(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
11 April 2013 (11.04.2013)

WIPO | PCT

(10) **International Publication Number**
WO 2013/052071 A1

(51) **International Patent Classification**:
B24B 37/04 (2012.01)

(21) **International Application Number**:
PCT/US2011/059683

(22) **International Filing Date**:
8 November 2011 (08.11.2011)

(25) **Filing Language**: English

(26) **Publication Language**: English

(30) **Priority Data**:
13/267,305 6 October 2011 (06.10.2011) US

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) **Title**: PIVOT-BALANCED FLOATING PLATEN LAPPING MACHINE

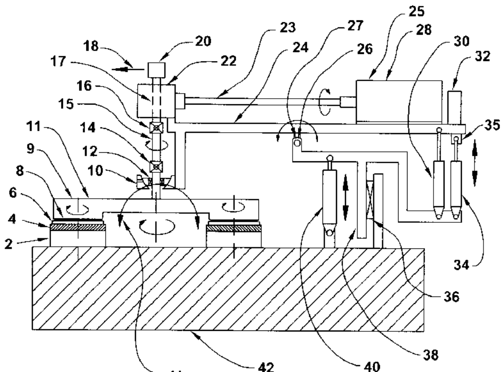

Fig. 1

(57) **Abstract**: A low friction flat-lapping abrading apparatus and method for releasably attaching flexible abrasive disks to a flat-surfaced platen that floats in three-point abrading contact with flat-surfaced workpieces that are attached to three rotary spindles. The rigid equal- height flat-surfaced rotatable fixed-position workpiece spindles are mounted on a flat abrading machine base. They are positioned to form a triangle to provide stable support of the floating platen. All three spindle-tops are co-planar aligned to provide a precision- flat reference plane for mounting of the workpieces. The lapping operation has very high abrading speeds and very low abrading forces. The lightweight but strong lapping machine employs a pivot-balance structure where the weight of the drive motor is used to balance the weight of the abrading platen. Use of low-friction air bearings provides the capability for precision control of the abrading forces. The lapping machine is robust and well suited for a harsh abrading environment.

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PIVOT-BALANCED FLOATING PLATEN LAPPING MACHINE

BACKGROUND OF THE INVENTION

1 Field of the Invention

The present invention relates to the field of abrasive treatment of surfaces such as grinding, polishing and lapping. In particular, the present invention relates to a high speed lapping system that provides simplicity, quality and efficiency to existing lapping technology using multiple floating platens.

Flat lapping of workpiece surfaces used to produce precision-flat and mirror smooth polished surfaces is required for many high-value parts such as semiconductor wafer and rotary seals. The accuracy of the lapping or abrading process is constantly increased as the workpiece performance, or process requirements, become more demanding. Workpiece feature tolerances for flatness accuracy, the amount of material removed, the absolute part-thickness and the smoothness of the polish become more progressively more difficult to achieve with existing abrading machines and abrading processes. In addition, it is necessary to reduce the processing costs without sacrificing performance. Also, it is highly desirable to eliminate the use of messy liquid abrasive slurries. Changing the abrading process set-up of most of the present abrading systems to accommodate different sized abrasive particles, different abrasive materials or to match abrasive disk features or the size of the abrasive disks to the workpiece sizes is typically tedious and difficult.

Fixed-Spindle-Floating-Platen System

The present invention relates to methods and devices for a single-sided lapping machine that is capable of producing ultra-thin semiconductor wafer workpieces at high abrading speeds. This is done by providing a flat surfaced granite machine base that is used for mounting three individual rigid flat-surfaced rotatable workpiece spindles. Flexible abrasive disks having annular bands of fixed-abrasive coated raised islands are attached to a rigid flat-surfaced rotary platen. The platen annular abrading surface floats in three-point abrading contact with flat surfaced workpieces that are mounted on the three equal-spaced flat-surfaced rotatable workpiece spindles. Water coolant is used with these raised island abrasive disks.

Presently, floating abrasive platens are used in double-sided lapping and double-sided micro-grinding (flat-honing) but the abrading speeds of both of these systems are very low. The upper floating platen used with these systems are positioned in conformal contact with multiple equal-thickness workpieces that are in flat contact with the flat abrading surface of a lower rotary platen. Both the upper and lower abrasive coated platens are typically concentric with each other and they are rotated independent of each other. Often the platens are rotated in opposite directions to minimize the net abrading forces that are applied to the workpieces that are sandwiched between the flat annular abrading surfaces of the two platens.

In order to compensate for the different abrading speeds that exist at the inner and outer radii of the annular band of abrasive that is present on the rotating platens, the workpieces are rotated. The speed of the rotated workpiece reduces the too-fast platen speed at the outer periphery of the platen and increases the too-slow speed at the inner periphery when the platen and the workpiece are both rotated in the same direction. However, if the upper abrasive platen and the lower abrasive platen are rotated in opposite directions, then rotation of the workpieces is favorable to the platen that is rotated in the same direction as the workpiece rotation and is unfavorable for the other platen that rotates in a direction that opposes the workpiece rotation direction. Here, the speed differential provided by the rotated workpiece acts against the abrading speed of the opposed rotation direction platen. Because the localized abrading speed represents the net speed difference between the workpieces and the platen, rotating them in opposite directions increases the localized abrading speeds to where it is too fast. Providing double-sided abrading where the upper and lower platens are rotated in opposed directions results over-speeding of the abrasive on one surface of a workpiece compared to an optimum abrading speed on the opposed workpiece surface.

In double-sided abrading, rotation of the workpieces is typically done with thin gear-driven planetary workholder disks that carry the individual workpieces while they are sandwiched between the two platens. Workpieces comprising semiconductor wafers are very thin so the planetary workholders must be even thinner to allow unimpeded abrading contact with both surfaces of the workpieces. The gear teeth on these thin workholder disks that are used to rotate the disks are very fragile, which prevents fast rotation of the workpieces. The resultant slow-rotation workpieces prevent fast abrading speeds of the abrasive platens. Also, because the workholder disks are fragile, the upper and lower platens are often rotated in opposite directions to minimize the net abrading forces on individual workpieces because a portion of this net workpiece abrading force is applied to the fragile disk-type workholders. It is not practical to abrade very thin workpieces with double-sided platen abrasive systems because the required very thin planetary workholder disks are so fragile.

Multiple workpieces are often abrasive slurry lapped using flat-surfaced single-sided platens that are coated with a layer of loose abrasive particles that are in a liquid mixture. Slurry lapping is very slow, and also, very messy.

The platen slurry abrasive surfaces also wear continually during the workpiece abrading action with the result that the platen abrasive surfaces become non-flat. Non-flat platen abrasive surfaces result in non-flat workpiece surfaces. These platen abrasive surfaces must be periodically reconditioned to provide flat workpieces. Conditioning rings are typically placed in abrading contact with the moving annular abrasive surface to re-establish the planar flatness of the platen annular band of abrasive.

In single-sided slurry lapping, a rigid rotating platen has a coating of abrasive in an annular band on its planar surface. Floating-type spherical-action workholder spindles hold individual workpieces in flat-surfaced abrading contact with the moving platen slurry abrasive with controlled abrading pressure.

The fixed-spindle-floating-platen abrading system has many unique features that allow it to provide flat-lapped precision-flat and smoothly-polished thin workpieces at very high abrading speeds. Here, the top flat surfaces of the individual spindles are aligned in a common plane where the flat surface of each spindle top is co-planar with each other. Each of the three rigid spindles is positioned with approximately equal spacing between them to form a triangle of spindles that provide three-point support of the rotary abrading platen. The rotational-centers of each of the spindles are positioned on the granite so that they are located at the radial center of the annular width of the precision-flat abrading platen surface. Equal-thickness flat-surfaced workpieces are attached to the flat-surfaced tops of each of the spindles. The rigid rotating floating-platen abrasive surface contacts all three rotating workpieces to perform single-sided abrading on the exposed surfaces of the workpieces. The fixed-spindle-floating platen system can be used at high abrading speeds with water cooling to produce precision-flat and mirror-smooth workpieces at very high production rates. There is no abrasive wear of the platen surface because it is protected by the attached flexible abrasive disks. Use of abrasive disks that have annular bands of abrasive coated raised islands prevents the common problem of hydroplaning of workpieces when contacting coolant water-wetted continuous-abrasive coatings. Hydroplaning of workpieces causes non-flat workpiece surfaces.

This abrading system can also be used to recondition the flat surface of the abrasive that is on the abrasive disk that is attached to the platen. A platen annular abrasive surface tends to experience uneven wear across the radial surface of the annular abrasive band after continued abrading contact with the flat surfaced workpieces. When the non-even wear of the abrasive surface becomes excessive and the abrasive can no longer provide precision-flat workpiece surfaces it must be reconditioned to re-establish its precision planar flatness. Reconditioning the platen abrasive surface can be easily accomplished with this fixed-spindle floating-platen system by attaching equal-thickness abrasive disks, or other abrasive devices such as abrasive coated conditioning rings, to the flat surfaces of the rotary spindle tops in place of the workpieces. Here, the platen annular abrasive surface reconditioning takes place by rotating the spindle abrasive disks, or conditioning rings, while they are in flat-surfaced abrading contact with the rotating platen abrasive annular band.

Also, the bare platen (no abrasive coating) annular abrading surface can be reconditioned with this fixed-spindle floating-platen system by attaching equal-thickness abrasive disks, or other abrasive devices such as abrasive coated conditioning rings, to the flat surfaces of the rotary spindle tops in place of the workpieces. Here, the platen annular abrading surface reconditioning takes place by rotating the spindle abrasive disks, or conditioning rings, while they are in flat-surfaced abrading contact with the rotating platen annular abrading surface. Most conventional platen abrading surfaces have original-condition flatness tolerances of 0.0001 inches (3 microns) that typically wear down into a non-flat condition during abrading operations to approximately 0.0006 inches (15 microns) before they are reconditioned to re-establish the original flatness variation of 0.0001 inches (3 microns).

Furthermore, the system can be used to recondition the flat surfaces of the spindles or the surfaces of workpiece carrier devices that are attached to the spindle tops by bringing an abrasive coated floating platen into abrading contact with the bare spindle tops, or into contact with the workpiece carrier devices that are attached to the spindle tops, while both the spindles and the platen are rotated.

This fixed-spindle-floating-platen system is particularly suited for flat-lapping large diameter semiconductor wafers. High-value large-sized workpieces such as 12 inch diameter (300 mm) semiconductor wafers can be attached with vacuum or by other means to ultra-precise flat-surfaced air bearing spindles for precision lapping of the wafers. Commercially available abrading machine components can be easily assembled to construct these lapper machines. Ultra-precise 12 inch diameter air bearing spindles can provide flat rotary mounting surfaces for flat wafer workpieces. These spindles typically provide spindle top flatness accuracy of 5 millionths of an inch (0.13 micron) (or less, if desired) during rotation. They are also very stiff for resisting abrading load deflections and can support loads of 900 lbs. A typical air bearing spindle having a stiffness of 4,000,000 lbs/inch is more resistant to deflections from abrading forces than a mechanical spindle having steel roller bearings.

The thicknesses of the workpieces can be measured during the abrading or lapping procedure by the use of laser, or other, measurement devices that can measure the workpiece thicknesses. These workpiece thickness measurements can be made by direct workpiece exposed-edge side measurements. They also can be made indirectly by measuring the location of the bottom position of the moving abrasive surface that makes contact with the workpiece surfaces as the abrasive surface location measurement is related to an established reference position.

Air bearing workpiece spindles can be replaced or extra units added as needed. These air bearing spindles are preferred because of their precision flatness of the spindle surfaces at all abrading speeds and their friction-free rotation. Commercial 12 inch (300 mm) diameter air bearing spindles that are suitable for high speed flat lapping are available from Nelson Air Corp, Milford, NH. Air bearing spindles are preferred for high speed flat lapping but suitable rotary flat-surfaced spindles having conventional roller bearings can also be used.

Thick-section granite bases that have the required surface flatness accuracy, structural stiffness and dimensional stability to support these heavy air bearing spindles without distortion are also commercially available from numerous sources. Fluid passageways can be provided within the granite bases to allow the circulation of heat transfer fluids that thermally stabilize the bases. This machine base temperature control system provides long-term dimensional stability of the precision-flat granite bases and isolates them from changes in the ambient temperature changes in a production facility. Floating platens having precision-flat planar annular abrading surfaces can also be fabricated or readily purchased.

The flexible abrasive disks that are attached to the platen annular abrading surfaces typically have annular bands of fixed-abrasive coated rigid raised-island structures. There is insignificant elastic distortion of the individual raised islands through the thickness of the raised island structures or elastic distortion of the complete thickness of the raised island abrasive disks when they are subjected to typical abrading pressures. These abrasive disks must also be precisely uniform in thickness across the full annular abrading surface of the disk. This is necessary to assure that uniform abrading takes place over the full flat surface of the workpieces that are attached onto the top surfaces of each of the three spindles. The term "precisely" as used herein refers to within ±5 wavelengths planarity and within ±0.01 degrees of perpendicular or parallel, and precisely coplanar means within ±0.01 degrees of parallel, thickness or flatness variations of less than 0.0001 inches (3 microns) and with a standard deviation between planes that does not exceed ±20 microns.

During an abrading or lapping procedure, both the workpieces and the abrasive platens are rotated simultaneously. Once a floating platen "assumes" a position as it rests conformably upon workpieces attached to the spindle tops and the platen is supported by the three spindles, the planar abrasive surface of the platen retains this nominal platen alignment even as the floating platen is rotated. The three-point spindles are located with approximately equal spacing between them circumferentially around the platen and their rotational centers are in alignment with the radial centerline of the platen annular abrading surface. A controlled abrading pressure is applied by the abrasive platen to the equal-thickness workpieces that are attached to the three rotary workpiece spindles. Due to the evenly-spaced three-point support of the floating platen, the equal-sized workpieces attached to the spindle tops experience the same shared platen-imposed abrading forces and abrading pressures. Here, precision-flat and smoothly polished semiconductor wafer surfaces can be simultaneously produced at all three spindle stations by the fixed-spindle-floating platen abrading system.

Because the floating-platen and fixed-spindle abrading system is a single-sided process, very thin workpieces such as semiconductor wafers or flat-surfaced solar panels can be attached to the rotatable spindle tops by vacuum or other attachment means. To provide abrading of the opposite side of a workpiece, it is removed from the spindle, flipped over and abraded with the floating platen. This is a simple two-step procedure. Here, the rotating spindles provide a workpiece surface that is precisely co-planar with the opposed workpiece surface.

The spindles and the platens can be rotated at very high speeds, particularly with the use of precision-thickness raised-island abrasive disks. These abrading speeds can exceed 10,000 surface feet per minute (SFPM) or 3,048 surface meters per minute. The abrading pressures used here for flat lapping are very low because of the extraordinary high material removal rates of superabrasives (including diamond or cubic boron nitride (CBN)) when operated at very high abrading speeds. The abrading pressures are often less than 1 pound per square inch (0.07 kilogram per square cm) which is a small fraction of the abrading pressures commonly used in abrading. Flat honing (micro-grinding) uses extremely high abrading pressures which can result in substantial sub-surface damage of high value workpieces. The low abrading pressures used here result in highly desired low subsurface damage. In addition, low abrading pressures result in lapper machines that have considerably less weight and bulk than conventional abrading machines.

Use of a platen vacuum disk attachment system allows quick set-up changes where abrasive disks having different sizes of abrasive particles and different types of abrasive material can be quickly attached to the flat platen annular abrading surfaces. Changing the sized of the abrasive particles on all of the other abrading systems is slow and tedious. Also, the use of messy loose-abrasive slurries is avoided by using the fixed-abrasive disks.

A minimum of three evenly-spaced spindles are used to obtain the three-point support of the upper floating platen by contacting the spaced workpieces. However, additional spindles can be mounted between any two of the three spindles that form three-point support of the floating platen. Here all of the workpieces attached to the spindle-tops are in mutual flat abrading contact with the rotating platen abrasive.

Semiconductor wafers or other workpieces can be processed with a fully automated easy-to-operate process that is especially easy to incorporate into the fixed-spindle floating-platen lapping or abrading system. Here, individual semiconductor wafers, workpieces or workpiece carriers can be changed on all three spindles with a robotic arm extending through a convenient gap-opening between two adjacent stand-alone workpiece rotary spindles. Flexible abrasive disks can be changed on the platen by using a robotic arm extending through a convenient gap-opening between two adjacent stand-alone workpiece rotary spindles.

This three-point fixed-spindle-floating-platen abrading system can also be used for chemical mechanical planarization (CMP) abrading of semiconductor wafers that are attached to the spindle-tops by using liquid abrasive slurry and chemical mixtures with resilient backed pads that are attached to the floating platen. The system can also be used with CMP-type fixed-abrasive shallow-island abrasive disks that are backed with resilient support pads. These abrasive shallow-islands can either be mold-formed on the surface of flexible backings or the abrasive shallow-islands can be coated on the backings using gravure-type coating techniques.

This three-point fixed-spindle-floating-platen abrading system can also be used for slurry lapping of the workpieces that are attached to the rotary spindle-tops by applying a coating of liquid abrasive slurry to the abrading surface of the platen. Also, a flat-surfaced annular metal or other material disk can be attached to the platen abrading surface and a coating of liquid abrasive slurry can be applied to the flat abrading surface of the attached annular disk.

The system has the capability to resist large mechanical abrading forces that can be present with abrading processes while maintaining unprecedented rotatable workpiece spindle tops flatness accuracies and minimum mechanical flatness out-of-planar variations, even at very high abrading speeds. There is no abrasive wear of the flat surfaces of the spindle tops because the workpieces are firmly attached to the spindle tops and there is no motion of the workpieces relative to the spindle tops. Rotary abrading platens are inherently robust, structurally stiff and resistant to deflections and surface flatness distortions when they are subjected to substantial abrading forces. Because the system is comprised of robust components, it has a long production usage lifetime with little maintenance even in the harsh abrading environment present with most abrading processes. Air bearing spindles are not prone to failure or degradation and provide a flexible system that is quickly adapted to different polishing processes. Drip shields can be attached to the air bearing spindles to prevent abrasive debris from contaminating the spindle.

All of the precision-flat abrading processes presently in commercial lapping use typically have very slow abrading speeds of about 5 mph (8 kph). By comparison, the high speed flat lapping system operates at or above 100 mph (160 kph). This is a speed difference ratio of 20 to 1. Increasing abrading speeds increase the material removal rates. High abrading speeds result in high workpiece production rates and large cost savings.

To provide precision-flat workpiece surfaces, it is important to maintain the required flatness of annular band of fixed-abrasive coated raised islands during the full abrading life of an abrasive disk. This is done by selecting abrasive disks where the full surface of the abrasive is contacted by the workpiece surface. This results in uniform wear-down of the abrasive.

The many techniques already developed to maintain the abrasive surface flatness are also very effective for the fixed-spindle floating-platen lapping system. The primary technique is to use the abraded workpieces themselves to keep the abrasive flat during the lapping process. Here large workpieces (or small workpieces grouped together) are also rotated as they span the radial width of the rotating annular abrasive band. Another technique uses driven planetary workholders that move workpieces in constant orbital spiral path motions across the abrasive band width. Other techniques include the periodic use of annular abrasive coated conditioning rings to abrade the non-flat surfaces of the platen abrasive or the platen body abrading surface. These conditioning rings can be rotated while remaining at stationary positions. They also can be moved around the circumference of the platen while they are rotated by planetary circulation mechanism devices. Conditioning rings have been used for years to maintain the flatness of slurry platens that utilize loose abrasive particles. These same types of conditioning rings are also used to periodically re-flatten the fixed-abrasive continuous coated platens used in micro-grinding (flat-honing).

Workpieces are often rotated at rotational speeds that are approximately equal to the rotational speeds of the platens to provide approximately equal localized abrading speeds across the full radial width of the platen abrasive when the workpiece spindles are rotated in the same rotation direction as the platens.

Unlike slurry lapping, there is no abrasive wear of raised island abrasive disk platens because only the non-abrasive flexible disk backing surface contacts the platen surface. Here, the abrasive disk is firmly attached to the platen flat annular abrading surface. Also, the precision flatness of the high speed flat lapper abrasive surfaces can be completely re-established by simply and quickly replacing an abrasive disk having a non-flat abrasive surface with another abrasive disk that has a precision-flat abrasive surface.

Vacuum is used to quickly attach flexible abrasive disks, having different sized particles, different abrasive materials and different array patterns and styles of raised islands. Each flexible disk conforms to the precision-flat platen surface provide precision-flat planar abrading surfaces. Quick lapping process set-up changes can be made to process a wide variety of workpieces having different materials and shapes with application-selected raised island abrasive disks that are optimized for them individually. Small and medium diameter disks are very light in weight and have very little bulk thickness. They can be stored or shipped flat where individual disks lay in layers in flat contact with other companion disks. Large and very large raised island fixed-abrasive disks can be rolled and stored or shipped in polymer protective tubes. Abrasive disk and floating platens can have a wide range of abrading surface diameters that range from 2 inches (5 cm) to 72 inches (183 cm) or even much greater diameters. Abrasive disks that have non-island continuous coatings of abrasive material can also be used on the fixed-spindle floating-platen abrading system

The abrasive disk quick change capability is especially desirable for laboratory lapping machines but it is also very useful for prototype lapping and for full-scale production lapping machines. This abrasive disk quick-change capability also provides a large advantage over micro-grinding (flat-honing) where it is necessary to change-out a worn heavy rigid platen or to replace it with one having different sized particles. Changing the non-flat fixed abrasive surface of a micro-grinding (flat-honing) thick abrasive wheel can not be done quickly because it is a bolted-on integral part of the rotating platen that supports it. Often, the abrasive particle sizes are sequentially changed from coarse to medium to fine during a flat lapping or abrading operation.

Hydroplaning of workpieces occurs when smooth abrasive surfaces, having a continuous thin-coated abrasive, are in fast-moving contact with a flat workpiece surface in the presence of surface water. However, hydroplaning does not occur when interrupted-surfaces, such as abrasive coated raised islands, contact a flat water-wetted workpiece surface. An analogy to the use of raised islands in the presence of coolant water films is the use of tread lugs on auto tires which are used on rain slicked roads. Tires with lugs grip the road at high speeds while bald smooth-surfaced tires hydroplane. In the same way, the abrasive coatings of the flat-surface tops of the raised islands remain in abrading contact with water-wetted flat-surfaced workpieces, even at very high abrading speeds.

A uniform thermal expansion and contraction of air bearing spindles occurs on all of the air bearing spindles mounted on the granite or other material machine bases when each of individual spindles are mounted with the same methods on the bases. The spindles can be mounted on spindle legs attached to the bottom of the spindles or the spindles can be mounted to legs that are attached to the upper portion of the spindle bodies and the length expansion or shrinkage of all of the spindles will be the same. This insures that precision abrading can be achieved with these fixed-spindle floating-platen abrading systems.

This invention references commonly assigned U.S. patents numbers 5,910,041; 5,967,882; 5,993,298; 6,048,254; 6,102,777; 6,120,352 ; 6,149,506; 6,607,157; 6,752,700; 6,769,969; 7,632,434 and 7,520,800, commonly assigned U.S. patent application published numbers 20100003904; 20080299875 and 20050118939 and U.S. patent application serial numbers 12/661,212, 12/799,841 and 12/807,802 and all contents of which are incorporated herein by reference.

U.S. Patent No. 7,614,939 (Tolles et al) describes a CMP polishing machine that uses flexible pads where a conditioner device is used to maintain the abrading characteristic of the pad. Multiple CMP pad stations are used where each station has different sized abrasive particles. U.S. Patent No. 4,593,495 (Kawakami et al) describes an abrading apparatus that uses planetary workholders. U.S. Patent No. 4,918,870 (Torbert et al) describes a CMP wafer polishing apparatus where wafers are attached to wafer carriers using vacuum, wax and surface tension using wafer. U.S. Patent No. 5,205,082 (Shendon et al) describes a CMP wafer polishing apparatus that uses a floating retainer ring. U.S. Patent No. 6,506,105 (Kajiwara et al) describes a CMP wafer polishing apparatus that uses a CMP with a separate retaining ring and wafer pr3essure control to minimize over-polishing of wafer peripheral edges. U.S. Patent No. 6,371,838 (Holzapfel) describes a CMP wafer polishing apparatus that has multiple wafer heads and pad conditioners where the wafers contact a pad attached to a rotating platen. U.S. Patent No. 6,398,906 (Kobayashi et al) describes a wafer transfer and wafer polishing apparatus. U.S. Patent No. 7,357,699 (Togawa et al) describes a wafer holding and polishing apparatus and where excessive rounding and polishing of the peripheral edge of wafers occurs. U.S. Patent No. 7,276,446 (Robinson et al) describes a web-type fixed-abrasive CMP wafer polishing apparatus.

U.S. Patent No. 6,786,810 (Muilenberg et al) describes a web-type fixed-abrasive CMP article. U.S. Patent No. 5,014,486 (Ravipati et al) and U.S. Patent No. 5,863,306 (Wei et al) describe a web-type fixed-abrasive article having shallow-islands of abrasive coated on a web backing using a rotogravure roll to deposit the abrasive islands on the web backing. U.S. 5,314,513 (Milleret al) describes the use of ceria for abrading.

U.S. Patent No. 6,001,801 (Fujimori et al) describes an abrasive dressing tool that is used for abrading a rotatable CMP polishing pad that is attached to a rigidly mounted lower rotatable platen.

U.S. Patent No. 6,077,153 (Fujita et al) describes a semiconductor wafer polishing machine where a polishing pad is attached to a rigid platen that rotates. The polishing pad is positioned to contact wafer-type workpieces that are attached to rotary workpiece spindles. These rotary workpiece spindles are mounted on a rigidly-mounted rotary platen. The rotatable abrasive polishing pad platen is rigidly mounted and travels along its rotation axis. However, it does not have a floating-platen action that allows the platen to have a spherical-action motion as it rotates. Because the workpiece spindles are mounted on a rotary platen they are not attached to a stationary machine base such as a granite base. Because of the configuration of the Fujita machine, it can not be used to provide a floating abrasive coated platen that allows the flat surface of the platen abrasive to be in floating conformal abrading contact with multiple workpieces that are attached to rotary workpiece spindles that are mounted on a rigid machine base.

U.S. Patent No. 6,425,809 (Ichimura et al) describes a semiconductor wafer polishing machine where a polishing pad is attached to a rigid rotary platen. The polishing pad is in abrading contact with flat-surfaced wafer-type workpieces that are attached to rotary workpiece holders. These workpiece holders have a spherical-action universal joint. The universal joint allows the workpieces to conform to the surface of the platen-mounted abrasive polishing pad as the platen rotates. However, the spherical-action device is the workpiece holder and is not the rotary platen that holds the fixed abrasive disk.

U.S. Patent No. 6,769,969 (Duescher) describes flexible abrasive disks that have annular bands of abrasive coated raised islands. These disks use fixed-abrasive particles for high speed flat lapping as compared with other lapping systems that use loose-abrasive liquid slurries. The flexible raised island abrasive disks are attached to the surface of a rotary platen to abrasively lap the surfaces of workpieces.

Various abrading machines and abrading processes are described in U.S. Patents 5,364,655 (Nakamura et al). 5,569,062 (Karlsrud), 5,643,067 (Katsuoka et al), 5,769,697 (Nisho), 5,800,254 (Motley et al), 5,916,009 (Izumi et al), 5,964,651 (hose), 5,975,997 (Minami, 5,989,104 (Kim et al), 6,089,959 (Nagahashi, 6,165,056 (Hayashi et al), 6,168,506 (McJunken), 6,217,433 (Herrman et al), 6,439,965 (Ichino), 6,893,332 (Castor), 6,896,584 (Perlov et al), 6,899,603 (Homma et al), 6,935,013 (Markevitch et al), 7,001,251 (Doan et al), 7,008,303 (White et al), 7,014,535 (Custer et al), 7,029,380 (Horiguchi et al), 7,033,251 (Elledge), 7,044,838 (Maloney et al), 7,125,313 (Zelenski et al), 7,144,304 (Moore), 7,147,541 (Nagayama et al), 7,166,016 (Chen), 7,250,368 (Kida et al), 7,367,867 (Boller), 7,393,790 (Britt et al), 7,422,634 (Powell et al), 7,446,018 (Brogan et al), 7,456,106 (Koyata et al), 7,470,169 (Taniguchi et al), 7,491,342

(Kamiyama et al), 7,507,148 (Kitahashi et al), 7,527,722 (Sharan) and 7,582,221 (Netsu et al).

SUMMARY OF THE INVENTION

The presently disclosed technology includes a fixed-spindle, floating-platen system which is a new configuration of a single-sided lapping machine system. This system is capable of producing ultra-flat thin semiconductor wafer workpieces at high abrading speeds. This can be done by providing a precision-flat, rigid (e.g., synthetic, composite or granite) machine base that is used as the planar mounting surface for at least three rigid flat-surfaced rotatable workpiece spindles. Precision-thickness flexible abrasive disks are attached to a rigid flat-surfaced rotary platen that floats in three-point abrading contact with the three equal-spaced flat-surfaced rotatable workpiece spindles. These abrasive coated raised island disks have disk thickness variations of less than 0.0001 inches (3 microns) across the full annular bands of abrasive-coated raised islands to allow flat-surfaced contact with workpieces at very high abrading speeds and to assure that all of the expensive diamond abrasive particles that are coated on the island are fully utilized during the abrading process. Use of a platen vacuum disk attachment system allows quick set-up changes where different sizes of abrasive particles and different types of abrasive material can be quickly attached to the flat platen surfaces.

Water coolant is used with these raised island abrasive disks, which allows them to be used at very high abrading speeds, often in excess of 10,000 SFPM (160 km per minute). The coolant water is typically applied directly to the top surfaces of the workpieces. The applied coolant water results in abrading debris being continually flushed from the abraded surface of the workpieces. Here, when the water-carried debris falls off the spindle top surfaces it is not carried along by the platen to contaminate and scratch the adjacent high-value workpieces, a process condition that occurs in double-sided abrading and with continuous-coated abrasive disks.

The fixed-spindle floating-platen flat lapping system has two primary planar references. One planar reference is the precision-flat annular abrading surface of the rotatable floating platen. The other planar reference is the precision co-planar alignment of the flat surfaces of the rotary spindle tops of the three workpiece spindles that provide three-point support of the floating platen.

Flat surfaced workpieces are attached to the spindle tops and are contacted by the abrasive coating on the platen abrading surface. Both the workpiece spindles and the abrasive coated platens are simultaneously rotated while the platen abrasive is in controlled abrading pressure contact with the exposed surfaces of the workpieces. Workpieces are sandwiched between the spindle tops and the floating platen. This lapping process is a single-sided workpiece abrading process. The opposite surfaces of the workpieces can be lapped by removing the workpieces from the spindle tops, flipping them over, attaching them to the spindle tops and abrading the second opposed workpiece surfaces with the platen abrasive.

A granite machine base provides a dimensionally stable platform upon which the three (or more) workpiece spindles are mounted. The spindles must be mounted where their spindle tops are precisely co-planar within 0.0001 inches (3 microns) in order to successfully perform high speed flat lapping. The rotary workpiece spindles must provide rotary spindle tops that remain precisely flat at all operating speeds. Also, the spindles must be structurally stiff to avoid deflections in reaction to static or dynamic abrading forces.

Air bearing spindles are the preferred choice over roller bearing spindles for high speed flat lapping. They are extremely stiff, can be operated at very high rotational speeds and are frictionless. Because the air bearing spindles have no friction, torque feedback signal data from the internal or external spindle drive motors can be used to determine the state-of-finish of lapped workpieces. Here, as workpieces become flatter and smoother, the water wetted adhesive bonding stiction between the flat surfaced workpieces and the flat-type abrasive media increase. The relationship between the state-of-finish of the workpieces and the adhesive stiction is a very predictable characteristic and can be readily used to control or terminate the flat lapping process.

Air bearing or mechanical roller bearing workpiece spindles having equal precision heights can be mounted on precisely flat granite bases to provide a system where the flat spindle tops are precisely co-planar with each other. These precision height spindles and precision flat granite bases are more expensive than commodity type spindles and granite bases. Commodity type air bearing spindles and non-precision flat granite bases can be utilized with the use of adjustable height legs that are attached to the bodies of the spindles. The flat surfaces of the spindle tops can be aligned to be precisely co-planar within the required 0.0001 inches (3 microns) with the use of a rotating leaser beam measurement device supplied by Hamar Laser Inc. of Danbury, CT.

An alternative method that can be used to attach spindles to granite bases is to provide spherical-action mounts for each spindle. These spherical mounts allow each spindle top to be aligned to be co-planar with the other attached spindles. Workpiece spindles are attached to the rotor portion of the spherical mount that has a spherical-action rotation within a spherical base that has a matching spherical shaped contacting area. The spherical-action base is attached to the flat surface of a granite machine base. After the spindle tops are precisely aligned to be co-planar with each other, a mechanical or adhesive-based fastener device is used to fixture or lock the spherical mount rotor to the spherical mount base. Using these spherical-action mounts, the precision aligned workpiece spindles are structurally attached to the granite base.

Another very simple technique that can be used for co-planar alignment of the spindle-tops is to use the precision-flat surface of a floating platen annular abrading surface as a physical planar reference datum for the spindle tops. Platens must have precision flat surfaces where the flatness variation is less than 0.0001 inches (3 microns) in order to successfully perform high speed flat lapping. Here, the precision-flat platen is brought into flat surfaced contact with the spindle-tops where pressurized air or a liquid can be applied through fluid passageways to form a spherical-action fluid bearing that allows the spherical rotor to freely float without friction within the spherical base. This platen surface contacting action aligns the spindle-tops with the flat platen surface. By this platen-to-spindles contacting action, the spindle tops are also aligned to be co-planar with each other. After co-planar alignment of the spindle tops, vacuum can be applied through the fluid passageways to temporarily lock the spherical rotors to the spherical bases. Then, a mechanical fastener or an adhesive-based fastener device is used to fixture or lock the spherical mount rotor to the spherical mount base. When using an adhesive rotor locking system, an adhesive can be applied in a small gap between a removable bracket that is attached to the spherical rotor and a removable bracket that is attached to the spherical base to rigidly bond the spherical rotor to the spherical base after the adhesive is solidified. If it is desired to re-align the spindle top, the removable spherical mount rotor and spherical base adhesive brackets can be discarded and replaced with new individual brackets that can be adhesively bonded together to again lock the spherical mount rotors to the respective spherical bases.

The fixed-platen floating-spindle lapping system can also be used to recondition the abrasive surface of the abrasive disk that is attached to the platen. This rotary platen annular abrasive surface tends to experience uneven wear across the radial surface of the annular abrasive band after continued abrading contact with the spindle workpieces. When the non-even wear of the abrasive surface becomes excessive and the abrasive can no longer provide precision-flat workpiece surfaces it must be reconditioned to re-establish its planar flatness.

Reconditioning the platen abrasive surface can be easily accomplished with this system by attaching equal-thickness abrasive disks to the flat surfaces of the spindles in place of the workpieces. Here, the abrasive surface reconditioning takes place by rotating the spindle abrasive disks while they are in flat-surfaced abrading contact with the rotating platen abrasive annular band.

In addition, the fixed-platen floating-spindle lapping system can also be used to recondition the platen bare (no abrasive coating) abrading surface by attaching equal-thickness abrasive disks, or other abrasive devices such as abrasive coated conditioning rings, to the flat surfaces of the rotary spindle tops in place of the workpieces. Here, the platen annular abrading surface reconditioning takes place by rotating the spindle abrasive disks, or conditioning rings, while they are in flat-surfaced abrading contact with the rotating platen annular abrading surface.

Automatic robotic devices can be added to the fixed-spindle-floating-platen system to change both the workpieces and the abrasive disks.

The fixed-platen floating-spindle lapping system has the capability to resist large mechanical abrading forces present with abrading processes with unprecedented flatness accuracies and minimum mechanical planar flatness variations. Because the system is comprised of robust components it has a long lifetime with little maintenance even in the harsh abrading environment present with most abrading processes. Air bearing spindles are not prone to failure or degradation and provide a flexible system that is quickly adapted to different polishing processes.

Platen surfaces have patterns of vacuum port holes that extend under the abrasive annular portion of an abrasive disk to assure that the disk is firmly attached to the platen surface. When an abrasive disk is attached to a flat platen surface with vacuum, the vacuum applies in excess of 10 pound per square inch (0.7 kg per square cm) hold-down clamping forces to bond the flexible abrasive disk to the platen. Because the typical abrasive disks have such a large surface area, the total vacuum clamping forces can easily exceed thousands of pounds of force which results in the flexible abrasive disk becoming an integral part of the structurally stiff and heavy platen. Use of the vacuum disk attachment system assures that each disk is in full conformal contact with the platen flat surface. Also, each individual disk can be marked so that it can be remounted in the exact same tangential position on the platen by using the vacuum attachment system.

Here, a disk that is “worn-in” to compensate for the flatness variation of a given platen will recapture the unique flatness characteristics of that platen position by orienting the disk and attaching it to the platen at its original platen circumference position. This abrasive disk will not have to be “worn-in” again upon reinstallation. Expensive diamond abrasive particles are sacrificed each time it is necessary to wear-in an abrasive disk to establish a precision flatness of the disk abrasive surface. The original surface-flatness of the abrasive disk is re-established by simply mounting the previously removed abrasive disk in the same circumferential location on the platen that it had before it was removed from that same platen

BRIEF DESCRIPTION OF THE DRAWING

Fig. 1 is a cross section view of a pivot-balance floating-platen lapper machine.

Fig. 2 is a cross section view of a raised pivot-balance floating-platen lapper machine.

Fig. 3 is a cross section view of a raised and tilted pivot-balance lapper machine.

Fig. 4 is a cross section view of a raised pivot-balance lapper with a horizontal platen.

Fig. 5 is a top view of a pivot-balance floating-platen lapper machine.

