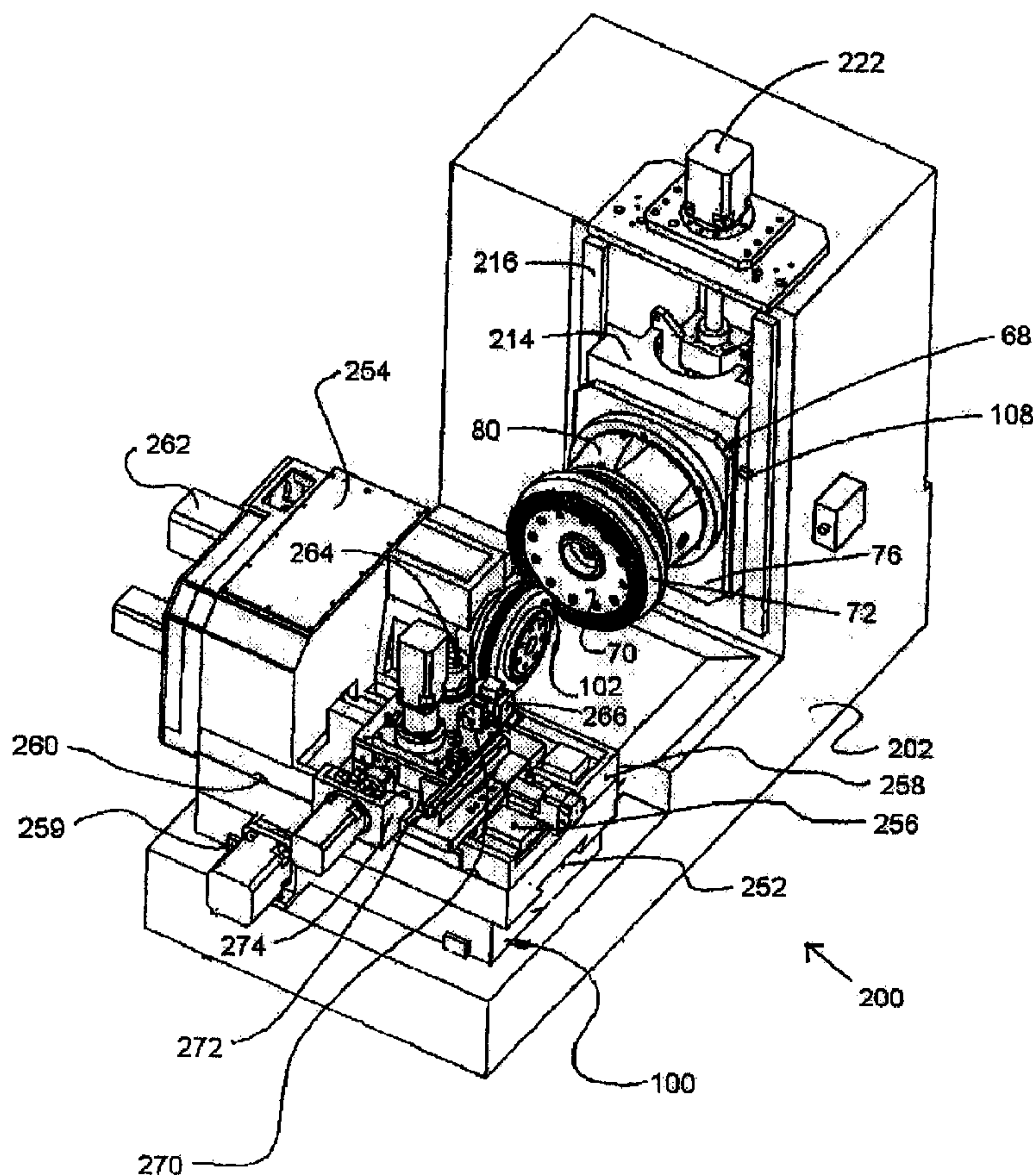




(86) Date de dépôt PCT/PCT Filing Date: 2005/02/03  
 (87) Date publication PCT/PCT Publication Date: 2006/08/10  
 (45) Date de délivrance/Issue Date: 2010/11/30  
 (85) Entrée phase nationale/National Entry: 2007/03/23  
 (86) N° demande PCT/PCT Application No.: IB 2005/000913  
 (87) N° publication PCT/PCT Publication No.: 2006/082470

(51) Cl.Int./Int.Cl. *B23F 15/06* (2006.01),  
*B23F 21/02* (2006.01), *B23F 23/08* (2006.01),  
*G05B 19/18* (2006.01)  
 (72) Inventeurs/Inventors:  
 FISHER, DAVID J., CA;  
 RUSSELL, ADRIAN, CA;  
 FOLPRECHT, GEORGE, CA;  
 WHELDON, GARTH A., CA  
 (73) Propriétaire/Owner:  
 NORTHSTAR AEROSPACE (CANADA) INC., CA  
 (74) Agent: FINLAYSON & SINGLEHURST

(54) Titre : PROCÉDE ET APPAREIL DE FABRICATION DE ROUE DE CHAMP  
 (54) Title: METHOD AND APPARATUS FOR MANUFACTURING A FACE GEAR



(57) Abrégé/Abstract:

A precision grinding apparatus for grinding face gears having a gear table portion controllably driven for rotation about a central axis, and also being movable in a vertical plane along an axis in a controlled manner. The apparatus further includes a case

(57) **Abrégé(suite)/Abstract(continued):**

hardened face mounted on the gear table portion. A grinding wheel mounted on the apparatus has controlled driven rotation about a central axis C, and is provided with a grinding surface of predetermined shape. The grinding wheel is movable in a controlled manner toward and away from the gear along a feed axis V, the grinding wheel being movable in a controlled manner in a tangential direction with respect to the gear and orthogonal to the feed axis along a tangential feed axis wherein the motion of the grinding wheel in the C, V and TF axes, and movement of the gear in B and W axes, is controlled by a central control means.

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

(19) World Intellectual Property Organization  
International Bureau(43) International Publication Date  
10 August 2006 (10.08.2006)

PCT

(10) International Publication Number  
**WO 2006/082470 A1**

(51) International Patent Classification:

*B23F 15/06* (2006.01)      *B23F 23/08* (2006.01)  
*B23F 21/02* (2006.01)      *G05B 19/18* (2006.01)

(21) International Application Number:

PCT/IB2005/000913

(22) International Filing Date: 3 February 2005 (03.02.2005)

(25) Filing Language:

English

(26) Publication Language:

English

(71) Applicants and

(72) Inventors: **FISHER, David, J.** [CA/CA]; 478 Bell Street, Milton, Ontario L9T 2B5 (CA). **RUSSELL, Adrian** [CA/CA]; 79 McCallum Drive, Richmond Hill, Ontario L4C 7T5 (CA). **FOLPRECHT, George** [CA/CA]; 43 Good View Road, Willowdale, Ontario M2J 2K7 (CA). **WHELDON, Garth, A.** [CA/CA]; 3125 Pinemeadow Drive, Unit 33, Burlington, Ontario L7M 3T7 (CA).

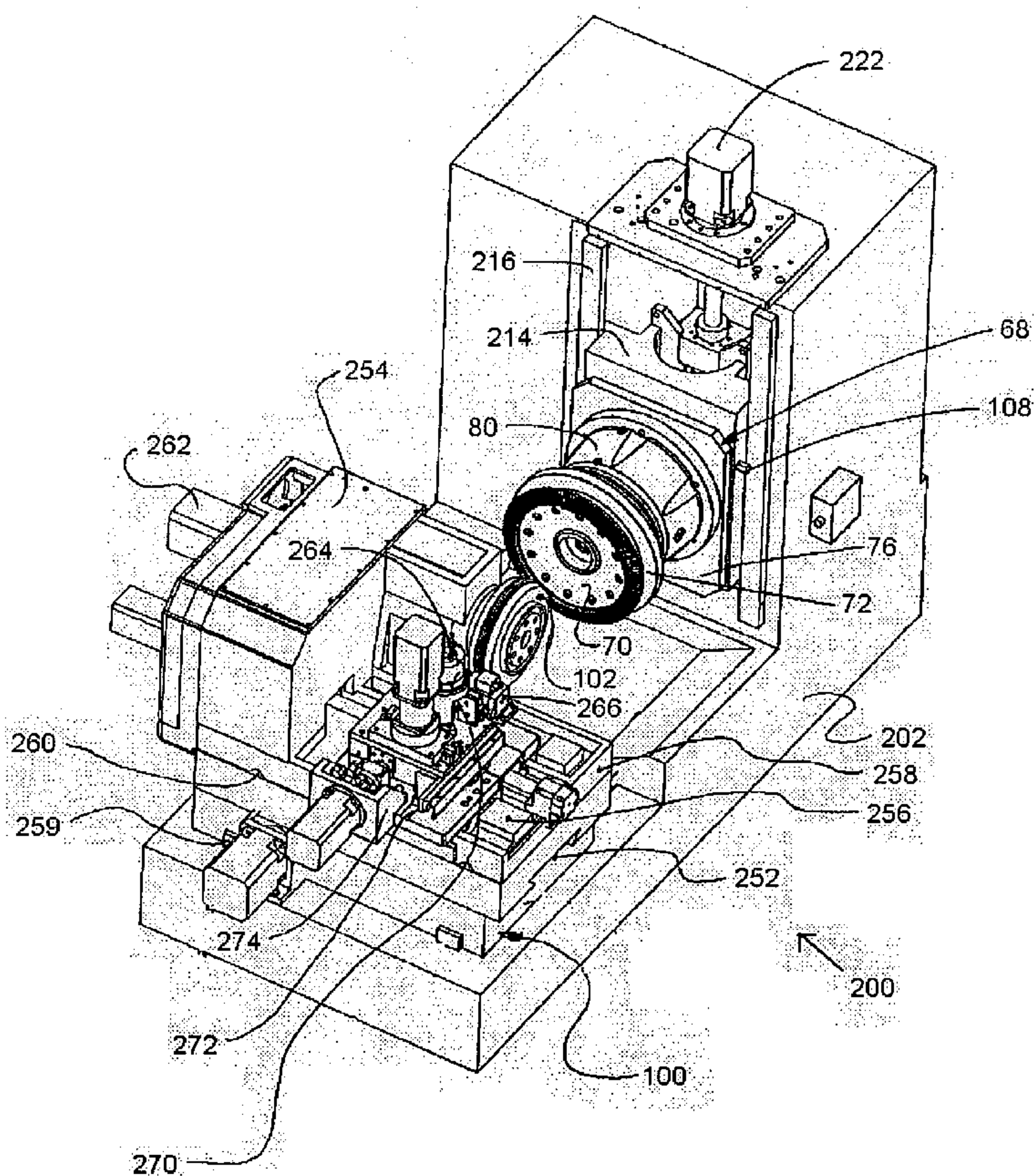
(74) Agent: **FINLAYSON & SINGLEHURST**; 70 Gloucester Street, Ottawa, Ontario K2P 0A2 (CA).

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

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: APPARATUS FOR MANUFACTURING A FACE GEAR



(57) Abstract: A precision grinding apparatus for grinding face gears having a gear table portion controllably driven for rotation about a central axis, and also being movable in a vertical plane along an axis in a controlled manner. The apparatus further includes a case hardened face mounted on the gear table portion. A grinding wheel mounted on the apparatus has controlled driven rotation about a central axis C, and is provided with a grinding surface of predetermined shape. The grinding wheel is movable in a controlled manner toward and away from the gear along a feed axis V, the grinding wheel being movable in a controlled manner in a tangential direction with respect to the gear and orthogonal to the feed axis along a tangential feed axis wherein the motion of the grinding wheel in the C, V and TF axes, and movement of the gear in B and W axes, is controlled by a central control means.

  
**WO 2006/082470 A1**

**WO 2006/082470 A1**



**Published:**

— *with international search report*

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

## **METHOD AND APPARATUS FOR MANUFACTURING A FACE GEAR**

### **BACKGROUND OF THE INVENTION**

**[0001]** The present invention is directed generally to a method and apparatus for the development of face gears and, more specifically, to a method and apparatus for the development of face gears suitable for high power transmission.

