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(54) Title: FLUID POWERED SPINDLE

(57) Abstract: A fluid-powered high-speed spindle (100) having a longitudinal axis (A) defining an upper end defined by a shank and a lower end accepting a tool. The spindle includes a body (120), a rotatable shaft (530) supported by at least one bearing (508) within the body (120), a seal housing (150) connected to the body (120) at the lower end thereof, a cover (180) connected to the seal housing (150) at the lower end thereof, a fluid channel system for directing fluid from an entry port (102) to a nozzle (576) for turning a turbine (570) attached to the shaft (530); and a flinger (660) attached to the shaft (530) and positioned above the turbine (570). The flinger (660) and the seal housing (150) combine to form a non-contact seal (900) configured to impede the flow of fluid toward the at least one bearing (508).



Fluid Powered Spindle

Related Applications

[0001] Priority is claimed to U.S. Provisional Patent Application No. 61/877,453, filed September 13, 2013, the contents of which are incorporated by reference in their entirety.

Field of the Invention

[0002] This disclosure is directed to machine spindles used for rotating a tool and removing material from a work piece. Particularly, this disclosure is directed to high speed spindles to be used in combination with small diameter tools, the high speed spindles being driven by fluid, particularly liquid.

Background

[0003] Machining with small diameter tools, for example less than 8 mm diameter, requires high speed machining capability in the range of 20,000, 30,000, 50,000 and in some cases over 100,000 RPM. Small diameter tools are typically used for applications requiring small geometries as well as general purposes applications in the semi finish and finish processes of most manufactured parts. Machining with small diameter tools is also referred to as micro machining.

[0004] In micro machining, the required rotation speeds are higher while the power requirements are relatively low compared to non-micro machining. High speed machining for semi finish and finish processes requires effective cutting tool and cutting location cooling as well as effective chip removal.

[0005] Computerized machining centers typically include an Automatic Tool Changer (ATC), such that multiple machining operations can be performed on the same part, i.e. using different tools that are changed automatically by the ATC, without removing the part. This capability provides significant cost savings, reduces manpower requirements and improves manufacturing quality and yield.

[0006] Most machining centers use electrical motor driven spindles to rotate the machining tools. General purpose machining spindles rotate at speeds of a few thousands RPM. Spindles capable of higher RPM are expensive and often used on dedicated equipment. The result is that many smaller diameter cutting tools are used at suboptimal machining conditions or that parts requiring semi finishing and or finishing operations have to be moved to other machine centers, with higher speed spindles. Both options are problematic.

[0007] Present solutions such as speed increasers and other non-electric spindles are often susceptible to problems.

Summary

[0008] In a typical fluid driven high speed spindle, pressurized fluid is imparted onto turbine blades. The turbine, which is comprised of turbine blades and a central ring to which the blades are attached to, is mounted on the rotating shaft. In some cases, the shaft and central ring to which the blades are attached to, are integrated, i.e. the shaft and turbine blades are machined from one metal bar such that the central ring is part of the shaft.

[0009] The turbine blades are designed such that pressurized fluid that is imparted on at least one blade will cause the turbine and the shaft to rotate and that the fluid will deflect off the blade in a preferred direction.

[0010] Bearing lubrication is a critical factor affecting the reliability of high speed spindles. Contamination of the bearing lubricant by fluid, debris or moisture is one of the main reasons for bearing failure. Similarly, removal of a significant portion of the original bearing grease caused by fluid flow in the vicinity and/or through the bearings must be prevented in that it will affect the reliability and working life of the high speed spindle.

[0011] All rotating systems have a gap between the rotating parts and the stationary parts. In some systems, a seal is incorporated to prevent fluid from traversing the gap. Contact seals including a flexible contact component and/or a sacrificial friction surface are most common but their effectiveness is significantly reduced by high speeds and more so, in smaller diameter systems. Non-contact seal are typically expensive and bulky.

[0012] There are cases in which a portion of the fluid, does not exit the turbine in the preferred direction. In such an event, fluid may seep into the bearing cavity via the gap between the stationary body of the high speed spindle and the rotating parts, e.g. the shaft.

[0013] In some other cases, the high pressure fluid retains small particles of solid debris even after being filtered.

[0014] In yet other cases, fluid may seep into the bearing cavity when the high speed spindle is stored in an automatic tool changer (ATC) or in storage in a horizontal or upside down (cutting tool up) position, after a machining session. In such an occurrence, residual fluid that is on the turbine blades,

shaft and other parts of the system, may seep into the bearing cavity via the gap between the stationary body of the high speed spindle and the rotating parts.

[0015] The phenomenon described herein is problematic in that bearing's performance degrades rapidly when the bearing comes in contact with debris and fluids, including droplets, spray, humidity etc. Performance degradation includes a reduction in stiffness which will lead to a reduction in machining accuracy. It will also reduce the bearing life span due to damage to the bearing rolling elements and or to the bearing races.

[0016] Causes for bearing damage include: changes in the lubricant properties caused by the fluid; and/or a reduction in the amount of lubricant available in the bearing because a portion of it has been washed of by the fluid; small solid debris particles that enter spaces between the bearing rolling elements and bearing races; change to the surface properties of the bearing rolling elements and or to the bearing races due for example to oxidation and/or contamination.

[0017] Reducing the gap distance between the stationary parts and the rotating parts is part of the solution. However, reducing the gap to a distance small enough such that high pressure fluid will not seep through while preventing friction contact between the parts is neither practical nor economical.

[0018] Friction components such as flexible contact seals that can prevent fluid seepage, or sealed bearings that insulate the bearing components, are used in larger and slower systems. However, they are not practical in small diameter systems designed for high speed and high fluid pressure. The seals tend to wear rapidly at the contact point (or contact line), resulting in reduced efficacy of the seal and introduction of debris into the system. Furthermore the friction caused by the seals reduces the amount of power available to the cutting process and the heat generated by the friction may require a cooling system.

[0019] Thus there is a need for sealing solutions that are economically effective for small high speed rotational systems and in particularly in systems incorporating high pressure fluid in the vicinity of the bearings.

[0020] The present invention may be cast in the form of the following paragraphs.

[0021] Paragraph 1. A liquid powered spindle (100) having a longitudinal axis (A) defining an upper end and a lower, shaft-tool end (598), comprising:

- a) a body (120) having a spindle cavity (440);

- b) at least one bearing (508) disposed in the cavity (440);
 - c) a shaft (530) supported by the at least one bearing (508) within the cavity (440);
 - d) a seal housing (150) connected to the body (120) at the lower end thereof;
 - e) a cover (180) connected to the seal housing (150) at the lower end thereof;
 - f) a fluid channel system for directing liquid from an entry port (102) to a nozzle (576);
 - g) a turbine (570) attached to the shaft (530), the turbine in fluid communication with the at least one nozzle for rotating the shaft; and
 - h) a flinger (660) attached to the shaft (530) and positioned above the turbine (570);
- wherein the seal housing (150) defines an annular fluid manifold (552) surrounding the shaft (530) for distributing liquid, deflected upward by the turbine (570), into a plurality of stationary fluid exit channels (556);
- wherein the flinger (660) and the seal housing (150) combine to form a non-contact seal (900) configured to impede the flow of liquid toward the at least one bearing (508).

[0022] Paragraph 2. The spindle of Paragraph 1, wherein the seal housing (150) further defines:

a major turbulence pocket (512) is defined by a recess (924) within the seal housing, and positioned adjacent to the shaft (530), the major turbulence pocket being disposed above the annular fluid manifold (552) and the flinger (660).

[0023] Paragraph 3. The spindle of Paragraph 2, wherein the recess (924) has a shoulder (934) extending from the radial inner portion thereof such that the recess is capable of retaining liquid when the spindle is inverted.

[0024] Paragraph 4. The spindle of Paragraph 2, wherein the major turbulence pocket (512) includes a large opening (926) facing the annular fluid manifold (552) and a small opening (936) defined by a gap between the seal housing (150) and the flinger (660), wherein turbulence within the liquid, impedes flow of the liquid into the small opening (936).

[0025] Paragraph 5. The spindle of Paragraph 4, wherein the seal housing (150) further defines a minor turbulence pocket (914), the minor turbulence pocket (914) in communication with the small opening (936), the minor turbulence pocket (914) defined by a step-like feature (916) adjacent to the

inner diameter of the seal housing (150), wherein the minor turbulence pocket (914) further impedes flow of the liquid through a vertical gap (922) between the seal housing (150) and the shaft (530).

[0026] Paragraph 7. The spindle of Paragraph 1, wherein the body (120) further comprises a vent (450) between the spindle cavity (440) and the exterior of the body, wherein the vent is sealed with a vent gasket (2054) capable of allowing flow in both directions.

[0027] Paragraph 9. The spindle of Paragraph 1, further comprising a sensor module (130) in communication with at least one aperture (334, 335) formed in the body (120), wherein the at least one aperture allows the sensor module to sense at least one physical property of the spindle.

[0028] Paragraph 11. The spindle of Paragraph 1, wherein the fluid channel system comprises:

- i) the entry port (102) associated with a shank (110);
- ii) a shank channel (416);
- iii) at least one primarily horizontal fluid channel (422) extending from the end of the shank channel;
- iv) at least one primary vertical fluid channel (426) extending from the at least one primary horizontal fluid channel through the body; and
- v) the at least one nozzle (576) in fluid communication with the at least one primary vertical fluid channel.

[0029] Paragraph 12. The spindle of Paragraph 1, wherein the spindle comprises a wrench grip (214) positioned between the body (120) and a shank (110) to accept a wrench and assist with mounting the spindle to a chuck.

[0030] Paragraph 14. The spindle of Paragraph 1, wherein the cover (180) comprises at least one first axial exit opening (588) at the bottom thereof, the at least one first axial exit opening (588) provides an exit for the liquid directed downward by the turbine (570).

[0031] Paragraph 15. The spindle of Paragraph 14, wherein the cover (180) comprises at least one second axial exit opening (586) disposed radially outward with respect to the at least one first axial exit

opening (588), the at least one second axial exit opening in fluid communication with the annular fluid manifold (552) in order to discharge the liquid deflected upward by the turbine (570).

[0032] Paragraph 16. The spindle of Paragraph 15, wherein the cover (180) comprises at least one axial fluid exit channel (982, 984) communicating with the at least one second axial exit opening (586), the axis of the axial fluid exit channel being angled with respect to the shaft (530) such that liquid exiting the at least one second axial exit opening (586) will be directed toward the longitudinal axis (A).

[0033] Paragraph 17. The spindle of Paragraph 1, wherein the at least one bearing is a plurality of bearings, and the plurality of bearings are of different types or dimensions.

[0034] Paragraph 19. The spindle of the Paragraph 1, wherein the at least one nozzle (576) is formed along the inner diameter of a nozzle ring (977), the nozzle ring (977) is disposed within the cover (180) to define a nozzle fluid manifold (578), wherein the at least one nozzle (576) is angled relative to the radial direction of the shaft (530) in order to impact with maximum force of the fluid on the turbine (570).

[0035] Paragraph 23. The spindle of Paragraph 1, wherein the body (102) comprises:

a) a shell (2120); and

b) a core (2130), the core comprising:

i) a bearing housing cavity (2142) surrounding the spindle cavity (440); and

ii) a shank (110); and

wherein the the fluid channel system further comprises:

i) the entry port (102) associated with the shank (110);

ii) a shank channel (416);

iii) at least one primary horizontal fluid channel (422) extending from the end of the shank channel through the bearing housing cavity (2142);

iv) at least one primary vertical fluid channel (426) in the shell, the at least one primary vertical fluid channel (426) in fluid communication with the at least one horizontal fluid channel through bearing housing cavity; and

v) the at least one nozzle (576) in fluid communication with the at least one primary vertical fluid channel.

[0036] Paragraph 24. The spindle of Paragraph 23, wherein the shell (2120) has a first material having a first density and a first hardness and the core (2130) has a second material having a second density and second hardness, wherein the first density is less than the second density and the first hardness is less than the second hardness.

[0037] Paragraph 25. The spindle of Paragraph 1, wherein:
the flinger (660) is a spring flinger (1040), the spring flinger (1040) having a flexible section (1044), the spring flinger attached to the shaft (530) and positioned above the turbine (570);
wherein :
when the shaft (530) is idle the flexible section (1044) has a first position relatively close to the shaft such that the flexible section contacts and seals with a portion of the seal housing (150), and
when the shaft is rotating, the centrifugal forces generated by the rotating shaft cause the flexible section (1044) to flex away from the shaft, providing a flinger surface for deflecting the liquid, and removing contact with the seal housing (150).

SPINDLES WITH SENSOR MODULE

[0038] Paragraph 105. A fluid powered spindle (100) having a longitudinal axis (A) defining an upper end and a lower, shaft-tool end (598), comprising:

- a) a body (120) having a fluid channel system, a spindle cavity (440), and at least one aperture (334);
- b) a shaft (530) having a turbine (570), wherein the shaft is rotated by a pressurized fluid striking the turbine; and
- c) at least one sensor module (130) mounted to the body in association with the at least one aperture such that the at least one aperture allows the at least one sensor module to sense at least one physical property of the spindle.

[0039] Paragraph 106. The spindle of Paragraph 105, wherein the at least one aperture is a sensing aperture providing a path from the sensor module to the spindle cavity.

[0040] Paragraph 107. The spindle of Paragraph 106, wherein the shaft includes a rotational position reference (714) for detection by the sensor module.

[0041] Paragraph 108. The spindle of Paragraph 105, wherein the at least one aperture includes a fluid aperture (335) in fluid communication with the fluid channel system to sense fluid system properties thereof.

[0042] Paragraph 109. The spindle of Paragraph 108, wherein the fluid system properties include at least one of fluid pressure, fluid velocity and fluid viscosity.

[0043] Paragraph 110. The spindle of Paragraph 105, wherein the at least one sensor module is wireless.

Brief Description of the Drawings

[0044] Figure 1A is a top perspective view of a spindle according to embodiments of the present disclosure.

[0045] Figure 1B is a bottom perspective view of the spindle shown in Figure 1A.

[0046] Figure 2 is an exploded view of the spindle shown in figures 1A and 1B.

[0047] Figure 3A shows a bottom perspective view (and bottom plan view), of the body (and shank) of the spindle from Figures 1A and 1B.

[0048] Figure 3B shows a top perspective view of the body (and shank) of the spindle from Figures 1A and 1B.

[0049] Figure 3C shows a top perspective view of the body of the spindle from Figure 1A and 1B with an alternative shank.

[0050] Figures 4A, 4B and 4C show cross sections through the body shown in Figures 3A at planes IVA-IVA, IVB-IVB and IVC-IVC respectively.

[0051] Figure 5 shows a partial cross section of the spindle shown in figures 1A and 1B, schematically showing the fluid flow therein.

[0052] Figure 6 shows a bottom perspective view of a first embodiment of the internal subsystem of the spindle from Figures 1A and 1B.

[0053] Figure 7 shows a cross section of the internal subsystem shown in Figure 6.

[0054] Figure 8A shows an exploded view of the internal subsystem shown in Figures 6 and 7.

[0055] Figure 8B shows a detailed exploded view of the shaft separate from the turbine.

[0056] Figure 9A shows a detailed view of the non-contact seal and cover portions of Figure 5.

[0057] Figure 9B shows a more detailed view of the non-contact seal of Figure 9A.

[0058] Figure 10A shows a detailed cross sectional view of a spindle having a contact seal in a first position, according to a first embodiment.

[0059] Figure 10B shows a detailed cross sectional view of a spindle having a contact seal in a second position, according to the first embodiment.

[0060] Figure 11A shows a partial bottom exploded view of the spindle of Figure 1B according to another embodiment thereof.

[0061] Figure 11B shows a detailed view of the non-contact seal and cover portion according to another embodiment.

[0062] Figure 12 shows a vent configuration as used in embodiments of the spindle of the present invention.

[0063] Figure 13 shows a partial exploded perspective view of a spindle having a two-part body according to embodiments of the present disclosure.

[0064] Figure 14A shows a cross sectional view of the core portion of the body shown in Figure 13.

[0065] Figures 14B, 14C and 14D show perspective, bottom and cross sectional views respectively of the shell portion of the body shown in Figure 13.

Detailed Description of the Disclosure

[0066] Exemplary embodiments of this disclosure are described below and illustrated in the accompanying figures, in which like numerals refer to like parts throughout the several views. The embodiments described provide examples and should not be interpreted as limiting the scope of the invention. Other embodiments, and modifications and improvements of the described embodiments, will occur to those skilled in the art and all such other embodiments, modifications and improvements

are within the scope of the present invention. Features from one embodiment or aspect may be combined with features from any other embodiment or aspect in any appropriate combination. For example, any individual or collective features of method aspects or embodiments may be applied to apparatus, product or component aspects or embodiments and vice versa.

Structure Substantially Consistent Among All Embodiments

[0067] Turning to Figures 1A and 1B, top and bottom perspective views of a high speed spindle (100) according to embodiments of the present disclosure is shown.

[0068] The high speed spindle (100) comprises a shank (110) by which the spindle (100) is mounted, typically to an electric spindle or other conventional machine. The shank (110) is connected to a high speed spindle body (120), which is further connected to a seal housing (150) and a cover (180). The high speed spindle (100) shown in Figures 1A and 1B includes an optional sensor module (130). In one embodiment, the sensor module is wireless.

[0069] In an embodiment the high speed spindle (100) is connected to the machine only at the shank (110). High pressure fluid is communicated to the high speed spindle (100), through a fluid entry port (102) that is at the shank's distal end or at the distal end of shank extensions (101).

