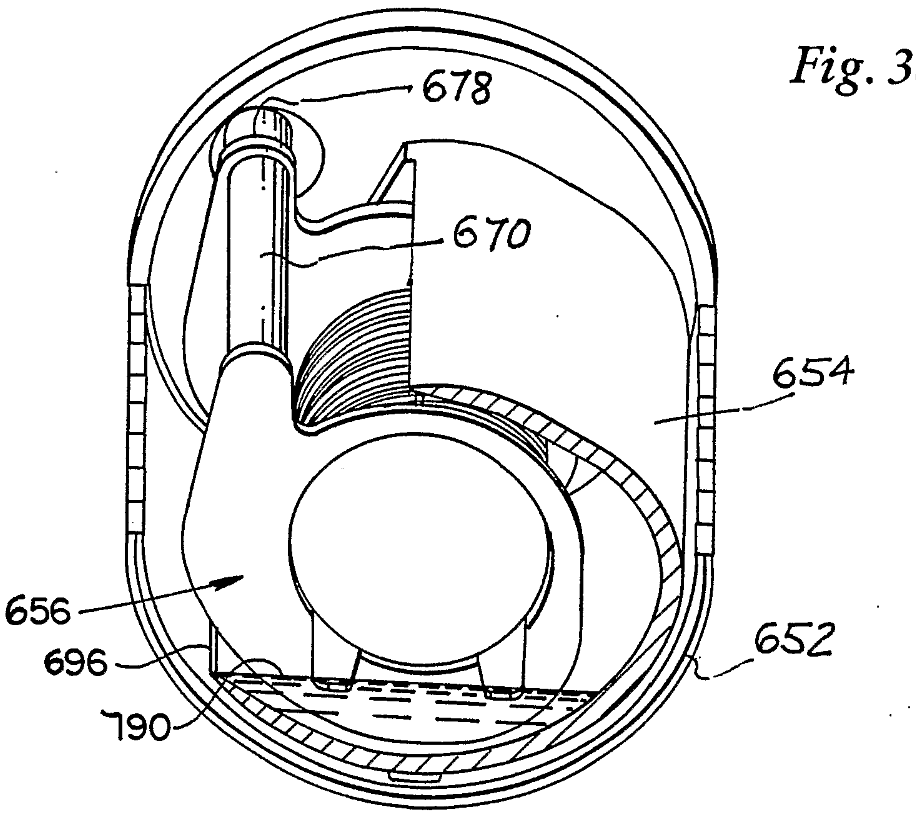
Fig. 38



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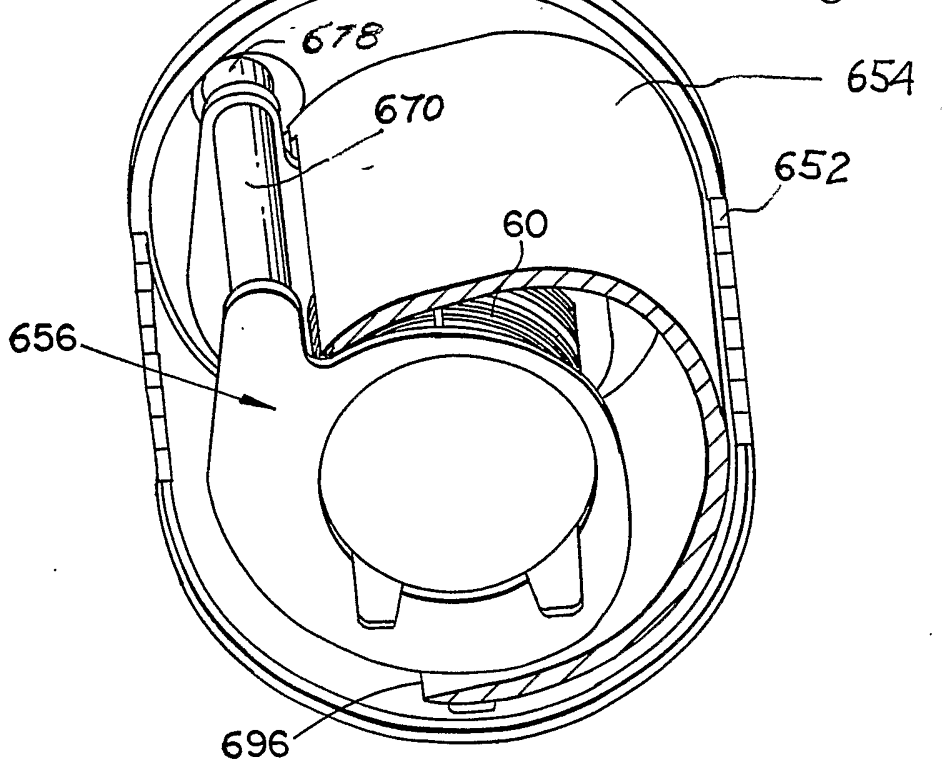