**[0002]** The development of face gears for high power transmission is a relatively recent phenomenon. Historically, the transmission of power through a face gear set has been limited to relatively low levels because of two factors: 1) the tooth profile of the mating gears has been generated by shaper cutting; and 2) although an acceptable tooth profile could be generated, the tooth produced by the shaping operation did not have a hardened surface. The tooth profile produced by the shaping operation required that the resulting face gear set be kept in almost perfect alignment. In the past, any operation performed on the face gear set to harden the surface of the shaped teeth tended to distort the shape of the face gear set during the hardening operation.

**[0003]** A previous method of manufacture of face gears was developed by Fellows Corporation. The method uses a gear shaper apparatus, and the finished product is useful for low power applications.

**[0004]** The Fellows Corporation method employs a metal cutting process for shaping the gear teeth of the face gear. This process can only be applied to materials with suitable hardness and metal cutting characteristics. If the material is too hard, the shaper tool will not cut effectively. This shaping process can only be used effectively for finish cutting face gear teeth from metals suitable for low power applications. This process does not give the accuracy and surface finish required for higher power applications.

**[0005]** The applicants have previously developed a novel method and apparatus for manufacturing face gear sets suitable for high power transmission applications, which method and method and apparatus are described in U.S. Patent Number 6,390,894 which may be referred to for further details.

### BRIEF SUMMARY OF THE INVENTION

**[0006]** The present invention is directed to a precision grinding apparatus for grinding face gears having a gear table portion controllably driven for rotation about a central axis **B** and also being movable in a vertical plane along an axis **W** in a controlled manner. The apparatus further includes a case hardened face gear mounted on the gear table portion. A grinding wheel mounted on the apparatus has controlled driven rotation about a central axis **C**, and is provided with a grinding surface of predetermined shape. The grinding wheel is movable in a controlled manner toward and away from the gear along a feed axis **V**, the grinding wheel being movable in a controlled manner in a tangential direction with respect to the gear and orthogonal to the feed axis **V** along a tangential feed axis **TF** wherein the motion of the grinding wheel in the **C**, **V** and **TF** axes, and movement of the gear in **B** and **W** axes, is controlled by a central control means.

**[0007]** In an alternate embodiment of the present invention, the apparatus further includes a feed mechanism for generating teeth on a face gear, said feed mechanism adapted to move said face gear in a composite vertical and horizontal direction such that said face gear traverses the entire width of the tooth face of said face gear.

**[0008]** In yet another embodiment, the present invention provides a grinding apparatus for a tapered pinion gear having a base with a grinding portion mounted

thereon for generating teeth in a gear by abrasion, a gear driving portion mounted on said base in juxtaposition to and cooperating with the grinding portion, and a case hardened tapered pinion gear having preformed teeth of a predetermined size and configuration mounted on the gear driving portion. In this embodiment, the gear driving portion has the capability of rotating the pinion gear in a manner controlled by a first CNC control portion in a central axis designated B1, and also has the capability of moving said pinion gear up and down in a vertical axis designated W in a manner controlled by a second CNC control portion. The grinding portion includes a grinding wheel having a grinding surface thereon in which a worm of predetermined configuration is generated, and is rotatably driven and controlled by a third CNC control portion to control the rotation of the grinding wheel in its central axis designated C. The grinding wheel also includes a fourth CNC control portion to control the motion of the grinding wheel toward and away from said pinion gear along a V axis, and a fifth CNC control portion to control the motion of the grinding wheel in a tangential direction with respect to the pinion gear and orthogonal to said V axis along a TF axis. The CNC control portions cooperate together to mesh said worm with said teeth of said pinion gear to form teeth in said gear in a continuous grinding operation.

**[0009]** Any of the described embodiments of the present invention may further include a high-pressure temperature-controlled coolant system to prevent burning of the gear teeth during grinding.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[00010]** FIG. 1 is an elevational view of a prior art spur gear cutting machine.

**[00011]** FIG. 2 is a partial view of a prior art blank grinding wheel (before the wheel is shaped).

[00012] FIG. 3 is a partial view of a spur gear grinding wheel of the prior art showing the dressing tool used to provide a cutting profile.

[00013] FIG. 4 is a perspective view of a face gear and a mating pinion gear.

[00014] FIG. 5 is a sectional view of a mating pinion and face gear.

[00015] FIG. 6 is a sectional view of a prior art face gear shaping apparatus.

[00016] FIG. 7 is an elevational view of a grinding apparatus of the present invention adapted for grinding teeth on regular, concave, and convex face gears.

[00017] FIG. 8 illustrates exemplary regular, concave, and convex face gears.

[00018] FIG. 9 is a perspective view of a complete grinding machine for grinding teeth on a convex face gear and constructed in accordance with the teachings of the present invention.

[00019] FIG. 10 is a plan view of the grinding wheel of the present invention showing associated dresser apparatus motion.

[00020] FIG. 11 is a plan view of a grinding machine constructed in accordance with the teachings of the present invention.

[00021] FIG. 12 is a spatial representation of the three major components of a face gear machine constructed in accordance with the teachings of the present invention, to more clearly illustrate the various component axes.

[00022] FIG. 13 is a spatial representation of the three major components of a face gear machine constructed in accordance with the teachings of the present invention and adapted for producing teeth on a pinion gear.

[00023] FIG. 14 is a perspective view of a face gear grinding apparatus adapted for producing teeth on a pinion gear.

[00024] FIG. 15 is an elevational view of a grinding wheel showing a typical face gear configuration used in this invention.

[00025] FIG. 16 is an end view of the machine of FIG. 9.

[00026] FIG. 17 is an elevational view of the machine of FIG. 9.

#### DETAILED DESCRIPTION OF THE INVENTION

[00027] Turning now to the drawings, wherein like numerals represent like parts, the numeral 10 represents generally a prior art spur gear grinding apparatus. A machine 12 (partially shown) is provided with a moveable carrier 14 that is capable of executing rectilinear motion, as indicated by a double arrow 16. Carrier 14 is provided with a gear driving head 18, which is connected to lead shaft 20. The end of shaft 20 remote from driving head 18 is centered in tailstock 22 in order to stabilize shaft 20. A spur gear 24 is mounted on shaft 20 so as to be controllably rotated by driving head 18.

[00028] A spur gear grinding wheel 26 is shown engaging the peripheral surface of spur gear 24. Grinding wheel 26 takes the same form as grinding wheel 36, shown in FIG. 3, and must be capable of movement toward and away from gear 24 as indicated by double arrow 28. The rotation of the grinding wheel is coordinated with the rotation of the spur gear.

[00029] To produce a ground spur gear, the grinding wheel 26 is advanced toward gear 24 while gear 24 is synchronously rotated to be in step with the "worm" profile at grinding wheel 26, until grinding wheel 26 has advanced to the desired depth into a selected area of the spur gear. The spur gear is now gradually

moved in an axial direction to permit grinding wheel 26 to complete the grinding along the tooth length of the gear. This process is repeated for increased material removal until tooth size and profile are achieved.

**[00030]** FIG. 2 shows a grinding wheel 30 of the prior art before being dressed to have a grinding profile.

**[00031]** FIG. 3 shows a grinding wheel 36 that contains a worm profile 38 (used for grinding spur gear teeth as previously described), which profile is formed by dressing tool 40, which carries a specially shaped dressing disc 42 to provide the worm profile. The dressing tool 40 is moved across the surface of the grinding wheel 36 as grinding wheel 36 rotates. Disc 42 is advanced into the surface of wheel 36 until the desired tooth form is achieved. The shape of profile 38 on the surface of wheel 36 is formed by the shape of the profile of grinding disc 42 (i.e. the axis of rotation of disc 42 is usually parallel to the axis of rotation of wheel 36).

**[00032]** FIG. 4 shows an illustration of a regular face gear 50 and a meshing piston 52. The teeth 54 on face gear 50 extend in a radial direction; the teeth 56 on pinion 52 are parallel to the axis of rotation of pinion 52.

**[00033]** FIG. 5 shows the face gear 50 and pinion in section. The teeth 54 and 56 are shown in a meshed condition.

**[00034]** FIG. 6 is an illustration of a prior art method of shaping the teeth on face gear 50 by shaper cutter 60. The shaper cutter 60 is reciprocated in an axial direction (as shown by arrows 62) while it and the face gear 50 and the shaper cutter 60 are constantly moving in a simulated meshing engagement, until the desired tooth form has been generated.

**[00035]** FIG. 7 depicts a face gear work head 68 and face gear grinding head 100 constructed in accordance with the teachings of the present invention. The embodiment shown in FIG. 7 is used for grinding the teeth of either regular, convex, or concave shaped face gears. In the illustration, a convex face gear 70 is shown mounted on a controllable rotating table 72 so as to rotate about axis 74. Rotating table 72 is directly mounted on CNC drive motor 80. Motor 80 serves to drive rotating table 72 and is mounted directly on base 76. Face gear work head 68 is able to swivel about swivel axis 78. The degree of swivel of face gear work head 68 is closely controlled by swivel selector 108, shown in FIG. 9. The entire rotating face gear head 68 is preferably capable of executing controlled motion in a vertical direction during a tooth grinding operation, as shown by arrow 90. CNC control permits controlled motion in the vertical axis. In the illustration shown, the gear axis of rotation is maintained in a horizontal orientation during grinding.

**[00036]** Grinding head 100 has a grinding wheel 102 rotatably mounted thereon. Grinding head 100 is precisely located with respect to face gear work head 68 and grinding wheel 102. The whole grinding head 100 must be capable of executing controlled motion in a horizontal direction during a tooth grinding operation as shown by arrow 210. CNC control permits controlled motion in the horizontal axis.

**[00037]** Grinding wheel 102 is provided with a special worm profile 268 (see, for example, FIGS. 10 and 15), and the grinding operation is carried out by advancing grinding wheel 102 toward face gear 70 so that grinding wheel profile 268 and the face gear mesh precisely (i.e. the worm of grinding wheel 102 has a profile that meshes with the teeth of face gear 70). The feed mechanism for generating the teeth on face gear 70 slowly moves face gear 70 in a composite vertical and horizontal direction until the grinding wheel has traversed the entire

width of tooth face 71 of face gear 70. Grinding wheel 102 is gradually advanced into the surface of tooth face 71 of face gear 70 with each succeeding pass, until the desired tooth profile 268 is produced.

**[00038]** FIG. 8 shows examples of configurations of face gears that the present invention is capable of grinding. Regular face gear 50, convex face gear 70, and concave face gear 106 can all be ground using the teachings of the present invention. The criteria used for determining the face gear description include the angle measurement between the gear tooth face 71 and the gear axis of rotation 82. The present invention can also be adapted to grind a pinion gear, detailed below, not shown in this figure.

**[00039]** FIG. 9 depicts a full grinding machine 200 constructed in accordance with the teachings of the present invention. A base 202 is provided to permit face gear work head 68 to be mounted thereon in a predetermined fashion. This apparatus drives rotating table 72 on which face gear 70 is mounted in a controlled manner about its axis (designated axis "B"). Rotating table 72 is directly mounted on CNC drive motor 80. Motor 80 serves to drive rotating table 72 and is directly mounted on base 76. Base 76 is mounted on work table 214, which allows face gear work head 68 to also swivel about its mounting on worktable 214. This permits the face gear to have a manually adjustable angular swivel setting designated as the "WTS" axis. Worktable 214 is constrained to permit it to move in a vertical plane along rails 216 by drive motor 222. This vertical axis is designated as the "W" axis.

