This invention relates to a machine tool and, more particularly to a precision grinding machine for finishing workpieces to extremely close tolerances.

Recent advances in technology relating to servo control mechanisms such as missile guidance and control systems has created a demand for machine tools which will finish workpieces to tolerances in the magnitude of a few millionths of an inch. In order to produce workpieces which are consistently within such tolerances, the machine tool equipment of operation on the workpieces must be built with the capacity to produce correspondingly accurate movements of the tool carrier. At the same time, the rate of movement must be slow enough to prevent the creation of excessive forces between the cutting tool and the workpiece which would spring and distort either the machine or the workpiece beyond allowable tolerances. In producing extremely slow movement of a tool carrier, another problem, that of stick-slip between relatively movable members, becomes very important.

An object of this invention is to provide an extremely accurate grinding machine capable of consistently machining workpieces to tolerances of a few millionths of an inch.

An object of this invention is to eliminate the stick-slip problem in the movement of a grinding wheel at a greatly reduced feed rate.

A further object of this invention is to provide a grinding machine having a wheelhead of unique construction which facilitates the movement of a grinding wheel at a rate slower than has been practical heretofore.

Still another object is to provide a grinding machine having the tool part of the workpiece moving very slowly under the grinding wheel and the workpiece carrier to avoid any occurrence of stick-slip motion.

Another object of this invention is to provide a grinding machine having a wheelhead having two portions relatively movable without the occurrence of stick-slip motion therebetween.

Yet another object is to provide a feed mechanism to produce an extremely slow rate of movement of a machine tool member.

It is an object of this invention to provide a machine tool feed mechanism that will produce a series of very small increments of movement of a member.

It is also an object of this invention to provide a grinding machine with a pickfeed that is infinitely variable between a maximum value and a minimum value approaching zero movement.

An object of this invention is to provide a feed mechanism in one part of a split wheelhead of a grinding machine which is independently operable to effect a tilting of one part of the wheelhead relative to the other part at an ultra fine rate of movement.

Another object of this invention is to provide a grinding machine having one split wheelhead and another split wheelhead, each having two separate feed mechanisms successively operable to move the grinding wheel in a machining cycle that includes a conventional feed movement followed by an arcuate swing of the grinding wheel at a greatly reduced rate.

An object of this invention also is to provide a grinding machine having an automatic infeed mechanism which is operable to minimize the stresses created between the workpiece and grinding wheel in accordance with the approach of a workpiece to final size.

An additional object is to provide a ultra precision grinding machine with a gauge controlled, interrupted grinding wheel feed cycle to relieve grinding pressure during infeed before the final infeed movement is completed.

Other objects and advantages of the present invention should be readily apparent by reference to the following specification, considered in conjunction with the accompanying drawings forming a part thereof, and it is to be understood that any modifications may be made in the exact structural details there shown and described, within the scope of the appended claims, without departing from or exceeding the spirit of the invention.

A grinding machine constructed in accordance with the preferred form of this invention has a grinding wheel carriage or wheelhead selectively supported for movement toward and away from a worktable in the conventional sliding manner. The wheelhead is split into two portions, however. The lower portion is received on the base for conventional sliding movement. An upper portion which defines the grinding wheel spindle housing is fixed on the lower portion by means of stiff, resilient, reed springs which are fixed between the upper and lower portions at their forward end nearest the worktable. When the rearmost end of the upper portion is lifted, the upper portion is tilted relative to the lower portion. The axis on which the upper portion tilts passes through the reed springs which are flexed to allow the tilting movement. The axis of rotation of the grinding wheel spindle is spaced from the axis of tilt. Therefore, by tilting the upper portion toward the worktable, the grinding wheel is caused to swing in an arc toward the worktable. The swinging motion is utilized as an ultra fine feed which is not affected by the stick-slip phenomenon. The entire relative motion between the upper and lower portions is accomplished by the flexing of the reed springs and there is no relative sliding motion between the upper and lower wheel head portions. The total amount of tilt is very small, being measured in thousandths of inches. Consequently, the total flexing of the reed springs is very small and their elastic limit is never approached. Thus, each time the springs are flexed, the same lifting force will produce the same tilt of the upper portion.

The feed mechanism which lifts the upper portion is a high mechanical advantage device which utilizes an overrunning clutch to rotate a shaft having an eccentric diameter portion. The clutch is reciprocally rotated to produce a series of increments of rotation of the shaft in one direction. The arcuate length of the clutch stroke is adjustable to any amount between a predetermined maximum and zero. Since the rotary stroke is infinitely variable between extremes, the ultra fine feed rate is infinitely variable between extremes. In the preferred form, the overrunning clutch is releasable to allow free relative rotation of the drive shaft and clutch. Therefore, the feed shaft may be rotated in the opposite direction by a reset mechanism at the completion of a grinding operation. The reverse rotation of the feed shaft retracts the grinding wheel from the workpiece and resets the upper wheel head portion back down on the lower portion.

Control of the grinding machine feed mechanism is by electro-hydraulic means which includes an in-process gauging device. The gauging device controls the complete infeed grinding cycle. It is used to provide a pause in the infeed movement to allow the grinding pressures to be relieved prior to the final infeed movement of the grinding wheel. The final feed results in movement of the grinding wheel a very short distance and is accom-
plished by the tilt feed mechanism. The workpiece is reduced to final size during the final feed movement at which time the wheelhead is retracted to withdraw the grinding wheel from the workpiece.

A clear understanding of this invention may be obtained from the following detailed description in which reference is made to the attached drawings wherein:

FIG. 1 is a front elevation of a grinding machine.
FIG. 2 is a side elevation of the machine in FIG. 1.
FIG. 3 is a section of FIG. 1 on line 3–3.
FIG. 4 is a section of FIG. 3 on line 4–4.
FIG. 5 is a section of FIG. 3 on line 5–5.
FIG. 6 is a section of FIG. 3 on line 6–6.
FIG. 7 is a top elevation, partly in section, of the clutch shown in section in FIG. 5.
FIG. 8 is a section of FIG. 3 on line 8–8.
FIG. 9 is a section of FIG. 10 on line 9–9.
FIG. 10 is a section of FIG. 9 on line 10–10 and is the lower portion of the wheelhead of FIG. 3.
FIG. 11 is a side elevation of the wheelhead handwheel mechanism partly in section.
FIG. 12 is a section of FIG. 11 on line 12–12.
FIG. 13 is a vertical section of the plunge feed mechanism at the rear of the grinding machine below the wheelhead.
FIG. 14 is a section of FIG. 13 on line 14–14.
FIGS. 15 and 16 are schematic hydraulic diagrams.
FIG. 17 is a schematic electrical control diagram.
FIG. 18 is a side elevation of the footstock and gauge mechanism.

The Machine in General

The general appearance of a center type grinding machine constructed in accordance with the preferred form of this invention is shown in FIGS. 1 and 2. The machine is built in and around a base 10. A carriage 12 which defines a reciprocally movable table is slidably supported on ways 14 (FIG. 11) in the top of the front of the base 10. A swivel table 16 is fixed on top of the table 12 and is releasable for pivotal adjustment to create an angular relationship between the longitudinal axis of the swivel table 16 and the ways 14. A headstock 18 and a footstock 20 are attached to opposite ends of the swivel table 16. Centers 22, 24 extend toward each other from the head and foot stocks 18, 20, respectively. The centers 22, 24 are adapted to support a workpiece therebetween during a grinding operation. Both the head and foot stocks 18, 20 are releasable for longitudinal adjustment along the swivel table 16 by operation of clamps 19 and 21. Various lengths of workpieces may then be accommodated by the machine. A motor 26 is attached to the top of the headstock 18 for rotation of a driver 28 around the center 22. The driver 28 is adapted to engage a dog (not shown) which would extend from a workpiece. By this means, a workpiece received between the centers 22, 24 would be rotated during a grinding operation. The table 12 is mechanically connected to the handwheel 29 for manual positioning on the ways 14. The table 12 is also connected to a piston and cylinder motor 31 (shown in the hydraulic circuit, FIG. 16) for automatic reciprocation on the ways 14.

A wheelhead 30 is slidably received on the base 10 for movement toward and away from the table 12. An abrasive grinding wheel 32 is rotatably supported in the wheelhead 30. It is partially covered by a wheelguard 34. A motor 36 is mounted on top of the wheelhead 30 and is connected through a belt drive 37 (FIG. 2) to the wheel spindle 39. The wheel spindle 39 is moved toward and away from the table 16 by operation of a feed mechanism contained in the unit 38 at the rear of the machine and to be described subsequently herein. The wheelhead 30 is also connected to the handwheel 40 for movement on the base 10 when the handwheel 40 is rotated either manually or by a power pickfeed unit inside the base apron 42.

A gauge unit 44 is also associated with the machine for control of the automatic grinding cycles. The gauge unit 44 is of the air electric type used for in-process gauging, that is, a workpiece measured while it is ground. These gauges are well known in the machine tool industry. The gauge calipers 46, FIGS. 1, 18, are swingably mounted on top of the footstock 20 for movement into contact with and away from a workpiece 11 supported between centers 22, 24.

The gauge calipers 46 are comprised of a support 43 in which a pair of adjustable jaws 45, 47 are received. Each of the jaws 45, 47 extends to close proximity with a workpiece 11, the jaws being on opposite sides of the workpiece. Air under closely regulated pressure is supplied to the passage 13. Each of the air passages 15, 17, respectively, in communication with the passage 13. The passages 15, 17 terminate in small orifices adjacent to and closely spaced from the workpiece 11. The pressure in the passage 13 is controlled by the escape of air from the two passages 15, 17. The passage 13 is connected back to the machine, especially FIG. 10, where it is in communication with a plurality of pneumatic relays. Each of these relays controls the condition of electrical contacts operated thereby in accordance with the back pressure in the passage 13. Each of the pneumatic relays is set to operate at a pressure different from the pressure at which the others operate. The operation of pneumatic relays in a similar back pressure gauge system is described in U.S. Patent 2,969,623 issued January 31, 1961 on application filed by K. D. Mehlohope and A. H. Faulhaber. The electrical circuit in which contacts of the gauge are used is described in detail in the description of electrical operation discussed in a subsequent section of this specification.

The Wheelhead

Stick-slip is basically a problem arising in systems where members are relatively slidable one on another. In a system where a movable object such as a grinding machine wheelhead has considerable weight and the rate of movement of the object is required to be in the neighborhood of 0.002 inch per minute or less, the movement of the object may not be satisfactorily accomplished by conventional sliding way systems due to stick-slip motion, the effect of which is amplified by the extremely slow rate of motion. Devices such as ball bearing ways have not been satisfactory to solve the problem since there is an inherent component of sliding friction due to deformation of the balls and ball tracks as the balls are moved therealong and pure rolling contact is not achieved although the problem is somewhat minimized. Ball bearing systems present another problem in that they do not have the damping qualities which eliminate chatter vibrations in a grinding machine unless the balls are preloaded. In preloading the balls, the component of sliding friction is increased and the stick-slip is likewise increased. Moreover, in preloading the bearings, stresses are introduced in the machine which can affect the accuracy and repeatability of the grinding. The problem is where extreme accuracy is required. For these reasons, the preferred embodiment of the grinding machine utilizes a unique wheelhead construction to eliminate stick slip in the final movement of the grinding wheel 32.