Fig. 6 is a cross section view of a pivot-balance lapper machine with universal joints.

Fig. 7 is a cross section view of a rotated pivot-balance floating-platen lapper machine.

Fig. 8 is a cross section view of a pivot-locked pivot-balance floating-platen lapper.

Fig. 9 is a cross section view of a brake-locked rotated pivot frame lapper machine.

Fig. 10 is a cross section view of a air cylinder driven pivot frame brake lock.

Fig. 11 is a cross section view of an off-set center of gravity of a rotating abrading platen. Fig. 12 is a cross section view of a floating-platen with a mechanical spherical brake.

Fig. 13 is a cross section view of a floating-platen having structural support ribs.

Fig. 14 is a cross section view of a platen having an external wear-resistant surface coating.

Fig. 14.1 is a top view of a floating-platen having an external annular support rib.

Fig. 14.2 is a top view of a floating-platen having an external annular support rib.

Fig. 15 is a cross section view of an air bearing air cylinder.

Fig. 16 is a cross section view of hydraulic cylinder pivot frame locking device.

Fig. 17 is an isometric view of a floating platen abrading system with three spindles.

Fig. 18 is an isometric view of three fixed-position spindles mounted on a granite base.

Fig. 19 is an isometric view of three-point workpiece spindles mounted on a granite base.

Fig. 20 is a top view of three-point fixed-spindles supporting a floating abrasive platen.

Fig. 21 is an isometric view of fixed-abrasive coated raised islands on an abrasive disk.

Fig. 22 is an isometric view of a flexible fixed-abrasive coated raised island abrasive disk.

Fig. 23 is a cross section view of raised island structures on a disk with water coolant.

Fig. 24 is a cross section view of a porous pad on a disk that is used with an abrasive-slurry

Fig. 25 is an isometric view of a workpiece spindle having three-point mounting legs.

Fig. 26 is a top view of a workpiece spindle having multiple circular workpieces.

Fig. 27 is a top view of a workpiece spindle having multiple rectangular workpieces.

Fig. 28 is a top view of multiple fixed-spindles that support a floating abrasive platen.

Fig. 29 is a top view of prior art pin-gear driven planetary workholders and workpieces.

Fig. 30 is a cross section view of prior art planetary workholders and workpieces.

Fig. 31 is a cross section view of adjustable legs on a workpiece spindle.

Fig. 32 is a cross section view of an adjustable spindle leg.

Fig. 33 is a cross section view of a compressed adjustable spindle leg.

Fig. 34 is an isometric view of a compressed adjustable spindle leg.

Fig. 35 is a cross section view of a recessed workpiece spindle driven by an internal motor.

Fig. 36 is a cross section view of a workpiece spindle driven by a fluid cooled motor.

Fig. 37 is a cross section view of a workpiece spindle driven by an external motor.

Fig. 38 is a cross section view of a workpiece spindle with a spindle top debris guard.

Fig. 39 is a top view of an automatic robotic workpiece loader for multiple spindles.

Fig. 40 is a side view of an automatic robotic workpiece loader for multiple spindles.

Fig. 41 is a top view of an automatic robotic abrasive disk loader for an upper platen.

Fig. 42 is a side view of an automatic robotic abrasive disk loader for an upper platen.

Fig. 43 is an isometric view of three-point co-planar aligned workpiece spindles.

Fig. 44 is a top view of three-point center-position laser aligned rotary workpiece spindles.

Fig. 45 is an isometric view of an air bearing spindle laser spindle alignment device.

Fig. 46 is a top view of an air bearing spindle laser co-planar spindle top alignment device.

Fig. 47 is a cross section view of an air bearing spindle laser spindle top alignment device.

Fig. 48 is a cross section view of an air bearing spindle laser arm used to align spindles.

Fig. 49 is a cross section view of an air bearing spindle laser spindle alignment device.

Fig. 50 is a top view of a spherical-action mounted air bearing spindle alignment device.

DETAILED DESCRIPTION OF THE INVENTION

The fixed-spindle floating-platen lapping machines used for high speed flat lapping require very precisely controlled abrading forces that change during a flat lapping procedure. Very low abrading forces are used because of the extraordinarily high cut rates when diamond abrasive particles are used at very high abrading speeds. As per Preston's equation, high abrading pressures result in high material removal rates. The high cut rates are used initially with coarse abrasive particles to develop the flatness of the non-flat workpiece. Then, lower cut rates are used with medium or fine sized abrasive particles during the polishing portion of the flat lapping operation.

When the abrading forces are accurately controlled, the friction that is present in the lapper machine components can create large variations in the abrading forces that are generated by machine members. Here, even though the generated forces are accurate, these forces are either increased or decreased by machine element friction. Abrading forces that are not precisely accurate prevent successful high speed flat lapping. Also, the lapping machines must be robust to resist abrading forces without distortion of the machine members in a way that affects the flatness of the workpieces. Further, the machine must be light in weight, easy to use and tolerant of the harsh abrasive environment.

Pivot-Balance Floating-Platen Machine

The fixed-spindle floating-platen lapping machines used for high speed flat lapping require very precisely controlled abrading forces that change during a flat lapping procedure. Very low abrading forces are used because of the extraordinarily high cut rates when diamond abrasive particles are used at very high abrading speeds. As per Preston's equation, high abrading pressures result in high material removal rates. The high cut rates are used initially with coarse abrasive particles to develop the flatness of the non-flat workpiece. Then, lower cut rates are used with medium or fine sized abrasive particles during the polishing portion of the flat lapping operation.

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Also, the lapping machines must be robust to resist abrading forces without distortion of the machine members in a way that affects the flatness of the workpieces. Further, the machine must be light in weight, easy to use and tolerant of the harsh abrasive environment

The pivot-balance floating-platen lapping machine provides these desirable features. The lapper machine components such as the platen drive motor are used to counterbalance the weight of the abrasive platen assembly. Low friction pivot bearings are used. The whole pivot frame can be raised or lowered from a machine base by an electric motor driven screw jack. Zero-friction air bearing cylinders can be used to apply the desired abrading forces to the platen as it is held in 3-point abrading contact with the workpieces attached to rotary spindles.

The air pressure applied to the air cylinder is typically provide by a I/P (electrical current-to-pressure) pressure regulator that is activated by an abrading process controller. The actual force generated by the air cylinder can be sensed and verified by an electronic force sensor load cell that is attached to the piston end of the air cylinder. The force sensor allows feed-back type closed-loop control of the abrading pressure that is applied to the workpieces. Abrading pressures on the workpieces can be precisely changed throughout the lapping operation by the lapping process controller.

The spindles are attached to a dimensionally stable granite base. Spherical bearings allow the platen to freely float during the lapping operation. A right-angle gear box has a hollow drive shaft to provide vacuum to attach raised island abrasive disks to the platen. A set of two constant velocity universal joints attached to drive shafts allow the spherical motion of the rotating platen.

When the pivot balance is adjusted where the weight of the drive motor and hardware equals the weight of the platen and its hardware, then the pivot balance frame has a “tared” or “zero” balance condition. To accomplish this, a counterbalance weight can be moved along the pivot balance frame. Also, weighted mechanical screw devices can be easily adjusted to provide a true balance condition. Use of frictionless air bearings at the rotational axis of the pivot frame allows this precision balancing to take place.

Fig. 1 is a cross section view of a pivot-balance floating-platen lapper machine. The pivot-balance floating-platen lapping machine **25** provides these desirable features. The lapper machine **25** components such as the platen drive motor **28** and a counterweight **32** are used to counterbalance the weight of the abrasive platen assembly **11** where the pivot frame **24** is balanced about the pivot frame **24** pivot center **27**.

The pivot frame **24** has a rotation axis centered at the pivot frame pivot center **27** where the platen assembly **11** is attached at one end of the pivot frame **24** from the pivot center **27** and the platen motor **28** and a counterbalance weight **32** are attached to the pivot frame **24** at the opposed end of the pivot frame **24** from the pivot center **27**. The pivot frame **24** has low friction rotary pivot bearings **26** at the pivot center **27** where the pivot bearings **26** can be frictionless air bearings or low friction roller bearings. The platen drive motor **28** is attached to the pivot frame **24** in a position where the weight of the platen drive motor **28** nominally or partially counterbalances the weight of the abrasive platen assembly **11**. A movable and weight-adjustable counterweight **32** is attached to the pivot frame **24** in a position where the weight of the counterweight **32** partially counterbalances the weight of the abrasive platen assembly **11**. The weight of the counterweight **32** is used together with the weight of the platen motor **28** to effectively counterbalance the weight of the abrasive platen assembly **11** that is also attached to the pivot frame **24**. When the pivot frame **24** is counterbalanced, the pivot frame **24** pivots freely about the pivot center **27**. The platen drive motor **28** rotates a drive shaft **23** that is coupled to the gear box **22** to rotate the gear box **22** hollow drive shaft **17**.

The whole pivot frame **24** can be raised or lowered from a machine base **42** by a elevation frame **38** lift device **40** that can be an electric motor driven screw jack lift device or a hydraulic lift device. The elevation frame **38** lift device **40** is attached to a linear slide **36** that is attached to the machine base **42** and also is attached to the elevation lift frame **38** where the elevation lift frame **38** lift device **40** can have a position sensor (not shown) that can be used to precisely control the vertical position of the elevation frame **38**. Zero-friction air bearing cylinders **34** can be used to apply the desired abrading forces to the platen **9** as it is held in 3-point abrading contact with the workpieces **6** attached to rotary spindles **2** having rotary spindle-tops **4**. One end of one or more air bearing cylinders **34** can be attached to the pivot frame **24** at different positions to apply forces to the pivot frame **24** where these applied forces provide an abrading force to the platen **9**. The support end of the air bearing cylinders can be attached to the elevation frame **38**.

Raised Elevation And Pivot Frames

The frame of the pivot-balance lapper is attached to a pair of linear slides where the frame can be raised with the use of a pair of electric jacks such as linear actuators. These actuators can provide closed-loop precision control of the position of the pivot frame and are well suited for long term use in a harsh abrading environment. When the pivot frame and floating platen are raised, workpieces can be changed and the abrasive disks that are attached to the platen can be easily changed. The platen is allowed to float with the use of a spherical-action platen shaft bearing.

Single or multiple friction-free air bearing air cylinders can be used to precisely control the abrading forces that are applied to the workpieces by the platen. These air cylinders are located at one end of the beam-balance pivot frame and the platen is located at the opposed end of the beam-balance pivot frame. Use of air bearings on the pivot frame pivot axis shaft eliminates any bearing friction. Cylindrical air bearings that are used on the pivot axis are available from New Way Air Bearing Co., Aston, PA.

Any force that is applied by the air cylinders is directly transmitted across the length of the pivot frame to the platen because of the lack of pivot bearing friction. Other bearings such as needle bearings, roller bearings or fluid lubricated journal bearings can be used but all of these have more rotational friction than the air bearings. Air bearing cylinders such as the AirPel® cylinders from Airpot Corporation of Norwalk, CT can be selected where the cylinder diameter can provide the desired range of abrading forces.

Once the frictionless pivot frame is balanced, any force applied by the abrading force cylinders on one end of the pivot frame is directly transmitted to the platen abrasive surface that is located at the other end of this balance-beam apparatus. To provide a wide range of abrading forces, multiple air cylinders of different diameter sizes can be used in parallel with each other. Because the range of air pressure supplied to the cylinders has a typical limited range of from 0 to 100 psia with limited allowable incremental pressure control changes, it is difficult to provide the extra-precise abrading force load changes required for high speed flat lapping. Use of small-diameter cylinders provide very finely adjusted abrading forces because these small cylinders have nominal force capabilities.

The exact forces that are generated by the air cylinders can be very accurately determined with load cell force sensors. The output of these load cells can be used by feedback controller devices to dynamically adjust the abrading forces on the platen abrasive throughout the lapping procedure. This abrading force control system can even be programmed to automatically change the applied-force cylinder forces to compensate for the very small weight loss experienced by an abrasive disk during a specific lapping operation. Also, the weight variation of "new" abrasive disks that are attached to a platen to provide different sized abrasive particles can be predetermined. Then the abrading force control system can be used to compensate for this abrasive disk weight change from the previous abrasive disk and provide the exact desired abrading force on the platen abrasive.

The abrading force feedback controller provides an electrical current input to an air pressure regulator referred to as an I/P (current to pressure) controller. The abrading force controller has the capability to change the pressures that are independently supplied to each of the parallel abrading force air cylinders. The actual force produced by each independently controlled air cylinder is determined by a respected force sensor load cell to close the feedback loop.

Fig. 2 is a cross section view of a raised pivot-balance floating-platen lapper machine. Here, the pivot frame is raised up to allow workpieces and abrasive disks to be changed. The pivot-balance floating-platen lapping machine **73** provides these desirable features. The lapper machine **73** components such as the platen drive motor **72** and a counterweight **76** are used to counterbalance the weight of the abrasive platen assembly **53** where the pivot frame **68** is balanced about the pivot frame **68** pivot center **71**.

The pivot frame **68** has a rotation axis centered at the pivot frame pivot center **71** where the platen assembly **53** is attached at one end of the pivot frame **68** from the pivot center **71** and the platen motor **72** and a counterbalance weight **76** are attached to the pivot frame **68** at the opposed end of the pivot frame **68** from the pivot center **71**. The pivot frame **68** has low friction rotary pivot bearings **70** at the pivot center **71** where the pivot bearings **70** can be frictionless air bearings or low friction roller bearings. The platen drive motor **72** is attached to the pivot frame **68** in a position where the weight of the platen drive motor **72** nominally or partially counterbalances the weight of the abrasive platen assembly **53**. A movable and weight-adjustable counterweight **76** is attached to the pivot frame **68** in a position where the weight of the counterweight **76** partially counterbalances the weight of the abrasive platen assembly **53**. The weight of the counterweight **76** is used together with the weight of the platen motor **72** to effectively counterbalance the weight of the abrasive platen assembly **53** that is also attached to the pivot frame **68**. When the pivot frame **68** is counterbalanced, the pivot frame **68** pivots freely about the pivot center **71**. The platen drive motor **72** rotates a drive shaft **23** that is coupled to the gear box **66** to rotate the gear box **66** hollow drive shaft.

The whole pivot frame **68** can be raised or lowered from a machine base **86** by a elevation frame **82** lift device **84** that can be an electric motor driven screw jack lift device or a hydraulic lift device. The elevation frame **82** lift device **84** can have a position sensor that can be used to precisely control the vertical position of the elevation frame **82**. Zero-friction air bearing cylinders **78** can be used to apply the desired abrading forces to the platen **52** as it is held in 3-point abrading contact with the workpieces **48** attached to rotary spindles **44** having rotary spindle-tops **46**. One end of one or more air bearing cylinders **78** can be attached to the pivot frame **68** at different positions to apply forces to the pivot frame **68** where these applied forces provide an abrading force to the platen **52**. The support end of the air bearing cylinders **78** can also be attached to the elevation frame **82**. The floating platen **52** has a spherical rotation and a cylindrical that is provided by the spherical-action platen support bearing **56** that supports the weight of the floating platen **52** where the spherical-action platen support bearing **56** is supported by the pivot frame **68**.

The air pressure applied to the air cylinder **78** is typically provide by an I/P (electrical current-to-pressure) pressure regulator (not shown) that is activated by an abrading process controller (not shown). The actual force generated by the air cylinder **78** can be sensed and verified by an electronic force sensor load cell **77** that is attached to the cylinder rod end of the air cylinder **78**. The force sensor **77** allows feed-back type closed-loop control of the abrading pressure that is applied to the workpieces **48**. Abrading pressures on the workpieces **48** can be precisely changed throughout the lapping operation by the lapping process controller.

The spindles **44** are attached to a dimensionally stable granite or epoxy-granite base **86**. A spherical-action bearing **56** allows the platen **52** to freely float with a spherical action motion during the lapping operation. A right-angle gear box **66** has a hollow drive shaft to provide vacuum to attach raised island abrasive disks **50** to the platen **52**. Vacuum **62** is applied to a rotary union **64** that allows rotation of the gear box **66** drive hollow shaft to route vacuum to the platen **52** through tubing or other passageway devices (not shown) where abrasive disks **50** can be attached to the platen **52** by vacuum. The spherical bearing **56** can be a roller bearing or an air bearing having an air passage **54** that allows pressurized air to be applied to create an air bearing effect or vacuum to be applied to lock the spherical bearing **56** rotor and housing components together. One or more conventional universal joints or plate-type universal joints or constant velocity universal joints or a set of two constant velocity universal joints **58**, **60** attached to the drive shaft **15** allow the spherical rotation and cylindrical rotation motion of the rotating platen **52**.

The pivot frame **68** can be rotated to desired positions and locked at the desired rotation position by use of a pivot frame locking device **74** that is attached to the pivot frame **68** and to the pivot frame **68** elevation frame **82**. The pivot frame **68** can be raised or lowered to selected elevation positions by the electric motor screw jack **84** or by a hydraulic jack **84** that is attached to the machine base **86** and to the pivot frame **68** elevation frame **82** where the pivot frame **68** elevation frame **82** is supported by a translatable slide device **80** that is attached to the machine base **86**.

Raised And Tilted Pivot Frame

When the pivot frame is raised by the electric actuator or by hydraulic cylinders, the floating platen can also be tilted by rotation of the pivot frame about the pivot frame rotation axis. Once the pivot frame is tilted, the frame can be locked in that tilted position with the use of a frame position hydraulic locking device. This hydraulic locking device allows hydraulic fluid to pass from one chamber of a linear piston-type cylinder to another chamber through by-pass tubing. By shutting a by-pass valve, hydraulic fluid can not pass from one chamber to another and the cylinder shaft is locked in position. During a lapping operation, the hydraulic locking device is deactivated to allow friction-free rotational motion of the pivot frame.

Fig. 3 is a cross section view of a raised and tilted pivot-balance floating-platen lapper machine. Here, the pivot frame is raised and rotated and the floating-platen is tilted away from a horizontal position. The pivot-balance floating-platen lapping machine **118** provides these desirable features. The lapper machine **118** components such as the platen drive motor **119** and a counterweight **122** are used to counterbalance the weight of the abrasive platen assembly **99** where the pivot frame **114** is balanced about the pivot frame **114** pivot center **116**.

The pivot frame **114** has a rotation axis centered at the pivot frame pivot center **116** where the platen assembly **99** is attached at one end of the pivot frame **114** from the pivot center **116** and the platen motor **119** and a counterbalance weight **122** are attached to the pivot frame **114** at the opposed end of the pivot frame **114** from the pivot center **116**. The pivot frame **114** has low friction rotary pivot bearings at the pivot center **116** where the pivot bearings can be frictionless air bearings or low friction roller bearings. The platen drive motor **119** is attached to the pivot frame **114** in a position where the weight of the platen drive motor **119** nominally or partially counterbalances the weight of the abrasive platen assembly **99**. A movable and weight-adjustable counterweight **122** is attached to the pivot frame **114** in a position where the weight of the counterweight **122** partially counterbalances the weight of the abrasive platen assembly **99**. The weight of the counterweight **122** is used together with the weight of the platen motor **119** to effectively counterbalance the weight of the abrasive platen assembly **99** that is also attached to the pivot frame **114**. When the pivot frame **114** is counterbalanced, the pivot frame **114** pivots freely about the pivot center **116**. The platen drive motor **119** rotates a drive shaft **23** that is coupled to the gear box **112** to rotate the gear box **112** hollow drive shaft.

The whole pivot frame **114** can be raised or lowered from a machine base **132** by a elevation frame **128** lift device **130** that can be an electric motor driven screw jack lift device or a hydraulic lift device. The elevation frame **128** lift device **130** can have a position sensor that can be used to precisely control the vertical position of the elevation frame **128**. Zero-friction air bearing cylinders **124** can be used to apply the desired abrading forces to the platen **98** as it is held in 3-point abrading contact with the workpieces **94** attached to rotary spindles **90** having rotary spindle-tops **92**. One end of one or more air bearing cylinders **124** can be attached to the pivot frame **114** at different positions to apply forces to the pivot frame **114** where these applied forces provide an abrading force to the platen **98**. The support end of the air bearing cylinders **124** can also be attached to the elevation frame **128**. The floating platen **98** has a spherical rotation and a cylindrical rotation that is provided by the spherical-action platen support bearing **102** that supports the weight of the floating platen **98** where the spherical-action platen support bearing **102** is supported by the pivot frame **114**.

The air pressure applied to the air cylinder **124** is typically provide by an I/P (electrical current-to-pressure) pressure regulator (not shown) that is activated by an abrading process controller (not shown). The actual force generated by the air cylinder **124** can be sensed and verified by an electronic force sensor load cell that is attached to the cylinder rod end of the air cylinder **124**. The force sensor allows feed-back type closed-loop control of the abrading pressure that is applied to the workpieces **94**. Abrading pressures on the workpieces **94** can be precisely changed throughout the lapping operation by the lapping process controller.

The spindles **90** are attached to a dimensionally stable granite or epoxy-granite base **132**. A spherical-action bearing **102** allows the platen **98** to freely float with a spherical action motion during the lapping operation. A right-angle gear box **112** has a hollow drive shaft to provide vacuum to attach raised island abrasive disks **96** to the platen **98**. Vacuum **108** is applied to a rotary union **110** that allows rotation of the gear box **112** drive hollow shaft to route vacuum to the platen **98** through tubing or other passageway devices (not shown) where abrasive disks **96** can be attached to the platen **98** by vacuum. The spherical bearing **102** can be a roller bearing or an air bearing having an air passage **100** that allows pressurized air to be applied to create an air bearing effect or vacuum to be applied to lock the spherical bearing **102** rotor and housing components together. One or more conventional universal joints or plate-type universal joints or constant velocity universal joints or a set of two constant velocity universal joints **104**, **106** attached to the drive shaft **15** allow the spherical motion of the rotating platen **98**.

The pivot frame **114** can be rotated to desired positions and locked at the desired rotation position by use of a pivot frame locking device **120** that is attached to the pivot frame **114** and to the pivot frame **114** elevation frame **128**. The pivot frame **114** can be raised or lowered to selected elevation positions by the electric motor screw jack **130** or by a hydraulic jack **130** that is attached to the machine base **132** and to the pivot frame **114** elevation frame **128** where the pivot frame **114** elevation frame **128** is supported by a translatable slide device **126** that is attached to the machine base **132**.

Pivot-Balance Platen Spherical Rotation

When the pivot frame is raised by the pair of electric actuators (or by hydraulic cylinders) and tilted, the floating platen can also be rotated back into a horizontal position because of the use of a spherical-action platen shaft bearing. The drive shafts that are used to rotate the platen are connected with constant velocity universal joints to the platen drive shaft and to the gear box drive shaft. These universal joints allow the floating platen to have a spherical rotation while rotational power is supplied by the drive shafts to rotate the platen. The constant velocity universal joints are sealed and are well suited for use in a harsh abrading environment. If desired, the platen can be rotated at very low speeds while the pivot frame is tilted and the platen is tilted back where the abrading surface is nominally horizontal.

Fig. 4 is a cross section view of a raised pivot-balance floating-platen lapper machine with a horizontal platen. Here, the pivot frame is raised and rotated and the floating-platen is rotated back to a nominally horizontal position. The pivot-balance floating-platen lapping machine **164** provides these desirable features. The lapper machine **164** components such as the platen drive motor **165** and a counterweight **168** are used to counterbalance the weight of the abrasive platen assembly **145** where the pivot frame **160** is balanced about the pivot frame **160** pivot center **162**.

The pivot frame **160** has a rotation axis centered at the pivot frame pivot center **162** where the platen assembly **145** is attached at one end of the pivot frame **160** from the pivot center **162** and the platen motor **165** and a counterbalance weight **168** are attached to the pivot frame **160** at the opposed end of the pivot frame **160** from the pivot center **162**. The pivot frame **160** has low friction rotary pivot bearings at the pivot center **162** where the pivot bearings can be frictionless air bearings or low friction roller bearings. The platen drive motor **165** is attached to the pivot frame **160** in a position where the weight of the platen drive motor **165** nominally or partially counterbalances the weight of the abrasive platen assembly **145**. A movable and weight-adjustable counterweight **168** is attached to the pivot frame **160** in a position where the weight of the counterweight **168** partially counterbalances the weight of the abrasive platen assembly **145**. The weight of the counterweight **168** is used together with the weight of the platen motor **165** to effectively counterbalance the weight of the abrasive platen assembly **145** that is also attached to the pivot frame **160**. When the pivot frame **160** is counterbalanced, the pivot frame **160** pivots freely about the pivot center **162**. The platen drive motor **165** rotates a drive shaft **23** that is coupled to the gear box **158** to rotate the gear box **158** hollow drive shaft.

The whole pivot frame **160** can be raised or lowered from a machine base **178** by a elevation frame **174** lift device **176** that can be an electric motor driven screw jack lift device or a hydraulic lift device. The elevation frame **174** lift device **176** can have a position sensor that can be used to precisely control the vertical position of the elevation frame **174**. Zero-friction air bearing cylinders **170** can be used to apply the desired abrading forces to the platen **144** as it is held in 3-point abrading contact with the workpieces **140** attached to rotary spindles **136** having rotary spindle-tops **138**. One end of one or more air bearing cylinders **170** can be attached to the pivot frame **160** at different positions to apply forces to the pivot frame **160** where these applied forces provide an abrading force to the platen **144**. The support end of the air bearing cylinders **170** can also be attached to the elevation frame **174**. The floating platen **144** has a spherical rotation and a cylindrical rotation that is provided by the spherical-action platen support bearing **148** that supports the weight of the floating platen **144** where the spherical-action platen support bearing **148** is supported by the pivot frame **160**.

The air pressure applied to the air cylinder **170** is typically provide by an I/P (electrical current-to-pressure) pressure regulator (not shown) that is activated by an abrading process controller (not shown). The actual force generated by the air cylinder **170** can be sensed and verified by an electronic force sensor load cell that is attached to the cylinder rod end of the air cylinder **170**. The force sensor allows feed-back type closed-loop control of the abrading pressure that is applied to the workpieces **140**. Abrading pressures on the workpieces **140** can be precisely changed throughout the lapping operation by the lapping process controller.

The spindles **136** are attached to a dimensionally stable granite or epoxy-granite base **178**. A spherical-action bearing **148** allows the platen **144** to freely float with a spherical action motion during the lapping operation. A right-angle gear box **158** has a hollow drive shaft to provide vacuum to attach raised island abrasive disks **142** to the platen **144**. Vacuum **154** is applied to a rotary union **110** that allows rotation of the gear box **158** drive hollow shaft to route vacuum to the platen **144** through tubing or other passageway devices (not shown) where abrasive disks **142** can be attached to the platen **144** by vacuum. The spherical bearing **148** can be a spherical roller bearing or an air bearing having an air passage **146** that allows pressurized air to be applied to create an air bearing effect or vacuum to be applied to lock the spherical bearing **148** rotor and housing components together. One or more conventional universal joints or plate-type universal joints or constant velocity universal joints or a set of two constant velocity universal joints **150**, **152** attached to the drive shaft **15** allow the spherical rotation motion and the cylindrical rotation motion of the rotating platen **144** that rotates the abrasive disk **142** when the abrasive disk **142** is in abrading contact with workpieces **140**.

The pivot frame **160** can be rotated to desired positions and locked at the desired rotation position by use of a pivot frame locking device **166** that is attached to the pivot frame **160** and to the pivot frame **160** elevation frame **174**. The pivot frame **160** can be raised or lowered to selected elevation positions by the electric motor screw jack **176** or by a hydraulic jack **176** that is attached to the machine base **178** and to the pivot frame **160** elevation frame **174** where the pivot frame **160** elevation frame **174** is supported by a translatable slide device **172** that is attached to the machine base **178**.

Pivot-Balance Lapper Frame

A top view of the pivot-balance lapping machine shows how this lightweight framework and platen assembly has widespread support members that provide unusual stiffness to the abrading system. The two primary supports of the pivot frame are the two linear slides that have a very wide stance by being positioned at the outboard sides of the rigid granite base. The two precision-type heavy-duty sealed pivot frame linear slides have roller bearings that provide great structural rigidity for the abrasive platen as the platen rotates during the lapping operation.

Very low friction pivot bearings are used on the pivot shaft to minimize the pivot shaft friction as the pivot frame rotates. Because this pivot shaft friction is so low, the exact abrading force that is generated by the pivot abrading force air cylinder is transmitted to the abrading platen during the lapping operation. Cylindrical air bearings can provide zero-friction rotation of the pivot frame support shaft even when the pivot frame and platen system is quite heavy.

Fig. 5 is a top view of a pivot-balance floating-platen lapper machine. The pivot-balance floating-platen lapping machine **182** components include the platen drive motor **202** and a counterweight **200** are that are used to counterbalance the weight of the abrasive platen assembly **205** where the pivot frame **188** is balanced about the pivot frame **188** pivot center **189** rotation axis **203**.

The pivot frame **188** has a rotation axis **203** centered at the pivot frame pivot center **189** where the platen assembly **205** is attached at one end of the pivot frame **188** from the pivot axis **203** and the platen motor **202** and a counterbalance weight **200** are attached to the pivot frame **188** at the opposed end of the pivot frame **188** from the pivot axis **203**. The pivot frame **188** has low friction rotary pivot bearings **204** at the pivot center **189** where the pivot bearings **204** can be frictionless air bearings or low friction roller bearings. The radial stiffness of these pivot frame **188** air bears **204** are typically much stiffer than equivalent roller bearings **204**. The platen drive motor **202** is attached to the pivot frame **188** in a position where the weight of the platen drive motor **202** nominally or partially counterbalances the weight of the abrasive platen assembly **205**. A movable and weight-adjustable counterweight **200** is attached to the pivot frame **188** in a position where the weight of the counterweight **200** partially counterbalances the weight of the abrasive platen assembly **205**. The weight of the counterweight **200** is used together with the weight of the platen motor **202** to effectively counterbalance the weight of the abrasive platen assembly **205** that is also attached to the pivot frame **188**. When the pivot frame **188** is counterbalanced, the pivot frame **188** pivots freely about the pivot axis **203**. The platen drive motor **202** rotates a drive shaft **186** that is coupled to the gearbox **184** to rotate the gearbox **184** hollow abrading platen **210** rotary drive shaft **208**.

The whole pivot frame **188** can be raised or lowered from a machine base **194** by a elevation frame **197** lift device **192** that can be an electric motor driven screw jack lift device or a hydraulic lift device. The elevation frame **197** lift device **192** is attached to a linear slide **190** that is attached to the machine base **194** and also is attached to the elevation lift frame **197** where the elevation lift frame **197** lift device **192** can have a position sensor (not shown) that can be used to precisely control the vertical position of the elevation lift frame **197**.

The elevation frame **197** can be raised with the use of an elevation frame **197** lift devices **192** such as a pair of electric jacks such as a linear actuator produced by Exlar Corporation, Minneapolis, MN. These linear actuators can provide closed-loop precision control of the position of the elevation frame **197** and are well suited for long term use in a harsh abrading environment. When the elevation frame **197** and the pivot frame **188** and the abrasive platen assembly **205** and the floating platen **210** are raised, workpieces can be changed and the abrasive disks (not shown) that are attached to the platen can be easily changed. Here the floating platen **210** is allowed to have a spherical motion floatation and cylindrical rotation with the use of a spherical-action platen shaft bearing (not shown that rotates the abrasive disk **268** when the abrasive disk is in abrading contact with workpieces (not shown).

Zero-friction air bearing cylinders **196** can be used to apply the desired abrading forces to the platen **210** as it is held in 3-point abrading contact with the workpieces **180** attached to rotary spindles **181** having rotary spindle-tops. One end of one or more air bearing cylinders **196** can be attached to the pivot frame **188** at different positions to apply forces to the pivot frame **188** where these applied forces provide an abrading force to the platen **210**. The support end of the air bearing cylinders can be attached to the elevation frame **197**.

The top view of the pivot-balance lapping machine **182** shows how this lightweight framework and platen assembly has widespread support members that provide unusual stiffness to the abrading system. The two primary supports of the pivot frame are the two linear slides **190** that have a very wide stance by being positioned at the outboard sides of the rigid granite, epoxy-granite, cast iron or steel machine base **194**. The two precision-type heavy-duty sealed pivot frame machine tool type linear slides **190** have roller bearings that provide great structural rigidity for the lapping machine **182** and particularly for the abrasive platen **210** when the platen **210** is rotated during the lapping operation.

Very low friction pivot bearings **204** are used on the pivot shaft **206** to minimize the pivot shaft **206** friction as the pivot frame **188** rotates. Because this pivot shaft **206** friction is so low, the abrading force that is generated by the pivot abrading force air cylinder **196** is transmitted without friction-distortion to the abrading platen **210** during the lapping operation. Cylindrical air bearings **204** can provide zero-friction rotation of the pivot frame **188** support shaft **206** even when the pivot frame **188** and platen assembly **205** is quite heavy.

The pivot-balance floating-platen lapping machine **182** is an elegantly simple abrading machine that provides extraordinary precision control of abrading forces for this abrasive high speed flat lapping system. All of its components are all robust and are well suited for operation in a harsh abrading atmosphere with minimal maintenance.

<u>Platen Spherical Bearing</u>

Vacuum is required to attach the flexible abrasive disk to the flat abrading surface of the rotary platen. Here, a right-angle gear box having a hollow shaft is used to drive the platen. Constant velocity universal joints are connected to a stub shaft that connects to the platen drive shaft. A flexible tubing is used to route the vacuum line around the two universal joints to provide a continuous vacuum connection from a rotary union attached to the gear box hollow shaft to the platen. The platen drive motor shaft engages the gear box input shaft on one side of the gear box and the gearbox output shaft is positioned at right angles to the input drive shaft. The platen spherical bearing allows the platen to float freely while the platen assembly weight is fully supported by the spherical bearing and the pivot frame assembly.

Fig. 6 is a cross section view of a pivot-balance floating-platen lapper machine with flexible vacuum tubing and universal joints. Vacuum is required to attach the flexible abrasive disk **240** to the flat abrading surface of the rotary platen **238**. Here, a right-angle gearbox **225** having a hollow shaft **220** is used to drive the platen **238**. Constant velocity universal joints **230**, **234** are connected to a stub shaft **232** that connects the gearbox **225** having a hollow shaft **220** to the platen **238** drive shaft **235**. A flexible hollow tubing **218** is used to route the vacuum around the two universal joints **230**, **234** to provide a continuous vacuum **222** connection from a rotary union **224** attached to the gear box **225** hollow shaft **220** to the platen **238**. The horizontal platen **238** drive motor shaft **226** is coupled to the gearbox **225** input shaft on one side of the gearbox **225** and the vertical hollow gearbox **225** output shaft **220** is positioned at right angles to the input drive shaft. The platen **238** spherical bearing rotor **216** that is supported by the platen **238** spherical bearing housing **214** allows the platen **238** to float freely with spherical rotation **236** and where the platen **302** has a spherical rotation about the platen **238** spherical bearing rotor **216** and the platen **238** spherical bearing housing **214** center of rotation **237**.

The platen **238** assembly weight is fully supported by the platen **238** spherical bearing rotor **216** that is supported by the platen **238** spherical bearing housing **214** that is attached to the pivot frame **228**. The platen **238** assembly weight is fully supported by the platen **238** spherical bearing rotor **216** that is supported by the platen **238** spherical bearing housing 214 where both the platen **238** spherical bearing rotor **216** and the platen **238** spherical bearing housing **214** have spherical surfaces that have the same spherical radii to assure that the platen **238** spherical bearing rotor **216** and the platen **238** spherical bearing housing **214** have mutual contact spherical-matching contact with each other.

The platen **238** spherical bearing housing **214** can have a fluid passageway **212** where a pressurized liquid fluid or a pressurized gas can be routed to the spherical joint between the spherical surfaces of the platen **238** spherical bearing rotor **216** and the platen **238** spherical bearing housing **214** to form a spherical action air bearing. Also, vacuum can be applied to the platen **238** spherical bearing housing **214** fluid passageway **212** to be routed to the spherical joint between the matching spherical surfaces of the platen **238** spherical bearing rotor **216** and the platen **238** spherical bearing housing **214** to lock the platen **238** spherical bearing rotor **216** to the platen **238** spherical bearing housing **214**.

Also, the platen **238** spherical bearing rotor **216** and the platen **238** spherical bearing housing **214** are constructed where the platen **238** spherical bearing rotor **216** is restrained in all directions, including horizontal and vertical, by the platen **238** spherical bearing housing **214**.

<u>Platen Universal Joints</u>

Vacuum is required to attach the flexible abrasive disk to the flat abrading surface of the rotary platen. Here, a right-angle gear box having a hollow shaft is used to drive the platen. Constant velocity universal joints are connected to a stub shaft that connects to the platen drive shaft. These universal joints allow the stub shaft between the gear box and the platen shaft to move through a spherical angle even when the platen is rotated to provide abrading action on the workpieces. The constant velocity universal joints are sealed and are well suited for use in a harsh abrading environment.

Fig. 7 is a cross section view of a rotated pivot-balance floating-platen lapper machine with flexible vacuum tubing and universal joints. Vacuum is required to attach the flexible abrasive disk **268** to the flat abrading surface of the rotary platen **266**. Here, a right-angle gearbox **254** having a hollow shaft **248** is used to drive the platen **266**. Constant velocity or conventional universal joints **260**, **264** are connected to a stub shaft **262** that connects the gearbox **254** having a hollow shaft **248** to the platen **266** drive shaft **265**. A flexible hollow tubing **246** is used to route the vacuum around the two universal joints **260**, **264** to provide a continuous vacuum **250** connection from a rotary union **252** attached to the gearbox **254** hollow shaft **248** to the platen **266**. The horizontal platen **266** drive motor shaft **256** is coupled to the gearbox **254** input shaft on one side of the gearbox **254** and the vertical hollow gearbox **254** output shaft **248** is positioned at right angles to the input drive shaft. The platen **266** spherical bearing rotor **244** that is supported by the platen **266** spherical bearing housing **243** allows the platen **266** to float freely with spherical rotation **242** and also allow the platen **266** to have cylindrical rotation that rotates the abrasive disk **268** when the abrasive disk **268** is in abrading contact with workpieces (not shown).