**[00040]** Grinding head 100, on which grinding wheel 102 is mounted, is mounted on base 202 in such a manner that grinding wheel 102 may be moved toward and away from face gear work head 68, and grinding wheel 102 may move tangentially to work head 68 as well. Grinding head 100 is permitted to move

along rails 259 to produce the motion of the carriage 254 toward and away from face gear work head 68. This is a feed axis, which is designated as the "V" axis. Carriage 254 is also mounted on rail 252 to produce the motion of grinding wheel 102 in a tangential direction with respect to face gear 70. This axis is designated as the "TF" axis. Grinding table 258 is capable of pivoting carriage 254 about pivot 260. This is the grinding wheel pivot axis and is designated as the "WT" axis. Grinding wheel 102 rotates about an axis designated as axis "C" and is driven by motor 262, which is integrally mounted on carriage 254. Grinding wheel 102 has a predetermined profile inscribed on its surface as shown in FIG. 10. Other views of the grinding machine of FIG. 9 are provided in FIGS. 16 and 17.

**[00041]** During the initial set up of machine 200, axes "TF" and "WT" are set and locked with respect to the tooth configuration already existing on face gear 70. (Face gear 70 has already undergone tooth shaping and surface hardening operations before being mounted in machine 200). During the initial approach of grinding wheel 102 to face gear 70, motor 262 is rotating grinding wheel 102 about axis "C" and motor 80 is rotating face gear 70 about axis B. The rotation of axis "C" & "B" are in a prescribed synchronized manner. Carriage 254 is fed along the "V" axis to carry grinding wheel 102 toward face gear 70 until the desired grinding position is reached. During grinding, face gear table 214 undergoes controlled movement along the feed axis "W" and grinding head 100 undergoes controlled movement along the feed axis "V" until the grinding wheel has moved sufficiently so that the entire tooth face 71 of face gear 70 has been traversed by grinding wheel 102. Grinding wheel 102 is then moved slightly toward table 214 and the grinding operation is repeated until the desired depth of the tooth form and shape is generated.

**[00042]** A rotary diamond dressing tool assembly 264 is also mounted on grinding table 258, along rail 256. Assembly 264 includes a rotary device 266, which rotates a diamond impregnated disc 280 (see FIG. 10). Disc 280 is used to generate (by abrasion) a prescribed form in grinding wheel 102. Device 266 is adjustable in height and angle on and about post 270, on which device 266 is mounted. The entire dresser assembly 264 is mounted on table 258 so as to be capable of controlled motion in three axes. A first axis of motion allows the dresser assembly mounted on feed table 274 to move backwards and forwards along rails 272 away from and towards grinding wheel 102. This axis is designated as the "Y" axis.

**[00043]** Movement of dressing tool assembly 264 along rails 256 in a translatory fashion (parallel to the axis of grinding wheel 102) is designated as the "X" axis. Movement of dresser wheel 280 about post 270 in an angular fashion will define the angular axis "A". The grinding wheel profile demands that the movement of feed table assembly 274 for dresser assembly 264 be synchronized with the rotation of grinding wheel 102 such that disc 280 of dresser assembly 264 properly meshes the profile of grinding wheel 102.

**[00044]** The grinding operation of the partially completed and surface hardened face gear 70 is as follows:

**[00045]** Rotating table 72 is manually set to a predetermined tilt (WTT) and swivel (WTS) settings and these positions are locked. The partially finished gear is mounted on rotating table 72 so as to have a predetermined angular position on axis "B". Grinding wheel carriage 254 is then set at the appropriate angle on the pivot axis WT and locked. Carriage 254 is moved along rail 252 until grinding wheel 102 is set at a predetermined position on the "TF" axis with respect to face gear 70.

**[00046]** The rotating grinding wheel 102 is now moved along the “V” “feed” axis to move toward the partially finished rotating face gear 70 in a horizontal direction. Next, rotating face gear 70 is moved along the “W” “feed” axis towards the engagement point with the rotating grinding wheel in a vertical direction. These linear axes can be moved independently or simultaneously under CNC control to achieve the initial face gear grinding position.

**[00047]** To perform the grinding of face gear 70, and to permit the grinding wheel 102 to traverse the entire width of tooth face 71 of gear 70, work table 214 is now moved vertically along rails 216. Carriage 254 is moved horizontally along rails 259 under CNC control in a composite manner. The combined CNC motion of the “V” & “W” feed axis enables the face gear manufacturing apparatus to grind various face gear configurations (concave to convex), as will be apparent to those of skill in the art upon reading this disclosure. This process is repeated in a series of grinding passes until the desired size and tooth configuration is generated in face gear 70.

**[00048]** Periodically, during the grinding operation, the profile of the grinding wheel 102 must be restored. When this is necessary, grinding wheel 102 is retracted from face gear 70 and dresser assembly 264 is brought into position on rails 272 and 256 to engage grinding wheel 102 and to restore the profile on wheel 102 to its original profile. Grinding disc 280 is engaged with grinding wheel 102 in accordance with CNC control to move in a controlled manner to restore the profile 268 to wheel 102 to its required dimensional shape.

**[00049]** FIG. 14 shows the apparatus of FIG. 9 modified to permit the finish grinding of a pinion gear 300. Pinion 300, in this instance, is a tapered spur gear pinion. Grinding wheel 302 now carries a significantly different profile from the

profile inscribed in the surface of grinding wheel 102 for face gear grinding. The profile inscribed on the surface of wheel 302 is similar to that shown in FIG. 3.

**[00050]** The face gear work head 68 of FIG. 9 has been replaced with work table 304, which supports and rotates pinion 300 during grinding.

**[00051]** Tapered pinion 300 rotates about an axis designated as "B1" in an angular motion synchronized with grinding wheel 302. The worktable assembly 304 is capable of vertical translatory motion along rails 216, designated the "W" axis as previously described with respect to FIG. 9. The motion of grinding wheel 302 along the "V" axis is CNC controlled, as is the movement of pinion 300 along the "W" axis. It will be obvious to those skilled in the art that the motion of grinding wheel 302 in the "V" axis must be carefully coordinated with the motion of table 304 along rails 216 in order to produce tapered spur gear pinion 300.

**[00052]** The dresser apparatus for grinding wheel 302 is required as previously, but is omitted from FIG. 14 for reasons of clarity.

**[00053]** It is further contemplated that any of the face gear grinding devices of the present invention may include a high-pressure temperature-controlled coolant system to prevent burning of the gear teeth being ground.

**[00054]** The axes defined herein are as follows:

AXIS	DEFINITION	CONTROL
C	Grinding Wheel 102 (302) Rotation	CNC
V	Grinding Wheel 102 (203) in Feed	CNC
WT	Grinding Wheel 102 (302) Tilt	Manual
TF	Grinding Wheel 102 (302) Tangential Feed	CNC or Manual

---

B	Rotating Table 72 Rotation (Face Gears)	CNC
B1	Driving head 318 Rotation (Tapered Spur Gear Pinion)	CNC
W	Work Table 214 Axial Feed	CNC
WTS	Work Head 212 (69, 304) Swivel	Manual
A	Dresser Tool 264 Rotary Feed	CNC
X	Dresser Tool 264 Cross Feed	CNC
Y	Dresser Tool 264 In Feed	CNC
DH	Dresser Tool 264 Height	Manual
DT	Dresser Tool 264 Tilt	Manual

---

**[00055] BASIC OPERATION OF THE FACE GEAR GRINDING MACHINE**

**[00056]** FIG. 11 provides a plan view of a face gear grinding machine constructed in accordance with the teachings of the present invention. Machine 200 utilizes a CNC system that enables the axes under its control to be moved in a predetermined manner via a set of instructions in a program. Numerous programs will be created to control the dressing cycle and gear grinding cycle of machine 200 for different configurations of gears. The CNC control enables the axes of motion to be continually synchronized even when switching between the dressing and grinding cycles.

**[00057] MANUAL SETTINGS**

**[00058]** The work table 212 swivel "WTS" is commonly set in the vertical position and locked for the gears described herein. This feature is incorporated for helical gear form requirements. Grinding wheel 102 tilt "WT" is set for lead angle

compensation. Grinding wheel tangential feed "TF" positions the wheel with respect to the central axis of the gear in a horizontal plane. This feature, when CNC controlled, is incorporated for helical gear form requirements. Dresser rotary device 266 tilt is set for angular clearance "DT" and diamond disc 280 grinding wheel 102 centerline height "DH".

**[00059] GRINDING WHEEL DRESSINGS CNC CONTROLLED**

**[00060]** CNC programs stored in the memory of the CNC control are selected to control this process. These programs command the motion of dresser axes X, Y, A, and grinding wheel 102 axis C in a prescribed manner to generate the required form on the grinding wheel. These programs control the speed and direction of rotation of grinding wheel 102 with respect to the speed and direction of motion of dresser assembly 264, axis X, Y and A.

**[00061]** Via the CNC and the selected program, the speed of rotation of grinding wheel 102 (axis C) relative to the speed of rotation of gear 70 (axis B) being ground is controlled. This relationship is controlled via an electronic gearbox, which is a feature of the CNC. It is an important feature as the grinding process simulates the meshing of a worm gear which is the grinding wheel 102 with a face gear such as 70, which is the gear being finish ground. Also via the program and CNC, the following functions are also controlled:

**[00062]** Depth of Cut (axis V) - infeed of grinding wheel 102 to workpiece (face gear 70);

**[00063]** Vertical feed of workpiece across grinding wheel 102 (axis W);

- [00064]** Tangential Feed (TF) – positioning of grinding wheel 102 to workpiece (face gear 70);
- [00065]** Dresser diamond disc 280 speed;
- [00066]** Control of dresser motion X,Y and A axis for initial and periodic re-dressing of the grinding wheel 102;
- [00067]** Dimensional offsets and adjustments; and
- [00068]** Coolant on/off, and machine lubrication.
- [00069]** Examples of the composition of the basic material for gear 70 that may be used successfully to practice the present invention is:

**(a) SAE 9310 having components**

- Iron - 94.765%
- Nickel - 3.25%
- Chromium - 1.20%
- Manganese - 0.55%
- Molybdenum - 0.11 %
- Carbon - 0.10%
- Silicon - 0.045% max.; or

TM

**(b) PYROWEAR ALLOY 53 having the following components:**

- Iron - 90.2%
- Molybdenum - 3.25%
- Copper - 2.00%
- Nickel - 2.00%
- Chromium - 1.00%
- Silicon - 1.00%

Carbon – 0.1%

Vanadium – 0.1 %

[00070] The foregoing description of the embodiments of the invention has been presented for purposes of illustration and description, and is not intended to be exhaustive or to limit the invention to the precise form disclosed. The description was selected to best explain the principles of the invention and practical application of these principles in order to enable others skilled in the art to best utilize the invention in various embodiments and with such modifications as are suited to the particular use contemplated. It is intended that the scope of the invention not be limited by the specification, but be defined by the claims as set forth below.

**WHAT IS CLAIMED IS:**

1. A precision grinding apparatus for grinding face gears comprising:

a suitable gear table portion being controllably driven for rotation about a central axis B, said gear table portion also being movable in a vertical plane along an axis W in a controlled manner;

a case hardened face mounted on said gear table portion, said face gear having a series of gear teeth formed therein; and

a grinding wheel mounted on said apparatus, said grinding wheel having controlled driven rotation about a central axis C, said grinding wheel being provided with a grinding surface of predetermined shape, said grinding wheel being movable in a controlled manner toward and away from said gear along a feed axis V, said grinding wheel being movable in a controlled manner toward in a tangential direction with respect to said gear and orthogonal to said feed axis V along a tangential feed axis TF,

wherein the motion of said grinding wheel in said C, V and TF axes, and movement of said table in B and W axes, is controlled by a central control means,

said grinding apparatus further comprising a coolant system and wherein said coolant system is a high-pressure temperature-controlled coolant system adapted to prevent burning of said teeth during grinding.

2. The precision grinding apparatus as claimed in claim 1 wherein a dressing apparatus is mounted on said apparatus in a predetermined relationship with said grinding wheel, said dressing apparatus comprising:

a driven grinding disc of a second predetermined shape for controlled motion toward and away from said grinding surface of said grinding wheel along a Y axis, said disc being mounted on said apparatus for movement along an axis X substantially parallel to said C axis of said grinding wheel, and wherein said X axis is orthogonal to said Y axis, said disc also being capable of angular movement about a central dressing axis A, and wherein said movement in said X, Y

and A axis is coordinated by and under the control of said central control means to create and restore said grinding surface of said grinding wheel to said predetermined shape.