[0070] In one embodiment, the high speed spindle body (120) does not rotate when the high speed spindle (100) is mounted to a machine; particularly the body (120) does not rotate when the high speed spindle (100) is in use, performing material removal, but can rotate during setup and/or before or after material removing operations.

[0071] In another embodiment, the spindle (100) is sufficiently balanced such that the high speed spindle body (120) may be rotated by an electric spindle at rates exceeding 500 RPM while the machine is performing material removal processes and during setup.

[0072] In an embodiment the shank (110) is held in a machine approximately on the spindle axis of rotation, corresponding to the longitudinal axis A of the high speed spindle (100). The longitudinal axis A is used to define relative positions of features within the spindle (100). The shank (110) is at the top or upper end, while the cover (180) is at the bottom or lower end. The longitudinal axis A, used interchangeably with the spindle axis or the shaft axis is also used to define the directional terms used herein. The terms horizontal and lateral are used herein or refer to elements or features that lie or extend generally perpendicular to the longitudinal axis. The terms vertical and axial are used herein to refer to elements or features that lie or extend generally parallel to the longitudinal axis.

[0073] In another embodiment the shank (110) is held in a machine at a vertical offset to the spindle axis of rotation. In another embodiment the shank (110) is held in a machine at an angle to the spindle axis of rotation. In another embodiment the shank (110) is held in a machine at a 90 degree angle to the spindle axis of rotation.

[0074] In an embodiment, the spindle (100) is shaped and sized to fit in a machining system Automatic Tool Changer (ATC). The ATC includes a robotic arm to extract the spindle (100) from a tool slot and position it in the machine as well as placing tools released from the machine in the ATC tool slots.

[0075] The ATC typically has slots for storing various tools. Different ATC's systems have varying slot configurations and sizes. In some embodiments, slots are designed to hold tools ranging in diameter from 100 to 30 mm.

[0076] The diameter of the high speed spindle body (120) can be less than 100 mm, less than 90 mm, less than 80 mm, less than 70 mm, less than 60 mm, or less than 50 mm. The maximum diameter of the high speed spindle body (120), including the sensor module (130), may be less than 120 mm, less than 100 mm, less than 90 mm, less than 80 mm, less than 70 mm, or even less than 60 mm.

[0077] Turning to Figure 2, an exploded view of the high speed spindle (100) is shown. The high speed spindle (100) can include a filtration unit comprising a filter mesh (206) and a filtration unit nut (204) that secures the filtration system to the shank (110).

[0078] An internal subsystem (240) is assembled with the seal housing (150) to be inserted into the high speed spindle body (120) and secured to the body (120) with first screws (252) that connect the seal housing (150) with the high speed spindle body (120).

[0079] The cover (180), with gasket (248), is secured to the seal housing (150) with second screws (282). A cutting tool (not shown) is connected to a shaft (not shown) with a collet (290) which is connected to the shaft with a collet nut (292).

[0080] Securing or releasing a cutting tool from the spindle (100) can be done with a wrench that secures the collet nut (292) connecting the cutting tool and spindle (100). In an embodiment, the high speed spindle (100) connects to the machine in similar fashion. The wrench may be a spanner wrench or an ER wrench, wherein the wrench will include at least one pin, flat, tab or similar feature, that coincide with the slots or other features in the respective nut.

[0081] The high speed spindle may include a wrench grip (214) between the shank (110) and the high speed spindle body (120). The wrench grip (214) is provided to facilitate installation and removal of the fluid powered spindle (100) from a chuck of an electric spindle. The wrench grip (214) may be circular,

hexagonal, or otherwise include flat portions for mating with a wrench. The wrench grip (214) is a larger diameter section at the bottom portion of the shank (110). The wrench grip (214) diameter is larger than the shank (110) diameter and smaller than the high speed spindle body (120) diameter. The wrench grip (214) height is larger than the thickness of a typical wrench including the wrench pin or tab that fits in a slotted nut.

[0082] A seal slot (218), on the horizontal ring surface of the wrench grip (214) seals the contacting surfaces of the high speed spindle (100) and the electric spindle in which it is held. In an embodiment, the seal slot (218) consists of at least one slot for an O-ring. In an embodiment, the seal slot is flat such that a flat ring seal or shaped seal can be positioned therein.

[0083] Further, the sensor module (130) is mounted at a mounting location (232). In an embodiment, the spindle may have a plurality of sensor modules (130) mounted to a plurality of mounting locations (232) around the body (120).

[0084] Turning to Figures 3A-3C, Figure 3A shows a bottom perspective view (and bottom plan view), of the body (120) and shank 110 of the high speed spindle. Figure 3B shows a top perspective view thereof. Figure 3C shows a top perspective view of the body (120) with an additional cone shank (312) having a larger diameter that integrates with the wrench grip 214.

[0085] As seen in Figures 3A-3C, the high speed spindle body (120) may be integrated with the shank (110) by which the high speed spindle is held. The body (120) includes at least one mounting location (232) for a sensor module (130). The mounting location (232) may include a sensing aperture (334) in the high speed spindle body. The sensing aperture (334) provides a path for the sensor module sensors to sense at least one physical property of the spindle by sensing elements within the body. In one embodiment, the sensing aperture (334) provides a path for the sensor module sensors to connect, without contact, with elements within the body. For example, aperture (334) provides a line of sight path for the sensor module sensors to sense elements within the body, or the sensing aperture (334) may be designed with materials that are optically opaque or translucent, but sufficiently transparent to specific frequencies of the electromagnetic spectrum for the operation of electromagnetic sensors.

[0086] A fluid aperture (335) in the mounting location (232) for a sensor module (130) may be fluidly connected to a high pressure fluid channel system within the high speed spindle body (120). The fluid aperture (335) provides a fluidic path for sensor module sensors to sense fluid system properties of the high pressure fluid system. Fluid system properties such as fluid pressure, fluid velocity and fluid viscosity.

[0087] Mounting threads (336) and one or more mounting slots (338) can be associated with the mounting location (232) with which the sensor module (130) can be secured to the high speed spindle body (120).

[0088] At the bottom end (398) of the high speed spindle body (120) there is a round slot that forms a first fluid manifold (370) when the high speed spindle body (120) is connected with the seal housing (150).

[0089] The bottom plan view of the high speed spindle body (120) shows bottom openings (354) for primary vertical fluid channels that fluidly communicate with the first fluid manifold (370). Threaded holes (352) are used to connect the seal housing (150) to the body (120).

[0090] An access opening (324) is provided in the high speed spindle body (120) from which at least one primary horizontal fluid channel is machined. The access opening (324) may include screw threads that are used to secure a plug or screw (not shown) that seals the opening.

[0091] Turning to Figures 4A-4C, Figure 4A is cross section IVA-IVA of the high speed spindle body, as seen in Figure 3A. The shank thread (412) near the shank end (404) of the high speed spindle body is used to connect components such as components of a filtration unit or shank extenders.

[0092] Figure 4A shows the fluid channel system within the high speed spindle body. The fluid channel system consists of the shank channel (416) within the shank (110) that fluidly connects the entry port (102) with the fluid channel junction (418). The fluid channel junction (418) fluidly connects with at least one primarily horizontal fluid channel (422). In the exemplified embodiment there are three primary horizontal fluid channels, spaced 120 degrees apart. The at least one primarily horizontal fluid channel (422) intersects with a respective primary vertical fluid channel (426), that spans the length of the high speed spindle body (120). In the exemplified embodiment, the primary vertical fluid channel (426) ends at the first fluid manifold (370).

[0093] In an embodiment the fluid channel system includes a pressure relief mechanism, such as a valve (not shown). In an embodiment the pressure relief mechanism is connected to the fluid channel system at the at least one access opening (324). In an embodiment the pressure relief mechanism is located in the high speed spindle cover (180).

[0094] The internal subsystem (240) is mounted with at least one bearing within the high speed spindle cavity (440). The external ring of the at least one bearing is positioned on a portion of the cavity surface (e.g. first bearing cavity-mounting surface 406 and second bearing cavity-mounting surface 408) whose

properties and surface finish are suitable for mounting bearing ring's to provide a tight fit and high accuracy during high speed rotation and high speed machining as best seen in Figure 5.

[0095] In an embodiment, the surface finish parameter, Ra, at the bearing mounting surfaces (406, 408) is less than 0.2 micron meter, i.e. N4 per ISO 1302. In an embodiment, the surface finish parameter, Ra, at the bearing mounting surfaces (406, 408) is less than 0.4 micron meter, i.e. N5 per ISO 1302. In an embodiment, the surface finish parameter, Ra, at the bearing mounting surfaces (406, 408) is less than 0.8 micron meter, i.e. N6 per ISO 1302. In an embodiment, the surface finish parameter, Ra, at the bearing mounting surfaces (406, 408) is less than 1.6 micron meter, i.e. N7 per ISO 1302.

[0096] In an embodiment, the concentricity tolerance at the bearing mounting surfaces (406, 408) is less than 2 micron meter. In an embodiment, the concentricity tolerance at the bearing mounting surfaces (406, 408) is less than 3 micron meter. In an embodiment, the concentricity tolerance at the bearing mounting surfaces (406, 408) is less than 4 micron meter. In an embodiment, the concentricity tolerance at the bearing mounting surfaces (406, 408) is less than 5 micron meter.

[0097] In an embodiment, the cylinder tolerance at the bearing mounting surfaces (406, 408) is less than 2 micron meter. In an embodiment, the cylinder tolerance at the bearing mounting surfaces (406, 408) is less than 3 micron meter. In an embodiment, the cylinder tolerance at the bearing mounting surfaces (406, 408) is less than 4 micron meter.

[0098] In the exemplified embodiment, there are two bearings that are mounted on bearing mounting surfaces: the first bearing cavity-mounting surface (406) and the second bearing cavity-mounting surface (408).

[0099] In the exemplified embodiment, there is a spacer shoulder (442) for positioning the bearing spacer (610, Figure 6) above the second bearing cavity-mounting surface (408). The shoulder consists of two sections: the larger-diameter section (446) and the smaller-diameter section (444). Wherein the diameter of the larger-diameter section (446) is larger than the diameter of the smaller-diameter section (444).

[00100] Also shown is sensor module mounting location (232). In the exemplified embodiment, there is a mounting slot (338) with which the sensor module can be positioned and secured to the high speed spindle body.

[00101] The fluid used to rotate the high speed spindle turbine is communicated to the turbine through a channel and nozzle system that starts at the shank channel (416) and spans the high speed spindle body (120) through at least one primarily horizontal fluid channel (422), through at least one primary vertical fluid channel (426) and ends at the first fluid manifold (370).

[00102] Figure 4B is cross section through plane IVB-IVB shown in Figure 3A of the high speed spindle body (120). The vent (450) in the spindle body fluidly connects the high speed spindle cavity (440) with the exterior (496) of the high speed spindle.

[00103] Although shown in the cross section as a single material, the body (120) and the shank (110) may be formed from multiple parts that are mechanically connected. Further, the body (120) may include a cone according to the ER standard (not shown). Fluid may enter the high speed spindle via external channels in the cone, that communicate with openings in the cone envelop that are the start of a channel and nozzle system that spans the spindle body and ends in proximity to turbine blades.

[00104] Figure 4C is cross section through plane IVC-IVC as seen in Figure 3A. Figure 4C shows a portion of the fluid channel system within the high speed spindle body. Specifically, Figure 4C shows at least one primarily horizontal fluid channel (422) that intersects with a primary vertical fluid channel (426) that spans the length of the high speed spindle body (120). In the exemplified embodiment, the primary vertical fluid channel (426) ends at the first fluid manifold (370). In the exemplified embodiment, there is a fluid aperture (335) fluidly connecting the primary vertical fluid channel (426) with the sensor module mounting location (232). In an embodiment, the sensor module includes a fluid pressure sensor that measures high pressure fluid pressure. Monitoring the fluid pressure and/or velocity can provide indications of the system stability. In an embodiment, the measurements are used to close a control loop on the high speed spindle.

Fluid Flow within a bottom-discharge Spindle

[00105] Turning to Figure 5, the fluid flow within the high speed spindle (100). In the preferred embodiment, the fluid is a liquid. Fluid enters the high speed spindle through entry port (102) in shank end (404). The fluid flows through the shank channel (416) to fluid channel junction (418). From the fluid channel junction (418) the fluid flows to at least one primarily horizontal fluid channel (422) and on to at least one primary vertical fluid channel (426) that spans the length of the high speed spindle body.

[00106] The fluid continues through secondary vertical fluid channel (527) in the seal housing (150) and through inlet channel (528) in the cover (180).

[00107] The fluid enters the seal housing (150) through secondary vertical fluid channel (527), continues to inlet channel (528) in the cover (180) to the nozzle fluid manifold (578) and to the at least one nozzle (576). The fluid exiting the at least one nozzle (576) is directed towards turbine (570) that causes a shaft (530) to rotate at high speed.

[00108] A portion of the fluid impacting the turbine (570) is diverted from the turbine to the central fluid exit (571) which is in proximity to the shaft (530) and towards the shaft tool end (598). In the exemplified embodiment, the central fluid exit (571) includes lower annular gap (572A), bottom annular cavity (587) and first axial exit opening (588) in the cover.

[00109] The remaining fluid is diverted from the turbine, to the second fluid exit (573). In the exemplified embodiment, the second fluid exit (573) includes upper annular gap (572B) between the rotating turbine and a nozzle ring; and a seal annular gap (574) under a rotating flinger, and second annular fluid manifold (552) both defined within in the seal housing (150).

[00110] In the exemplified embodiment, the second fluid exit (573) also includes a stationary fluid exit channel (556) which is fluidly connected to the cover exit channel (583) in the cover (180) and to at least one second axial exit opening (586). In the exemplified embodiment, fluid exiting the second fluid exit (573) is directed towards the shaft tool end (598). The fluid exiting the second fluid exit (573) is directed towards the shaft tool end (598) at an angle α . In one embodiment, α is greater than 10 degrees, in another embodiment α is greater than 20 degrees.

[00111] Due to fluid pressure fluctuations in the turbine (570) and lower and upper annular gaps (572A, 572B), a portion of the fluid in the seal annular gap (574) under the rotating flinger may continue above the flinger. In one embodiment, a major turbulence pocket (512) is created as a recess within the seal housing (150) above the second annular fluid manifold (552).

[00112] The objective of the sealing system is to prevent fluid exiting the turbine (570) from flowing to a gap (506) below a second bearing (508).

[00113] In some cases, the high speed spindle (100) is stored in an ATC, or other storage, after it has been used, and the storage position is vertical, wherein the cutting tool is facing up or horizontal or at any other angle. In such cases there is a concern that residual fluid that remains on the cutting tool, on the turbine (570) or in the seal housing (150), will traverse the non-contact seal and flow toward the second bearing (508). The major turbulence pocket (512) is configured to retain a portion, or all, of the residual fluid in a recess (924) when the spindle is in an inverted position.

[00114] Note that the direction of rotation of the shaft (530) is determined by the shape of the fins on turbine (570), those fins being symmetrical or non-symmetrical, and the nozzle direction. In one embodiment the turbine fins and nozzles are formed to rotate the shaft in a counter clock wise (CCW) direction. In another embodiment the turbine fins and nozzles are formed to rotate the shaft in a clock wise (CW) direction.

Internal Subsystem

[00115] Turning to Figure 6, Figure 6 shows a bottom perspective view of a first embodiment of the internal subsystem (240) and seal housing (150) of the spindle from Figures 1A and 1B.

[00116] The internal subsystem (240) includes: a shaft (530), a first bearing (606); a second bearing (not visible), a bearing spacer (610) that is positioned next to the first bearing (606) outer ring and second bearing out ring (not shown); a flinger (660) and the turbine (570A, where "A" is added to designate an alternative embodiment, in this case the turbine being separate as opposed to integral) attached to the shaft (530). The seal housing (150) is disposed around at least a portion of the internal subsystem (240) to provide a non-contact seal helping to impede fluid from reaching the second bearing (508, see Figure 5).

[00117] In the bottom surface (651) of seal housing there are: counter bores (656) for bolts used to connect the internal subsystem (240) and the seal housing (150) to the spindle body (120), vertical fluid channel's bottom openings (354), threaded holes (352) for connecting the spindle cover (180) to the seal housing (150) and seal housing fluid exit holes (686), external shoulder (622) and internal shoulder (623) that bench a flat gasket (not shown) that is inserted between the bottom surface (651) of seal housing and the cover. Wherein the bottom surface (651) of seal housing is the surface closest to the cover (180).

[00118] The bearing spacer (610) can include a bearing spacer opening (612). In conjunction with the sensing aperture (334), the bearing spacer opening (612) can also provide a line of sight path for the sensor module sensors to sense rotation, or the bearing spacer opening (612) may be designed with materials that are optically opaque or translucent, but sufficiently transparent to specific frequencies of the electromagnetic spectrum for the operation of electromagnetic sensors.

[00119] Turning to Figure 7, a cross-section through axis VII-VII of Figure 6 is shown. The internal subsystem (240) includes: a shaft (530); first bearing (606) and second bearing (508); a bearing spacer (610) that is positioned next to the first and second bearing outer rings (716, 718); a flinger (660), at least one turbine (570A) attached to the shaft (530), collet mounting surface (794) and a thread (795) for the collet nut on the distal lower end of the shaft (530).

[00120] The shaft is symmetrical along its length axis and dynamically balanced for high speed rotation with minimal vibration.