A longitudinal section of the wheelhead 30 is shown in FIG. 3. The wheelhead 30 is comprised of two portions. The lower portion 48 rests directly on ways 50, 52 (FIG. 10) in the rear of the base 10 and is slidably movable toward and away from the table 16 (FIG. 2). The upper portion 54 of the wheelhead 30 defines a spindle housing in which the grinding wheel 32 is supported for high speed rotation by the motor 36 (shown in FIG. 1 but omitted in FIG. 3 for simplicity) and connected to the motor 35 by a belt drive 37. The motor 35 attaches to the mounting plate 33 which is positionable on the cover plate 49 that is fixed to and extends across the top of the sides of the lower portion 48 of the wheelhead (see FIGS. 6 and 8). The positioning screw 35 is loosely journalled
in the mounting plate 33 and threaded deeply through a hole 41 that is fixed in the cover plate 49. By rotation of the screw 35, the mounting plate 33 together with the motor 36 can be positioned on the wheelhead 30 to put the belts 37 under the proper tension.

FIG. 5. The mounting plate 34 of the wheelhead 30 is attached to the lower portion 48 by a set of relatively stiff reed springs 55, 56. The spring 55 is fixed between the front ends (the end toward the table 12) of the upper and lower portions by machine screws 57, 58. The spring 55 is centered between the sides of the wheelhead 30 and is arranged parallel with a vertical axis when the upper portion 54 is tilted. The bending of the spring occurs at the reduced section area 55a. On either side of the spring 55 are the reed springs 56 which are fixed between the upper and lower portions 48, 54 and are designed to bend away from a horizontal axis when the upper portion 54 is tilted. The springs 56 are also adapted to bend at reduced section areas 56a which are in line with the reduced section areas 55a of the spring 55. A line through the centers of the reduced section areas 55a, 56a then defines the axis about which the upper portion 54 tilts when the rear of the upper portion is lifted.

The spindle 39 is spaced from the springs 55, 56 and therefore, as the upper portion is tilted, the grinding wheel 32 is swung in an arc. The upper portion 54 is fixed to the lower portion 48 only by the springs 55, 56. The weight of the upper portion 54 as well as the tension in the belt 37 serves to tilt the upper portion 54 clockwise as viewed in FIG. 3. A pair of springs 59, 60 (FIG. 8) are compressed between the cover plate 49 and the rear end of the upper portion 54 and these, too, tend to rotate the upper portion 54 clockwise. A bushing 61 is fixed in the upper portion 54 at its rear and defines a ball socket which receives a ball end pin 62 that rests on a lever 63. The lever 63 controls the elevation of the rear of the upper portion 54. The forces tending to rotate the upper portion 54 clockwise will hold the bushing 61 firmly on the pin 62 and as long as the lever 63 is stationary on the lower portion 48, the upper and lower portions 48, 54 act as a single grinding wheel. The upper portion 54 will tilt toward the worktable only when the lever 63 is raised.

The Tilt Feed Mechanism

The mechanism which is operable to raise and lower the lever 63 (FIGS. 3 and 4) is contained in the lower portion 48 of the wheelhead 30. The lever 63 is pivotally on a ball 64 (FIG. 4) seated in a socket 65 fixed in the lower portion 48. The ball end pin 62 is received at one end in a socket in the lever 63 which is offset from the ball 64 to provide a short lever arm from the pivot assembly. The other end of the pin 62 is received in the socket bushing 61 that is fixed in the rear of the upper wheelhead portion 54. The end of the lever 63 opposite the ball 64 is pushed downward by a spring 66 which is compressed between the lever 63 and the cover plate 49. The spring 66 produces a force which tends to rotate the lever 63 counter-clockwise around the ball 64. Therefore, the lever 63 is held firmly against the slightly eccentric diameter portion 67a of the tilt feed shaft 67.

As shown in FIG. 3, the tilt feed shaft 67 is rotatable in bearings 68, 69 that are received between the shaft 67 and a bushing 70 fixed in the lower wheelhead portion 48. An overrunning clutch mechanism 71 is received on one end of the tilt feed shaft 67. The clutch 71 is an overrunning sprag type clutch which engages with the clutch bushing 72 that is keyed to rotate with the shaft 67. As shown in FIG. 3, the clutch 71 is composed of a casing member 73 which is adapted to be rotated relative to the lower portion 48 a limited amount. Inside the casing 73 is a cylindrical sprag pin 74 which is held in close proximity with the bushing 72 by an adjustable plunger 75. The sprag pin 74 is held in contact with the face of the casing member 73 with the bushing 72 by a spring loaded plunger 76 which tends to move the sprag pin 74 toward the fixed pin 77. As shown in FIGS. 6 and 7, the fixed pin 77 is attached to a bracket 78 that is fixed to the lower portion 48 by machine screws 79, 80. The pin 77 then is fixed relative to the casing 73 and the shaft 67 on which the bushing 72 is fixed. The longitudinal axis of the plunger 75 does not pass through the center of the shaft 67 but is slightly offset below that center as viewed in FIG. 5. Therefore the upper edge of the plunger 75 is nearer the bushing 72 than is the lower edge to define a slightly wedge shaped space between the bushing 72 and plunger 75.

When the casing 73 is rotated clockwise as viewed in FIG. 5, the sprag pin 74 which is greater in diameter than the minimum clearance between the plunger 75 and the bushing 72 is caused to grip the bushing and to rotate the shaft 67 with the rotation of the casing 73. This occurs because the sprag pin 74 is wedged tightly between the plunger 75 and the bushing 72 since it is caused to tend to move relatively toward the closed end of the wedge space between the plunger 75 and bushing 72.

The amount of clockwise rotation is limited by the clearance between the pin 77 and the upper internal edge of the cavity in the casing 73. When the casing 73 is rotated in a counter-clockwise direction as viewed in FIG. 5, the sprag pin 74 is released and is only loosely held. The open end of the wedge space between the plunger 75 and bushing 72 is moved toward the sprag pin 74 with the counter-clockwise rotation. The spring loaded plunger 76 causes the pin 74 to follow back around the bushing 72 with the casing 73 until the pin 74 engages the fixed pin 77 which causes the plunger 76 to shift slightly and allow the pin 74 to stop slightly before the casing 73 is stopped. This moves the sprag pin 74 out of contact with the casing 73 and the bushing 72. The pin 74 is then released in the wedge space between the plunger 75 and bushing 72 and the shaft 67 and bushing 72 may be freely rotated in either direction relative to the clutch mechanism 71.

There is a slight relative rotation between the bushing 72 and casing 73 which is required to move the clutch mechanism 71 from a released position to an engaging position. It is the difference between the point in the wedge space at which the pin 74 grips and at which it doesn’t grip. The amount of movement required between release and engagement can be adjusted by moving the plunger 75 relative to the bushing 72 to increase or decrease the wedge space. This in effect is a sensitivity adjustment and the mechanism may be adjusted to the point where a very few thousandths of an inch of circumferential movement of the casing 73 is all that is required.

The spring 81, FIG. 5, which is in compression between the casing 73 and the lower portion 48, tends to rotate the casing 73 counter-clockwise to the released position. A cam following roller 82 is rotatably fixed in the top of the clutch casing 73 (FIGS. 3, 5, 6). The roller 82 is engaged with a conical cam 83 which is fixed to a piston shaft 84. The piston shaft 84 is slidable received at one end on a cylinder bushing 85 that is fixed in the right side, as viewed in FIG. 6, of the lower portion 48. The other end of the piston shaft 84 is slidable received in a bushing 86 and is rotatable therewith since a key 87 is received therewith. The bushing 86 is received in bearings 89, 90 for rotation in the left side of the lower portion 48. A cap 90 is fixed to the bushing 86 and the knurled head screw 91 is loosely received through the cap 90 and is in threaded engagement through a flange portion of the bushing 86 to abut against a ring 92 fixed to the left side of the lower portion 48. When the screw 91 is tightened against the ring 92, the bushing 86 is locked against rotation. A plug 93 is received in one end of the bushing 86 against the cap 90. A spring 94 is compressed between the plug 93 and the end of the piston shaft 84. The spring 94 tends to hold the piston shaft to the right in the position shown in FIG. 6. In that position, the roller 82 is stopped by the cam 83 with
the clutch 71 released. The clutch 71 is held in a released position by the spring 81 (FIG. 5). When hydraulic fluid under pressure is connected to the cylinder bushing 85 at the right end (as viewed in FIG. 6) of the piston shaft 84, the spring 94 yields and the cam 83 is shifted left. The cam 83 is conical but is rotatably adjustable on an axis that is parallel to one side of a face when the bushing 86 is rotated with the piston shaft 84. As shown in FIG. 6, the upper side of the cam 83 is parallel to the axis of rotation of the piston shaft 84. Therefore, the lower side of the cam is the most eccentric surface portion of the cam 83. As the cam 83 is moved left, it forces the roller 82 to move closer to the surface. In FIG. 5, 6 with the casing 73 of the clutch mechanism. As described, this moves the clutch 71 to an engaging position and imparts rotation to the tilt feed shaft 67. When pressure is disconnected from the cylinder bushing 85, the spring 94 returns the cam 83 to the position shown. The spring 83 rotates the clutch 71 to the released position at the same time. The shaft 67 remains in the angular position to which it is rotated by the clockwise rotation of the clutch 71.

When the shaft 67 is rotated clockwise as viewed in FIGS. 6, 4 and 5, the eccentric diameter 67a of the shaft 67 raises the lever 63 which in turn raises the pin 62 to lift the rear of the upper wheelhead portion 50. When the grinding wheel 32 (FIG. 2) toward the table 12. The force between the lever 63 and eccentric diameter 67a created by the spring 66 is enough to produce a friction force to ensure that the shaft 67 will not rotate when the clutch 71 is released.

The shaft 67 must be rotated in the opposite direction (counterclockwise as viewed in FIGS. 4.5) to lower the lever 63 and to tilt the upper portion 54 away from the table 12. A gear 95 (FIG. 3) is fixed to the clutch bushing 72 to rotate with the shaft 67 and clutch bushing 72. A reset pinion 96 (FIGS. 5, 8) extends transversely across the gear 95 and has a rack portion 96a which engages with the gear 95. The pinion 96 is carried along to the left as viewed in FIG. 8 when the gear 95 is rotated clockwise with the shaft 67 by operation of the clutch 71. At some predetermined point in a machine cycle, the clutch 71 is stopped in its released position and the cam 83 is stopped. At this time the reset pinion 96 may be shifted to the right, as viewed in FIG. 8, to rotate the shaft 67 counter-clockwise until the pinion 96 engages the stop 97. The upper portion 54 is then tilted back down to the lower portion 48 of the shaft 67, and the grinding wheel 32 is retracted from the table 12.

