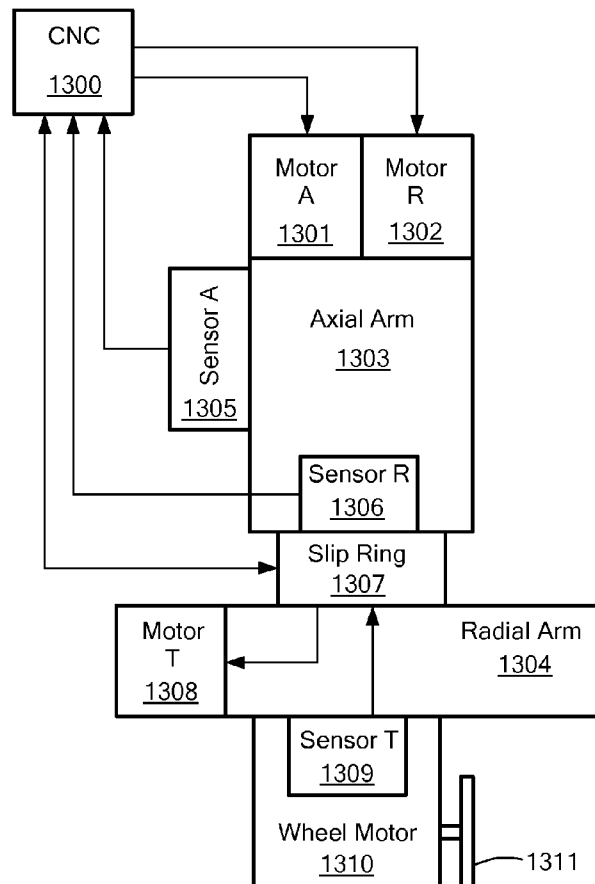




US 20120003900A1

(19) **United States**(12) **Patent Application Publication**
Hudson et al.(10) **Pub. No.: US 2012/0003900 A1**(43) **Pub. Date: Jan. 5, 2012**(54) **APPARATUS AND METHOD FOR
REFINISHING A SURFACE IN-SITU****Publication Classification**(51) **Int. Cl.**
B24B 51/00 (2006.01)
B24B 15/04 (2006.01)
(52) **U.S. Cl.** **451/5; 451/252**(57) **ABSTRACT**

A rotary grinding system includes a support frame and a grinding assembly coupled to the support frame for longitudinal movement, with respect to a workpiece attached to the support frame. A radial arm is suspended below the grinding assembly and rotated in a plane parallel to the workpiece. A grinding wheel traverses the radial arm, thereby working a circular, annular or sector portion of the workpiece. The height, and therefore the depth of cut, of the grinding wheel may be precisely adjusted via a single point adjustment screw or the like. Optionally, the grinding system may be controlled by a computer numeric controller (CNC) to automatically refinish programmed portions or all of the workpiece. Eccentric pins extending from the support frame and into the workpiece may be used to adjust the lateral position of the support frame, relative to the workpiece. Support members may be used to offload the weight of at least a portion of the grinding assembly, thereby relieving bearings of this weight, such as during shipment or storage of the system.

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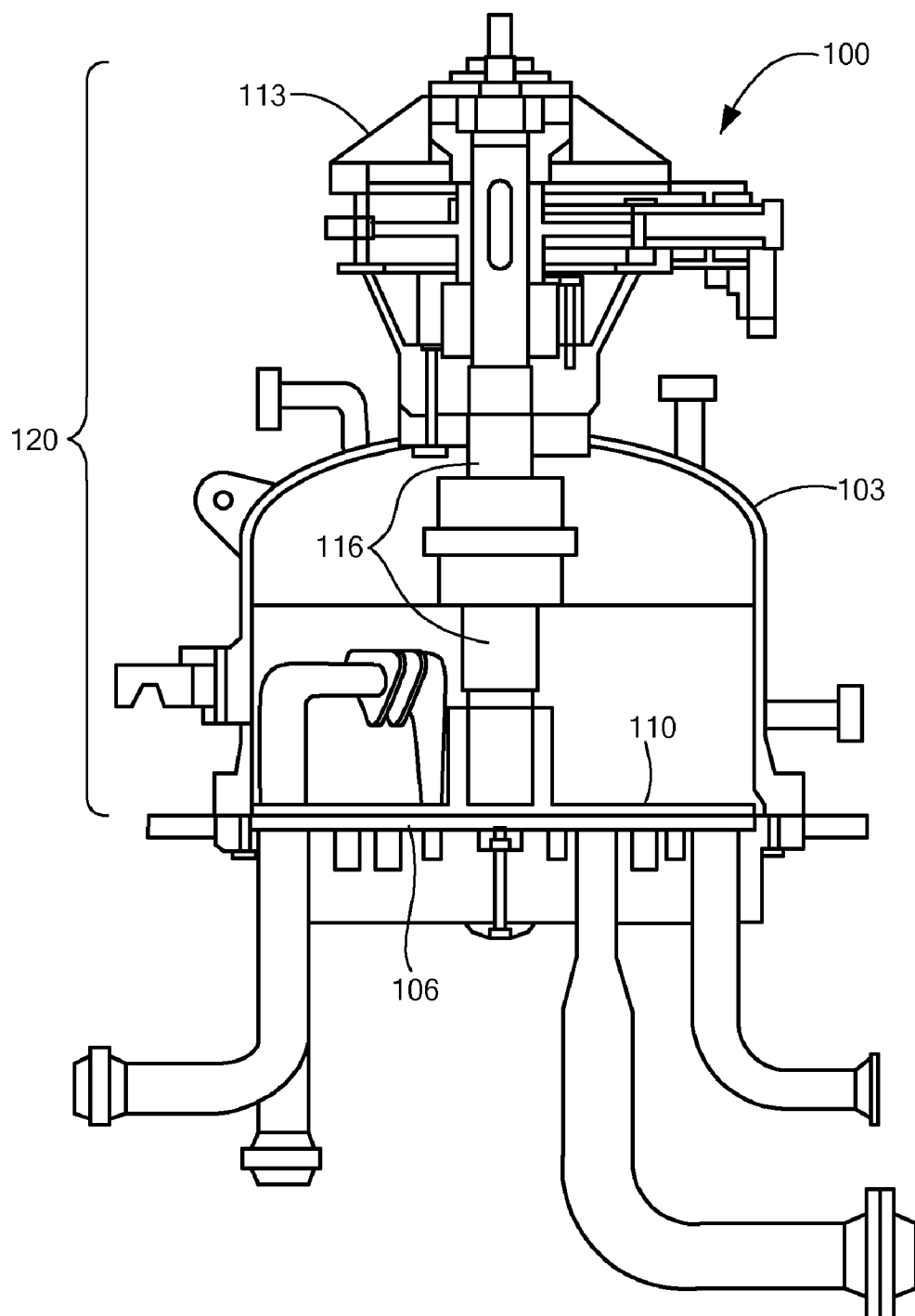