3. The grinding apparatus of claim 1 wherein said grinding surface is shaped in the form of a worm for meeting with and grinding the gear teeth existing on said gear to a predetermined finished shape.

4. The grinding apparatus of claim 1 wherein said grinding wheel is movable in a direction along an axis TF tangential to said gear and orthogonal to said V axis, and said grinding wheel is capable of being tilted about a tilt axis WT.

5. The grinding apparatus of claim 3 wherein a dressing means is provided for creating and restoring the profile of said worm of said grinding wheel.

6. The grinding apparatus of claim 1 wherein said grinding wheel is movable along an axis TF tangential to said gear, and said grinding wheel is tiltable about a pivot axis WT.

7. The grinding apparatus of claim 1 further comprising a feed mechanism for generating teeth on a face gear, said feed mechanism adapted to move said face gear in a composite vertical and horizontal direction such that said face gear traverses the entire width of the tooth face of said face gear.

8. The grinding apparatus of claim 1 wherein said central control means is a computer numerical control (CNC).

9. The grinding apparatus of claim 1 wherein said apparatus is adapted for producing teeth of a gear having a shape selected from the group consisting of regular, concave and convex.

10. A precision grinding apparatus for a tapered pinion gear comprising:
- a base having a grinding portion mounted thereon for generating teeth in a gear by abrasion;
  - a gear driving means portion mounted on said base in juxtaposition to and cooperating with said grinding portion; and
  - a case hardened tapered pinion gear having preformed teeth of a predetermined size and configuration mounted on said gear driving portion,
- said gear driving portion having the capability of rotating said pinion gear in a manner controlled by a first CNC control portion in a central axis designated B1, said gear driving portion also being provided with the capability of moving said pinion gear up and down in a vertical axis designated W in a manner controlled by a second CNC control portion,
- said grinding portion comprising a grinding wheel having a grinding surface thereon in which a worm of predetermined configuration is generated therein, said grinding wheel being rotatably driven and controlled by a third CNC control portion to control the rotation of said grinding wheel in its central axis designated C, said grinding wheel further having a fourth CNC control portion operably associated therewith to control the motion of said grinding wheel toward and away from said pinion gear along a V axis, and said grinding wheel further having a fifth CNC control portion operably associated therewith to control the motion of said grinding wheel in a tangential direction with respect to said pinion gear and orthogonal to said V axis along a TF axis,
- wherein said CNC control portions cooperate together to mesh said worm with said teeth of said pinion gear to form teeth in said gear in a continuous grinding operation,
- said grinding apparatus further comprising a coolant system and wherein said coolant system is a high-pressure temperature-sensitive coolant system adapted to prevent burning of said teeth during grinding.
11. The grinding apparatus of claim 10 wherein said grinding wheel portion is movable along an axis tangential to said gear designated TF, and said grinding wheel portion is tiltable about a pivot axis designated WT.

12. The grinding apparatus of claim 11 further comprising a grinding wheel dressing portion mounted in cooperating relationship with said grinding portion to engage said grinding surface in a manner controlled by three additional CNC control portions to create said worm and restore said worm to its predetermined configuration when a predetermined amount of distortion is present in said worm.

13. The grinding apparatus of claim 12 wherein said three additional CNC control portions include:

a sixth CNC control portion to operably associated with said dressing portion to control the motion of said dressing portion toward and away from said grinding surface along an axis designated Y;

a seventh CNC control portion operably associated with said dressing portion to control the motion of said dressing portion along an axis substantially parallel to said C axis, designated X; and

an eighth CNC control portion operably associated with said dressing portion to control angular motion of said dressing portion about a pivot axis designated as A.

14. The grinding apparatus of claim 12 wherein said dressing portion comprises a disc having a predetermined shape for engaging said surface of said grinding wheel to restore said worm configuration by abrasion.

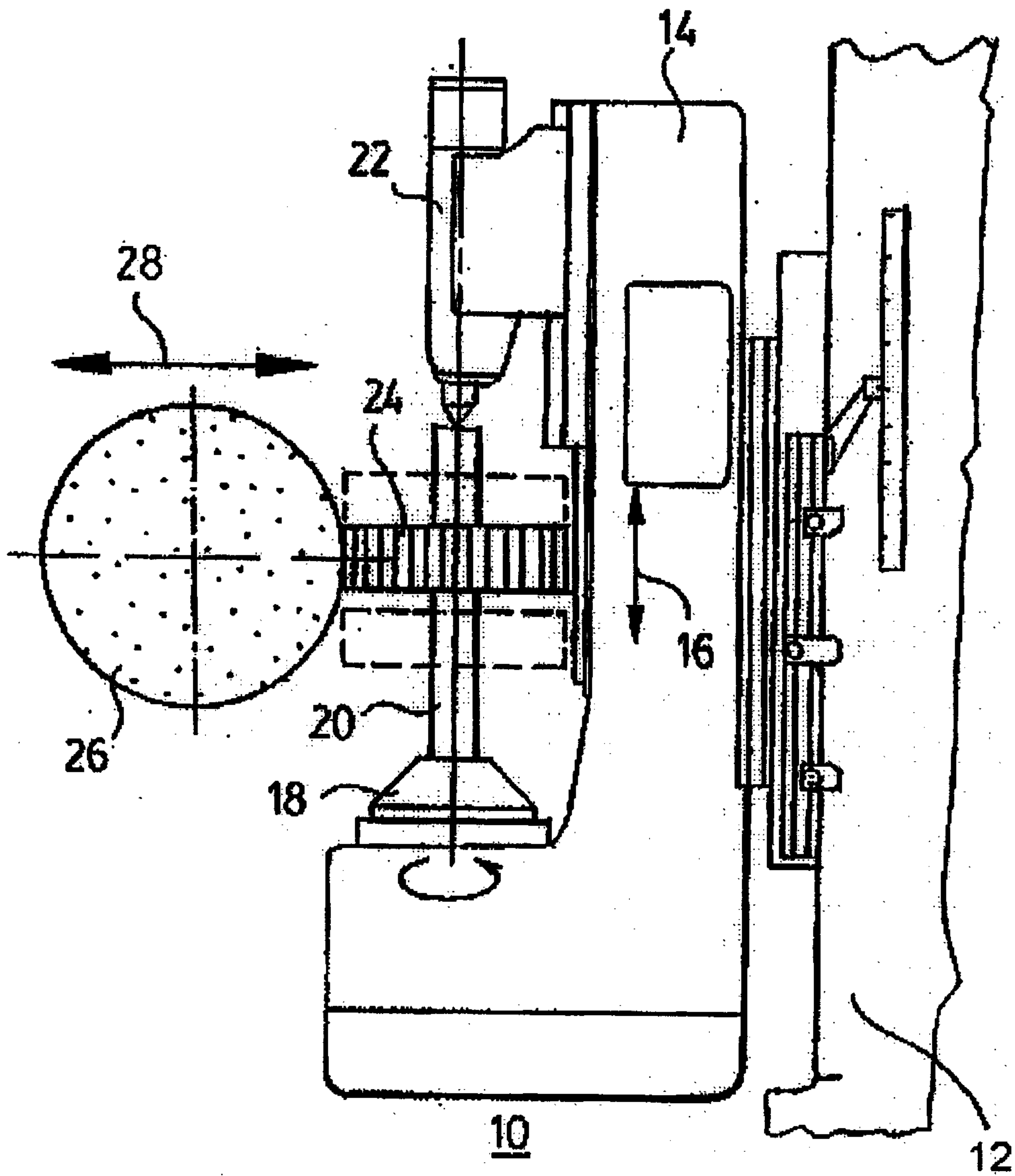


FIG. 1. (PRIOR ART)

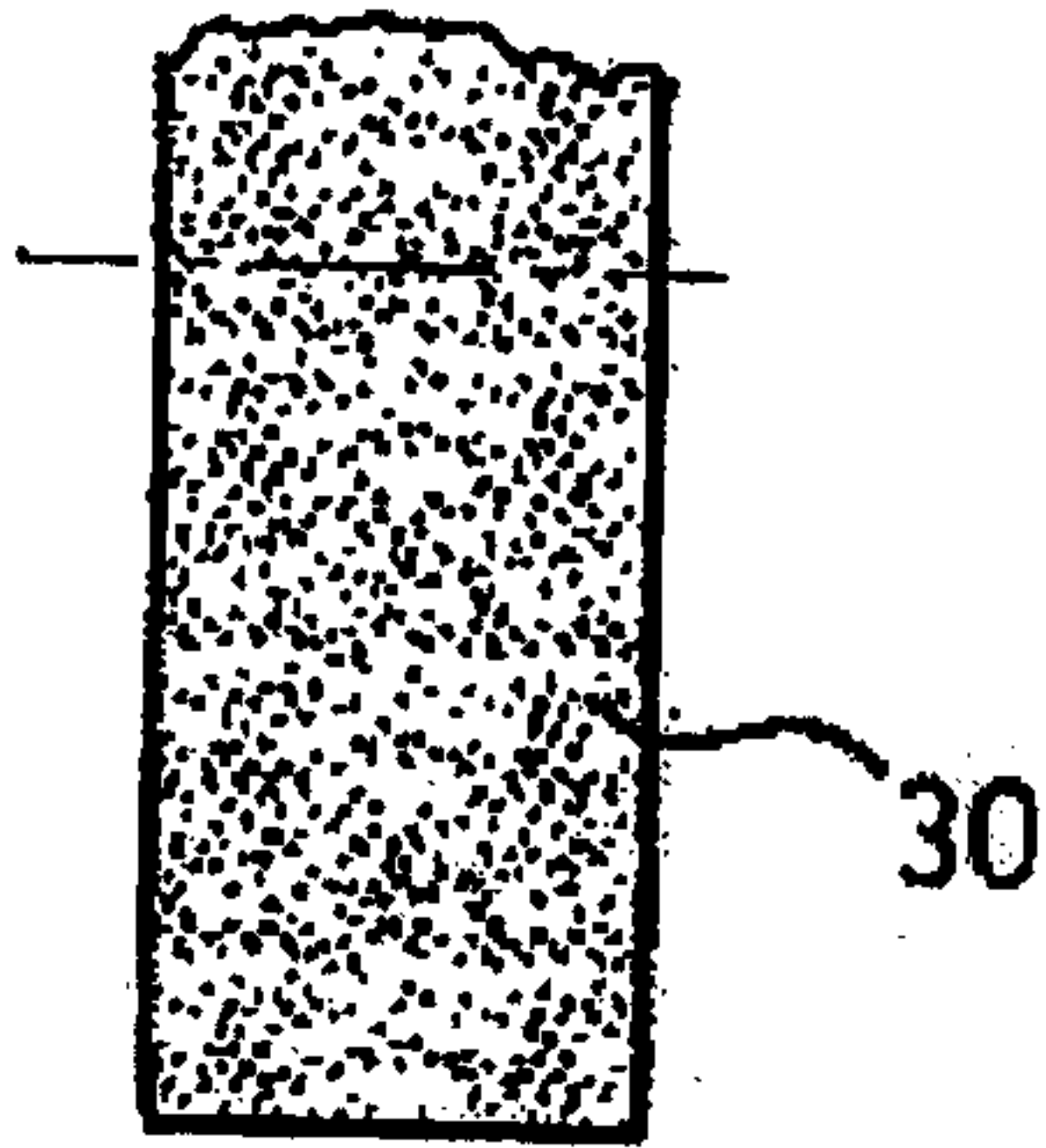


FIG. 2. (PRIOR ART)