Thus it can be seen that the described feed mechanism is a high mechanical advantage device which will produce a series of very small steps or increments of movement of the grinding wheel 32 toward the work area. Since all of the components in the mechanism move quickly to produce each step, no detectable stick-slip is present in the tilt feed. In the embodiment of the machine described, a range of net tilt feed movement from .00025 inch per minute down to .00005 inch per minute is available. The total range of tilt feed movement in the machine is .001 inch. In sliding feed systems it is generally conceded that a feed of less than .0003 inch per minute is impractical.

The Coarse Pickfeed Mechanism

The wheelhead 30 (FIGS. 1, 2) may be moved on the base 10 by rotation of the handwheel 40 which is fixed on the end of a shaft 98 (FIGS. 9, 11) which extends from the front of the machine at the base apron 42 into the rear base portion 158 below the wheelhead 30. The end of the shaft 98 below the wheelhead 30 has one side 99 that contains two shoulders. The end of the shaft 98 extends into a sleeve 99 which is rotatably received in bearings 100, 101. The bearings 100, 101 are fixed in a depending portion 48a of the lower portion 48. The depending portion 48a defines a yoke to which conventional sliding feed forces are transmitted to move the entire wheelhead 30. A pinion gear 102 is integral with the sleeve 99 and meshes with a gear 103. The gear 103 is fixed to rotate with a sleeve 104 by a key 105. The sleeve 104 is rotatably received in bearings 132, 133 which are fixed in the yoke 48a above the sleeve 99. The sleeve 104 is internally threaded and engaged with a feed screw 106. The feed screw 106 is not rotatable but axially movable when released from axial restraint. The screw 106 is not released for axial movement during coarse pickfeed. Therefore when the sleeve 104 is rotated, the wheelhead 39 is forced to move on the ways 50, 52 (FIG. 10).

The sleeve 99 is adapted to loosely receive the flat side of the end of the shaft 98. A roller collar 107 is fixed to the end of the sleeve 99 by pins 108. The collar 107 as a set of axles 109, 110, 111, FIG. 10, spaced thereon and releasably fixed therein. One of the axles 109 has a journal diameter 109a on which a double ball bearing roller 113 is rotatably received. The roller 112 is engaged to straddle the flat surface 96c and to roll therealong as the shaft 98 and sleeve 99 are relatively axially moved as when the wheelhead 30 is moved on ways 50, 52 (FIG. 10). The double roller 112 is held firmly in contact with the flat surface 96c by the single ball bearing rollers 113, 114 which are rotatably received on the journal diameter 110a, 111a, 112a of the roller 113, 114. The rollers 113, 114 roll on the cylindrical surface of the shaft 98. The journal diameters 109a, 110a, 111a are all round but eccentric relative to the longitudinal axes of the axles 109, 110, 111.

The axles are releasably held in the collar 107 by set screws (not shown). When the axles 109, 110, 111 are released, they may be rotated to swing the eccentric diameters 109a, 110a, 111a to bring the rollers 112, 113, 114 into forcible contact with the shaft 98. This preload the rollers 113, 114, 115. Since the roller 112 is forcibly engaged with the flat surface 96c of the flat surface 96c of the grinding wheel 32, a resultant torque from the shaft 98 to the sleeve 99 cause the sleeve 99 and shaft 98 to rotate in unison.

The shaft 98 may be rotated by the handwheel 40, FIG. 11. Handwheel 40 may be manually driven or it may be rotated by means of a pick-feed mechanism as shown in FIGS. 11, 12. A toothed clutch member 115 is fixed by a key 115 to rotate with the shaft 98. A clutch bushing 117 is journaled over the clutch 115 and is rotatable relative thereto. A releasable overrunning clutch mechanism 118 similar to the one 71 previously described in the tilt feed mechanism comprising a casing 119, a fixed pin 120, and a sprag pin 121 is received over the bushing 117. The clearance within the clutch 118 is a fixed amount in this instance since the sprag pin 121 is received between the bushing 117 and a seat 122 fixed in the casing 119. A ball end pin 151 extends from the casing 119 and is received in a notch in a piston rod 123 which is reciprocated by a piston and cylinder motor 125. When the rod 123 is reciprocated, the casing 119 is reciprocally rotated. A counter-clockwise rotation of the casing 119 as viewed in FIG. 12 will force the sprag pin 121 to drive the bushing 117 in the same direction. As shown in FIG. 12, the rod 123 is moving downward to pull the casing 119 counter-clockwise. On reversal of movement of the rod 123, the casing is rotated clockwise until the fixed pin 120 that is attached to the journal member 25 (FIG. 11) fixed in the base 10 moves the sprag pin 121 against the spring loaded plunger 126 to a released position. The amount that the casing is rotated depends on the allowable extremes defined by the motor 125 and the cam 127.

The rotation of the bushing 117 is transmitted to the handwheel 40 by the pin 130, FIG. 11, which is fixed in the handwheel 40 and received in the flange portion of
the bushing 117. A clutch member 131 is fixed in the handwheel 40 over the shaft 98 which is loosely received in the handwheel 40. The clutch 131 mates with and drives the clutch 115 when the handwheel 40 is rotated. Since clutch 115 is fixed to the shaft 98, the incremental rotation of the bushing 117 by the clutch mechanism 115 and driven to the handwheel 40 is caused to rotate the shaft 98. This rotation of the shaft 98 results in a rotation of the sleeve 104 (FIG. 9) which will result in movement of the wheelhead 30 as described. The pickfeed cycles of the particular machine described are gauge controlled and therefore no provision for automatic pickfeed reset is included in the feed mechanism exemplified. The pickfeed can be driven in reverse and would be retracted and reset by manual rotation of the handwheel 40.

The Plunge Feed Mechanism

The force which produces the plunge infed for the described machine is produced in a backlash cylinder 134 shown in FIG. 13. Fluid under pressure is maintained at the right end of the piston 135 in the cylinder 134. The piston 135 pushes against a block 136 which is fixed to the rear of the lower wheelhead portion 40 (see also FIG. 3). Thus a constant force is applied to the wheelhead 30 tending to move it forward toward the table 12 (FIG. 2).

The feed mechanism shown in FIG. 14 acts as a brake to restrain movement of the wheelhead 30 and to release it for movement at selected rates. The feed mechanism of FIG. 14 is of the type shown in U.S. Patent 2,718,101, issued September 20, 1955, on application filed by A. D. Stuckey and Jacob Decker. However, in this application, the mechanism is adapted to restrain the feed toward the table, the actual feed force toward the table being developed by the backlash cylinder 134 and piston 135 as described.

A collar 137 is fixed on a feed shaft 138 which is axially in line with the feed screw 106 (FIG. 9). The screw 169 is rigidly connected to the shaft 138 by coupling members 139, 140. The coupling members 139, 140 are attached to the ends of the screw 106 and shaft 138, respectively, and are bolted together. The feed shaft 138 and screw 106 are prevented from rotating by a pair of rollers 141 which are rotateably fixed to the feed box 38. The rollers 141 engage the flat sides of a tongue 142 extending radially from the shaft 138 and comprised of the two side members 142a, 142b which are secured together and fixed to the end of the shaft 138. The shaft 138 is axially movable in the feed box 38. The force produced in the cylinder 134 tending to move the wheelhead 30 forward is transmitted to the shaft 138. The shaft 138 is restrained from moving by the walking beam 143 which is pivotally connected to the collar 137. The walking beam 143 is attached at one end to a piston 144 (FIG. 14). The other end is attached to a rotatable shaft 145. The piston 144 is normally held in the position shown by the application of fluid under pressure to its left end (as viewed in FIG. 14) through the fluid line 199. Upon connection of the low pressure to the left end of the piston 144 the end of the walking beam 143 attached thereto is lowered to swing to the left due to the pull from the wheelhead 30 created by the piston 135 and cylinder 134. The fluid leaves the space ahead of the piston 144 at a rapid rate and the shaft 138 and screw 106 are shifted forward at a rapid rate for a fixed stroke. This allows the entire wheelhead 30 to advance toward the table 12 a fixed amount at a rapid rate.

After the completion of the rapid advance stroke, the shaft 145 is rotated by a piston 146 (FIG. 15) which is transverse to and below the shaft 145. The piston 146 has a rack 146a thereon which is engaged by a gear 147 that turns the shaft 145 for rotation therewith. The shaft 145 has a threaded member 148 fixed thereto. The threaded member 148 is engaged through a nut 149. The nut 149 is fixed in the feed box 38. Therefore, the shaft 145 is moved axially during infed. This movement is from right to left (as viewed in FIG. 14) at a feed rate determined by the rate at which the piston 146 (FIG. 15) is moved.

The feed screw 106 is advanced a selected distance by the plunge infed mechanism after the rapid advance stroke. At the end of the plunge infed, the tilt feed mechanism described may be utilized to further feed the grinding wheel toward the work as shown in Table 13 to reduce a workpiece to the final selected size determined by the adjustment of the gauge unit 44. At the end of the grinding operation, pressure is again applied to the left end of the piston 144 and the piston 144 pulls the end of the walking beam 143 attached thereto back to the position shown. At the same time, the pressure fluid is connected to the piston 146 to reversely rotate the shaft 145. This returns the other end of the walking beam 143 to the retracted position shown. The walking beam 143 is returned against the force of the backlash cylinder 134.

Hydraulic Circuit

The hydraulic operating circuit for the table 12 and pickfeed mechanism is shown in FIG. 16. A control lever 150 is connected by a gear 152 to rotate the spool 153 of a valve relative to a sleeve 155 fixed in the valve. The valve is indicated by sections 154a, 154b. Prior to starting the machine cycle, the main pressure line 161 which connects with the source of pressure 156 (FIG. 15) is connected through section 154a to line 157 and also to line 158 through section 154b. This puts pressure on each side of the piston 159 in the motor 31 connected for movement of the table 12. There is no movement of the table 12 with the control circuit in this condition.

When the lever 150 is rotated to the position indicated at 159a, the spool 153 is rotated clockwise to connect lines 157 and 158 to lines 163, 164, respectively. Lines 163 and 164 connect with the table reversing valve 165. The direction of fluid under pressure from line 161 to lines 163, 164 is controlled by the position of the valve plunger 165a within the valve sleeve 165b. With plunger 165a in the position shown, pressure is connected to line 163. Line 163 is now connected to line 157. At this same time line 164 connects with line 166. Line 166 is connected through the pilot reverse valve 167 to line 168 which connects to the variable resistance valve 169 through which line 168 is connected to the main return line 162. The rate valve 169 controls the rate of fluid discharge from the line 168. Therefore, with the circuit in the condition described, the table 12 is moving to the right at a rate controlled by the setting of valve 169.

