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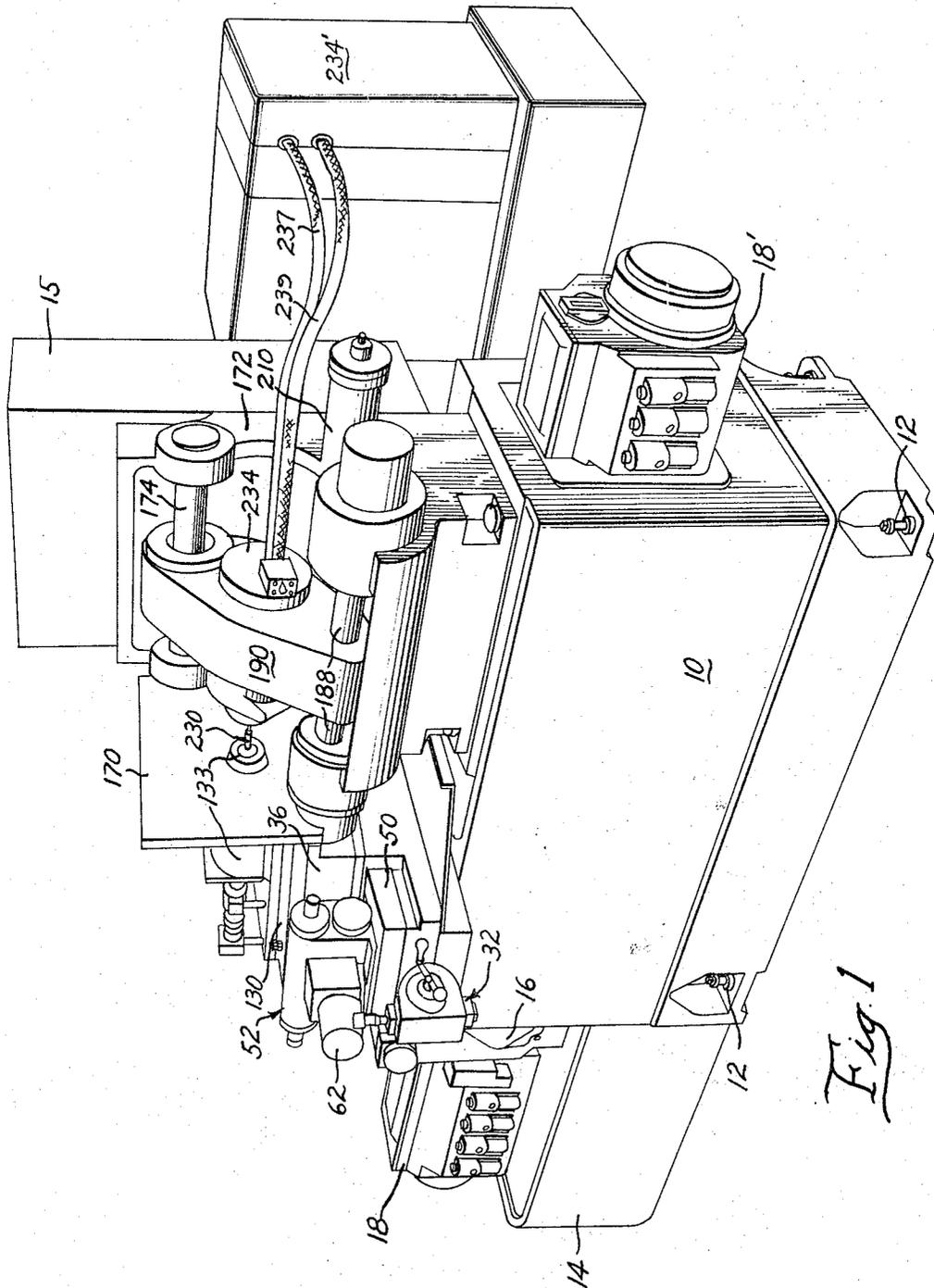
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3,345,782

INTERNAL GRINDING MACHINE

Original Filed Jan. 14, 1963

10 Sheets-Sheet 1



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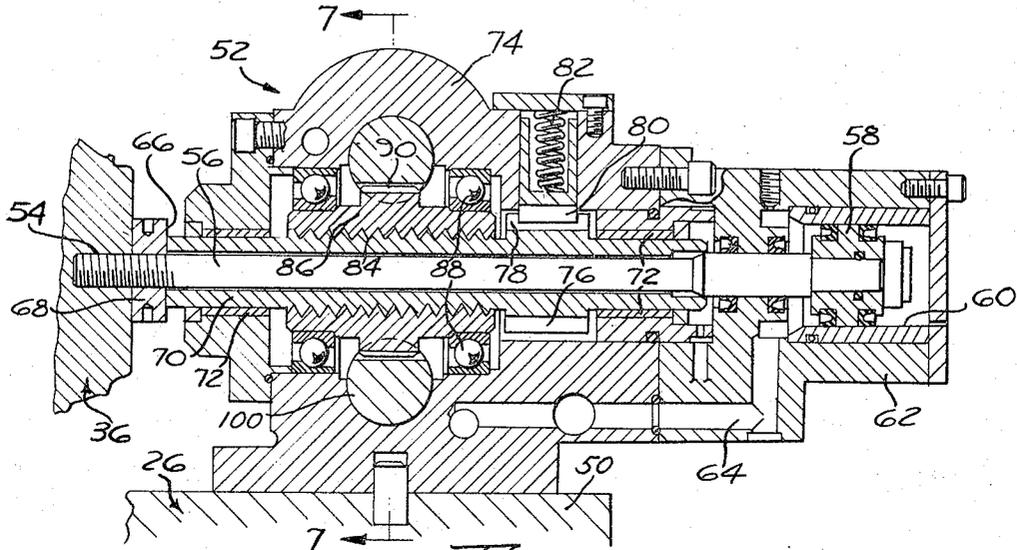


Fig. 6

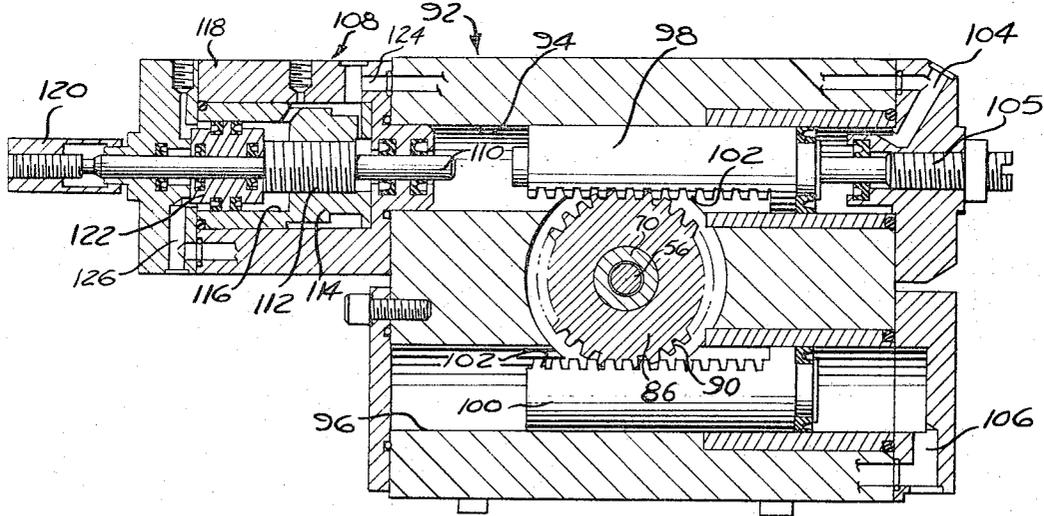


Fig. 7

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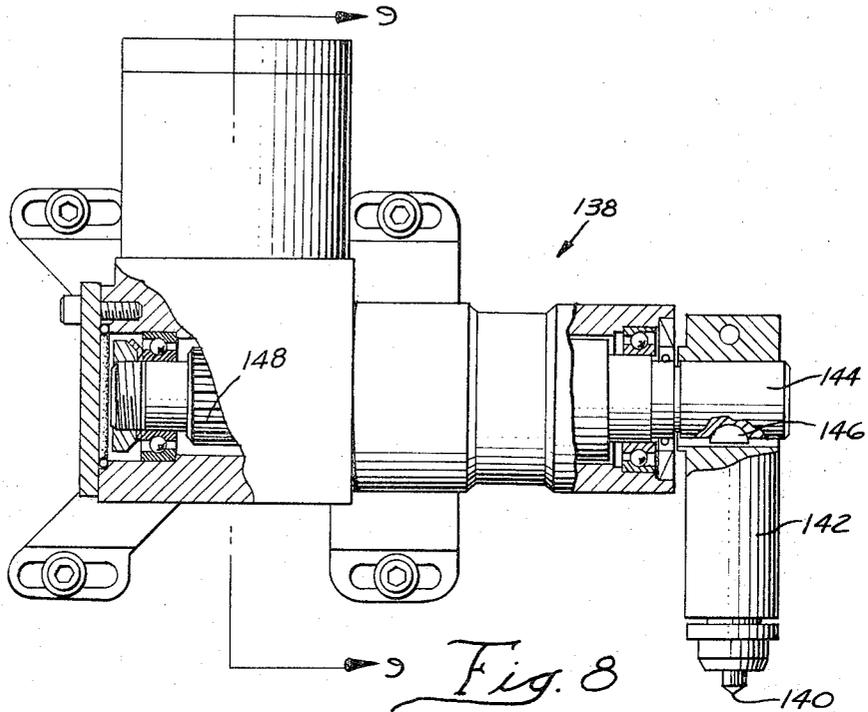