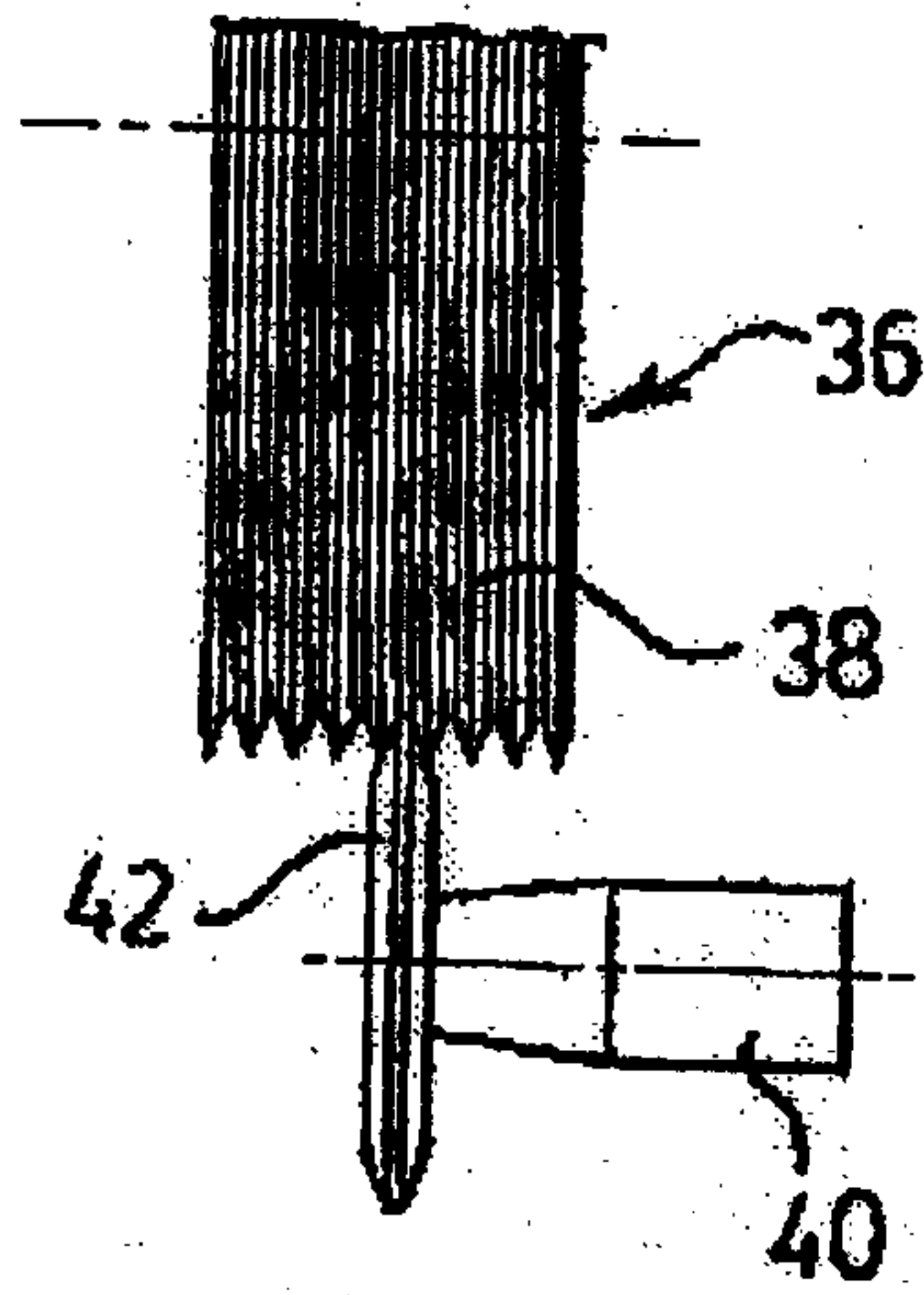
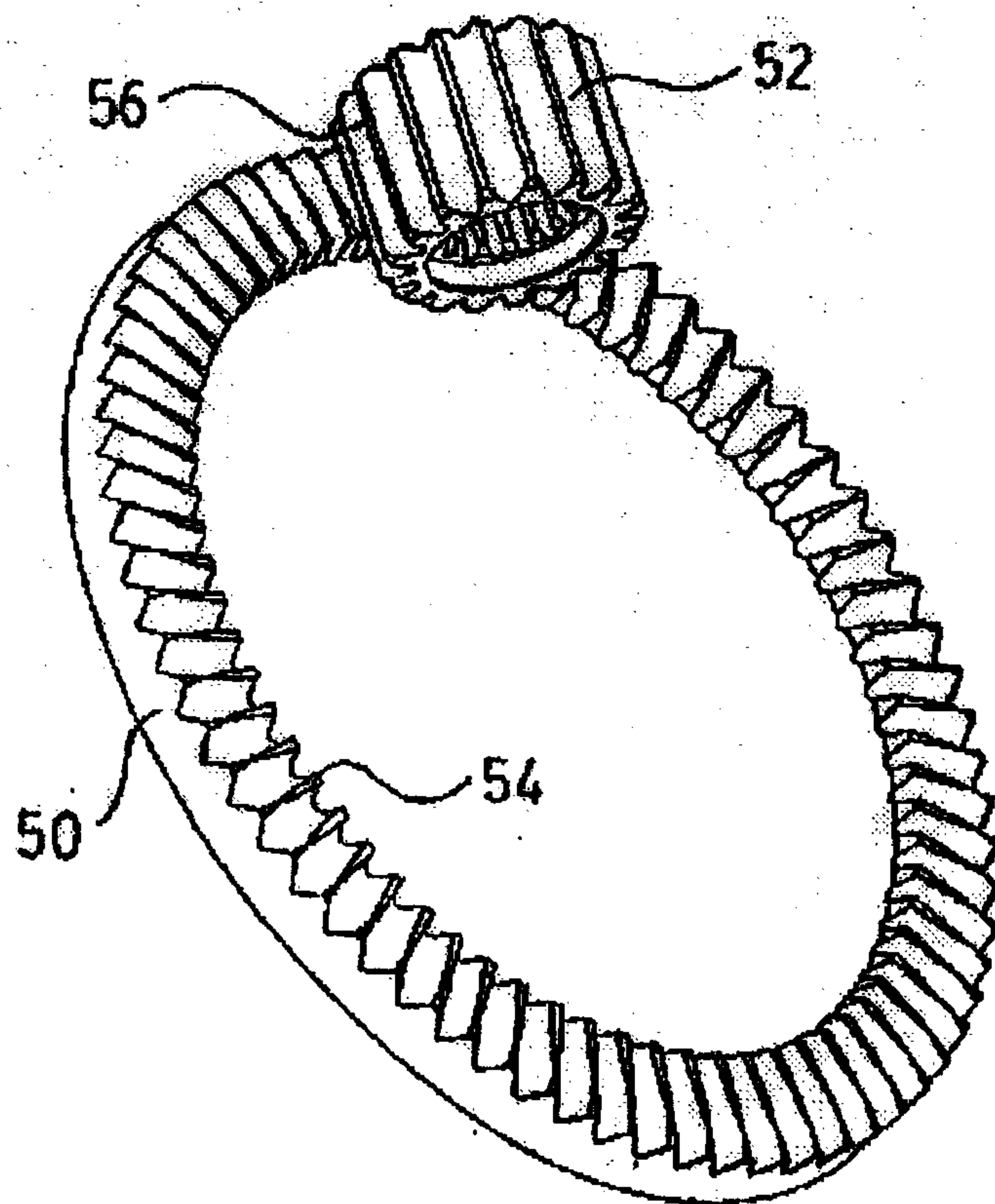


FIG. 3. (PRIOR ART)

FIG. 4. (PRIOR ART)



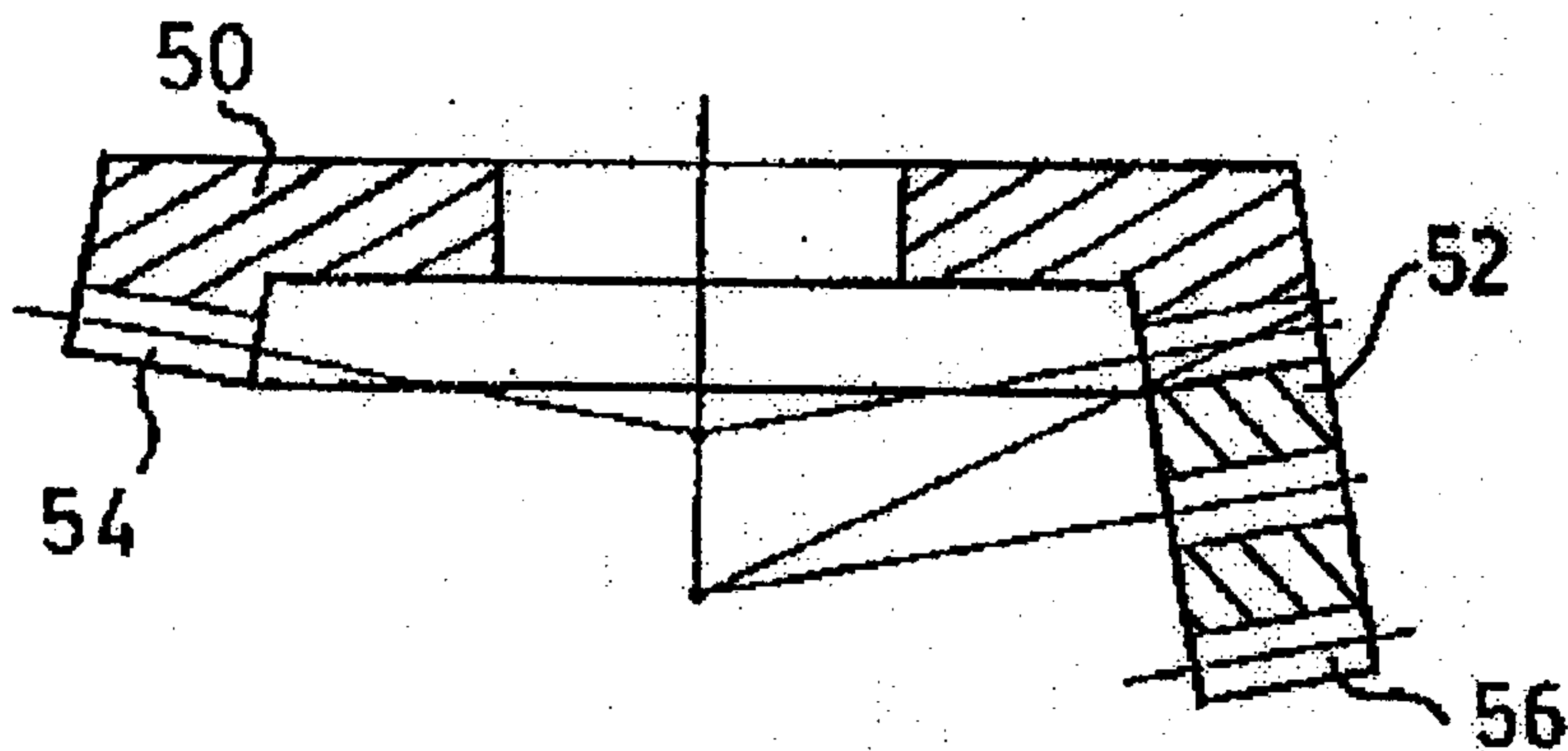


FIG. 5. (PRIOR ART)