The position of the valve plunger 165a is controlled by the position of the valve plunger 167a in the valve sleeve 167b. As shown, the plunger 167a is in its upper-most position and fluid is connected to the line 170 from line 161 through the valve 167. This pressure is applied through the variable restriction valve 171 to line 172 and from there to the upper end of the plunger 165a to hold it as shown. As the table 12 moves to the right, a dog 173 attached to the table 12 engages the reversing lever 174 to swing it clockwise as viewed in FIG. 16. Through the gearing 175, 176, the bell crank 177 is pivoted counter-clockwise to lower the plunger 167a to its lower-most position. Line 170 is then connected to the return line 162. Line 178 is connected to the main pressure line 161. Fluid line 176 connects with the variable restriction valve 179 which connects fluid under pressure to the line 180. Line 180 connects to the lower end of the plunger 165a. The plunger 165a begins to move upward at a rate controlled by the variable restriction 179. The fluid line 163 continues to be connected to pressure line 161 through valve 165 for a period of time while the plunger 165a is moving upward. At this same time, fluid pressure is connected from line 161 to line 166 through the valve 167 whose plunger 167a has changed positions. Line 166 remains connected to line 164 for the brief time while line 163 is connected to the main pressure line 161.
Therefore both ends of the piston 159 are under pressure and the table 12 is stopped. The length of time that the table is stopped depends on the adjustment of the restriction 179. After a determinate time, the plunger 165a has moved upward to completely block line 163 from pressure line 161 and to begin to connect it to line 181. Line 181 connects through valve 167 at this time to line 168. At this same time line 164 is connected to line 161 through valve 164 and the piston 159 begins to move to the left. The fluid discharged ahead of the piston 159 from line 157 to line 163 to line 161 and to line 164 flows through the rate valve 169 to determine the rate of movement of the table 12 to the left.

At a predetermined point in movement to the left, another dog similar to the dog 173 engages the lever 174 and swings it back counter-clockwise and bell crank 177 moves the plunger 167a back upward to the position shown. The fluid pressure differential on the plunger 168 is reversed and the plunger moves back downward to the position shown at a rate determined by the setting of the restriction 171. The table 12 is stopped in a similar manner as described until the pressure connection from valve 165 to lines 163, 164 is reversed. By adjustment of the restrictions 171, 179, the amount of delay or tarry is variable at each end of a table stroke. It may be varied from a very short time to an extremely long time.

The pickfeed mechanism is controlled by the shift of the valve 167 at the reversing points. Fluid line 170 connects from the valve 167 to part of the plunger pilot valve 182 as well as to the tarry rate valve 171. The fluid line 178 connects to the ultra fine feed reset valve 213 (FIG. 15) and in normal pick feed operation line 178 is connected to line 164 through that valve. Line 184 is connected to the left end of the valve 182 (FIG. 16). Both lines 179 and 184 are connected through dynamic resistances 185, 186, respectively, before connection to valve 182. Since lines 170 and 184 are connected through the dynamic resistances 185, 186, full pressure will not be connected through the line to the ends of the valve 182. Main pressure line 161 also connects to the valve 182 at one side or the other of the large diameter land 182d depending on the end to which the spool 182a has shifted. In the position shown, the valve spool 182 will not shift against the force produced on the land 1825 until nearly full pressure is felt on its right end.

The operation of the valve 182 is as follows. Assume that the table 12 is moving away from the left toward the right reversing point and that valve 167 is in the condition shown in FIG. 16. As the table 12 reaches the right side reversing point, the lever 174 in FIG. 15 swings to move the plunger 167a downward and pressure is connected to line 178 while line 170 is connected to the low pressure return. Line 179 connects to line 184. At this same time, the line 184 is connected to line 167 through the valve 182. Line 187 is connected to the fluid line 185 through the selector valve 189 when the spool 189a is in the position shown. Line 188 connects to the piston and cylinder pickfeed motor 123 and the piston 190 is shifted away from the position shown to rotate the clutch casing 119 counter-clockwise to produce an increment of feed as previously described. The piston 190 moves since the resistance to movement is less than the resistance to shift of the plunger 182a offered by the force on the large diameter land 182b. The piston 190 moves until it engages the stop cam 127. When the piston 190 stops, the pressure in line 184 at the valve 182 rises due to the stopping of flow through the dynamic resistance 186. Subsequent force is then created on the spool 182a to shift it to its left end position (as viewed in FIG. 16). Line 187 is then connected to line 191 through valve 182. Line 191 is connected through the selector valve 189 to the main return line 162. Pressure is then taken off of the right end of the piston 190 (as viewed in FIG. 16). Line 184 is connected to line 192 through the valve 182 now and line 192 connects directly to the motor 123 at the other end of the piston 190. Thus, the piston 190 is shifted back to the position shown when the valve spool 182 shifts and the clutch casing 119 is rotated clockwise to the released position.

When the table 12 has moved back to the left and the pressure differential in lines 170 and 184 has again changed the valve spool 182a changes immediately back to the position shown. This is so since the spool 189a blocks line 193 from line 191 and no pressure is connected from there to line 187 and from line 185. Line 189 connects with the motor 123. The spool 182a then is in a position to cause pickfeed only at the right end reversing point of the table 12. The spool may be positioned in one of these other positions indicated at 194, 195, 196 in which pickfeed may be also produced at the left end of a table stroke (195) and at both ends of a table stroke (196). In the 4th position (194) no pickfeed is produced at all since the connections from line 187 to line 189 would be blocked completely to prevent a shift of the piston 190 away from the position shown. In the pick at left end position 195 of the spool 189a, the fluid line 183 would be connected to line 191 and pressure would be connected from line 187 between the resistance 185 and valve 162 to line 187 through the valve 182 at the instant of reversal of the table 12 from feed left to feed right (plunger 182a would be shifted to the left end of valve 182 at that instant). With the valve 189a in the pickfeed at both end position 196, the line 193 would connect through the valve 189 to line 197 and from there to line 191 when the table 12 reaches the left end reversal point. Line 187 would continue to connect through valve 189 to line 186 with the spool 189a in both the pickfeed at left and both end positions. Line 194 would continue to connect through valve 182 to line 187. However, when the table reaches the right end reversing point when the spool is in the pickfeed at left end position 195, pressure would be felt on both ends of the piston 190 to prevent a shift of the piston 190 to rotate the casing 119. This is so since line 191 would be blocked by the spool 189a to prevent escape of fluid ahead of the piston 190. Therefore pressure on one end of piston 190 would be applied to the other end by the piston 190 itself.

In FIG. 15, the hydraulic circuit for operation of the plunge feed mechanism of FIG. 14 is shown. The rapid advance valve 198 is operated by solenoid 250. In the condition shown with solenoid 250 deenergized, pressure is connected from main pressure line 161 to line 199. Line 199 connects with the feed box 351 (FIG. 14) where it connects to the piston 144 which is spring loaded against the previously described pull on feed shaft 134. When the solenoid 250 is energized, the spool 189a is shifted to the left and pressure is disconnected from line 199. Line 199 is then connected to the main return line 162. The piston 144 (FIG. 14) is moved rapidly to the left by the pull on feed shaft 134. Thus the rapid advance movement of the wheelhead is allowed.

Solenoid SSOL operates the plunge feed valve 200. In the deenergized condition, solenoid SSOL allows the valve spool 206a to be held in the position shown. Pressure from line 161 is then connected to the right end of the piston 146 from line 201 which is connected to line 161 through valve 206. This holds the feed piston 146 in the feed retracted position. Upon the completion of a rapid advance stroke, the solenoid SSOL is energized to shift the plunger 200a to the left. Line 201 is then connected to the spool 202a which connects with line 203 through the dwell valve 284. Line 203 is connected with the slow rate valve 205. The fast feed cut-out valve 206 is operated by solenoid 450 and solenoid 450 is normally energized at the same time that the plunge feed valve 200 is first energized. Thus, line 202 is connected to line 207 through the valve 206 past the spool 206a which has now shifted left. Line
13. The solenoid 450L is energized and fluid line 202 is disconnected from the fluid line 207. The fluid leaving the piston 146 through line 201 is then returned by way of rate move to line 205. The rate of rotation of the gear 147 and shaft 145 is reduced to reduce the rate of the wheelhead 20 of the slow rate, the solenoid 150 which operates valve 204 is energized to shift the plunger 204 a to the left to block line 202 from line 205 thereby blocking the return flow of fluid from the piston 146. The clutch is then stopped.

At the same time that the solenoid 150 is energized, the tilt feed solenoid 650L and reset solenoid 750L are energized to operate the valves 210 and 213 to shift the plunger 210a to 213a to the left. This connects fluid line 211 and 212 and blocks line 215 from pressure line 161. Line 211 is connected to pressure line 163 around the ultra fine feed reset valve 213. Line 212 is connected through the dynamic resistance 214 to the ultra fine feed cylinder bushing 85 (FIG. 6) to shut the cam 83 to the left (as viewed in FIG. 6). At the completion of one stroke of the cam 83, the solenoid 650L is deenergized and fluid line 212 is connected to the main return line 216 to allow the spring 217 to return the cam 83 to the right. Upon return of the cam 83 to the right, the solenoid 650L is reenergized to again stroke the cam 83 to the left. This reciprocating movement of the cam 83 produces tilt feed of the grinding wheel 32 (FIG. 2) in small steps as described.

When the grinding wheel 32 has been fed a predetermined amount and the workpiece has reached final size, the solenoid 650L is no longer energized and solenoid 750L is also deenergized. Solenoid 750L operates the reset valve 213. When deenergized, solenoid 750L allows the spool 213a to shift to the right to connect pressure line 161 to fluid line 215 which connects to the left end of the reset piston 96 (FIG. 8) to cause the piston to reset the ultra fine feed mechanism as previously described.

At the same time that solenoid 750L is deenergized to reset the ultra fine feed, solenoids 650L, 250L and 650L are deenergized. This applies fluid under pressure to the rapid advice piston 144 at its left end as viewed in FIG. 14 through fluid line 199. Fluid under pressure is also applied to fluid line 201 which connects with the right end of the feed piston 146 (FIG. 15) to return the feed shaft 145 to the position from which it started. Solenoid 450L was previously deenergized. The infeed plunger and retraction cycle is now completed.

In a traverse grinding operation, the rapid advance solenoid 250L is energized to bring the wheelhead 12 (FIG. 2) forward to a grinding position. The lever 150 is then swung counter-clockwise to bring the table traverse. The pickfeed mechanism operates as described at the selected reversing point or points. When the workpiece reaches a predetermined size, the reset valve spool 153 is shifted to the left by energization of solenoid 750L. This blocks the reversing line 184 from line 178 to the table reversing valve 167 (FIG. 16). Pressure is applied to line 184 from line 161 through valve 213 and the pressure is connected through lines 187, 189 to hold the piston 190 to the left as viewed in FIG. 16. This stops the pickfeed. Line 178 continues to have the alternate connection to pressure and return through valve 167 since the table continues to reciprocate. This operates a plunger 126 which in turn operates a limit switch 95L which signals the solenoid 650L to energize at a selected end of the table stroke to produce a single reciprocation of the cam 83 (FIG. 6). The electrical circuit to be described in detail in the next section provides the control for the solenoid 650L which is dependent upon the operation of limit switch 95L.