[00121] In an embodiment, the bearings (606, 508) are angular contact bearings. In other embodiments the bearings (606, 508) are contact bearings such as deep groove, roller or needle. In

other embodiments, the bearings (606, 508) have no rolling element, such as slip ring bearings, friction bearings, magnetic bearing, air or hydraulic bearings.

[00122] In some embodiments, in order to avoid excitation of bearings natural frequencies, the bearings (606, 508) are not of identical design, for example different diameters, widths and/or types.

[00123] In some embodiments, the bearings are integrated with the shaft such that the bearing inner race is integral to the shaft (not shown) and the bearing is assembled on the shaft. Integrated bearings enable smaller diameter and lighter weight systems.

[00124] In an example embodiment, the first and second bearings (606, 508) are mounted on the shaft (530) with an axial preload. The bearings may be preloaded during assembly with their respective first and second bearing inner rings (717, 719) glued to the shaft (530). The bearing preload can be defined by two factors: the dimensions and properties of the at least one bearing spacer (610) that is mounted between the bearing outer rings (716, 718); and the assembly process in which the bearings are loaded while the glue is setting. In an embodiment, the first bearing inner ring (717) is mounted against a shoulder or similar feature in the shaft, first bearing mounting shoulder (733). In an embodiment, the second bearing inner ring (719) is mounted against a shoulder or similar feature in the shaft, second bearing mounting shoulder (738). In an embodiment, the system is preloaded with a shaft top screw (704) that is threaded into the shaft and tightened against the first bearing inner ring (717). The shaft top screw (704) that is threaded into the shaft prevents rotation of the first bearing inner ring (717) such that the shaft top screw (704) is threaded into the shaft is tightened and locked such that it provides preload to the bearings.

[00125] The turbine (570A) with at least one turbine fin is positioned next to the non-contact seal housing, toward the shaft tool end (598). In an embodiment, a turbine ring (774) that supports at least one turbine fin is mounted on the shaft. This design enables using different types of turbines (570A) on the same shaft design.

[00126] In another embodiment the turbine (570) with at least one turbine fin is integrated with the shaft (530). That is, the shaft and turbine are machined together from one piece. Integrating the shaft and turbine simplifies assembly and provides precise axial symmetry.

[00127] In an embodiment, there is a shaft lock hole (734) in the shaft. The shaft lock hole (734) is used to secure the shaft with an external tool (not shown), when the collet is being tightened.

[00128] The external tool is inserted through a corresponding shaft lock hole in the high speed spindle body. In an embodiment, the corresponding shaft lock hole in the high speed spindle body is the vent (450) in the spindle body.

[00129] The bearing spacer (610) is designed to facilitate positioning of the at least one bearing and support the preload required. In the exemplified embodiment, the bearing spacer is positioned between the first bearing outer ring (716) and the second bearing outer ring (718). In this configuration, the bearing spacer (610) does not rotate with the shaft (530).

[00130] In an embodiment, the bearing spacer (610) will include a feature that will position it relative to the high speed body spindle (not shown). In the exemplified embodiment, the bearing spacer (610) includes a positioning shoulder (711) that is benched against a corresponding spacer shoulder (442) in the high speed spindle cavity (440).

[00131] As discussed above with respect to Figure 6, a bearing spacer opening (612) can be provided in bearing spacer (610).

[00132] In an embodiment, the shaft includes a rotational position reference (714) by which the shaft's rotation speed can be determined. The rotational position reference (714) is designed such that it does not affect the axial symmetry and balancing of the shaft (530). In one example, the rotational position reference is one or more through holes in the shaft along the shaft's radial axis. In another example, the position reference is defined by multiple holes that do not traverse the shaft diameter from side to side. In other embodiments the rotational position reference is a flat, a slot, a fin like protrusion, a cutout, a pin or a tab that extrudes from the shaft or placed within cavities within the shaft. In other embodiments, the reference is defined by a local change in shaft properties such as color, surface finish, electrical or magnetic properties. In other embodiments, the reference is defined by adding a ring or cover on the shaft, wherein the ring or cover has local features that can be identified by a sensor. In an embodiment, a magnet is placed in a through hole. In an embodiment, a material that is different than the shaft material is placed in a through, or non-through, hole.

[00133] In an embodiment, at least one bearing inner ring (717, 719) is mounted on the bearing shaft-mounting surface (732, 736). In the exemplified embodiment there are two shaft bearing mounting surfaces: the first bearing shaft-mounting surface (732) and the second bearing shaft-mounting surface (736). Both surfaces have similar surface properties as detailed for bearing mounting surfaces (406, 408) within the high speed spindle cavity (440).

[00134] Turning to Figure 8A, an exploded view of Figure 6 is shown. In the exemplary embodiment the shaft (530) is integrated with the flinger (660) and turbine (570). The shaft is machined to include first bearing shaft-mounting surface (732) and second bearing shaft-mounting surface (736).

[00135] The seal housing (150) is positioned on the shaft, with the bottom surface (651) facing towards the shaft tool end (598). Once the seal housing (150) is in place, second bearing (508), bearing spacer (610) and first bearing (606) are assembled on the shaft. Closing the assembly is shaft top screw (704).

[00136] Turning to Figure 8B, the at least one turbine (570A) is connected to a turbine ring (774) which is assembled and connected on the shaft from the shaft tool end (598). The advantage of using a turbine ring is that it provides flexibility of assembling different turbine designs on to the same shaft and internal subsystems. In an embodiment, the flinger (660A) is mounted on a ring which is assembled and connected on the shaft from the shaft tool end (598). In an embodiment, the flinger is mounted on an elongated turbine ring (not shown) which is assembled and connected on the shaft from the shaft tool end (598).

The Non-Contact Seal (shown in an axial discharge spindle)

[00137] A non-contact seal is primarily provided by the combination of the seal housing (150) and the rotating flinger (660). The rotating flinger is attached to (660A) or integral with (660) the shaft (530), and impedes flow of fluid toward the second bearing (508).

[00138] The non-contact seal design is such that it will not create contact friction when the system is rotating. Similarly, there will be no contact friction wear and tear. In an embodiment, the non-contact seal is compact in length. In an embodiment, the length is less than twice the maximum shaft diameter. In another embodiment the length is less than the maximum shaft diameter. In another embodiment the length is less than one-half the maximum shaft diameter.

[00139] The seal system is comprised of a non-contact seal, and may or may not further include at least one contact seal. The seal system length compact. In an embodiment, the length is less than twice the maximum shaft diameter. In another embodiment the length is less than the maximum shaft diameter. In another embodiment the length is less than one-half the maximum shaft diameter.

[00140] If a contact seal is present, the contact seal maintains contact between the stationary elements and the rotating elements of the spindle (100) when the spindle is at rest or at low rotation speeds. Furthermore, when the spindle is at rest or at low rotation speeds, the contact seal maintains contact with both the stationary and rotation elements regardless of system orientation.

[00141] However, when the spindle is at high rotation speeds the contact seal maintains contact with only one of the stationary elements or the rotating elements, depending on contact seal type. Because the contact seal maintains contact with only the stationary elements or the rotating elements

during high speed rotation, there is little wear and tear on the contact seal or to the components it comes in contact with. Similarly, there is a minimal amount of debris due to contact friction.

[00142] The non-contact seal is a friction free system wherein there is no friction between solid parts. The only friction in the system is caused by fluid and/or debris that is rotated between the stationary and rotating elements.

[00143] Turning to Figure 9A, a partial cross section of the spindle from Figure 1A is shown. The illustrated portion generally represents a non-contact seal (900). The non-contact seal (900) is designed to prevent fluid exiting the turbine (570) to flow to gap (506) below second bearing (508).

[00144] The non-contact seal (900) is comprised of two elements: a rotating element, particularly flinger (660), which is part of the shaft or connected to it, and a stationary element, particularly seal housing (150), secured to the high speed spindle body (120). In an embodiment (see Figures 11A and 11B), the stationary element is comprised of a first stationary element (seal housing 150) that is secured to the high speed spindle body (120) and a second stationary element (stationary ring 1340) that is connected to the seal housing (150).

[00145] The non-contact seal (900) is located between the second bearing (508) which is mounted on the shaft (530) and turbine (570). High pressure fluid enters the non-contact seal (900) through secondary vertical fluid channel (527) in the seal housing (150) and continues to inlet channel (528) in the cover (180), to the annular nozzle fluid manifold (578) and to the at least one nozzle (576)

[00146] In the exemplified embodiment, the nozzle fluid manifold (578) is defined by the nozzle ring (977) and the cover inner surface (979) of the cover (180).

[00147] The non-contact seal (900) includes the seal housing (150) which at least partially defines the second annular fluid manifold (552), and the stationary fluid exit channel (556). The stationary fluid exit channel (556) fluidly communicates with the axial fluid exit channels, both section one (982) and section two (984) in the cover (180). The seal housing (150) also at least partially defines the seal annular gap (574) under the rotating flinger (660) that fluidly communicates with upper cover annular gap (572) and bottom annular cavity (587). The non-contact seal (900) also includes the rotating flinger (660).

[00148] The seal housing (150) is connected on one side to the high speed spindle body (120) and on the other side to the cover (180). A gasket (248) between the seal housing (150) and the cover (180) provides a seal so that high-pressure fluid, flowing in channels that span both parts, does not leak.

[00149] The annular gap sections between the rotating components and the stationary components, through which, fluid flows, include: the upper cover annular gap (572) between the turbine and the nozzle ring, and the seal annular gap (574) under the rotating flinger (660).

[00150] The fluid exits through the cover (180) via the first axial exit opening (588) near the shaft (530) and through the second axial exit opening (586) which exits the cover (180) closer to the cover radial perimeter (981).

[00151] High pressure fluid flowing through the at least one nozzle (576) and directed at the at least one turbine (570) causes the turbine to rotate at high speed. A portion of the fluid impacting the turbine is diverted from the turbine towards the shaft tool end (598), i.e. the bottom of the spindle (100), into bottom annular cavity (587) and through first axial exit opening (588).

[00152] Due to the high centrifugal forces, the remaining fluid is diverted from the turbine, into the upper cover annular gap (572) between the rotating turbine and nozzle ring. From there, the fluid flows into the seal annular gap (574) under the rotating flinger (660).

[00153] The seal annular gap (574) under the rotating flinger is formed between a shaft first section (932), above the turbine area (969) and the seal housing inner surface (954). The seal annular gap (574) under the rotating flinger is fluidly connected to the second annular fluid manifold (552) in the seal housing (150).

[00154] From the seal annular gap (574), most of the fluid will flow toward the rotating flinger lower surface (962) and will be diverted towards the stationary fluid exit channel (556) which is fluidly connected to the second annular fluid manifold (552) on one side and further to the axial fluid exit channels in the cover (180), particularly axial fluid exit channel section one (982) which is fluidly connected to axial fluid exit channel section two (984). From axial fluid exit channel section two (984), the fluid exits the high speed spindle through at least one second axial exit opening (586).

[00155] As best seen in Figure 9B, a portion of the fluid in the seal annular gap (574) under the rotating flinger that flows toward the rotating flinger lower surface (962), continues past the flinger edge surface (964) and above the flinger upper surface (966).

[00156] The flow of fluid above the flinger upper surface (966) is impeded primarily by two elements of the non-contact seal.

[00157] The first element is the major turbulence pocket (512) defined primarily by an annular recess (924) in the seal housing (150) and the rotating flinger upper surface (966). The major turbulence pocket (512) has two openings, a large opening (926) facing the second annular fluid manifold (552)

from which fluid flows in to the major turbulence pocket and a small opening (936). A slot shoulder (934) forms the radially inner wall of the annular recess (924).

[00158] The relative motion between recess (924) in the seal housing (150) and the rotating flinger upper surface (966) creates fluid turbulence. Additional turbulence may be created due to the pocket shape. Most of the fluid entering the major turbulence pocket (512) from the large opening (926), flows towards recess (924). Most of the fluid cannot continue through the small opening (936) because its cross section is much smaller, the fluid flow is deflected toward the flinger upper surface (966) resulting in additional turbulence. The fluid turbulence imparted by the separate elements collectively impede the flow of fluid toward the small opening (936).

[00159] Fluid that does pass the major turbulence pocket (512) reaches the small opening (936) between the seal housing (150) and the shaft (530), in the exemplary, embodiment, between a slot shoulder (934) and a rotating ledge (938) above the rotating flinger (660).

[00160] The second element is the minor turbulence pocket (914) defined by a step-like feature (916) on the inner diameter of the seal housing (150) and the opposing shaft section (918). In an embodiment, more than two turbulence pockets may be used. For example three or more turbulence pockets can be arranged concentrically. In other example plural minor turbulence pockets (914) can be stacked along the axial direction. The use of more than two turbulence pockets may increase seal efficacy, but the tradeoff of an increased number of turbulence pockets is space, fluid friction and manufacturing costs.

[00161] The flow pattern of fluid entering the minor turbulence pocket (914) will be turbulent. The relative motion between step-like feature (916) and the opposing shaft section (918) creates fluid turbulence. The fluid turbulence impedes the flow of fluid. Centrifugal forces acting on the fluid within the minor turbulence pocket (914) will concentrate the fluid on the larger diameter portion of the minor turbulence pocket (914), towards the seal housing (150) and away from the vertical gap (922) between the seal housing (150) and the shaft (530).

[00162] In order for the shaft to rotate without contact, there is a small gap between the seal housing (150) and the shaft (530) that is closest to the second bearings (508). In the exemplary embodiment, the gap is the vertical gap (922) between the seal housing (150) and the shaft (530).

Optional Contact Seals

[00163] Turning to Figure 10, a second sealing system for use in the spindle (100) is shown. The second sealing system can include a seal housing (150) defining a major turbulence pocket (512) and a

minor turbulence pocket (914) like the non-contact seal (900) of the first sealing system discussed above. This second sealing system further comprises a contact seal located between the second bearing (508) and turbine (570). Preferably, the contact seal is positioned as close as possible to the second bearing (508).

[00164] The contact seal is designed to prevent fluid, droplets and contamination from reaching the second bearing (508) when the spindle is at rest, even if the high speed spindle is stored in an ATC, or other storage, after it has been used, where the storage position is vertical (i.e. wherein the cutting tool is facing up) or horizontal or at any other angle. In such cases there is a concern that residual fluid that remains on the cutting tool, on the turbine or in the seal housing, will flow toward the second bearing.

[00165] The contact seal is designed to prevent these residual fluids from reaching the second bearing (508).

[00166] The contact seal spans the gap between the seal housing (150) that is connected to the high speed spindle body (120) and the rotating shaft (530) when the spindle is at rest.

[00167] The contact seal is designed to maintain contact with the seal housing (150) and the rotating shaft (530) when the shaft is at rest or rotating at low RPM, no more than 10% of the high speed spindle unloaded rotation speed.

[00168] The contact seal is designed to break contact between the seal housing (150) and the rotating shaft (530) when the shaft is rotating at high RPM. When the shaft is rotating at high RPM, there is no contact or friction between stationary components and the rotating components. In an embodiment, when the shaft is rotating, there is no contact or friction between stationary components and the rotating components.

[00169] Referring to Figure 10A, a spring flinger (1040) is positioned on the rotating shaft (530) and rotates therewith. In this embodiment, the spring flinger may replace the relatively rigid flinger (660) found in the first sealing system embodiment. The spring flinger (1040) has the overall shape of an angular flap or skirt mounted on the shaft. Spring flinger (1040) includes flexible materials such as rubber or other elastomers or a shaped spring made of stiffer materials. The flexible materials allow the spring flinger to stretch and change shape when centrifugal forces are applied due to the shaft rotation.

[00170] In the illustrated embodiment, spring flinger (1040) has a spring flinger mounting surface (1043) that is used to mount the spring flinger on the shaft (530) and a flexible, thinner section (1044) with a spring flinger cross-section (1045). When the shaft (530) is not rotating, the flexible thinner section (1044) is positioned such that the spring flinger upper surface (1042) is in contact with

seal housing (150). In the exemplified embodiment, spring flinger upper surface (1042) is in contact with stationary surface (1024). The contact line between spring flinger (1040) and seal housing (150) prevents fluid passage from one side of the contact line (area or ring) to the other.

[00171] Referring to Figure 10B, during rotation of the shaft (530), centrifugal forces are applied on the spring flinger (1040) due to the shaft rotation. The flexible material allows the spring flinger (1040) to stretch such that spring flinger upper surface (1042) is relocated slightly away from stationary surface (1024) resulting in a lack of contact. The spring flinger (1040) functions as a flinger diverting fluid from the turbine area into second annular fluid manifold (552).

[00172] The spring flinger (1040) may include a heavier component (not shown), positioned on or within the flexible, thinner section (1044) that provides a weight for stretching the spring flinger (1040) during rotation. Where present, the heavier component may be ring or doughnut shaped or comprised of a plurality of sections. Where present, the heavier component may be molded to or within the spring flinger.

[00173]

Optional Flow Control Feature

[00174] Referring to Figures 11A and 11B, the illustrated embodiment of the spindle includes a non-contact seal between spindle body (120) and cover (180) substantially similar to the non-contact seal (900), wherein the illustrated embodiment further comprises a second stationary element (1340) connected to the seal housing (150).