FIG. 1

PRIOR ART

FIG. 2

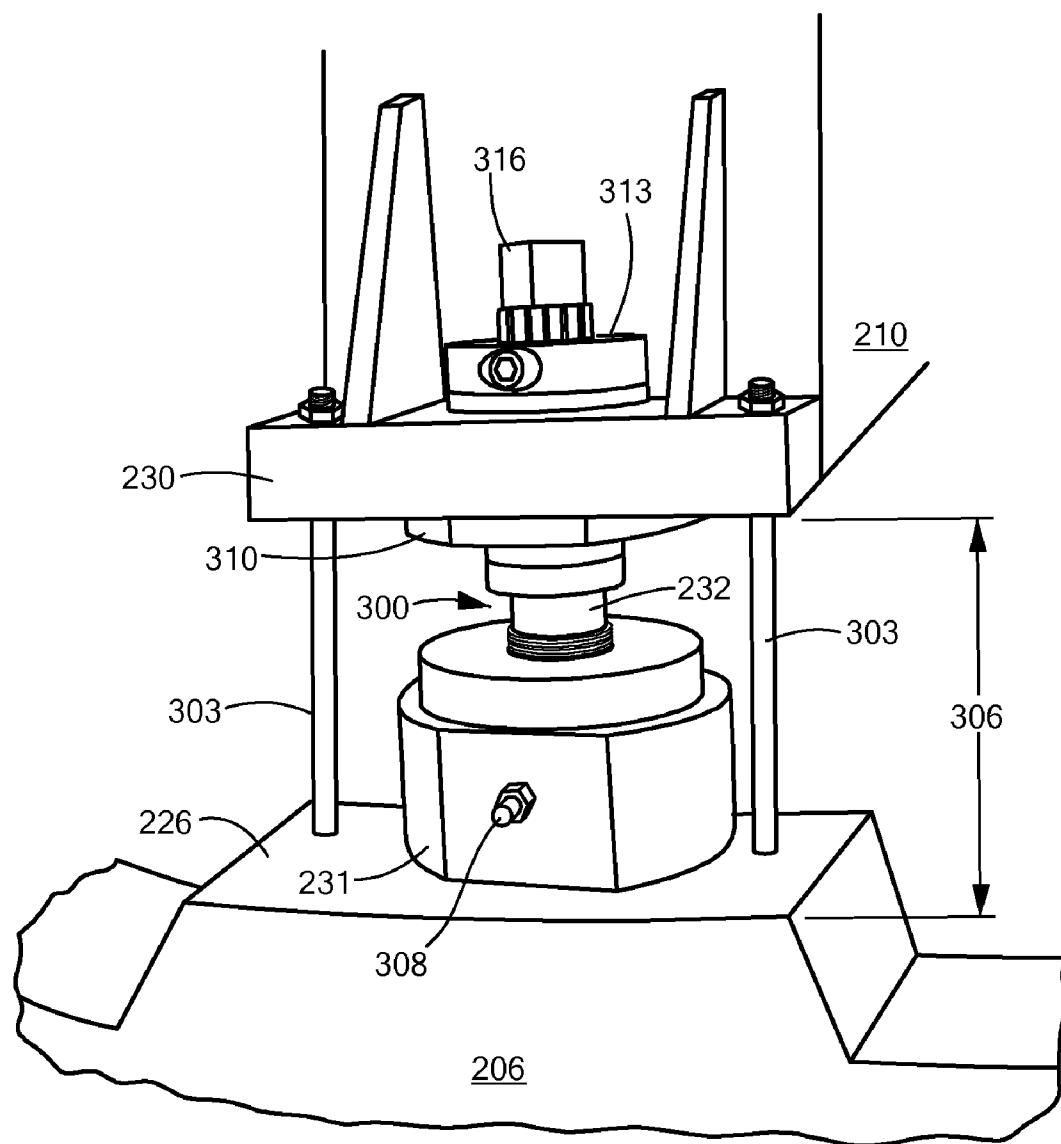


FIG. 3

FIG. 4

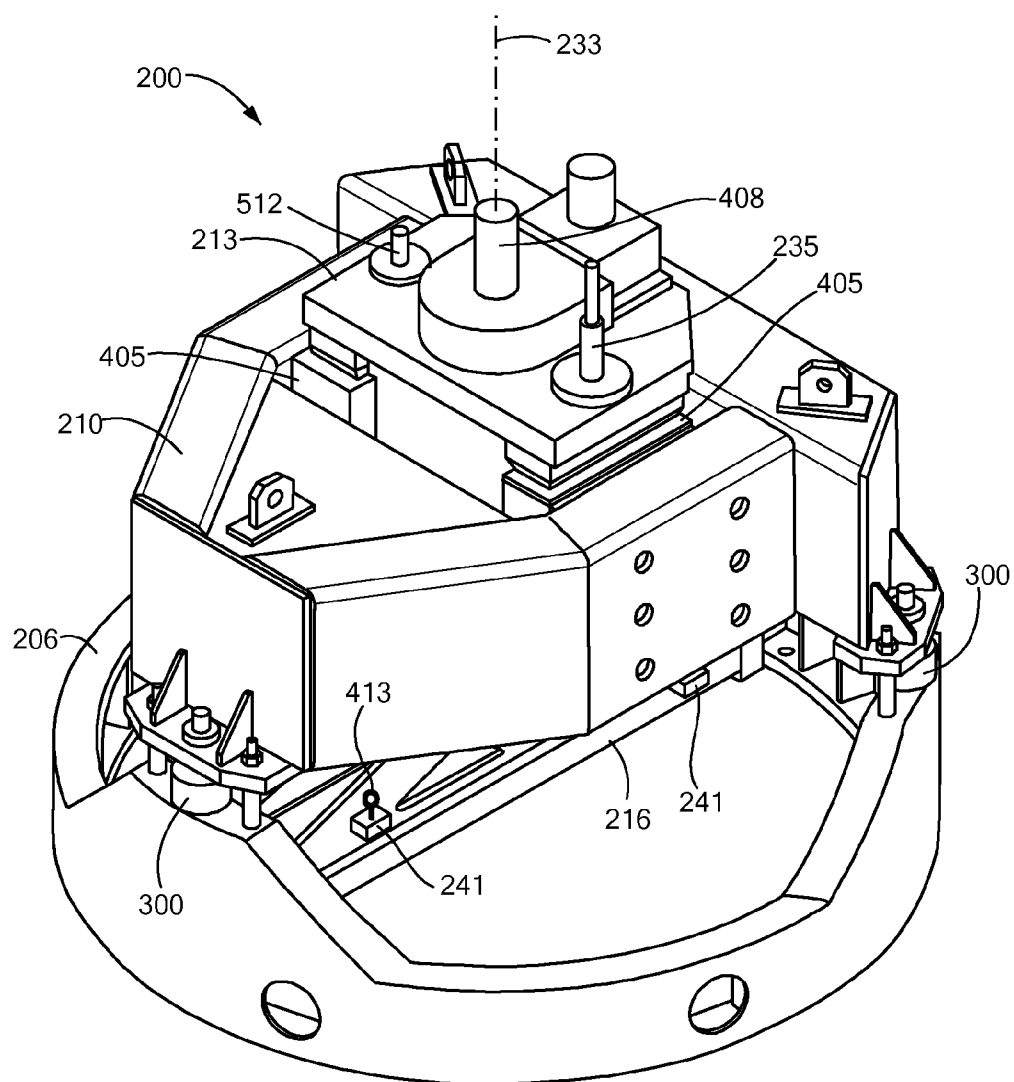


FIG. 5

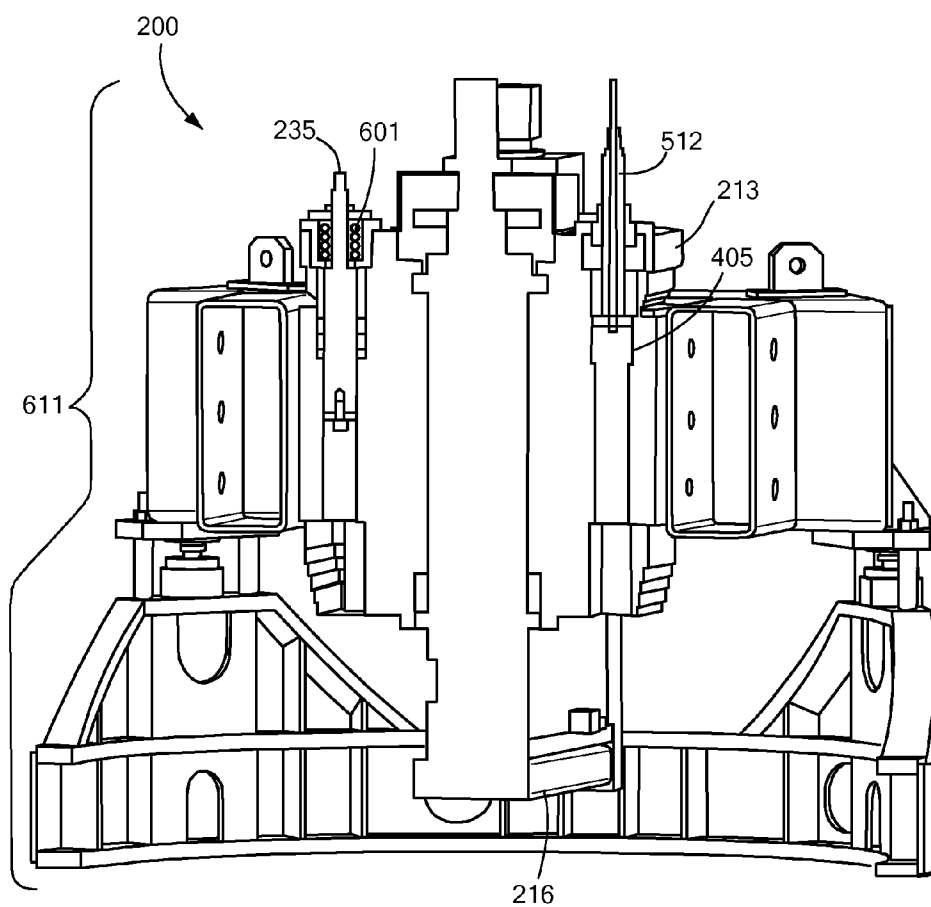


FIG. 6

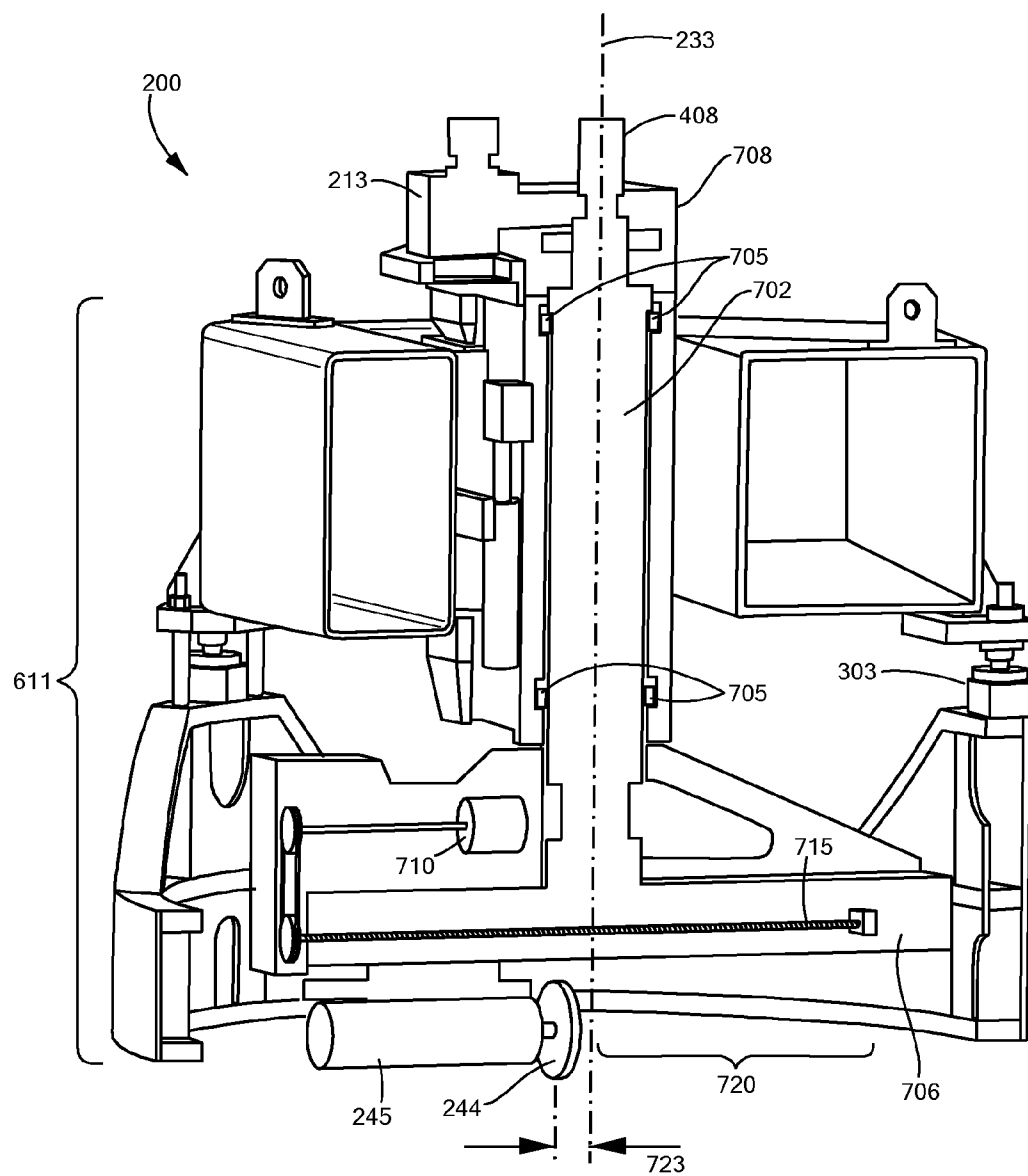


FIG. 7

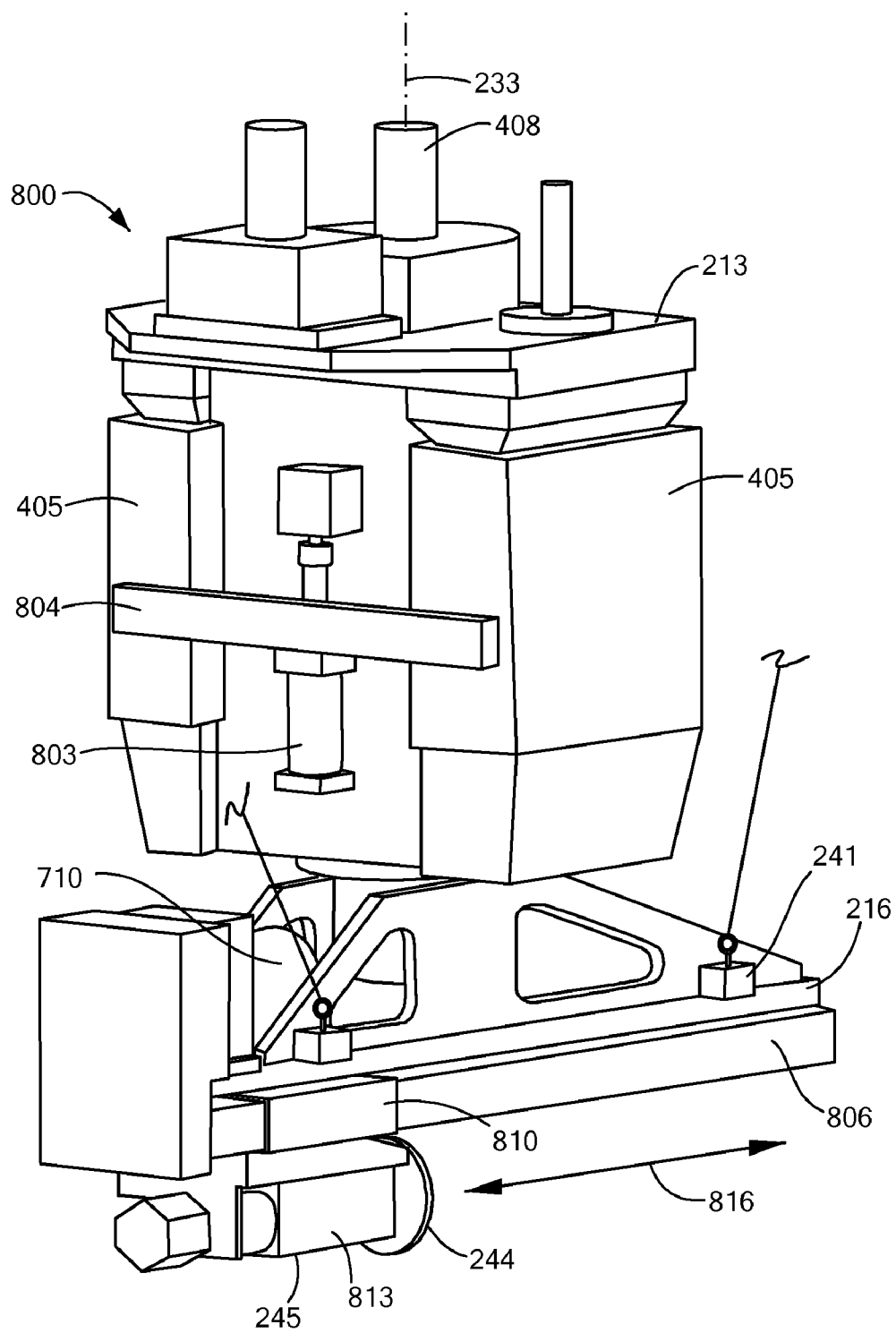


FIG. 8

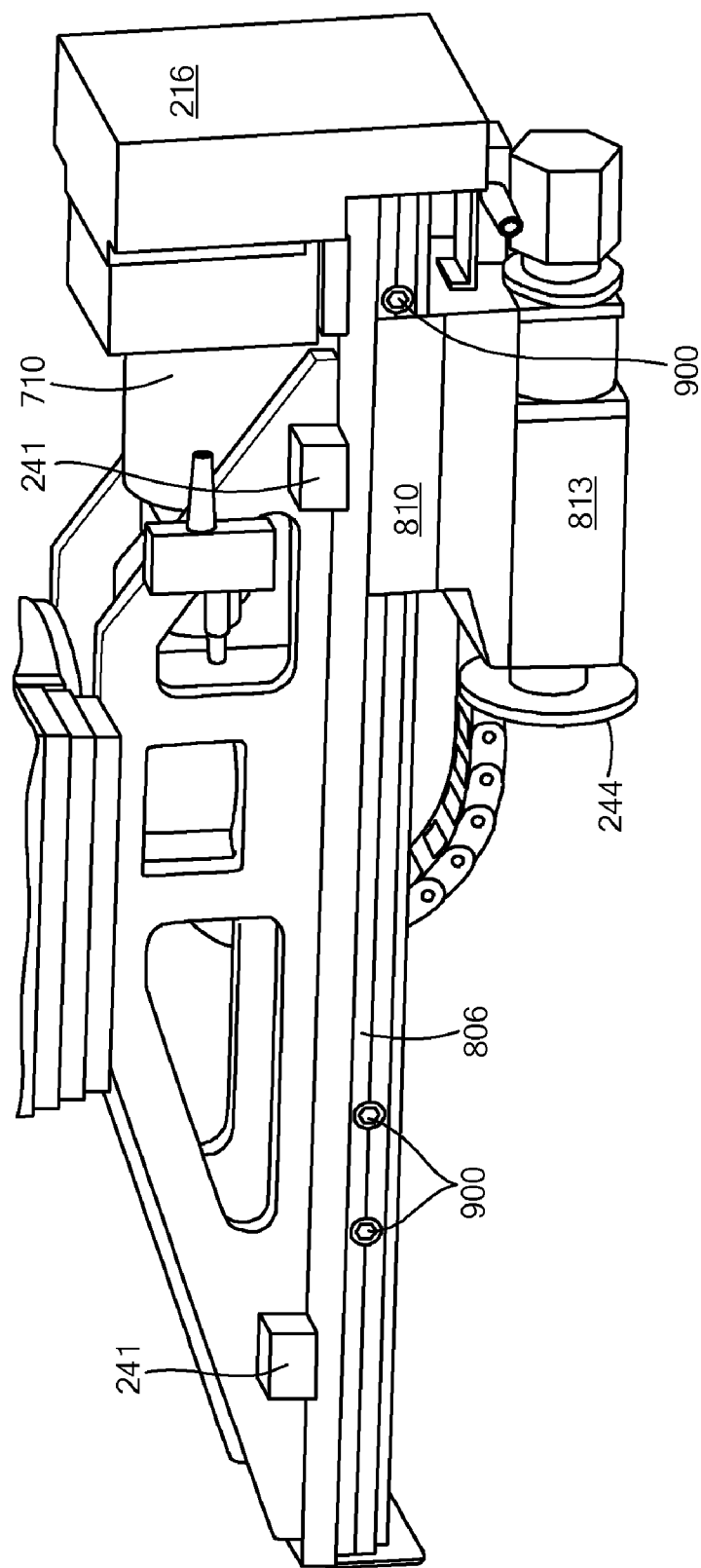


FIG. 9

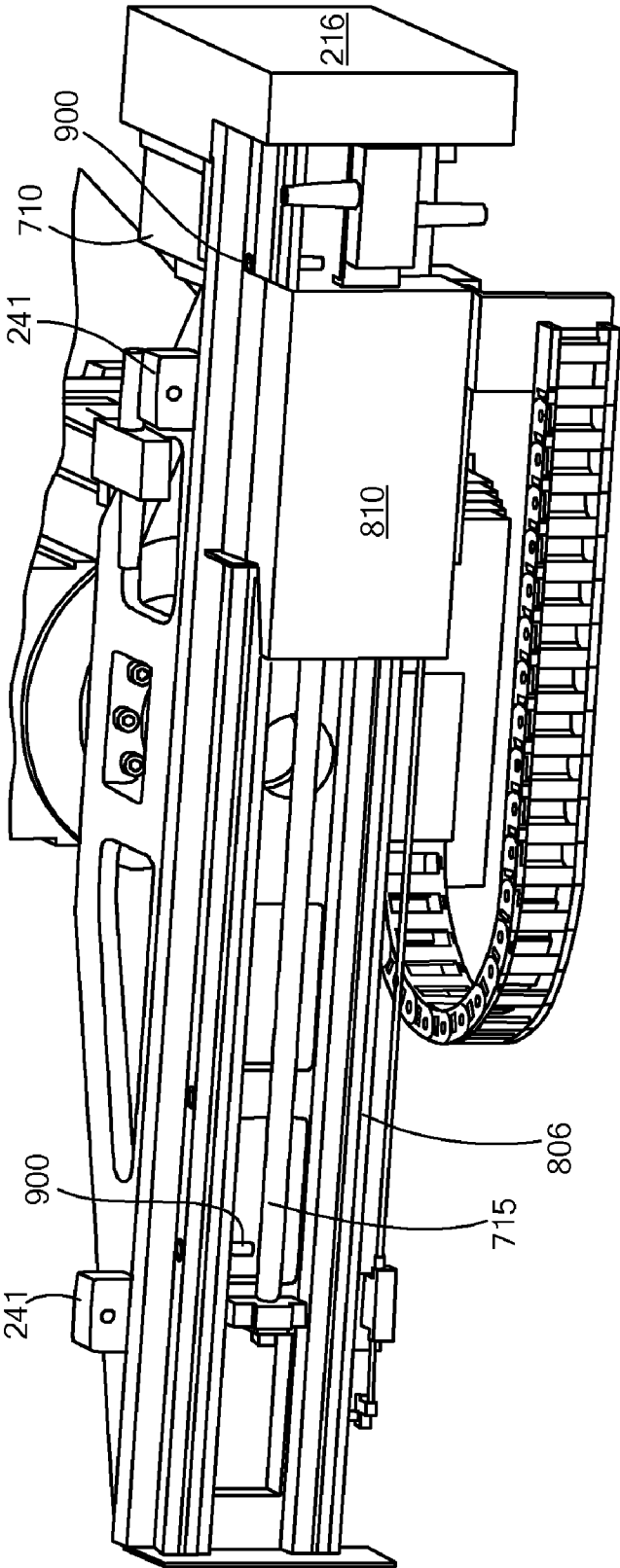


FIG. 10

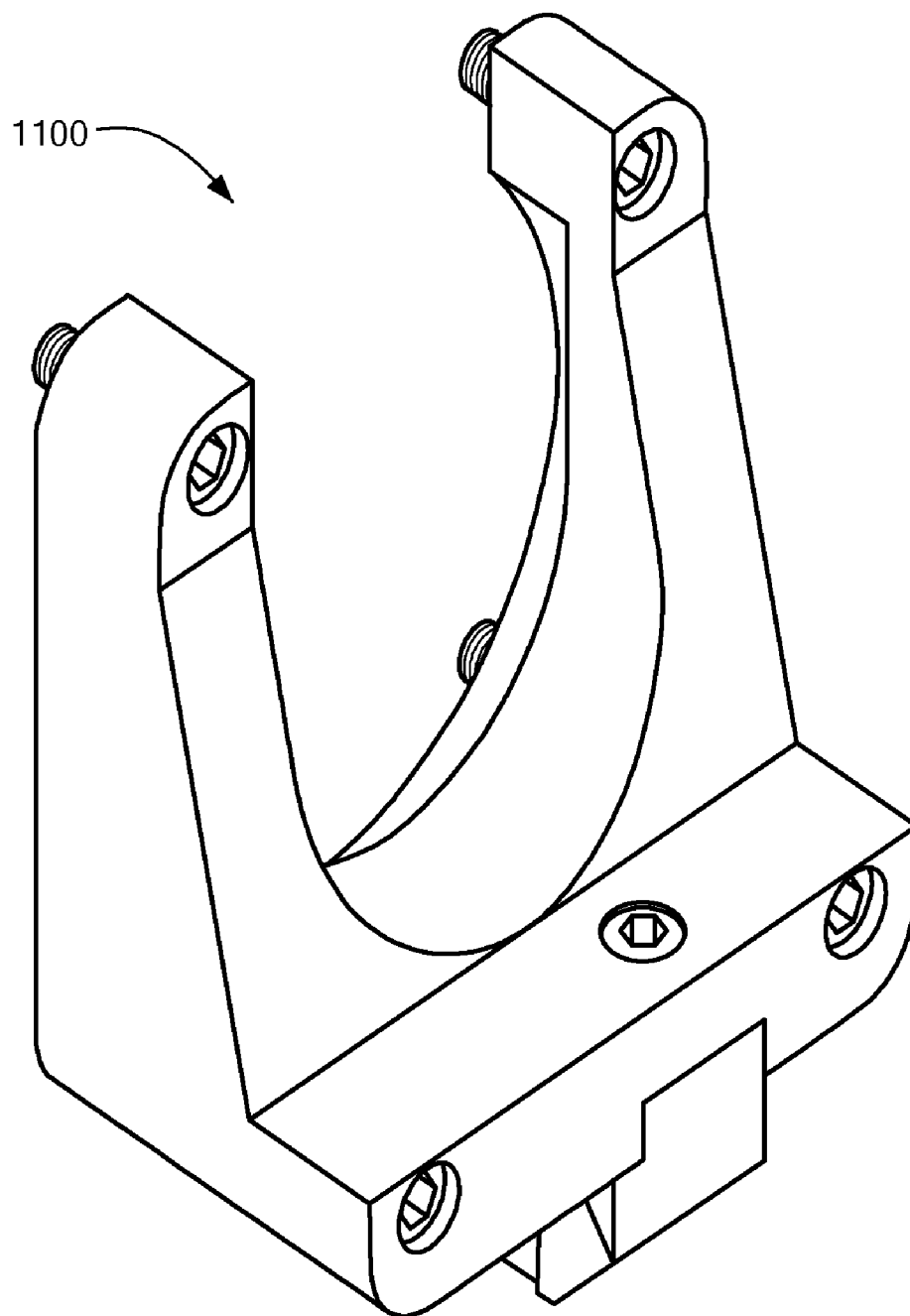


FIG. 11

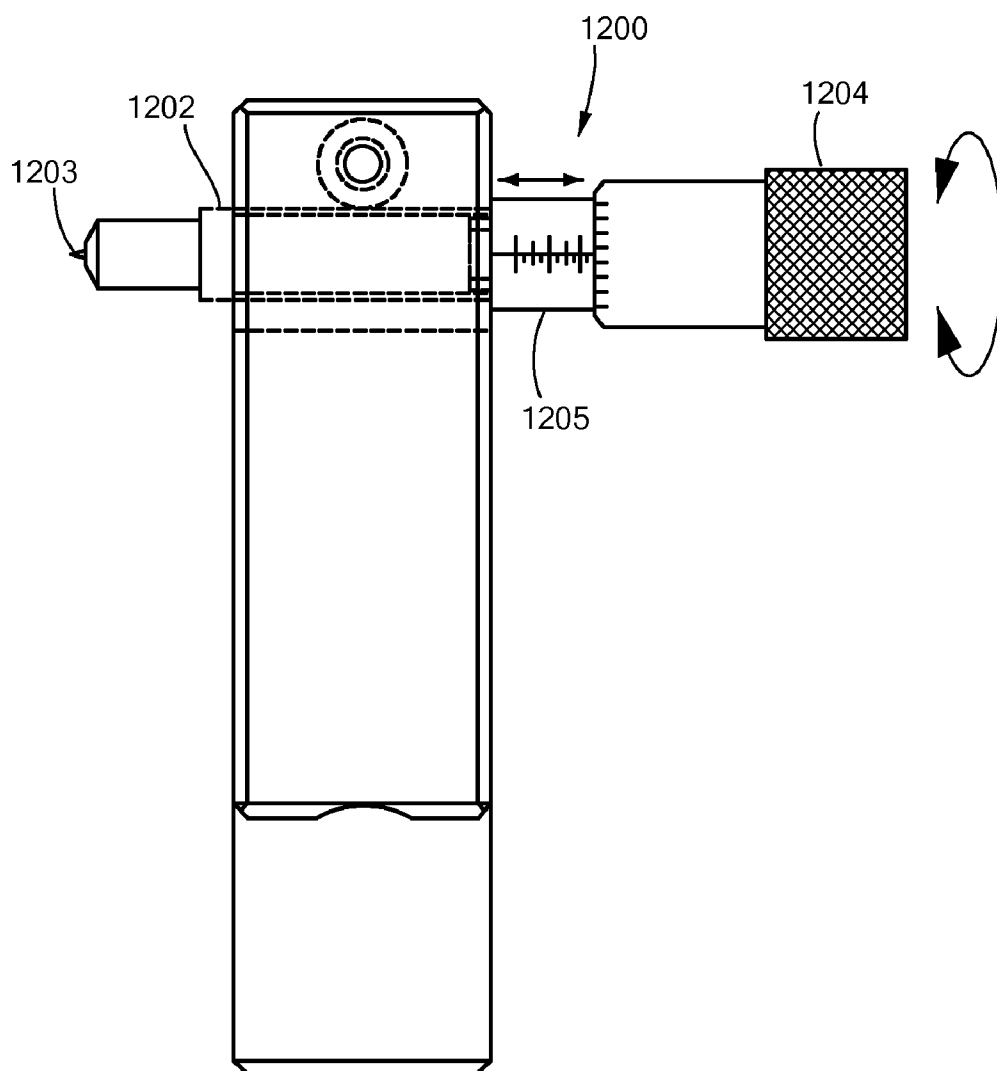


FIG. 12

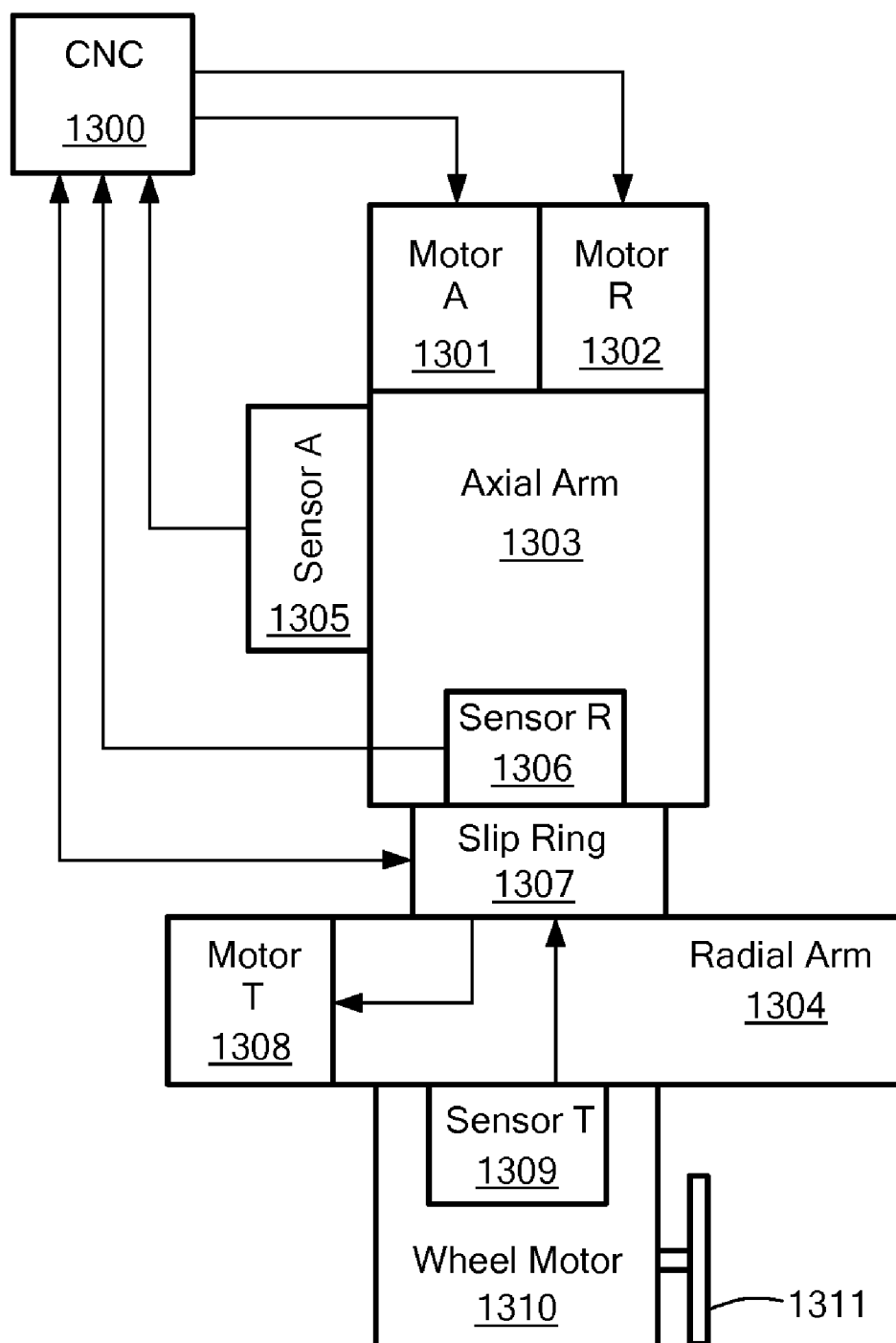


FIG. 13

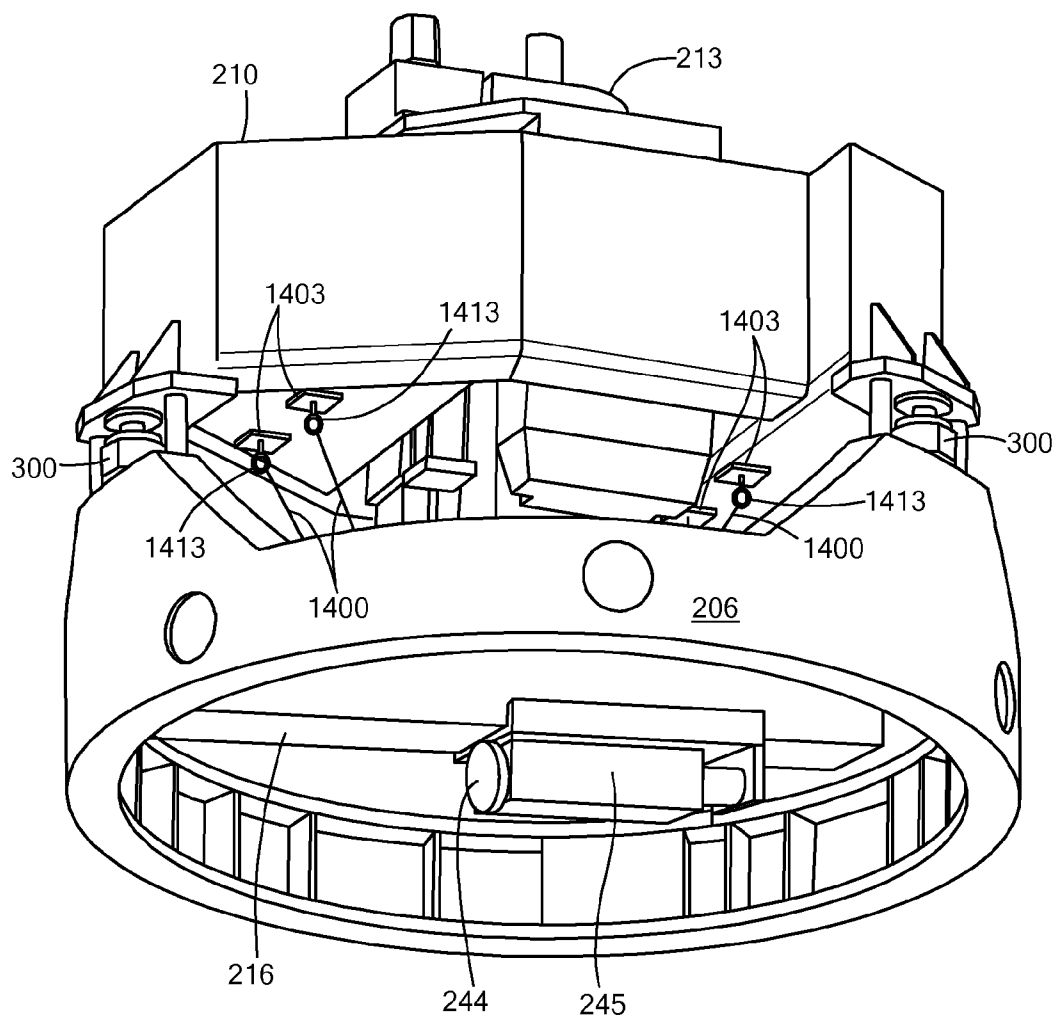


FIG. 14

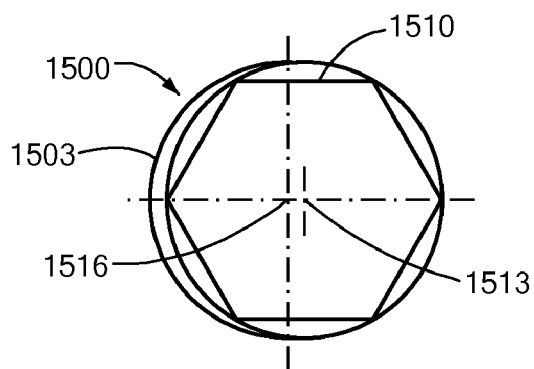


FIG. 15

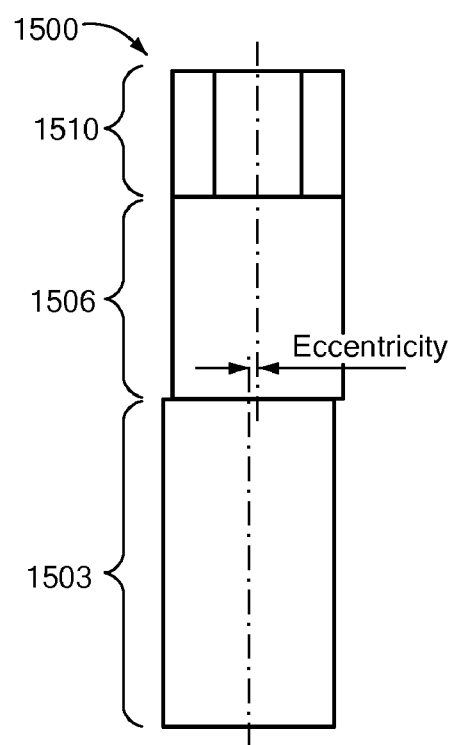


FIG. 16

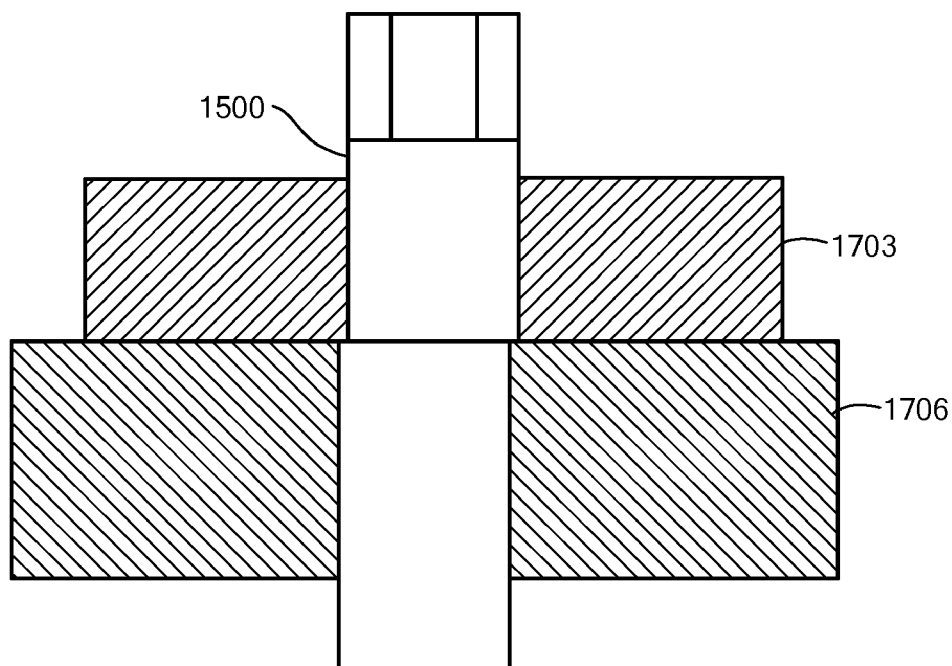


FIG. 17

APPARATUS AND METHOD FOR REFINISHING A SURFACE IN-SITU

TECHNICAL FIELD

[0001] The present invention relates to rotary grinders and more particularly to vertically axised rotary grinders.

BACKGROUND ART

[0002] A rotary valve is a valve, a part of which rotates intermittently to control fluid flow, such as in an oil refinery. A rotary valve typically includes a track plate, a rotor plate and an upper pressure-tight shell or casing. The casing and the track plate form a fluid-tight housing totally enclosing the rotor plate. The rotor plate is maintained in fluid-tight contact with the track plate and typically rotates in a horizontal plane. The rotor plate has a slick, smooth surface, referred to as a “seal surface,” and a number of channels and holes and/or ports that communicate with corresponding channels, holes and/or ports in the track plate in order to direct the flow of fluid within the rotary valve.

[0003] Wear and tear to the surface of the track plate during use can cause it to become damaged to such an extent that the necessary sealing required for proper fluid control is impaired. Such damage can be caused by corrosion, erosion, friction or distortion, or by the presence of foreign objects. Once the surface is damaged, either repair or replacement is necessary to reestablish an acceptable seal, so that the function of the rotary valve for the particular fluid control application is restored. To avoid the significant cost of replacing a worn track plate, the surface of the track plate may be refinished by a process commonly referred to as “resurfacing.”