The platen **266** assembly weight is fully supported by the platen **266** spherical bearing rotor **244** that is supported by the platen **266** spherical bearing housing **243** that is attached to the pivot frame **258**. The platen **266** assembly weight is fully supported by the platen **266** spherical bearing rotor **244** that is supported by the platen **266** spherical bearing housing **243** where both the platen **266** spherical bearing rotor **244** and the platen **266** spherical bearing housing **243** have spherical surfaces that have the same spherical radii to assure that the platen **266** spherical bearing rotor **244** and the platen **266** spherical bearing housing **243** have mutual contact spherical-matching contact with each other.

The platen **266** spherical bearing housing **243** can have a fluid passageway **241** where a pressurized liquid fluid or a pressurized gas can be routed to the spherical joint between the spherical surfaces of the platen **266** spherical bearing rotor **244** and the platen **266** spherical bearing housing **243** to form a spherical action air bearing. Also, vacuum can be applied to the platen **266** spherical bearing housing **243** fluid passageway **241** to be routed to the spherical joint between the matching spherical surfaces of the platen **266** spherical bearing rotor **244** and the platen **266** spherical bearing housing **243** to lock the platen **266** spherical bearing rotor **244** to the platen **266** spherical bearing housing **243**. The platen **266** spherical bearing housing **243** has a roller bearing **263** which supports the platen **266** rotary drive shaft **265** that allows the platen **266** to have cylindrical rotation while the platen **266** spherical bearing rotor **244** and the platen **266** spherical bearing housing **243** allow the platen **266** to have spherical rotation.

Also, the platen **266** spherical bearing rotor **244** and the platen **266** spherical bearing housing **243** are constructed where the platen **266** spherical bearing rotor **244** is restrained in all directions, including horizontal and vertical, by the platen **266** spherical bearing housing **243**.

Platen Spherical Device Air Bearing

When a pivot frame is raised by the electric actuator or by hydraulic cylinders, the floating platen can be tilted because of the use of a spherical-action platen shaft bearing. To fixture the tilted platen in a selected position, a spherical air bearing can be used as the platen shaft spherical bearing. Here, pressurized air can be supplied to the spherical air bearing to provide friction-free spherical rotation of the platen. The spherical air bearing rotation device can allow cylindrical rotation of the platen and/or allow the spherical rotation of the platen about the spherical rotation device center of rotation. When it is desired to lock the platen in a selected tilted position, vacuum can be supplied to the same spherical air bearing. The vacuum draws the spherical bearing platen shaft rotor into direct contact with the spherical air bearing housing that is attached to the platen pivot frame. The platen becomes locked to the pivot frame in the selected position by the vacuum applied to the spherical air bearing.

Fig. 8 is a cross section view of a rotated pivot-balance floating-platen lapper machine having flexible vacuum tubing and universal joints where the platen can be locked in a spherical rotation position. Vacuum is required to attach a flexible abrasive disk (not shown) to the flat abrading surface of the rotary platen **302**. Here, a right-angle gearbox **280** having a hollow shaft **774** is used to drive the platen **302**. Constant velocity or conventional universal joints **288**, **292** are connected to a stub shaft **290** that connects the gearbox **280** having a hollow shaft **774** to the platen **302** drive shaft **298**. A flexible hollow tubing **278** is used to route the vacuum around the two universal joints **288**, **292** to provide a continuous vacuum **284** connection from a rotary union (not shown) attached to the gearbox **280** hollow shaft **774** to the platen **302**. The horizontal platen **302** drive motor shaft (not shown) is coupled to the gearbox **280** input shaft on one side of the gearbox **280** and the vertical hollow gearbox **280** output shaft **282** is positioned at right angles to the input drive shaft. The platen **302** spherical bearing rotor **276** that is supported by the platen **302** spherical bearing housing **274** allows the platen **302** to float freely with spherical rotation **300** and also allow the platen **302** to have cylindrical rotation that rotates the abrasive disk when the abrasive disk is in abrading contact with workpieces (not shown).

The platen **302** assembly weight is fully supported by the platen **302** spherical bearing rotor **276** that is supported by the platen **302** spherical bearing housing **274** that is attached to the pivot frame **286**. The platen **302** assembly weight is fully supported by the platen **302** spherical bearing rotor **276** that is supported by the platen **302** spherical bearing housing **274** where both the platen **302** spherical bearing rotor **276** and the platen **302** spherical bearing housing **274** have spherical surfaces that have the same spherical radii to assure that the platen **302** spherical bearing rotor **276** and the platen **302** spherical bearing housing **274** have mutual contact spherical-matching contact with each other.

The platen **302** spherical bearing housing **274** can have a fluid passageway **270** where a pressurized liquid fluid **296** or a pressurized gas **296** can be routed through the passageway **270** to the spherical joint between the spherical surfaces of the platen **302** spherical bearing rotor **276** and the platen **302** spherical bearing housing **274** to form a spherical action air bearing. Also, vacuum **272** can be applied to the platen **302** spherical bearing housing **274** fluid passageway **270** to be routed to the spherical joint between the matching spherical surfaces of the platen **302** spherical bearing rotor **276** and the platen **302** spherical bearing housing **274** to lock the platen **302** spherical bearing rotor **276** to the platen **302** spherical bearing housing **274**. The platen **302** spherical bearing housing **274** has a roller bearing **294** which supports the platen **302** rotary drive shaft **298** that allows the platen **302** to have cylindrical rotation while the platen **302** spherical bearing rotor **276** and the platen **302** spherical bearing housing **274** allow the platen **302** to have spherical rotation about the platen **302** spherical bearing rotor **276** and the platen **302** spherical bearing housing **274** center of rotation **271**.

Also, the platen **302** spherical bearing rotor **276** and the platen **302** spherical bearing housing **274** are constructed where the platen **302** spherical bearing rotor **276** is restrained in all directions, including horizontal and vertical, by the platen **302** spherical bearing housing **274**.

Platen Spherical Rotation Lock

To fixture a tilted platen in a selected position, a spherical roller bearing and a spherical rotor brake pad system can be used together. Both the spherical roller bearing and the spherical brake rotor share the same spherical center of rotation. The brake pad surface also has the same spherical surface curvature as the spherical roller bearing and the spherical brake rotor. During a typical lapping operation, the brake pad is withdrawn from contacting the brake rotor and the platen is allowed to float freely with spherical motion

When it is desired to lock the platen in a selected tilted position, the brake pad is forced by an electric solenoid against the surface of the spherical brake rotor to hold the platen in the selected position. The brake pad is attached to a shaft that extends out from the electric solenoid device where the axis of the solenoid brake shaft intersects the spherical center of rotation of the spherical platen bearing. Because the brake pad shaft axis intersects the spherical center of rotation, the brake pad does not impart any tilting torque on the freely floating platen. This results in the platen being fixtured at the desired tilted location when the solenoid is activated.

Fig. 9 is a cross section view of a rotated pivot frame with a horizontal platen using a brake pad spherical action lock where the platen can be locked in a spherical rotation position. Vacuum is required to attach a flexible abrasive disk (not shown) to the flat abrading surface of the rotary platen **304**. Here, a right-angle gearbox **324** having a hollow shaft **326** is used to drive the platen **304**. Constant velocity or conventional universal joints **322**, **316** are connected to a stub shaft **318** that connects the gearbox **324** having a hollow shaft **326** to the platen **304** drive shaft **308**. A flexible hollow tubing **320** is used to route the vacuum around the two universal joints **322**, **316** to provide a continuous vacuum **328** connection from a rotary union (not shown) attached to the gearbox **324** hollow shaft **326** to the platen **304**. The horizontal platen **304** drive motor shaft (not shown) is coupled to the gearbox **324** input shaft on one side of the gearbox **324** and the vertical hollow gearbox **324** output shaft **326** is positioned at right angles to the input drive shaft. The platen **304** spherical bearing rotor **312** that is supported by the platen **304** spherical bearing housing **310** allows the platen **304** to float freely with spherical rotation **306** and also allow the platen **304** to have cylindrical rotation that rotates the abrasive disk (not shown) when the abrasive disk is in abrading contact with workpieces (not shown).

The platen **304** assembly weight is fully supported by the platen **304** spherical bearing rotor **312** that is supported by the platen **304** spherical bearing housing **310** that is attached to the pivot frame **330**. The platen **304** assembly weight is fully supported by the platen **304** spherical bearing rotor **312** that is supported by the platen **304** spherical bearing housing **310** where both the platen **304** spherical bearing rotor **312** and the platen **304** spherical bearing housing **310** have spherical surfaces that have the same spherical radii to assure that the platen **304** spherical bearing rotor **312** and the platen **304** spherical bearing housing **310** have mutual contact spherical-matching contact with each other.

The platen **304** spherical bearing housing **310** can have a fluid passageway (not shown) where a pressurized liquid fluid or a pressurized gas can be routed through the passageway to the spherical joint between the spherical surfaces of the platen **304** spherical bearing rotor **312** and the platen **304** spherical bearing housing **310** to form a spherical action air bearing. Or the spherical bearing rotor **312** and the platen **304** spherical bearing housing **310** can be mechanical roller bearings. Here, the platen **304** spherical bearing housing **310** can have has a roller bearing **312** which supports the platen **304** rotary drive shaft **308** that allows the platen **304** to have cylindrical rotation while the platen **304** spherical bearing rotor **312** and the platen **304** spherical bearing housing **310** allow the platen **304** to have spherical rotation.

Also, the platen **304** spherical bearing rotor **312** and the platen **304** spherical bearing housing **310** are constructed where the platen **304** spherical bearing rotor **312** is restrained in all directions, including horizontal and vertical, by the platen **304** spherical bearing housing **310**.

A mechanical brake rotor **314** is attached to the platen **304** drive shaft **308** where the mechanical brake rotor **314** has a spherical surface that has a spherical center of rotation **340** that is coincident with and shared in common with the spherical center of rotation **340** of the platen **304** spherical centers of rotation of both the spherical bearing rotor **312** and the platen **304** spherical bearing housing **310**.

A spherical surfaced brake pad **338** is attached to a brake activation force device **334** brake pad shaft **336** that can be an air cylinder, spring-return air cylinder, a solenoid or a piezo-electric brake activation force device **334** where the axis **332** of the brake activation force device **334** brake pad shaft **336** is aligned to pass through the mechanical brake rotor **314** spherical surface spherical center of rotation **340**. When the brake pad **338** is forced against the mechanical brake rotor **314** by the brake activation force device **334** to lock the platen **304** in a selected spherical rotation position, the brake pad **338** does not apply a torque to the mechanical brake rotor **314**, which could tilt the platen **304**, because the axis of the brake activation force device **334** brake pad shaft **336** is aligned to pass through the mechanical brake rotor **314** spherical surface spherical center of rotation **340**.

<u>Air Cylinder Platen Spherical Lock</u>

Another technique that can be used to fixture a floating platen is to use a brake pad attached to a spring-return air cylinder. Here, a spherical roller bearing and a spherical rotor brake pad system can be used together. Both the spherical roller bearing and the spherical brake rotor share the same spherical center of rotation. The brake pad surface also has the same spherical surface curvature as the spherical roller bearing and the spherical brake rotor. During a typical lapping operation, the brake pad is withdrawn from contacting the brake rotor and the platen is allowed to float freely with spherical motion.

The spherical-surfaced brake pad is attached to a spring-return air cylinder where it is necessary to apply air pressure to disengage the brake pad. During a typical lapping operation, the brake pad is withdrawn from contacting the brake rotor and the platen is allowed to float freely with spherical motion. When it is desired to lock the platen in a selected tilted position, the air pressure is interrupted and the brake pad is forced by the air cylinder return spring against the surface of the spherical brake rotor to hold the platen in the selected position.

The brake pad is attached to a shaft that extends out from the air cylinder where the axis of the solenoid brake shaft intersects the spherical center of rotation of the spherical platen bearing. Because the brake pad shaft axis intersects the spherical center of rotation, the brake pad does not impart any tilting torque on the freely floating platen. This results in the platen being fixtured at the desired tilted location when the solenoid is activated.

Fig. 10 is a cross section view of a rotated pivot frame with a horizontal platen using a spring-return brake pad spherical action lock where the platen can be locked in a spherical rotation position. Constant velocity or conventional universal joints **350** are connected to a stub shaft that connects the gearbox (not shown) having a hollow shaft not shown) to the platen **372** drive shaft **344**. The platen **372** spherical bearing rotor **368** that is supported by the platen **372** spherical bearing housing **346** allows the platen **372** to float freely with spherical rotation **342** and also allow the platen **372** to have cylindrical rotation that rotates the abrasive disk (not shown) when the abrasive disk is in abrading contact with workpieces (not shown).

The platen **372** assembly weight is fully supported by the platen **372** spherical bearing rotor **368** that is supported by the platen **372** spherical bearing housing **346** that is attached to the pivot frame **352**. The platen **372** assembly weight is fully supported by the platen **372** spherical bearing rotor **368** that is supported by the platen **372** spherical bearing housing **346** where both the platen **372** spherical bearing rotor **368** and the platen **372** spherical bearing housing **346** have spherical surfaces that have the same spherical radii to assure that the platen **372** spherical bearing rotor **368** and the platen **372** spherical bearing housing **346** have mutual contact spherical-matching contact with each other.

The spherical bearing rotor **368** and the platen **372** spherical bearing housing **346** can be mechanical roller bearings. Here, the platen **372** spherical bearing housing **346** can have has a roller bearing **368** which supports the platen **372** rotary drive shaft **344** that allows the platen **372** to have cylindrical rotation while the platen **372** spherical bearing rotor **368** and the platen **372** spherical bearing housing **346** allow the platen **372** to have spherical rotation.

Also, the platen **372** spherical bearing rotor **368** and the platen **372** spherical bearing housing **346** are constructed where the platen **372** spherical bearing rotor **368** is restrained in all directions, including horizontal and vertical, by the platen **372** spherical bearing housing **346**.

A mechanical brake rotor **348** is attached to the platen **372** drive shaft **344** where the mechanical brake rotor **348** has a spherical surface that has a spherical center of rotation **370** that is coincident with and shared in common with the spherical center of rotation **370** of the platen **372** spherical centers of rotation of both the spherical bearing rotor **368** and the platen **372** spherical bearing housing **346**.

A spherical surfaced brake pad **366** is attached to a brake activation force device **354** brake pad shaft **364** that can be a spring-return air cylinder force device **354** where the axis **356** of the brake activation force device **354** brake pad shaft **364** is aligned to pass through the mechanical brake rotor **348** spherical surface spherical center of rotation **370**. When the brake pad **366** is forced against the mechanical brake rotor **348** by the brake activation force device **354** to lock the platen **372** in a selected spherical rotation position, the brake pad **366** does not apply a torque to the mechanical brake rotor **348**, which could tilt the platen **372**, because the axis of the brake activation force device **354** brake pad shaft **364** is aligned to pass through the mechanical brake rotor **348** spherical surface spherical center of rotation **370**.

The spring-return air cylinder force device **354** has a return spring **358** that pushes against an air cylinder piston **360** to provide forced contact of the brake pad **366** with the mechanical brake rotor **348** to prevent free spherical motion of the platen **372**. When pressurized air **362** is used to act against the air cylinder piston **360** return spring **358**, this action prevents return spring induced contact of the brake pad **366** with the mechanical brake rotor **348** to allow free spherical rotation motion of the platen **372**. Spherical rotation motion of the platen **372** is prevented when there is not sufficient air pressure of the pressurized air **362** to push the cylinder piston **360** against the return spring **358** to prevent contact of the of the brake pad **366** with the mechanical brake rotor **348.**

<u>Platen Center Of Gravity Offset</u>

Fig. 11 is a cross section view of a pivot-balance floating-platen lapper machine where the center of gravity of the rotating platen is off-set from the center of spherical rotation of the platen spherical rotation device. The abrading platen **390** has an attached flexible abrasive disk **398** where the abrading platen **390** has a mass center **394** that has an off-set distance **396** that is less than 3 inches (7.6 cm) or preferred to be less than 2 inches (5 cm) and more preferred to be less than 1 inch (2.5 cm) and most preferred to be less than 0.5 inches (1.3 cm) and most highly preferred to be less than 0.25 inches (0.64 cm) from the center of spherical rotation of the platen spherical rotation device **392**.

The platen **390** has a platen rotation drive shaft **386** that is rotationally driven by a gearbox **376** with an universal joint **384**. Vacuum is supplied to the platen **390** by a rotary union **378** and the gearbox **376** is attached to and supported by a pivot frame **382** where a platen drive motor (not shown) rotates a gearbox **376** input drive shaft **380**. The platen spherical rotation bearing rotor **374** is supported by a platen spherical rotation bearing housing **388** that is supported by the pivot frame **382**.

<u>Brake Pad Platen Center Of Gravity Offset</u>

Fig. 12 is a cross section view of a pivot-balance floating-platen lapper machine having a mechanical friction spherical brake where the center of gravity of the rotating platen is off-set from the center of spherical rotation of the platen spherical rotation device. The abrading platen **400** has an attached flexible abrasive disk **422** where the abrading platen **400** has a mass center **420** that has an off-set distance **421** that is less than 3 inches (7.6 cm) or preferred to be less than 2 inches (5 cm) and more preferred to be less than 1 inch (2.5 cm) and most preferred to be less than 0.5 inches (1.3 cm) and most highly preferred to be less than 0.25 inches (0.64 cm) from the center of spherical rotation **392** of the platen spherical rotation device **402**.

The platen **400** has a platen rotation drive shaft **424** that is rotationally driven by a gearbox (not shown) with an universal joint **406**. The platen spherical rotation bearing **402** is supported by the pivot frame **408**. The pivot frame **408** also supports a return-spring air cylinder drive device **414** that has a return spring **410** that forces a spherical-surfaced brake pad **416** against a spherical-surfaced rotor **404** that is attached to the platen **400** drive shaft **424** where the brake pad **416** translated linearly along a axis **412** that intersects the center of spherical rotation **392** of the platen spherical rotation device **402**.

<u>Platen Reinforcing Support Ribs</u>

To provide extra rigidity to the platen annular body, platen support ribs can be attached to the platen where the ribs extend to the annular center of the platen. Here, abrading forces that are applied by the pivot frame that supports the rotatable platen are transferred to the hub that surrounds the platen drive shaft. Portions of the applied abrading forces are then transferred to the center of the platen annular body by the very stiff platen support ribs. Without the platen support ribs, the applied abrading forces are transferred through the thickness of the platen body. The platen support ribs minimize the out-of-plane distortion of the platen annular abrading surface.

It is critical that the applied abrading forces do not distort the platen annular body where the flatness variation of the platen abrading surface exceeds 0.0001 inches (3 microns) to successfully accomplish flat lapping of workpieces. The abrading forces are applied through the pivot frame that holds the stationary part of the spherical roller bearing. These abrading forces are typically just a fraction of the weight of the platen assembly. However, if the abrading forces do exceed the weight of the platen these abrading forces are transferred through the spherical roller bearing device.

Internal platen support ribs can be attached to the platen where these radial ribs extend from the drive shaft hub to the annular center of the platen. These ribs typically are equal in number to the external platen stiffening ribs and are attached to the platen at the same tangential locations as the internal platen stiffening ribs. Here, the adhesively attached platen support ribs and the respective radial platen stiffening ribs form continuous beam structures that are exceedingly stiff. Collectively, these radial rib structures, which are evenly distributed around the annular platen, can transfer large abrading forces without distorting the precision-flat platen abrading surface.

Here, abrading forces that are applied by the pivot frame that supports the rotatable platen are transferred to the hub that surrounds the platen drive shaft. Portions of the applied abrading forces are then transferred to the center of the platen annular body by the very stiff platen support ribs. Without the platen support ribs, the applied abrading forces are transferred only through the thickness of the platen body. Use of non-rib platen annular bodies that have very thick cross-sections can also provide a radial stiffness equal to a platen having the external platen support ribs.

Fig. 13 is a cross section view of a floating-platen having structural support ribs. The abrading platen **426** has an attached flexible abrasive disk **446** that is attached with vacuum to the flat annular surface **445** of the platen **426**. The platen **426** has a platen rotation drive shaft **444** that is rotationally driven by a gearbox (not shown) with an universal joint **434**. The platen spherical rotation bearing **430** is supported by the pivot frame **436**. The pivot frame **436** also supports a return-spring air cylinder drive device **440** that has a return spring **438** that forces a spherical-surfaced brake pad **442** against a spherical-surfaced rotor **432** that is attached to the platen **426** drive shaft **444**.

The platen **426** has reinforcing radial ribs **428** that extend out radially from an annular platen **426** hub **443** where the reinforcing radial ribs **428** are positioned around the circumference of the platen **426**. Abrading forces are applied by the platen spherical rotation bearing **430** and are transferred to the platen **426** annular hub **443** where the abrading forces are then transferred to the center of the platen **426** annular abrading area **445** by the reinforcing radial ribs **428**. Use of the reinforcing radial ribs **428** minimizes the distortion of the platen **426** body by the abrading forces where the precision-flat annular bottom abrading surface **445** of the platen **426** remains precisely flat. The precision-flat annular bottom abrading surface **445** of the platen **426** remains flat so that the abrasive surface of the abrasive disk **446** is held in flat-surfaced abrading contact with workpieces (not shown).

<u>Platen Surface Wear Resistant Coating</u>

To provide a wear resistant coating on the abrasive disk side of the platen, a cast aluminum annular bottom plate can be provided with a “hard coat” anodized surface. A 0.003 inches (76 micron) thick coating can be formed on the platen surface. This aluminum oxide coating is extremely hard and wear resistant. Many precision products such as air bearing spindles are fabricated from aluminum and where components are anodized to create a hard surface that can be ground to provide precisely-flat surfaces.

A distinct advantage is that the anodized coating is an integral part of the dimensionally stable cast aluminum platen components. Because the anodized coating is so thin compared to the platen annular bottom plate, the anodized coating does not distort the platen precision-flat abrading surface when the platen is subjected to temperature changes. In addition, sapphire (aluminum oxide) hollow orifice inserts can be positioned in the platen annular bottom plate to provide wear resistant vacuum port holes. These orifice inserts act as vacuum passageways to tangential grooves cut in the platen abrading surface that allow abrasive disks to be attached to the platen.

Another method of providing the platen abrading surface with a wear resistant coating is to attach aluminum oxide beads to the platen surface with a structural adhesive. These equal-sized aluminum oxide beads are very hard and wear resistant. They can be applied to platens constructed from a wide variety of materials including aluminum and cast iron. Aluminum platens are desirable because they are lightweight, are structurally stiff, and provide low mass inertia that minimize the torsional platen drive forces that accelerate and decelerate the high speed rotation of the platens. The beads can be solid aluminum oxide and they can be vitrified aluminum oxide if desired. Beads can also be filled with other abrasive particles such as diamond or CBN. The bead adhesive can also be filled with abrasive particles such as aluminum oxide or diamond to increase its resistance to abrading. After the beads are attached to the platen, the coated-bead common exposed surface is ground precisely flat. Worn beads are easy to remove from platen surfaces and can be replaced by applying a new layer of beads.

A distinct advantage is that the bead coating is that it becomes an integral part of the dimensionally stable cast aluminum platen components. Because the individual beads are so small, as compared to the platen annular bottom plate, the distributed bead coating does not distort the platen precision-flat abrading surface when the platen is subjected to temperature changes.

In addition, sapphire (aluminum oxide) hollow orifice inserts can be positioned in the platen annular bottom plate to provide wear resistant vacuum port holes. These orifice inserts act as vacuum passageways to tangential grooves cut in the platen abrading surface that allow abrasive disks to be attached to the platen. Abrasive debris that is captured by the abrasive disk vacuum attachment system can abrade and enlarge the individual platen vacuum port holes. Use of the extremely hard sapphire inserts having a hardness of 9 mhos (where diamond has a hardness of 10 mhos) provides assurance that the wear of the vacuum port holes is minimized.

The tangential grooves cut in the platen abrading surface to act as vacuum passageways for the vacuum attachment of the flexible abrasive disks intersect the vacuum port holes that extend into the platen surface to intersect radial and tangential vacuum passageways that are located internal to the platen body. The typical size of the hard aluminum oxide beads that are coated on a platen surface can range from less than 0.005 inches (0.127 mm) to more than 0.010 inches (0.254 mm). The surface of a platen can be re-ground repetitively before the beads have to be replaced. The flatness of the ground surface of the bead coated platen surface typically has a variation of less than 0.0001 inches (3 microns). Both the upper and lower surfaces of the platen can be coated with beads and ground flat.

The tangential vacuum grooves in the bead coated surface have a depth that is less than the diameter of the beads, when the platen is first fabricated. The typical groove width can range from 0.002 inches (0.051 mm) to 0.060 inches (1.52 mm) or the groove width can be optimized as desired and the grooves can be ground into individual beads. Vacuum grooves can be re-ground when the platen abrading surface is re-ground.

Fig. 14 is a cross section view of a floating-platen having an external wear-resistant surface coating. The abrading platen **454** has a top annular surface plate **456**, an outer periphery annular wall **458** and an internal radial reinforcing rib **452**. The internal radial reinforcing rib **452** has a vacuum passageway **450** that is cut into the bottom of the radial rib **452** where the vacuum passageway **450** extends along the length of the rib **452**. The vacuum passageway **450** intersects platen **454** vacuum port holes **462** that extend to tangential vacuum grooves **464** and where the tangential vacuum grooves **464** extend around the circumference of the platen annular abrading surface **466**. The vacuum port holes **462** can have sapphire or hardened through-hole inserts **468** that are constructed from aluminum oxide or hardened metals.

The platen **454** has a bottom annular plate **460** that is coated with a layer of adhesive **448** where spherical hard-material beads or particles **470** are bonded to the platen **454** bottom plate **460** by the adhesive **448**. The hard material beads or particles **470** can be made from materials selected from the group of ceramics, aluminum oxide, diamond, cubic boron nitride (CBN) and metals. A size coating of adhesive or particle-filled adhesive can be applied to the exposed surface of the spherical hard-material beads or particles **470** to fill the gaps between individual spherical hard-material beads or particles **470**. When the adhesive **448** is fully solidified, the exposed surface of the spherical hard-material beads or particles **470** can be ground to form a precision-flat platen **454** annular abrading surface **466**.

Rigid Platen External Annular Support Rib

Fig. 14.1 is a cross section view of a floating-platen having an external annular support rib. Using external annular support ribs that are integrally attached to the top surface of the annular platen provides very substantial circumferential rigidity to the platen and provides uniform distribution of the applied abrading forces across the radial width of the annular abrading platen. Also, the associated plated rotary platen drive hub is also very stiff structurally. Multiple platen attachment devices that are simple to use are evenly distributed around the circumference of the platen. This particular platen attachment structure design provides a maximum of structural stiffness with a minimum of structure weight and rotational mass inertia. This allows the transmission of large torque forces that can quickly accelerate and decelerate the platens to and from their high rotational speeds. Providing quick platen speed-ups and platen braking times decreases the process time for high speed flat lapping of workpieces. In addition, a flexible bellows-type device (not shown) can be used to provide a seal for the platen **38a** device where abrasive debris generated by the abrasive lapping process does not contaminate the components of platen **38a** lapping device. This platen **38a** system is well suited for use in a harsh abrading environment.

The annular abrading platen **38a** has an attached flexible abrasive disk **36a** that is attached with vacuum to the flat annular surface **35a** of the annular platen **38a**. The annular platen **38a** has a platen rotation drive shaft **30a** that is rotationally driven by a gearbox (not shown) using an universal joint **20a**. The annular platen **38a** also has a platen circular drive base plate **32a** that is attached to the platen rotation drive shaft **30a**. The annular platen **38a** platen circular base plate **32a** is also attached to a platen rotational drive annular hub **29a** that is attached to an annular platen support plate **14a** that is attached to an annular platen **38a** annular reinforcing rib **10a** by use of fastener-devices **12a**.

The annular platen **38a** annular reinforcing rib **10a** provides substantial circumferential rigidity to the annular platen **38a** which provides assurance that the abrading forces that are applied by the platen drive shaft **30a** are uniformly distributed around the circumference of the annular platen **38a**. Also, the annular platen **38a** annular reinforcing rib **10a** has a triangular cross-section shape that is positioned in the radial center of the annular platen **38a** to provide that the applied abrading forces are uniformly distributed across the radial width of the annular platen **38a**. The annular platen **38a** annular platen support structure **10a** is attached to the top flat surface of the annular platen **38a** where the annular platen support structure **10a** extends around the circumference of the platen **38a**. A platen **38a** cover plate **34a** provides flat-surfaced support for the central area of the flexible abrasive disks **36a** that are attached to the platen **38a**.

The platen spherical rotation bearing **16a** is supported by the pivot frame **22a**. The pivot frame **22a** also supports a return-spring air cylinder drive device **26a** that has a return spring **24a** that forces a spherical-surfaced brake pad **28a** against a spherical-surfaced rotor **18a** that is attached to the platen **38a** drive shaft **30a**.

Abrading forces are applied by the platen spherical rotation bearing **16a** and are transferred to the platen **38a** annular hub **29a** where the abrading forces are then transferred to the center of the platen **38a** annular abrading area **35a** by the annular reinforcing rib **10a**. Use of the annular reinforcing rib **10a** minimizes the distortion of the platen **38a** body by the abrading forces where the precision-flat annular bottom abrading surface **35a** of the platen **38a** remains precisely flat. The precision-flat annular bottom abrading surface **35a** of the platen **38a** remains flat so that the abrasive surface of the abrasive disk **36a** is held in flat-surfaced abrading contact with workpieces.

Fig. 14.2 is a top view of a floating-platen having an external annular support rib. A rotary platen **42a** is driven in a rotational direction by a drive shaft **48a** that is attached to a platen **42a** platen circular base plate **46a**. The platen circular base plate **46a** is also attached to a platen rotational drive annular hub (not shown) that is attached to an annular platen support plate **40a**. The annular platen support plate **40a** is attached to an annular platen **42a** annular reinforcing rib **50a** by use of fastener-devices **44a**.

<u>Air Bearing Pivot Frame Cylinder</u>

It is important that the air cylinder that applies abrading forces to the platen is friction free to avoid creating unwanted friction force effects that generate errors in the selected abrading forces. One technique to do this is to use a friction-free air bearing air cylinder. Here, an air bearing cylinder has shaft air bearings to eliminate any friction drag on the cylinder shaft as it moves. Also, in this device, the pressurized air that is supplied to the cylinder shaft air bearing located within the body of the air cylinder has an air barrier. This is done to minimize the entrance of pressurized air bearing air into the air cylinder chamber located at the free end of the cylinder shaft contained within the cylinder.

Air pressure applied to this lower chamber sets the force that is generated by the air cylinder. The upper end of the air bearing cylinder is vented to allow free passage of the upper air bearing exit air to the ambient. The force produced by the air bearing cylinder increases with a size increase of the cylinder. A pleated flexible cover can be attached to the shaft end of the cylinder to prevent contamination of the external end shaft air bearing. These air bearing cylinders are very robust, durable and well suited for harsh abrading environments.

The exact forces that are generated by the air cylinders can be very accurately determined with load cell force sensors. The output of these load cells can be used by feedback controller devices to dynamically adjust the abrading forces on the platen abrasive throughout the lapping procedure. This abrading force control system can even be programmed to automatically change the applied-force cylinder forces to compensate for the very small weight loss experienced by an abrasive disk during a specific lapping operation. Also, the weight variation of “new” abrasive disks that are attached to a platen to provide different sized abrasive particles can be predetermined. Then the abrading force control system can be used to compensate for this abrasive disk weight change from the previous abrasive disk and provide the exact desired abrading force on the platen abrasive.

The abrading force feedback controller provides an electrical current input to an air pressure regulator referred to as an I/P (current to pressure) controller. The abrading force controller has the capability to change the pressures that are independently supplied to each of the parallel abrading force air cylinders. The actual force produced by each independently controlled air cylinder is determined by a respected force sensor load cell to close the feedback loop.

Fig. 15 is a cross section view of an air bearing air cylinder. The air bearing air cylinder **473** provides frictionless linear motion of a cylinder rod **484** that has a pivot pin **482** connection to an apparatus. The cylinder rod **484** is guided by frictionless air bearings **480** and **476** where exhaust air from the air bearing **476** is blocked by an air bearing seal **474** that minimizes the amount of pressurized air **494** that is applied to the air bearing **473** port **492** to supply air to the air bearing **476** from leaking into the lower cylinder **473** internal chamber **496**. Excess pressurized air **486** that is applied at the cylinder **473** port hole **488** supplies pressurized air **486** to the rod air bearing **480** where some of the air **486** leaks into the cylinder **473** rod end internal chamber **478**. Excess pressurized air **486** can be exhausted from the cylinder **473** rod end internal chamber **478** through the cylinder **473** vent hole **490**. Controlled pressure air **497** is supplied to the cylinder **473** port **495** where this pressurized air **497** originates the cylinder **473** force that is applied to the cylinder rod **484** and the cylinder **473** force ii proportional to the cross section area of the cylinder rod **484**. The mounting end **498** of the cylinder **473** has a pivot pin **472**. These air bearing air cylinders **473** are very robust and are well suited for use in a harsh abrading environment.

Hydraulic Locking Cylinder

When the pivot frame is raised by the electric actuator or by hydraulic cylinders, the floating platen can also be tilted by rotation of the pivot frame about the pivot frame rotation axis. Once the pivot frame is tilted, the frame can be locked in that tilted position with the use of a frame position hydraulic locking device. This hydraulic locking device allows hydraulic fluid to pass from one chamber of a linear piston-type cylinder to another chamber through by-pass tubing. By shutting a by-pass valve, hydraulic fluid can not pass from one chamber to another and the cylinder shaft is locked in position. During a lapping operation, the hydraulic locking device is deactivated to allow friction-free rotational motion of the pivot frame.

A manually adjusted metering valve can also be located in the hydraulic by-pass line to restrict the flow of the hydraulic fluid in the by-pass line. Restriction of the by-pass hydraulic fluid provides hydraulic damping which attenuates any vibration that is induced in the lapping machine system by platen abrading action. Here, positional excursions from the vibrations move the cylinder piston with periodic oscillations which oscillates hydraulic fluid in the by-pass tubing. As the oscillating fluid travels past the restrictor valve, this fluid is sheared and creates fluid forces that oppose the induced mechanical vibrations. If desired, the platen can be rotated at very low speeds while the frame is tilted.

Fig. 16 is a cross section view of hydraulic cylinder pivot frame locking and vibration damping device. The hydraulic cylinder **515** provides linear motion of a cylinder rod **514** that has a pivot pin **512** connection to an apparatus and a cylinder **515** cylinder mounting end **528** that has a pivot pin **500** connection to a mounting apparatus. The cylinder rod **514** is guided by a rod end bearing **510** and a moving rod piston **504** that is sealed against the inside cylindrical surface of the hydraulic cylinder **515**. The cylinder **515** has a cylinder rod **514** end internal hydraulic chamber **508** and also has a mounting end **528** internal hydraulic chamber **502** and a by-pass tube **524**. The by-pass tube **524** allows passage of non-air entrained hydraulic fluid that is present in the internal mounting end **528** internal hydraulic chamber **502** and the cylinder rod **514** end internal hydraulic chamber **508** and in the by-pass tube **524**.

The by-pass tube **524** has a metering valve **516** that can be operated by a manual handle **518** or by an actuator screw device (not shown) to adjust a flow restrictor orifice that is an integral part of the restrictor metering valve **516**. The by-pass tube **524** also has a shut-off valve **520** that can be operated manually or operated by a solenoid operator device **522** where flow of the incompressible hydraulic fluid in the by-pass tube **524** can be stopped. When this by-pass tube **524** hydraulic flow is stopped, the hydraulic cylinder **515** piston **504** is stopped and motion of the cylinder rod **514** is stopped because hydraulic fluid can not flow between the internal mounting end **528** internal hydraulic chamber **502** and the cylinder rod **514** end internal hydraulic chamber **508**. Stopping the motion of the cylinder rod **514** prevents the pivot frame (not shown) that is attached to the cylinder rod **514** from rotating.

The pivot frame hydraulic cylinder can also be used to limit the rotational speed of the pivot frame and to attenuate vibrations of the pivot frame by controlling the flow of the hydraulic fluid that flows between the internal mounting end **528** internal hydraulic chamber **502** and the cylinder rod **514** end internal hydraulic chamber **508** as the moving cylinder rod **514** is translated relative to the external surface of the hydraulic cylinder body **515**. Here, when the hydraulic metering valve **516** hydraulic flow orifice is adjusted to be partially closed, a hydraulic damping force is generated by restricting the flow of the hydraulic fluid as it passes between the cylinder rod **514** end internal hydraulic chamber **508** and the cylinder mounting base mounting end **528** end internal hydraulic chamber **502** as the moving cylinder rod **514** and the cylinder piston **504** that is attached to the cylinder rod **514** is translated relative to the external surface of the cylinder **515**.

When the respective hydraulic damping force is applied to the cylinder piston **504** in a direction that opposes the movement direction of the cylinder rod **514** that is moved by the rotation motion of the pivot frame wherein the rotation motion of the pivot frame is slowed by the respective hydraulic damping force. Also, rotation oscillations of the pivot frame are resisted by hydraulic damping forces that are applied to the cylinder piston **504** in directions that oppose the oscillating movement of the cylinder rod **514** that is moved by the oscillating rotation motion of the pivot frame. Further, the rotation motion of the pivot frame is slowed by the respective hydraulic damping forces. Metering the flow of the hydraulic fluid in the by-pass tube **524** effectively attenuates vibrations and reduces oscillations of the pivot frame.