[00175] In the exemplified embodiment, the second stationary element (1340) is a stationary ring that is positioned on a corresponding feature in the seal housing (150). For example, the corresponding feature in the seal housing (150) is a step defined by the seal housing inner surface (954), a first surface (1355) which is primarily perpendicular to seal housing inner surface (954) and second surface (1358) which is primarily perpendicular to the first surface (1355). The dimensions of the outer diameter of the second stationary element (1340) and the diameter of the seal housing inner surface (954) are such that there is an interference fit between the second stationary element (1340) and seal housing (150). Alternatively the second stationary element (1340) is connected to the seal housing (150) with an adhesive or any other means.

[00176] The second stationary element (1340) forms a more narrow seal annular channel (1374) below flinger (660), than in the embodiment of Figure 5. The narrow seal annular channel (1374) directs fluid coming from cover annular gap (572) to the root (1363) of the flinger lower surface (962). Due to

fluid pressure and centrifugal forces acting on the fluid, fluid will flow towards the stationary fluid exit channel (556) through stationary second annular fluid manifold (552) and to a fluid opening in the cover (180) or to a fluid opening (see Figure 14) in the seal housing (150).

Optional Cavity Vents

[00177] Turning to Figure 12, the details of the vent (450) in the high speed spindle body (120) is shown. The vent (450) can be used in any of the embodiments of the spindles discussed above. The vent (450) reduces pressure fluctuations that may occur due to the high speed rotating elements within the spindle cavity (440). The vent connects the high speed spindle cavity (440) with the exterior (496) of the high speed spindle, through the high speed spindle body (120). The vent (450) is sealed with a vent gasket (2054) that remains closed at one atmosphere but will leak when the pressure differs between both sides of the gasket, allowing for pressure equalization.

[00178] Vent gasket (2054) will leak due to changes to its geometry, caused by an imbalance of pressure on both of its faces. The change in geometry provides a conduit for fluid to pass to and from the high speed spindle cavity (440) to and from the exterior to the high speed spindle.

[00179] For example, the vent gasket (2054) may leak when the pressure fluctuates by 0.05 atmospheres, 0.1 atmospheres or up to 0.17 atmosphere difference.

[00180] The vent gasket (2054) is made of a flexible material. In one example, the gasket is made of rubber. In some embodiments, the vent gasket (2054) is made of a flexible material with at least one slit. In one example, the gasket is made of a flexible material with more than one slit in different directions. In other examples, the gasket is made of a one part that includes at least one flexible feature. For example, the gasket may be made of a multi-part system that includes at least one flexible feature or spring.

[00181] The vent gasket (2054) can be positioned and held in place by two nuts: an internal nut (2052) and an external nut (2056). In this embodiment, the vent gasket (2054) can be assembled and tested prior to insertion into the vent channel.

[00182] In other embodiments, the vent gasket (2054) is positioned and held in place by at least one external nut (2056) and supported by a shoulder in the vent channel (not shown). The shoulder in the vent channel providing similar support as does the internal nut. In other embodiments, the vent gasket (2054) is positioned and held in place by at least one nut and a partial support in the vent channel (not shown). In other embodiments, the gasket may be positioned and held in place by a support in the vent channel such as a groove.

[00183] The vent (450) can be used as a conduit to insert a tool to lock the shaft in position by inserting the tool through the vent (450) in the spindle body (120) and the vent gasket (2054). The inserted tool connects to a corresponding feature on the shaft such that the shaft can be locked in place while torque is applied to the bottom of the shaft. In the exemplified embodiment, the feature on the shaft is a bore (not shown) whose diameter is larger than the diameter of the tool end. In the exemplified embodiment the shaft lock hole in the shaft traverses the shaft on a radial axis. In an embodiment, the feature on the shaft is a flat. In an embodiment, the feature on the shaft is a slot. In an embodiment, the vent gasket (2054) is flexible enough to return to its original shape.

Alternative 2-part Spindle Body

[00184] Referring to Figure 13, another embodiment of spindle body (120A) is shown in an exploded view, where the spindle body (120A) includes a shell (2120) and a core (2130). There are many advantages to dividing the high speed spindle body into multiple parts, such as reduction of material costs, design flexibility in production of multiple versions of similar products for different applications, and embedding of electronics for monitoring and/or communications in the shell. In an embodiment, the two part high speed spindle body (120A) is lighter than a comparable one part high speed spindle body.

[00185] In an embodiment, the shell (2120) and core (2130) are made from different materials. In an embodiment the core is made from hardened materials such as stainless steel or steel. The core materials must provide sufficient hardness in the bearing mounting areas and high stiffness for spindle accuracy. In an embodiment, the shell is made from lighter materials such as aluminum, composite materials, or plastic. The shell material has to have sufficient strength to support the high pressure fluid channels that are incorporated there.

[00186] In the exemplified embodiment, the two part high speed spindle body (120A) is interchangeable with a one part high speed spindle body (120, Figure 4) such that minimal

modifications, if any, need to be made to other system parts. In some embodiments, the shell can be modified to add functionality such as sensors and housings for monitoring and control components.

[00187] Figure 13 shows a shell (2120), a core (2130), a first O-ring (2107), and a second O-ring (2109) that are positioned between the shell (2120) and the shank (110) portion of the core (2130). A third O-ring (2111) and a fourth O-ring (2113) are positioned around the core (2130) in second O-ring slots (2112).

[00188] The core (2130) includes a shank (110), a wider diameter portion that is the bearing cavity housing (2142), an opening of the primarily horizontal fluid channel (422) and a core vent opening (2152). The shell (2120) includes a shell vent opening (2150).

[00189] Referring to Figure 14A, section A-A is a cross section of the core (2130). Figure 14A shows a portion of the fluid channel system within the two part high speed spindle body (120A). The fluid channel system consists of the shank channel (416) within the shank (110) that fluidly connects the fluid entrance (102) with the fluid channel junction (418). The fluid channel junction (418) fluidly connects with at least one primarily horizontal fluid channel (422).

[00190] The core (2130) also includes: a high speed spindle cavity housing (2142), the high speed spindle cavity (440), a core vent opening (2152), core surface (2228) which benches against the shell when the two parts are assembled, a first O-ring slot (2209) and second O-ring slots (2112) at the distal end of the core (2130), first bearing cavity-mounting surface (406), second bearing cavity-mounting surface (408) and a sensing aperture (334A) in the core. The sensing aperture (334A) in the core (2130) is substantially similar to the sensing aperture (334) in the entire body (120) as discussed above.

[00191] Referring to Figure 14B, the shell (2120) includes a shell vent opening (2150). Although not shown, the shell (2120) can include a sensing aperture in communication the sensing aperture (334A) within the core (2130) in order to provide sensing access from the exterior through to the shaft (530).

[00192] Referring to Figure 14C, the shell bottom view includes vertical fluid channel openings (2268) the fluidly communicates with the first fluid manifold (370), and shell threaded holes (2266) that are used to connect a seal housing (not shown).

[00193] Referring to Figure 14D, section XXIID is a cross section of the shell (2120). Figure 14D shows a portion of the fluid channel system within the two part high speed spindle body (120A), including: at least one secondary horizontal fluid channel (2224) that fluidly connects to at least one

primarily horizontal fluid channel (422) within the core, and to the primary vertical fluid channel (426) within the shell, that is further fluidly connected to the first fluid manifold (370).

[00194] Figure 14D also includes: a shell vent opening (2150), shell surface (2238) which benches against core surface (2228) when the two parts are assembled.

Bearings

[00195] Many factors governing the selection of the optimal bearings for use with the spindles of this disclosure. These factors include the available space, the loads the bearing will encounter, the speeds (including acceleration and deceleration requirements), the required stiffness and precision, noise level, cost considerations and more.

[00196] The high speed rotation spindle may incorporate at least one contact bearing. Examples of suitable contact bearings may include radial contact bearings, an angular contact ball bearing, a deep groove ball bearing, a cylindrical roller bearing, a needle roller bearing, a spherical roller bearing, and a tapered roller bearing.

[00197] All of the above bearing types may be open, shielded or sealed designs.

[00198] Preferably, at least one bearing is a shielded type bearing. The shielding rings insulate the bearing race and rolling elements from their environment. However, the insulation of the shield is not 100% hermetic, that is, it does not completely prevent seepage of fluid, moisture, humidity etc., to spaces in proximity to the bearing rolling elements and the races, but it does reduce the amount that seeps through. Furthermore, it is very effective in blocking solid particles from entering spaces in proximity to the bearing rolling elements and the races.

[00199] In some embodiments, the shielded bearing includes two shields, one on each side of the rolling elements. The shields can be mounted in the grooves of the inner and outer bearing races or the shields can be mounted on the exterior portion of the races.

[00200] In some embodiments, one shield is mounted in either or both grooves of the inner and outer bearing races while one shield is mounted on the exterior portion of the races, in the direction from which insulation from the environment is most needed.

[00201] Preferably, at least two bearings are mounted on the shaft. In some embodiments the at least two bearings have the same radial dimensions. In some embodiments, the at least two bearings have the same height dimensions.

[00202] Alternatively, the at least two bearings may have different radial and/or height dimensions. In an embodiment, the bearing closer to the cutting tool end is designed to carrying a

higher portion of the load during shaft rotation. In an embodiment, the bearing closer to the cutting tool end is the largest bearing mounted on the rotating shaft. In an embodiment, a second bearing is mounted further away from the cutting tool end than a first bearing. In an embodiment, the second bearing is designed to have axial expansion capabilities.

[00203] In an embodiment, the at least two bearing having different dimensions to reduce vibration in elements in which they are in contact. In an embodiment, the at least two bearing having different dimensions to reduce vibration in elements of the high speed spindle. In an embodiment, at least two bearing have different dimensions to reduce high frequency vibration in elements in which they are in contact with. In an embodiment, the at least two bearing having different dimensions reduce high frequency vibration in elements of the high speed spindle.

[00204] In an embodiment, the at least one bearing dimensions are (12, 28, 8). In an embodiment the at least second bearing dimensions are (10, 26, 8). Wherein bearing dimensions are provided in mm using the following convention: (inner diameter, outer diameter, bearing thickness or width).

[00205] In an embodiment, the at least one bearing dimensions are (15, 28, 7) or (17, 30, 7). In an embodiment the at least second bearing dimensions are (10, 22, 6) or (10, 24, 6) or (12, 24, 6) or (10, 30, 9).

[00206] In an embodiment, the at least one bearing inner diameter dimensions are smaller than 10, 11, 12, 13, 14, 15, or 16 mm. In an embodiment, the at least one bearing outer diameter dimensions are smaller than 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, or 30 mm.

[00207] In an embodiment, more at least three bearings are mounted on the shaft. In an embodiment, at least four bearings are mounted on the shaft.

[00208] In an embodiment the fluid driven high speed spindle is cooled by the high pressure fluid flowing in the fluid channel system. In an embodiment the fluid channels are in sufficient proximity to the bearings to remove heat generated by the bearing during high speed rotation.

Bearing Lubrication

[00209] The choice of lubricant is important. Contact bearings are lubricated with numerous types of greases and oils. The choice of a lubricant depends primarily on the operating conditions, i.e. the temperature range and speeds as well as the influence of the surroundings. In fluid driven high

speed spindle, the lubricant must support high speed rotation while being insensitive to small amounts of fluid.

[00210] In an embodiment the bearing rolling elements and races are protected from fluid, vapors, moisture and solid particles by lubrication material. In an embodiment the lubrication material is grease.

[00211] In an embodiment the grease shall be a compound from synthetic oil and metal soap thickener and or additives. An example of possible synthetic oil also known base oil is PAO (poly-alpha-olefin).

[00212] Metal soap thickeners include lithium soap and lithium complex soap. Additives include rust inhibitors and or PFPE and or PTFE compounds. Greases containing PFPE and PTFE compounds are typically insoluble in water, acids, bases, and most organic solvents and can withstand extreme pressure and high mechanical stress. For example UniFlor PerFluoroPolyether (PFPE) lubricants, compounds: #8172; #8981; #8917; #8512; #8950 and others from the same and or other manufacturers.

[00213] In an embodiment space constraints are defined based on ATC requirements. In an embodiment, the maximum diameter of the high speed spindle is 80 mm.

Shaft

[00214] The shaft design includes conflicting considerations such as high stiffness dictating larger diameter and higher speeds requiring less mass and less friction dictating a smaller shaft diameter. The shaft design considerations also availability of space and volume in the system as well as cutting tool diameter.

[00215] In an embodiment, the maximum cutting tool diameter is 7 mm. In an embodiment, the maximum cutting tool diameter is 7 mm and the rotational speed is at least 25,000 revolutions per second. In an embodiment, the maximum cutting tool diameter is 6 mm and the rotational speed is at least 35,000 revolutions per second.

[00216] In an embodiment, the cutting tool is secured to the shaft by means adhering to requirements defined by the ER 11 standard.

[00217] In an embodiment, the shaft diameter varies along its length. In an embodiment, the shaft diameter is larger at the cutting tool end than at the mounting location of at least one bearing. In an embodiment, the shaft diameter is at least 12 mm in proximity to the collet and or at least 17 mm above the cutting tool end. In an embodiment the shaft diameter at the mounting location of at least one bearing is at least 10 mm. In an embodiment, the shaft diameter at the mounting location of at least

a second bearing is larger than the shaft diameter at the mounting location of at least one bearing. In an embodiment, the shaft diameter at the mounting location of at least a second bearing is smaller than the shaft diameter at the mounting location of at least one bearing.

Fluid System Considerations

[00218] In an embodiment the fluid pressure entering the high speed spindle is more than 10 bar. In an embodiment the fluid pressure entering the high speed spindle is more than 17 bar. In an embodiment the fluid pressure entering the high speed spindle is more than 20 bar. In an embodiment the fluid pressure entering the high speed spindle is more than 25 bar. In an embodiment the fluid pressure entering the high speed spindle is more than 40 bar.

[00219] In an embodiment the fluid flow entering the high speed spindle is more than 5 liter per minute. In an embodiment the fluid flow entering the high speed spindle is more than 10 liter per minute. In an embodiment the fluid flow entering the high speed spindle is more than 17 liter per minute. In an embodiment the fluid flow entering the high speed spindle is more than 20 liter per minute.

[00220] In an embodiment the fluid pressure entering the high speed spindle is 17 bar and the flow is 12 Liter per minute. In an embodiment the fluid pressure entering the high speed spindle is 17 bar and the flow is 9 Liter per minute.

[00221] In an embodiment the fluid is primarily water based. In an embodiment the fluid is an emulsion used in machining processes. In an embodiment the fluid is primarily oil based.

Example Spindle Operation Characteristics

[00222] In an embodiment the axial load applied on the cutting tool tip is less than 25 N. In an embodiment the axial load applied on the cutting tool tip is less than 50 N. In an embodiment the axial load applied on the cutting tool tip is less than 75 N.

[00223] In an embodiment the perpendicular load applied on the cutting tool tip is less than 50 N. In an embodiment the perpendicular load applied on the cutting tool tip is less than 100 N. In an embodiment the perpendicular load applied on the cutting tool tip is less than 170 N. In an embodiment the perpendicular load applied on the cutting tool tip is less than 200 N.

[00224] In an embodiment the acceleration and deceleration of the high speed spindle rotational velocity is less than $1700 \text{ rad} / \text{sec}^2$. In an embodiment the acceleration and deceleration of the high speed spindle rotational velocity is less than $1700 \text{ rad} / \text{sec}^2$. In an embodiment the

acceleration and deceleration of the high speed spindle rotational velocity is less than $2000 \text{ rad} / \text{sec}^2$.
In an embodiment the acceleration and deceleration of the high speed spindle rotational velocity is less than $3000 \text{ rad} / \text{sec}^2$.

[00225] In an embodiment the precision of rotation between the shank and the shaft end is less than 2.5 micron. In an embodiment the precision of rotation between the shank and the shaft end is less than 5 micron. In an embodiment the precision of rotation between the shank and the shaft end is less than 10 micron. In an embodiment the precision of rotation between the shank and the shaft end is less than 17 micron.