Electrical Control Circuit

The schematic electrical control circuit shown in FIG. 17 controls the operation of the hydraulic actuating circuit described. A source of alternating current 219 supplies the power to the various control relays and contactors which are oriented on horizontal lines, the location of which is indicated by a number with the prefix "14". The numbers run consecutively along the left side of the circuit. The location reference will be given in parentheses with the circuit items as they are identified in the next text to follow.

The master start relay 1ML (L3) is connected across power lines 220, 221 and in series with the master start switch SW1 and master start switch SW2. The master start switch SW2 is normally closed while the master start switch SW1 is normally open. Closing switch SW1 results in the energizing of relay 1M and its latch contacts 1M-1 (L59) close to energize the hydraulic pump motor 222 (FIG. 15). The master start switch SW1 also has contacts in series with the grinding wheel motor start relay 2M (L10) which close at the same time that the switch SW1 is closed. A pressure switch IPS is also in series with the contacts of relay 2M and is actuated to close when the fluid pressure at the source 150 (FIG. 15) reaches a predetermined level. The switch SW1 (L8, L10, FIG. 17) must be closed a second time after a period sufficient to allow the fluid pressure to build up and close the pressure switch IPS. When the pressure switch IPS and switch SW1 are simultaneously closed, the relay 2M (L10) is energized. The relay 2M has contacts (not shown) which close in the power circuit to the grinding wheel motor 36 (FIGS. 1 and 2) to energize that motor and rotate the grinding wheel 32.

After allowing sufficient time for warm-up of the grinding wheel motor and hydraulic fluid, the machine is prepared for the automatic cycle. The first cycle to be described is a gauge controlled plunge grinding cycle in which the cycle of movement to grind a workpiece includes a rapid advance, a fast feed, a slow feed, a pause, and an ultra fine feed to final size. Upon the workpiece's reaching final size, the grinding wheel is withdrawn from the workpiece.

To prepare the machine circuit, the detented switch SW3 (L19) in the energizing circuit for the headstock motor starting relay 4M is closed as shown. The relay 4M is not immediately energized since the circuit is not yet complete between the power lines 221 and 222a (connected to line 220 through the master start switch SW2 and relay contacts 1M-1 at L9). The detented gauge energizing switch SW5 (L12) is also closed to energize the relay 6CR and to apply power to the left side of the four sets of contacts ACR-1, BCR-1, ACR-2, BCR-2 (L13, L14, L15, L16, respectively) which are electrical contacts of the gauge unit 14 (FIG. 1) operated by the pneumatic relays included in the unit. The gauge cycle selector switch SW7 (FIG. 1), the contacts of which are shown only in part in FIG. 17, is set in a position to close contact 222a-7-5 (L17) to energize relay 109CR. At this time, the wheelhead feed mechanisms are in the retracted and reset positions and limit switch 4LS (FIG. 15) is operated by the plunger 223 which is forced to the right (as viewed in FIG. 15) by pressure through fluid lines 224, 225, 226 in communication with the high pressure end of the piston 146. Limit switch 11LS (FIG. 5)
is operated by the dog 227 (FIGS. 3, 6) fixed in the end of the ultra fine feed shaft 67. Therefore the contacts 4LS–1 and 11LS–1 (L31, FIG. 17) are closed as shown and relay 7CR is energized. The machine is ready for a cycle and a workpiece is placed between the centers 22, 24 (FIG. 1) and engaged to be driven by the driver 28. The dog 227 calipers 46 are swung in position over the workpiece.

The cycle start switch SW8 (L22, FIG. 17) is closed instantaneously to start the grinding cycle. Relay 1CR is energized momentarily through the switch SW8 and the retract switch SW9. Relay 2CR (L32) is then energized through the contacts 7CR–1 and 1CR–1 in the moment that relay 1CR is energized. (Relay contacts are shown in the normal or relay deenergized condition, a normally closed contact being indicated by a slanting line through the contacts. Contacts of a relay are identified by the same reference symbols followed by a contact designator. Thus contact 1CR–1 is contacts of the relay 1CR.)

Relay 2CR latches in the energized condition, a circuit being completed through its own contacts 2CR–1 (L26) and the normally closed contacts 104CR–1. When relay 2CR is energized, solenoid 2SOL (L3 and FIG. 15) is energized through the contacts 2CR–2, 2CR–3. This causes the rapid advance stroke of the wheelhead 20 as described in the hydraulic operation. At this same time, relay 116CR (L30, FIG. 17) is energized through the contacts 109CR–1, 102CR–1 and 2CR–4. Thus the contacts 116CR–1 and 116CR–2 (L2) are opened to deenergize the solenoid 1SOL (also on FIG. 15) to prepare the hydraulic feed circuit for producing the fast and slow feed rates.

At the same time that the relay 2CR (L23) is energized and latched, the timing relay 1TR (L26) is energized and latched. The contacts 1TR–1 (L20) are closed to complete the energizing circuit of the cam 1TR (L19) which starts the headstock motor 26 (FIG. 1) to rotate the driver 28. At the end of the rapid advance stroke, the limit switch 5LS (FIG. 13) is operated by movement of the rod 228 which is attached to the dog 229 (FIG. 14). The dog 229 is attached to the rapid advance piston 144 for movement parallel therewith. The condition of the contacts 5LS–1 (L21) in reversed from the condition shown and the relay 3CR (L20) is energized through contacts 5LS–1 and latched through contacts 3CR–1 and 1TR–1. Relay 5CR (L28) is also energized at this time since a circuit is complete through the contacts 2CR–5, 6CR–1, 3CR–2, 19CR–1, 19CR–2 and 101CR–1 (L28). Solenoids 5SOL and 4SOL (L5, L4, respectively, and in FIG. 15) are energized through the contacts 2CR–2, 3CR–3 and 5CR–1, 5CR–2. The hydraulic circuit is then conditioned to allow fast movement of the feed shaft 138 (FIG. 16) as previously described. The limit switch 4LS (FIG. 15) is then released and relay 7CR (L31) is deenergized.

Stock is removed from the workpiece during the fast feed movement and the gauge calipers 46 (FIG. 1) sense a change in size. When the workpiece reaches a predetermined size, the first pressure operated switch contacts ACR–1 (L13) are closed and relay 161CR is energized. The relay contacts 101CR–1 (L28) are opened and the relay 8CR is deenergized. As the relay 8CR is deenergized, so is the solenoid 4SOL (L4 and FIG. 15). The feed rate is reduced to a slow rate as described. Stock remaining to be removed from the workpiece and when it reaches a second smaller predetermined size, the second pressure operated gauge contacts BCR–1 (L14) close and relay 102CR is energized. The contacts 102CR–1 (L39) are opened and relay 161CR is deenergized. When relay 116CR is deenergized the contacts 116CR–1 and 116CR–2 (L2) are closed and the solenoid 1SOL (also FIG. 15) is energized. When solenoid 1SOL is energized, the hydraulic feed circuit is blocked to stop movement of the entire wheelhead 30 as a unit.

During the fast and slow feed movements of the wheelhead 30 (FIGS. 1, 2), pressure develops between the grinding wheel 32 and a workpiece. This pressure causes the machine parts and workpiece to spring slightly tending to move the workpiece and grinding wheel apart. When the feed is stopped, the pressure is gradually reduced. The workpiece and machine parts will return to their unstressed condition and a small amount of stock will be removed from the workpiece since the workpiece and grinding wheel move toward one another when the described stresses are removed. The result is a further reduction in size of the workpiece. When the workpiece reaches a third predetermined small size, the third pressure operated gauge contacts ACR–2 (L15) close to energize the relay 103CR.

At the time that the fast feed is first started, the ultra fine feed hydraulic circuit is prepared for operation. When relay 116CR (L30) is first picked up, the contacts 116CR–3 close and a circuit is completed through the contacts 116CR–3, and 163CR–1 (L32) to energize relay 118CR (L37). Relay 118CR latches through the contacts 3CR–4 and 118CR–1 (L33). Solenoid 7SOL (L7, and FIG. 15) is then energized and the pressure is taken off of the reset position 96 (FIG. 8). When relay 118CR (L33) is energized, the relay 117CR (L32) is energized through the contacts 3CR–4, 118CR–1 (L33), 18CR–2, 13LS–1, 19CR–2, 12LS–1, and 103CR–1 (L35). The limit switch 1LS (FIG. 6) is operated by the ultra fine feed cam 83 in the retracted position as shown in FIG. 3 at the start of a feed stroke of the cam 83. Relay 117CR (L32) is latched energized around the switch contacts 13LS–1 through contacts 117CR–1 (L36) since the contacts 13LS–1 (L35) open as soon as movement of the cam 83 is begun. The limit switch 1LS (FIG. 6) is operated by the cam 83 at the end of an ultra fine feed stroke and its operation opens contact 12LS–1 (L35) to deenergize the relay 117CR (L32). The relay 117CR is not reenergized until limit switch 12LS is operated by the cam 83 at its starting position. When relay 117CR is energized, solenoid 6SOL (L6, and FIG. 15) is energized through contacts 117CR–2, 117CR–3. When solenoid 6SOL is energized, fluid under pressure is connected to the right end of the piston shaft 84, as viewed in FIG. 6, to move it leftward. The described intermittent operation of the relay 117CR (L32) provides continued stroking of the cam 83 (FIG. 6) until the workpiece reaches final size, the feed now being provided in a succession of steps by operation of the described tilt feed mechanism. The net speed of the tilt feed per unit of time is greatly reduced from the rate of movement by the sliding feed mechanism.

The fourth pressure operated contacts BCR–2 (L16, FIG. 17) of the gauge unit 44, are closed when the workpiece reaches the predetermined final size. Relay 104CR (L16) is then energized and the contacts 104CR–2 (L35) are opened and relay 117CR (L32) is deenergized. With relay 117CR deenergized the solenoid 6SOL (L6) is deenergized also. The contacts 104CR–1 (L26) are also opened and relay 2CR (L23) is deenergized. Solenoid 2SOL (L3) is then deenergized and the wheelhead 30 (FIGS. 1, 2) is retracted rapidly due to pressure on the piston 144 (FIG. 14). Relay 1TR (L26) is also deenergized when relay 104CR (L16) is energized but the contacts 1TR–1 (L29) delay opening for a brief time before relays 4M (L19) and 3CR (L28) are deenergized thereby, the limit switch contacts 5LS–1 opening at the start of the rapid retraction stroke. Thus, the solenoid 5SOL (L5) is held energized and the headstock motor 26 (FIG. 1) continues to run until driven by the momentary deenergizing effect of the solenoid 5SOL. As a result, the workpiece is removed from the grinding position and moved back to the position shown in FIG. 15. When relay 3CR is deenergized, the relay 118CR (L37) is deenergized also by the opening of contacts 3CR–4 (L33). The solenoid 7SOL (L7) is then deenergized by
the opening of contacts 118CR-2 and 118CR-3 and pressure is applied to the reset piston 96 (FIG. 8) to reset the ultra fine feed mechanism. When the piston 96 has reset the ultra fine feed mechanism, limit switch 11LS (FIG. 3) is operated. When the feed piston 145 is returned, limit switch 4LS (FIG. 15) is also operated. The contacts 4LS-1 and 11LS-1 (L13) are closed and the relay 7CR is energized. The workpiece may then be removed from the machine. A new workpiece may be inserted between centers 22, 24 (FIG. 1) and the calipers 46 placed thereon. The contacts ACR-1, BCR-1, ACR-2, BCR-2 (L13 to L16) are then opened to deenergize relays 100CR, 120CR and 104CR. The machine is now ready for another plunge inch feed cycle.