Fig. 8

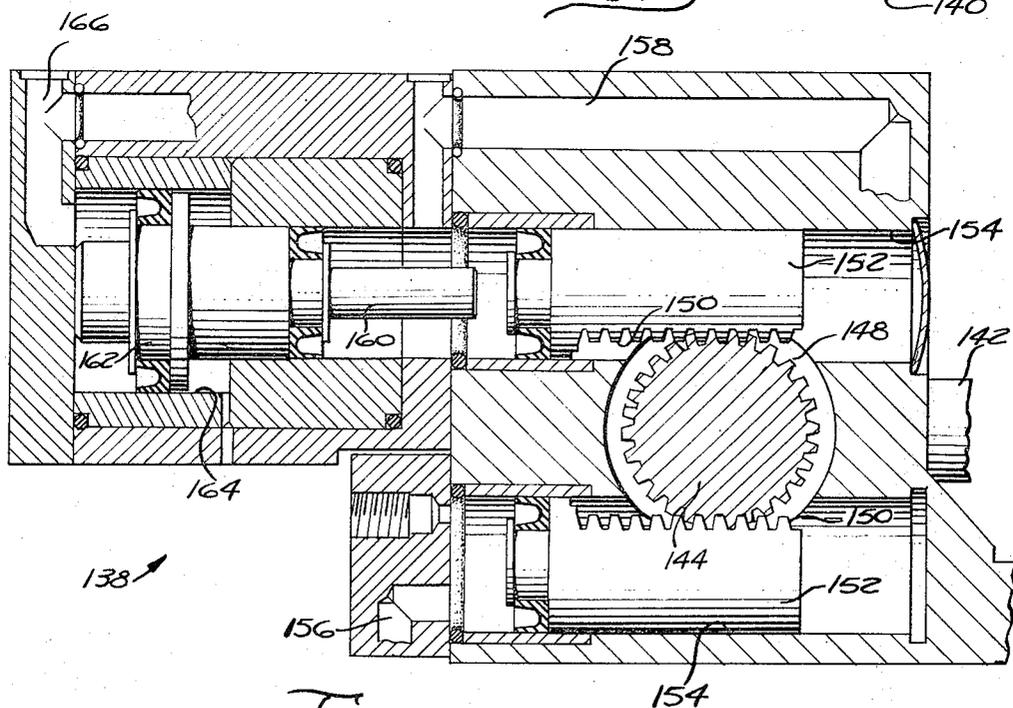


Fig. 9

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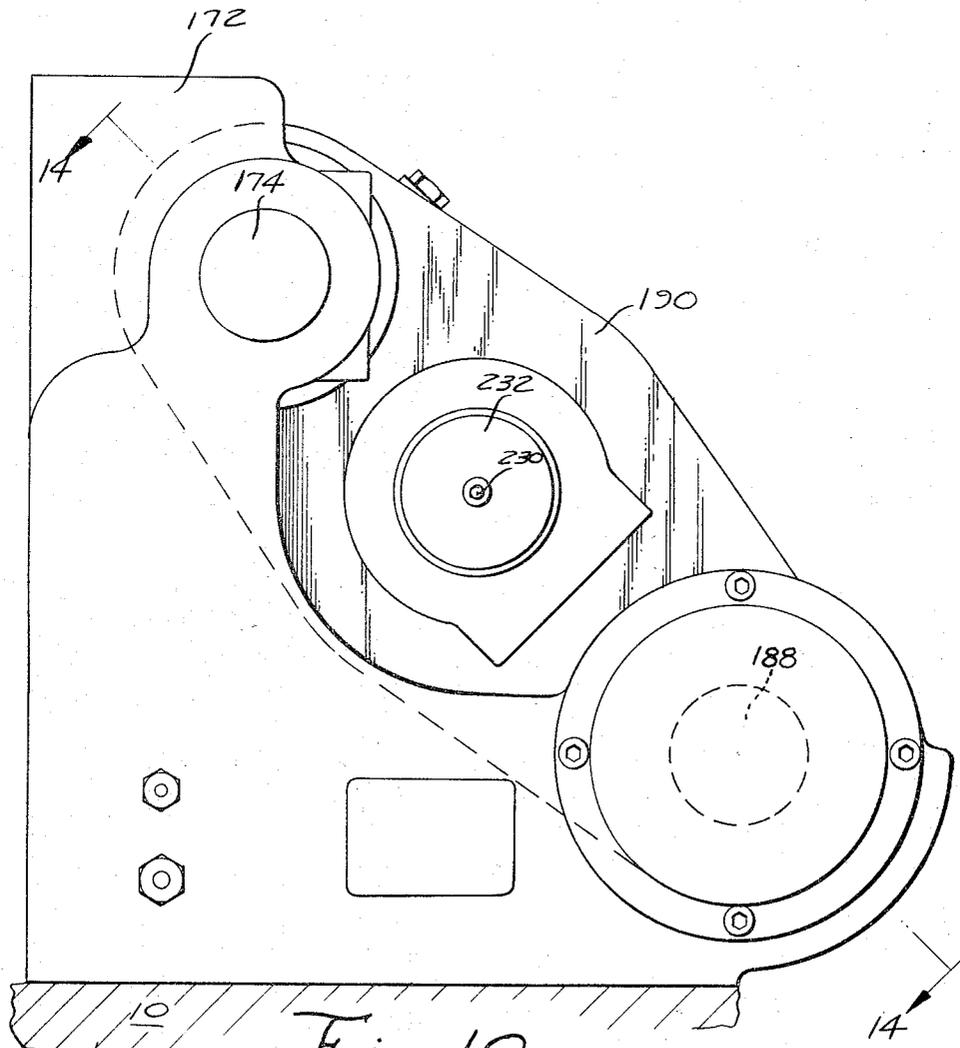


Fig. 10

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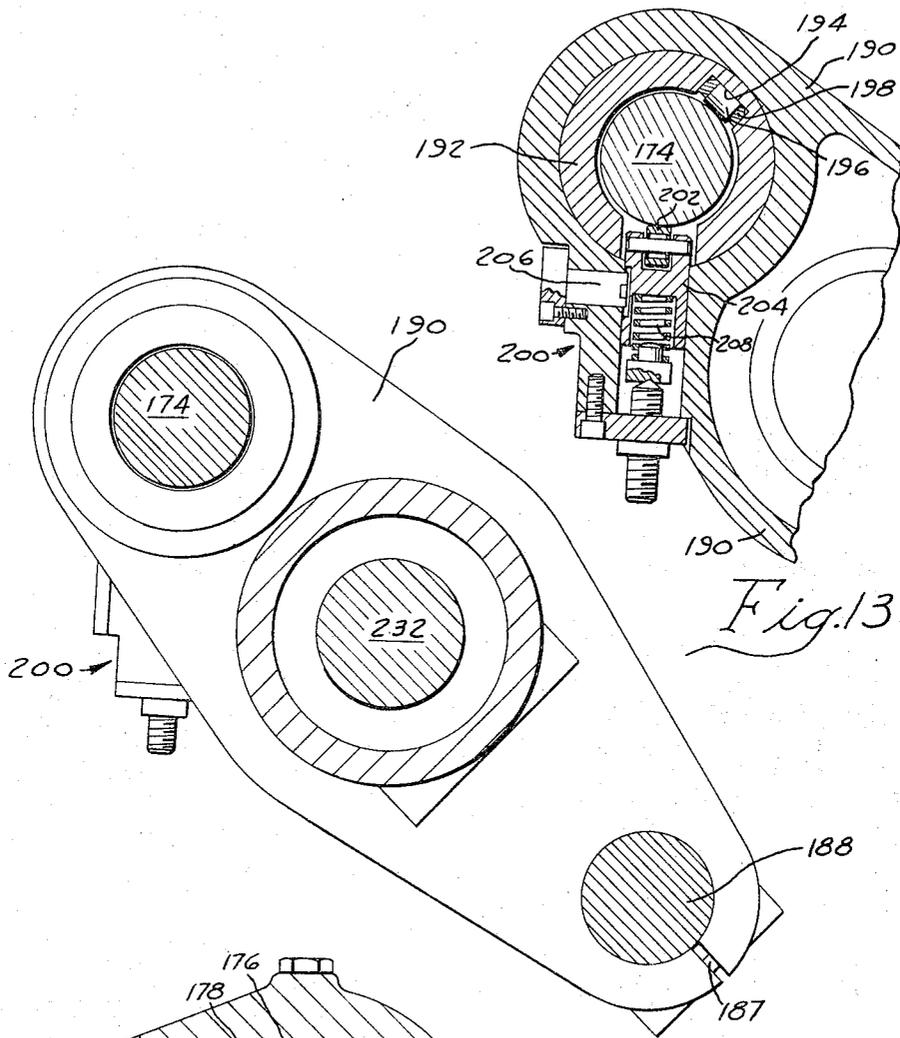