[00226] Parts list

Number	Part Names
A	Longitudinal axis
100	Spindle
101	Shank extension
102	Entry port
110	Shank
120, 120A	Body
130	Sensor module
150, 150A, 150B	Seal housing
180, 180A, 180B	Cover
204	Filtration unit nut
206	Mesh
214	Wrench grip

218	Seal slot
232	Mounting location
240	Internal subsystem
248	Gasket
252	First screws
282	Second screws
290	Collet
292	Collet nut
312	Cone shank
324	Access opening
334	Sensing aperture
335	Fluid aperture
336	Mounting threads
338	Mounting slots
352	Threaded holes
354	Bottom openings
370	First fluid manifold
398	Bottom end
404	Shank end
406	First bearing cavity mounting surface

408	Second bearing cavity mounting surface
412	Shank thread
416	Shank channel
418	Fluid channel junction
422	Primary horizontal fluid channel
426	Primary vertical fluid channel
440	Cavity
442	Spacer shoulder
444	Smaller-diameter section
446	Larger-diameter section
450	Vent
496	Exterior
506	Gap
508	Second bearing
512	Major turbulence pocket
527	Secondary vertical fluid channel
528	Inlet channel
530	Shaft
552	Second annular fluid manifold
556	Stationary fluid exit channel

570, 570A	Turbine
571	Central fluid exit
572A	Lower annular gap
572B	Upper annular gap
572	Annular gap
573	Second fluid exit
574	Seal annular gap
576	Nozzle
578	Nozzle fluid manifold
583	Exit channel
586	Second axial exit opening
587	Bottom annular cavity
588, 588A	First axial exit opening
598	Shaft tool end
606	First bearing
610	Bearing spacer
612	Bearing spacer opening
622	External shoulder
623	Internal shoulder
651	Bottom surface

656	Counter bores
660, 660A	Flinger
686	Seal housing fluid exit holes
704	Shaft top screw
711	Positioning shoulder
714	Rotational position reference
716	First-bearing outer ring
717	First-bearing inner ring
718	Second-bearing outer ring
719	Second-bearing inner ring
732	First bearing shaft mounting surface
733	First bearing shaft mounting shoulder
734	Shaft lock hole
736	Second bearing mounting surface
738	Second bearing mounting shoulder
774	Turbine ring
794	Collet mounting surface
795	Thread
900, 900A	Non-contact seal
914	Minor turbulence pocket

916	Step-like feature
918	Opposing shaft section
922	Vertical gap
923	Flat upper surface
924	Recess
925	Slot wall
926	Large opening
932	Shaft first section
934	Slot shoulder
936	Annular horizontal gap
938	Rotating ledge
954	Seal housing inner surface
961	Second flinger
962	Flinger lower surface
963	Second-flinger lower surface
964	Flinger edge surface
966	Flinger upper surface
969	Turbine area
977	Nozzle ring
979	Cover inner surface

981	Radial perimeter
982	Axial fluid exit channel first section
984	Axial fluid exit channel second section
1024	Stationary surface
1040	Spring flinger
1042	Spring flinger upper surface
1043	Spring flinger mounting surface
1044	Thinner section
1045	Spring flinger cross-section
1340	Stationary ring
1355	First surface
1358	Second surface
1363	Root
1374	Narrow seal annular channel
2052	Internal nut
2054	Vent gasket
2056	External nut
2107	First O-ring
2109	Second O-ring
2111	Third O-ring

2112	Second O-ring slots
2113	Fourth O-ring
2120	Shell
2130	Core
2142	Cavity housing
2150	Shell vent opening
2152	Core vent opening
2209	First O-ring slot
2224	Secondary horizontal fluid channel
2228	Core surface
2238	Shell surface
2266	Shell threaded holes
2268	Vertical fluid channel openings

Claims

What is claimed is:

1. A liquid powered spindle (100) having a longitudinal axis (A) defining an upper end and a lower, shaft-tool end (598), comprising:
 - a) a body (120) having a spindle cavity (440);
 - b) at least one bearing (508) disposed in the cavity (440);
 - c) a shaft (530) supported by the at least one bearing (508) within the cavity (440);
 - d) a seal housing (150) connected to the body (120) at the lower end thereof;
 - e) a cover (180) connected to the seal housing (150) at the lower end thereof;
 - f) a fluid channel system for directing liquid from an entry port (102) to a nozzle (576);
 - g) a turbine (570) attached to the shaft (530), the turbine in fluid communication with the at least one nozzle for rotating the shaft; and
 - h) a flinger (660) attached to the shaft (530) and positioned above the turbine (570);wherein the seal housing (150) defines an annular fluid manifold (552) surrounding the shaft (530) for distributing liquid, deflected upward by the turbine (570), into a plurality of stationary fluid exit channels (556);
wherein the flinger (660) and the seal housing (150) combine to form a non-contact seal (900) configured to impede the flow of liquid toward the at least one bearing (508).
2. The spindle of claim 1, wherein the seal housing (150) further defines:
a major turbulence pocket (512) is defined by a recess (924) within the seal housing, and positioned adjacent to the shaft (530), the major turbulence pocket being disposed above the annular fluid manifold (552) and the flinger (660).
3. The spindle of claim 2, wherein the recess (924) has a shoulder (934) extending from the radial inner portion thereof such that the recess is capable of retaining liquid when the spindle is inverted.
4. The spindle of claim 2, wherein the major turbulence pocket (512) includes a large opening (926) facing the annular fluid manifold (552) and a small opening (936) defined by a gap between the

seal housing (150) and the flinger (660), wherein turbulence within the liquid, impedes flow of the liquid into the small opening (936).

5. The spindle of claim 4, wherein:

the seal housing (150) further defines a minor turbulence pocket (914) radially inward of the major turbulence pocket (512) and in communication with the small opening (936), the minor turbulence pocket (914) defined by a step-like feature (916) adjacent to the inner diameter of the seal housing (150), and

the minor turbulence pocket (914) further impedes flow of the liquid through a vertical gap (922) between the seal housing (150) and the shaft (530).

6. The spindle of claim 1, wherein the body (120) further comprises a vent (450) between the spindle cavity (440) and the exterior of the body, wherein the vent is sealed with a vent gasket (2054) capable of allowing flow in both directions.

7. The spindle of claim 1, further comprising a sensor module (130) in communication with at least one aperture (334, 335) formed in the body (120), wherein the at least one aperture allows the sensor module to sense at least one physical property of the spindle.

8. The spindle of claim 1, wherein the fluid channel system comprises:

i) the entry port (102) associated with a shank (110);

ii) a shank channel (416);

iii) at least one primarily horizontal fluid channel (422) extending from the end of the shank channel;

iv) at least one primary vertical fluid channel (426) extending from the at least one primary horizontal fluid channel through the body; and

v) the at least one nozzle (576) in fluid communication with the at least one primary vertical fluid channel.

9. The spindle of claim 1, wherein the spindle comprises a wrench grip (214) positioned between the body (120) and a shank (110) to accept a wrench and assist with mounting the spindle to a chuck.

10. The spindle of claim 1, wherein the cover (180) comprises at least one first axial exit opening (588) at the bottom thereof, the at least one first axial exit opening (588) provides an exit for the liquid directed downward by the turbine (570).
11. The spindle of claim 10, wherein the cover (180) comprises at least one second axial exit opening (586) disposed radially outward with respect to the at least one first axial exit opening (588), the at least one second axial exit opening in fluid communication with the annular fluid manifold (552) in order to discharge the liquid deflected upward by the turbine (570).
12. The spindle of claim 11, wherein the cover (180) comprises at least one axial fluid exit channel (982, 984) communicating with the at least one second axial exit opening (586), the axis of the axial fluid exit channel being angled with respect to the shaft (530) such that liquid exiting the at least one second axial exit opening (586) will be directed toward the longitudinal axis (A).
13. The spindle of claim 1, wherein the at least one bearing is a plurality of bearings, and the plurality of bearings are of different types or dimensions.
14. The spindle of the claim 1, wherein:
the at least one nozzle (576) is formed along the inner diameter of a nozzle ring (977), the nozzle ring (977) is disposed within the cover (180) to define a nozzle fluid manifold (578),
the at least one nozzle (576) is angled relative to the radial direction of the shaft (530) in order to impact with maximum force of the fluid on the turbine (570).
15. The spindle of claim 1, wherein the body (102) comprises:
a) a shell (2120); and
b) a core (2130), the core comprising:
i) a bearing housing cavity (2142) surrounding the spindle cavity (440); and
ii) a shank (110); and
wherein the the fluid channel system further comprises:
i) the entry port (102) associated with the shank (110);
ii) a shank channel (416);

iii) at least one primary horizontal fluid channel (422) extending from the end of the shank channel through the bearing housing cavity (2142);

iv) at least one primary vertical fluid channel (426) in the shell, the at least one primary vertical fluid channel (426) in fluid communication with the at least one horizontal fluid channel through bearing housing cavity; and

v) the at least one nozzle (576) in fluid communication with the at least one primary vertical fluid channel.

16. The spindle of claim 15, wherein:

the shell (2120) has a first material having a first density and a first hardness and the core (2130) has a second material having a second density and second hardness, and

the first density is less than the second density and the first hardness is less than the second hardness.

17. The spindle of claim 1, wherein:

the flinger (660) is a spring flinger (1040), the spring flinger (1040) having a flexible section (1044), the spring flinger attached to the shaft (530) and positioned above the turbine (570); and wherein:

when the shaft (530) is idle the flexible section (1044) has a first position relatively close to the shaft such that the flexible section contacts and seals with a portion of the seal housing (150), and

when the shaft is rotating; the centrifugal forces generated by the rotating shaft cause the flexible section (1044) to flex away from the shaft, providing a flinger surface for deflecting the liquid, and removing contact with the seal housing (150).

18. A fluid powered spindle (100) having a longitudinal axis (A) defining an upper end and a lower, shaft-tool end (598), comprising:

a) a body (120) having a fluid channel system, a spindle cavity (440), and at least one aperture (334);

b) a shaft (530) having a turbine (570), wherein the shaft is rotated by a pressurized fluid striking the turbine; and

c) at least one sensor module (130) mounted to the body in association with the at least one aperture such that the at least one aperture allows the at least one sensor module to sense at least one physical property of the spindle.

19. The spindle of claim 18, wherein the at least one aperture is a sensing aperture providing a path from the sensor module to the spindle cavity.

20. The spindle of claim 19, wherein the shaft includes a rotational position reference (714) for detection by the sensor module.

21. The spindle of claim 18, wherein the at least one aperture includes a fluid aperture (335) in fluid communication with the fluid channel system to sense fluid system properties thereof.

22. The spindle of claim 21, wherein the fluid system properties include at least one of fluid pressure, fluid velocity and fluid viscosity.

23. The spindle of claim 18, wherein the at least one sensor module is wireless.

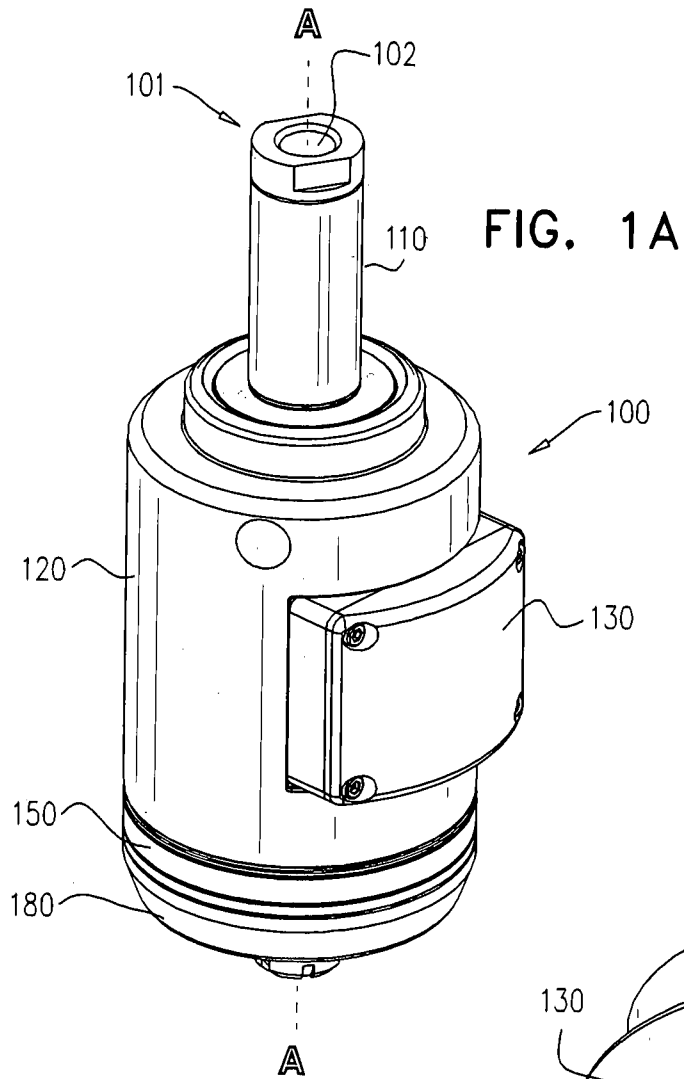
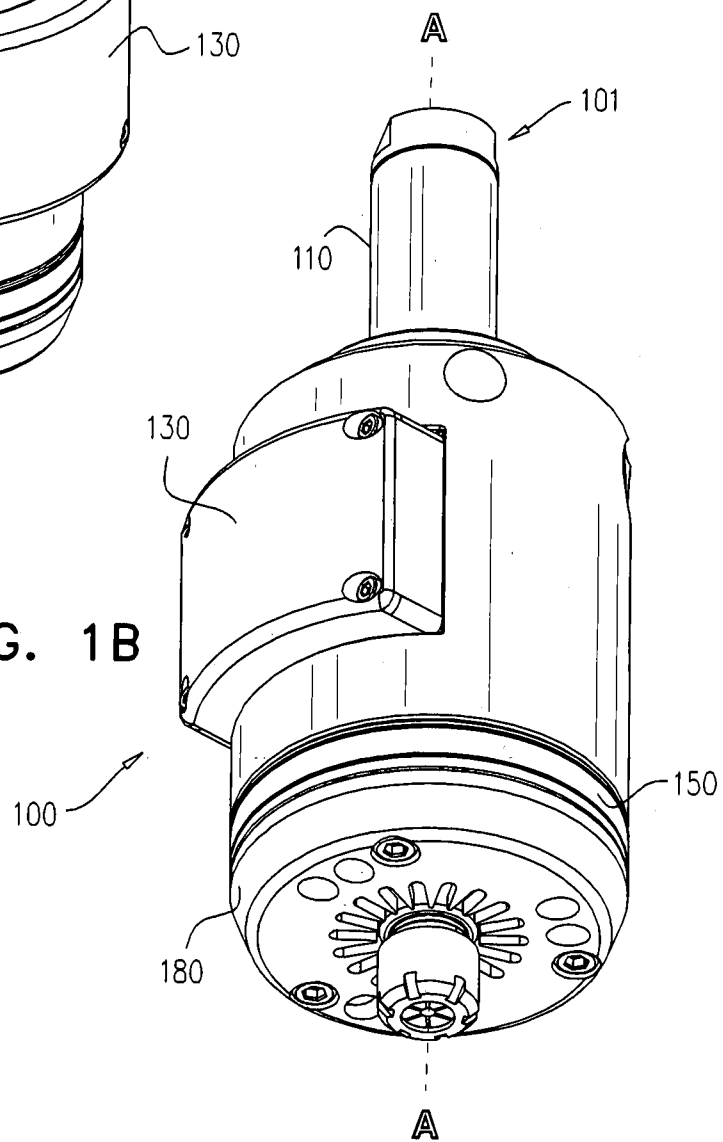