After allowing for sufficient warmup of the hydraulic system motor 222 (FIG. 15) and grinding wheel motor 56 (FIGS. 1 and 2) as earlier described, the machine can be set to produce a traverse grinding cycle. In the cycle to be described, the grinding wheel 32 will be moved through the rapid advance and plunge feed strokes until the plunge feed is stopped by the positive stop 230 which is engaged by the feed screw 106 (FIG. 9). The table 12 (FIG. 2) is traversed and the coarse pickfeed is engaged until the workpiece is ground to a predetermined intermediate size. The coarse pickfeed is then stopped and the grinding pressures are relieved. The ultra fine pickfeed is then started and the workpiece is reduced in size to the final predetermined size at which time the wheelhead is retracted through reverse operation of the rapid advance and plunge feed mechanisms. The coarse pickfeed is manually reset at the end of the cycle, there being no provision for automatic reset in the described embodiment.

Prior to starting the cycle, the gauge selector switch SW7 (FIGS. 1 and 7) is set in position 9 to close contacts SW7-9 (L18, FIG. 17) and relay 113CR is energized thereby. The traverse selector switch SW4 (L27) is put in its traverse position to complete the circuit to energize relay 18CR. The ultra fine pickfeed switch SW6 (L38, L39) is placed in one or the other positions to produce pickfeed at the left or right end of a table stroke. Assume it is in the pickfed at left end position and the lower contacts SW6 (L39) are closed. The gauge energizing switch SW5 (L12) is closed to energize relay 6CR and to apply voltage to one side of the gauge pressure sensitive switches ACR-1, BCR-1, ACR-2, BCR-2 (L13 to L16). As in the previous cycle, the wheelhead 39 (FIG. 2) is retracted and relay 7CR (L31) is energized.

Now the cycle start switch SW8 (L22) is momentarily closed to energize relay 1CR. Relay 2CR (L23) is then energized along with relay 1TR (L26). Relays 2CR and 1TR are latched through the contacts 108CR-1 (L26) and the parallel lamp circuit including contacts 18CR-2, 6CR-2, and 125CR-1 (L24). Relay 120CR (L39) is energized at the same time relay 2CR (L23) is energized through the contacts 113CR-1, 102CR-2, 2CR-6, SW6-1, and 115CR-1 (L38, L39). Solenoid 5SOI (L3, and FIG. 15) is then energized and the wheelhead 39 (FIG. 2) is moved forward at a rapid advance rate. Relay 4M (L19) is also energized through contacts 1TR-1 (L20) to start the headstock motor 26 (FIG. 1).

At the same time that the relay 2CR (L23) is energized, the relay SCR (L28) is energized through the contacts 2CR-5 (L28), 7LS-1 and 18CR-3 (L29). Thus when relay 3CR (L20) is energized by the operation of limit switch 5LS (L21) at the end of the rapid approach stroke, the solenoids 4SOI and 4SOI (L14, L5) are energized to produce a fast feed plunge of the wheelhead 30 toward the table 12 (FIG. 2). The positive stop 230 (FIG. 9) stops the plunge feed movement of the feed screw 106 and of the wheelhead 30 on the ways 50, 52. At the end of the fast feed, limit switch 7LS (L29) is operated by the dog 231 (FIG. 14) which revolves with the feed screw 145 during plunge feed. Relay SCR (L28) is then deenergized. The solenoid 4SOI (L4, FIG. 17) is deenergized to put the hydraulic circuit in the slow feed condition as it reaches the positive stop 230 (FIG. 9). The wheelhead 30 is stopped in the horizontal position by the positive stop 230. Grinding of the workpiece has not yet started but the grinding wheel 32 is approximately at the surface of the workpiece. The operator then swings the lever 150 (FIG. 16) to the traverse position 150a to begin the traverse grinding and coarse pickfeed described in the hydraulic control section. This coarse pickfeed continues until the workpiece size has reduced to the point at which the second pressure operated gauge contacts BCR-1 (L14, FIG. 17) have closed. (The first contact ACR-1, L13, has no effect on the circuit in this cycle.) The relay 102CR is energized when the contacts BCR-1 close.

When the relay 102CR is energized, a circuit is completed through the contacts 113CR-1, 102CR-2, 2CR-6 (L38) to energize relay 118CR (L37). When relay 118CR is energized, the solenoid 75SOI (L7, and FIG. 15) is energized through the contacts 118CR-2, 118CR-3 (L38). This effects a shift of valve spool 213a and blocks fluid lines 17S, 184 (FIG. 15) to stop the coarse pickfeed. At the same time fluid under pressure is removed from the ultra fine feed reset piston 96 (FIG. 8) by the blocking action of the fluid line 215 (FIG. 8, FIG. 15). The ultra fine feed mechanism is ready for operation when the coarse pickfeed is stopped. The ultra fine pickfeed does not immediately start when the coarse pickfeed is stopped, however. The table 12 continues to reciprocate and a small amount of material is removed from the workpiece due to grinding pressures having been built up as in the plunge cycle.

The workpiece will be reduced in size while the grinding pressures are relieved and when the workpiece is reduced to a predetermined smaller size, the pressure operated contacts ACR-2 (L15) will close to energize relay 108CR. The energizing of relay 108CR will put control voltage through the contacts 108CR-2 (L32) on the left side of the parallel contacts 119CR-1 and 120CR-2 (L32, L33). If one or the other of the contacts 119CR-1 and 120CR-2 is closed, relay 117CR will be energized. When relay 117CR is energized, the contacts 117CR-2, 117CR-3 (L6), are closed and solenoid 65SOI (also FIG. 15) is energized to cause fluid under pressure to become connected to the right end of piston shaft 84 (FIG. 6) to cause it to move left against the return spring 94. When relay 117CR (L32) is deenergized, the piston shaft 84 is returned to the right (as viewed in FIG. 6). This produces an ultra fine increment of movement as described previously.

Alternate energizing of the relays 119CR (L38) and 120CR (L39) is controlled by the operation of limit switch 9LS (FIG. 15). The limit switch 9LS is operated by the plunger 216 when pressure is connected to line 178 from valve 167 (FIG. 16) when the table 12 (FIG. 1) reaches the left end of its stroke and during the return movement of the table 12 from left to right. When the limit switch 9LS is operated, the contacts 9LS-1 (L40, FIG. 17) are closed and the relay 115CR is energized. With the switch SW6 (L38, L39) in its lower position as described in this case, the relay 120CR will be deenergized at the time that the table 12 reaches its leftward position and will continue to be deenergized during movement to the right. Relay 119CR (L38) will not energize at any time with switch SW6 in the described position. At the end of a stroke of the table 12, the contacts 9LS-1 (L40) will open and relay 115CR will be deenergized. Relay 120CR will be energized then and relay 117CR (L32) will be energized in turn to cause an ultra fine pickfeed step. The ultra fine feed piston shaft 84 (viewed as in FIG. 6) then moves to the left at the time that the table reaches the right side reversal point of the table and will move back to the right at the left side reversal point. This produces an ultra fine feed increment only at the arrival of the table at its rightward reversal point. The reverse positioning of the switch.
SW6 (L38, L39, FIG. 17) to close the contacts SW6–1 will effect an ultra fine pickfeed at the left end of the table stroke.

The ultra fine pickfeed will continue automatically until the fourth pressure operated contact BCR–2 (L16) is closed. This occurs at the time the workpiece is reduced to final size. Relay 104CR is then energized. This energizes the latch contacts 104CR–1 (L26) to deenergize relays 2CR (L23) and 1TR (L26). These relays will not deenergize immediately if the table (FIG. 1) is in the process of moving from the right to left due to relay 120CR (L39) being energized and a parallel latch circuit through the contacts 1CR–2, 6CR–2, 12CR–1 (L24) would still exist. Upon completion of that stroke, the relay 120CR will deenergize and relays 2CR and 1TR will be deenergized. The deenergization of relay 2CR will cause the rapid retraction stroke as in the plunge grind cycle. The relays 3CR (L120) and 4M (L19) will be deenergized. Relays 117CR (L32), 118CR (L37) and 120CR (L39) will also be deenergized to stop the ultra fine feed mechanism by causing the deenergization of solenoid 6SOL (L6) and 7SOL (L7). The ultra fine feed will be reset at this time as pressure would be reconnected to line 215 (FIGS. 15, 16). The plunge feed mechanism will also be retracted as in the plunge feed description. There is no provision for automatic reset of the coarse pickfeed mechanism in this embodiment. The machine operator must then manually reset the handwheel 48 (FIG. 1) upon the retraction of the plunge feed and ultra fine feed mechanisms at the end of the traverse cycle.

While the invention has been described in connection with one possible form or embodiment thereof, it is to be understood that the present disclosure is illustrative rather than restrictive and that changes and modifications may be resorted to without departing from the spirit of the invention or the scope of the claims which follow.

What is claimed is:

1. A grinding machine comprising:
   (a) a base having a working supporting area and ways thereon extending toward said area, and ways thereon extending toward said area, 
   10 (b) a wheelhead member slidably received on said ways, 
   (c) a spindle housing having a rotatable spindle therein, said spindle housing having a grinding wheel fixed thereto, 
   (d) means resiliently to attach said spindle housing to said wheelhead member, 
   (e) a feed mechanism selectively to move said wheelhead member on said ways toward said support- 
   30 ing area for movement of said grinding wheel in a cutting operation, 
   (f) means selectively to overcome said resilient means and tilts said spindle housing on said wheelhead member in steps to produce movement of said grinding wheel relative to said wheelhead member toward said work supporting area to complete said cutting op- 
   eration, and 
   (g) means reversely to operate said feed mechanism and to reset said means to tilt to retract said grinding wheel from the work supporting area upon completion of a cutting operation. 

2. A grinding machine comprising:
   (a) a base having a worktable thereon and ways extending toward said worktable, said worktable adapted to rotatably support a workpiece during a grinding operation, 
   (b) a wheelhead member slidably received on said ways, 
   (c) a spindle housing having a rotatable spindle there- 
   40 in, said spindle housing having a grinding wheel fixed thereto, 
   (d) reed springs fixed between said wheelhead member and spindle housing to resiliently fix said spindle housing on said wheelhead member, 
   (e) a first feed mechanism operable selectively to move said wheelhead member on said ways toward said worktable for movement of said grinding wheel in a grinding operation, 
   (f) a second feed mechanism operable to raise one end of said spindle housing to flex said reed springs and tilt said grinding wheel toward said worktable to complete the grinding operation, and 
   (g) means reversely to operate said first feed mechanism and to reset said second feed mechanism to retract said grinding wheel from the worktable upon completion of a grinding operation.