Fig. 13

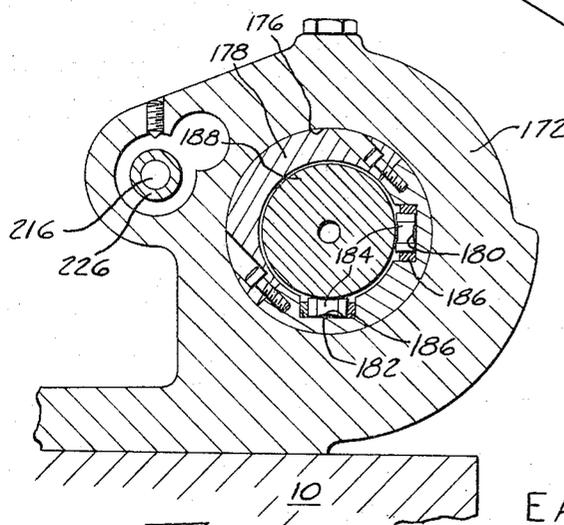


Fig. 12

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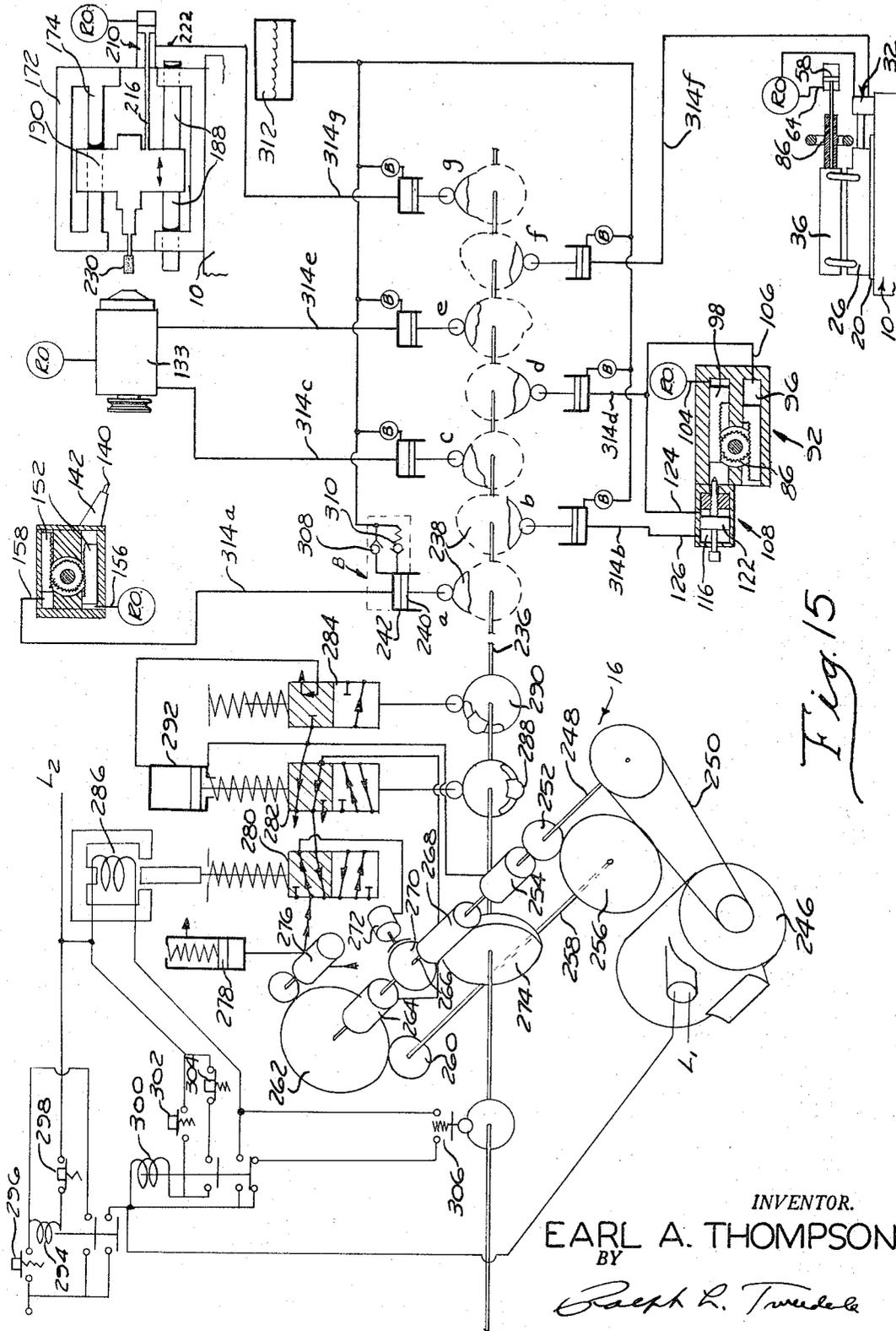


Fig. 15

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3,345,782

INTERNAL GRINDING MACHINE

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Continuation of application Ser. No. 253,022, Jan. 14, 1963. This application Aug. 30, 1965, Ser. No. 487,964 31 Claims. (Cl. 51—50)

This application is a continuation of my copending application Ser. No. 253,022 filed Jan. 14, 1963 which is to be abandoned, and which was filed as a continuation-in-part of my then copending and now abandoned application Ser. No. 49,748 filed Aug. 15, 1960. This invention relates to machine tools and more particularly to shiftable members on a machine tool, for example a grinding wheel carriage on an internal grinder.

Obtaining precision operations on machine tools designed for mass production of workpieces depends upon the accuracy and speed with which very heavy machine elements can be shifted back and forth on a base. Heavy shiftable members can be guided accurately to move in a precise path by friction bearings or guides such as dove-tailed or V-ways. But such ways introduce a great deal of frictional resistance, which requires the use of wastefully powerful apparatus to do the moving, and because the resistance varies, introduce the annoying phenomenon of stick-slip. This latter prevents accurate movement of a heavy member to an exact position in its path. Anti-friction bearings or guides have been proposed to eliminate or reduce friction and stick-slip. Anti-friction is used here with its customary designation of bearings in which a first surface is supported by a second surface so that it can move parallel to the second surface while sliding contact between the two surfaces is precluded. Well known examples of such anti-friction bearings are rollers, balls, and air, oil or other fluid bearing devices. Such anti-friction devices have heretofore required increased tolerances and have resulted in inaccuracy of the path of movement which prevents precision machining.

These problems are especially severe on precision internal grinding machines, in relation to which the broadly useable elements of this invention are disclosed, by way of example only. On such grinders, a small diameter grinding wheel rotating at high speed must be inserted into a revolving workpiece, then moved radially against the workpiece and then moved back and forth axially in order to remove material from the workpiece. The wheel must also be moved radially from time to time to compensate for material removed from the wheel by frequent dressing operations. These compound motions coupled with temperature changes and other variables intensify the above problems.

Accordingly it is one object of the invention to provide an improved anti-friction bearing or guide device on a machine tool which minimizes resistance to movement and which repeatedly guides the shiftable member along the same precise path.

Another object of the invention is to provide improved high precision anti-friction bearings or guides for guiding a shiftable member on a machine tool which bearings or guides confine to a single plane any movement due to dimensional variations of the shiftable member (which might be caused by conditions such as temperature changes for example). Confining such movements to a single plane allows them to be easily compensated.

Another object of the invention is to provide improved high precision anti-friction bearings or guides for guiding a shiftable member on a machine tool which obtain maximum accuracy with minimum constraint by avoiding any unnecessary duplication of locating means while retaining stability through the use of only three supporting means

acting at well spaced points to provide a wide rigid base.

Another object of the invention is to provide plural high precision, anti-friction bearings or guides for a shiftable member on a machine tool which are all preloaded to desired amounts by a single, easily adjusted yieldable pre-loading means to avoid significant variation due to stress in the machine.

Especially it is an object to achieve the foregoing objectives with improved bearings including rolling members.

A further object is to provide high precision anti-friction ways or guides for one shiftable member on a machine in combination with another shiftable member supported on an anti-friction parallel link arrangement whereby a tool may be supported on one member for movement in one direction and a workpiece may be supported on the other member for movement in another direction to obtain compound motion between the workpiece and the tool.

A further object is to provide an internal grinder wherein the wheel is reciprocable axially, and the workpiece is movable to-and-fro in one direction of translation by two separate means, one means determining and also compensating for the amount of wheel reduction by dressing and the other means presenting successive workpiece radially to the wheel until a presettable finished dimension is produced on a workpiece.

A further object is to provide, in association with an internal grinder, a power and control unit of the mechano-hydraulic variety including rotary cam actuated transmitters for transferring motion through liquid columns to fluid motors on the machine.

Further objects and advantages of the present invention will be apparent from the following detailed description, with reference to the accompanying drawings in which like reference characters refer to the same parts throughout the several views, and in which:

FIGURE 1 is a perspective view of an internal grinding machine embodying the features of this invention;

FIGURE 2 is an elevational view of the machine shown in FIGURE 1;

FIGURE 3 is an overall plan view of the same machine;

FIGURE 4 is an end view on an enlarged scale of a portion of the machine looking from line 4—4 of FIGURE 2;

FIGURE 5 is a sectional view along line 5—5 of FIGURE 4 showing a torsion bar interconnected parallel link arrangement for supporting the work carrier;

FIGURE 6 is a sectional view along line 6—6 of FIGURE 3 showing the lead screw feed arrangement for the parallel link supported carrier;

FIGURE 7 is a sectional view along line 7—7 of FIGURE 6 showing the fluid motor for actuating the lead screw feed arrangement;

FIGURE 8 is a plan view with parts broken away of the dressing apparatus;

FIGURE 9 is a sectional view along line 9—9 of FIGURE 8 showing the fluid motor for moving the dressing apparatus between its operative and in operative positions;

FIGURE 10 is a sectional view along line 10—10 of FIGURE 2 showing the grinding wheel end of the frame supporting the wheel carriage;

FIGURE 11 is a sectional view along line 11—11 of FIGURE 14 showing the general arrangement for supporting the wheel carriage;

FIGURE 12 is a sectional view along line 12—12 of FIGURE 14 showing the lower preloaded roller support for the wheel carriage;

FIGURE 13 is a sectional view along line 13—13 of FIGURE 14 showing the preloaded rollers supporting the

upper portion of the wheel carriage and the bearing pre-load arrangement;

FIGURE 14 is a sectional view along line 14—14 of FIGURE 10 showing the three spaced point support arrangement for the wheel carriage; and

FIGURE 15 is a view in schematic fashion of the mechanico-hydraulic motivator utilized by this invention.

Looking at FIGURES 1, 2 and 3, the internal grinding machine which embodies the features of this invention comprises a generally rectangular base 10 for movably supporting the compound slide rests, to be explained, and provided with a suitable leveling means 12 for fixedly supporting the entire mechanism on a floor. A mechanico-hydraulic drive unit comprising a base assembly 14 and a plural-speed transmission 16 driving a main camshaft 236 which may extend from either side thereof and through the length of the base 10 to drive rotary cams in at least two cams case housings 18, 18' (all to be later described) supported on opposite ends of the base 10 and protruding therefrom in a conveniently accessible fashion. A housing 15 for electrical controls, and a coolant tank 17 with a pump 19 may be provided after the known fashion.