[0004] It is known in the prior art to use a rotary grinder to refinish a surface of an item (a “workpiece”), such as a track plate. Due to the complexity, time and expense required to remove or ship such items, it is advantageous to be able to refinish the surface of a track plate without shipping the track plate or the entire valve to a refinishing facility.

[0005] Apparatus, such as those described in U.S. Pat. No. 6,921,322, for refinishing the surface of a track plate on site generally include height adjusting mechanisms to control depths of cuts made by a traversing rotary grinding wheel. A typical prior art refinishing machine includes a lower frame member and an upper frame member connected to each other by three adjustable assemblies spatially distributed around the peripheries of the frame members. In use, the lower frame member is rigidly attached to the track plate, and the grinding wheel is attached to the upper frame member. Adjusting the assemblies changes the height and orientation of the upper frame member and, consequently, the height and orientation of the grinding wheel, with respect to the lower frame member and the track plate. The height of the grinding wheel determines the depth of a refinishing pass over the track plate.

[0006] Adjusting the height of the grinding wheel to set the depth of a refinishing pass requires separately and precisely adjusting each one of the three assemblies. For a given refinishing pass, all the assemblies must be adjusted by precisely the same amount, which is difficult to do efficiently and consistently without stopping the machine, even for skilled operators. Many passes of the grinding wheel are typically required to resurface a track plate, because each pass removes

only a small amount of material. Consequently, refinishing a track plate can be time consuming and labor intensive.

SUMMARY OF EMBODIMENTS