3. A grinding machine comprising:
   (a) a base having a worktable thereon and ways extending toward said worktable, said worktable adapted to rotatably support a workpiece during a grinding operation, 
   (b) a wheelhead member slidably received on said ways, 
   (c) a spindle housing having a rotatable spindle there- 
   50 in, said spindle housing having a grinding wheel fixed thereto, 
   (d) a plurality of reed springs fixed between said wheelhead member and spindle housing to resiliently fix said spindle housing on said wheelhead member, each of said reed springs having a reduced section area, said reduced section areas of the reed springs aligned to define an axis of tilt for said spindle housing, 
   (e) a first feed mechanism operable selectively to move said wheelhead member a predetermined distance on said ways toward said worktable for movement of said grinding wheel in a grinding operation, 
   (f) a second feed mechanism operable selectively to raise one end of said spindle housing to flex said reed springs at said reduced area sections and swing said grinding wheel around the axis of tilt toward said worktable to complete the grinding operation, and 
   (g) means reversely to operate said first feed mechanism and to reset said second feed mechanism to retract said grinding wheel from the worktable at the completion of a grinding operation.

4. A grinding machine comprising:
   (a) a base having a worktable thereon and ways extending toward said worktable, said worktable adapted to rotatably support a workpiece during a grinding operation, 
   (b) a wheelhead member slidably received on said ways, 
   (c) a spindle housing having a rotatable spindle there- 
   60 in, said spindle housing having a grinding wheel fixed thereto, 
   (d) a plurality of reed springs fixed between said wheelhead member and spindle housing to resiliently fix said spindle housing on said wheelhead member, each of said reed springs having a reduced section area, said reed springs alternately angularly oriented one to another with said reduced area sections in align- 
   ment to define an axis of tilt for said spindle housing, 
   (e) a first feed mechanism operable selectively to move said wheelhead member toward said worktable at a plurality of rates for movement of said grinding wheel in a grinding operation, 
   (f) a second feed mechanism operable selectively to raise one end of said spindle housing in a succession of steps to flex said reed springs at said reduced area sections and swing said grinding wheel around the axis of tilt toward said worktable at a net rate greatly reduced from the rate of movement effected by said first feed mechanism to complete the grinding opera- 
   tion, and 
   (g) means reversely to operate said first feed mecha- 
   70 nism and to reset said second feed mechanism to retract said grinding wheel from the worktable at completion of a grinding operation.

5. A grinding machine comprising:
   (a) a base having a worktable thereon and ways extending toward said worktable, said worktable adapt-
ed to rotatably support a workpiece during a grinding operation,
(b) a wheelhead member slidably received on said ways,
(c) a spindle housing,
(d) a plurality of reed springs fixed between the front end of the wheelhead member toward the worktable and the lower portion of the front end of the spindle housing thereby resiliently fixing said spindle housing on said wheelhead member, each of said reed springs having a reduced section area, said reed springs alternately angularly oriented one to another with said reduced area sections in alignment to define an axis of tilt for said spindle housing,
(e) a spindle rotatably supported in said spindle housing arising above said axis of tilt and having a grinding wheel fixed thereto,
(f) a first feed mechanism operable selectively to move said wheelhead member toward said worktable at a plurality of rates for movement of said grinding wheel in a grinding operation,
(g) a second feed mechanism operable selectively to raise the rear end of said spindle housing in series of steps to flex said reed springs at said reduced area section and swing said grinding wheel around the 25 axis of tilt toward said worktable at a selected rate greatly reduced from the rate of movement effected by said first feed mechanism to complete the grinding operation, and
(h) means reversely to operate said first feed mechanism and to reset said second feed mechanism to retract said grinding wheel from the worktable at completion of a grinding operation.
6. A grinding machine comprising:
(a) a base having a reciprocally movable worktable thereon adapted to support and rotate a workpiece during a grinding operation, said base having ways thereon extending transversely toward said worktable,
(b) a mechanism connected to said worktable operable to produce reciprocal motion thereon,
(c) a wheelhead member slidably received on said ways,
(d) a spindle housing rotatably having a spindle therein, said spindle having a grinding wheel fixed thereto,
(e) means resiliently to attach said spindle housing to said wheelhead member,
(f) first feed means selectively to move said wheelhead member in steps toward said worktable to produce a first feed movement of said grinding wheel,
(g) second feed means selectively to overcome said resilient means and tilt said spindle housing on said wheelhead member to produce a second feed movement of said grinding wheel in steps toward said worktable, and
(h) means responsive to reciprocation of said worktable to initiate each step of said first and second feed means.
7. A grinding machine comprising:
(a) a base having a reciprocally movable worktable thereon adapted to support and rotate a workpiece during a grinding operation, said base having ways thereon extending transversely toward said worktable,
(b) a mechanism connected to said worktable to produce reciprocal motion thereof on said base between reversing points,
(c) a wheelhead member slidably received on said ways,
(d) a spindle housing rotatably having a spindle therein, said spindle having a grinding wheel fixed thereto,
(e) reed springs fixed between said wheelhead mem-ber and spindle housing to resiliently fix said spindle housing on said wheelhead member,
(f) a first feed mechanism operable selectively to move said wheelhead member on said ways in steps toward said worktable for movement of said grinding wheel in a grinding operation,
(g) a second feed mechanism operable to raise one end of said spindle housing in steps to flex said reed springs and tilt said grinding wheel toward said worktable to complete the grinding operation,
(h) means responsive to the arrival of said worktable at a reversing point to initiate each step of said feed mechanisms, and
(i) means reversely to drive said feed mechanisms to retract said grinding wheel away from said worktable upon completion of a grinding operation.
8. A grinding machine comprising:
(a) a base having a reciprocally movable worktable thereon, said worktable adapted to support and rotate a workpiece during a grinding operation, said base having ways thereon extending transversely toward said worktable,
(b) a worktable drive mechanism connected to said worktable and operable to move said worktable alternately between predetermined reversing points,
(c) a wheelhead member slidably received on said ways,
(d) a spindle housing rotatably having a spindle therein, said spindle having a grinding wheel fixed thereto,
(e) a plurality of reed springs fixed between one end of said wheelhead member and one end of said spindle housing to resiliently fix said spindle housing on said wheelhead member, each of said reed springs having a reduced cross sectional area portion, said springs alternately angularly oriented one to another with said reduced cross sectional portions in alignment to define an axis of tilt around which said spindle housing swings,
(f) a first feed mechanism operable selectively to move said wheelhead member on said ways in steps toward said worktable for movement of said grinding wheel in a grinding operation,
(g) a second feed mechanism operable to raise one end of said spindle housing in steps to flex said reed springs at said reduced sectional areas and tilt said grinding wheel around said axis of tilt toward said worktable to complete the grinding operation,
(h) a control mechanism operated by said worktable at the reversing points to initiate the steps of said first feed mechanism for a predetermined movement of the wheelhead member toward the worktable and thereafter to initiate the steps of said second feed mechanism to tilt said grinding wheel and complete the grinding operation, and
(i) means reversely to drive said first feed mechanism and to reset said second feed mechanism to retract said grinding wheel upon completion of the grinding operation.
9. In a machine tool having a tiltable tool carrier, a tilt feed mechanism comprising:
(a) a feed shaft operably connected to said tool carrier to lift one end thereof when rotated to tilt the tool carrier from its initial position,
(b) an overrunning clutch received on said feed shaft for limited rotation therewith, said clutch releasably engageable to transmit rotational motion in one direction to said feed shaft,
(c) a reciprocally movable cam,
(d) a cam follower fixed to said clutch and engaged with said cam, said cam operable to transmit an increment of rotation to said tool carrier in said one direction through said follower when said cam is shifted away from a starting position,
(e) means to release said clutch when said cam is returned to its starting position, and
10. In a machine tool having a tilt feed tool carrier, a tilt feed mechanism comprising:
(a) a feed shaft operably connected to said tool carrier to lift one end thereof when rotated to tilt the tool carrier from its initial position,
(b) an overrunning clutch receiving rotation to said feed shaft for rotation therewith in one direction,
(c) a reciprocally movable, conically shaped cam rotatably adjustable about an eccentric longitudinal axis,
(d) a cam follower mechanically connected with said clutch and engaged with said cam, said cam operable to impart an increment of rotation through said follower to said clutch in said one direction when said cam is shifted axially away from a starting position, the magnitude of the increment of rotation determined by the relative eccentricity of the surface of said cam engaged by said follower, and
(e) means selectively operable to move said cam away from and back to its starting position to impart incremental rotation to said feed shaft.

11. In a machine tool having a tilt feed tool carrier, a tilt feed mechanism comprising:
(a) a rotatable feed shaft having an eccentric diameter portion,
(b) a mechanical linkage between the tool carrier and said eccentric portion operable to lift one end of the tool carrier when the eccentric portion is rotated in one direction from an initial position thereof,
(c) an overrunning clutch received on said feed shaft for limited rotation therewith, said clutch releasably engageable to transmit rotational motion in one direction to said feed shaft, said feed shaft freely rotatable in both directions relative to said clutch in its released condition,
(d) a reciprocally movable, conically shaped cam eccentrically adjustable around a longitudinal axis parallel to one side of said cam,
(e) a cam follower fixed to said clutch and engaged with said cam, said cam operable to impart an increment of rotation to said clutch in said one direction through said follower, the magnitude of the increment of rotation determined by the eccentricity of the surface of said cam engaged by said follower relative to the axis about which said cam is rotatably adjustable,
(f) means to shift said clutch to the released condition when said cam is returned to its starting position,
(g) a yieldable spring mechanism connected at one end of said cam tending to hold said cam in its starting position,
(h) a fluid actuated piston mechanism connected to said cam at the other end thereof and selectively operable to overcome said yieldable spring mechanism at the one end of said cam for movement thereof away from the starting position, and
(i) a fluid control circuit associated with said cam and piston to intermittently effect operation of said piston to produce a reciprocating motion of said cam away from and back to its starting position to impart incremental rotation to said feed shaft.

12. In a machine tool having a tilt feed tool carrier, a tilt feed mechanism comprising:
(a) a rotatable feed shaft having an eccentric diameter portion,
(b) a mechanical linkage between the tool carrier and said eccentric portion operable to lift one end of the tool carrier when the eccentric portion is rotated in one direction from an initial position thereof,
(c) an overrunning clutch received on said feed shaft for limited rotation therewith, said clutch releasably engageable to transmit rotational motion in said one direction to said feed shaft, said feed shaft freely rotatable in both directions relative to said clutch in its released condition,
(d) a reciprocally movable, conically shaped cam rotatably adjustable about a longitudinal axis parallel to one side of said cam,
(e) a cam follower fixed to said clutch and engaged with said cam, said cam operable to impart an increment of rotation to said clutch in said one direction through said follower, the magnitude of the increment of rotation determined by the eccentricity of the surface of said cam engaged by said follower relative to the axis about which said cam is rotatably adjustable,
(f) means to rotate said clutch in the other direction and to shift said clutch to the released condition thereof when said cam is returned to its starting position,
(g) a pinion fixed on said feed shaft,
(h) a rack engaged with said pinion, and
(i) means to move said rack to rotate said feed shaft in the other direction to return said tool carrier to its initial position after said feed shaft has rotated a selected amount in said one direction and when said clutch is in the released condition to reset the feed mechanism.