Fixed-Spindles Floating-Platen

Fig. 17 is an isometric view of an abrading system **45** having three-point fixed- position rotating workpiece spindles supporting a floating rotating abrasive platen. Three evenly-spaced rotatable spindles **532** (one not shown) having rotating tops **550** that have attached workpieces **534** support a floating abrasive platen **544**. The platen **544** has a vacuum, or other, abrasive disk attachment device (not shown) that is used to attach an annular abrasive disk **548** to the precision-flat platen **544** abrasive-disk mounting surface **536**. The abrasive disk **548** is in flat abrasive surface contact with all three of the workpieces **534**. The rotating floating platen **544** is driven through a spherical-action universal-joint type of device **538** having a platen drive shaft **540** to which is applied an abrasive contact force **542** to control the abrading pressure applied to the workpieces **534**. The workpiece rotary spindles **532** are mounted on a granite, or other material, base **552** that has a flat surface **554**. The three workpiece spindles **532** have spindle top surfaces that are co-planar. The workpiece spindles **532** can be interchanged or a new workpiece spindle **532** can be changed with an existing spindle **532** where the flat top surfaces of the spindles **532** are co-planar. Here, the equal-thickness workpieces **534** are in the same plane and are abraded uniformly across each individual workpiece **534** surface by the platen **544** precision-flat planar abrasive disk **548** abrading surface. The planar abrading surface **536** of the floating platen **544** is approximately co-planar with the flat surface **554** of the granite base **552**.

The spindle **532** rotating surfaces spindle tops **550** can driven by different techniques comprising spindle **532** internal spindle shafts (not shown), external spindle **532** flexible drive belts (not shown) and spindle **532** internal drive motors (not shown). The individual spindle **532** spindle tops **550** can be driven independently in both rotation directions and at a wide range of rotation speeds including very high speeds of 10,000 surface feet per minute (3,048 meters per minute). Typically the spindles **532** are air bearing spindles that are very stiff to maintain high rigidity against abrading forces and they have very low friction and can operate at very high rotational speeds. Suitable roller bearing spindles can also be used in place of air bearing spindles.

Abrasive disks (not shown) can be attached to the spindle **532** spindle tops **550** to abrade the platen **544** annular flat surface **536** by rotating the spindle tops **550** while the platen **544** flat surface **536** is positioned in abrading contact with the spindle abrasive disks that are rotated in selected directions and at selected rotational speeds when the platen **544** is rotated at selected speeds and selected rotation direction when applying a controlled abrading force **542**. The top surfaces **530** of the individual three-point spindle **532** rotating spindle tops **550** can be also be abraded by the platen **544** planar abrasive disk **548** by placing the platen **544** and the abrasive disk **548** in flat conformal contact with the top surfaces **530** of the workpiece spindles **532** as both the platen **544** and the spindle tops **550** are rotated in selected directions when an abrading pressure force **542** is applied. The top surfaces **530** of the spindles **532** abraded by the platen **544** results in all of the spindle **532** top surfaces **530** being in a common plane.

The granite base **552** is known to provide a time-stable precision-flat surface **554** to which the precision-flat three-point spindles **532** can be mounted. One unique capability provided by this abrading system **546** is that the primary datum-reference can be the fixed-position granite base **552** flat surface **554**. Here, spindles **532** can all have the precisely equal heights where they are mounted on a precision-flat surface **554** of a granite base **552** where the flat surfaces **530** of the spindle tops **550** are co-planar with each other.

When the abrading system is initially assembled it can provide extremely flat abrading workpiece **534** spindle **532** top **550** mounting surfaces and extremely flat platen **544** abrading surfaces **536**. The extreme flatness accuracy of the abrading system **546** provides the capability of abrading ultra-thin and large-diameter and high-value workpieces **534**, such as semiconductor wafers, at very high abrading speeds with a fully automated workpiece **534** robotic device (not shown).

In addition, the system **546** can provide unprecedented system **546** component flatness and workpiece abrading accuracy by using the system **546** components to “abrasively dress” other of these same-machine system **546** critical components such as the spindle tops **550** and the platen **544** planar-surface **536**. These spindle top **550** and the platen **544** annular planar surface **536** component dressing actions can be alternatively repeated on each other to progressively bring the system **546** critical components comprising the spindle tops **550** and the platen **544** planar-surface **536** into a higher state of operational flatness perfection than existed when the system **546** was initially assembled. This system **546** self-dressing process is simple, easy to do and can be done as often as desired to reestablish the precision flatness of the system **546** component or to improve their flatness for specific abrading operations.

This single-sided abrading system **546** self-enhancement surface-flattening process is unique among conventional floating-platen abrasive systems. Other abrading systems use floating platens but these systems are typically double-sided abrading systems. These other systems comprise slurry lapping and micro-grinding (flat-honing) systems that have rigid bearing-supported rotated lower abrasive coated platens. They also have equal-thickness flat-surfaced workpieces in flat contact with the annular abrasive surfaces of the lower platens. The floating upper platen annular abrasive surface is in abrading contact with these multiple workpieces where these multiple workpieces support the upper floating platen as it is rotated. The result is that the floating platens of these other floating platen systems are supported by a single-item moving-reference device, the rotating lower platen.

Large diameter rotating lower platens that are typically used for double-sided slurry lapping and micro-grinding (flat-honing) often have substantial abrasive-surface out-of-plane variations. These undesired abrading surface variations are due to many causes comprising: relatively compliant (non-stiff) platen support bearings that transmit or magnify bearing dimension variations to the outboard tangential abrading surfaces of the lower platen abrasive surface; radial and tangential out-of-plane variations in the large platen surface; time-dependent platen material creep distortions; abrading machine operating-temperature variations that result in expansion or shrinkage distortion of the lower platen surface; and the constant wear-down of the lower platen abrading surface by abrading contact with the workpieces that are in moving abrading contact with the lower platen abrasive surface. The single-sided abrading system **546** is completely different than the double-sided system (not-shown).

The floating platen **544** system **546** performance is based on supporting a floating abrasive platen **544** on the top surfaces **530** of three-point spaced fixed-position rotary workpiece spindles **532** that are mounted on a stable machine base **552** flat surface **554** where the top surfaces **530** of the spindles **532** are precisely located in a common plane. The top surfaces **530** of the spindles **532** can be approximately or substantially co-planar with the precision-flat surface **554** of a rigid fixed-position granite, or other material, base **552** or the top surfaces **530** of the spindles **532** can be precisely co-planar with the precision-flat surface **554** of a rigid fixed-position granite, or other material, base **552**. The three-point support is required to provide a stable support for the floating platen **544** as rigid components, in general, only contact each other at three points. As an option, additional spindles **532** can be added to the system **546** by attaching them to the granite base **552** at locations between the original three spindles **532**.

This three-point workpiece spindle abrading system **546** can also be used for abrasive slurry lapping (not shown), for micro-grinding (flat-honing) (not shown) and also for chemical mechanical planarization (CMP) (not shown) abrading to provide ultra-flat abraded workpieces **534**. Fig. 18 is an isometric view of three-point fixed-position spindles mounted on a granite base. A granite base **564** has a precision-flat top surface **556** that supports three attached workpiece spindles **562** that have rotatable driven tops **560** where flat-surfaced workpieces **558** are attached to the flat-surfaced spindle tops **560**.

Fig. 19 is a cross section view of three-point fixed-position spindles supporting a rotating floating abrasive platen. A floating circular platen **572** has a spherical-action rotating drive mechanism **578** having a drive shaft **588** where the platen **572** rotates about an axis **586**. Three workpiece spindles **594** (one not shown) having rotatable spindle tops **566** that have flat top surfaces **584** are mounted to the top precision-flat surface **590** of a machine base **596** that is constructed from granite, metal or composite or other materials. The flat top surfaces of the spindle tops **566** are all in a common plane **580** where the spindle plane **580** is precisely co-planar with the top flat surface **590** of the machine base **596**. Equal-thickness flat-surfaced workpieces **568** are attached to the spindle top **566** flat surfaces **584** by a vacuum, or other, disk attachment device where the top surfaces of the three workpieces **568** are mutually contacted by the abrading surface **582** of an annular abrasive disk **570** that is attached to the platen **572**. The platen **572** disk attachment surface **574** is precisely flat and the precision-thickness abrasive disk **570** annular abrasive surface **582** is precisely co-planar with the platen **572** disk attachment surface **574**. The annular abrasive surface **582** is precisely co-planar with the flat top surfaces of each of the three independent spindle top **566** flat surfaces **584** and also, co-planar with the spindle plane **580.** The floating platen **572** is supported by the three equally-spaced spindles **594** where the flat disk attachment surface **574** of the platen **572** is co-planar with the top surface **590** of the machine base **596**. The three equally-spaced spindles **594** of the three-point set of spindles **594** provide stable support to the floating platen **572**. The spherical platen **572** drive mechanism **578** restrains the platen **572** in a circular platen **572** radial direction. The spindle tops **566** are driven (not shown) in either clockwise or counterclockwise directions with rotation axes **576** and

592 while the rotating platen **572** is also driven. Typically, the spindle tops **566** are driven in the same rotation direction as the platen **572**. The workpiece spindle **594** tops **566** can be rotationally driven by motors (not shown) that are an integral part of the spindles **594** or the tops **566** can be driven by internal spindle shafts (not shown) that extend through the bottom mounting surface of the spindles **594** and into or through the granite machine base **596** or the spindles **594** can be driven by external drive belts (not shown).

Fig. 20 is a top view of three-point fixed-spindles supporting a floating abrasive platen. Workpieces **602** are attached to three rotatable spindles **598** where the workpieces **602** are in abrading contact with an annular band of abrasive **600** where the workpieces **602** overhang the outer periphery of the abrasive **600** by a distance **604** and overhang the inner periphery of the abrasive **600** by a distance **69f**. Each of the three spindles **598** are shown separated by an angle **606** of approximately 120 degrees to provide three-point support of the rotating platen (not shown) having an annular band of abrasive **600**.

Fig. 21 is an isometric view of fixed-abrasive coated raised islands on an abrasive disk. Abrasive particle **612** coated raised islands **614** are attached to an abrasive disk **610** backing **616**. Fig. 22 is an isometric view of a flexible fixed-abrasive coated raised island abrasive disk. Abrasive particle coated raised islands **618** are attached to an abrasive disk **622** backing **620**.

Fig. 23 is a cross section view of raised island structures on a disk that is used with water coolant to abrade a workpiece that is attached to a fixed-position rotary spindle. A disk **474** having attached raised island structures **642** is attached to the flat-surfaced abrading-surface **630** of a rotary platen **632** that has a spherical-action spherical device **640** that allows the platen **632** to float while the platen **632** is rotated about a platen **632** rotation axis **638**. A flat-surfaced workpiece **628** is attached to the flat surface of a rotary spindle **624** rotatable spindle-top **626**. The spindle **624** is attached to an abrading machine base **648** and the spindle-top **626** rotates about a spindle axis **634**. A liquid jet device **646** is attached to the machine base **648** and has a liquid stream of liquid droplets **644** where the liquid **644** comprises water, a slurry liquid that contains abrasive particles, including ceria, and chemicals including abrasive action enhancing chemicals and abrading agents including those used in chemical mechanical planarization (CMP) abrading processes.

Fig. 24 is a cross section view of a porous pad on a disk that is used with an abrasive-slurry to abrade a workpiece that is attached to a fixed-position rotary spindle. A disk **662** having an attached porous pad **668** is attached to the flat-surfaced abrading-surface **656** of a rotary platen **658** that has a spherical-action spherical device **666** that allows the platen **658** to float while the platen **658** is rotated about a platen **658** rotation axis **664**. A flat-surfaced workpiece **654** is attached to the flat surface of a rotary spindle **650** rotatable spindle-top **652**. The spindle **650** is attached to an abrading machine base **512** and the spindle-top **652** rotates about a spindle axis **660**. A liquid jet device **672** is attached to the machine base **512** and has a liquid stream of liquid droplets **670** where the liquid **670** comprises water, a slurry liquid that contains abrasive particles, including ceria, and chemicals including abrasive action enhancing chemicals and abrading agents including those used in chemical mechanical planarization (CMP) abrading processes.

Fig. 25 is an isometric view of a workpiece spindle having three-point mounting legs. The workpiece rotary spindle **684** has a rotary top **686** that has a precision-flat surface **688** to which is attached a precision-flat vacuum chuck device **678** that has co-planar opposed flat surfaces. A flat-surfaced workpiece **680** has an exposed flat surface **682** that is abraded by an abrasive coated platen (not shown). The workpiece spindle **684** is three-point supported by spindle legs **676**. The workpiece **680** shown here has a diameter of almost 12 inches (300 mm) and is supported by a spindle **684** having a 12 inch (300 mm) diameter and a rotary top **686** top flat surface **688** that has a diameter of 12 inches (300 mm). Fig. 26 is a top view of a workpiece spindle having multiple circular workpieces. A workpiece rotary spindle **694** having three-point support legs **690** where the spindle **694** supports small circular flat-surfaced workpieces **692** that are abraded by an abrasive coated platen (not shown). Fig. 27 is a top view of a workpiece spindle having multiple rectangular workpieces. A workpiece rotary spindle **698** having three-point support legs **700** where the spindle **698** supports small circular flat-surfaced workpieces **696** that are abraded by an abrasive coated platen (not shown). The spindle **698** has a spindle diameter **702**. Fig. 28 is a top view of multiple fixed-spindles that support a floating abrasive platen. A flat-surfaced granite base **708** supports multiple fixed-position air bearing spindles **704** that have rotating flat-surfaced tops **706**. The multiple spindles **704** support a floating abrasive platen (not shown) flat abrading surface on the multiple spindle top **706** flat surfaces that are all co-planar.

Fig. 29 is a top view of prior art pin-gear driven planetary workholders and workpieces on an abrasive platen. A rotating annular abrasive coated platen **718** and three planetary workholder disks, **722**, **728** and **710** that are driven by a platen **718** outer periphery pin-gear **716** and a platen **718** inner periphery pin-gear **714** are shown. Typically the outer periphery pin-gear **716** and the inner periphery pin-gear **714** are driven in opposite directions where the three planetary workholder disks **722**, **728** and **710** rotate about a workholder rotation axis **720** but maintain a stationary position relative to the platen **718** rotation axis **724** or they slowly rotate about the platen **718** rotation axis **724** as the platen **718** rotates about the platen rotation axis **724**. The outer pin-gears **716** and the inner pin-gears **714** rotate independently in either rotation direction and at different rotation speeds to provide different rotation speeds of the workholder disks **722**, **728** and **710** about the workholder rotation axes **720** and also to provide different rotation directions and speeds of the workholders disks **722**, **728** and **710** about the platen **718** rotation axis **724**. A single individual large-diameter flat-surfaced workpiece **712** is positioned inside the rotating workholder **710** and multiple small-diameter flat-surfaced workpieces **726** are positioned inside the rotating workholder **728**. The workholder **722** does not contain a workpiece.

Fig. 30 is a cross section view of prior art planetary workholders, workpieces and a double-sided abrasive platen. The abrading surface **732** of a rotating upper floating platen **740** and the abrading surface **754** of a rotating lower rigid platen **746** are in abrading contact with flat-surfaced workpieces **734** and **738**. A planetary workholder **730** contains a single large-sized workpiece **734** and the planetary workholder **744**contains multiple small-sized workpieces **738**. The planetary flat-surfaced workholder disks **730** and **744** rotate about a workholder axis **742** and the workholder disks **730** and **744** are driven by outer periphery pin-gears **756** and inner periphery pin-gears **748**. The inner periphery pin-gears **748** are mounted on a rotary drive spindle that has a spindle shaft **750**. The rigid-mounted lower platen **746** is supported by platen bearings **752**. The floating upper spindle **740** is driven by a spherical rotation device **736** that allows the platen **740** to be conformably supported by the equal-thickness workpieces **734** and **738** that are supported by the lower rigid platen **746**.

Fig. 31 is a cross section view of adjustable legs on a workpiece spindle. A rotary workpiece spindle **762** is attached to a granite base **774** by fasteners **770** that are used to bolt the spindle legs **760** to the granite base **774**. The spindle **762** has three equally spaced spindle legs **760** that are attached to the bottom portion of the spindle **762** where there is a space gap **764** between the bottom of the spindle and the flat surface **758** of the granite base **774**. The spindle **762** has a rotary spindle top **768** that rotates about a spindle axis **766** and the three spindle legs are height-adjusted to align the spindle axis

766 precisely perpendicular with the top surface **758** of the granite base **774**. To adjust the height of the spindle leg **760**, transverse bolts **772** are tightened to squeeze-adjust the spindle leg **760** where the spindle leg **760** distorts along the spindle axis **766** thereby raising the portion of the spindle **762** located adjacent to the transverse bolts **772** squeeze-adjusted spindle leg **760**. After the three spindle legs **760** are adjusted to provide the desired height of the top flat surface of the spindle top **768** and provide the perpendicular alignment of the spindle axis **766** perpendicular with the top surface **758** of the granite base **774**, the spindle hold-down attachment bolts **770** are torque-controlled tightened to attach the spindle **762** to the granite base **774**.

The hold-down bolts **770** can be loosened and the spindle **762** removed and the spindle **762** then brought back to the same spindle **762** location and position on the granite base **774** for re-mounting on the granite base **774** without affecting the height of the spindle top **768** or perpendicular alignment of the spindle axis **766** because the controlled compressive force applied by the hold-down bolts **770** does not substantially affect the desired size-height distortion of the spindle legs **760** along the spindle rotation axis **766**. The height adjustments provided by this adjustable spindle leg **760** can be extremely small, as little as 1 or 2 micrometers, which is adequate for precision alignment adjustments required for air bearing spindles **762** that are typically used for the fixed-spindle floating-platen abrasive system (not shown). Also, these spindle leg **760** height adjustments are dimensionally stable over long periods of time because the squeeze forces produced by the transverse bolts **772** do not stress the spindle leg **760** material past its elastic limit. Here, the spindle leg **760** acts as a compression-spring where the spindle leg **760** height can be reversibly changed by changing the force applied by the transverse bolts **772** which is changed by changing the tightening-torque that is applied to these threaded transverse bolts **772**.

Fig. 32 is a cross section view of an adjustable spindle leg. A spindle leg **778** has transverse tightening bolts **782** that compress the spindle leg **778** along the axis of the transverse bolts **290**. Spindle (not shown) hold-down bolts **780** are threaded to engage threads (not shown) in the granite base **776** but the compressive action applied on the spindle leg **778** by the hold-down bolts **780** along the axis of the hold-down bolt **780** is carefully controlled in concert with the compressive action of the transverse bolts **782** to provide the desired distortion of the spindle leg **778** along the axis of the hold-down bolts **780**.

Fig. 33 is a cross section view of a compressed adjustable spindle leg. A spindle leg **788** has transverse tightening bolts **794** that compress the spindle leg **788** along the axis of the transverse bolts **794** by a distortion amount **790**. Spindle (not shown) hold-down bolts **792** are threaded to engage threads (not shown) in the granite base **784** but the compressive action applied on the spindle leg **788** by the hold-down bolts **792** along the axis of the hold-down bolt **792** is carefully controlled in relationship with the compressive action of the transverse bolts **794** on the spindle leg **788** to provide the desired distortion **796** of the spindle leg **788** along the axis of the hold-down bolts **792**. The transverse bolts **794** create a transverse squeezing distortion **790** that is present on the spindle leg **788** and this transverse distortion **790** produces the desired height distortion **796** of the spindle leg **788**. When the spindle leg **788** is distorted by the amount **796**, the spindle is raised away from the surface **786** of the granite base **784** by this distance amount **796**.

Fig. 34 is an isometric view of a compressed adjustable spindle leg. A spindle leg **808** has transverse tightening bolts **802** that compress the spindle leg **800** along the axis of the transverse bolts **802**. The spindle **806** has attached spindle legs **808** that have spindle hold-down bolts **810** that are threaded to engage threads (not shown) in the granite base **814**. The compressive action applied on the spindle leg **808** by the hold-down bolts **810** along the axis of the hold-down bolt **810** is carefully controlled in concert with the compressive action of the transverse bolts **802** to provide the desired distortion **816** of the spindle leg **808** along the axis of the hold-down bolts **810**. The transverse bolts **802** create a transverse squeezing distortion that is present on the spindle leg **808** and this transverse distortion produces the desired height distortion **816** of the spindle leg **808**. When the spindle leg **808** is distorted by the amount **816**, the spindle **806** is raised away from the surface **812** of the granite base **814** by this distance amount **816**. A spindle leg **808** integral flat-base **818** having a distortion-isolation wall **798** provides flat-contact of the spindle leg **808** with the flat surface **812**of the granite base **814**. The distortion-curvature **800** of the spindle leg **808** is shown where the spindle leg **808** leg-base **818** remains flat where it contacts the granite base **814** flat surface **812**. A narrow but stiff bridge section **804** that is an integral portion of the spindle leg **808** isolates the spindle leg **808** distortion **816** from the body of the spindle **806**.

Internal Motor Driven Spindle

Fig. 35 is a cross section view of a recessed workpiece spindle driven by an internal motor. A rotary workpiece air bearing spindle **854** is mounted on a machine base **852** with spindle legs **844** that are attached to the spindle **854** body. The spindle **854** has a flat-surfaced spindle-top **834** that rotates about a spindle axis **840** where the spindle-top **834** has a flat top surface **842**. The spindle-top **834** has a hollow spindle shaft **856** that is driven by an internal motor armature **838** that is driven by an electrical motor winding **836**. The spindle **854** is recessed into the machine base **852** because the spindle **854** support legs **844** are attached to the spindle **854** body near the top of the spindle **854**. The spindle **854** is attached to a spherical rotor **846** with fasteners **832** where the rotor **846** is mounted in a spherical base **848** that is attached to the machine base **852**. After co-planar alignment of spindle-tops **834** with other spindle-tops **834** (not shown), the spherical rotor **846** is locked to the spherical base **848** with fasteners **850**. This spindle **854** spherical mount system comprising the rotor **846** and base **848,** allows inexpensive, but dimensionally stable, machine bases having non-precision flat top surfaces to be used to mount the spindles **854** where the spindle-tops **834** can be precisely aligned to be co-planar with each other.

Here, the separation-line **858** between the spindle-top **834** and the spindle **854** body is a close distance from the spindle **854** mounting surface of the machine base **852**. Because the separation distance is short, heat from the motor electrical winding **836** that tends to thermally expand the length of the spindle **854** is minimized and the there is little thermally-induced vertical movement of the spindle-top **834** due to the motor heat. Also, the pressurized air that is supplied to the air bearing spindle **854** expands as it travels through the spindle **854** which lowers the temperature of the spindle air. This cool spindle air exits the spindle body at the separation line **858** where it cools the spindle **854** internally and at the interface between the spindle-top **834** and the spindle **854** which reduces the thermal-expansion effects from the heat generated by the electrical internal motor windings **836**. Thermal growth in the length of the spindles **854** tends to be equal for all three spindles **854** used in the fixed-spindle floating platen abrading systems (not shown). Any spindle **854** thermal distortion effects are uniform across all of the system spindles **854** and there is little affect on the abrading process because the floating abrasive platen simply contacts all of these same-expanded spindles **854** in a three-point contact stance. When the spindles **854** are mounted where the bottom of the spindle **854** extends below the surface of the machine base **852** the effect of the thermal growth of the spindles **854** along the spindle length is diminished.

The spindles **854** are attached to spherical rotors **846** that are mounted in a spherical base **848** where pressurized air or a liquid **822** can be applied through a fluid passageways **820** to allow the spherical rotor **846** to float without friction in the spherical base **848** when the spindle-tops **834** (others not shown) are aligned to be co-planar in a common plane after which vacuum **824** can be applied through fluid passageways **820** to lock the spherical rotor **846** to the spherical base **848** and fasteners **850** can be used to attach the spherical rotor **846** to the spherical base **848**. The spherical rotor **846** and the spherical base **848** have a mutually common spherical diameter. Another technique of locking the spherical rotor **846** to the spherical base **848** after the spindle-tops **834** are aligned to be co-planar is to apply a liquid adhesive **828** in the gap between a removable bracket **830** that is attached to the spherical rotor **846** and a removable bracket **826** that is attached to the spherical base **848** where the liquid adhesive **828** becomes solidified and provides structural locking attachment of the spherical rotor **846** to the spherical base **848**. For future co-planar realignment of the spindle-tops **834** to be co-planar, the brackets **830** and **826** that are adhesively bonded together can be removed by detaching them from the rotor **846** and the housing base **848** and other individual replacement brackets **830** and **826** can be attached to the rotor **846** and the housing base **848**. Then, when the spindle-tops **834** are aligned to be co-planar an adhesive **828** is applied in the gap between a removable bracket **830** that is attached to the spherical rotor **846** and a removable bracket **826** that is attached to the spherical base **848** to bond the spherical rotor **846** to the spherical base **848**.

The spindle-tops **834** can be aligned to be co-planar with the use of measurement instruments (not shown) or with the use of laser alignment devices (not shown). Also, a very simple technique that can be used for co-planar alignment of the spindle-tops **834** is to bring a precision-flat surface of a floating platen (not shown) annular abrading surface into flat surfaced contact with the spindle-tops **834** where pressurized air or a liquid **822** can be applied through a fluid passageways **820** to form a spherical-action fluid bearing that allows the spherical rotor **846** to float without friction in the spherical base **848**. Here, the spindle-tops **834** are aligned to be co-planar in a common plane after which vacuum **824** can be applied through fluid passageways **820** to lock the spherical rotor **846** to the spherical base **848**. If desired, pressurized air can be applied to the internal passageways (not shown) connected to the spindle-tops **834** flat surfaces during the procedure of co-planar alignment of the spindle-tops **834**. This is done to reduce the friction between the spindle-tops **834** and the platen abrading surface which provides assurance that the spindle-tops **834** and the platen abrading surface are mutually in flat contact with each other. After co-planar alignment of the spindle-tops **834**, vacuum can be applied to these spindle-tops **834** flat surfaces to temporarily bond the spindle-tops **834** to the platen before or while vacuum **824** is applied through fluid passageways **820** to lock the spherical rotor **846** to the spherical base **848**. Then, when the spindle-tops **834** are aligned to be co-planar, an adhesive **828** is applied in the gap between a removable bracket **830** that is attached to the spherical rotor **846** and a removable bracket **826** that is attached to the spherical base **848** to rigidly bond the spherical rotor **846** to the spherical base **848**.

This same technique of applying fluid pressure and vacuum to the fluid passageways **820** to form a spherical-action fluid bearing that allows the spherical rotor **846** to float without friction in the spherical base **848** can be used with the fasteners **850** to attach the spherical rotor **846** to the spherical base **848**. Another alternative, but closely related, spindle-tops **834** co-planar alignment technique is to apply pressurized fluid and then vacuum to vacuum abrasive mounting holes in the platen abrading surface to perform the procedure of co-planar alignment of the spindle-tops. Those abrasive disk vacuum holes in the platen that are not in contact with the spindle-tops **834** are temporarily plugged using adhesive tape or by other means during the spindle-tops **834** co-planar alignment procedure.

Fig. 36 is a cross section view of a workpiece spindle driven by a fluid cooled internal motor. A spindle **864** has a flat-surfaced rotary spindle-top **872** where the spindle-top **872** is rotated about a spindle axis **870**. The spindle **864** is mounted on a machine base **860** by fasteners that attach spindle support legs **862** that are attached to the spindle **864** body to the machine base **860**. The spindle-top **872** is driven by a hollow shaft **880** that is driven by a motor armature **868** that is driven by an internal motor winding **866**. The spindle-top **872** hollow drive shaft **880** has an attached hollow shaft **886** that has an attached to a stationary rotary union **884** that is coupled to a vacuum source **882** that supplies vacuum to the spindle-top **872**. A water or coolant jacket **874** is shown wrapped around the spindle **864** body where the water jacket **874** has temperature-controlled coolant water **876** that enters the water jacket **874** and exits the water jacket as exit water **878** where the water **876** cools the spindle **864** to remove the heat generated by the motor windings **866** to prevent thermal distortion of the spindle **864** and thermal displacement of the spindle-top **872**.

Fig. 37 is a cross section view of a workpiece spindle driven by an external motor. A spindle **894** having a flat-surfaced spindle-top **892** that rotates about a spindle axis **890** is mounted to a machine base **888**. An external motor **904** drives the spindle-top **892** with a bellows-type drive coupler **896** that allows slight misalignments between the motor **904** rotation axis and the spindle-top **892** axis of rotation **890**. The bellows-type coupler **896** provides stiff torsional load capabilities for accelerating or decelerating the spindle-top **892**. A rotary union device **902** supplies vacuum **900** to the spindle-top **892** through a flexible tube **898**. The motor **904** is attached to the machine base **888** with motor brackets **906**.

Fig. 38 is a cross section view of a workpiece spindle with a spindle top debris guard. A cylindrical workpiece spindle **908** has a rotary top **916** that rotates about a spindle axis **914** where the spindle top **916** has a circumferential separation line **912** that separates the spindle top **916** from the spindle **908** base **920**. Where these spindles **908** are used in abrading atmospheres, water mist, abrading debris and very small sized abrasive particles are present in the atmosphere surrounding the spindle **908**. To prevent entry of this debris, water moisture and abrasive particles in the spindle **908** separation line **912** area, a circumferential drip-shield **910** is provided where the drip shield **910** has a drip lip **918**that extends below the separation line **912**. Unwanted debris material and water simply drips off the surface of the drip shield **910**. Build-up of debris matter on the drip shield **910** is typically avoided because of the continued presence of abrasive coolant water that continually washes the surface of the drip shield **910**. When the workpiece spindles **908** are used in abrading processes, often special chemical additives are added to the coolant water to enhance the abrading action on workpieces (not shown) in abrading procedures such as chemical mechanical planarization. Both the cylindrical spindle **908** cylindrical drip shields **910** and the spindles **908** are constructed from materials that are resistant to materials comprising water coolants, chemical additives, abrading debris and abrasive particles.

<u>Automated Workpiece and Abrasive Disk Loader</u>

Fig. 39 is a top view of an automatic robotic workpiece loader for multiple spindles. An automated robotic device **938** has a rotatable shaft **936** that has an arm **934** to which is connected a pivot arm **932** that, in turn, supports another pivot arm **944**. A pivot joint **942** joins pivot arms **944** and **932** and pivot joint **940** joins pivot arms **932** and **934**. A workpiece carrier holder **948** attached to the pivot arm **944** holds a workpiece carrier **950** that contains a workpiece **922** where the robotic device **938** positions the workpiece **922** and carrier **950** on and concentric with the workpiece rotary spindle **946**. Other workpieces **926** and carriers **924** are shown on a moving workpiece transfer belt **930** where they are picked up by the carrier holder **928**. The workpieces

922 and **926** and workpiece carriers **950**, **924** can also be temporarily stored in other devices comprising cassette storage devices (not shown). The workpieces **922**, **926** and workpiece carriers **950**, **924** can also be removed from the spindles **946** after the workpieces **950**, **924** are abraded and the workpieces **922**, **926** and workpiece carriers **950**, **924** can then be placed in or on a moving belt (not shown) or a cassette device (not shown). The workpieces **922**, **926** can also optionally be loaded directly on the spindles **946** without the use of the workpiece carriers **950**, **924**. Access for the robotic device **938** is provided in the open access area between two wide-spaced adjacent spindles **946**.

Fig. 40 is a side view of an automatic robotic workpiece loader for multiple spindles. An automated workpiece loader device **960** (partially shown) can be used to load workpieces **958, 966** onto spindles **968** that have spindle tops that have flat surfaces **952** and where the spindle tops rotate about the spindle axis **956**. A floating platen **964** that is rotationally driven by a spherical-action device **962** has an annular abrasive surface **954** that contacts the equal-thickness workpieces **958** and **966** where the platen **964** is partially supported by abrading contact with the three independent three-point spindles **968** and the abrading pressure on the workpieces **958** and **966** is controlled by controlled force-loading of the spherical action device **962**. The spindles **968** are supported by a granite machine base **970**.

Fig. 41 is a top view of an automatic robotic abrasive disk loader for an upper platen. An automated robotic device **986** has a rotatable shaft **984** that has an arm **982** to which is connected a pivot arm **988** that, in turn, supports another pivot arm **990**. An abrasive disk carrier holder **992** attached to the pivot arm **990** holds an abrasive disk carrier **974** that contains an abrasive disk **976** where the robotic device **986** positions the abrasive disk **976** and disk carrier **974** on and concentric with the platen **972**. Another abrasive disk **978** and abrasive disk carrier plate **980** are shown in a remote location where the abrasive disk **978** can also be temporarily stored in other devices comprising cassette storage devices (not shown). Guide or stop devices (not shown) can be used to aid concentric alignment of the abrasive disk **976** and the platen **972** and the robotic device can position the abrasive disk **976** in flat conformal contact with the flat-surfaced platen **972** after which, vacuum (not shown) is applied to attach the disk **976** to the platen **972** flat abrading surface (not shown). Then the pivot arms **990**, **988** and **982** and the carrier holder **238** and the disk carrier **974** are translated back to a location away from the platen **972**.

Fig. 42 is a side view of an automatic robotic abrasive disk loader for an upper platen. An automated robotic device **1014** (partially shown) has a carrier holder plate **996** that has an attached resilient annular disk support pad **1012** that supports an abrasive disk **1004** that has an abrasive layer **998**. The abrasive disk carrier holder **996** that contains an abrasive disk **1004** is moved where the robotic device **1014** positions the abrasive disk **1004** and disk carrier **996** on to and concentric with the platen **1010**. The resilient layer pad **1012** on the carrier holder **996** allows the back-disk-mounting side of the abrasive disk **1004** to be in flat conformal contact with the platen **1010** abrading surface **1008** before the vacuum **1000** is activated. The platen has vacuum **1000** that is applied through vacuum port holes **1002** to attach the abrasive disk **1004** to the abrading surface **1008** of the platen **1010**. The floating platen **1010** is driven rotationally by a spherical action device **1006** to allow the floating platen **1010** abrading surface **1008** to be in flat contact with equal-thickness flat-surface workpieces (not shown) that are attached with flat surface contact to the flat top rotating component **994** of three three-point spindles **1016** (one not shown) that are mounted on a granite base **1018**. After the abrasive disk **1004** is attached to the platen **1010** the robotic device **1014** carrier holder **996** is withdraw from the platen **1010** area.

Co-Planar Aligned Workpiece Spindles

Fig. 43 is an isometric view of three-point co-planar aligned workpiece spindles that have a spindle-common plane where the spindles are mounted on a granite machine base. Three spindles **1032** having rotary spindle-tops **1020** that have spindle-top **1020** rotational center points **1034** where all of the spindle-tops **1020** flat surfaces **1026** are co-planar as represented by a planar surface **1022**. The spindles **1032** are mounted on a machine base **1024**. The spindles **1032** are attached to the flat surface **1030** of a granite, or other base material, base **1028**.

Fig. 44 is a top view of three-point center-position laser aligned rotary workpiece spindles on a granite base. Three-point spindles **1052** are mounted on a machine base **1046** where a rotary laser device **1054** having a rotary laser head **1042** that sweeps a laser beam **1036** in a laser plane circle **1040**. The rotary laser **1054** is mounted on the machine base **1046** at a central position between the three spindles **1052** to minimize the laser beam **1036** distance between the rotary laser head **1042** and the reflective laser mirror targets **1038** that are mounted on the spindles **1052** spindle-top flat surfaces **1050**. The spindles **1052** spindle-top **1048** surfaces **1050** are aligned to be co-planar with the use of the rotary-beam laser device **1054** to form a spindle-top **1048** alignment plane **1044**

Three fixed-position rotary workpiece spindles **1052** hat are mounted on a granite base are shown being aligned with a L-740 Ultra Precision Leveling Laser **1042** provided by Hamar Laser of Danbury, CT. This laser device **1042** has a flatness alignment capability that is approximately three times better than the desired 0.0001 inch (2.5 micron) co-planar spindle-top alignment that is required for high speed flat lapping. Reflective laser mirrors **1038** are attached to the flat top surfaces **1050** of the spindle-tops **1048** to reflect a laser beam **1036** that is emitted by the rotating laser head **1042** back to a laser device **1054** sensor (not shown) The rotary laser device **1054** can be mounted at a central position between the three spindles **1052** to minimize the distance between the reflective mirrors **1038** and the rotating laser beam **1036** laser device **1054** laser head **1042** source. Each spindle **1052** is independently tilt-adjusted to attain this precision co-planar alignment of the spindle-tops **1048** flat surfaces **1050** prior to structurally attaching the spindles **1052** to the granite base **1056**. The spindle-tops **1048** alignments are retained for long periods of time because of the dimensional stability of the granite base **1056**. The spindles **1052** can be attached directly to the granite base **1056** or they can be attached to spindle **1052** spherical-action spindle mounts (not shown) after the spindle-tops **1048** are aligned to be co-planar to each other.

Fig. 45 is an isometric view of an air bearing spindle mounted laser co-planar spindle top alignment device. An air bearing rotary alignment spindle **1088** is mounted on a granite lapper machine base **1078** having a flat surface **1076** where the rotary alignment spindle **1088** is positioned at the center of the machine base **1078**. Rotary workpiece spindles **1060** having rotary spindle-tops **1062** are located at the outer periphery of the circular shaped machine base **1078** where these workpiece spindles **1060** are positioned with near-equal distances between them and they surround the alignment spindle **1088**. A laser sensor arm **1066** is attached to the top flat surface **1073** of the rotary alignment spindle **1088** spindle-top **1086** where the rotary spindle-top **1086** of the alignment spindle **1088** can be rotated to selected positions.