[0007] An embodiment of the present invention provides a rotary grinder system that may be coupled with a workpiece. The rotary grinder system includes a support frame, a grinder assembly and a grinder wheel. The support frame may include an upper frame coupled to a lower frame. The support frame has an engagement region configured to be coupled to the workpiece. The grinder assembly is coupled to the support frame. The grinder assembly includes an axial arm and a radial arm coupled to the axial arm. The radial arm is coupled to the axial arm in a substantially orthogonal orientation. The radial arm is coupled to the axial arm, such that the radial arm rotates about an axis of the axial arm. The grinder wheel is rotatably coupled to the radial arm of the grinder assembly via a grinder wheel driver. The grinder wheel is translatable along the radial arm. The rotary grinder system also includes a single point axial positioner configured to drive the radial arm of the grinder assembly along the axis of the axial arm. The single point axial positioner is configured to drive the radial arm translationally, with respect to the support frame.

[0008] The single point axial positioner may include a ball screw system and, optionally, a mechanical slide. Optionally or alternatively, the single point axial positioner may be configured to drive the radial arm through translation of the axial arm or through rotation of the axial arm or through extension of the axial arm.

[0009] The grinder assembly may be coupled to the support frame via at least one slide assembly connected to the axial arm of the grinding assembly and to the support frame.

[0010] The axial arm may include a telescoping arm configured to change length upon application of force from the single point axial positioner.

[0011] The grinder wheel may be coupled to a mechanical slide on the radial arm and configured to translate along an axis of the radial arm. In this case, translation of the mechanical slide along the radial arm displaces the grinder wheel.

[0012] The radial arm may include a telescoping arm, and the grinder wheel may be coupled to the radial arm.

[0013] The rotary grinding system may also include a counterweight coupled to the grinder assembly and to the support frame. Such a counterweight may be configured to urge the grinder assembly in a direction away from the workpiece, along the axis of the axial arm. The counterweight may include a hydraulic device, a spring and/or a mass-based counterweight.