At one end of the base 10 is a bed 20 having suitable guide ways 22 on the upper portion thereof which extend horizontally at right angles to the center line 24 of the machine's base. As more clearly seen in FIGURES 4 and 5, the guide ways 22 of the bed 20 support a slide member 26 by means of mating guide elements 28 for sliding motion crosswise of the machine. An extension 30 of the bed 20 supports a fluid motor actuated ratchet mechanism 32 for rotating a lead screw mechanism 34 connected to the slide member 26 to move it to and fro on the guide ways 22. Hydraulic fluid pulsed to the fluid motor of the ratchet mechanism 32 once on each cycle of the grinding machine rotates the lead screw mechanism 34 to pull the slide member 26 toward the ratchet mechanism for a small distance equivalent to the amount of material that is to be dressed off the grinding wheel, as more fully explained below.

A work feeding carrier 36 is supported for to-and-fro motion upon the slide member 26 by means of a parallel link antifriction arrangement. Two opposed cut out areas 38 on the upper surface of slide member 26 are opposed by similar cut out areas 38 on the under side of carrier 36 to provide clearance for the torsion bar interconnected parallel link arrangements 40, two of which are used to support the carrier on the slide member in the current embodiment. Each anti-friction link arrangement comprises two links 42 each journalled at 44 near their lower end in the slide member 26 and journalled at 46 near their upper ends in the carrier 36. The two links 42 are made unitary with, and are rigidly interconnected by, a bar 48 having quantities of resistance to torsional forces sufficient to insure precise parallelism between the two links.

Thus the carrier 36 is supported for limited arcuate motion on the slide member 26 by four spaced links, each pivotally mounted near the corners of the two members forming similar parallelograms on each side. The two torsion elements 48 interconnect adjacent pairs of the links 42 to insure precise parallelism therebetween. The axially aligned locations 44 where the lower portion of each pair of links is pivoted in the slide member 26 are on a line extending parallel with the centerline 24 of the machine.

Supported on an extension 50 of the slide member 26 is the feed mechanism 52 for imparting arcuate motion to the carrier 36. Viewing FIGURE 6, the carrier 36 and the slide member 26 in relation to which it moves, are fragmentally shown. Threaded at 54 into the end of the carrier 36 is a shaft 56 made of flexible steel and terminating in a piston 58 reciprocable in a cylinder 60 formed in a cup-shaped housing 62. Oil under pressure admitted through a connection 64 continually urges the piston 58 toward the right hand end of the cylinder 60, and con-

sequently biases the carrier 36 toward the feed means 52 fixed on the extension 50 of the slide 26.

The motion towards the feed means 52 is limited by the smooth face 66 of a block 68, which is also secured to the carrier 36 by means of the screw threads 54, abutting the end of a hollow shaft 70 journalled in sleeve bearings 72 in the main housing 74 of the feed means 52. Hollow shaft 70 has an enlarged annular portion 76 which includes at least one tapered longitudinal groove or way 78 into which a similarly tapered key 80 is urged by a spring 82, thus securing shaft 70 against rotary motion, but allowing it reciprocatory motion. As the shaft 70 moves to the left in FIGURE 6, it pushes against the smooth face 66 of the block 68 on the carrier 36, and the carrier 36 swings away from the feed means 52. Since the motion of the carrier 36 is arcuate and not precisely rectilinear, a very small amount of up and down motion will accompany the limited forward motion. This is absorbed by the yieldable shaft 56 which will flex upwardly within hollow shaft 70 as carrier 36 moves upwardly with its smooth face 66 sliding on the end of the non-flexing shaft 70.

Hollow shaft 70 is in effect a travelling lead screw with external threads 84 thereon which mate with the internal threads of a rotating nut 86 journalled in rugged bearings 88 in the housing 74. Around the periphery of nut 86 are gear teeth 90 engaged by opposed racks for turning the nut. As nut 86 is rotated, hollow shaft 70 will move carrier 36. The racks are part of an expansible chamber type double headed anti-lash fluid motor 92 which comprises an upper cylinder 94 and a lower cylinder 96 having pistons 98, 100 reciprocable therein, respectively. Each piston has rack teeth 102 formed lengthwise thereon which engage on opposite sides with the teeth 90 on the periphery of nut 86. Oil for moving the upper piston 98 to the left (and lower piston 100 to the right) is admitted to cylinder 94 through a connection 104, and oil for rotating the nut in the other direction is admitted through a connection 106 to the lower cylinder 96 to move the lower piston 100 to the left (and upper piston 98 back to the right). An adjustable stop 105 limits the rightward stroke of piston 98 which in turn determines the length of the feed stroke imparted to the carrier 36.

Attached to the left end of upper cylinder 94 is a diamond wear compensator 108. The compensator comprises a limit stop or abutment 110 for the upper piston 98 of motor 92, which is adjustable by means of an enlarged thread portion 112 thereon having threads which mate with similar threads in a fixed stepped sleeve insert 114 which also contains a cylinder 116 of the same effective area as cylinder 96 and is itself contained within a housing 118 secured to the housing for the motor 92. A manually turntable handle 120 on the outer end of the adjustable limit stop shaft 110 serves to move it in and out to determine the stroke of piston 98 in the cylinder 94 to change the rest position of the arcuately movable carrier 36 in relation to the slide member 26. Loosely received on the abutment shaft 110 is an apertured free piston 122 which reciprocates in the cylinder 116 when the enlarged screw thread portion 112 of the limit stop is screwed inwardly toward piston 98. A connection 124 admits fluid communication with one end of cylinder 116, and another connection 126 admits pressurized fluid to the other end thereof, both in a manner later to be described. When the limit stop 110 is fully retracted to allow a maximum stroke of piston 98, the enlarged screw thread portion 112 locks the free piston 122 and prohibits reciprocation; however, when limit stop 110 has moved in the other direction to limit the displacement of piston 98, the piston 122 will be freely movable for a distance to produce similar displacement in the variable volume chamber 116.

FIGS. 2, 3 and 4 show a work holder 133 and dressing apparatus 138 mounted on a swivel plate 130 which is fixedly secured in a desired position on the carrier 36

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by suitable means such as bolts 132 is a work holder and a dressing apparatus. The work holder 133 comprises a collet or chuck which can grip or un grip workpieces and eject finished workpieces with mechanism powered by fluid motors, not shown, enclosed within the collet housing. The collet can be rotated by a belt 134 driven from a motor 136 also mounted on the swivel plate 130.

As shown in FIG. 8 the dressing apparatus 138 comprises a dressing tool such as diamond point 140 fixedly mounted on an arm 142. The arm is pivotable about the axis of a shaft 144 between two positions: one an operative position, and the other an inoperative position. The arm 142 is keyed at 146 to the shaft 144, and as shown in FIG. 9 the shaft 144 has gear teeth 148 which mesh with the teeth 150 of opposed racks made integral with alternatively powered pistons 152 in parallel cylinders 154. Oil pulsed through a connection 156 to the lower of the cylinders 154 moves the lower piston 152 to the right (FIGURE 9) and pivots the diamond arm 142 upwardly to the inoperative position. Fluid under pressure admitted through a connection 158 to the left hand end of the upper of the cylinders 154 moves the upper piston 152 to the right, and the lower piston back to the left, to pivot the diamond arm 142 downwardly and hold it in the operative position, as can be understood.

The stroke of the upper of the pistons 152 is limited by an abutment 160 secured to a large area piston 162 reciprocable in a cylinder 164. Oil admitted through a connection 166 behind the piston 162 serves to move the limit stop 160 to the right and prevent the diamond arm 142 from pivoting away from its lower operative position. Oil is admitted through connection 166 by manual or other suitable control means not part of the regular sequence or cycle of grinding operations when, for instance, it is necessary to hold the diamond arm down to dress a new wheel which has just been installed in the machine.

Attached also to the swivel plate 130 is a tooling plate 170 upon which suitable mechanism (not shown) may be mounted for moving a new workpiece from a supply source such as a loading chute to the collet holder 133, and then removing the finished workpiece from the collet and depositing it in an unloading chute or other suitable discharge mechanism to render the grinding machine entirely automatic. It will be understood that any suitable loading and unloading mechanism may be utilized, depending upon the size or the configuration of the workpiece to be ground, such as the mechanism disclosed in Earl A. Thompson Patent 2,978,117 issued Apr. 4, 1961 for Automatic Loading Device.

Thus it will be seen in FIG. 4 that the workpiece chucked in the work holder 133 has several motions in relation to the base 10. First, there is the motion transverse to the horizontal longitudinal centerline 24 of the machine which is accomplished by the slide member 26 moved by the lead screw arrangement 34 under control of the ratchet mechanism 32. Secondly, there is an arcuate motion of the work holder 133 about the lower extremities of the parallel links 42 which is movement about a line parallel with the base longitudinal centerline; this motion is extremely limited and approaches a short horizontal movement substantially parallel to the first motion described. It is accomplished by a fluid motor actuated lead screw 70 in conjunction with the flexible retaining shaft 56, FIG. 6. The workpiece is also rotated by means of the motor 136 during grinding operations (FIGS. 2, 3). The diamond dressing apparatus 138 is positioned in a fixed location with respect to the work in what is often referred to as a "diamond sizing" arrangement.

FIGS. 1 and 2 show on the other end of the base 10, near the work carrying arrangements just described, a framework 172 which supports a tool such as a grinding wheel 230 for to-and-fro motion along a line parallel to the machine centerline. Fixed to the frame 172 is an upper guide bar 174 parallel with the base centerline for guiding movement of a grinding wheel carriage. As shown

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in FIG. 14 on the lower portion of the frame 172 are two opposed bores 176 axially aligned parallel to the bar 174. The center lines of the bar 174 and the bores define a plane which is parallel to the base centerline and inclined from the vertical. Within each bore 176 as shown in FIG. 12 is a sleeve-like insert 178 with parallel tracks having faces 180 accurately machined lengthwise therein. The inserts 178 are positioned circumferentially so that one supporting face 180 is generally vertical; and the other face 182 is generally horizontal. The angle formed by these two bottom faces is generally bisected by the plane of the axes of the bores 176 and bar 174. Freely rollable in each track of each sleeve insert are rolling devices, preferably cylindrical rollers 184 spaced by suitable retaining cages 186 (FIG. 14). The rollers 184 may have a concavity around their mid-portion to provide line contact with a slide bar 188 (described immediately below) while the cylindrical ends of each roller make line contact with the flat bottoms of the roller tracks. The rolls 184 are thus arranged in the different tracks with their axes perpendicular in V fashion.