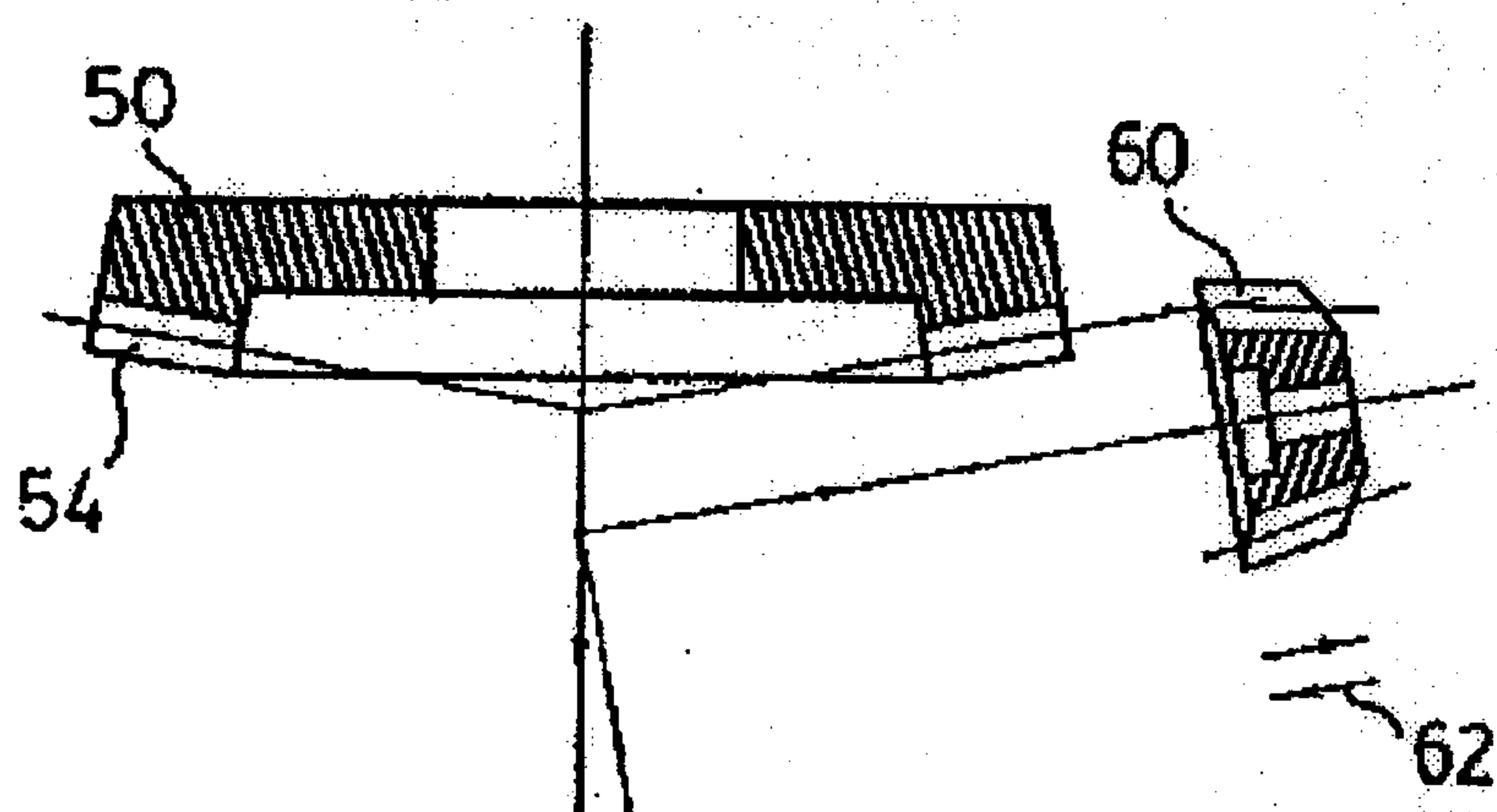


FIG. 6. (PRIOR ART)