[0014] The rotary grinding system may also include a counterweight that is movably coupled to the radial arm. Such a counterweight may be configured to move along the radial arm a distance proportional to, and in a direction opposite, the grinder wheel.

[0015] A rotary grinding system according to claim 13, wherein the counterweight includes at least one of a chain drive, a screw drive and a dual rack with an interconnecting gear drive.

[0016] A rotary grinding system according to claim 1, further comprising a micrometer adjustable dressing tool configured to dress the grinder wheel.

[0017] Optionally, the rotary grinding system includes one or more eccentric pins. Each such eccentric pin extends through a respective hole defined by the support frame and

into the workpiece. Rotation of at least one of the eccentric pins laterally displaces the support frame, relative to the workpiece.

[0018] Optionally, the rotary grinding system includes at least one support member connected between the support frame and the grinder assembly. Such a support member may be configured to selectively support weight of at least a portion of the grinder assembly.

[0019] Optionally, the rotary grinding system may be computer numerically controlled. Actuators may be employed to adjust various elements of the rotary grinding system. A computer numerical control may be electrically connected to a first actuator, which may be configured to adjust the single point axial positioner. In addition, the computer numerical control may be electrically connected to a second actuator, which may be configured to translate the grinder wheel driver along the radial arm. Each of the actuators may include an encoder for measuring the magnitude of the respective adjustment and translation.

[0020] Optionally, the grinder assembly includes at least one slip ring configured to transmit electrical signals to the radial arm during rotation of the radial arm. Optionally or alternatively, the grinder assembly may include at least one hydraulic rotary union configured to transmit hydraulic fluid to the radial arm during rotation of the radial arm.

[0021] The grinder assembly may include at least one mechanical stop on the axial arm or on the radial arm.

[0022] The grinder wheel may be retractable translationally beyond a zero point on the radial arm, so as to expose a diameter of the workpiece.