Supported on the rollers 184 is a slide bar 188 free to move axially to and fro on the rolls which will in turn roll to and fro in their tracks within the bores. Slide bar 188 is in effect a portion of the wheel carriage 190 which, as seen in FIG. 11, is clamped around the bar by suitable bolts 187. The two ends of the bar extend in opposite directions from the carriage proper.

The upper end of the carriage 190 surrounds the guide bar 174 which has a slide bearing in the carriage, in the form of another sleeve-like or tubular insert 192 (FIG. 13) having an internal dimension somewhat larger than the diameter of the bar 174 and containing a way 194 extending lengthwise along the internal surface thereof. Rolling in the track 194 are anti-friction bearing devices, preferably cylindrical rollers 196 in a suitable cage 198 for supporting the upper portion of the carriage 190 on the guide bar 174 against pivoting about the axis of the lower slide bar 188. The axes of the rollers 196 extend parallel to the plane in which the axes of bars 174, 188 lie and perpendicular to the geometrical projection on that plane of the axes of the two bars. Thus as the carriage 190 is moved to and fro, the upper portion of the carriage rolls on rollers 196 along the guide bar 174 fixed in the frame 172, and the lower portion of the carriage 190 which comprises the slide bar 188 rolls on the V rollers 184 in the axially aligned bores 176 in the framework.

FIG. 13 shows directly below the guide bar 174 a yieldable bearing preload device including a spring loaded roller unit 200 which comprises a concave surfaced roller 202 journaled in a sliding member 204 which is splined at 206 against rotation and is urged upwardly toward the bar 174 by a spring 208 to urge the wheel carriage 190 yieldingly downward toward the guide bar 174. This mechanism 200 maintains a continual load on the upper rolls 196, and prevents motion of the carriage 190 radially of the bar 174 which might otherwise result from vibratory or other conditions. Additionally, the unit 200 effects a downward bias that preloads the lower roller bearings 184 as well as the rollers 196. As seen in FIGURES 11, 12 and 13, the preload 200 does not act at right angles to the plane in which the axes of the two bars 188 and 174 lie; instead, the yieldable bias acts at approximately a forty-five degree angle thereto, providing a force component acting along the plane between the two bars and urging the wheel carriage 190 and its slide bar means 188 into the V formed by the rollers 184. While the particular forces on each bearing will of course vary with the weight of the carriage, the location of its natural center of gravity, the angle of inclination and spacing of the two bars, the angle of the spring preload unit, and especially the adjustable force of the spring preload unit, and the like, it will be clear that these con-

ditions may be controlled so that the forces resolve themselves into a resultant vector which may be directed into and included within the angle formed by the lower V formed by rollers 184. This prevents the lower end of the carriage from swinging upwardly out of the V bearing about the upper bar 174 upon application of working loads, allows a rigid three-point support wherein a light carriage preloads all bearings in a manner normally encountered only in much more massive slides, confines travel of the carriage strictly to the desired path yet includes a compensating arrangement for size changes of the carriage, and accomplishes all this in an extremely simple and practical manner.

The carriage 190 is suspended between the mid-portions of the two bars 174, 188 which are positioned parallel to one another with their axes in a plane inclined to the horizontal. The carriage is supported on the frame at three spaced locations. The lower rollers 184 in the aligned bores support, by means of the extremities of the lower carriage bar 188, one end of the carriage 190, while the upper rollers 196 in contact with the central portion of the fixed frame bar 174 support the upper portion of the carriage 190. The lower roller bearing supporting mechanisms allow movement of the carriage only in an accurately defined direction of travel parallel to the centerline of the base. The upper roller bearing arrangement 196 supports the carriage on the bar 174 for movement in any direction parallel to the plane in which the axes of the two bars lie; for instance, if the carriage 190 should expand lengthwise (FIGURE 11) as a result of temperature changes or other conditions of stress encountered during grinding operations, the upper cylindrical rollers 196 will move along their own axes, which moves their surfaces tangentially in relation to the guide bar 174.

For moving the wheel carriage 190 toward and away from the work, FIG. 14 shows a fluid motor 210 attached to the framework 172. This comprises a cylinder 212 containing a piston 214, the rod 216 of which is rigidly attached at 218 to the wheel carriage 190. Fluid under pressure admitted through a connection 220 will move the piston 214 to the left in its cylinder 212 and consequently move the wheel carriage 190 (including its guide bar 188) toward the work holder 133. Fluid admitted through connection 222 at the other end of cylinder 212 will move the wheel carriage oppositely. One portion of the piston rod 216 is enlarged by means of a sleeve 224 to form an abutment portion which limits the stroke of the piston 214 by contact with a threaded stop member 226 in the cylinder surrounding the rod 216 adjusted by a rotating nut 228.

FIG. 14 shows the internal grinding wheel 230 supported for high speed rotary motion by a spindle 232 rotatably driven by suitable mechanism such as a high speed turbine 234 which in turn is powered by fluid from a remote source. Such a source may be a pump unit 234' driven by a suitable motor 235 (FIG. 3) which pumps fluid through a line 237 (FIGS. 1, 14) to the turbine, and returns fluid through a similar line 239. This results in a very high speed drive for the wheel while maintaining a light weight carriage 190 which, because of the flexible hoses 237, 239, does not require that the power unit for the grinding wheel be positioned on the carriage itself.

For the purpose of giving coordinated motivation to the various fluid motors described above, there is provided a mechanico-hydraulic programming system for repeatedly producing a cycle of coordinated movement, illustrated schematically in FIGURES 1, 2 and 3 and diagrammatically in detail in FIGURE 15. This system may be constructed as a unit having its own housing which may be positioned at any convenient location on or adjacent the machine base 10 and connected to the various hydraulic cylinders by suitable flexible piping. The mechanico-hydraulic drive unit comprises a master camshaft 236 carrying a plurality of cams 238 in two groups within the

casings 18, 18' at opposite ends thereof, the followers of which operate transmitter pistons 240, each of which forms part of an expansible chamber-liquid column type motion transfer device of which there are seven units or sections shown in the diagram of FIGURE 15. Each piston reciprocates in a cylinder 242 having a head B which contains a suitable inlet replenishing check valve 308 and a high pressure relief valve 310, both of which communicate with a low pressure oil reservoir 312 preferably formed in a housing enclosing the drive unit.

For turning the camshaft 236, a motor 246 drives an input shaft 248 of the two-speed transmission 16 through a belt drive 250. The input shaft 248 drives a pinion 252 and also the input member of a hydraulically-engaged, spring-released clutch 254. Pinion 252 drives a gear 256 secured to a counter-shaft 258 which carries a pinion 260 at its opposite end. Pinion 260 drives a gear 262 and therewith constitutes a set of change speed gears. Gear 262 drives the input member of a second hydraulically-engaged, spring-released clutch 264. The driven members of clutches 254 and 264 are secured to the opposite ends of a shaft 266, having a worm 268 thereon and a brake drum 270. The latter has a spring-biased hydraulic motor 272 for engaging the brake. Worm 268 drives a worm wheel 274 secured to the master camshaft 236.

For the purpose of automatically controlling the starting, stopping, and speed of the transmission, there is provided a hydraulic control pump 276 driven from gear 262, which may circulate a body of oil contained in the housing surrounding the transmission. The pump 276 may deliver to a combined accumulator and relief valve comprising a spring loaded piston 278 and also supplies oil to a bank of control valves 280, 282 and 284. In the diagrams each valve is shown as a two-position valve, spring-biased to the position illustrated in which the connections shown in the cross-hatched rectangles are established. Single-headed arrows are used to indicate flow at reservoir pressure and double-headed arrows to indicate flow at pump delivery pressure. Each of the valves, when shifted, establishes the connections shown in the unhatched rectangles immediately below the hatched rectangles.

Valve 280 is arranged to be shifted by a solenoid 286. Valves 282 and 284 are arranged to be shifted by the adjustable cams 288 and 290, respectively, which are positioned on camshaft 236. In addition, the valve 282 has a hydraulic holding cylinder 292 which holds the valve 282 in its shifted position until it is released by the shifting of valve 284. Valve 280 in the position shown delivers pressure fluid to engage the brake 272 and also exhausts fluid to release the low speed clutch 264. When shifted, valve 280 exhausts fluid to release brake 272 and supplies pressure fluid to engage the low speed clutch 264, subject, however, to a conjoint control by the valve 282.

The latter valve, in the position illustrated, exhausts fluid to release the high speed clutch 254 and places the low speed clutch 264 under the control of valve 280. In its shifted position, valve 282, provided valve 280 has been shifted, delivers pressure fluid to engage high speed clutch 254 and exhausts fluid to release low speed clutch 264. As previously explained, the valve 284 is merely a reset valve for bypassing the holding cylinder 292 to permit valve 282 to return to its spring biased position shown in the drawings.

Thus, energization of solenoid 286 will start the camshaft rotating at slow speed. Thereafter, the cam 288 will shift the transmission to drive the camshaft at high speed, and still later the cam 290 will again shift the transmission to slow speed. So long as the solenoid 286 remains energized, the camshaft 236 will continue to rotate, first at a slow speed and then at a high speed during each revolution, controlling its speed changes by operation of the cams 288 and 290.