FIG. 1B



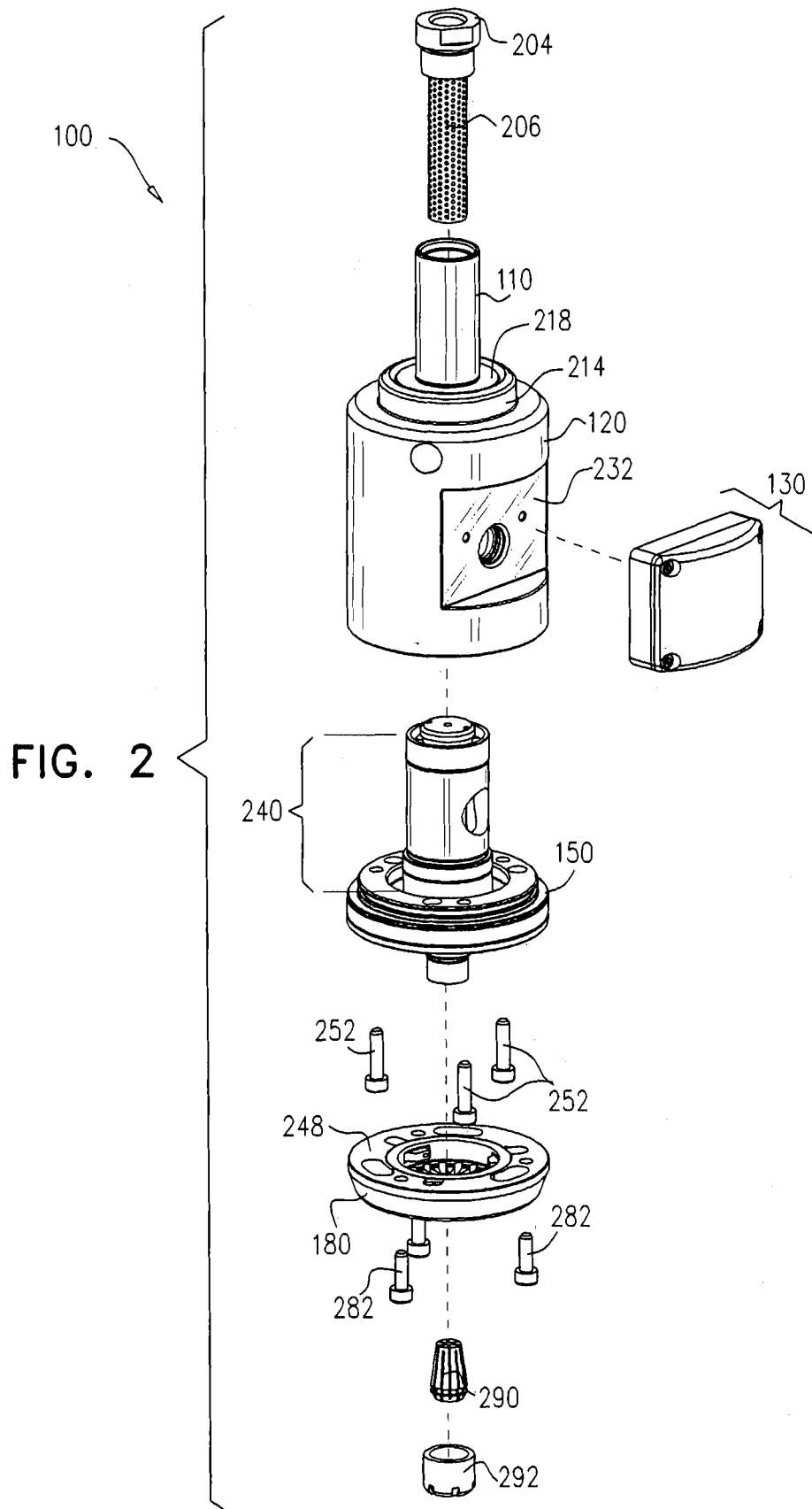


FIG. 3A

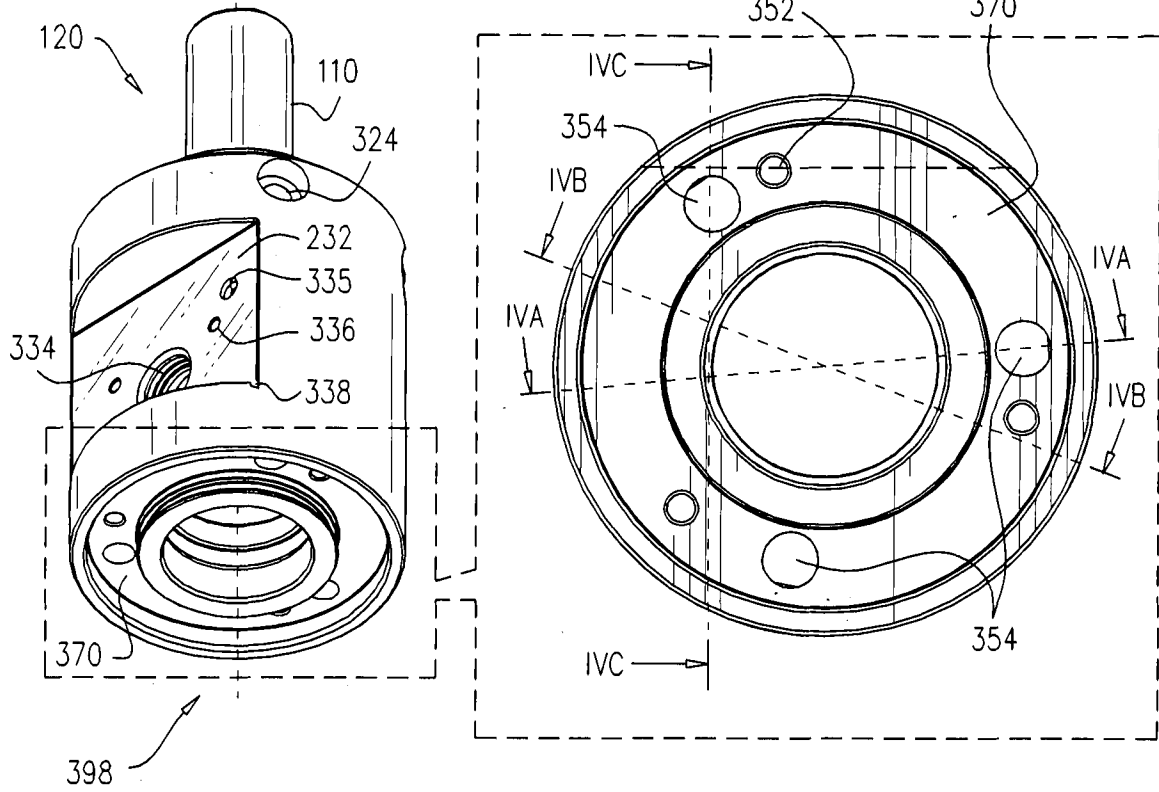


FIG. 3B

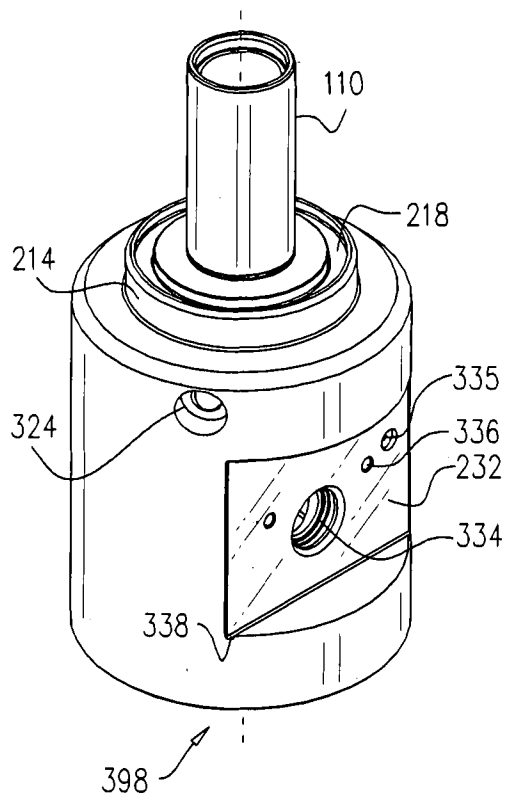


FIG. 3C

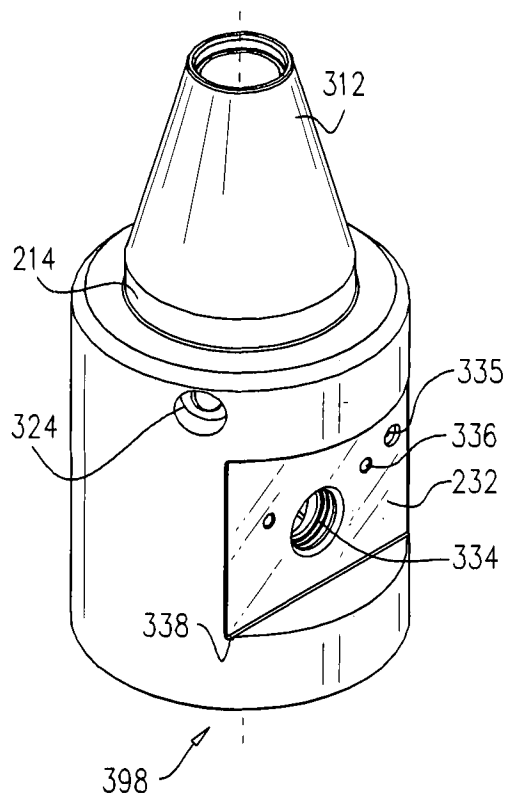


FIG. 4A

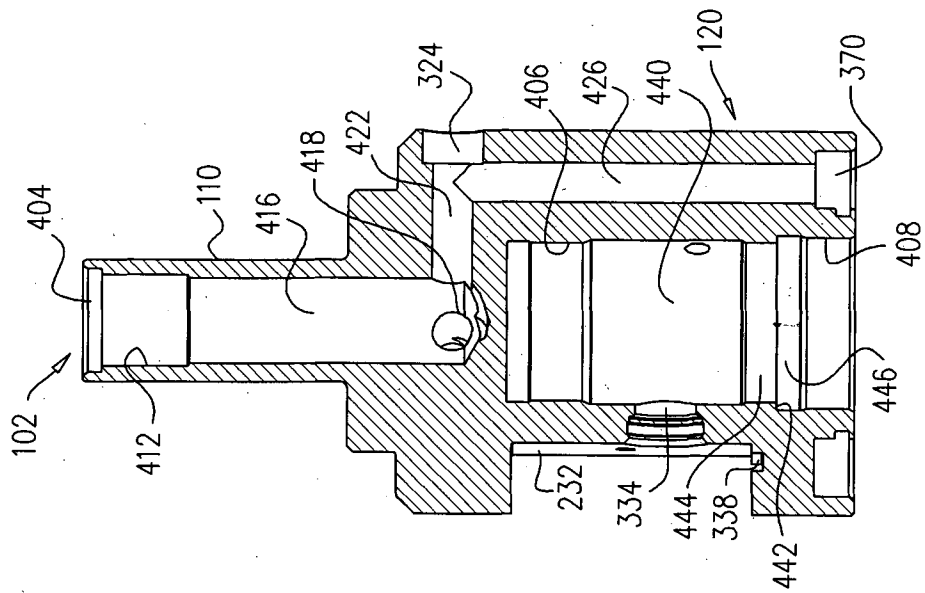


FIG. 4B

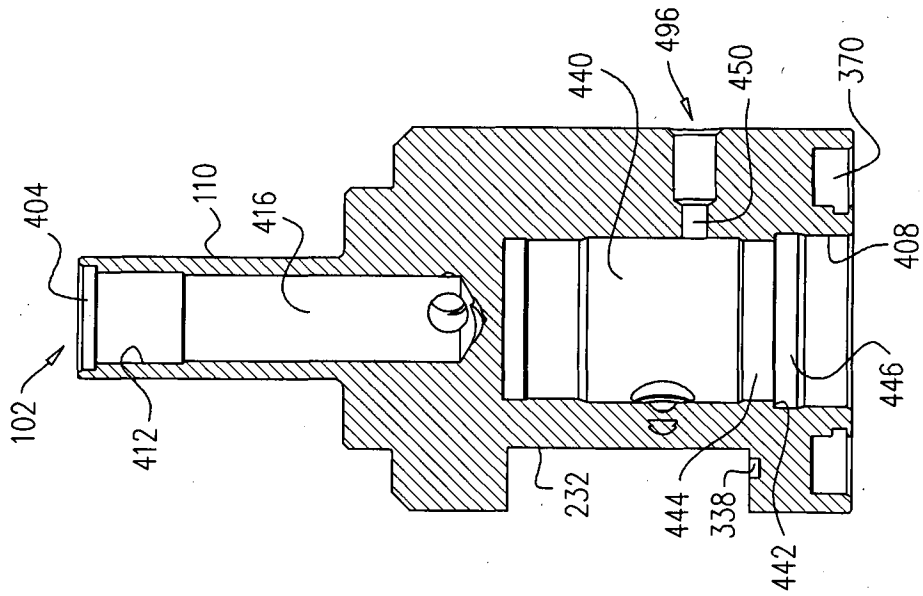
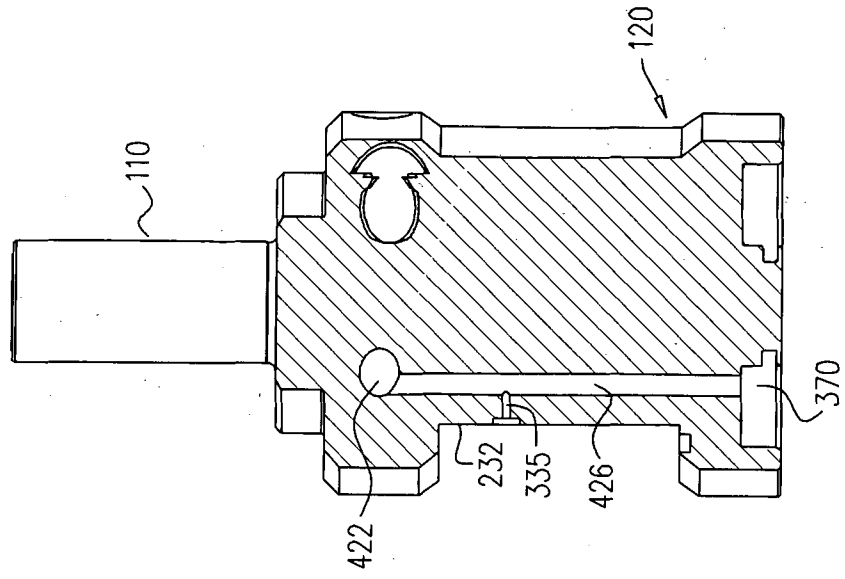
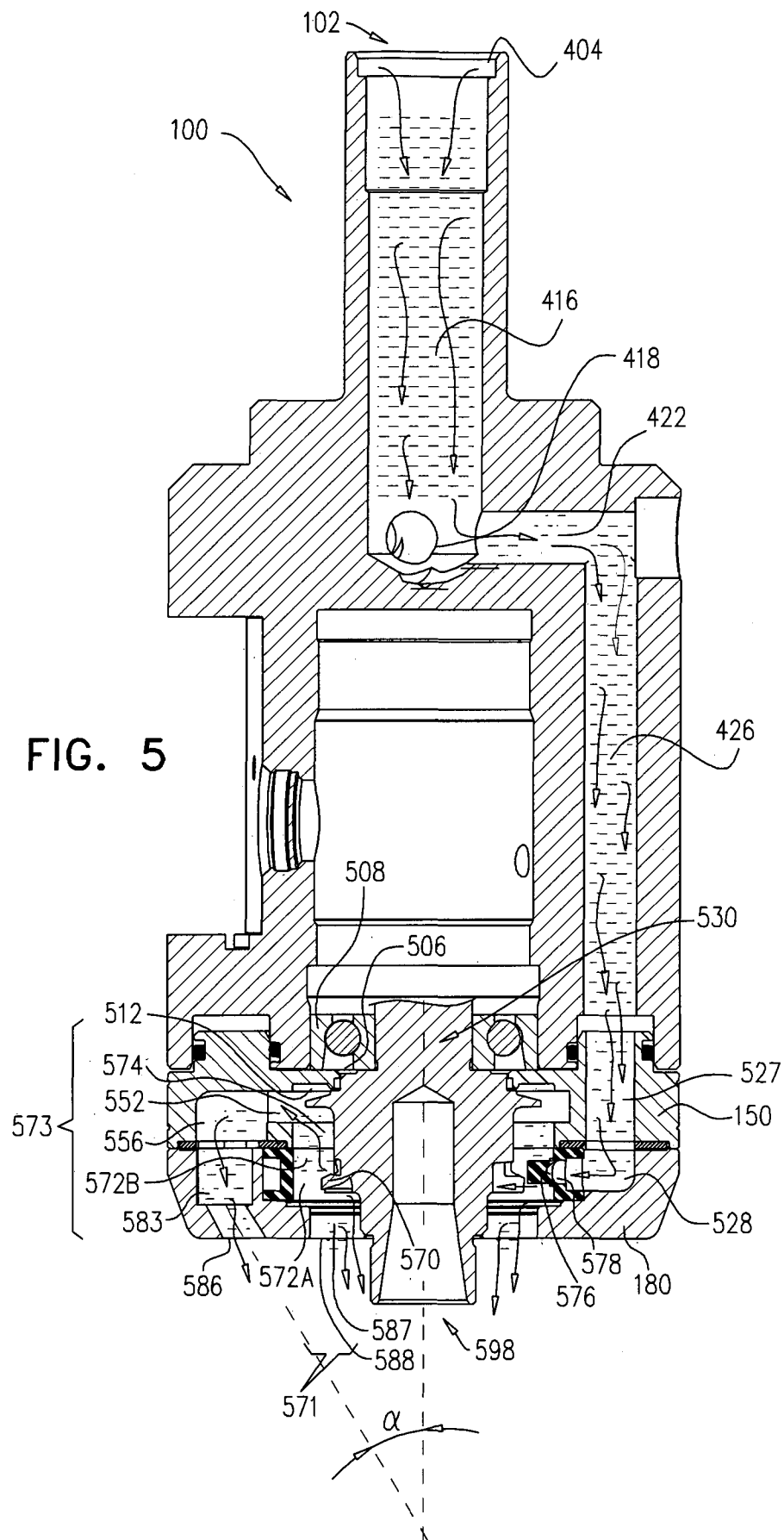
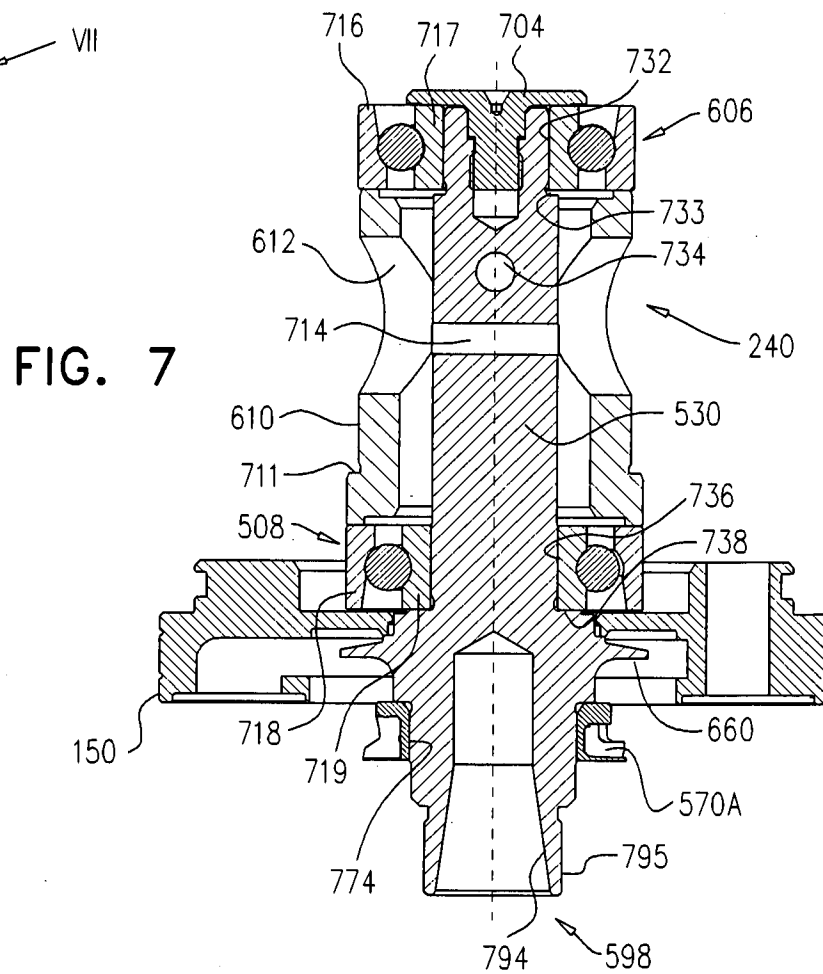
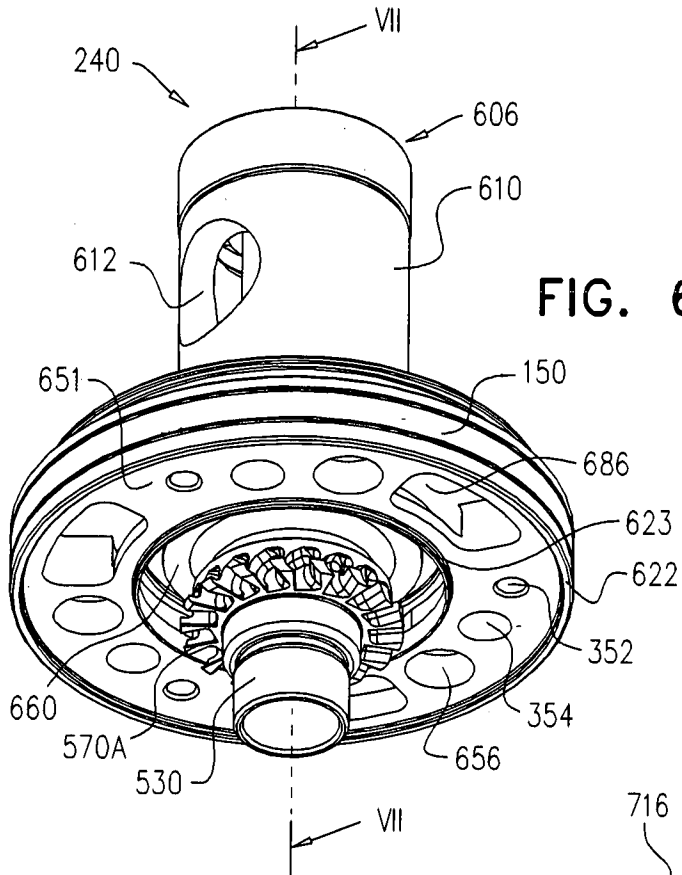