[0023] The rotary grinding system may include an adapter plate. In this case, the support frame may be configured to be coupled to the workpiece via the adapter plate.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The invention will be more fully understood by referring to the following Detailed Description of Specific Embodiments in conjunction with the Drawings, of which:

[0025] FIG. 1 is a cut-away view of a prior art rotary valve assembly, with which embodiments of the present invention may be used;

[0026] FIG. 2 is an exploded perspective view of a rotary grinding system, in accordance with an embodiment of the present invention;

[0027] FIG. 3 is a close-up perspective view of a height-adjustable connector of the rotary grinding system of FIG. 2;

[0028] FIG. 4 is a perspective view of the rotary grinding system of FIG. 2, as seen from one side;

[0029] FIG. 5 is a perspective view of the rotary grinding system of FIG. 2, as seen from another side;

[0030] FIG. 6 is a cutaway view of the rotary grinding system of FIG. 2;

[0031] FIG. 7 is another cutaway view of the rotary grinding system of FIG. 2;

[0032] FIG. 8 is a perspective view of a rotary grinding assembly portion of the grinding system of FIG. 2;

[0033] FIG. 9 is a perspective view, from one side, of a radial arm portion of the rotary grinding system of FIG. 2;

[0034] FIG. 10 is a perspective view, from below, of the radial arm of FIG. 9;

[0035] FIG. 11 is a perspective view of a single point tool holder for a rotary grinding system, in accordance with an embodiment of the present invention;

[0036] FIG. 12 is a side view of an adjustable grinding wheel dressing tool holder, according to an embodiment of the present invention;

[0037] FIG. 13 is a schematic block diagram of a computer-controlled rotary grinding system, according to an embodiment of the present invention;

[0038] FIG. 14 is a perspective view, from below, of the rotary grinding system of FIG. 2; and

[0039] FIGS. 15, 16 and 17 are respective top, side and sectional views of an eccentric adjuster, according to an embodiment of the present invention.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[0040] In accordance with preferred embodiments of the present invention, methods and apparatus are disclosed for a rotary grinding system useful in resurfacing applications, particularly where a workpiece requires resurfacing without removal from its environment. Advantageously, the cutting depth of the grinding system can be adjusted at a single point. Consequently, depth-of-cut adjustments can be made more precisely, because equal adjustments need not be made on multiple connecting members. Furthermore, the depth-of-cut adjustments may be made while the grinding system is in operation, thereby significantly reducing the total amount of time to resurface a workpiece.

[0041] The rotary grinding system may be coupled to a workpiece via a support frame of the rotary grinding system. A grinding assembly, coupled to the support frame, may be axially re-positioned through precise adjustments made at a single location. The axial repositioning may be vertical repositioning, or the grinding assembly may be disposed in an alternative orientation, for example horizontally, in which case the axial repositioning would be horizontal. As noted, such adjustments may serve to alter the depth of a grinding wheel that is coupled to a radial arm of the grinding assembly, thereby changing the amount of material the wheel removes from the workpiece in one pass across the workpiece.

[0042] The radial arm may be rotated in a plane parallel to the workpiece to move the grinding wheel in a circular pattern across the surface of the workpiece, and the grinding wheel may be translated radially across the surface of the workpiece. Accordingly, an entire circular area, or an annular portion, of a workpiece may be resurfaced using embodiments of the present invention, and the depth of the resurfacing cut may be accurately and quickly adjusted via adjustments of a single re-positioning mechanism, such as a single point screw adjuster. The grinding system makes the grinding/machining process more accurate and efficient, thereby decreasing the down time experienced by an end-user.

[0043] FIG. 1 illustrates a typical prior art rotary valve 100, with which embodiments of the present invention may be used. As noted, a rotary valve 100 typically includes an upper pressure-tight shell or casing 103 with a track plate 106 and a rotor plate 110 disposed within the shell 103. The rotor plate 110 is maintained in fluid-tight contact with the track plate 106 and typically rotates in a horizontal plane. The rotor plate 110 is driven by a drive assembly 113 and a drive shaft 116. If the track plate 106 becomes damaged, an upper portion 120 of the rotary valve 100, from (and including) the rotor plate 110 up, may be removed from the rotary valve 100. Upon removal of the upper portion 120, a rotary grinding system (not shown) according to the present disclosure may be mounted to the track plate 106 or another portion of the rotary valve 100, and

the rotary grinding system may be used to refinish the surface of the track plate 106. Alternatively, the track plate 106 may also be removed, and the rotary grinding system may be attached to the track plate 106 to refinish it.

[0044] FIG. 2 is an exploded view of a rotary grinding system 200, according to an embodiment of the present invention. Also shown in FIG. 2 is an exemplary track plate 204, to which the rotary grinding system 200 may be attached. The rotary grinding system 200 includes four main subassemblies: a lower frame 206, an upper frame 210, an axial drive assembly 213 and a radial drive assembly 216, each of which is described in detail below. The lower frame 206 is attached to a workpiece, such as the track plate 204. The upper frame 210 is rigidly, but adjustably, attached to the lower frame 206. The lower frame 206 and the upper frame 210 are collectively referred to as a support frame. The axial drive assembly 213 is attached to the upper frame 210, such that the height of the axial drive assembly 213 above the track plate 204 can be adjusted by a single adjustment point. The radial drive assembly 216 is suspended by and below the axial drive assembly 213.

[0045] The upper and lower frames 206 and 210 are designed to provide a known and engineered amount of deflection, which allows for specific amounts of flexibility in the system. Various parts of frames 206 and/or 210 may include hollow or tubular members to minimize the weight of the frames 206 and/or 210.

[0046] As noted, the lower frame 206 may be rigidly attached, such as by bolts, to the track plate 204 or to another workpiece or to another portion of a rotary valve. The bolts (not shown) may be inserted through some or all holes 220 defined in the lower frame 206 and into corresponding holes 223 in the track plate 204. Optionally or alternatively, an adapter plate (not shown) may be placed between the lower frame 206 and the track plate 204 or another workpiece, in case the workpiece lacks holes 223 that align with the holes 220 in the lower frame 206 or in case the workpiece is of a size or shape that is otherwise incompatible with the lower frame 206. Such an adapter may have holes that align with the holes 220 in the lower frame 206 and additional holes that align with holes in the workpiece. Optionally or alternatively, the adapter may provide hooks, bosses, threads or other features that may be used to secure the adapter to the workpiece.

[0047] Prior to tightening the bolts to secure the lower frame 206 to the track plate 204, eccentric pins inserted through some of the holes 220 and into corresponding holes 223 in the workpiece 204 may be used to laterally adjust the position of the lower frame 206, relative to the workpiece 204. An exemplary eccentric pin 1500 is shown in FIGS. 15, 16 and 17. Each eccentric pin 1500 includes a lower portion 1503 and an upper portion 1506, as well as a hexagonal or other suitably shaped drive portion 1510. Centers 1513 and 1516 of the upper and lower portions 1506 and 1503 of the pin 1500 do not coincide, thereby providing the eccentricity. FIG. 17 is a cross-sectional view of a portion 1703 of the lower frame and a portion 1706 of the workpiece, with an eccentric pin 1500 inserted in corresponding holes defined by the lower frame and by the workpiece. Rotating the pin 1500 displaces the lower frame, relative to the workpiece.

[0048] Returning to FIG. 2, the rotary grinding system 200 includes a multi-point mounting system. The lower frame 206 may include a number (preferably three) of raised flats 226 to facilitate attaching the upper frame 210 to the lower frame 206. The upper frame 210 may include a corresponding num-

ber of ribbed flanges 230, only two of which are visible in FIG. 2. The flats 226 define through holes that correspond to holes defined in flanges 230. The upper frame 210 is oriented such that the holes in the flanges 230 register over the holes in the flats 226, and height-adjustable connectors, such as lockable bolts passed through the holes, are used to connect the upper frame 210 to the lower frame 206. Portions 231 and 232 of one such height-adjustable connector are shown.

[0049] FIG. 3 is a close-up view of an exemplary height-adjustable connector 300 installed between one of the flats 226 and one of the corresponding flanges 230. Two stress-offloading bolts 303 are also installed between the flat 226 and the flange 230 to support the weight of the upper frame 210 while the grinding system 200 is transported or stored, thereby relieving the connector 300 from bearing this weight. However, in use, the stress-offloading bolts 303 are loosened or removed, leaving the connector 300 to bear the weight of the upper frame 210 and to control the distance 306 between the flat 226 and the flange 230.

[0050] The connector 300 includes a lower portion 231 rigidly attached to the flat 226 of the lower frame 206. The connector 300 includes a bearing (spherical) for misalignment and flexibility, and a nut. The lower connector portion 231 defines a precision threaded hole, into which a precision threaded bolt 232 is threaded. The lower connector portion 231 may include a grease fitting 308 to facilitate lubricating the bolt 232. The bolt 232 is vertically captured above and below the flange 230 by capture members 310 and 313, such that the vertical position of the flange 230 is defined by the position of the bolt 232. The height of the upper frame 210 may, therefore, be adjusted, relative to the lower frame 206, by turning the bolt 232, such as via a square 316 or another shaped drive portion defined by the top of the bolt 232. Once a desired separation distance between the flat 226 and the flange 230 is achieved, further rotation of the bolt 232 may be prevented by tightening the capture member 313, which may include a split locking collar, or the bolt 232 may be self-locking to maintain its position.

[0051] Returning to FIG. 2, the height and orientation of the upper frame 210 may be adjusted, relative to the lower frame 206, by making suitable adjustments to one or more of the connectors 300 (not shown in FIG. 2, but visible in FIG. 3). Once the lower frame 206 is rigidly attached to the track plate 204, adjusting the connectors 300 also adjusts the height and orientation of the upper frame 210, relative to the track plate 204. It should be noted that the distances between respective corresponding flats 226 and flanges 230 need not be equal. That is, the connectors 300 may be adjusted as needed until the axis 233 of the upper frame 210 is perpendicular to the track plate 204. These adjustments may compensate for irregularities in the sizes or shapes of the frames 206 and 210 or for an imperfect mating between the lower frame 206 and the track plate 204. Once the upper frame 210 is properly oriented, relative to the track plate 204, the adjustable connectors 300 may be locked to prevent changes in the height or orientation of the upper frame 210 during the refinishing process. Alternatively, the connectors 300 may be non-adjustable.

[0052] The axial drive assembly 213 is height-adjustably attached to the upper frame 210. Thus, the axial drive assembly 213 may be moved up or down, relative to the upper frame 210, as indicated by arrow 234. In one embodiment, the axial drive assembly 213 is moveably attached to the upper frame 210 via two hardened way slides. One portion (not shown) of

each hardened way slide is attached to the upper frame **210** at **236**, and the other portion **240** of each hardened way slide is attached to the axial drive assembly **213**. A suitable height adjuster, such as a ball thread, rack and pinion, chain and gear or telescoping hydraulic member, may be used to adjust the height of the axial drive assembly **213**, relative to the upper frame **210**. Advantageously, the height of the axial drive assembly **213** may be adjusted by a single point adjustment **235**.

[0053] To prevent or limit stress on bearing assemblies of the axial drive spindle during shipment or storage of the rotary grinding system **200**, the combined weight of the radial arm assembly **216** and the upper frame **210** may be borne by removable links, such as wires, cables, chains, hooks or the like, installed between the radial arm assembly **216** and the upper frame **210**. The links may be shortened, and/or the height adjuster may be adjusted to lower the axial drive assembly **213** and the radial arm assembly **216**, until the combined weight is borne by the links.

[0054] In one embodiment, the radial arm assembly **216** includes four lugs **241** (only two of which are visible in FIG. 2) and a lift eye **413** (not shown in FIG. 2, but shown in FIGS. 4 and 5) is attached to each lug **241**. Four corresponding lift eyes **1413** (not visible in FIG. 2, 4 or 5, but shown in FIG. 14) are attached to the bottom of the upper frame **210**. In preparation for shipment or storage of the rotary grinding system **200**, a suitable link, such as a chain and turnbuckle, may be connected between each pair of corresponding lift eyes **413** and **1413**. FIG. 14 schematically shows four such links **1400** and four pads **1403** on the bottom of the upper frame **210** to which the upper lift eyes **1413** may be attached. The links **1400** may be shortened as needed, such as by adjusting the turnbuckles (not visible) to tension the links **1400**, thereby reducing or offloading the combined weight of the radial arm assembly **216** and the axial drive assembly **213**. Optionally or alternatively, the axial drive assembly **213** may be adjusted to lower the radial arm assembly **216** until the links **1400** bear its weight. The load on the height adjuster **300** may be offloaded by placing sleeves around one or both bolts **303** and lowering the upper frame **210** until the sleeve(s) bear the weight.