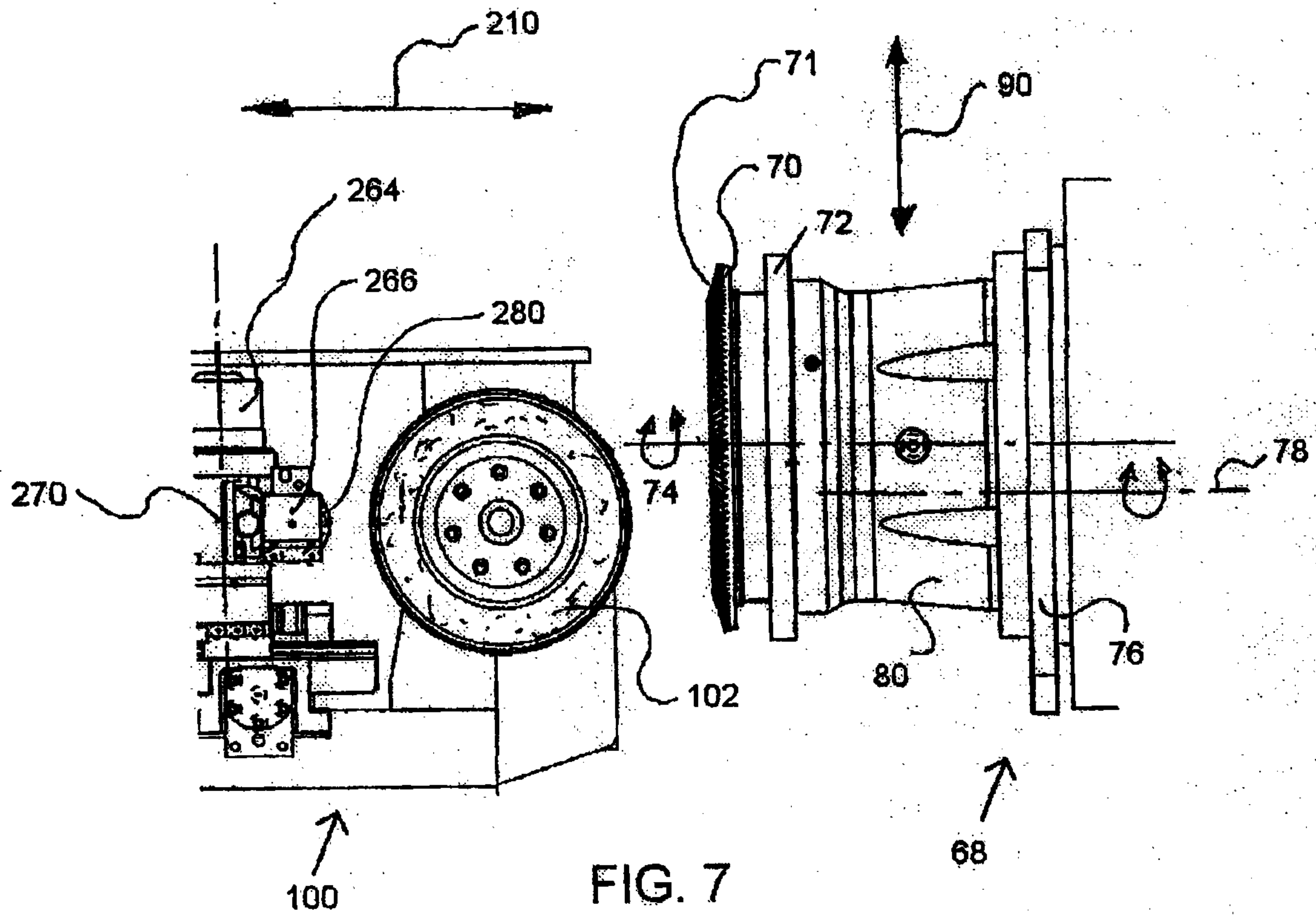


FIG. 7

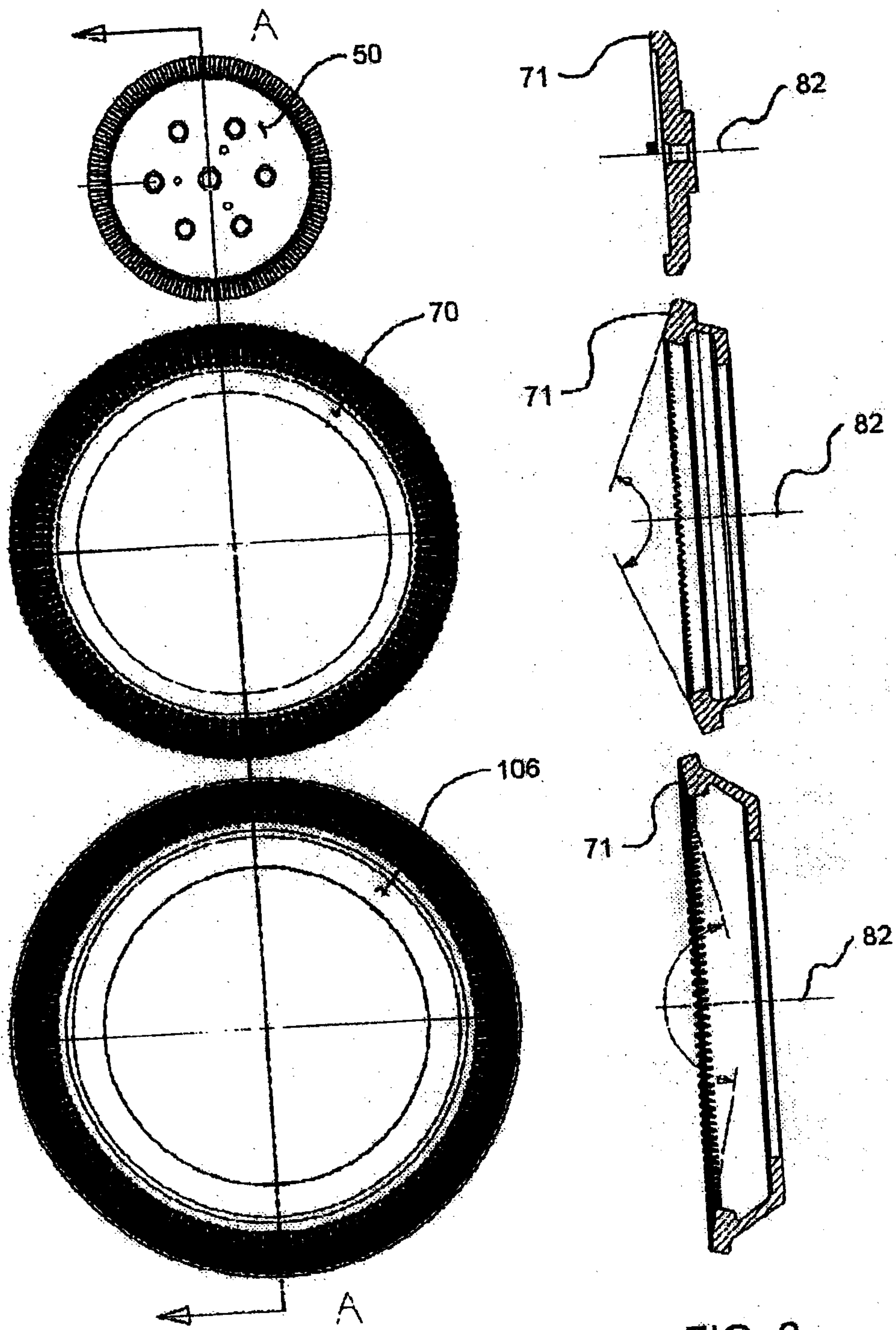


FIG. 8

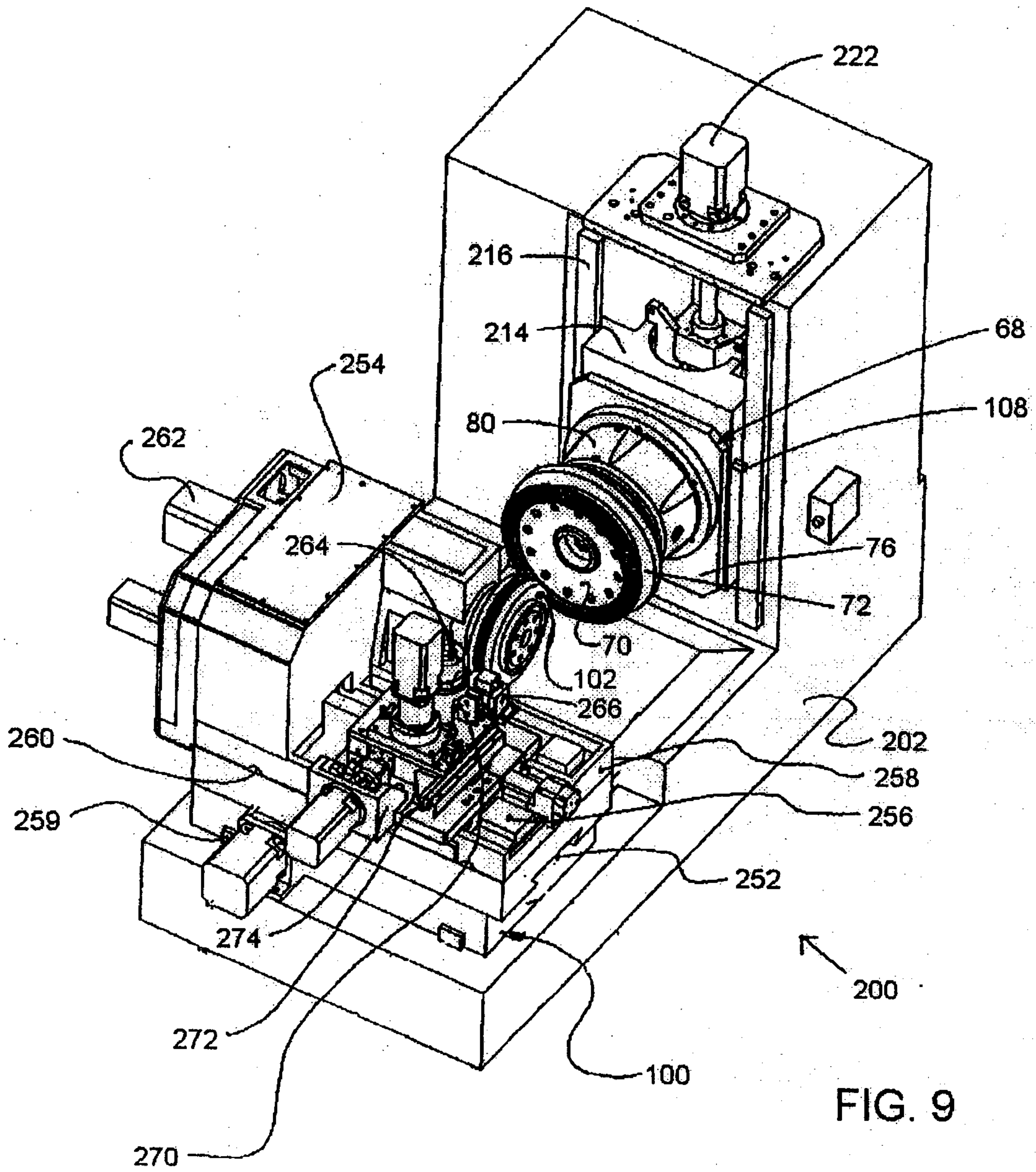


FIG. 9

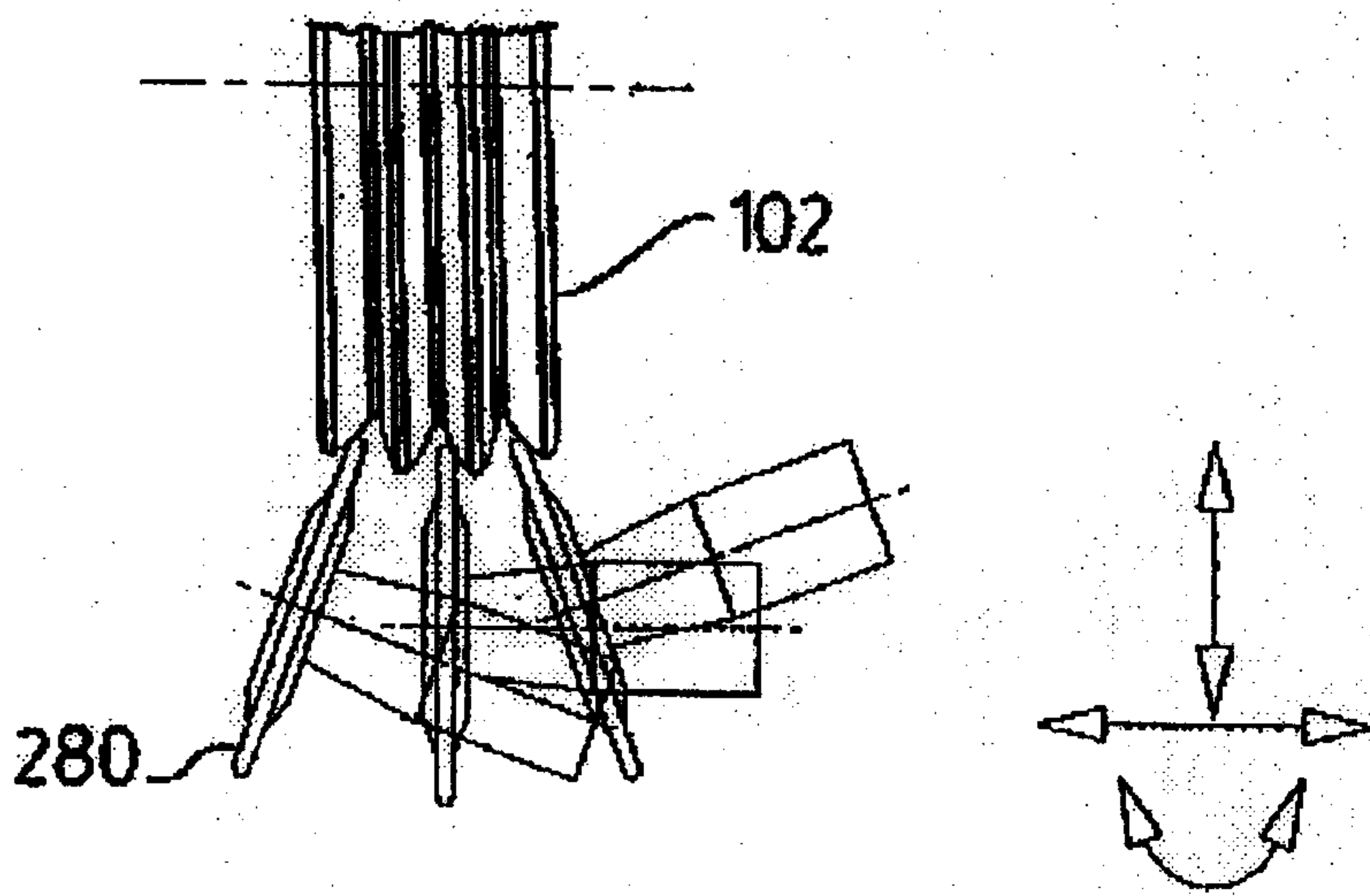


FIG. 10.