FIG. 4C







7/17

FIG. 8A

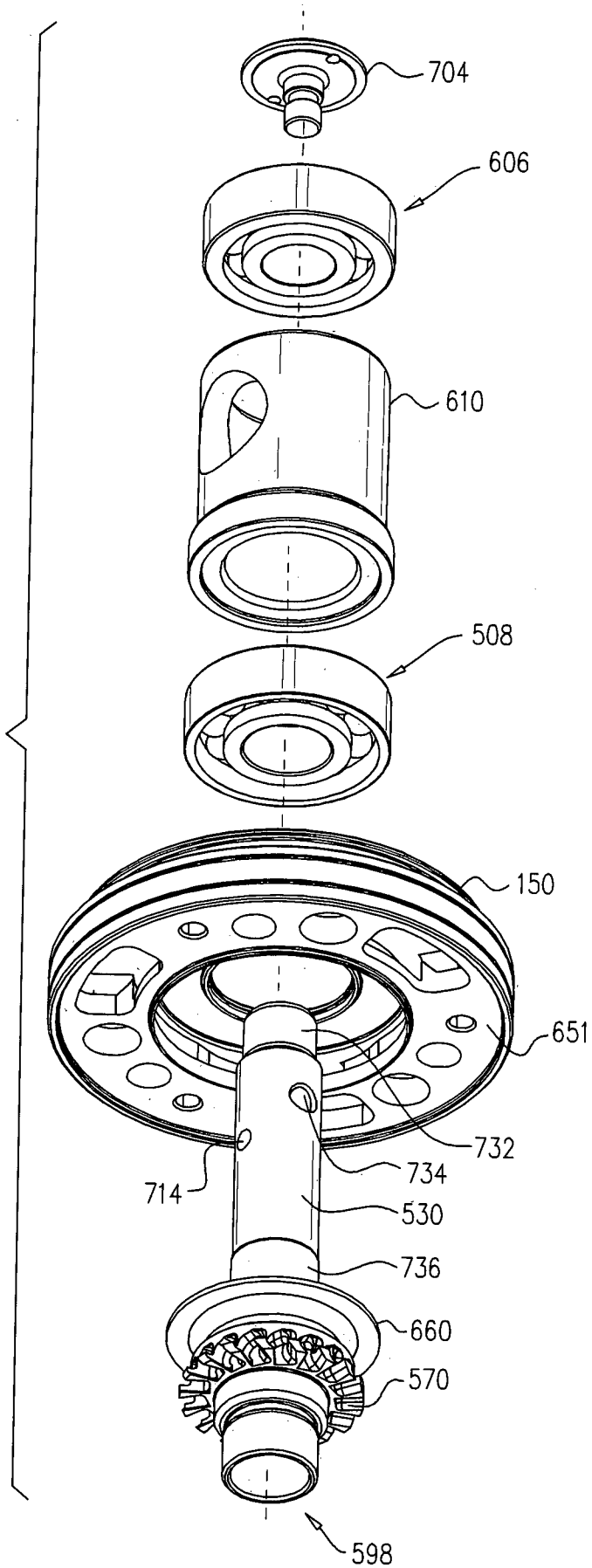
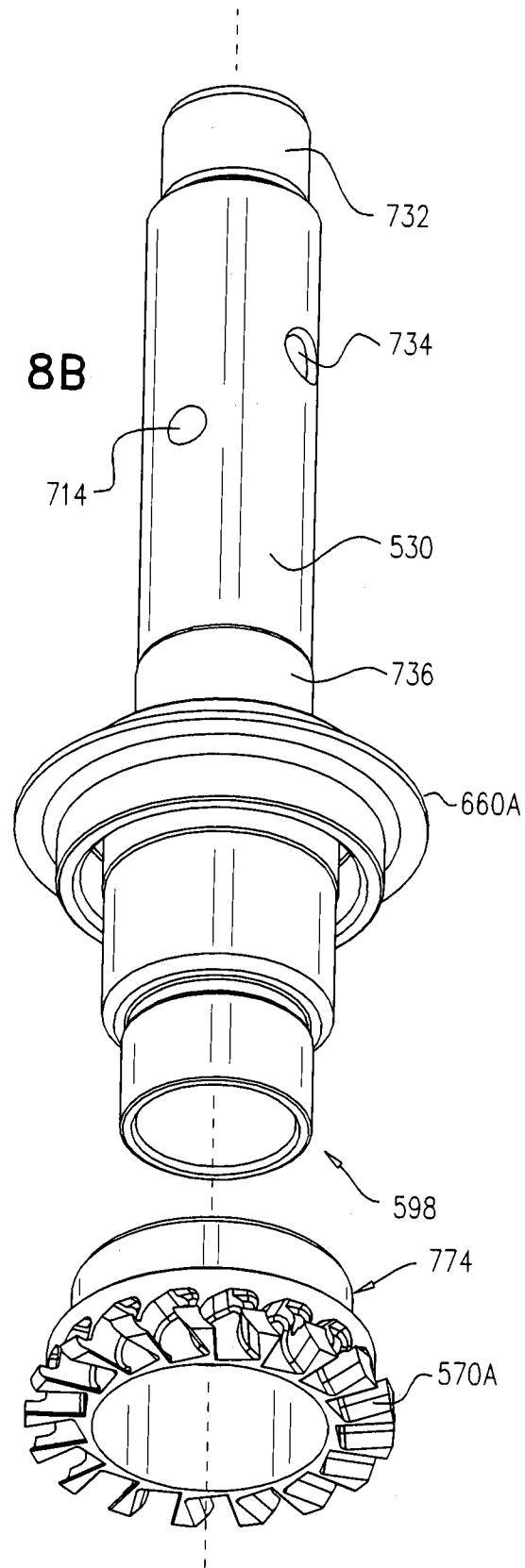
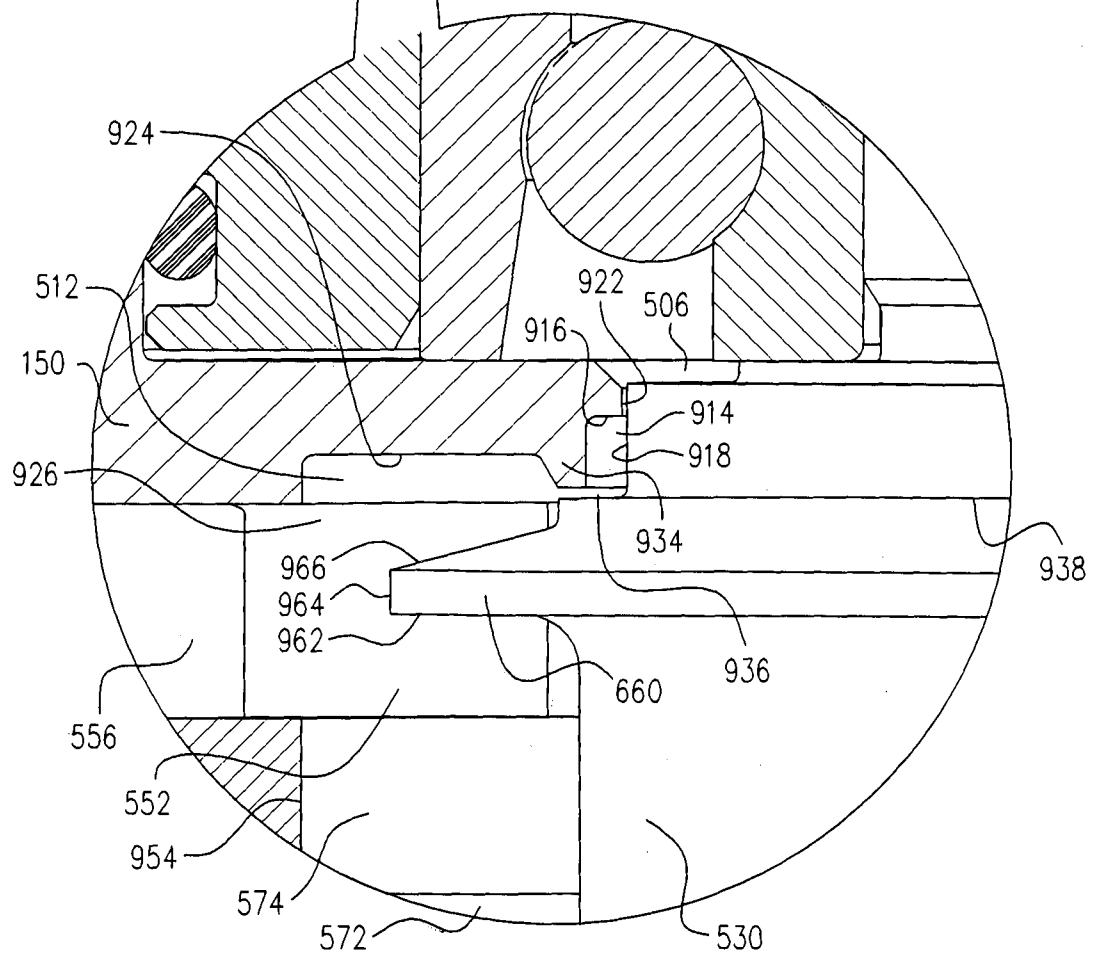
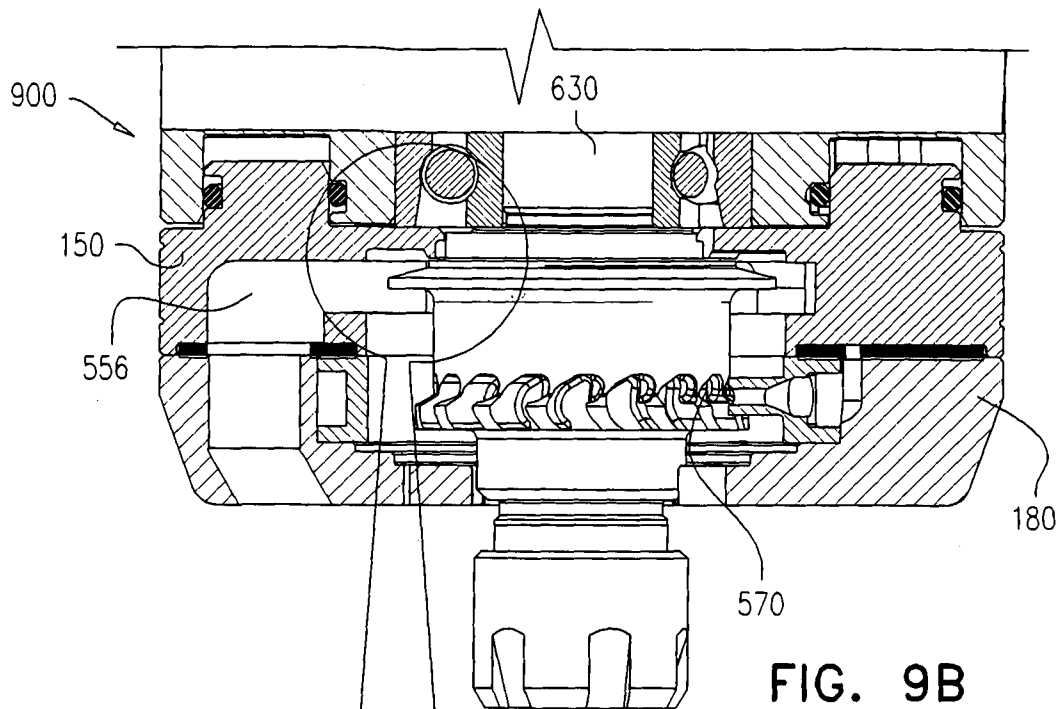


FIG. 8B





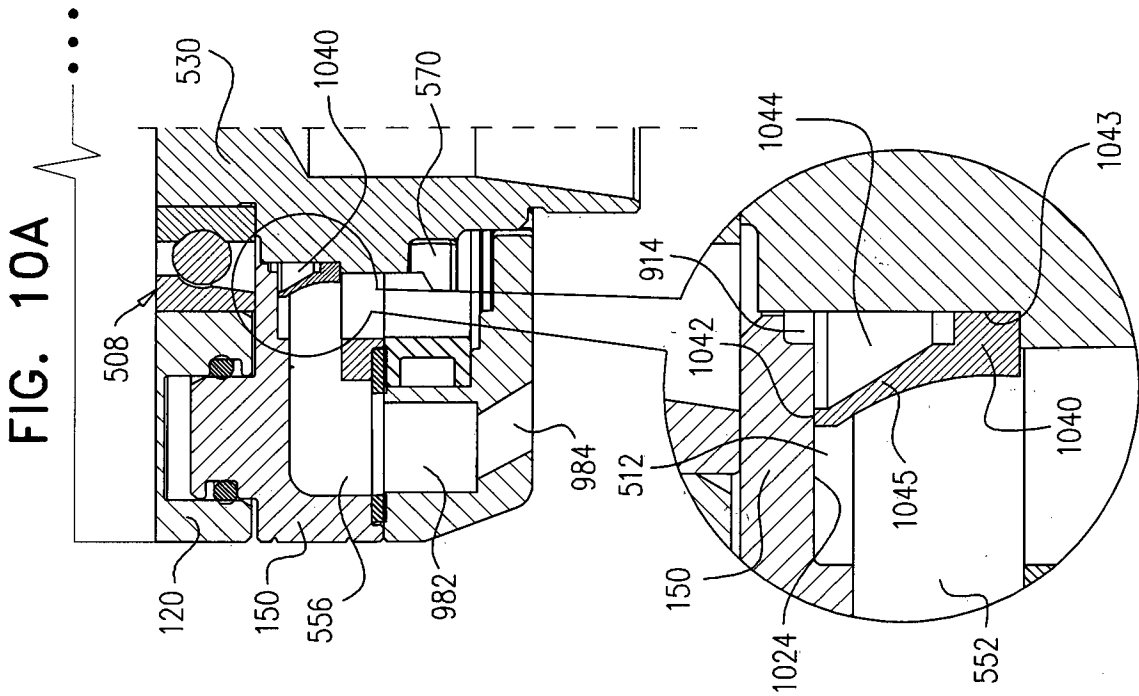
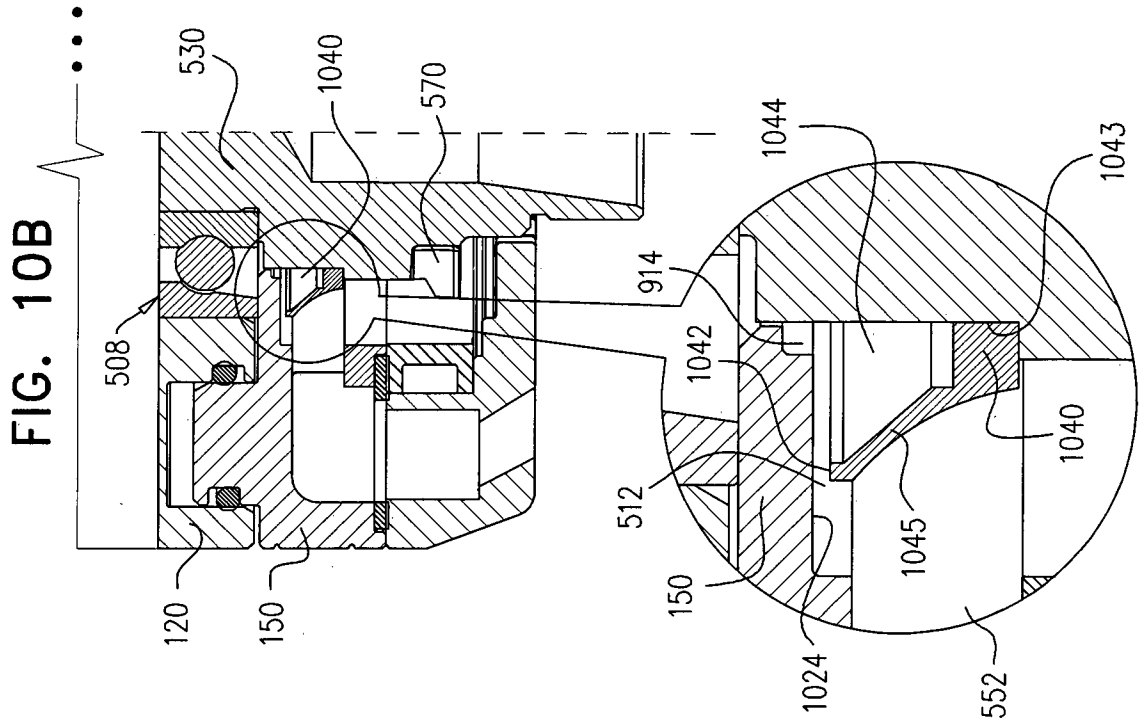