[0055] Returning to FIG. 2, the radial drive assembly **216** (also referred to as a “radial arm”) is suspended by an axial drive shaft (not visible) (also referred to as an “axial arm”) below the axial drive assembly **213**. Thus, the radial drive assembly **216** moves up and down with the axial drive assembly **213**. The axial drive assembly **213** includes a motor coupled to the axial drive shaft for rotating the radial arm assembly **216** about the axis **233** of the upper frame **210**, as indicated by arrow **243**. The axial drive assembly may be capable of driving the radial arm assembly **216** in one or both of the directions indicated by the arrow **243**.

[0056] The radial drive assembly **216** includes a grinding wheel **244** and a motor **245** to rotate the grinding wheel **244**. The radial drive assembly **216** also includes a track **246** and another motor (not visible) to translate the grinding wheel **244** along at least part of the length of the radial drive assembly **216**, as indicated by arrow **250**. Thus, in operation, the combination of rotating the axial drive shaft and translating the grinding wheel **244** back and forth causes the grinding wheel **244** to work on all or a desired annular portion of the track plate **204**. Adjusting the height of the axial drive assembly **213** alters the depth to which the grinding wheel **244** cuts.

[0057] FIG. 4 is a perspective view of the rotary grinding system **200** of FIG. 2. The grinding system **200** includes a

support system **411** that includes the upper frame **210** and the lower frame **206**. The lower frame **206** has a circular base that may be engaged with a circular workpiece (not shown in FIG. 4). The upper frame **210** is rigidly attached to the lower frame **206** via three connection assemblies **300**, only two of which are visible in FIG. 4. As noted, in some embodiments, the connection assemblies **300** may be adjustable, whereby the level and/or orientation of the upper frame **210** may be varied, relative to the lower frame **206**. Although an embodiment with three connection assemblies **300** is described, other embodiments may include other numbers of connection assemblies. The support frame **411** may be disassembled, such as by detaching the upper frame **210** from the lower frame **206**, such as for ease of shipment, storage or installation.

[0058] The support frame **411** shown in FIG. 4 is merely exemplary, and various other configurations may be provided in accordance with other embodiments of the present invention. Alternative configurations of the support frame **411** include uni-body constructions and alternatively shaped support frame members. The shape(s) may be chosen to suit a particular grinding application, as dictated by a particular workpiece.

[0059] FIG. 4 also shows the axial drive assembly **213** attached to the support frame **411**. The axial drive assembly **213** may be moved vertically along the axis **233** through adjustments to the single point adjustment screw **235**. The axial drive assembly **213** maintains its alignment, with respect to the support frame **411**, when moved along the axis **233** via sliders **405** (which may be implemented as hardened way slides, dovetail slides or any other suitable translating device) engaging the axial drive assembly **213** and the support frame **411**. In this embodiment, sliders **405** are located on opposite sides of the axial arm **408** of the axial drive assembly **213**. In other embodiments, other numbers (including one) of slides may be used and/or the slides may be positioned differently than shown in FIG. 4. The radial drive assembly **216**, which may be rotated about the axis **233** of the axial drive assembly **213**, is partially shown in FIG. 4.

[0060] FIG. 5 is a perspective view of the rotary grinding system **200** shown in FIG. 4 illustrating another side of the system. In this figure, a third connection assembly **300** between the lower frame **206** and the upper frame **210** is visible. Additionally, both of the vertical slides **405**, each located on an opposite side of the axial drive assembly **213**, are visible. The single point adjustment screw **235** is also shown. In this embodiment, the height of the axial drive assembly **213** and, therefore, the depth of cut, may be adjusted by turning the adjustment screw **235** on top of the axial drive assembly **213**. In other embodiments of the invention, the single point adjustment **235** may be located at alternative locations.

[0061] Optionally, the single point adjustment **235** may be provided via an alternative adjustment mechanism capable of translating the axial drive assembly **213** along axis **233**. For example, the axial arm **408** of axial drive assembly **213** may include a telescoping arm to move the radial drive assembly **216** and the grinding wheel attached thereto (not visible) closer to, or further from, the workpiece. A telescoping axial arm may be extended or retracted using hydraulic pressure or any other suitable driver.

[0062] The rotary grinding system **200** may also include a locking mechanism **512** or fixed or adjustable vertical stop to prevent and/or limit vertical travel of the axial drive assembly

213, relative to the upper frame **210**, beyond upper and/or lower predetermined limits, for example so as to prevent grinding below a predetermined depth or to prevent back-driving during operation. Optionally or alternatively, the vertical locking mechanism **512** can be locked to prevent vertical movement of the axial drive assembly **213**, such as during shipment or storage. Locking vertical movement of the axial drive assembly **213**, relative to the upper frame **210**, and then installing links to support the weight of the radial arm assembly **216** below the upper frame **210** (as described above) offloads roller bearings **705** (described below, in relation to FIG. 7) in the axial drive assembly **213**.

[0063] FIG. 6 is a cutaway view of the rotary grinding system **200** shown in FIGS. 4 and 5. FIG. 6 further illustrates the single point vertical screw adjustment mechanism **235**. A ball screw assembly **601** includes a ball screw and a housing and is used to impart linear motion to the axial drive assembly **213**. The ball screw assembly **601** allows precision vertical, i.e., depth-of-cut, adjustments. The ball screw or the housing is secured to the support frame **611**. Accordingly, when the screw is turned causing it to move with respect to the housing (or vice versa depending on which is secured to the support frame **611**), the axial drive assembly **213** is translated along the axis **233**, with respect to the support frame **611**.

[0064] FIG. 7 is another cutaway view of the rotary grinding system **200** shown in FIGS. 4 and 5 showing both the axial arm **708** of the axial drive assembly **213** and the radial arm **706**. The radial arm **706** is generally orthogonal to the axial arm **708**. In this embodiment, an axle **702** is housed within a housing of the axial drive assembly **213**. The housing also includes roller bearings **705**, which maintain the orientation of the axle **702** while allowing it to rotate within the housing. The radial arm **706** is coupled to, and suspended below, the axle **702**. Accordingly, rotating the axle **702** rotates the radial arm **706**, which moves the grinding wheel **244** in a circular motion across the surface of the workpiece. The motor **245** rotates the grinding wheel **244**.

[0065] A motor **710** directly or indirectly drives a ball screw drive shaft **715**. The grinding wheel motor **245** is attached to a carriage that is translated by the ball screw drive shaft **715**, as the ball screw **715** turns. In normal operation, the grinding wheel **244** is translated within a region **720**, so as to refinish a portion of a workpiece. However, as shown, the grinding wheel **244** may be retracted a distance **723** beyond the center point or axis **233**, i.e., to the left, in FIG. 7. This feature enables the grinding wheel **244** to be retracted, so as to expose a diameter of the workpiece. Thus, an operator or an automatic measuring system may measure flatness of a workpiece, such as by inserting a precision bar or by shining a laser beam across the diameter of the workpiece.

[0066] The axial arm **708** may also include a slip ring (not visible) to allow the use of electrical equipment options, such as cameras, lasers, inspection equipment, sensors, actuators or other tools that allow precision monitoring and/or maneuvering of components of the rotary grinding system **200**. Such equipment increases the range of operations that are achievable by the grinding system. For example, embodiments of the invention may be used to machine contours into a workpiece.

[0067] FIG. 8 illustrates a grinding assembly **800** of the rotary grinding system **200** shown in FIGS. 4 and 5, without the support system **411**. The axial arm **408** of the grinding assembly **800** is shown still connected, via the axial drive assembly **213**, to the dual vertical slides **405**. The axial arm

408 of grinding assembly **800** also includes a hydraulic piston **803**, which serves as a counterbalance to relieve weight on the vertical height adjustment mechanism, i.e., the ball screw assembly. The piston **803** is connected between the axial drive assembly **213** and the saddles **405** by a bar **804**. Optionally or alternatively, another suitable counterweight, such as a pre-loaded spring or a chain and mass, may be used.

[0068] FIG. 8 also illustrates a track **806**, along which a carriage **810** may ride to translate the grinding wheel assembly **813**, as driven by the ball screw **715** (FIG. 7), as indicated by arrow **816**.

[0069] Some embodiments of the present invention include scales that provide position feedback, in the form of electrical signals, of the displacement of the grinding wheel **244** along the track **806** of radial arm **216**, as well as the radial arm displacement in the vertical direction along the axis **233** of the axial arm **408**. A rotational scale may be used to determine the rotational phase of the radial arm **216** about the axis **233**.

[0070] FIG. 9 illustrates the radial arm **216** to show possible locations of mechanical stops **900** to limit travel of the carriage **810** along the track **806** to prevent the grinding wheel assembly **813** from being displaced further along the track **806** than desired predetermined distances. Multiple fixed mechanical stops **900** may be used, so that various stopping limits may be set for workpieces of different sizes. The mechanical stops **900** may be fixed, with respect to their radial distances along radial arm **216**, or the mechanical stops **900** may be adjustable. One or more of the mechanical stops **900** may be positioned in a protruding manner (as further illustrated in FIG. 10) to prevent motion of grinding wheel assembly **813** along the track **806**, or one or more of the mechanical stops **900** may be re-positioned in a retracted position to allow the grinding wheel assembly **813** to pass these stops **900** on track **806**. Alternatively, one or more adjustable mechanical stops (not shown) may be used, each of which may be engaged at a desired location along the track **806**.

[0071] In some embodiments, the radial arm **216** includes a dynamic counterweight (not shown). The counterweight may be dynamic in the sense that, as the grinding wheel assembly **813** is moved along the track **806**, the counterweight automatically moves in equal and opposite directions to reduce any deflection that may occur in the radial arm **216**. Such a dynamic counterweight may be implemented using a chain drive, a screw drive, a dual-rack with an interconnecting gear drive, or any other suitable drive. A screw with two opposing threads may be used to drive both the carriage **810** and the dynamic counterweight in opposite directions.

[0072] The radial arm **216** may also be equipped with lines (not shown) that allow cooling fluids or gases, such as air, to be introduced at the grinding wheel **244** as the surface of the workpiece is being machined, thereby allowing better surface finishes, more efficient machining and extended wheel life.

[0073] FIG. 10 shows the radial arm **216** of FIG. 9 from below. In this figure, the grinding wheel **244** and the grinding wheel motor **245** are omitted for clarity. The bottom of the carriage **810** (i.e. the portion that connects the motor **245** and wheel **244** to the track **806** of radial arm **216**) is shown attached to track **806**. The ball screw drive shaft **715** of the drive mechanism that displaces the carriage **810** is also shown. As noted, the carriage **810** may be displaced by rotational motion imparted by the motor **710** (not visible in FIG. 10) to the ball screw **715**. Accordingly, the ball screw drive shaft **715** may be a threaded shaft whose spiral path is

designed to engage ball bearings housed within a ball bearing housing connected to the base of the carriage **810**. Thus, when the ball screw drive shaft **715** is rotated, the carriage **810** and the attached motor **245** and grinding wheel **244** translate along the path of the track **806**. The track **806** helps maintain the carriage **810** in the proper orientation during this translation. Alternative drive mechanism may be used to impart linear motion to the carriage **810**. Examples of other drive mechanisms include, but are not limited to, a lead screw system, a rack and pinion system, a chain drive system and hydraulic rod or rodless cylinder. Alternatively, some embodiments of the invention may include a linear motor to move the carriage **810**.