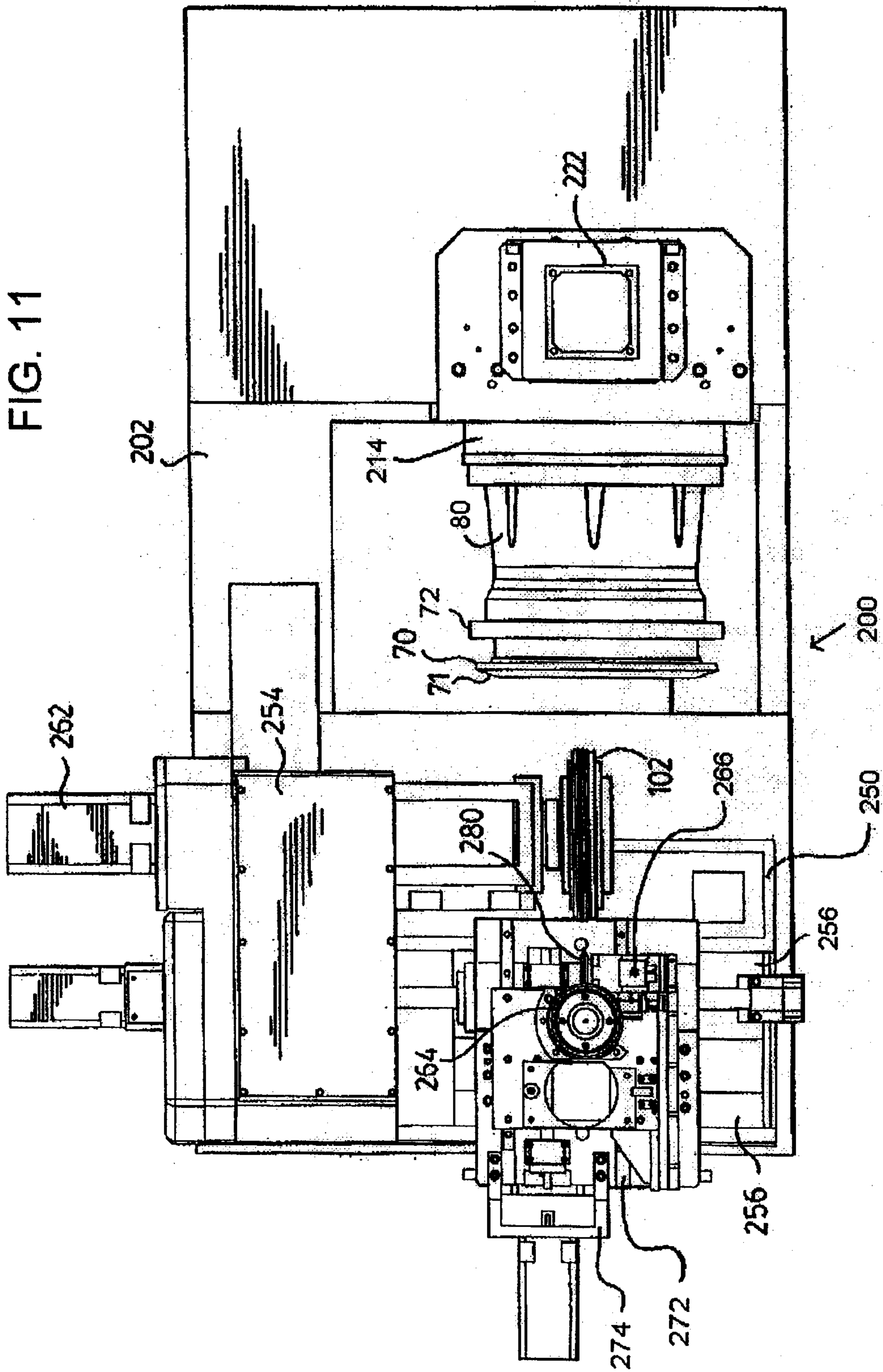




FIG. 13

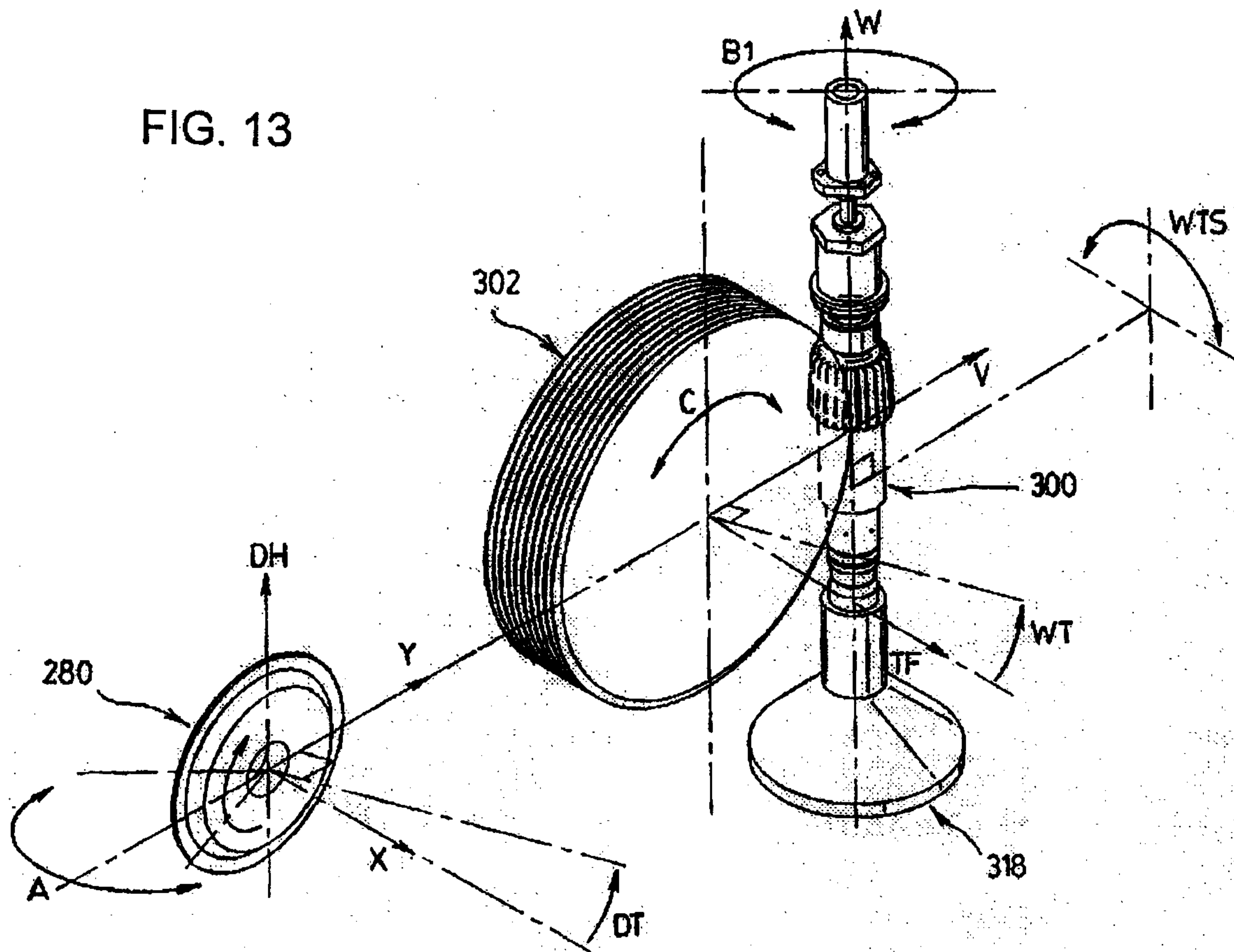


FIG. 14

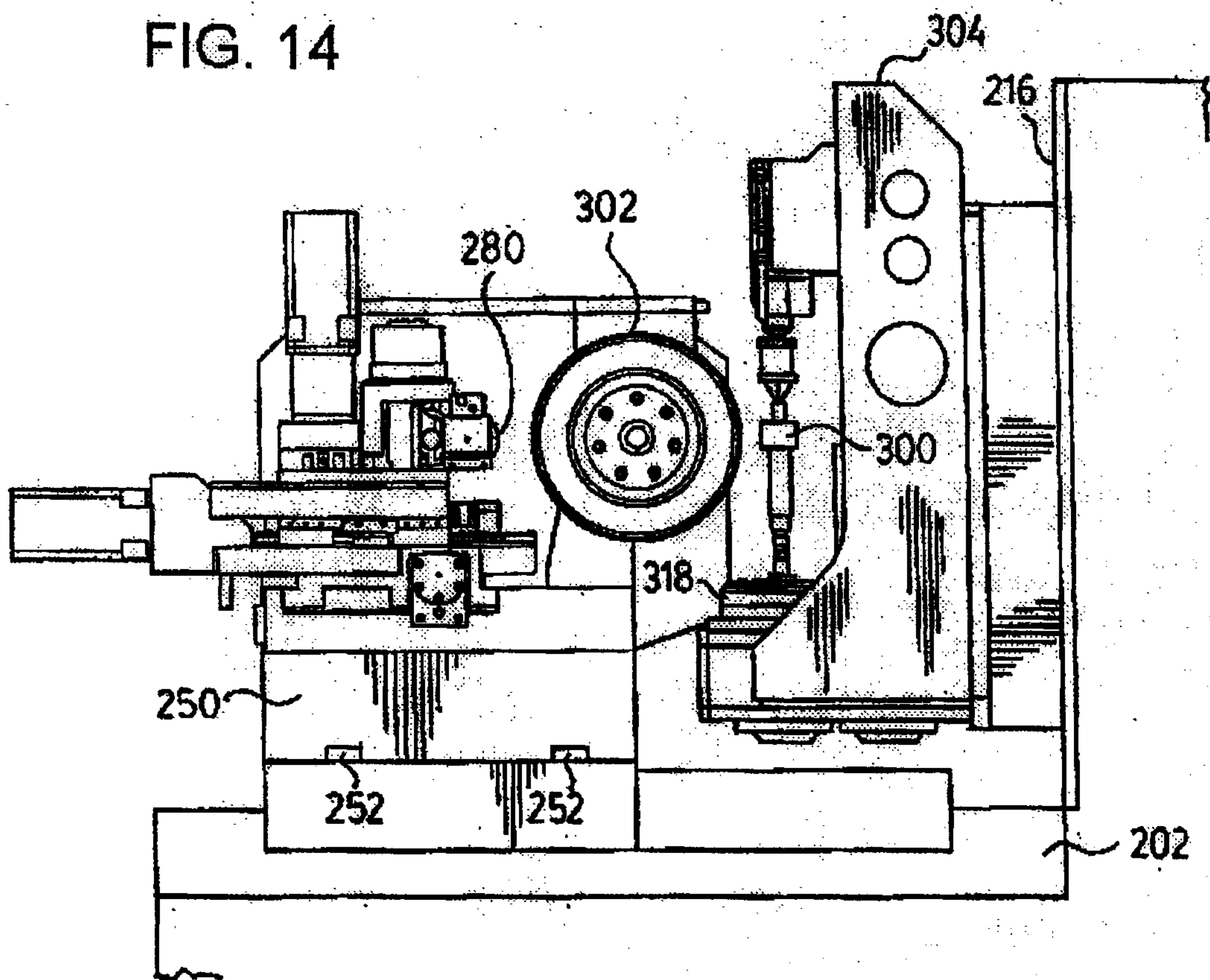


FIG. 15

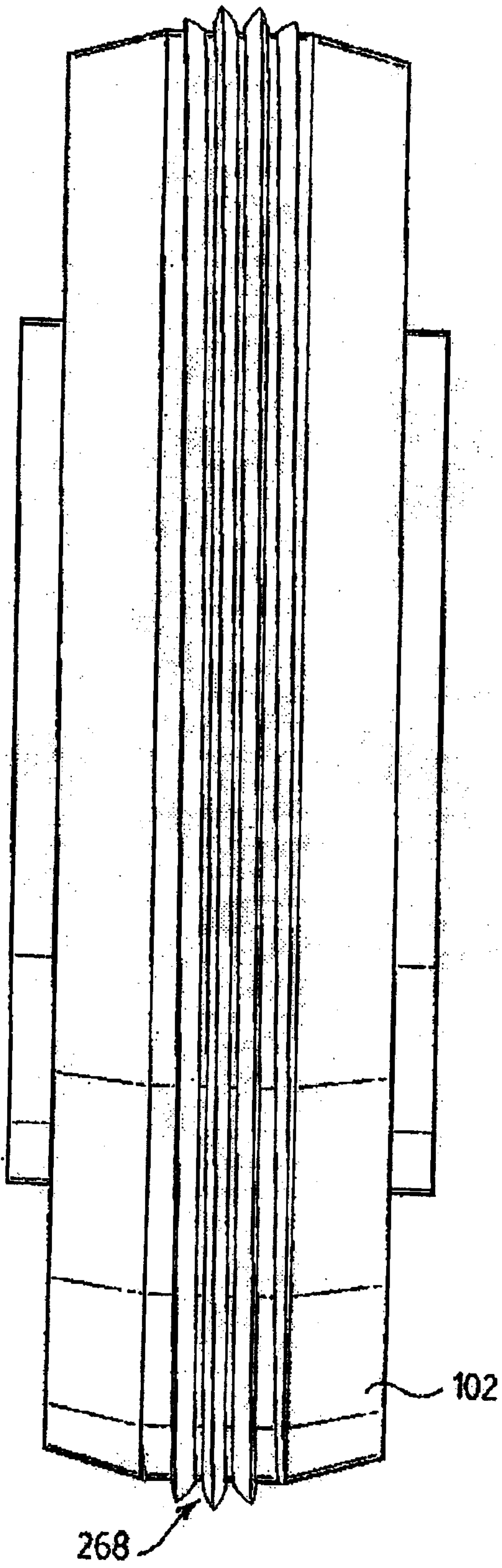


FIG. 16

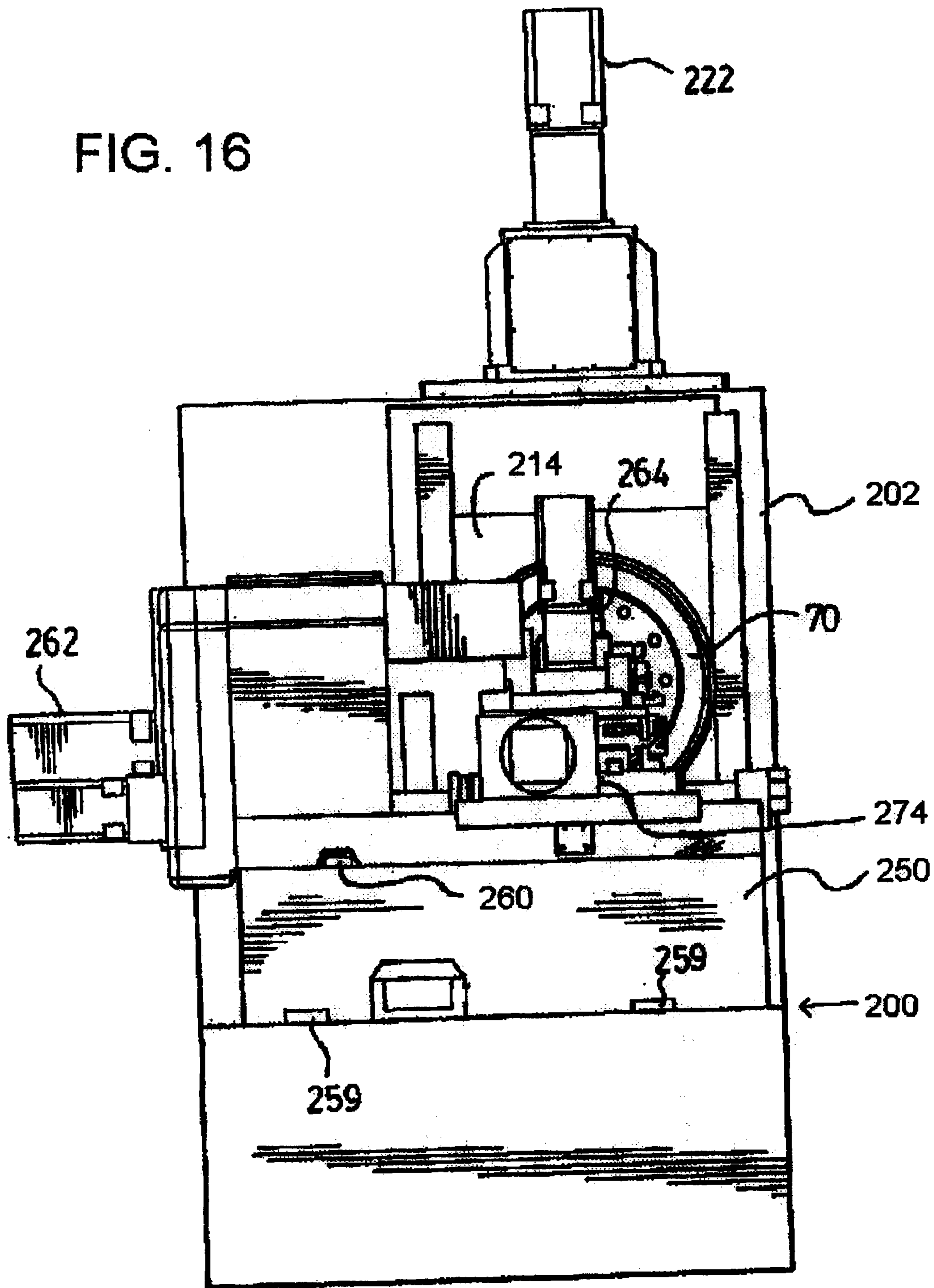


FIG. 17