FIG. 11A

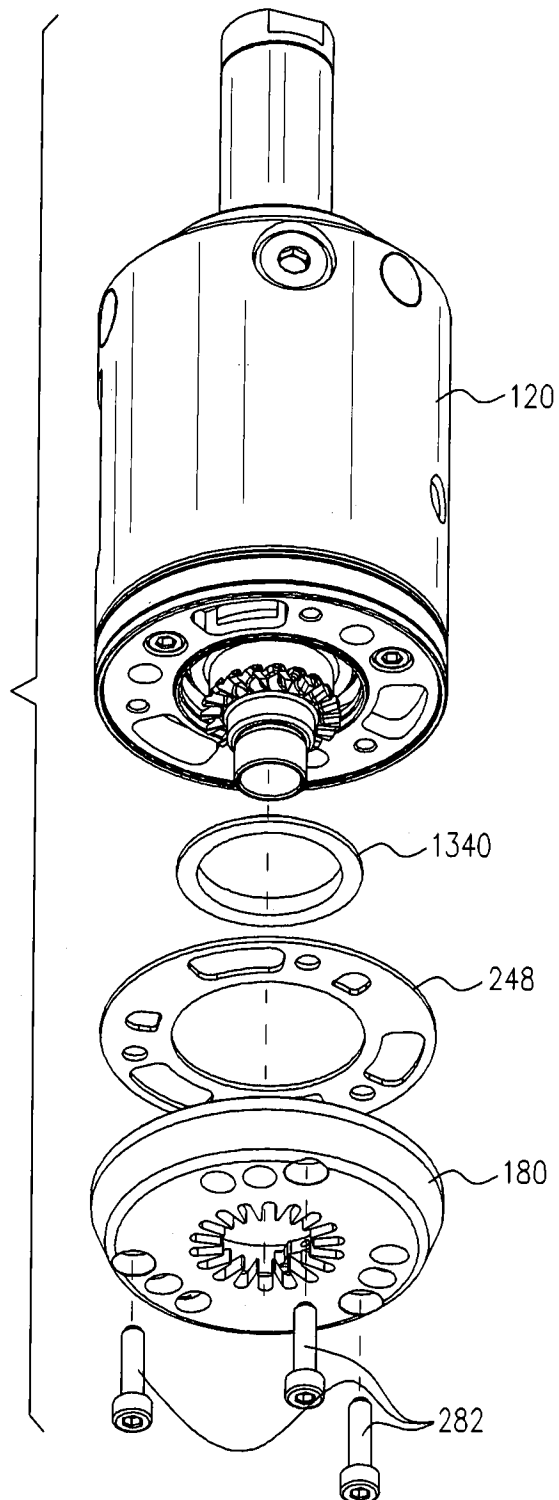


FIG. 12

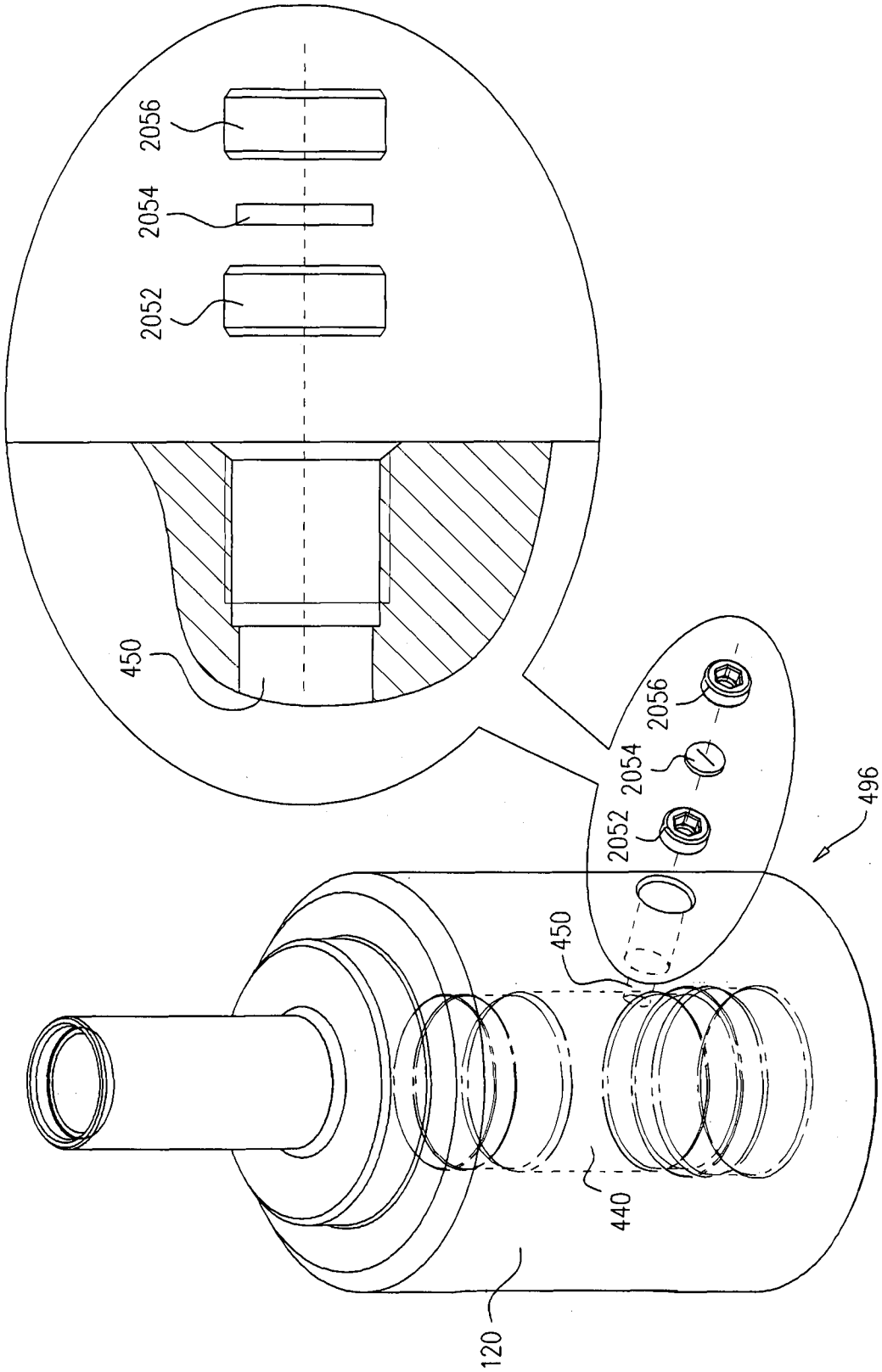


FIG. 13

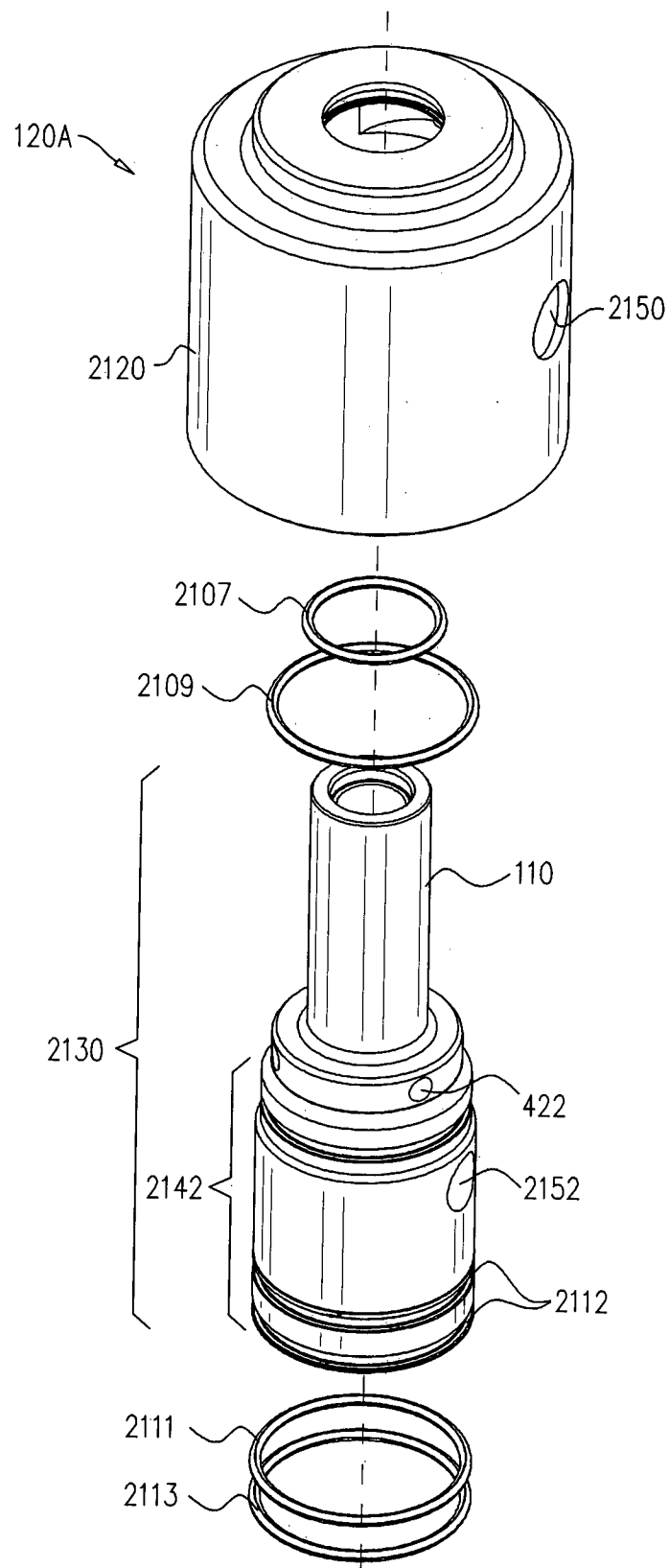


FIG. 14A

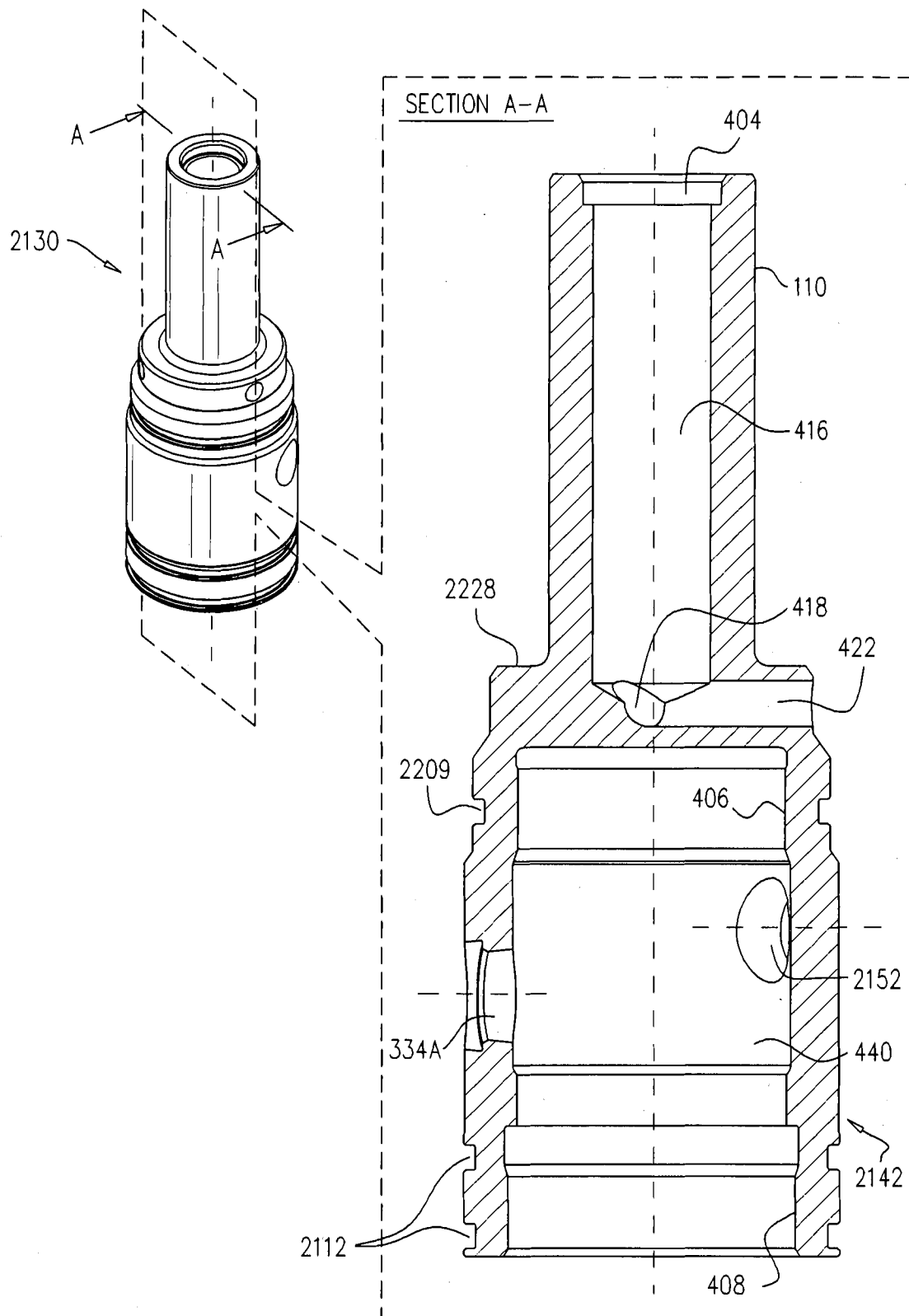


FIG. 14B

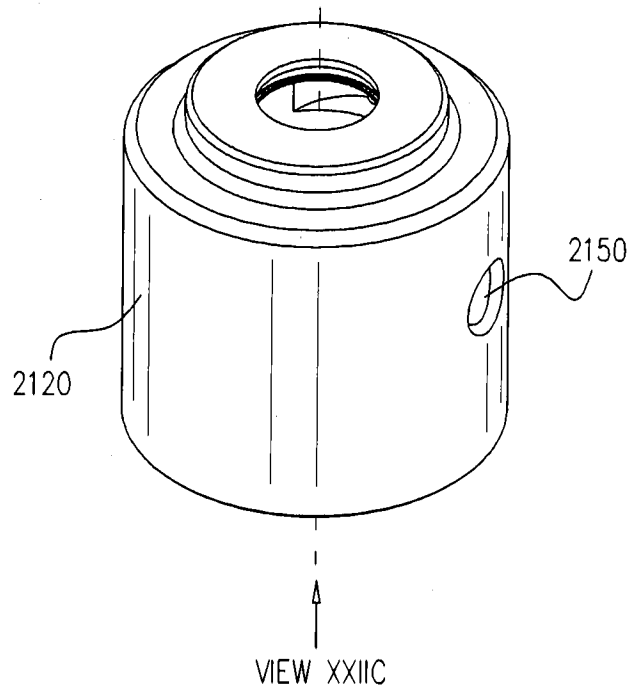


FIG. 14C

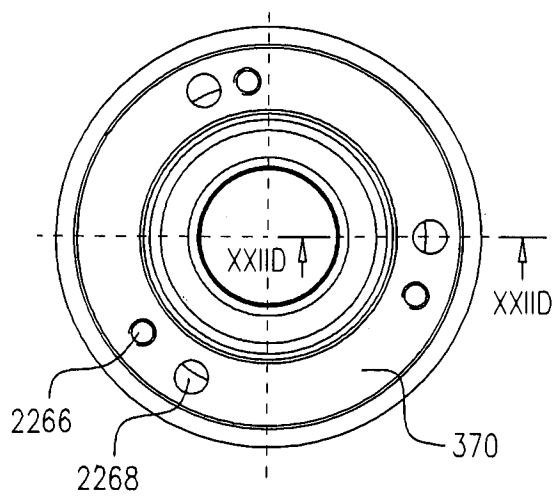


FIG. 14D