Three laser distance sensors **1064** are shown attached to the laser sensor arm **1066** where the laser distance sensors **1064** can be used to measure the precise laser span distance between the laser sensor **1064** bottom laser sensor end (not shown) and targets **1068**, **1080**, **1082** located on the flat surfaces **1070** of the workpiece spindle-tops **1062**. One or more of the three laser distance sensors **1064** can also be used to measure the precise laser span distances to select targets **1074** that are located on the flat surface **1076** of the machine base **1078**. The select targets **1074** that are located on the flat surface **1076** of the machine base **1078** are typically aligned in a line that extends radially from the center of the machine base **1078** so that the laser span distances of all three select targets **1074** can be measured simultaneously by the distance measuring sensors **1064**. The laser sensor arm **1066** that is attached to the top flat surface **1073** of the rotary alignment spindle **1088** spindle-top **1086** can be rotated to align the laser distance sensors **1064** with the selected measurement targets **1068**, **1080**, **1082** located on the surfaces **1070** of the workpiece spindle-tops **1062** and also to be aligned with targets **1074** that are located on the flat surface **1076** of the machine base **1078**.

Commercial air bearing alignment spindles **1088** that are suitable for precision co-planar alignment of the workpiece spindles **1060** spindle-tops **1062** flat surfaces **1070** are available from Nelson Air Corp, Milford, NH. Air bearing spindles are preferred for this co-planar alignment procedure but suitable rotary flat-surfaced alignment spindles **1088** having conventional roller bearings can also be used. These air bearing alignment spindles **1088** typically provide spindle top **1086** flat surface **1073** flatness accuracy of 5 millionths of an inch (0.13 microns) but can have spindle top **1086** flat surface **1073** flatness accuracies of only 2 millionths of an inch (0.05 microns). These alignment spindle **1088** flatness accuracies are more than adequate to co-planar align the workpiece spindles **1060** spindle-tops **1062** flat surfaces **1070** within the 0.0001 inches (3 microns) required for high speed flat lapping. In addition, the air bearing alignment spindles **1088** are also very stiff for resisting any torsion loads imposed by overhanging the laser sensor arm **1066** past the peripheral edge of the alignment spindles **1088** which prevents deflection of the sensor **1064** end of the laser sensor arm **1066** during all phases of the procedure for co-planar alignment of all the individual workpiece spindles **1060** spindle-tops **1062** flat surfaces **1070**.

Typically three workpiece spindles **1060** are used for a lapper machine but more than three workpiece spindles **1060** can be attached to the machine base **1078** and be co-planar aligned using this alignment system. The preferred distance sensors **1064** are laser sensors but they can also be mechanical distance measurement sensors **1064** such as micrometers and also can be ultrasonic distance sensors **1064**.

The procedure for co-planar alignment of the workpiece spindle's **1060** spindle-tops **1062** flat surfaces **1070** includes attaching the alignment spindle **1088** to the machine base **1078** flat surface **1076** and attaching the laser sensing arm **1066** having the distance sensors **1064** to the alignment spindle **1088** rotary spindle top **1086** flat surface **1073**. Then the laser sensing arm **1066** is rotated to select target positions **1074** on the machine base **1078** and laser span distance measurements are made between the ends of the laser sensors **1064** and the select target positions **1074** on the machine base **1078** to adjust the heights of the rotary alignment spindle **1088** support legs **1084** where the top flat surface **1073** of the rotary spindle-top **1086** of the alignment spindle **1088** is aligned to be co-planar with the top flat surface **1076** of the granite, metal or epoxy-granite machine base **1078**.

Each of the workpiece spindles **1060** spindle-tops **1062** flat surfaces **1070** are individually aligned to be co-planar aligned with the top flat surface **1073** of the rotary spindle-top **1086** of the alignment spindle **1088** by adjusting the height of the workpiece spindle **1060** support legs **1058**. The co-planar alignment of the workpiece spindles **1060** spindle-tops **1062** flat surfaces **1070** is done by making distance measurements from the ends of the laser sensors **1064** to selected targets **1068**, **1080**, **1082** on the flat surfaces **1070** of the workpiece spindles **1060** spindle-tops **1062**. The laser sensing arm **1066** is rotated to align the laser sensors **1064** with the selected targets **1068**, **1080**, **1082** on the flat surfaces **1070** of the workpiece spindles **1060** spindle-tops **1062** by manually rotating the rotary spindle-top **1086** of the alignment spindle **1088**. When all of the individual workpiece spindles **1060** spindle-tops **1062** flat surfaces **1076** are individually aligned to be co-planar aligned with the with the top flat surface **1073** of the rotary spindle-top **1086** of the alignment spindle **1088**, the alignment spindle **1088** is removed from the machine base **1078**. This co-planar alignment of the workpiece spindle's **1060** spindle-tops **1062** flat surfaces **1070** can be done periodically to re-establish or verify the accuracy of the workpiece spindles **1060** co-planar alignment. The workpiece spindles **1060** spindle tops **1062** rotate about a spindle tops **1062** target point **1068** that is located at the geometric centers of the spindle-tops **1062**.

The three workpiece spindles **1060** are mounted on the flat surface **1076** of the machine base **1078** where the rotational axis **1077** of the spindle tops **1062** intersects a target point **1068** and where the rotational axes **1077** of the spindle tops **1062** intersect a spindle-circle **1065** where the spindle-circle **1065** is coincident with the machine base **1078** nominally-flat top surface **1076**.

Fig. 46 is a top view of an air bearing spindle mounted laser co-planar spindle top alignment device. An air bearing rotary alignment spindle **1100** is mounted on a granite lapper machine base **1093** having a flat surface **1096** where the rotary alignment spindle

1100 is positioned at the center of the machine base **1093**. Rotary workpiece spindles **1091** having flat surfaces **1090** are located at the outer periphery of the circular shaped machine base **1093** where these workpiece spindles **1091** are positioned with near-equal distances between them and they surround the alignment spindle **1100**. A laser sensor arm **1106** is attached to the rotary alignment spindle **1100** spindle-top **1097** where the rotary spindle-top **1097** of the alignment spindle **1100** can be rotated to selected positions.

Three laser distance sensors **1108** are shown attached to the laser sensor arm **1106** where the laser distance sensors **1108** having respective laser beam axes **1110** can be used to measure the precise laser span distance between the laser sensor **1108** bottom laser sensor end (not shown) and targets **1104** located on the flat surfaces **1090** of the workpiece spindle's **1091** spindle-tops **1103**. One or more of the three laser distance sensors **1108** can also be used to measure the precise laser span distances to select targets **1092** that are located on the flat surface **1096** of the machine base **1093**. The select targets **1092** that are located on the flat surface **1096** of the machine base **1093** are typically aligned in a line that extends radially from the center of the machine base **1093** so that the laser span distances of all three select targets **1092** can be measured simultaneously by the distance measuring sensors **1108**.

The laser sensor arm **1106** that is attached to the top flat surface of the rotary alignment spindle **1100** spindle-top **1097** can be rotated to align the laser distance sensors **1108** with the selected measurement targets **1104** located on the surfaces of the workpiece spindles **1091** spindle-tops **1103** and also to be aligned with targets **1092** that are located on the flat surface **1096** of the machine base **1093**. The laser sensor arm **1106** is shown also in an alternative measurement location as laser sensor arm **1098**. Each of the workpiece spindles **1091** have height adjustable support legs **1094** that are adjusted in height to align the workpiece spindle-tops **1103** to be co-planar with the alignment spindle **1100** spindle-top flat surface **1105**. Also, the alignment spindle **1100** has height adjustable support legs **1102** that are adjusted in height to align the flat top surface **1105** of the alignment spindle **1100** spindle-tops **1097** to be co-planar with the granite base **1093** flat surface **1096**. The three workpiece spindles **1091** are mounted on the flat surface **1096** of the machine base **1093** where the rotational axes of the spindle tops **1103** that intersects the spindle tops **1103** rotation-center target point **1104** intersects a spindle-circle **1095** where the spindle-circle **1095** is coincident with the machine base **1093** nominally-flat top surface **1096**.

Fig. 47 is a cross section view of an air bearing spindle mounted laser co-planar spindle top alignment device. An air bearing rotary alignment spindle **1122** is mounted on a granite lapper machine base **1128** having a flat surface where the rotary alignment spindle **1122** is positioned at the center of the machine base **1128**. Rotary workpiece spindles **1134** having flat surfaces are located at the outer periphery of the circular or rectangular shaped machine base **1128** where these workpiece spindles **1134** are positioned with near-equal distances between them and they surround the alignment spindle **1122**. A laser sensor arm **1116** is attached to the rotary alignment spindle **1122** spindle-top **1120** where the rotary spindle-top **1120** of the alignment spindle **1122** can be rotated about an axis **1118** to selected positions.

Three laser distance sensors **1114** are shown attached to the laser sensor arm **1116** where the laser distance sensors **1114** having respective laser beam axes **1113** can be used to measure the precise laser span distance **1112** between the laser sensor **1114** bottom laser sensor end **1131** and targets **1133** located on the flat surfaces of the workpiece spindle's **1134** spindle-tops **1132**. One or more of the three laser distance sensors **1114** can also be used to measure the precise laser span distances to select targets that are located on the flat surface of the machine base **1128**. The select targets that are located on the flat surface of the machine base **1128** are typically aligned in a line that extends radially from the center of the machine base **1128** so that the laser span distances of all three select targets can be measured simultaneously by the distance measuring sensors **1114**.

The laser sensor arm **1116** that is attached to the top flat surface of the rotary alignment spindle **1122** spindle-top **1120** can be rotated to align the laser distance sensors **1114** with the selected measurement targets **1133** located on the surfaces of the workpiece spindles **1134** spindle-tops **1132** and also to be aligned with targets that are located on the flat surface of the machine base **1128**. Each of the workpiece spindles **1134** have height adjustable support legs **1124** that are adjusted in height to align the top flat surfaces of the workpiece spindle-tops **1132** to be co-planar in a plane **1130** with the alignment spindle **1122** spindle-top flat surface. Also, the alignment spindle **1122** has height adjustable support legs that are adjusted in height to align the flat top surface of the alignment spindle **1122** spindle-top **1120** to be co-planar with the granite base **1128** flat top surface.

The workpiece spindles **1134** are rotated about an axis **1126** to incremental positions or the workpiece spindles **1134** are rotated about an axis **1126** at rotational speeds when the laser span distances **1112** are measured to provide span distance **1112** measurements having improved-accuracy dynamic readings by averaging multiple target **1133** points on the circumference of the spindle-tops **1132** as the spindle-tops **1132** are rotated. The granite construction material of the machine base **1128** provides long term dimensional stability and rigidity that allows the workpiece spindle's **1134** spindle-tops **1132** precision co-planar alignment to be maintained over long periods of time even when the workpiece spindles **1134** spindle are subjected to abrading forces during flat lapping operations.

Fig. 48 is a cross section view of an air bearing spindle mounted laser arm used to align the alignment spindle device. An air bearing rotary alignment spindle **1146** is mounted on a granite lapper machine base **1152** having a flat top surface **1141** where the rotary alignment spindle **1146** is positioned at the center of the machine base **1152**. Rotary workpiece spindles **1150** having flat rotary surfaces are located at the outer periphery of the circular or rectangular shaped machine base **1152** where these workpiece spindles **1150** are positioned with near-equal distances between them and they surround the alignment spindle **1146**. A laser sensor arm **1140** is attached to the rotary alignment spindle **1146** spindle-top **1144** where the rotary spindle-top **1144** of the alignment spindle **1146** can be rotated about an axis **1142** to selected positions.

Three laser distance sensors **1138** are shown attached to the laser sensor arm **1140** where the laser distance sensors **1138** having respective laser beam axes **1137** can be used to measure the precise laser span distance **1136** between the laser sensors **1138** bottom laser sensor ends **1153** and targets **1154** located on the flat surface **1141** of the machine base **1152**. The select targets **1154** that are located on the flat surface **1141** of the machine base **1152** are typically aligned in a line that extends radially from the center of the machine base **1152** so that the laser span distances **1136** of all three select targets can be measured simultaneously by the respective three distance measuring sensors **1138**.

The laser sensor arm **1140** that is attached to the top flat surface of the rotary alignment spindle **1146** spindle-top **1144** can be rotated manually or by a rotation drive device (not shown) about the axis **1142** to align the laser distance sensors **1138** with the selected measurement targets **1154** that are located on the flat top surface **1141** of the machine base **1152**. The alignment spindle **1146** has height-adjustable support legs **1148** that are adjusted in height to align the flat top surface of the alignment spindle **1146** spindle-top **1144** to be co-planar with the granite base **1152** flat top surface **1141**.

Fig. 49 is a cross section view of an elevated air bearing spindle mounted laser spindle alignment device. An air bearing rotary alignment spindle **1162** is mounted on a granite lapper machine base **1170** having a flat surface where the rotary alignment spindle **1162** is positioned at the center of the machine base **1170**. Rotary workpiece spindles **1176** having flat surfaces are located at the outer periphery of the circular or rectangular shaped machine base **1170** where these workpiece spindles **1176** are positioned with near-equal distances between them and they surround the alignment spindle **1162**. A laser sensor arm **1160** is attached to the rotary alignment spindle **1162** spindle-top **1165** where the rotary spindle-top **1165** of the alignment spindle **1162** can be rotated about an axis **1164** to selected positions.

Three laser distance sensors **1158** are shown attached to the laser sensor arm **1160** where the laser distance sensors **1158** having respective laser beam axes can be used to measure the precise laser span distance **1156** between the laser sensor **1158** bottom laser sensor end and targets **1174** located on the flat surfaces of the workpiece spindle's **1176** spindle-tops **1172**. One or more of the three laser distance sensors **1158** can also be used to measure the precise laser span distances to select targets that are located on the flat surface of the machine base **1170**. The select targets that are located on the flat surface of the machine base **1170** are typically aligned in a line that extends radially from the center of the machine base **1170** so that the laser span distances of all three select targets can be measured simultaneously by the distance measuring sensors **1158**.

The laser sensor arm **1160** that is attached to the top flat surface of the rotary alignment spindle **1162** spindle-top **1165** can be rotated to align the laser distance sensors **1158** with the selected measurement targets **1174** located on the surfaces of the workpiece spindles **1176** spindle-tops **1172** and also to be aligned with targets that are located on the flat surface of the machine base **1170**. Each of the workpiece spindles **1176** have spherical-action spindle mounts **1168** that are rotated to align the top flat surfaces of the workpiece spindle-tops **1172** to be co-planar in a plane **1171** that is offset by a distance **1166** and is parallel to the alignment spindle **1162** spindle-top flat surface. Also, the alignment spindle **1162** has spherical-action spindle mounts **1168** that are rotated to align the flat top surface of the alignment spindle **1162** spindle-top **1165** to be co-planar with the granite base **1170** flat top surface.

The workpiece spindles **1176** are rotated about an axis **1167** to incremental positions or the workpiece spindles **1176** are rotated about an axis **1167** at rotational speeds when the laser span distances **1156** are measured to provide span distance **1156** measurements having improved-accuracy dynamic readings by averaging multiple target **1174** points on the circumference of the spindle-tops **1172** as the spindle-tops **1172** are rotated. The granite construction material of the machine base **1170** provides long term dimensional stability and rigidity that allows the workpiece spindle's **1176** spindle-tops **1172** precision co-planar alignment to be maintained over long periods of time even when the workpiece spindles **1176** spindle are subjected to abrading forces during flat lapping operations.

Fig. 50 is a top view of a spherical-action mounted air bearing spindle laser co-planar spindle top alignment device. An air bearing rotary alignment spindle **1208** is mounted on a granite lapper machine base **1186** having a flat surface **1190** where the rotary alignment spindle **1208** is positioned at the center of the machine base **1186**. Rotary workpiece spindles **1180** having flat surfaces **1178** are located at the outer periphery of the circular shaped machine base **1186** where these workpiece spindles **1180** are positioned with near-equal distances between them and they surround the alignment spindle **1208**. A laser sensor arm **1202** is attached to the rotary alignment spindle **1208** spindle-top **1192** where the rotary spindle-top **1192** of the alignment spindle **1208** can be rotated to selected positions.

Three laser distance sensors **1204** are shown attached to the laser sensor arm **1202** where the laser distance sensors **1204** having respective laser beam axes **1206** can be used to measure the precise laser span distance between the laser sensor **1204** bottom laser sensor end (not shown) and targets **1200** located on the flat surfaces **1178** of the workpiece spindle's **1180** spindle-tops **1198**. One or more of the three laser distance sensors **1204** can also be used to measure the precise laser span distances to select targets **1184** that are located on the flat surface **1190** of the machine base **1186**. The select targets **1184** that are located on the flat surface **1190** of the machine base **1186** are typically aligned in a line that extends radially from the center of the machine base **1186** so that the laser span distances of all three select targets **1184** can be measured simultaneously by the distance measuring sensors **1204**.

The laser sensor arm **1202** that is attached to the top flat surface of the rotary alignment spindle **1208** spindle-top **1192** can be rotated to align the laser distance sensors **1204** with the selected measurement targets **1200** located on the surfaces of the workpiece spindles **1180** spindle-tops **1198** and also to be aligned with targets **1184** that are located on the flat surface **1190** of the machine base **1186**. The laser sensor arm **1202** is shown also in an alternative measurement location as laser sensor arm **1194**.

Each of the workpiece spindles **1180** is mounted on a spherical-action spindle mount **1188** that can be adjusted by spherical rotation to align the workpiece spindle-top's **1198** flat surfaces **1178** to be co-planar with the alignment spindle **1208** spindle-top flat surface **1201**. Also, the alignment spindle **1208** is mounted on a spherical-action spindle mount **1196** that can be adjusted by spherical rotation to align the flat top surface **1201** of the alignment spindle **1208** spindle-tops **1192** to be co-planar with the granite base **1186** flat surface **1190**. The three workpiece spindles **1180** are mounted on the flat surface **1190** of the machine base **1186** where the rotational axes of the spindle tops **1198** that intersects the spindle tops **1198** rotation-center target point **1200** intersects a spindle-circle **1182** where the spindle-circle **1182** is coincident with the machine base **1186** nominally-flat top surface **1190**.

Pivot-Balanced Floating-Platen System Description

The pivot-balance floating-platen lapping system has many unique features, configurations and operational procedures. The basic system is an at least three-point, fixed-spindle floating-platen abrading machine comprising:

a) at least three rotary spindles having rotatable flat-surfaced spindle-tops that each have a spindle-top axis of rotation at the center of a respective rotatable flat-surfaced spindle-top for respective rotary spindles;

b) wherein the at least three spindle-tops' axes of rotation are perpendicular to the respective spindle-tops' flat surfaces;

c) an abrading machine base having a horizontal nominally-flat top surface and a spindle-circle where the spindle-circle is coincident with the machine base nominally-flat top surface;

d) wherein the at least three rotary spindles are located with near-equal spacing between the respective at least three of the rotary spindles where the respective at least three spindle-tops' axes of rotation intersect the machine base spindle-circle and where the respective at least three rotary spindles are mechanically attached to the machine base;

e) wherein the at least three spindle-tops' flat surfaces can be aligned to be co-planar with each other;

f) a rotatable floating abrading platen having a flat annular abrading surface where the floating abrading platen is supported by and is rotationally driven about a floating abrading platen cylindrical-rotation axis located at a cylindrical-rotation center of the floating abrading platen and perpendicular to the rotatable floating abrading platen flat annular abrading surface by a spherical-action rotation device located coincident with the cylindrical-rotation axis of the floating abrading platen where the floating abrading platen spherical-action rotation device restrains the floating abrading platen in a radial direction relative to the floating abrading platen cylindrical-rotation axis where the floating abrading platen cylindrical-rotation axis is nominally concentric with and perpendicular to the machine base spindle-circle where the floating abrading platen spherical-action rotation device has a spherical center of rotation that is coincident with the floating abrading platen cylindrical-rotation axis where the floating abrading platen has a center of mass that is coincident with the floating abrading platen cylindrical-rotation axis;

g) wherein the floating abrading platen spherical-action rotation device allows spherical motion of the floating abrading platen about the floating abrading platen spherical-action rotation device spherical center of rotation where the flat annular abrading surface of the floating abrading platen that is supported by the floating abrading platen spherical-action rotation device is nominally horizontal; and

h) a pivot frame that has a pivot frame pivot center, a pivot frame floating abrading platen end and a pivot frame floating abrading platen drive motor end where the pivot frame can rotate about a pivot frame rotation axis that intersects the pivot frame pivot center where the pivot frame rotation axis is perpendicular to the length of the pivot frame that extends from the pivot frame floating abrading platen end to the pivot frame floating abrading platen drive motor end where the pivot frame has one or more low friction pivot frame rotation bearings that are concentric with the pivot frame rotation axis;

i) a platen drive motor that is attached to the pivot frame on the pivot frame floating abrading platen drive motor end and a counterbalance weight that is attached to the pivot frame on the pivot frame floating abrading platen drive motor end and a right-angle gearbox having a hollow output platen drive shaft where the right-angle gearbox is attached to the pivot frame on the pivot frame floating abrading platen end and where the floating abrading platen is attached to the pivot frame on the pivot frame floating abrading platen end and where the floating abrading platen spherical-action rotation device is attached to the pivot frame on the pivot frame floating abrading platen end;

j) where the floating abrading platen drive motor is connected to and rotates a platen drive motor drive shaft that is attached to and rotates a right-angle gearbox input drive shaft where the right-angle gearbox hollow output platen drive shaft is attached to a universal joint that is attached to a floating abrading platen rotary drive shaft that rotates the floating abrading platen;

k) where the floating abrading platen drive motor and the counterbalance weight are positioned on the pivot frame floating abrading platen drive motor end to act as a counterbalance to the right-angle gearbox, the rotatable floating abrading platen and the floating abrading platen spherical-action rotation device that are positioned on the pivot frame floating abrading platen end wherein the pivot frame is nominally balanced about the pivot frame pivot rotation axis;

l) flexible abrasive disk articles having annular bands of abrasive coated surfaces where a selected flexible abrasive disk is attached in flat conformal contact with the floating abrading platen flat annular abrading surface such that the attached abrasive disk is concentric with the floating abrading platen flat annular abrading surface;

m) wherein equal-thickness workpieces having parallel opposed flat workpiece top surfaces and flat workpiece bottom surfaces are attached to the respective at least three spindle-tops where the flat workpiece bottom surfaces are in flat-surfaced contact with the flat surfaces of the respective at least three spindle-tops;

n) an elevation frame that supports the pivot frame at the pivot frame pivot center where the elevation frame is attached to a linear slide device that is attached to the abrading machine base wherein the elevation frame can be raised and lowered by an elevation frame lift device;

o) wherein the floating abrading platen can be moved vertically by activating the lift frame lift device to allow the abrasive surface of the flexible abrasive disk that is attached to the floating abrading platen flat annular abrading surface to contact the top surfaces of the workpieces that are attached to the flat surfaces of the respective at least three spindle-tops wherein the at least three rotary spindles provide at least three-point support of the floating abrading platen and wherein the floating abrading platen spherical-action rotation device allows spherical motion of the floating abrading platen about the floating abrading platen spherical-action rotation device spherical center of rotation to provide uniform abrading contact of the abrasive surface of the flexible abrasive disk with the respective workpieces;

p) a pivot frame locking device that is attached to both the pivot frame and the pivot frame lift frame where the pivot frame locking device can be activated to lock the pivot frame that is rotated about the pivot frame rotation axis at selected pivot frame rotated position;

q) an abrading contact force device that is attached to both the pivot frame and the pivot frame lift frame where the abrading contact force device can apply an abrading contact force to the pivot frame wherein the pivot frame tends to be rotated about the pivot frame pivot rotation axis where the abrading contact force device applies an abrading contact force to the pivot frame and the pivot frame applies the abrading contact force to the floating abrading platen spherical-action rotation device that is attached to the pivot frame wherein the applied abrading contact force is applied to the floating abrading platen by the floating abrading platen spherical-action rotation device and the applied abrading contact force is applied to the workpieces by the floating abrading platen;

r) wherein the total floating abrading platen abrading contact force applied to workpieces that are attached to the respective at least three spindle-top flat surfaces by contact of the abrasive surface of the flexible abrasive disk that is attached to the floating abrading platen flat annular abrading surface with the top surfaces of the workpieces is controlled through the floating abrading platen spherical-action floating abrading platen rotation device to allow the total floating abrading platen abrading contact force to be evenly distributed to the workpieces attached to the respective at least three spindle-tops; and

s) wherein the at least three spindle-tops having attached equal-thickness workpieces can be rotated about the respective spindle-tops' rotation axes and the floating abrading platen having the attached flexible abrasive disk can be rotated about the floating abrading platen cylindrical-rotation axis to single-side abrade the workpieces that are attached to the flat surfaces of the at least three spindle-tops while the moving abrasive surface of the flexible abrasive disk that is attached to the moving floating abrading platen flat annular abrading surface is in force-controlled abrading contact with the top surfaces of the workpieces that are attached to the respective at least three spindle-tops.

The basic pivot-balance floating-platen lapping system utilizes flexible abrasive disks where each flexible abrasive disk is attached in flat conformal contact with the floating abrading platen flat annular abrading surface by disk attachment techniques selected from the group consisting of vacuum disk attachment techniques, mechanical disk attachment techniques and adhesive disk attachment techniques. Also, the basic lapping system uses dimensionally stable machine bases where the machine base structural material is selected from the group consisting of granite, epoxy-granite, cast iron and steel and wherein the machine base structural material and the machine base structural material is either solid or is temperature controlled by a temperature-controlled fluid that circulates in fluid passageways that are internal to the machine base structural materials. Here, at least three rotary spindles are typically air bearing rotary spindles to provide the precision rotary spindle spindle-top flatness that is required for high speed flat lapping of workpieces.

Further, pivot-balance floating-platen lapping system can utilize an air bearing spherical-action rotation device having a spherical-action rotation device air bearing rotor that supports the floating abrading platen and the abrading platen spherical-action rotation device has a spherical-action rotation device air bearing housing that is attached to the pivot frame where pressurized air is supplied to the air bearing spherical-action rotation device air bearing housing to create a friction-free air film that is positioned between the spherical-action rotation device air bearing rotor and the spherical-action rotation device air bearing housing to allow friction-free spherical rotation of the spherical-action rotation device air bearing rotor. Also, the floating abrading platen spherical-action rotation device can be a roller bearing having spherical-action rotation capabilities where the roller bearing spherical-action rotation device has a spherical-action rotation device roller bearing rotor that supports the floating abrading platen and the abrading platen spherical-action rotation device has a spherical-action rotation device roller bearing housing that is attached to the pivot frame to allow spherical rotation of the spherical-action rotation device air bearing rotor.

In addition, the pivot-balance floating-platen lapping system can utilize pivot frame abrading contact force devices that are selected from the group consisting of air cylinders, air bearing air cylinders, hydraulic cylinders, electric solenoid devices and piezo-electric devices wherein a force sensor can be attached to the pivot frame abrading contact force device to measure the magnitude of the abrading contact force that is applied by the pivot frame abrading contact force device to the pivot frame. Here, the pivot frame locking devices can be selected from the group consisting of hydraulic cylinders, electric solenoid devices and friction brake devices and where the pivot frame locking device can also have the capability to provide vibration damping of the pivot frame.

In particular, the pivot frame locking device can be a hydraulic cylinder comprising:

a) a cylinder body, a cylinder body external surface, a cylinder body internal portion, two cylinder internal hydraulic chambers, a hydraulic by-pass tube, nominally-incompressible non-air-entrained hydraulic fluid that completely fills the cylinder internal hydraulic chambers and fills the hydraulic by-pass tube;

b) a movable linear translating cylinder rod, the cylinder rod having a cylinder rod attachment end and a cylinder rod piston end, a cylinder hydraulic rod seal, a cylinder body rod end and a cylinder body mounting base end where a movable cylinder piston that is positioned internally in the cylinder body internal portion has hydraulic fluid contact with the hydraulic fluid contained in the two cylinder hydraulic chambers and the movable cylinder piston is attached to the cylinder rod piston end;

c) where a cylinder rod end internal hydraulic chamber extends from the cylinder piston to the cylinder rod end of the cylinder and where a cylinder mounting base internal hydraulic chamber extends from the cylinder piston to the cylinder mounting base end of the cylinder where the cylinder piston acts as a hydraulic seal between the cylinder rod end internal hydraulic chamber and the cylinder mounting base internal hydraulic chamber;

d) wherein the cylinder rod has an integral rod section that is located internal to the cylinder body and has an integral rod section that extends external to the cylinder body external surface where the cylinder rod extends continuously from the cylinder piston past a cylinder hydraulic rod seal located at the cylinder body cylinder rod end to the cylinder rod attachment end wherein the cylinder rod attachment end can be attached to the pivot frame;

e) wherein a by-pass tube having an integral by-pass hydraulic shut-off valve and an integral adjustable hydraulic metering valve allows hydraulic fluid to pass between the cylinder rod end internal hydraulic chamber and the cylinder mounting base end internal hydraulic chamber as the moving cylinder rod and the cylinder piston that is attached to the cylinder rod is translated relative to the external surface of the cylinder;

f) wherein the integral by-pass hydraulic shut-off valve can be operated manually or operated by electrical devices such as an electric solenoid and the integral adjustable hydraulic metering valve can be adjusted manually or operated by electrical devices such as an electric screw device;

g) wherein by closing the by-pass hydraulic shut-off valve, the nominally-incompressible hydraulic fluid can not pass between the cylinder rod end internal hydraulic chamber and the cylinder mounting base internal hydraulic chamber with the result that the cylinder piston and the cylinder rod are locked in place relative to the cylinder body and the pivot frame that is attached to the cylinder rod attachment end can not be rotated and is locked in place by the hydraulic cylinder pivot frame locking device.

Also, the pivot frame hydraulic cylinder locking device can be used to limit the rotational speed of the pivot frame and to attenuate vibrations of the pivot frame comprising:

a) where the hydraulic by-pass tube integral adjustable hydraulic metering valve has an adjustable hydraulic flow orifice that acts as a hydraulic fluid flow restriction device that can restrict the flow of hydraulic fluid in the hydraulic by-pass tube as the hydraulic fluid passes between the cylinder rod end internal hydraulic chamber and the cylinder mounting base end internal hydraulic chamber as the moving cylinder rod is translated relative to the external surface of the cylinder body;

b) whereby, when the hydraulic metering valve hydraulic flow orifice is adjusted to be fully open, the hydraulic metering valve hydraulic flow orifice allows the moving hydraulic fluid in the hydraulic by-pass tube to pass freely between the cylinder rod end internal hydraulic chamber and the cylinder mounting base end internal hydraulic chamber of the cylinder as the moving cylinder rod is translated relative to the external surface of the cylinder body;

c) whereby, when the hydraulic metering valve hydraulic flow orifice is adjusted to be partially closed to act as a hydraulic fluid flow restriction device, the fluid orifice provides a hydraulic flow restriction to the moving hydraulic fluid in the hydraulic by-pass tube as hydraulic fluid passes between the cylinder rod end internal hydraulic chamber and the cylinder mounting base end internal hydraulic chamber as the moving cylinder rod is translated relative to the external surface of the cylinder body;

d) whereby, when the hydraulic metering valve hydraulic flow orifice is adjusted to be partially closed, a hydraulic damping force is generated by restricting the flow of the hydraulic fluid as it passes between the cylinder rod end internal hydraulic chamber and the cylinder mounting base end internal hydraulic chamber as the moving cylinder rod and the cylinder piston that is attached to the cylinder rod is translated relative to the external surface of the cylinder wherein the respective hydraulic damping force is applied to the cylinder piston in a direction that opposes the movement of the cylinder rod that is moved by the rotation motion of the pivot frame wherein the rotation motion of the pivot frame is slowed by the respective hydraulic damping force and wherein rotation oscillations of the pivot frame are resisted by hydraulic damping forces that are applied to the cylinder piston in directions that oppose the oscillating movement of the cylinder rod that is moved by the oscillating rotation motion of the pivot frame wherein the rotation motion of the pivot frame is slowed by the respective hydraulic damping forces.

The basic pivot-balance floating-platen lapping system can utilize components where the elevation frame is raised and lowered by a elevation frame lift device where the elevation frame lift device is selected from the group consisting of electric motor driven screw jack lift devices and a hydraulic lift device where the elevation frame lift device can have a elevation frame lift device vertical position sensor that can be used to sense the vertical position of the elevation frame whereby the elevation frame lift device vertical position sensor can be used to control the position of the elevation frame and whereby where the elevation frame lift device vertical position sensor can be used to indirectly control the position of the floating abrading platen abrasive coating relative to the workpieces that are attached to the rotary workpiece spindles. Further, one or more universal joints can be attached to a floating abrading platen idler drive shaft that is used to couple the right-angle gearbox hollow output platen drive shaft to the floating abrading platen rotary drive shaft that rotates the floating abrading platen where the universal joints can be selected from the group consisting of conventional universal joints, plate-type universal joints and constant velocity universal joints.

In addition, a rotary union device can be attached to the right-angle gearbox hollow output platen drive shaft to provide vacuum to the right-angle gearbox hollow output platen drive shaft wherein a flexible vacuum tube can be attached to the right-angle gearbox hollow output platen drive shaft and also attached to the floating abrading platen rotary drive shaft to provide a vacuum passageway from the right-angle gearbox hollow output platen drive shaft to the floating abrading platen rotary drive shaft where vacuum passages within the floating abrading platen are routed to the floating abrading platen flat annular abrading surface such that a flexible abrasive disk can be attached to the floating abrading platen by the vacuum supplied by the rotary union device.

Further, a spherical action locking device can be used to lock the floating abrading platen spherical-action rotation device to prevent spherical rotation of the floating abrading platen spherical-action rotation device which prevents spherical rotation of the floating abrading platen whereby the floating abrading platen is locked in a selected spherical-rotation position.

Another variation is where a floating abrading platen spherical action locking device is an integral part of a floating abrading platen air bearing spherical-action rotation device having a spherical-action rotation device air bearing rotor that supports the floating abrading platen and the abrading platen spherical-action rotation device has a spherical-action rotation device air bearing housing that is attached to the pivot frame where pressurized air is supplied to the air bearing spherical-action rotation device air bearing housing to create a friction-free air film that is positioned between the spherical-action rotation device air bearing rotor and the spherical-action rotation device air bearing housing to allow friction-free spherical rotation of the spherical-action rotation device air bearing rotor and friction-free spherical rotation of the floating abrading platen and wherein vacuum that is supplied to the air bearing spherical-action rotation device spherical-action rotation device air bearing housing can lock the spherical-action rotation device air bearing rotor to the spherical-action rotation device air bearing housing whereby the floating abrading platen is locked in a selected spherical-rotation position.

In another configuration, the basic pivot-balance floating-platen lapping system can have a floating abrading platen spherical action locking device that is a mechanical brake device comprising:

a) a mechanical brake rotor having a spherical brake rotor surface that has a spherical center of rotation that coincides with the floating abrading platen spherical-action rotation device spherical center of rotation;

b) where the floating abrading platen spherical action locking device mechanical brake device has a mechanical brake pad having a spherical brake pad surface that has a spherical center of rotation that coincides with the floating abrading platen spherical-action rotation device spherical center of rotation;

c) wherein the spherical radius of the mechanical brake device mechanical brake pad is nominally equal to the spherical radius of the mechanical brake device mechanical brake rotor; and

d) where the floating abrading platen spherical-action rotation device mechanical brake pad can be moved along an axis that intersects the floating abrading platen spherical-action rotation device spherical center of rotation by a floating abrading platen anti-rotation braking force device into forced contact with the floating abrading platen spherical-action rotation device mechanical brake rotor to lock the floating abrading platen spherical-action rotation device mechanical brake pad to the floating abrading platen spherical-action rotation device mechanical brake rotor to prevent spherical rotation of the floating abrading platen spherical-action rotation device which prevents spherical rotation of the floating abrading platen spherical-action rotation device mechanical brake rotor;

e) whereby the floating abrading platen spherical-action rotation device is locked in a selected spherical-rotation position whereby the floating abrading platen is locked in a selected spherical-rotation position.

Also, the floating abrading platen spherical-action rotation device mechanical brake pad can be moved from a position that is separated from the floating abrading platen spherical action locking device mechanical brake rotor into braking contact with the floating abrading platen spherical action locking device mechanical brake rotor by a floating abrading platen anti-rotation braking force device selected from the group consisting of air cylinders, spring-return air cylinders, hydraulic cylinders, electric solenoid devices and piezo-electric devices wherein the anti-rotation braking force device can be activated to move the floating abrading platen spherical action locking device mechanical brake pad manually or by electrical devices into braking contact with the floating abrading platen spherical action locking device mechanical brake rotor.

In addition, the basic pivot-balance floating-platen lapping system can be configured where the center of mass of the floating abrading platen is less than 2 inches from the spherical center of rotation of the floating abrading platen spherical-action rotation device. Also, the lapping system can be configured where the center of mass of the floating abrading platen is less that 0.5 inches from the spherical center of rotation of the floating abrading platen spherical-action rotation device and further, where it is even less than 0.25 inches from the spherical center of rotation of the floating abrading platen spherical-action rotation device.