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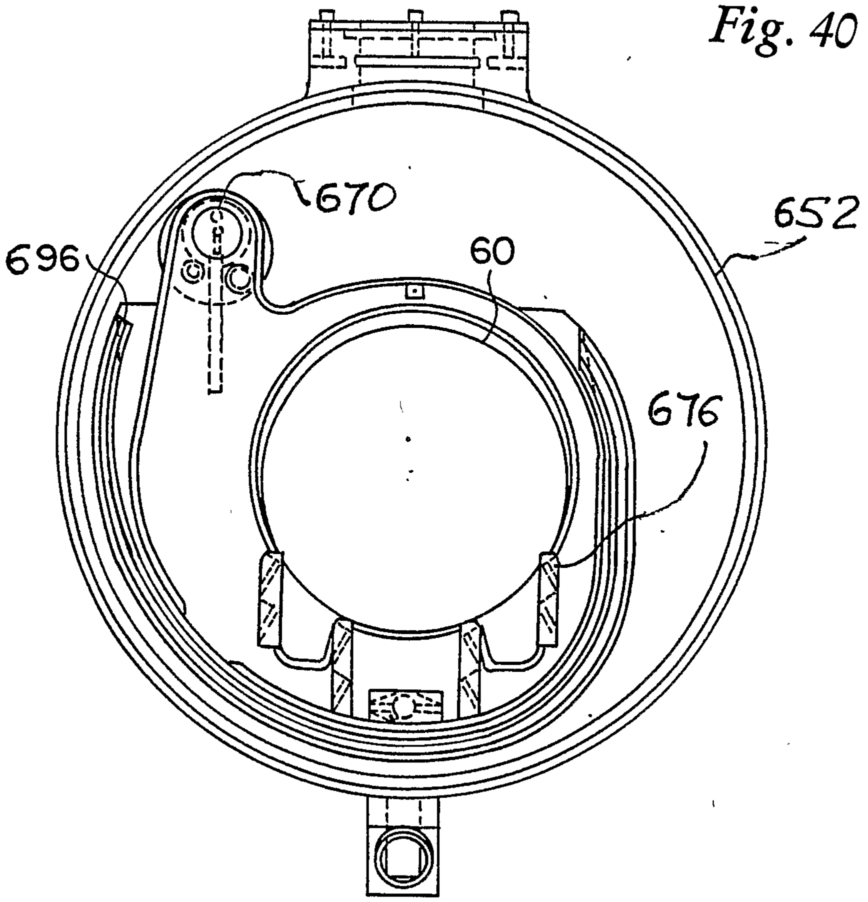

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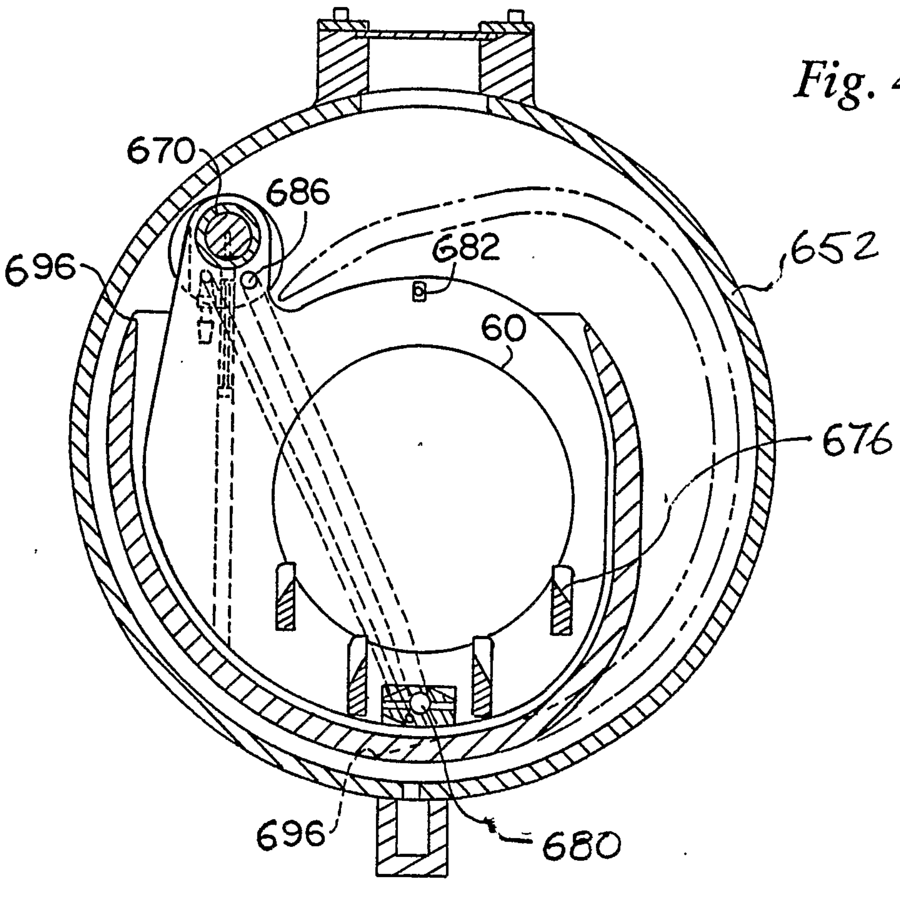

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US02/23296

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : B08B 3/00, 3/02, 3/04, 7/04
US CL : 134/26, 30, 117, 119, 120, 121, 902
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 134/26, 30, 117, 119, 120, 121, 902

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WEST search terms: chamber, pivot, drain, wafer, workpiece, rotor, opening

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,664,337 A (DAVIS et al) 09 September 1997 (09.09.1997), entire document.	1-92
A	US 5,660,517 A (THOMPSON et al) 26 August 1997 (26.08.1997), entire document.	1-92
A	WO 00/02675 A (SEMITOOL, INC.) 20 January 2000 (20.01.2000), entire document.	1-92

☐ Further documents are listed in the continuation of Box C.　☐ See patent family annex.

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"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

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

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

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Date of the actual completion of the international search	Date of mailing of the international search report
17 November 2002 (17.11.2002)	11 DEC 2002

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Alexander Markoff
Facsimile No. (703)305-3230	Telephone No. 703-308-0651

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