[0074] The drive mechanism is used to propel the grinding wheel assembly along the tracks of the radial arm. The radial drive may be equipped to allow for slow or rapid traversing. The drive mechanism may be a rotary motor and may include a drive system to convert the rotary motion into linear motion of the grinding wheel assembly. As discussed above the drive mechanism may provide various drive speeds. The drive mechanism may use a hydraulic motor, clutch, brake, gearing, torque limiters, etc. to achieve a range of drive speeds.

[0075] FIG. 11 illustrates a single point tool holder **1100** in accordance with embodiments of the present invention. The tool holder **1100** may be configured for mounting to the grinding wheel assembly **813** (FIGS. 8 and 9). When a tool, such as a carbide cutting tool, is held by the tool holder and the tool holder is mounted to the grinding wheel assembly in lieu of a wheel guard, the tool may be positioned to engage the workpiece, instead of the grinding wheel engaging the workpiece. Rotation of the axial arm **408** (FIGS. 5, 7 and 8) causes the tool to make circular or spiral cuts in the workpiece. Such an arrangement may be used to more rapidly remove larger amounts of material from the workpiece than can be removed by the grinding wheel, albeit possibly resulting in lower surface finish quality than when using the grinding wheel. Such an operation may be advantageous when, for example, the workpiece is badly damaged. The single point tool may be used to remove the bulk of the workpiece material that is to be removed. After the bulk of the material is thus removed, the single point tool and holder **1100** may be removed, and the grinding wheel may be used to finish the workpiece, as described above.

[0076] FIG. 12 illustrates a tool holder **1200** for dressing the grinding wheel **244** (FIGS. 2, 7, 8 and 9), in accordance with various embodiments of the present invention. The tool holder **1200** may be manually slid into or out of a precision slot in the grinding wheel guard in order to prepare the wheel for grinding. The tool holder **1200** includes a micrometer adjuster, such that displacements of the business end **1203**, with respect to the tool holder, may be precisely measured. The spindle **1202** of the micrometer may be coupled to a dressing tool, such as a dressing diamond, at the business end **1203**. Thus, when the thimble **1204** of the micrometer is rotated, the dressing tool moves in or out, and the amount of motion is indicated on the scale located on the sleeve **1205** of the micrometer. Accordingly, the depth of the cut for the dressing tool may be precisely controlled.

[0077] FIG. 13 is a schematic block diagram of a computer-controlled embodiment of the present invention. In this embodiment, a computer numerical control (CNC) system **1300** controls various operations of the rotary grinding system **200** (FIGS. 2 and 4-7). A feedback control system consisting of sensors and/or actuators on components of the

grinding system **200** connects with CNC **1300** to drive components and measure the corresponding displacements and rotations. For example, the CNC **1300** may be connected to motor A **1301**, motor R **1302**, and motor T **1308**. Motor A **1301** may be used to translate the axial arm **1303** in an axial direction via a single point axial positioner, such as by rotating the single point height adjuster **235** (FIG. 4). The amount of translation may be controlled via CNC **1300**. Sensor A **1305** provides feedback to CNC **1300** indicating the amount of axial translation that axial arm **1303** has experienced.

[0078] The amount or phase of axial rotation may also be controlled via CNC **1300**. Motor R **1302** may be used to rotate the axial arm **1303**. Sensor R **1306** provides feedback to CNC **1300** indicating the amount or phase of axial rotation that radial arm **1304** has experienced.

[0079] The amount of translation experienced by grinding wheel motor **1310** and grinding wheel **1311** along the radial arm **1304** may also be controlled via CNC **1300**. Motor T **1308** may be used to drive the translation mechanism of the radial arm **1304**. Sensor T **1309** provides feedback to CNC **1300** indicating the amounting of radial translation that grinding wheel motor **1310** and the grinding wheel **1311** have experienced. The CNC **1300** may also control the grinding wheel motor **1310**. CNC **1300** may be electrically connected to the sensors and motors on the radial arm **1304** via slip ring **1307**. Slip ring **1307** allows electrical signals to be sent and received from electrical components disposed on the radial arm during rotation of the radial arm.

[0080] The CNC **1300** may be used to automate all or part of a refinishing operation. For example, many track plates have annular “lands” that need to be refinished, while annular portions (“spaces”) between the lands need not be refinished. The CNC **1300** may be programmed to operate the motor T **1308** so as to move the grinding wheel **1311** back and forth over one of the land portions (and not over adjacent spaces) and to operate the motor R **1302** so as to rotate the axial arm **1303** one or a predetermined number of full revolutions, so the grinding wheel **1311** makes one or the predetermined number of complete passes over the land. The CNC **1300** may then operate the motor A **1301** so as to incrementally lower the axial arm **1303**. Another complete pass or set of passes may then be made over the land. This process may be repeated as necessary to refinish the land to a predetermined height or smoothness.

[0081] The CNC **1300** may be programmed to skip over the spaces, i.e., operate the motor T **1308** to translate the grinding wheel **1311** over the spaces as quickly as possible, and refinish only lands of a workpiece. If a sector, rather than an annular portion, of the workpiece is to be refinished, the CNC **1300** may be programmed to operate the motor R **1302** so the grinding wheel **1311** traverses over only the sector of the workpiece. In either case, time may be saved by avoiding having the grinding wheel **1311** pass over portions of the workpiece that need not be refinished.

[0082] As the grinding wheel **1311** is used to remove material from a workpiece, the grinding wheel **1311** wears down, causing a reduction in the radius of the grinding wheel **1311**. The CNC **1300** may be programmed to compensate for this decrease in radius by periodically or occasionally operating the motor A **1301** to lower the grinding wheel **1311** an amount approximately equal to the actual or estimated reduction in the grinding wheel's radius, while the rotary grinding system is refinishing a workpiece. The rate at which the grinding wheel's radius is worn down may be estimated, based on the

composition of the grinding wheel, the type of material being worked, the amount of time the grinding wheel **1311** has been operating and/or the area of the workpiece that has been refinished. The area may be calculated or estimated, based on the cumulative distance the grinding wheel **1311** has passed over the workpiece. Optionally or alternatively, a laser or other measuring instrument may be used to automatically measure the radius of the grinding wheel **1311**.

[0083] Thus far, use of the rotary grinding system has been described in the context of refinishing workpieces so as to leave level finished surfaces. However, the CNC **1300** may be programmed to operate the motors **1301**, **1032** and/or **1308** so as to leave sloped or contoured (i.e., curved) surfaces. Furthermore, the smoothness of a finished surface may be controlled by adjusting the radial feedrate of the grinding wheel, the speed of the grinding wheel, the depth of cut, and the rotational speed of the radial drive assembly. Thus, the CNC **1300** may be programmed to finish different portions of a workpiece to different grades of smoothness.

[0084] The motors used in various embodiments of the present invention may be hydraulic, pneumatic or electric motors. Similarly, sensors, scales, etc. used in various embodiments may be electronic, electromechanical, pneumatic or any other suitable types of sensors.

[0085] While the invention is described through the above-described exemplary embodiments, it will be understood by those of ordinary skill in the art that modifications to, and variations of, the illustrated embodiments may be made without departing from the inventive concepts disclosed herein. Furthermore, disclosed aspects, or portions of these aspects, may be combined in ways not listed above. Accordingly, the invention should not be viewed as being limited to the disclosed embodiments.

What is claimed is:

1. A rotary grinder system for coupling with a workpiece, comprising:
 - a support frame having an engagement region configured to be coupled to the workpiece;
 - a grinder assembly coupled to the support frame, the grinder assembly having an axial arm and a radial arm coupled to the axial arm in a substantially orthogonal orientation, the radial arm coupled to the axial arm such that the radial arm rotates about an axis of the axial arm;
 - a grinder wheel rotatably coupled to the radial arm of the grinder assembly via a grinder wheel driver and translatable along the radial arm; and
 - a single point axial positioner configured to translationally drive, with respect to the support frame, the radial arm of the grinder assembly along the axis of the axial arm.
2. A rotary grinding system according to claim 1, wherein the single point axial positioner comprises a ball screw system.
3. A rotary grinding system according to claim 2, wherein the single point axial positioner comprises a mechanical slide.
4. A rotary grinding system according to claim 1, wherein the single point axial positioner is configured to drive the radial arm through translation of the axial arm.
5. A rotary grinding system according to claim 1, wherein the single point axial positioner is configured to drive the radial arm through rotation of the axial arm.
6. A rotary grinding system according to claim 1, wherein the single point axial positioner is configured to drive the radial arm through extension of the axial arm.

7. A rotary grinding system according to claim 1, wherein the grinder assembly is coupled to the support frame via at least one slide assembly connected to the axial arm of the grinding assembly and to the support frame.

8. A rotary grinding system according to claim 1, wherein the axial arm comprises a telescoping arm configured to change length upon application of force from the single point axial positioner.

9. A rotary grinding system according to claim 1, wherein the grinder wheel is coupled to a mechanical slide on the radial arm and configured to translate along an axis of the radial arm, wherein translation of the mechanical slide along the radial arm displaces the grinder wheel.

10. A rotary grinding system according to claim 1, wherein the radial arm includes a telescoping arm, the grinder wheel coupled thereto.

11. A rotary grinding system according to claim 1, further comprising a counterweight coupled to the grinder assembly and to the support frame and configured to urge the grinder assembly in a direction away from the workpiece, along the axis of the axial arm.

12. A rotary grinding system according to claim 11, wherein the counterweight comprises at least one of a hydraulic device, a spring and a mass-based counterweight.

13. A rotary grinding system according to claim 1, further comprising a counterweight movably coupled to the radial arm and configured to move along the radial arm a distance proportional to, and in a direction opposite, the grinder wheel.

14. A rotary grinding system according to claim 13, wherein the counterweight includes at least one of a chain drive, a screw drive and a dual rack with an interconnecting gear drive.

15. A rotary grinding system according to claim 1, further comprising a micrometer adjustable dressing tool configured to dress the grinder wheel.

16. A rotary grinding system according to claim 1, wherein the support frame comprises an upper frame coupled to a lower frame.

17. A rotary grinding system according to claim 1, further comprising a plurality of eccentric pins, each eccentric pin extending through a respective hole defined by the support frame and into the workpiece, such that rotation of at least one of the eccentric pins laterally displaces the support frame, relative to the workpiece.

18. A rotary grinding system according to claim 1, further comprising at least one support member connected between the support frame and the grinder assembly and configured to selectively support weight of at least a portion of the grinder assembly.

19. A rotary grinding system according to claim 1, further comprising a computer numerical control electrically connected to a first actuator configured to adjust the single point axial positioner and to a second actuator configured to translate the grinder wheel driver along the radial arm, each of the actuators including encoders for measuring magnitude of the respective adjustment and translation.

20. A rotary grinding system according to claim 1, wherein the grinder assembly includes at least one slip ring configured to transmit electrical signals to the radial arm during rotation of the radial arm.

21. A rotary grinding system according to claim 1, wherein the grinder assembly includes at least one hydraulic rotary union configured to transmit hydraulic fluid to the radial arm during rotation of the radial arm.

22. A rotary grinding system according to claim 1, wherein the grinder assembly includes at least one mechanical stop on at least one of the axial arm and the radial arm.

23. A rotary grinding system according to claim 1, wherein the grinder wheel is retractable translationally beyond a zero point on the radial arm, so as to expose a diameter of the workpiece.

24. A rotary grinding system according to claim 1, further comprising an adapter plate, wherein the support frame is configured to be coupled to the workpiece via the adapter plate.

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