WHAT IS CLAIMED:

1. An at least three-point, fixed-spindle floating-platen abrading machine comprising:

a) at least three rotary spindles having rotatable flat-surfaced spindle-tops that each have a spindle-top axis of rotation at the center of a respective rotatable flat-surfaced spindle-top for each respective rotary spindles;

b) wherein the at least three spindle-tops' axes of rotation are perpendicular to the respective spindle-tops' flat surfaces;

c) an abrading machine base having a horizontal, nominally-flat top surface and a spindle-circle where the spindle-circle is coincident with the machine base nominally-flat top surface;

d) wherein the at least three rotary spindles are located with near-equal spacing between the respective at least three of the rotary spindles where the respective at least three spindle-tops' axes of rotation intersect the machine base spindle-circle and where the respective at least three rotary spindles are mechanically attached to the machine base;

e) wherein the at least three spindle-tops' flat surfaces are adjustably alignable to be co-planar with each other;

f) a rotatable floating abrading platen having a flat annular abrading surface where the floating abrading platen is supported by and is rotationally driven about a floating abrading platen cylindrical-rotation axis located at a cylindrical-rotation center of the floating abrading platen and perpendicular to the rotatable floating abrading platen flat annular abrading surface by a spherical-action rotation device located coincident with the cylindrical-rotation axis of the floating abrading platen where the floating abrading platen spherical-action rotation device restrains the floating abrading platen in a radial direction relative to the floating abrading platen cylindrical-rotation axis where the floating abrading platen cylindrical-rotation axis is nominally concentric with and perpendicular to the machine base spindle-circle where the floating abrading platen spherical-action rotation device has a spherical center of rotation that is coincident with the floating abrading platen cylindrical-rotation axis where the floating abrading platen has a center of mass that is coincident with the floating abrading platen cylindrical-rotation axis;

g) wherein the floating abrading platen spherical-action rotation device allows spherical motion of the floating abrading platen about the floating abrading platen spherical-action rotation device spherical center of rotation where the flat annular abrading surface of the floating abrading platen that is supported by the floating abrading platen spherical-action rotation device is nominally horizontal; and

h) a pivot frame that has a pivot frame pivot center, a pivot frame floating abrading platen end and a pivot frame floating abrading platen drive motor end where the pivot frame rotates about a pivot frame rotation axis that intersects the pivot frame pivot center where the pivot frame rotation axis is perpendicular to the length of the pivot frame that extends from the pivot frame floating abrading platen end to the pivot frame floating abrading platen drive motor end where the pivot frame comprises a –low friction pivot frame rotation bearing that is concentric with the pivot frame rotation axis;

i) a platen drive motor is attached to the pivot frame on the pivot frame floating abrading platen drive motor end and a counterbalance weight is attached to the pivot frame on the pivot frame floating abrading platen drive motor end, and a right-angle gearbox having a hollow output platen drive shaft is attached to the pivot frame on the pivot frame floating abrading platen end and the floating abrading platen is attached to the pivot frame on the pivot frame floating abrading platen end and the floating abrading platen spherical-action rotation device is attached to the pivot frame on the pivot frame floating abrading platen end;

j) the floating abrading platen drive motor is connected to and rotates a platen drive motor drive shaft attached to and rotates a right-angle gearbox input drive shaft and the right-angle gearbox hollow output platen drive shaft is attached to a universal joint attached to a floating abrading platen rotary drive shaft that rotates the floating abrading platen;

k) wherein the floating abrading platen drive motor and the counterbalance weight are positioned on the pivot frame floating abrading platen drive motor end to act as a counterbalance to the right-angle gearbox, the rotatable floating abrading platen and the floating abrading platen spherical-action rotation device that are positioned on the pivot frame floating abrading platen end wherein the pivot frame is nominally balanced about the pivot frame pivot rotation axis;

l) flexible abrasive disk articles having annular bands of abrasive coated surfaces where a selected flexible abrasive disk is attached in flat conformal contact with the floating abrading platen flat annular abrading surface such that the attached abrasive disk is concentric with the floating abrading platen flat annular abrading surface;

m) wherein equal-thickness workpieces having parallel opposed flat workpiece top surfaces and flat workpiece bottom surfaces are attached to the respective at least three spindle-tops where the flat workpiece bottom surfaces are in flat-surfaced contact with the flat surfaces of the respective at least three spindle-tops;

n) an elevation frame that supports the pivot frame at the pivot frame pivot center where the elevation frame is attached to a linear slide device that is attached to the abrading machine base wherein the elevation frame can be raised and lowered by an elevation frame lift device;

o) wherein the floating abrading platen can be moved vertically by activating the lift frame lift device to allow the abrasive surface of the flexible abrasive disk that is attached to the floating abrading platen flat annular abrading surface to contact the top surfaces of the workpieces that are attached to the flat surfaces of the respective at least three spindle-tops wherein the at least three rotary spindles provide at least three-point support of the floating abrading platen and wherein the floating abrading platen spherical-action rotation device allows spherical motion of the floating abrading platen about the floating abrading platen spherical-action rotation device spherical center of rotation to provide uniform abrading contact of the abrasive surface of the flexible abrasive disk with the respective workpieces;

p) a pivot frame locking device that is attached to both the pivot frame and the pivot frame lift frame where the pivot frame locking device can be activated to lock the pivot frame that is rotated about the pivot frame rotation axis at selected pivot frame rotated position;

q) an abrading contact force device that is attached to both the pivot frame and the pivot frame lift frame where the abrading contact force device can apply an abrading contact force to the pivot frame wherein the pivot frame tends to be rotated about the pivot frame pivot rotation axis where the abrading contact force device applies an abrading contact force to the pivot frame and the pivot frame applies the abrading contact force to the floating abrading platen spherical-action rotation device that is attached to the pivot frame wherein the applied abrading contact force is applied to the floating abrading platen by the floating abrading platen spherical-action rotation device and the applied abrading contact force is applied to the workpieces by the floating abrading platen;

r) wherein the total floating abrading platen abrading contact force applied to workpieces that are attached to the respective at least three spindle-top flat surfaces by contact of the abrasive surface of the flexible abrasive disk that is attached to the floating abrading platen flat annular abrading surface with the top surfaces of the workpieces is controlled through the floating abrading platen spherical-action floating abrading platen rotation device to allow the total floating abrading platen abrading contact force to be evenly distributed to the workpieces attached to the respective at least three spindle-tops; and

s) wherein the at least three spindle-tops having attached equal-thickness workpieces can be rotated about the respective spindle-tops' rotation axes and the floating abrading platen having the attached flexible abrasive disk can be rotated about the floating abrading platen cylindrical-rotation axis to single-side abrade the workpieces that are attached to the flat surfaces of the at least three spindle-tops while the moving abrasive surface of the flexible abrasive disk that is attached to the moving floating abrading platen flat annular abrading surface is in force-controlled abrading contact with the top surfaces of the workpieces that are attached to the respective at least three spindle-tops.

2. The machine of claim 1 wherein each flexible abrasive disk is attached in flat conformal contact with the floating abrading platen flat annular abrading surface by disk attachment techniques selected from the group consisting of vacuum disk attachment techniques, mechanical disk attachment techniques and adhesive disk attachment techniques.

3. The machine of claim 1 wherein the machine base structural material is selected from the group consisting of granite, epoxy-granite, cast iron and steel and wherein the machine base structural material and the machine base structural material is either solid or is temperature controlled by a temperature-controlled fluid that circulates in fluid passageways internal to the machine base structural materials.

4. The machine of claim 1 wherein the at least three rotary spindles are air bearing rotary spindles.

5. The machine of claim 1 wherein the floating abrading platen spherical-action rotation device is an air bearing spherical-action rotation device having a spherical-action rotation device air bearing rotor that supports the floating abrading platen and the abrading platen spherical-action rotation device has a spherical-action rotation device air bearing housing that is attached to the pivot frame where pressurized air is supplied to the air bearing spherical-action rotation device air bearing housing to create a friction-free air film that is positioned between the spherical-action rotation device air bearing rotor and the spherical-action rotation device air bearing housing to allow friction-free spherical rotation of the spherical-action rotation device air bearing rotor.

6. The machine of claim 1 wherein the floating abrading platen spherical-action rotation device is a roller bearing having spherical-action rotation capabilities where the roller bearing spherical-action rotation device has a spherical-action rotation device roller bearing rotor that supports the floating abrading platen and the abrading platen spherical-action rotation device has a spherical-action rotation device roller bearing housing that is attached to the pivot frame to allow spherical rotation of the spherical-action rotation device air bearing rotor.

7. The machine of claim 1 wherein the pivot frame abrading contact force devices are selected from the group consisting of air cylinders, air bearing air cylinders, hydraulic cylinders, electric solenoid devices and piezo-electric devices wherein a force sensor can be attached to the pivot frame abrading contact force device to measure the magnitude of the abrading contact force that is applied by the pivot frame abrading contact force device to the pivot frame.

8. The machine of claim 1 wherein the pivot frame locking device is selected from the group consisting of hydraulic cylinders, electric solenoid devices and friction brake devices and where the pivot frame locking device can also have the capability to provide vibration damping of the pivot frame.

9. The machine of claim 8 wherein the pivot frame locking device is a hydraulic cylinder comprising:

a) a cylinder body, a cylinder body external surface, a cylinder body internal portion, two cylinder internal hydraulic chambers, a hydraulic by-pass tube, nominally-incompressible non-air-entrained hydraulic fluid that completely fills the cylinder internal hydraulic chambers and fills the hydraulic by-pass tube;

b) a movable linear translating cylinder rod, the cylinder rod having a cylinder rod attachment end and a cylinder rod piston end, a cylinder hydraulic rod seal, a cylinder body rod end and a cylinder body mounting base end where a movable cylinder piston that is positioned internally in the cylinder body internal portion has hydraulic fluid contact with the hydraulic fluid contained in the two cylinder hydraulic chambers and the movable cylinder piston is attached to the cylinder rod piston end;

c) where a cylinder rod end internal hydraulic chamber extends from the cylinder piston to the cylinder rod end of the cylinder and where a cylinder mounting base internal hydraulic chamber extends from the cylinder piston to the cylinder mounting base end of the cylinder where the cylinder piston acts as a hydraulic seal between the cylinder rod end internal hydraulic chamber and the cylinder mounting base internal hydraulic chamber;

d) wherein the cylinder rod has an integral rod section that is located internal to the cylinder body and has an integral rod section that extends external to the cylinder body external surface where the cylinder rod extends continuously from the cylinder piston past a cylinder hydraulic rod seal located at the cylinder body cylinder rod end to the cylinder rod attachment end wherein the cylinder rod attachment end can be attached to the pivot frame;

e) wherein a by-pass tube having an integral by-pass hydraulic shut-off valve and an integral adjustable hydraulic metering valve allows hydraulic fluid to pass between the cylinder rod end internal hydraulic chamber and the cylinder mounting base end internal hydraulic chamber as the moving cylinder rod and the cylinder piston that is attached to the cylinder rod is translated relative to the external surface of the cylinder;

f) wherein the integral by-pass hydraulic shut-off valve can be operated manually or operated by electrical devices such as an electric solenoid and the integral adjustable hydraulic metering valve can be adjusted manually or operated by electrical devices such as an electric screw device;

g) wherein by closing the by-pass hydraulic shut-off valve, the nominally-incompressible hydraulic fluid can not pass between the cylinder rod end internal hydraulic chamber and the cylinder mounting base internal hydraulic chamber with the result that the cylinder piston and the cylinder rod are locked in place relative to the cylinder body and the pivot frame that is attached to the cylinder rod attachment end can not be rotated and is locked in place by the hydraulic cylinder pivot frame locking device.

10. The machine of claim 9 wherein the pivot frame hydraulic cylinder locking device can be used to limit the rotational speed of the pivot frame and to attenuate vibrations of the pivot frame comprising:

a) where the hydraulic by-pass tube integral adjustable hydraulic metering valve has an adjustable hydraulic flow orifice that acts as a hydraulic fluid flow restriction device that can restrict the flow of hydraulic fluid in the hydraulic by-pass tube as the hydraulic fluid passes between the cylinder rod end internal hydraulic chamber and the cylinder mounting base end internal hydraulic chamber as the moving cylinder rod is translated relative to the external surface of the cylinder body;

b) whereby, when the hydraulic metering valve hydraulic flow orifice is adjusted to be fully open, the hydraulic metering valve hydraulic flow orifice allows the moving hydraulic fluid in the hydraulic by-pass tube to pass freely between the cylinder rod end internal hydraulic chamber and the cylinder mounting base end internal hydraulic chamber of the cylinder as the moving cylinder rod is translated relative to the external surface of the cylinder body;

c) whereby, when the hydraulic metering valve hydraulic flow orifice is adjusted to be partially closed to act as a hydraulic fluid flow restriction device, the fluid orifice provides a hydraulic flow restriction to the moving hydraulic fluid in the hydraulic by-pass tube as hydraulic fluid passes between the cylinder rod end internal hydraulic chamber and the cylinder mounting base end internal hydraulic chamber as the moving cylinder rod is translated relative to the external surface of the cylinder body;

d) whereby, when the hydraulic metering valve hydraulic flow orifice is adjusted to be partially closed, a hydraulic damping force is generated by restricting the flow of the hydraulic fluid as it passes between the cylinder rod end internal hydraulic chamber and the cylinder mounting base end internal hydraulic chamber as the moving cylinder rod and the cylinder piston that is attached to the cylinder rod is translated relative to the external surface of the cylinder wherein the respective hydraulic damping force is applied to the cylinder piston in a direction that opposes the movement of the cylinder rod that is moved by the rotation motion of the pivot frame wherein the rotation motion of the pivot frame is slowed by the respective hydraulic damping force and wherein rotation oscillations of the pivot frame are resisted by hydraulic damping forces that are applied to the cylinder piston in directions that oppose the oscillating movement of the cylinder rod that is moved by the oscillating rotation motion of the pivot frame wherein the rotation motion of the pivot frame is slowed by the respective hydraulic damping forces.

11. The machine of claim 1 wherein the elevation frame is raised and lowered by a elevation frame lift device where the elevation frame lift device is selected from the group consisting of electric motor driven screw jack lift devices and a hydraulic lift device where the elevation frame lift device can have a elevation frame lift device vertical position sensor that can be used to sense the vertical position of the elevation frame whereby the elevation frame lift device vertical position sensor can be used to control the position of the elevation frame and whereby where the elevation frame lift device vertical position sensor can be used to indirectly control the position of the floating abrading platen abrasive coating relative to the workpieces that are attached to the rotary workpiece spindles.

12. The machine of claim 1 wherein one or more universal joints can be attached to a floating abrading platen idler drive shaft that is used to couple the right-angle gearbox hollow output platen drive shaft to the floating abrading platen rotary drive shaft that rotates the floating abrading platen where the universal joints can be selected from the group consisting of conventional universal joints, plate-type universal joints and constant velocity universal joints.

13. The machine of claim 1 where a rotary union device is attached to the right-angle gearbox hollow output platen drive shaft to provide vacuum to the right-angle gearbox hollow output platen drive shaft wherein a flexible vacuum tube can be attached to the right-angle gearbox hollow output platen drive shaft and also attached to the floating abrading platen rotary drive shaft to provide a vacuum passageway from the right-

angle gearbox hollow output platen drive shaft to the floating abrading platen rotary drive shaft where vacuum passages within the floating abrading platen are routed to the floating abrading platen flat annular abrading surface such that a flexible abrasive disk can be attached to the floating abrading platen by the vacuum supplied by the rotary union device.

14. The machine of claim 1 where a spherical action locking device can be used to lock the floating abrading platen spherical-action rotation device to prevent spherical rotation of the floating abrading platen spherical-action rotation device which prevents spherical rotation of the floating abrading platen whereby the floating abrading platen is locked in a selected spherical-rotation position.

15. The machine of claim 14 where a floating abrading platen spherical action locking device is an integral part of a floating abrading platen air bearing spherical-action rotation device having a spherical-action rotation device air bearing rotor that supports the floating abrading platen and the abrading platen spherical-action rotation device has a spherical-action rotation device air bearing housing that is attached to the pivot frame where pressurized air is supplied to the air bearing spherical-action rotation device air bearing housing to create a friction-free air film that is positioned between the spherical-action rotation device air bearing rotor and the spherical-action rotation device air bearing housing to allow friction-free spherical rotation of the spherical-action rotation device air bearing rotor and friction-free spherical rotation of the floating abrading platen and wherein vacuum that is supplied to the air bearing spherical-action rotation device spherical-action rotation device air bearing housing can lock the spherical-action rotation device air bearing rotor to the spherical-action rotation device air bearing housing whereby the floating abrading platen is locked in a selected spherical-rotation position.

16. The machine of claim 14 where a floating abrading platen spherical action locking device is a mechanical brake device comprising:

a) a mechanical brake rotor having a spherical brake rotor surface that has a spherical center of rotation that coincides with the floating abrading platen spherical-action rotation device spherical center of rotation;

b) where the floating abrading platen spherical action locking device mechanical brake device has a mechanical brake pad having a spherical brake pad surface that has a spherical center of rotation that coincides with the floating abrading platen spherical-action rotation device spherical center of rotation;

c) wherein the spherical radius of the mechanical brake device mechanical brake pad is nominally equal to the spherical radius of the mechanical brake device mechanical brake rotor; and

d) where the floating abrading platen spherical-action rotation device mechanical brake pad can be moved along an axis that intersects the floating abrading platen spherical-action rotation device spherical center of rotation by a floating abrading platen anti-rotation braking force device into forced contact with the floating abrading platen spherical-action rotation device mechanical brake rotor to lock the floating abrading platen spherical-action rotation device mechanical brake pad to the floating abrading platen spherical-action rotation device mechanical brake rotor to prevent spherical rotation of the floating abrading platen spherical-action rotation device which prevents spherical rotation of the floating abrading platen spherical-action rotation device mechanical brake rotor;

e) whereby the floating abrading platen spherical-action rotation device is locked in a selected spherical-rotation position whereby the floating abrading platen is locked in a selected spherical-rotation position.

17. The machine of claim 16 where the floating abrading platen spherical action locking device mechanical brake pad can be moved from a position that is separated from the floating abrading platen spherical action locking device mechanical brake rotor into braking contact with the floating abrading platen spherical action locking device mechanical brake rotor by a floating abrading platen anti-rotation braking force device selected from the group consisting of air cylinders, spring-return air cylinders, hydraulic cylinders, electric solenoid devices and piezo-electric devices wherein the anti-rotation braking force device can be activated to move the floating abrading platen spherical action locking device mechanical brake pad manually or by electrical devices into braking contact with the floating abrading platen spherical action locking device mechanical brake rotor.

18. The machine of claim 1 where the center of mass of the floating abrading platen is less that 2 inches from the spherical center of rotation of the floating abrading platen spherical-action rotation device.

19. The machine of claim 1 where the center of mass of the floating abrading platen is less that 0.5 inches from the spherical center of rotation of the floating abrading platen spherical-action rotation device.

20. A process of providing abrasive flat lapping using an at least three-point, fixed-spindle floating-platen abrading machine comprising:

a) providing least three rotary spindles having rotatable flat-surfaced spindle-tops that each have a spindle-top axis of rotation at the center of a respective rotatable flat-surfaced spindle-top for respective rotary spindles;

b) providing that the at least three spindle-tops' axes of rotation are perpendicular to the respective spindle-tops' flat surfaces;

c) providing an abrading machine base having a horizontal nominally-flat top surface and a spindle-circle where the spindle-circle is coincident with the machine base nominally-flat top surface;

d) positioning the at least three rotary spindles to be located with near-equal spacing between the respective at least three of the rotary spindles where the respective at least three spindle-tops' axes of rotation intersect the machine base spindle-circle and where the respective at least three rotary spindles are mechanically attached to the machine base;

e) aligning the at least three spindle-tops' flat surfaces to be co-planar with each other;

f) providing a rotatable floating abrading platen having a flat annular abrading surface where the floating abrading platen is supported by and is rotationally driven about a floating abrading platen cylindrical-rotation axis located at a cylindrical-rotation center of the floating abrading platen and perpendicular to the rotatable floating abrading platen flat annular abrading surface by a spherical-action rotation device located coincident with the cylindrical-rotation axis of the floating abrading platen where the floating abrading platen spherical-action rotation device restrains the floating abrading platen in a radial direction relative to the floating abrading platen cylindrical-rotation axis where the floating abrading platen cylindrical-rotation axis is nominally concentric with and perpendicular to the machine base spindle-circle where the floating abrading platen spherical-action rotation device has a spherical center of rotation that is coincident with the floating abrading platen cylindrical-rotation axis where the floating abrading platen has a center of mass that is coincident with the floating abrading platen cylindrical-rotation axis;

g) providing that the floating abrading platen spherical-action rotation device allows spherical motion of the floating abrading platen about the floating abrading platen spherical-action rotation device spherical center of rotation where the flat annular abrading surface of the floating abrading platen that is supported by the floating abrading platen spherical-action rotation device is nominally horizontal; and

h)providing a pivot frame that has a pivot frame pivot center, a pivot frame floating abrading platen end and a pivot frame floating abrading platen drive motor end where the pivot frame can rotate about a pivot frame rotation axis that intersects the pivot frame pivot center where the pivot frame rotation axis is perpendicular to the length of the pivot frame that extends from the pivot frame floating abrading platen end to the pivot frame floating abrading platen drive motor end where the pivot frame has one or more low friction pivot frame rotation bearings that are concentric with the pivot frame rotation axis;

i) providing a platen drive motor that is attached to the pivot frame on the pivot frame floating abrading platen drive motor end and providing a counterbalance weight that is attached to the pivot frame on the pivot frame floating abrading platen drive motor end and providing a right-angle gearbox having a hollow output platen drive shaft where the right-angle gearbox is attached to the pivot frame on the pivot frame floating abrading platen end and where the floating abrading platen is attached to the pivot frame on the pivot frame floating abrading platen end and where the floating abrading platen spherical-action rotation device is attached to the pivot frame on the pivot frame floating abrading platen end;

j) providing that the floating abrading platen drive motor is connected to and rotates a platen drive motor drive shaft that is attached to and rotates a right-angle gearbox input drive shaft where the right-angle gearbox hollow output platen drive shaft is attached to a provided universal joint that is attached to a floating abrading platen rotary drive shaft that rotates the floating abrading platen;

k) positioning the floating abrading platen drive motor and the counterbalance weight on the pivot frame floating abrading platen drive motor end to act as a counterbalance to the right-angle gearbox, the rotatable floating abrading platen and the floating abrading platen spherical-action rotation device that are positioned on the pivot frame floating abrading platen end wherein the pivot frame is nominally balanced about the pivot frame pivot rotation axis;

l) providing flexible abrasive disk articles having annular bands of abrasive coated surfaces where a selected flexible abrasive disk is attached in flat conformal contact with the floating abrading platen flat annular abrading surface such that the attached abrasive disk is concentric with the floating abrading platen flat annular abrading surface;

m) providing equal-thickness workpieces having parallel opposed flat workpiece top surfaces and flat workpiece bottom surfaces that are attached to the respective at least three spindle-tops where the flat workpiece bottom surfaces are in flat-surfaced contact with the flat surfaces of the respective at least three spindle-tops;

n) providing an elevation frame that supports the pivot frame at the pivot frame pivot center where the elevation frame is attached to a linear slide device that is attached to the abrading machine base wherein the elevation frame can be raised and lowered by an elevation frame lift device;

o) moving the floating abrading platen vertically by activating the lift frame lift device to position the abrasive surface of the flexible abrasive disk that is attached to the floating abrading platen flat annular abrading surface to contact the top surfaces of the workpieces that are attached to the flat surfaces of the respective at least three spindle-tops wherein the at least three rotary spindles provide at least three-point support of the floating abrading platen and wherein the floating abrading platen spherical-action rotation device allows spherical motion of the floating abrading platen about the floating abrading platen spherical-action rotation device spherical center of rotation to provide uniform abrading contact of the abrasive surface of the flexible abrasive disk with all of the workpieces;

p) providing a pivot frame locking device that is attached to both the pivot frame and the pivot frame lift frame where the pivot frame locking device can be activated to lock the pivot frame that is rotated about the pivot frame rotation axis at that pivot frame rotated position;

q) providing an abrading contact force device that is attached to both the pivot frame and the pivot frame lift frame where the abrading contact force device can apply an abrading contact force to the pivot frame wherein the pivot frame tends to be rotated about the pivot frame pivot rotation axis where the abrading contact force device applies an abrading contact force to the pivot frame and the pivot frame applies the abrading contact force to the floating abrading platen spherical-action rotation device that is attached to the pivot frame wherein the applied abrading contact force is applied to the floating abrading platen by the floating abrading platen spherical-action rotation device and the applied abrading contact force is applied to the workpieces by the floating abrading platen;

r) providing that the total floating abrading platen abrading contact force applied to workpieces that are attached to the respective at least three spindle-top flat surfaces by contact of the abrasive surface of the flexible abrasive disk that is attached to the floating abrading platen flat annular abrading surface with the top surfaces of the workpieces is controlled through the floating abrading platen spherical-action floating abrading platen rotation device to allow the total floating abrading platen abrading contact force to be evenly distributed to the workpieces attached to the respective at least three spindle-tops; and

s) rotating the at least three spindle-tops having the attached equal-thickness workpieces about the respective spindle-tops' rotation axes and rotating the floating abrading platen having the attached flexible abrasive disk about the floating abrading platen cylindrical-rotation axis to single-side abrade the workpieces that are attached to the flat surfaces of the at least three spindle-tops while the moving abrasive surface of the flexible abrasive disk that is attached to the moving floating abrading platen flat annular abrading surface is in force-controlled abrading contact with the top surfaces of the workpieces that are attached to the respective at least three spindle-tops.

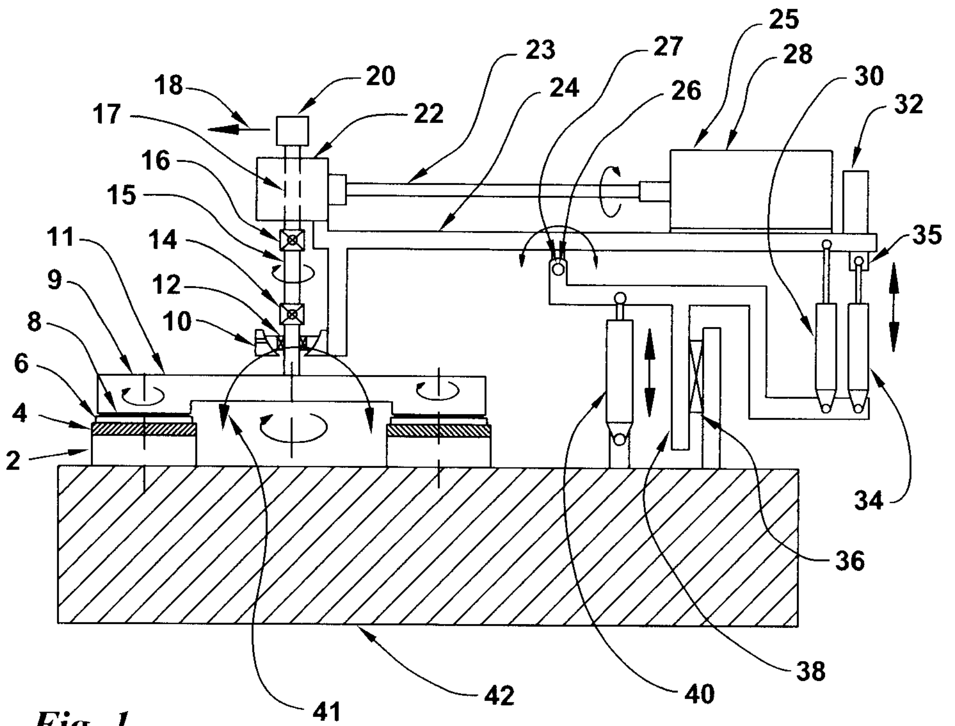
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Fig. 1

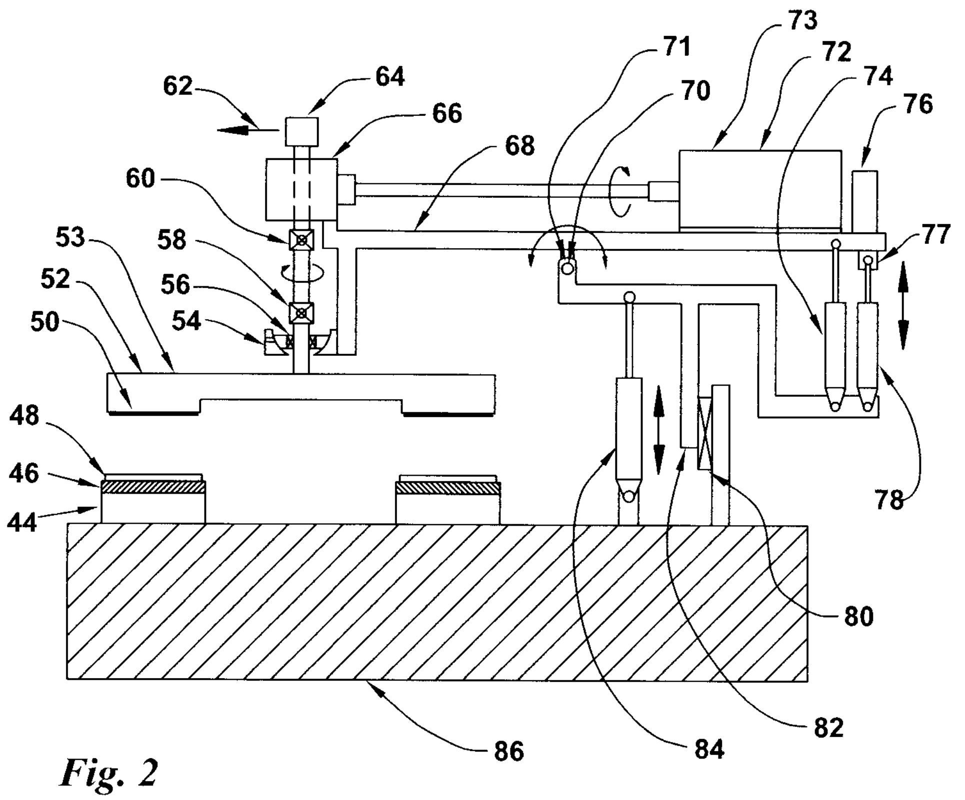
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Fig. 2

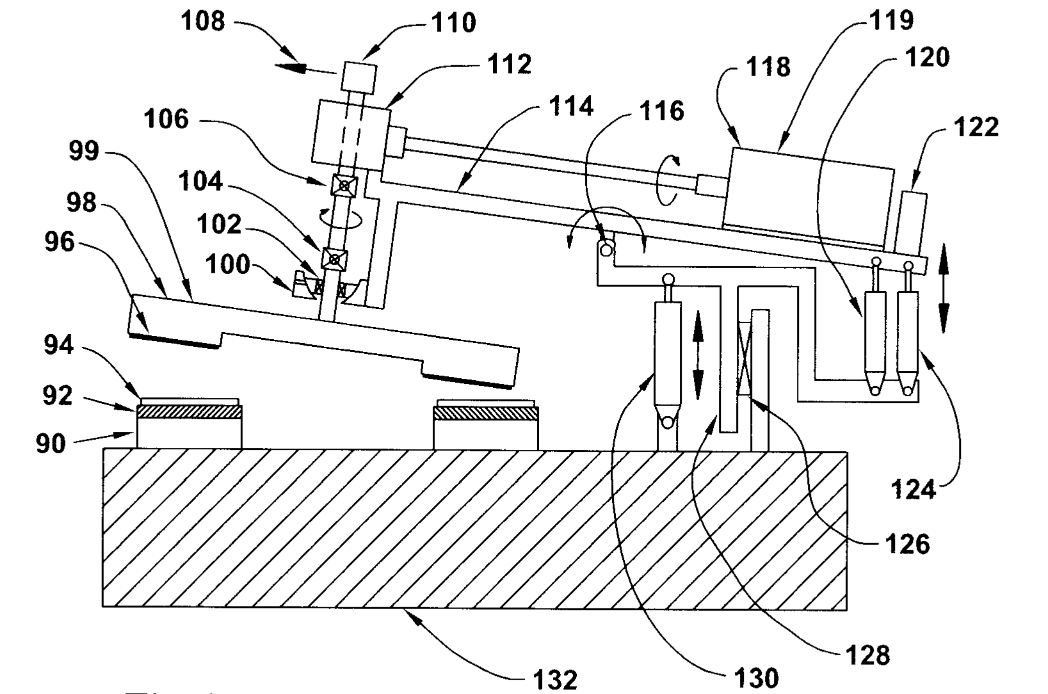
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Fig. 3

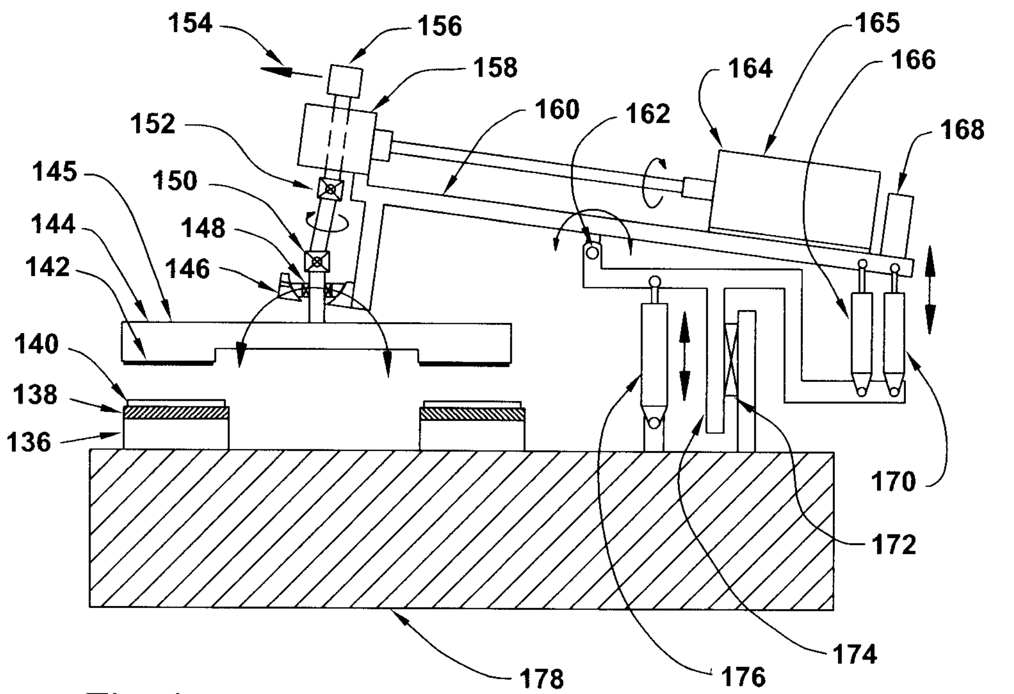
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Fig. 4

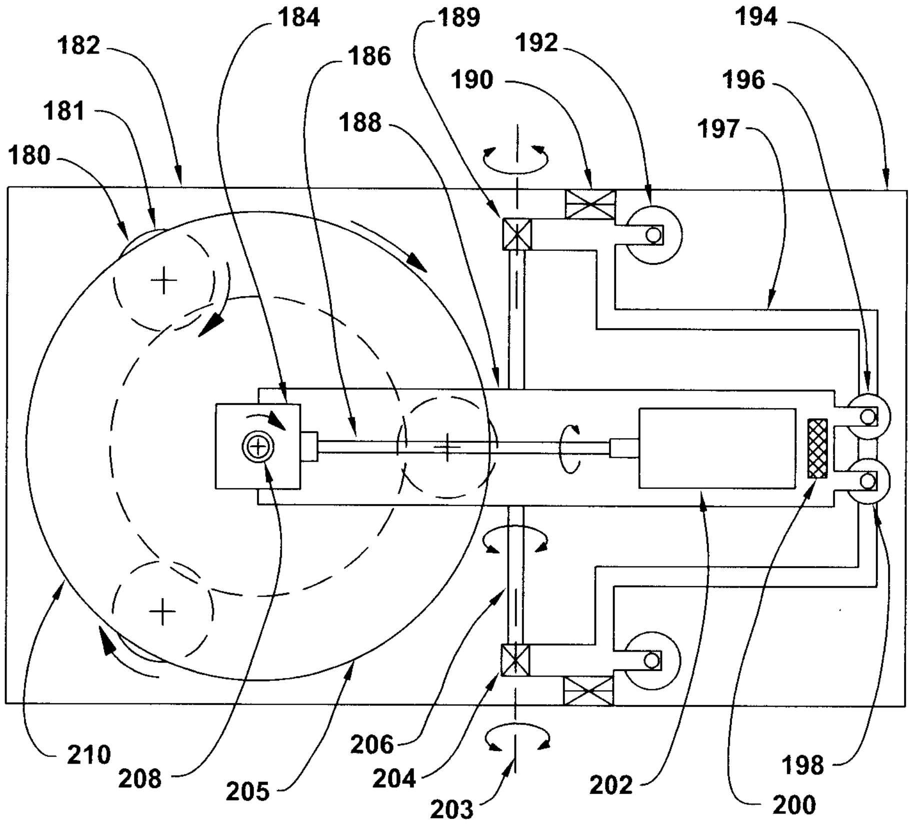
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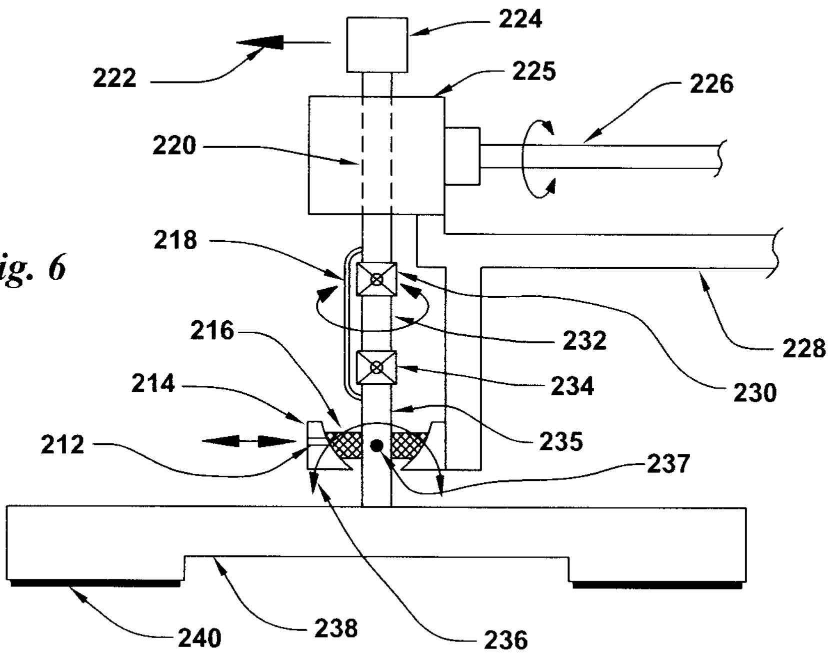
Fig. 5