For the purpose of controlling the drive motor 246 and solenoid 286, there is provided an electric control circuit

connected between a pair of electric supply lines, designated L1 and L2. The circuit may include a master relay 294 of the holding type having a manual master start switch 296 and a manual master stop switch 298. Relay 294 controls the motor 246 and also a cycle control relay 300 of the holding type having a manual cycle start switch 302 and a manual cycle stop switch 304. The normally open contacts of relay 300, which are of the make-before-break type, control energization of cycle solenoid 286 directly. The normally closed contacts of relay 300 also control solenoid 286, but are in series with a cam switch 306 on the end of the camshaft 236 and arranged to be opened once during each revolution thereof. The arrangement is such that when the cycle stop switch 304 is operated at any point in the rotation of camshaft 236, relay 300 will be de-energized, but solenoid 286 will remain energized until cam switch 306 opens at the predetermined stopping point. Operation of the master stop switch 298, however, will de-energize solenoid 286 immediately, regardless of the point in the cycle and will also de-energize motor 246.

The camshaft 236, as previously mentioned, drives a number of cam operated hydraulic pulsator sections designated *a* through *g*, inclusive and shown diagrammatically on the right hand end thereof. Other sections, not shown, may be located on the left hand end of the camshaft on the opposite side of the plural-speed transmission. Each section may comprise units duplicating the single acting pulsating cylinder 242, the head B of which contains the replenishing check valve 308 and the spring closed relief valve 310. All the replenishing and relief valves are connected to a common oil reservoir 312 formed in the housing 18, 18' of each unit. The reservoir 312 is preferably subjected to a low, super-atmospheric pressure by a body of compressed air or other pressure maintaining arrangements. Check valves 308 allow flow from the reservoir 312 to the cylinder 242, while relief valves 310 allow flow oppositely when the cylinder pressure exceeds a certain valve. Thus each of the pairs of valves 308 and 310 may be referred to as a balancing valve and serve to balance the volume of fluid in each of the liquid column sections, as will be later described.

The pulsator section *a* is connected by a closed liquid column line 314a with the upper cylinder 154 of the fluid motor which moves the diamond dressing arm 142 between the operative and the inoperative positions. The pulsator section *b* connects by a closed liquid column line 314b with the diamond compensator unit 108 through connection 126 to impart motion to the compensator piston 122 when it is free to move. Pulsator section *d* connects by means of a liquid column 314d with the connection 106 of the cylinder 96 of the fluid motor 92 which imparts limited arcuate motion to the parallel link supported carrier 36; line 314d also extends to connection 124 for conveying surplus hydraulic fluid from the compensator cylinder 116. Pulsator section *f* is connected by a closed liquid column 314f with the ratchet feed mechanism 32 for imparting motion to the slide member 26. Pulsator section *g* is connected by a liquid column 314g with the motor 210 for moving the wheel carriage to and fro on the frame 172. Pulsator section *c* may connect by means of a flexible line 314c with the workpiece holder 133 for actuating the workpiece gripping collet; similarly, pulsator section *e* may connect by a line 314e with the holder 133 for ejecting a finished workpiece upon completion of the grinding operation. Other pulsator sections on either end of the shaft 236, not shown, may be utilized for operating various tooling mounted on the upright plate 170 for loading workpieces to and unloading them from the holder.

In order to insure proper synchronization of the driving and driven elements of each pulsator section, it is desirable to provide slightly more fluid displacement in the driving or transmitting elements 240-242 than is present in their respective fluid motors at the opposite end

of the liquid column line. Thus, at the end of each advancing stroke of the transmitter piston 240, a small amount of fluid will be discharged to reservoir 312 through its relief valve 310. This amount plus any amount lost by leakage will be returned to the liquid column at the end of the return stroke by the operation of the replenishing valve 308. The amount blown over the relief valve at section *b* will depend upon the amount of movement allowed piston 122.

In FIGURE 15 there are shown several circles marked RO connected to the end of some of the motive cylinders opposite the liquid column connections. These symbols designate the return oil connections by means of which a pulsator system may be hydraulically biased so as to maintain the follower in close contact with the cam as the falling portion of the cam contour recedes from the follower. This bias is maintained by a high pressure accumulator or oil reservoir, not shown, which may be provided with a manifold whereby all of the RO connections are joined together and to the high pressure reservoir. The showing of separate return oil connections in FIGURE 15 is indicative of any suitable type of biasing pressure source, whether it be a single accumulator or multiplicity thereof. The contours of the individual cams 238 are likewise not illustrated in specific detail since they may be formed in accordance with the usual practice to cause motivation of each of the respective hydraulic motors in accordance with the particular operating cycle desired for the machine. Likewise, the speed ratio between the high and low speeds of the cam shaft 236, and the duration of the high speed portion of the cycle may be selected as desired through use of the appropriate change gears 260-262 and through the adjustment of the cams 288 and 290, if desired. Of course, the two speed feature of the transmission 16 may be omitted and the high speed clutch 254, the cams 288 and 290 and the valves 282 and 284 eliminated.

In operation, the machine works through a repeated cycle of coordinated motions actuated by the cams 238 during one complete revolution of the camshaft 236. At the beginning of each cycle with the transmission in high speed, suitably designed pulsator sections, not shown, actuate loading mechanism on the tooling plate 170 to position a workpiece having an internal surface to be ground in the work holding mechanism 133. The cam 238 at pulsator section *c* will then operate mechanism to clamp the workpiece in the grinding position, where it is rotated by the motor 136. As soon as the work is suitably clamped for grinding, the turbine driven internal grinding wheel 230, supported on the carriage 190, is moved forward by the motor 210 to locate the wheel within the workpiece. At this point the fluid motor 92 will begin to pull the parallel link supported carrier 36 through a short arcuate motion (several thousandths of an inch) until the wheel 230 is positioned immediately adjacent the internal surface of the workpiece which is to be ground.

At this point, the transmission shifts itself to low or feed speed and the remainder of the arcuate motion of the work carrier 36 progresses at a slower, closely controlled rate as the wheel 230 grinds the internal surface of the workpiece in the manner desired. Upon completion of this motion, the length of which is determined by the stroke of piston 98 in motor 92 against the limit stop 105, a period of "spark-out" is allowed in which the stressed members of the machine are relaxed to lighten the pressure of the grinding wheel against the surface of the workpiece and obtain a highly finished, unburned surface. During the grinding operation, suitable oscillating mechanism such as the cam of the pulsator section *g* which controls the movement of the wheel carriage 190 may impart oscillatory motion to the carriage to axially reciprocate the grinding wheel within the workpiece to improve the finished surface.

Upon completion of the grinding portion of the cycle, the link supported carrier 36 is quickly returned along its arcuate path to its rest position determined by the limit stop 110 for the piston 98. With the work thus removed from contact with the grinding wheel, the motor 210 starts to retract the grinding wheel from the workpiece, whereupon the pulsator section *a* moves the pistons 152 to lower the diamond arm 142 to the operative position in which the diamond point 140 is in the path of the periphery of the grinding wheel. Then pulsator section *f* actuates the ratchet mechanism 32 which causes the lead screw mechanism 34 to pull the slide member 26 laterally on the machine through the small distance that is desired to be dressed off of the grinding wheel. As the wheel carriage 190 continues its retracting movement, the wheel is transversed across the newly located diamond point 140 to satisfactorily dress the wheel for the next grinding operation. Then, the pistons 152 associated with pulsator section *a* pivot the diamond arm 142 upwardly to the inoperative position as the transmission 16 shifts itself again to the rapid speed. Mechanism in the workpiece holder 133 actuated by pulsator section *c* may ungrasp the workpiece, and ejecting mechanism operated by section *e* may push the workpiece out of the collet where it is picked up by unloading mechanism on the tooling plate 170 to remove the finished workpiece from the vicinity of the grinding machine and complete the cycle.

To maintain the accuracy of the "diamond sizing" dressing operation as the diamond point 140 wears down through continual use, the handle 120 on the compensator mechanism 108 may be turned slightly to advance the limit stop 110. This determines the rest position, which is also the dressing position, of the link supported carrier 36. As the displacement of pistons 98 and 100 is thus shortened, surplus oil will be needed to keep cylinder 96 and liquid column 314*d* full as cam 238 of section *d* recedes to its base circle in order that the original timing of the feed stroke be maintained. This oil is obtained from a quantity maintained in the variable volume compensator cylinder 116 and supplied to the liquid column line 314*d* through the connection 124 by movement of the expelling piston 122 under the timed control of pulsator section *b*, which presents its base circle during the start of the feed stroke so the piston 122 will shift prior to piston 100.

Thus a fully automatic machine tool is provided which moves a tool and a workpiece relative to one another during the work performing operation. The high speed grinding wheel is approached by the internal surface of the workpiece quite rapidly until contact is almost made, to conserve non-productive time. Then the approach is slowed to a precisely controlled rate to produce the desired action of the wheel on the work. The position of the parts of the machine at the point of finish grind or "spark out" is accurately controlled by the limit stop 105 which halts the feed carrier at an identical point in relation to the dressed periphery of the wheel on every cycle, thus discounting discrepancies in the lead of the feed screws—or lead screw error. These operations are all powered and controlled by the mechanico-hydraulic motivator which produces a program of coordinated motions in any sequence determined by the contours of the rotary cams. Finally, the accuracy of these operations is increased by the preloaded high precision anti-friction roller ways for the shiftable members on the machine tool.

While the above described embodiment constitutes a preferred mode of carrying out this invention, many other forms might be adopted within the scope of the invention, which is variously claimed as:

1. A machine comprising a frame fixed on the machine, a pair of bars supported in parallel spaced relation on the frame, a carriage supported by the two bars for to-and-fro motion relative to the frame, anti-friction bearing means connected to one bar for movably supporting the carriage and positioned in a plane parallel to the plane in which

the axes of the two bars lie and extending normal to the projection on said plane of the axes of the bars, yieldable means continually biasing the bearing means toward the one bar, and supporting means connected to the other bar which permits longitudinal reciprocation of the carriage relative to the frame.

2. A machine comprising in combination a frame fixed to the machine, a pair of spaced parallel bars supported on the frame, a carriage supported by the two bars and movable to-and-fro in the direction of the length of the bars, means supporting one end of the carriage on one bar and preventing movement transverse to the one bar, and rolling bearing means supporting the other end of the carriage on the other bar and including a generally cylindrical roller having its axis in a plane parallel to the plane of the axes of the two bars, said roller bearing means permitting movement of said other end of the carriage in all directions in the plane of the axis of the roller bearing means.

3. A machine comprising in combination a frame fixed to the machine, a pair of spaced parallel bars supported on the frame, a carriage supported by the two bars and movable to-and-fro in the direction of the length of the bars, means supporting one end of the carriage on one bar and preventing movement transverse to the one bar, and anti-friction bearing means supporting the other end of the carriage on the other bar and permitting movement of said other end of the carriage in all directions in the plane of the axes of the bars.

4. A machine comprising in combination a frame fixed to the machine, a pair of spaced parallel bars supported on the frame, a carriage supported by the two bars and movable to-and-fro in the direction of the length of the bars, bearing means connected to one bar and permitting said to-and-fro movement while preventing movement of the carriage transverse to the one bar, rolling bearing means supporting the other end of the carriage on the other bar and including a generally cylindrical roller having its axis in a plane parallel to the plane of the axes of the two bars, said rolling bearing means permitting movement of said other end of the carriage in all directions in a plane parallel to the axes of the roller, and yieldable means continuously urging the rolling bearing means toward said other bar.

5. A machine comprising in combination a frame fixed to the machine, a pair of spaced parallel bars supported on the frame, a carriage supported by the two bars and movable to-and-fro in the direction of the length of the bars, bearing means connected to one bar and permitting said to-and-fro movement while preventing movement of the carriage transverse to the one bar, anti-friction rolling bearing means supporting the other end of the carriage on the other bar and parallel to the plane of the axes of the two bars, said anti-friction bearing means permitting movement of said other end of the carriage in all directions in a plane parallel to the axis of the bars, and yieldable means continuously urging the bearing means toward said other bar.

6. A machine comprising in combination a frame fixed to the machine, a pair of spaced parallel bars supported on the frame, a carriage supported by the two bars and movable to-and-fro in the direction of the length of the bars, means supporting one end of the carriage on one bar and preventing movement of the carriage transverse to the one bar, and rolling bearing means supporting the other end of the carriage on the other bar and including a generally cylindrical roller having its axis in a plane parallel to the plane of the axes of the two bars, said rollers slidable transverse to the other bar to permit movement of said other end of the carriage in all directions in a plane parallel to the axis of the roller.

7. A machine comprising in combination a frame fixed to the machine, a pair of spaced parallel bars supported on the frame, a carriage supported by the two bars and movable to-and-fro in the direction of the length of the

bars, means supporting one end of the carriage on one bar and preventing movement of the carriage transverse to the one bar, and bearing means supporting the other end of the carriage on the other bar and including an anti-friction bearing in a plane parallel to the plane of the axes of the two bars, said anti-friction bearing being slidable transverse to the other bar to permit movement of said other end of the carriage in all directions in a plane parallel to the axes of the bars.

8. A machine comprising in combination a frame fixed on the machine and supporting a pair of spaced parallel bars near their ends; a carriage supported by the bars between their ends; bearing means permitting longitudinal reciprocation of said first bar relative to the frame, said bearing means including a pair of rollers inclined to each other in V fashion supporting the first bar near each end and tracks in the frame in which the rollers may roll to-and-fro in an accurately defined straight line; structure rigidly securing the carriage to the first bar intermediate its ends; roller bearing means associated with the second bar for movably supporting the carriage on said second bar and having the axis of the roller bearing means positioned in a plane parallel to the plane of the axes of the two bars and extending axially normal to the geometric projection of the axes of the bars on said parallel plane; and yieldable means continually urging the roller bearing means and the second bar toward each other.

9. A machine comprising in combination a frame fixed on the machine and supporting a pair of spaced parallel bars near their ends, a carriage supported by the bars between their ends, bearing means permitting longitudinal reciprocation of said first bar relative to the frame, said bearing means including a pair of anti-friction bearings inclined to each other in V fashion supporting the first bar near each end for movement to-and-fro in an accurately defined straight line, structure rigidly securing the carriage to the first bar intermediate its ends, anti-friction bearing means associated with the second bar for movably supporting the carriage on said second bar and positioned in a plane parallel to the plane of the axes of the two bars and extending axially normal to the geometric projection of the axes of the bars on said parallel plane, and yieldable means continually urging the last mentioned bearing means and the second bar toward each other.

10. A machine comprising a frame, a pair of spaced parallel bars supported near their ends by the frame, a carriage supported by the bars between their ends, bearing means permitting longitudinal reciprocation of one bar relative to the frame, said bearing means including a pair of rollers inclined to each other in V fashion supporting said one bar near each end and tracks in the frame in which the rollers may roll to-and-fro in an accurately defined straight line, structure rigidly securing the carriage to the one bar, a cylindrical roller for movably supporting the carriage on said other bar and positioned with its axis in a plane parallel to the plane of the axes of the two bars and extending normal to the geometrical projection on said parallel plane of the axes of the bars, and yieldable means continually urging the cylindrical roller and the other bar toward each other and urging the carriage toward the pair of rollers in a direction lying between the two rollers of each pair.

11. A machine comprising a frame, a pair of spaced parallel bars supported near their ends by the frame, a carriage supported by the bars between their ends, bearing means permitting longitudinal reciprocation of one bar relative to the frame, said bearing means including a pair of anti-friction bearings inclined to each other in V fashion supporting said one bar near each end for movement to-and-fro in an accurately defined straight line, structure rigidly securing the carriage to the one bar, a cylindrical roller for movably supporting the carriage on said other bar and positioned with its axis in a plane parallel to the plane of the axes of the two bars and

extending normal to the geometrical projection on said parallel plane of the axes of the bars, and yieldable means continually urging the cylindrical roller and the other bar toward each other and urging the carriage toward the pair of anti-friction bearings in a direction lying between the two bearings of each pair.

12. A machine comprising in combination a frame, a pair of spaced parallel bars supported on the frame, a carriage supported by the two bars for to-and-fro motion relative to the frame, rolling bearing means for supporting the carriage on one bar and including generally cylindrical rollers having their axes positioned in a plane parallel to the plane of the axes of the two bars and extending perpendicular to the geometrical projection on said first mentioned plane of the axes of the bars, the carriage being movable with respect to said one bar in the direction normal to the bars, and means associated with the other bar for guiding the carriage accurately parallel to the bars.

13. A machine comprising in combination a frame, a pair of spaced parallel bars supported on the frame, a carriage supported by the two bars for to-and-fro motion relative to the frame, anti-friction bearing means for supporting the carriage on one bar and positioned in a plane parallel to the plane of the axes of the two bars and extending perpendicular to the geometrical projection on said first mentioned plane of the axes of the bars, the carriage being movable with respect to said one bar in the direction normal to the bars, and means associated with the other bar for guiding the carriage accurately parallel to the bars.

14. A machine comprising in combination a frame, a carriage mounted on the frame for movement to-and-fro along a given path, bearing means between the frame and the carriage at at least two locations spaced apart in a direction lateral to the given path to guide shifting of the carriage along the given path, the bearing means at one location including a first rolling bearing and at the other location including a pair of second rolling bearings inclined to each other in V fashion, and yieldable biasing means connected between the carriage and the frame to create a preload force on the first rolling bearing at said one location and in a direction between the rolling bearings at the other location.

15. A machine comprising in combination a frame, a carriage mounted on the frame for movement to-and-fro along a given path, bearing means between the frame and the carriage at at least two locations spaced apart in a direction lateral to the given path to guide shifting of the carriage along the given path, the bearing means at one location an anti-friction bearing and at the other location including a pair of second anti-friction bearings inclined to each other in V fashion, and yieldable biasing means connected between the carriage and the frame to create a preload force on the first anti-friction bearing at said one location and in a direction between the anti-friction bearings at the other location.

16. A machine comprising in combination a frame, a carriage mounted on the frame for to-and-fro movement along a given path, bearing means between the frame and the carriage at at least two locations spaced in a direction lateral to the given path to guide the carriage along the given path, the bearing means at one location including a rolling bearing and at the other location including a pair of roller bearings inclined to each other in V fashion, and yieldable biasing means connected between the carriage and the frame to create a preload force on the bearing means at both spaced locations.

17. A machine comprising in combination a frame, a carriage mounted on the frame for to-and-fro movement along a given path, bearing means between the frame and the carriage at at least two locations spaced apart in a direction lateral to the given path to guide the carriage along the given path, the bearing at one location including an anti-friction bearing and at the other location including

a pair of anti-friction bearings inclined to each other in V fashion, and yieldable biasing means connected between the carriage and the frame to urge the carriage toward the frame at both spaced locations.

18. In a work performing machine, the combination of a frame, a guide rod, a pair of spaced aligned bores in the frame parallel with and spaced from the rod, a carriage surrounding the guide rod and including slide rod means extending from opposite sides of the carriage into each bore, a work holder and a tool, one supported on the frame and the other on the carriage, bearings in the bores rendering the slide rod means freely reciprocable therein, motive means connected between the frame and the carriage for reciprocating the carriage for causing relative movement between the work holder and the tool, an anti-friction bearing supporting the carriage on the guide rod, and yieldable means biasing the guide rod and the anti-friction bearing toward each other.

19. In a work performing machine having a base with a centerline, the combination of a tool and a work holder, one supported on a carriage having two ends and the other supported on a carrier for relative movement toward and away from the one during work performing operations, anti-friction bearing means supporting the carriage on the base and permitting limited motion of one end of the carriage in any direction in a first plane parallel to the base centerline, a slide member mounted on the base for limited to-and-fro motion such that a point on the slide member moves in a second plane parallel to the base centerline, and pivoted link means on the slide member connected thereto and to the carrier to permit limited arcuate motion of the carrier such that a point on the carrier moves in a third plane normal to the base centerline.

20. In a work performing machine having a base with a longitudinal centerline, a tool and a work holder, one supported on a carriage and the other on a carrier for movement toward and away from one another during work performing operations, anti-friction means on the base permitting limited to-and-fro motion of the carriage in a first direction parallel to the base centerline, a slide member mounted on the base for limited to-and-fro motion of a point on the line slide in a plane at right angles to the base centerline, and pivoted link means on the slide member connected to the carrier to permit to-and-fro arcuate motion of the carrier about an axis parallel to the base centerline.