Fig. 6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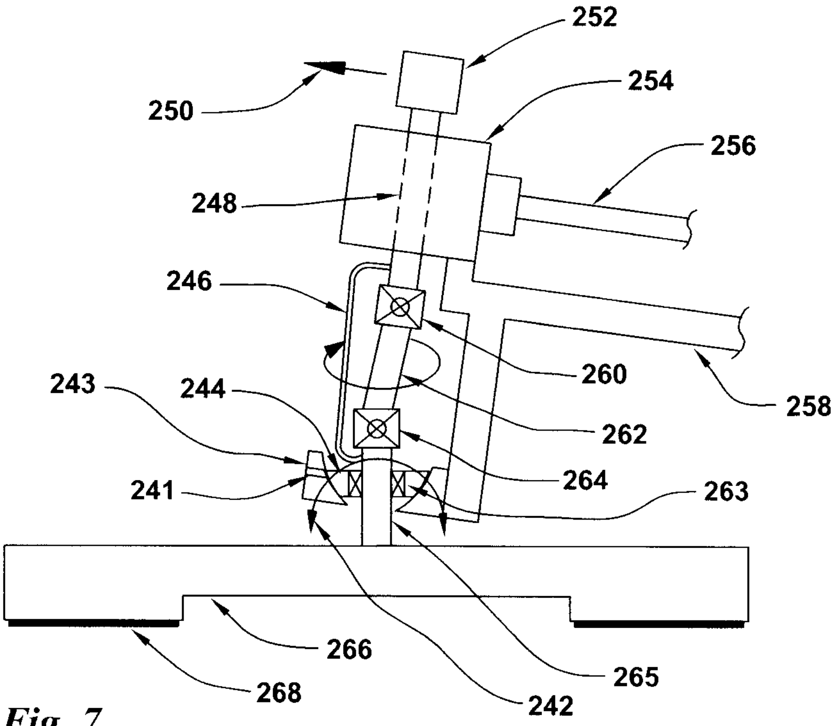

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Fig. 7

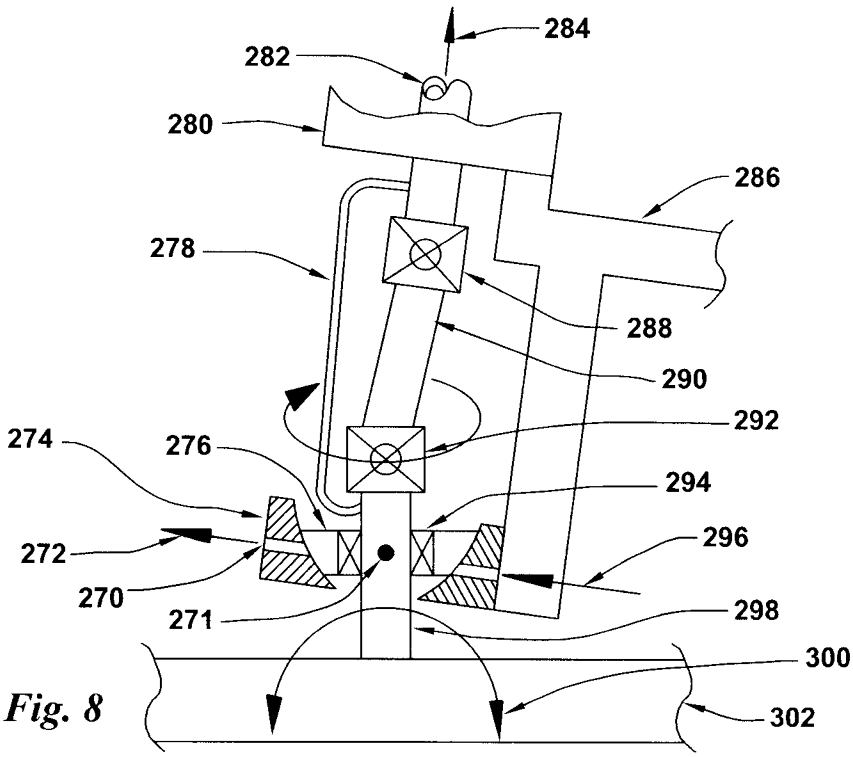

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Fig. 8

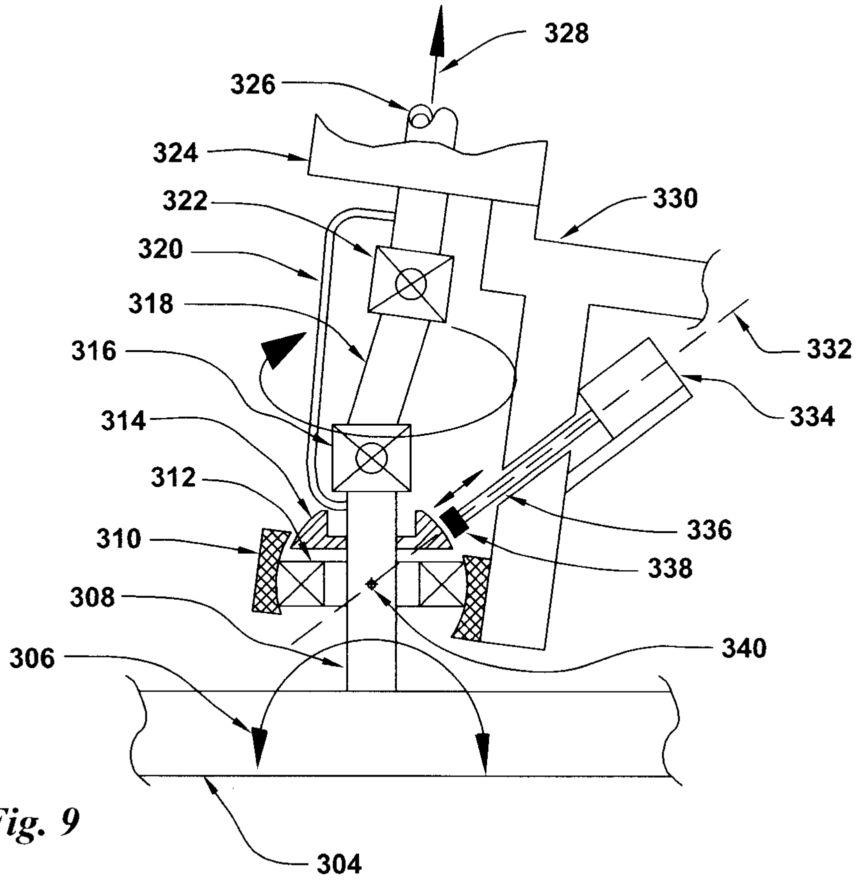
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Fig. 9

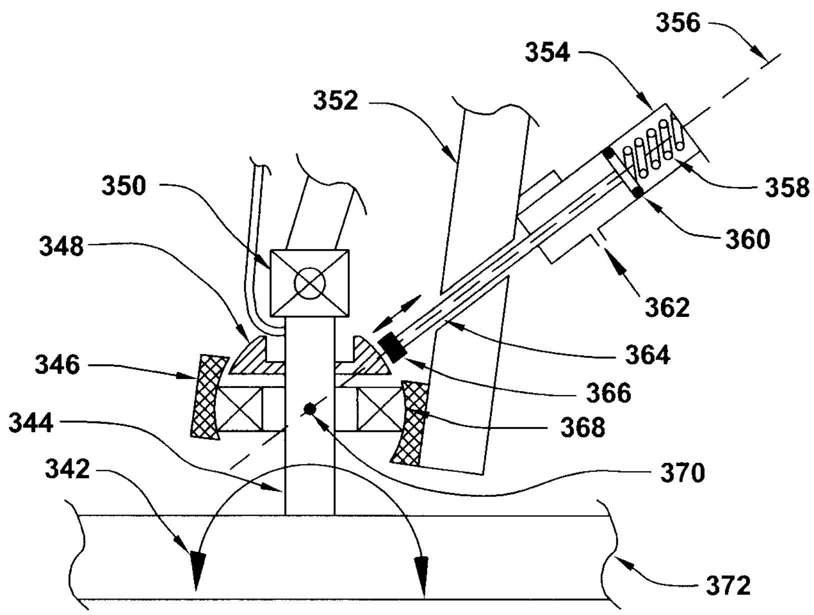
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Fig. 10

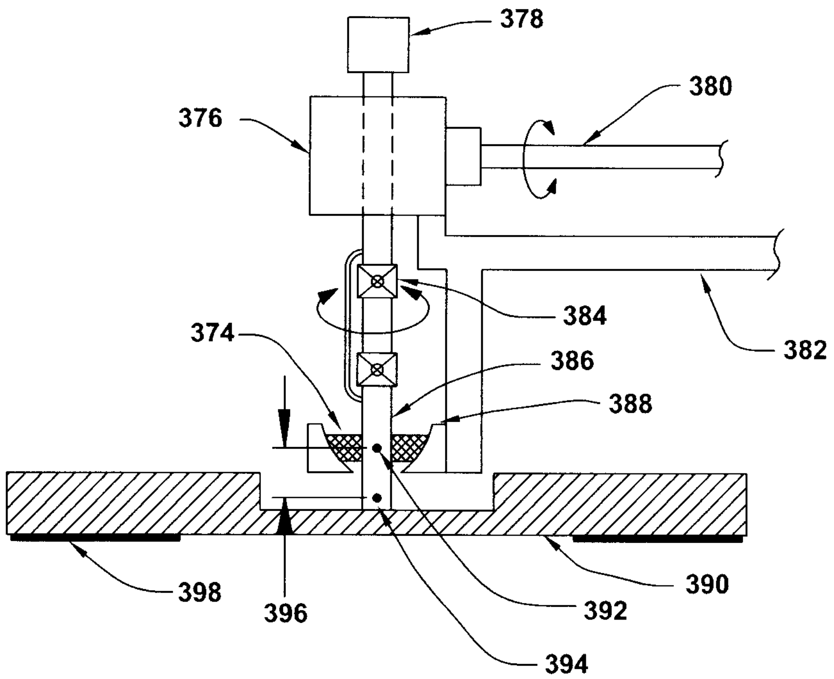
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Fig. 11

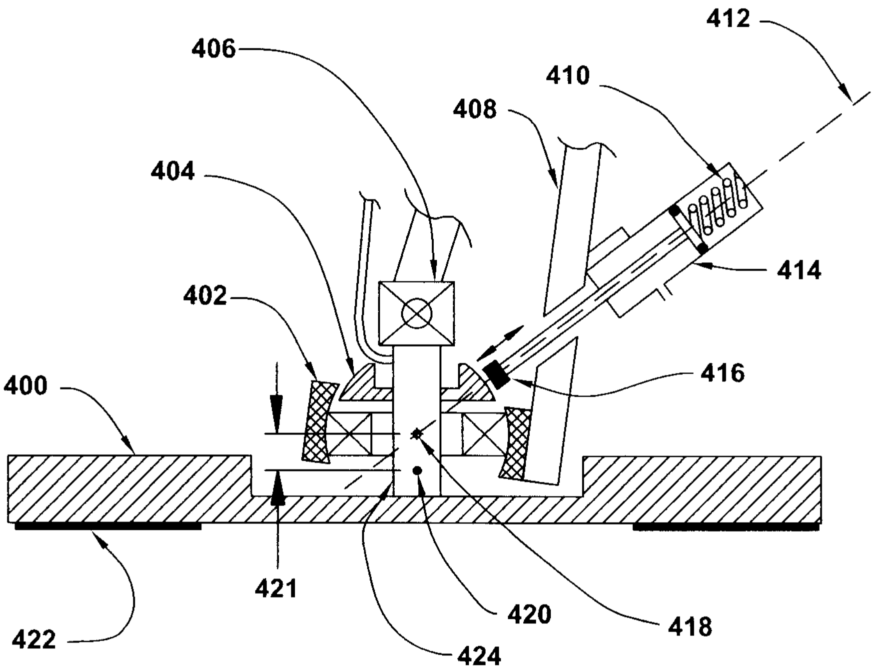
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Fig. 12

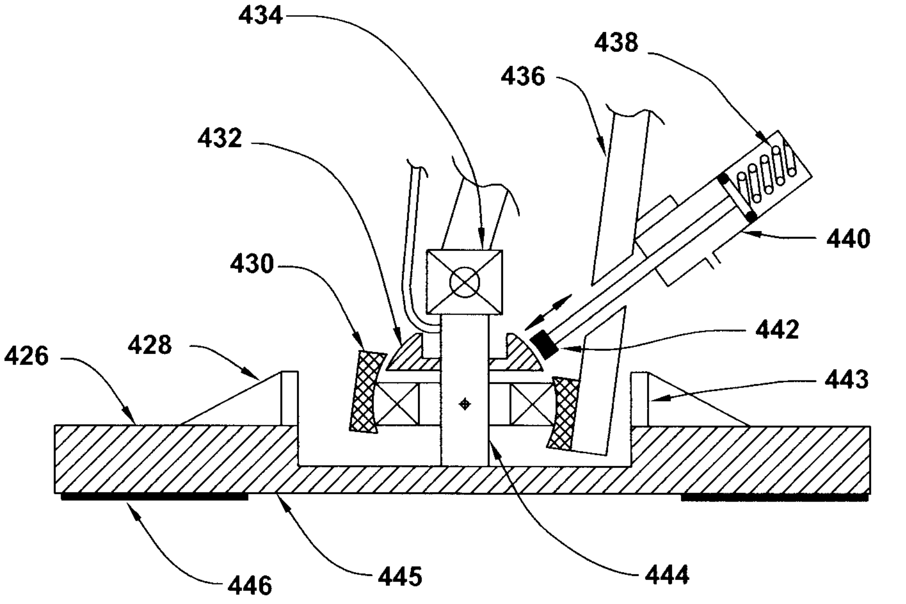
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Fig. 13

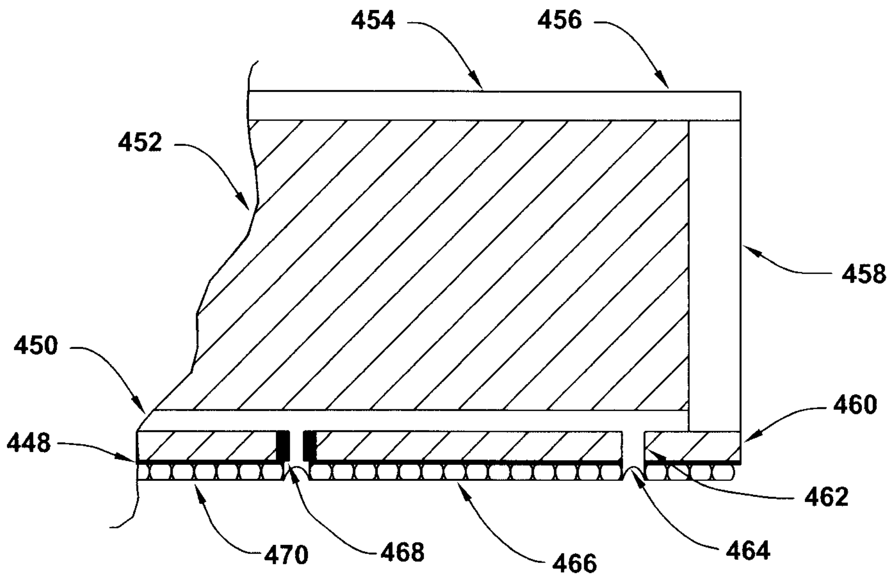
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Fig. 14

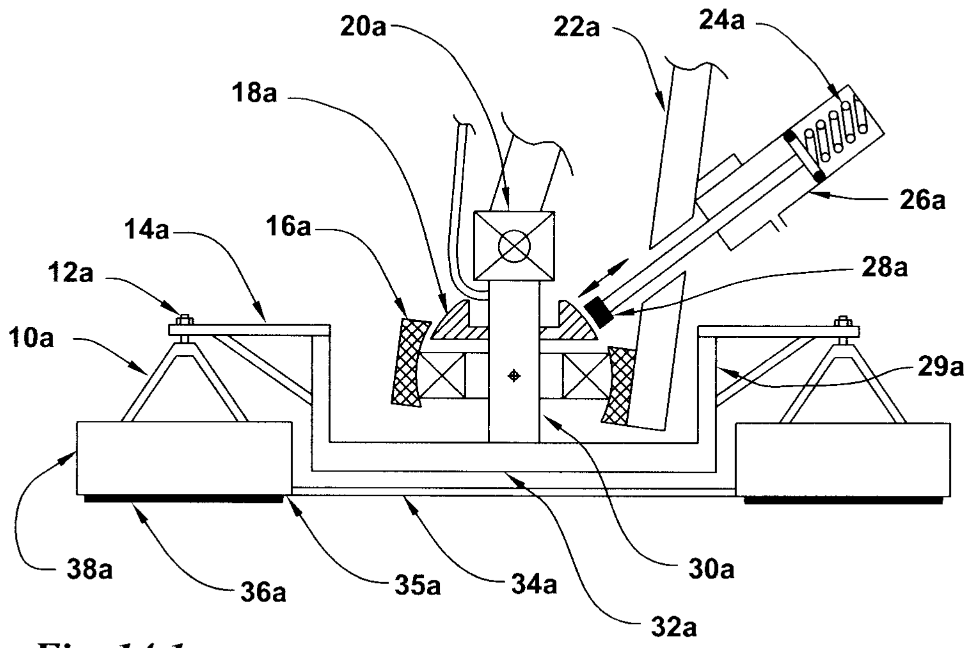

Fig. 14.1

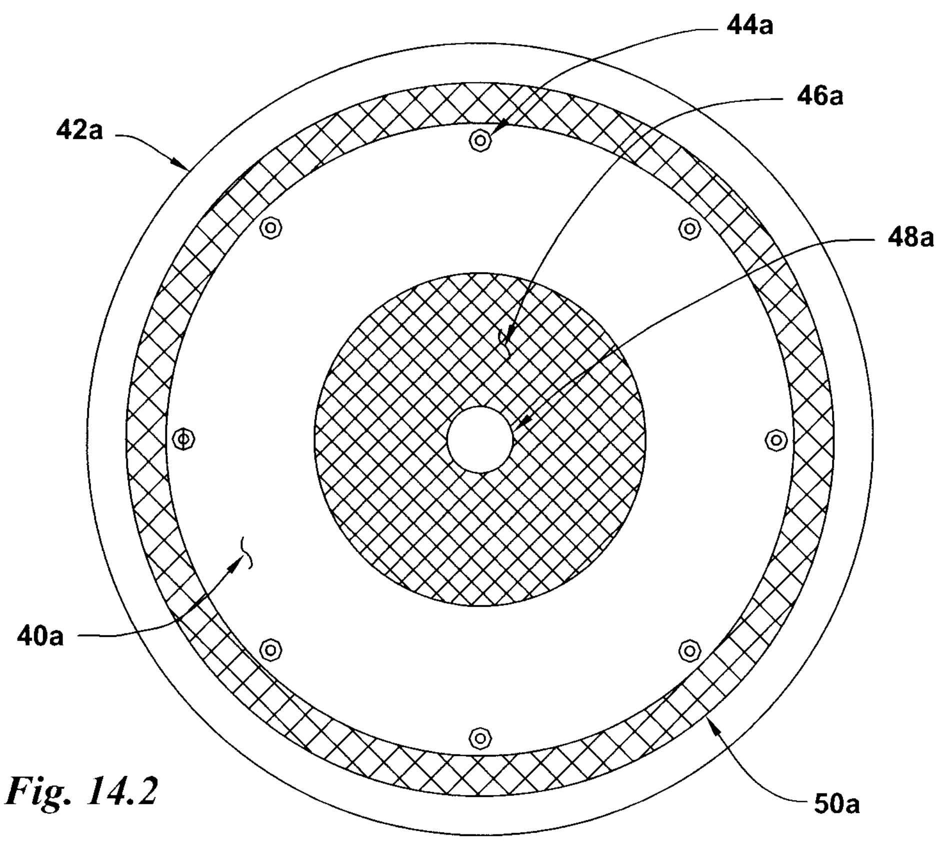

Fig. 14.2

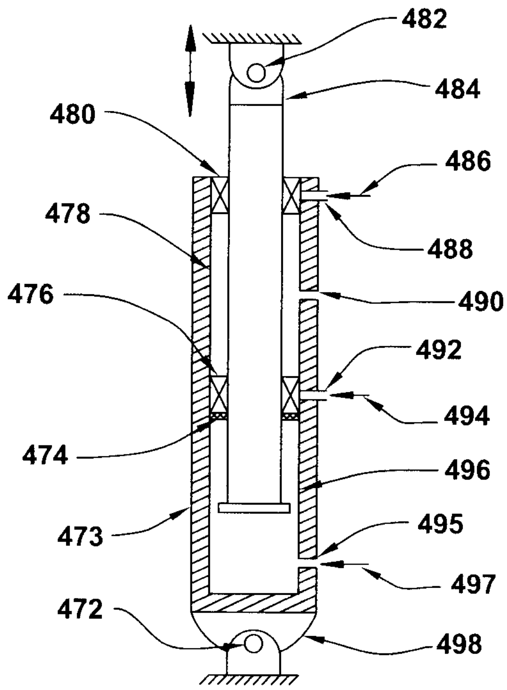
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Fig. 15

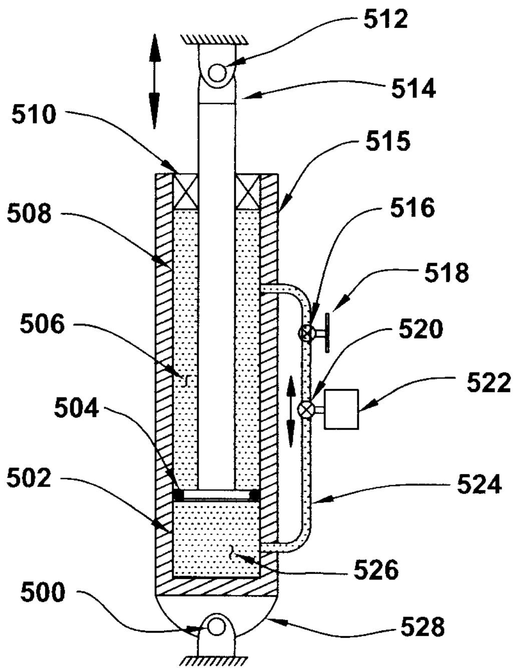
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Fig. 16

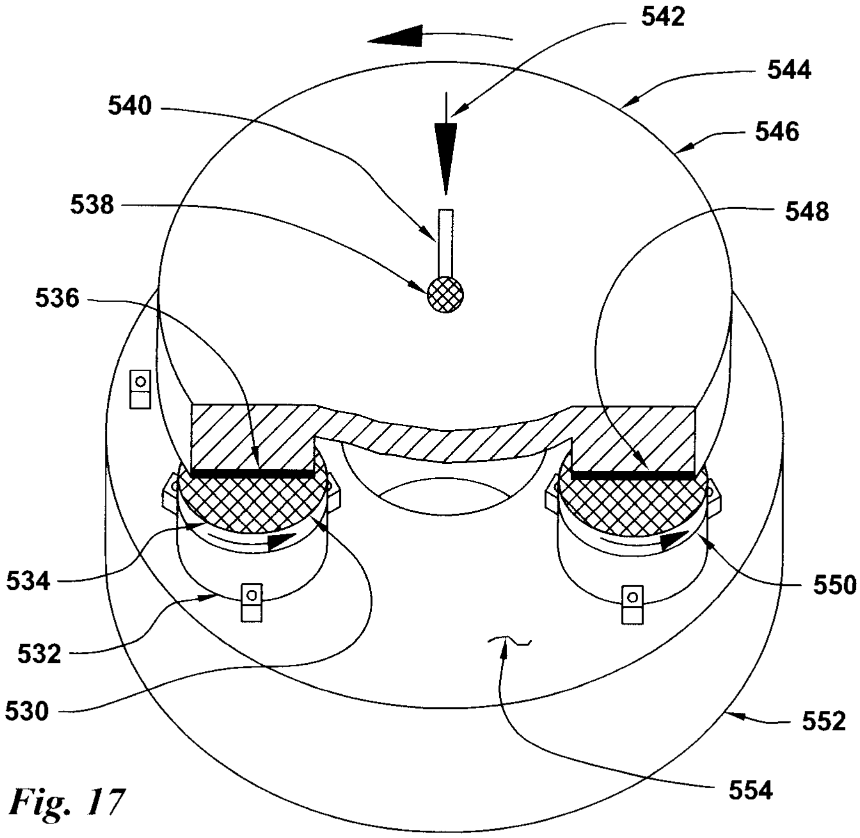
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Fig. 17

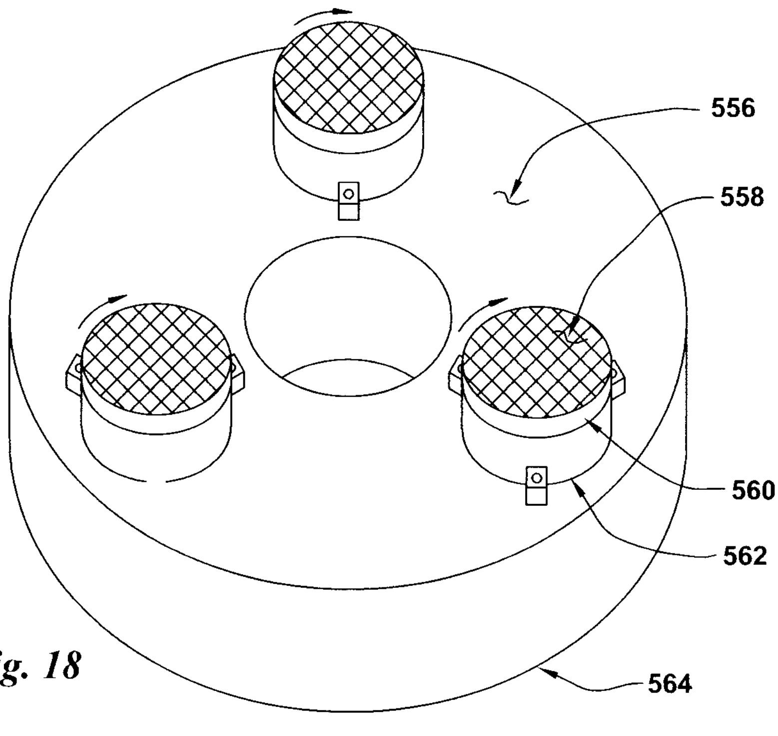
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Fig. 18

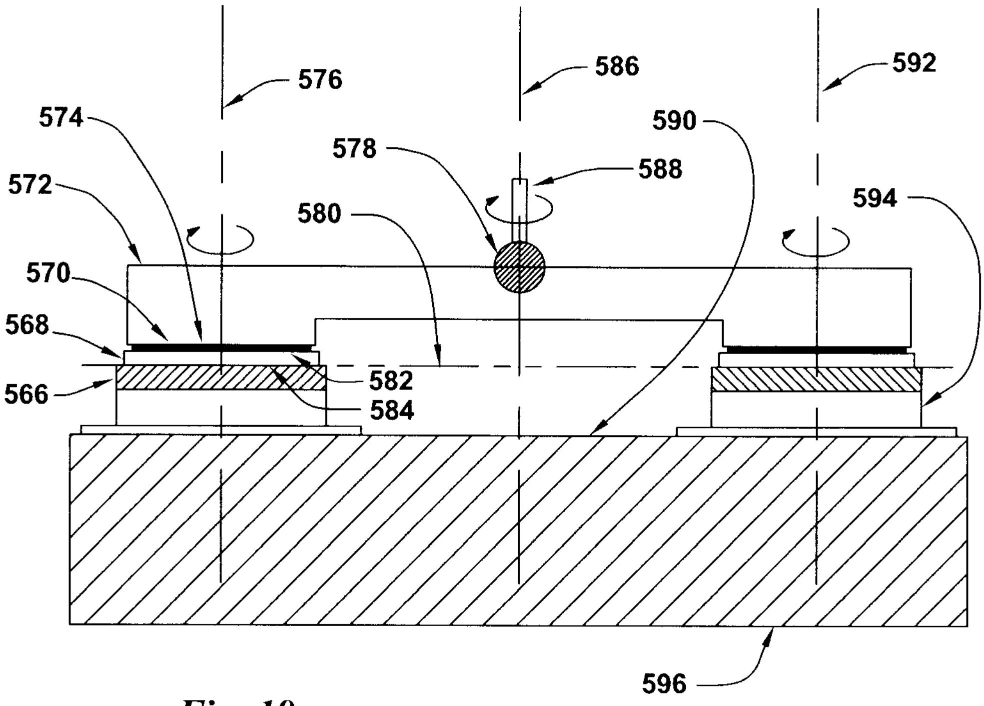
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Fig. 19

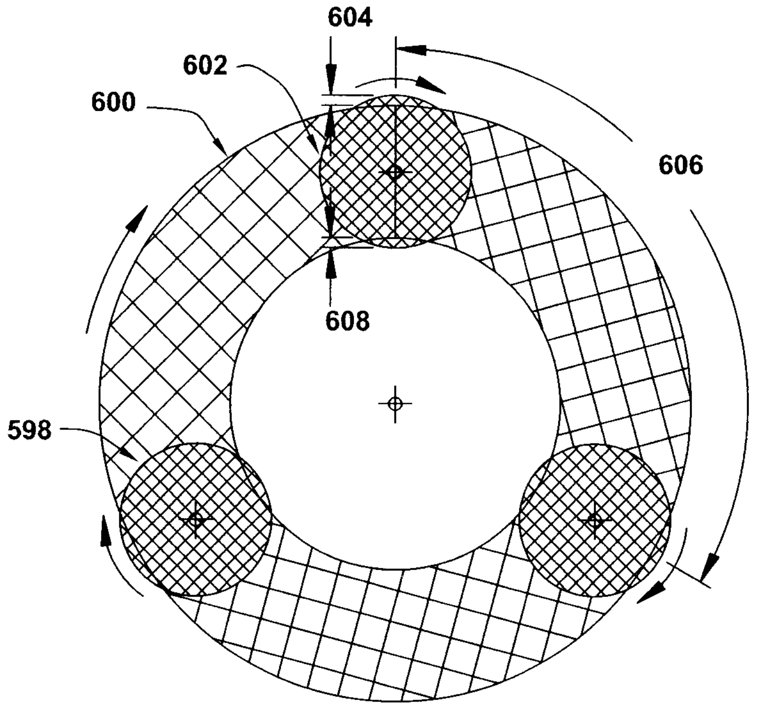
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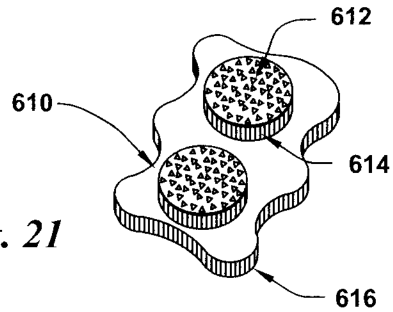
Fig. 20



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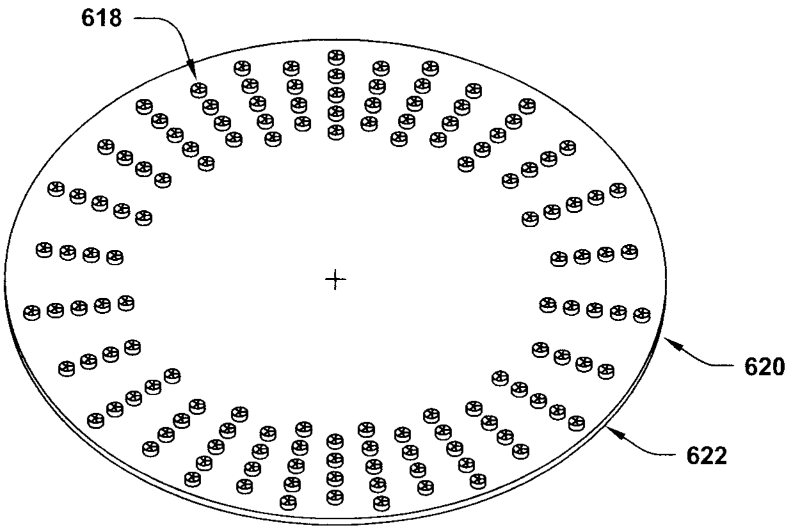

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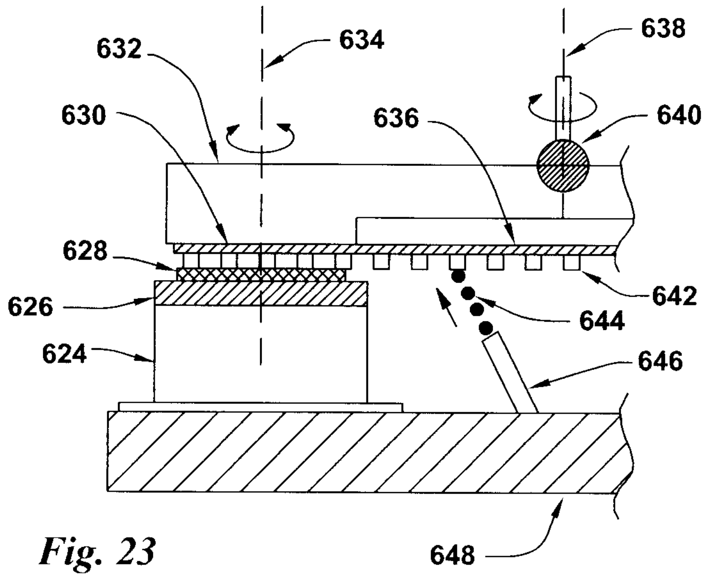
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Fig. 23

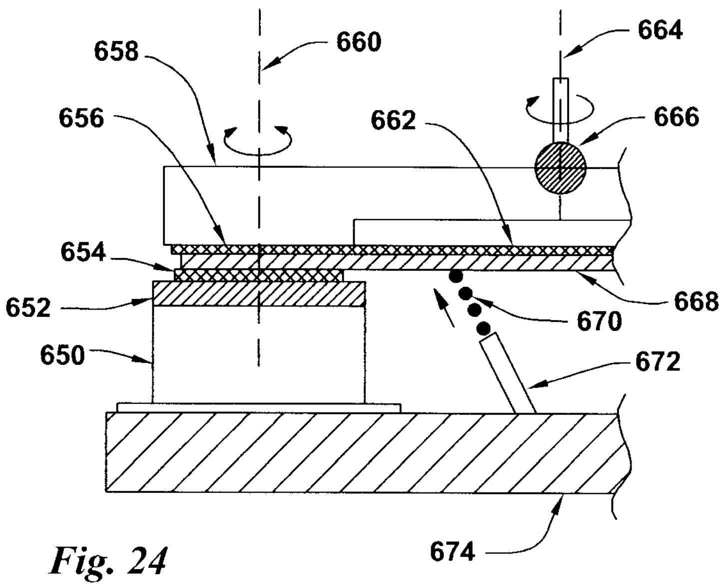
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Fig. 24

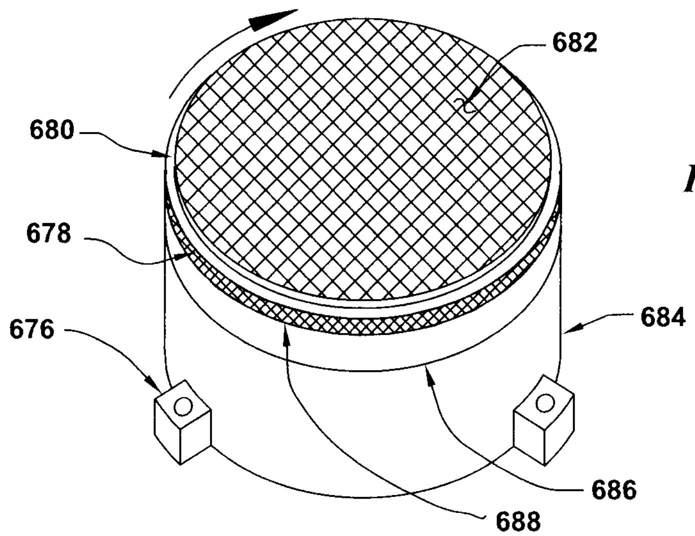


Fig. 25

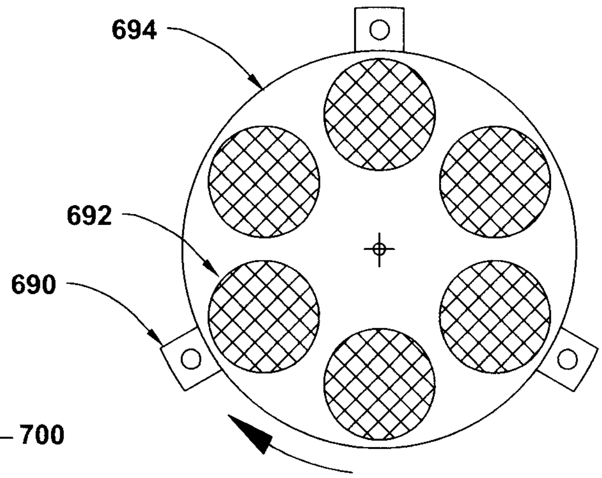
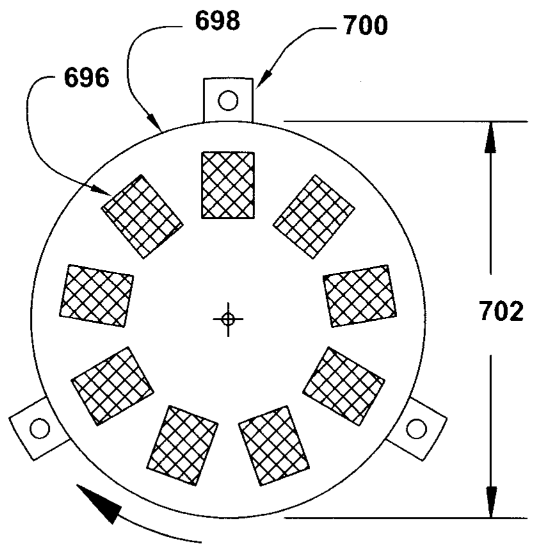