21. In a work performing machine, the combination of a base having a longitudinal centerline, a carriage supporting a tool, anti-friction bearing means between the base and the carriage supporting the carriage for limited to-and-fro motion of the tool in a line of travel parallel to the base centerline, a slide member mounted on the base adjacent the carriage for limited-to-and-fro motion such that a point on the carriage moves in a plane which is at right angles to the base centerline, feed means on the base connected to the slide member for controlling the to-and-fro motion of the slide member, a carrier supporting a work holder, a pair of parallel links pivotally connected between the slide member and the carrier permitting limited to-and-fro motion of the work holder in an arcuate path intersecting the line of travel of the tool and about an axis parallel to the base centerline, a lead screw arrangement on the slide member connected to the carrier for controlling the arcuate motion of the carrier, and an adjustable limit stop associated with the lead screw arrangement for arresting motion of the work holder at a predetermined location with respect to the slide member.

22. In a grinding machine, a base rigidly supporting a frame, a carriage supporting a grinding wheel and mechanism for rotating it, anti-friction means between the frame and the carriage supporting the carriage and arranged to permit limited to-and-fro motion of the wheel along a rectilinear path, a slide member mounted on the base adjacent the frame for limited to-and-fro motion in a

direction such that a point on the slide member moves in a plane which is at right angles to the path of the wheel, cyclically actuated automatic feed means on the base for imparting movement to and controlling motion of the slide member, a carrier supporting both a work holder and wheel dressing apparatus in fixed relation to one another, means mounting the carrier for limited movement on the slide member in a direction corresponding to the direction of motion of the slide member on the base, lead screw means on the slide member connected to the carrier for imparting movement to and controlling motion of the carrier to move the work holder and the dressing apparatus toward and from the path of the wheel, and fluid means acting between the wheel carriage and the frame to move the wheel along its path in a manner which intersects the lateral paths of the work holder and the dressing apparatus.

23. In a grinding machine, a base rigidly supporting a frame, a carriage supporting a grinding wheel and mechanism for rotating it, anti-friction bearing means between the frame and the carriage permitting limited to-and-fro motion of the wheel along a rectilinear path, a slide member mounted on the base for limited to-and-fro motion in a direction such that a point on the slide member moves in a plane which is at right angles to the path of the wheel, cyclically actuated automatic feed means on the base connected to control the motion of the slide member, a carrier supporting a work holder and wheel dressing apparatus in fixed relation to one another, a pair of parallel links pivotally connected between the slide member and the carrier permitting limited to-and-fro motion of the work holder and the dressing apparatus in similar arcuate paths about an axis parallel to the path of the wheel, lead screw means on the slide member connected to the carrier for controlling motion of the carrier to swing the work holder and the dressing apparatus toward and from the path of the wheel, means on the carrier connected to move the dressing apparatus between an operative and an inoperative position thereon, and means acting between the wheel carriage and the frame to move the wheel along its path in a manner which intersects the arcuate path of the dressing apparatus in the operative position only.

24. In a grinding machine, a base rigidly supporting a frame, a carriage supporting a grinding wheel and mechanism for rotating it, anti-friction bearing means between the frame and the carriage permitting limited to-and-fro motion of the wheel along a rectilinear path, a slide member mounted on the base for limited to-and-fro motion in a direction such that a point on the slide member moves in a plane which is at right angles to the path of the wheel, cyclically actuated automatic feed means on the base connected to control the motion of the slide member, a carrier supporting a work holder and wheel dressing apparatus in fixed relation to one another, a pair of parallel links pivotally connected between the slide member and the carrier permitting limited to-and-fro motion of the work holder and the dressing apparatus in similar arcuate paths about an axis parallel to the path of the wheel, lead screw means on the slide member connected to the carrier for controlling motion of the carrier to swing the work holder and the dressing apparatus toward and from the path of the wheel, means on the carrier connected to move the dressing apparatus between an operative and an inoperative position thereon, and means acting between the wheel carriage and the frame to move the wheel along its path, each of the named means being operable by fluid motors, and a mechanico-hydraulic motivator comprising a common camshaft and a plurality of liquid column type motion transfer devices connected to actuate each of the fluid motors which operate the named means through a coordinated program of movements.

25. In a work performing machine, the combination of a base having a centerline, a tool and a work holder,

one supported on a carriage and the other on a carrier for first movement toward and away from one another during work performing operations, anti-friction bearing means on the base permitting second limited movement of a portion of the carriage in any direction in a first plane parallel to the base centerline, a slide member mounted on the base for limited to-and-fro third movement in a second plane parallel to the base centerline, and pivoted link means on the slide member connected thereto and to the carrier to permit limited fourth arcuate movement of the carrier in a third plane normal to the base centerline, fluid actuated means for causing the first, third and fourth movements, and a mechanico-hydraulic motivator comprising a plurality of rotary cams on a common camshaft extending through the base and a plurality of liquid column type motion transfer devices responsive to the cams and connected to operate the fluid actuated means through a coordinated program of motions.

26. In a work performing machine, the combination of an elongated base, two slide rests mounted on the base for limited to-and-fro motion in different directions, a tool and a work holder, one supported on each slide for plural movements in different directions relative to one another, handling mechanism connected to impart manipulative movement to the work holder on its slide, fluid actuated means for causing said movements, a camshaft extending lengthwise through the base, a cam case protruding from each end of the base enclosing the ends of the camshaft, a plurality of rotary cams fixed on each end of the camshaft beyond the base and within the cases, a plurality of liquid column type motion transfer devices responsive to the cams and connected to operate the fluid actuated means on the machine, and a prime mover connected to drive the camshaft.

27. In a work performing machine, the combination of an elongated generally rectangular base, at tool and a work holder supported for plural movements in different directions relative to one another on the base, fluid actuated means for causing the movements, a camshaft extending lengthwise through the base, a plural-speed transmission in a housing mounted on one end of the base connected to drive the camshaft, a cam case protruding from the other end of the base and enclosing one end of the camshaft, another cam case protruding from the transmission housing and enclosing the outer end of the camshaft, a plurality of rotary cams fixed on the one end of the camshaft beyond the base and on the other end beyond the transmission housing within the cam cases, a plurality of liquid column type motion transfer devices responsive to the cams and connected to operate the fluid actuated means on the machine, and a prime mover connected to drive the plural-speed transmission whereby rotary motion is imparted to the camshaft to cause movement of the workholder and the tool relative to one another through a coordinated program of movements.

28. A machine tool comprising in combination a frame, a pair of parallel bars supported near their ends on the frame, a carriage supported on the bars between their ends, first anti-friction bearing means connected to one bar for permitting movement of the carriage along the axis of said one bar and preventing movement of the carriage transverse to said axis, and second anti-friction bearing means connected to the other bar permitting movement of one end of the carriage in all directions in a plane parallel to the axes of the two bars.

29. A machine tool comprising in combination a frame, a pair of parallel bars supported near their ends on the frame, a carriage supported on the bars between their ends, first anti-friction bearing means connected to one bar for permitting movement of the carriage along the axis of said one bar and preventing movement of the carriage transverse to said axis, second anti-friction bearing means connected to the other bar permitting move-

ment of one end of the carriage in all directions in a plane parallel to the axes of the two bars and means continually urging the second anti-friction bearing means toward said other bar.

30. A machine tool comprising in combination a frame, a pair of parallel bars supported near their ends on the frame, a carriage supported on the bars between their ends, first anti-friction bearing means connected to one bar for permitting movement of the carriage along the axis of said one bar and preventing movement of the carriage transverse to said axis, second anti-friction bearing means connected to the other bar permitting movement of one end of the carriage in all directions in a plane parallel to the axes of the two bars and means continually urging the second anti-friction bearing means toward said other bar and urging the one bar toward the first anti-friction bearing means.

31. In a grinding machine, the combination of a base rigidly supporting a frame; a carriage supporting a grinding wheel and mechanism for rotating it; a pair of spaced round parallel bars supported near their ends on the frame with their axes horizontal in a common inclined plane, the carriage being supported by the bars between their ends and being rigidly secured to the lower bar; means permitting longitudinal reciprocation of the lower bar in the frame to move the wheel in a straight line including a pair of bores surrounding the ends of the lower bar, a pair of hour-glass shaped rollers between each end of the lower bar and its associated bore, and tracks in the bore supporting the ends of the rollers and guiding the movement of the rollers in an accurate straight line, the rollers of each pair being inclined to each other in a V; a cylindrical roller between the carriage and the upper bar, which latter is fixed in the frame, the axis of said cylindrical roller being parallel to the plane of the axes of the bars and normal to the geometrical projection on that plane of the axes of the bars, and the surface of the cylindrical roller being tangent to and slidable on the surface of the upper bar; a spring loaded roller in the carriage urging the cylindrical roller toward the upper bar and urging the carriage toward the lower bar in a plane within the V's of the hour-glass rollers; a slide member mounted on the base for limited to-and-fro motion in a direction such that a point on the slide member moves in a plane which is at right angles to the path of the wheel; cyclically actuated automatic feed means on the base connected to control the motion of the slide member; a carrier supporting a work holder and wheel dressing apparatus in fixed relation to one another; a pair of parallel links pivotally connected between the slide member and the carrier permitting limited to-and-fro motion of the work holder and the dressing apparatus in similar arcuate paths about an axis parallel to the path of the wheel; lead screw means on the slide member connected to the carrier for controlling motion of the carrier to swing the work holder and the dressing apparatus toward and from the path of the wheel; means on the carrier connected to move the dressing apparatus between an operative and an inoperative position thereon; means acting between the wheel carriage and the frame to move the wheel along its path, each of the last two named means being operable by fluid motors; a mechanico-hydraulic motivator comprising a common camshaft and a plurality of liquid column type motion devices operated by the cams and operating the fluid motors; and means for rotating the camshaft to operate the fluid motors in a programmed sequence and duration of movement.

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