Fig. 26



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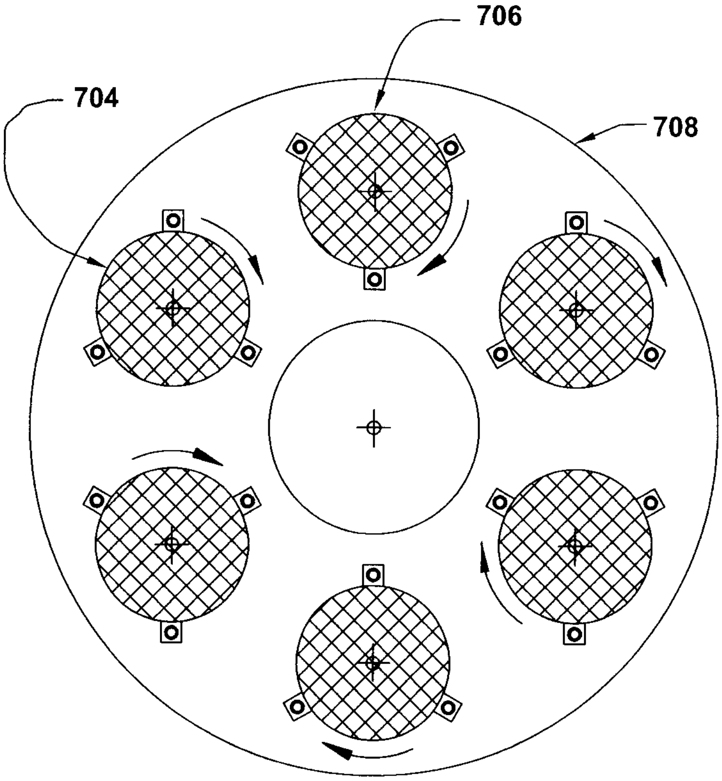

Fig. 28

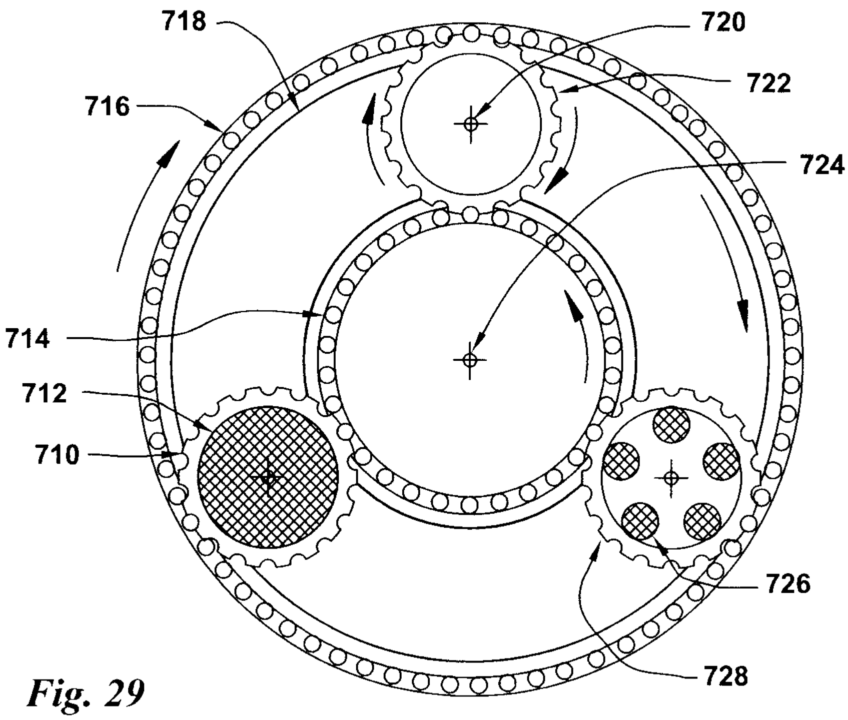

Fig. 29
Prior Art

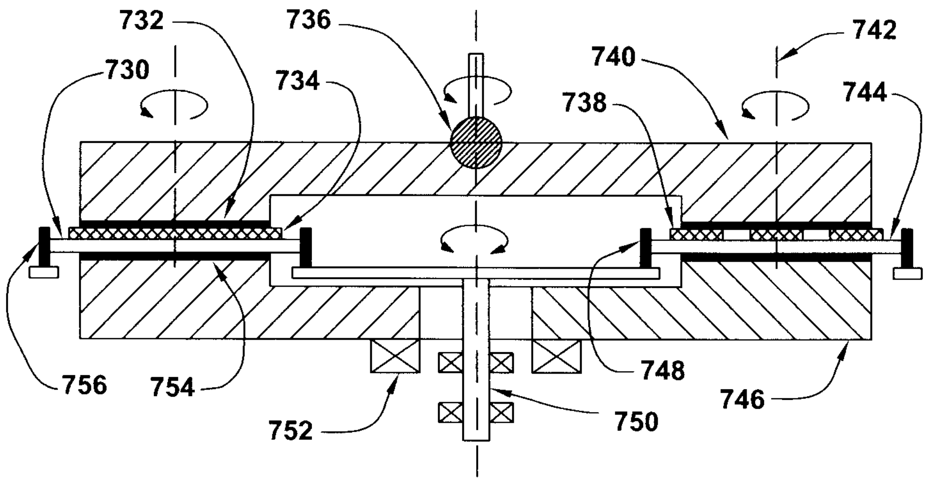

Fig. 30
Prior Art

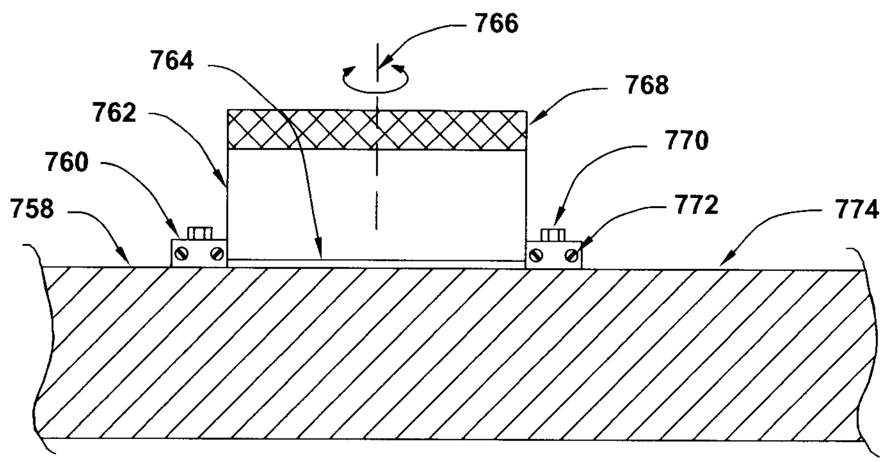

Fig. 31

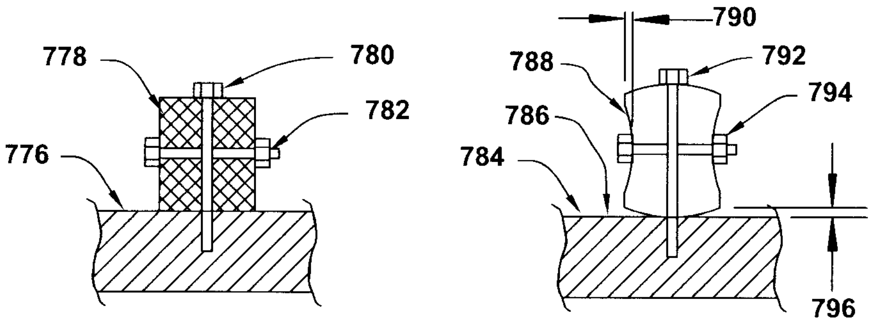

Fig. 32

Fig. 33

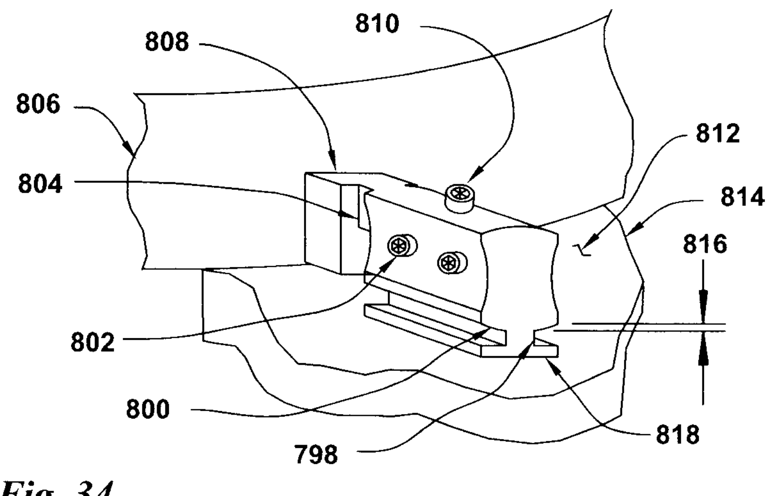

Fig. 34

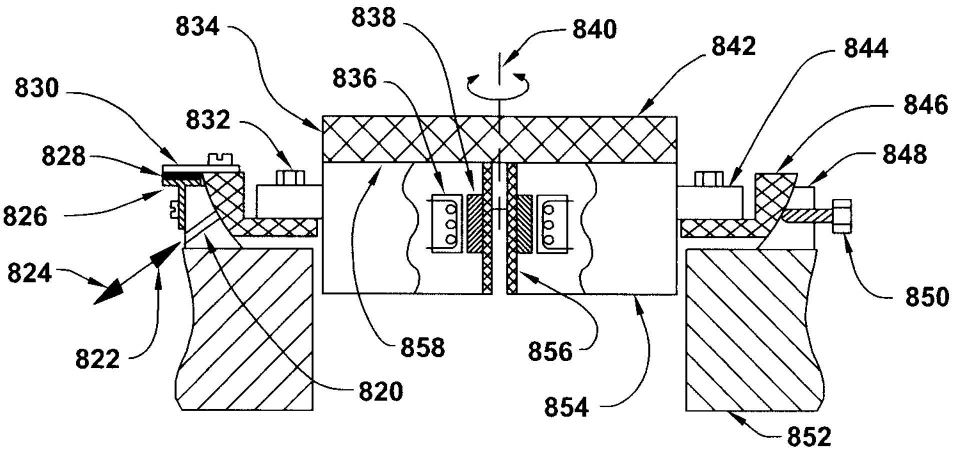

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Fig. 35

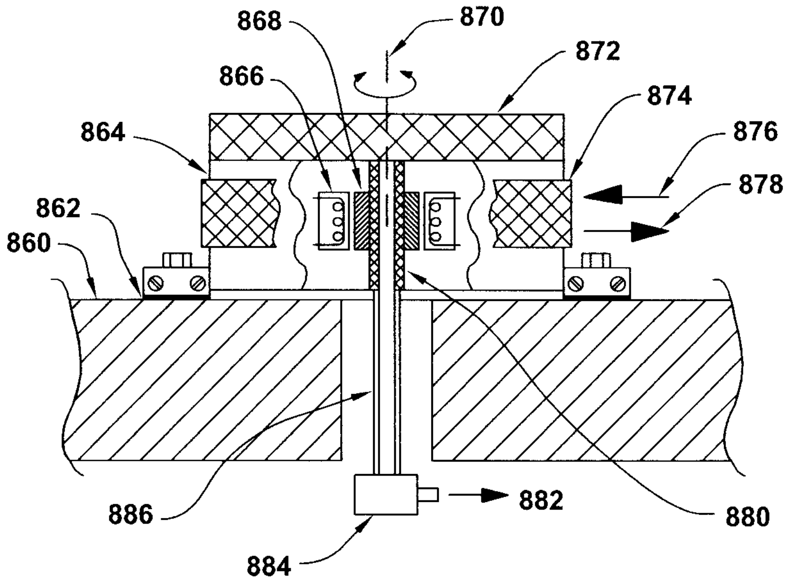

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Fig. 36

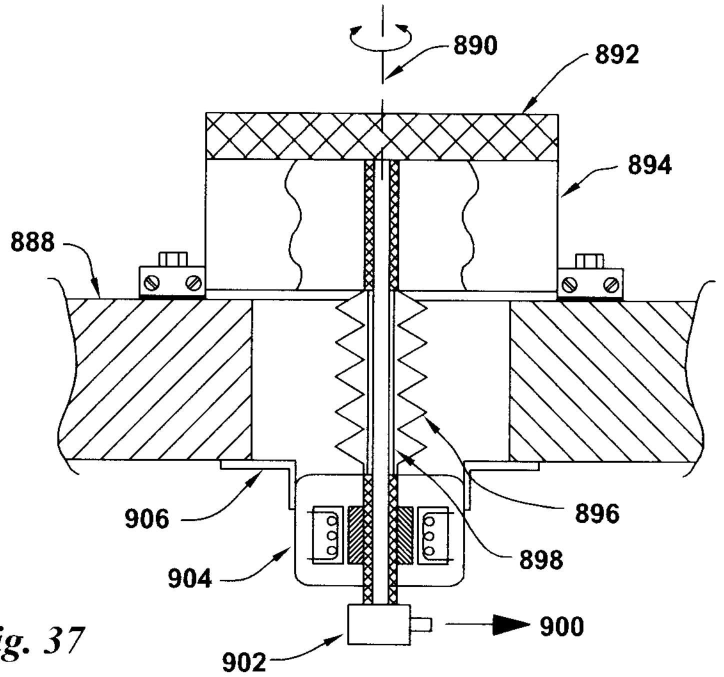
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Fig. 37

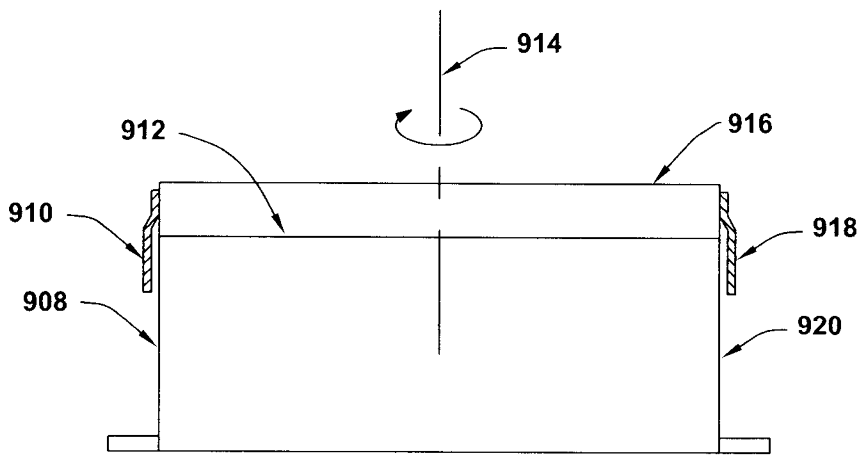
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Fig. 38

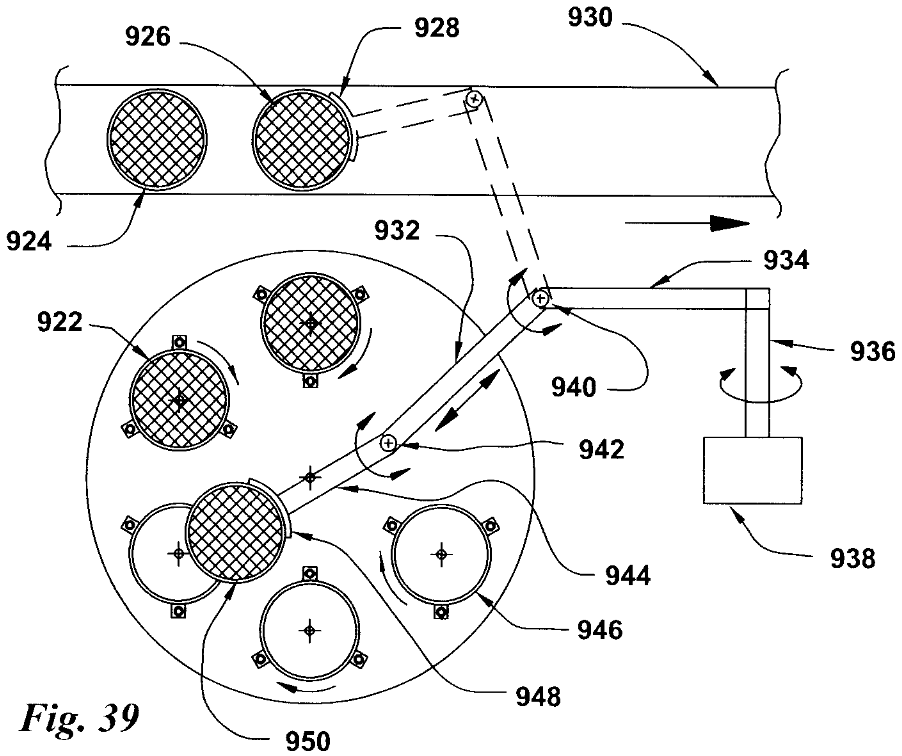
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Fig. 39

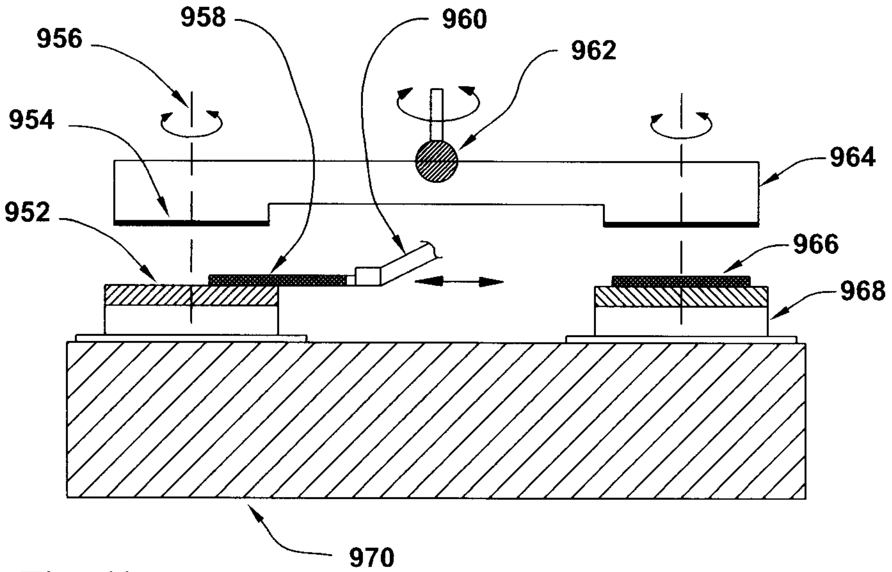
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Fig. 40

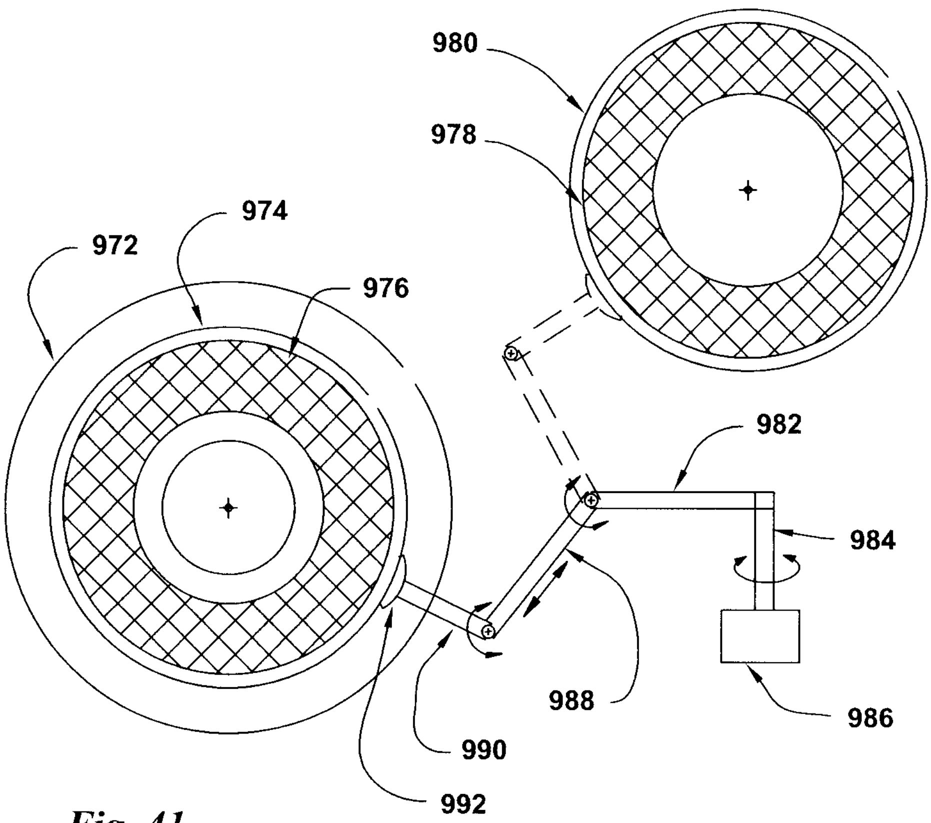
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Fig. 41

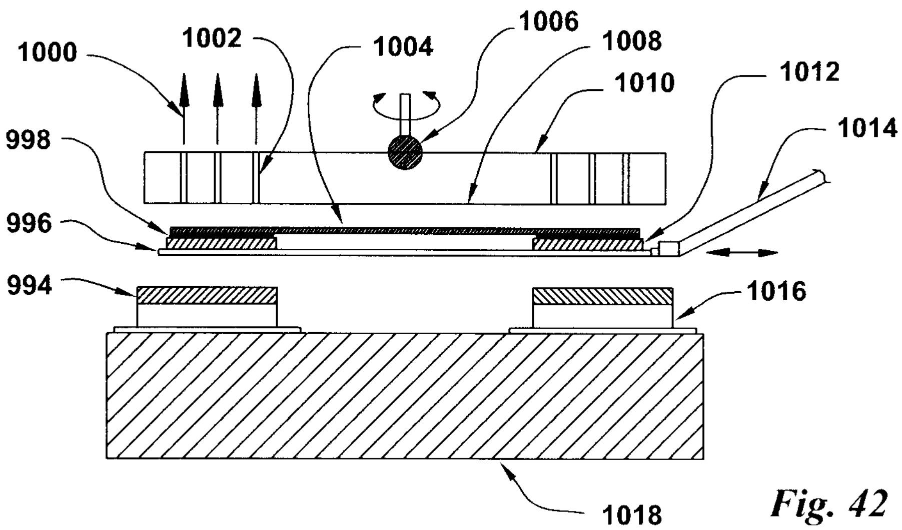
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Fig. 42

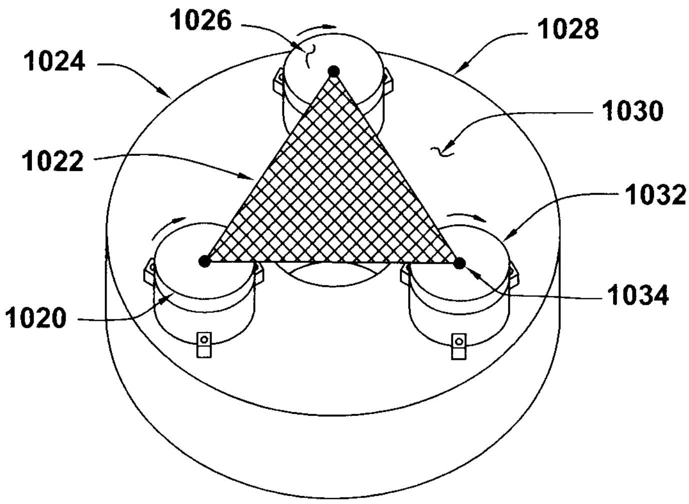
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Fig. 43

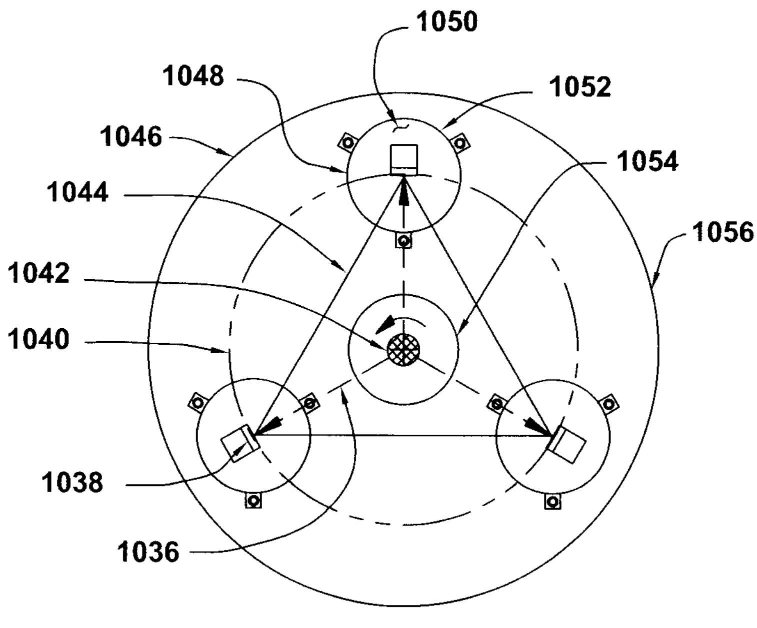
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Fig. 44

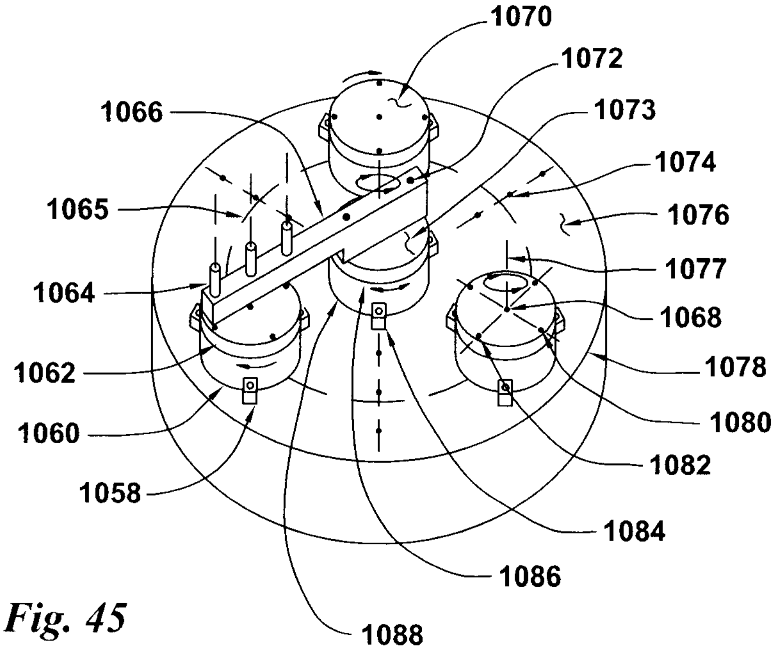
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Fig. 45

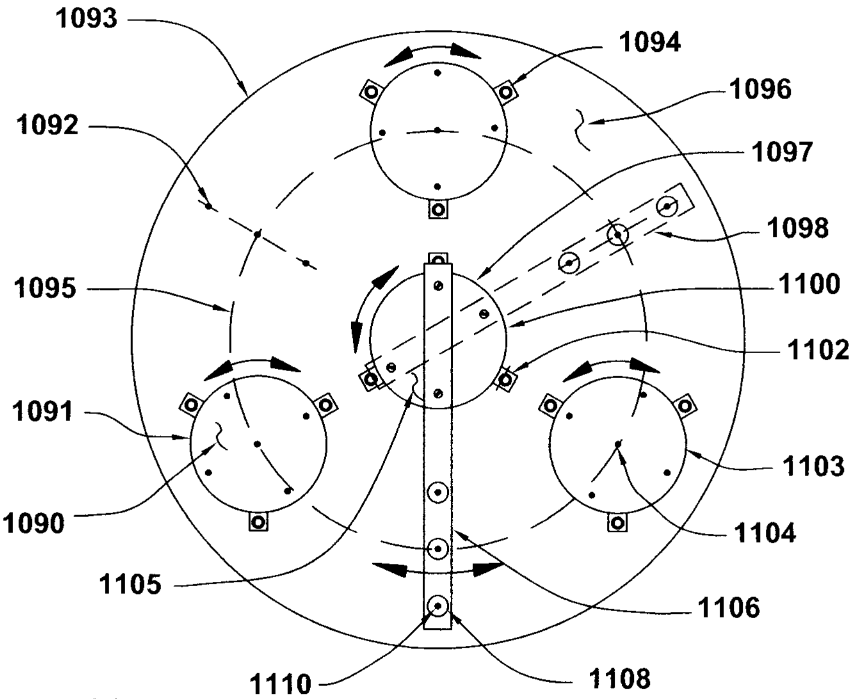
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Fig. 46

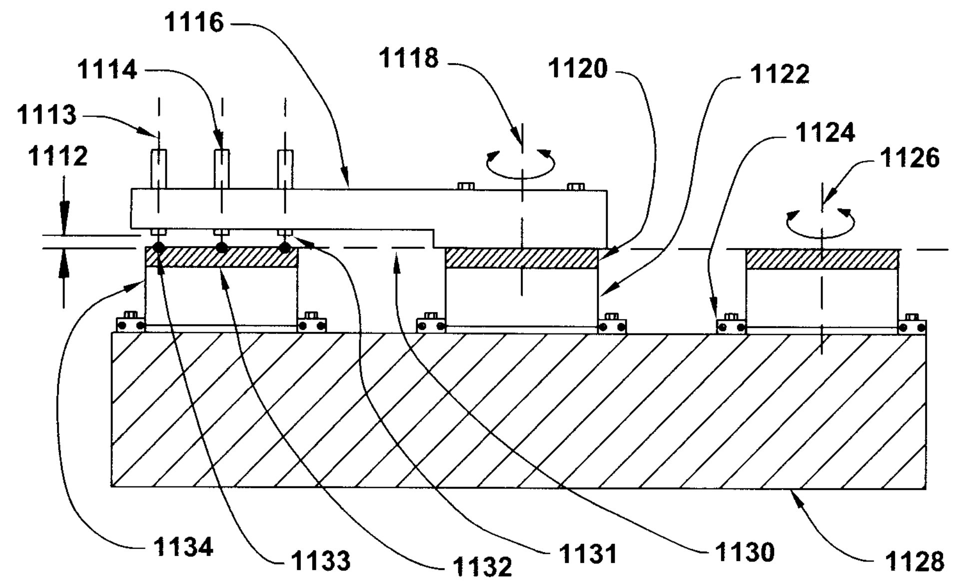
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Fig. 47

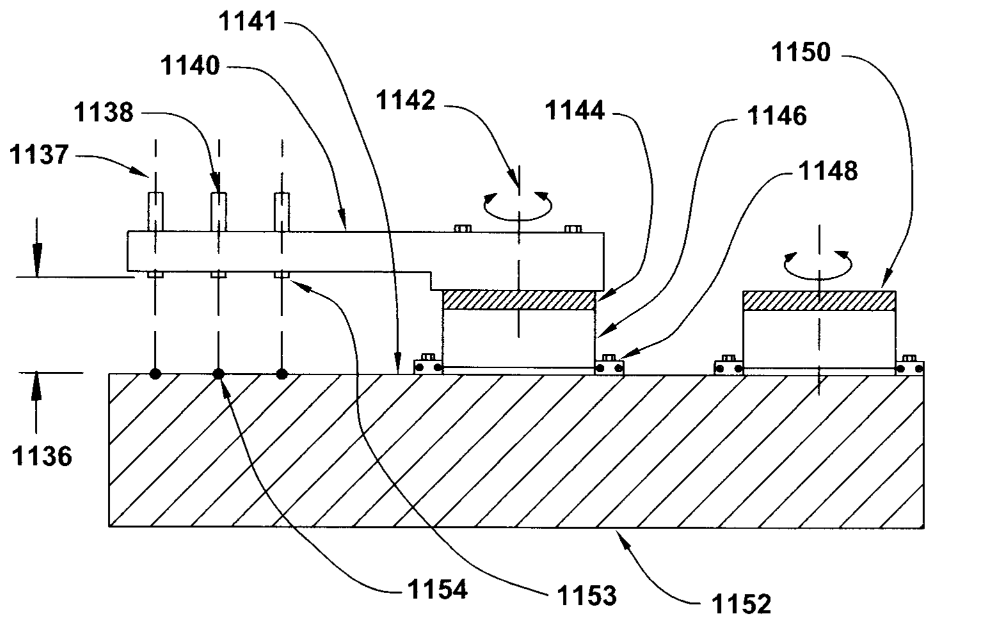
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Fig. 48

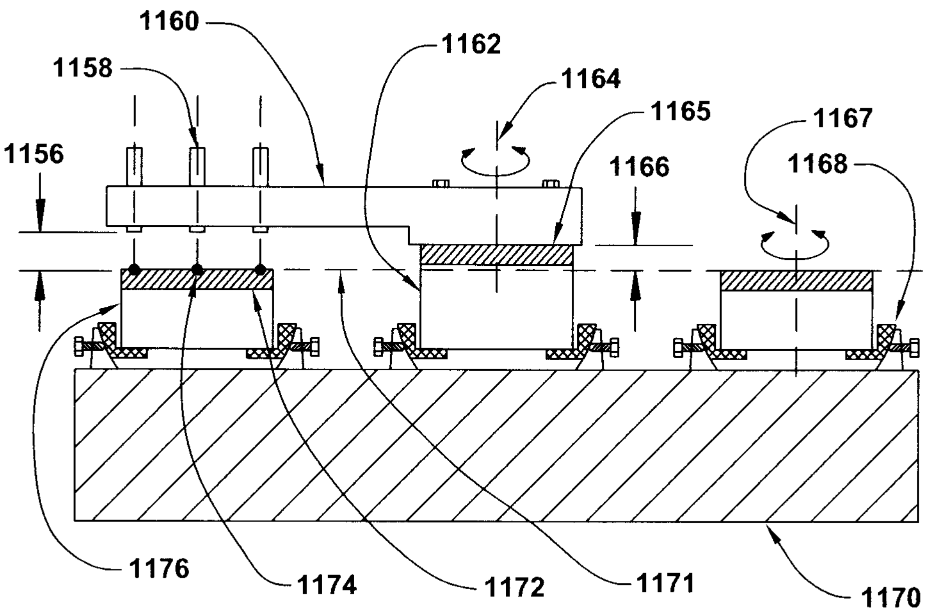
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Fig. 49

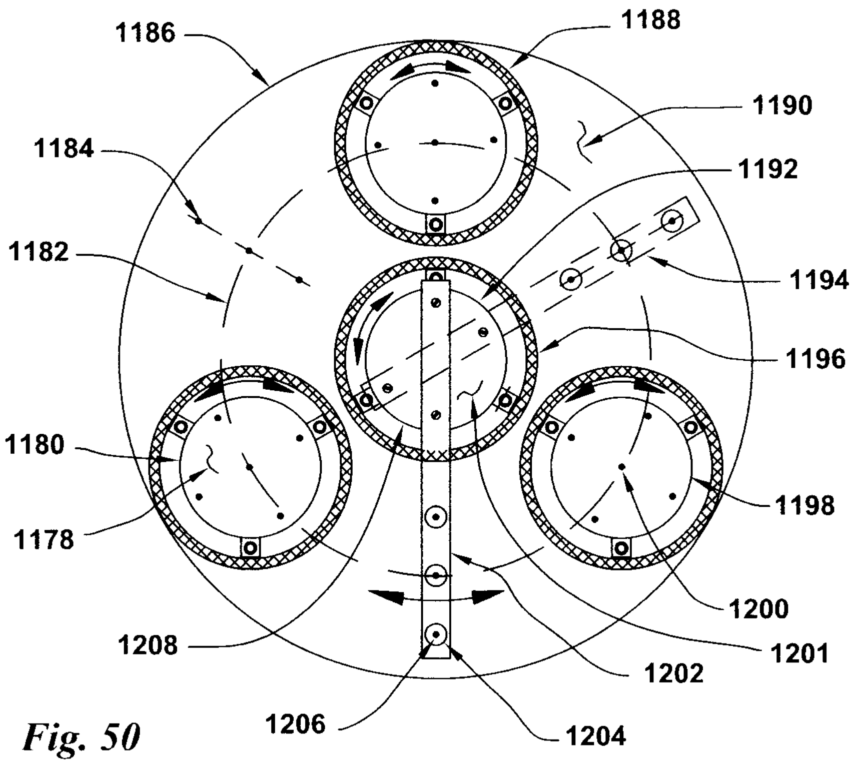
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Fig. 50

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2011/059683

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B24B 37/04 (2012.01)
USPC - 451/11
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - B24B 5/00, 5/313, 7/00, 37/00, 37/04, 37/07, 37/08, 37/10, 37/27, 37/28, 37/30, 41/00, 41/06, 49/00, 49/16 (2012.01)
USPC - 451/11, 24, 26, 285-288, 290, 342, 343, 398

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2011/0223835 A1 (DUESCHER) 15 September 2011 (15.09.2011) entire document	1-20
A	US 4,811,522 A (GILL JR) 14 March 1989 (14.03.1989) entire document	1-20
A	US 4,742,651 A (WITTSTOCK) 10 May 1988 (10.05.1988) entire document	1-20
A	US 4,450,652 A (WALSH) 29 May 1984 (29.05.1984) entire document	1-20

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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
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Date of the actual completion of the international search
05 March 2012

Date of mailing of the international search report
09 MAR 2012

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