13. In a machine tool having a tilt feed tool carrier, a tilt feed mechanism comprising:
(a) a rotatable feed shaft having an eccentric diameter portion,
(b) a mechanical linkage between the tool carrier and said eccentric portion operable to lift one end of the tool carrier when the eccentric portion is rotated in one direction from an initial position thereof,
(c) an overrunning clutch received on said feed shaft for limited rotation therewith, said clutch releasably engageable to transmit rotational motion in said one direction to said feed shaft, said feed shaft freely rotatable in both directions relative to said clutch in its released condition,
(d) a reciprocally movable, conically shaped cam rotatably adjustable about a longitudinal axis parallel to one side of said cam,
(e) a cam follower fixed to said clutch and engaged with said cam, said cam operable to impart an increment of rotation to said clutch in said one direction through said follower, the magnitude of the increment of rotation determined by the eccentricity of the surface of said cam engaged by said follower relative to the axis about which said cam is rotatably adjustable,
(d) a conically shaped cam rotatably adjustable about an eccentric longitudinal axis and axially reciprocable,
(e) a cam follower fixed to said clutch and engaged with said cam, said cam operable during shifting away from a starting position to impart an increment of rotation to said clutch in said one direction through said follower, the magnitude of the increment of rotation determined by the eccentricity of the surface of said cam engaged by said follower,
(f) a spring mechanism operable to rotate said clutch in the other direction and to shift said clutch to the released condition when said cam is returned to its starting position,
(g) a yieldable spring mechanism connected at one end of said cam tending to hold said cam in its starting position,
(h) a fluid actuated feed piston connected to said cam at the other end thereof and selectively operable to overcome said yieldable spring mechanism at the one end of said cam for movement thereof away from the starting position,
(i) a pinion fixed to said feed shaft,
(j) a reset piston having a rack thereon engaged with said pinion, said reset piston operable when fluid pressure is applied thereto and said pinion is released to rotate said feed shaft in the other direction to lower said tool carrier and reset the feed mechanism,
(k) a fluid control circuit associated with the feed mechanism to intermittently effect operation of said feed piston to produce reciprocation of said cam to impart incremental rotation to said feed shaft in said one direction and to apply fluid under pressure to said reset piston when the feed shaft has rotated a selected total amount in said one direction for return rotation of said feed shaft in the other direction,
15. In a machine tool having a movable tool carrier, a feed mechanism comprising:
(e) a rotatable feed shaft operatively connected to said tool carrier for advancement thereof when said feed shaft is rotated in one direction and for retraction thereof when said feed shaft is rotated in the other direction,
(b) an overrunning clutch received over said feed shaft, said clutch rotatable and releasable engagable to transmit rotational motion in said one direction to said feed shaft, said feed shaft freely rotatable in both directions relative to said clutch when said clutch is in the released condition,
(c) a piston and cylinder motor operable to produce a force to shift said clutch from the released condition to the engaged condition and to rotate said clutch in said one direction to effect rotation of said feed shaft in said one direction,
(d) means to adjust the amount of rotation of said clutch in said one direction produced by said motor,
(e) means to intermittently energize said motor to effect a series of increments of rotation of said feed shaft in said one direction thereby effecting advancement of said tool carrier in steps, and
(f) means to rotate said feed shaft in the other direction after a selected advancement of the tool carrier for retraction thereof,
16. In a machine tool having a movable tool carrier, a feed mechanism comprising:
(a) a rotatable feed shaft operatively connected to said tool carrier for advancement thereof when said feed shaft is rotated in one direction and for retraction thereof when said feed shaft is rotated in the other direction,
(b) a releasable overrunning clutch received over said feed shaft, said clutch rotatable when engaged to transmit rotation to said feed shaft in one direction, said feed shaft freely rotatable in both directions relative to said clutch when said clutch is in the released condition,
(c) a piston and cylinder feed motor operable to produce a force to shift said clutch from the released condition to the engaged condition and to rotate said clutch in said one direction to effect rotation of said feed shaft in said one direction,
(d) a cam member rotatably adjustable to control the amount of rotation of said clutch produced by said feed motor,
(e) a motor control mechanism operable to intermittently energize said feed motor to effect a series of increments of rotation of said feed shaft in said one direction thereby effecting advancement of said tool carrier in steps, the magnitude of said steps dependent upon the adjustment of said cam member, and
(f) a reset mechanism operable to drive said feed shaft in the other direction after a selected advancement of said tool carrier for retraction thereof,
17. A precision grinding machine comprising:
(a) a base having a work area in which a workpiece is rotatably supportable and ways thereon extending toward the work area,
(b) a wheelhead member slidably received on said ways for movement toward and away from said work area,
(c) a spindle housing having a spindle rotatably mounted therein, said spindle having a grinding wheel fixed thereon,
(d) means resiliently to attach said spindle housing to said wheelhead member,
(e) means selectively to move said wheelhead member on said ways to produce a first feed movement of said grinding wheel toward the work area,
(f) a feed shaft operably connected to said spindle housing to lift said end thereof when rotated in one direction to tilt said spindle housing on said wheelhead member to effect a second feed movement of said grinding wheel toward the work area,
(g) an overrunning clutch received on said feed shaft, said clutch releasably engagable to transmit rotational motion in said one direction to said feed shaft, said feed shaft freely rotatable in both directions relative to said clutch when said clutch is released,
(h) means selectively operable after completion of the first feed movement to shift said clutch from the released condition and to transmit rotary motion through said clutch to said feed shaft in said one direction,
(i) means to rotate said feed shaft in the other direction to lower said one end of the spindle housing to reverse the second feed movement after a selected amount of second feed movement, and
(j) means to reverse the operation of said means producing the first feed movement after the selected amount of second feed movement to retract the wheelhead member from the work area.
18. A precision grinding machine comprising:
(a) a base having a worktable thereon and ways extending toward said worktable, said worktable adapted to rotatably support a workpiece during a grinding operation,
(b) a wheelhead member slidably received on said ways,
(c) a spindle housing having a rotatable spindle therein, said spindle having a grinding wheel fixed thereto,
(d) reed springs fixed between said wheelhead member and spindle housing to resiliently fix said spindle housing on said wheelhead member,
(e) a first feed mechanism operable selectively to move said wheelhead member toward said worktable for movement of said grinding wheel in a grinding operation,
(f) a rotatable feed shaft journalled for rotation in
said wheelhead member and having an eccentric diameter portion,

(g) a reciprocal linkage between the spindle housing and said eccentric portion operable to lift one end of said spindle housing when the eccentric portion is rotated in one direction from an initial position thereof to flex said reed springs and tilt the spindle housing for swinging the grinding wheel toward the worktable to complete a grinding operation,

(h) an overrunning clutch received on said feed shaft for limited rotation therewith, said clutch releasably engageable to transmit rotational motion in one direction to said feed shaft, said feed shaft freely rotatable in both directions relative to said clutch when said clutch is released,

(i) means selectively to shift said clutch from the released condition and to impart increments of rotation to said clutch in said one direction,

(j) means operable to shift said clutch to the released condition after each increment of rotation,

(k) means to rotate said feed shaft in the other direction after the completion of a grinding operation to return the spindle carrier to its initial position on the wheelhead member, and

(l) means to reversely operate said first feed mechanism after completion of a grinding operation to retract said wheelhead member from the worktable.

19. A precision grinding machine comprising:

(a) a base having a worktable thereon and ways extending toward said worktable, said worktable adapted to rotatably support a workpiece during a grinding operation,

(b) a wheelhead member slidably received on said ways,

(c) a spindle housing having a rotatable spindle therein, said spindle having a grinding wheel fixed thereto,

(d) a plurality of reed springs fixed between said wheelhead member and spindle housing to resiliently fix said spindle housing on said wheelhead member, each of said reed springs having a reduced section area, said reduced section areas of the reed springs aligned to define an axis of tilt for the spindle housing around which it swings when one end thereof is lifted,

(e) a first feed mechanism operable selectively to move said wheelhead member on said ways toward said worktable for movement of said grinding wheel in a grinding operation,

(f) a feed shaft journaled for rotation in said wheelhead member, said feed shaft having an eccentric diameter portion,

(g) a mechanical linkage between the spindle housing and the eccentric portion operable to lift one end of the tool carrier when the eccentric portion is rotated in one direction from an initial position thereof,

(h) an overrunning clutch received on said feed shaft for limited rotation therewith, said clutch releasably engageable to transmit rotational motion in said one direction to said feed shaft, said feed shaft freely rotatable in both directions relative to said clutch in its released condition,

(i) a reciprocally movable, conically shaped cam received in said wheelhead member and rotatably adjustable around an eccentric longitudinal axis,

(j) a cam follower fixed to said clutch and engaged with said cam, said cam operable during shifting away from a starting position to impart increments of rotation to said clutch in said one direction through said follower, the magnitude of the increments of rotation determined by the relative eccentricity of the surface of said cam engaged by said follower,

(k) a mechanism operable to shift said clutch to the released condition when said cam is returned to its starting position,

(l) a spring connected at one end of said cam to hold said cam in its starting position,
(n) a fluid control mechanism associated with said cam and feed piston to intermittently effect operation of said feed piston to produce a reciprocating motion of said cam away from and back to its starting position to impart incremental rotation to said feed shaft and including an angle gauge mechanism to stop said incremental rotation after movement of said grinding wheel a predetermined distance relative to a workpiece,

(o) means to reversely operate said first feed mechanism to retract said wheelhead member from the grinding area after said predetermined movement of the grinding wheel,

(p) a pinion fixed on said feed shaft,

(q) a reset piston having a rack thereon engaged with said pinion, said reset piston operable when fluid is applied thereto to rotate said feed shaft in the other direction to its initial position to lower said spindle housing and swing the grinding wheel away from the grinding area, and

(r) means to apply fluid under pressure to said reset piston after said predetermined movement of the grinding wheel.

21. In a precision grinding machine, a grinding wheel feed mechanism operable to move the grinding wheel forward from a retracted position through an automatic cycle for grinding a workpiece to a predetermined final size, the feed mechanism comprising:

(a) the grinding wheel from the retracted position to an advanced position adjacent the workpiece at a rapid rate,

(b) second means to move the grinding wheel forward from said advanced position at a fast grinding rate,

(c) third means to move the grinding wheel forward at an ultra fine grinding rate, and

(d) an automatic gauging mechanism having a plurality of sets of size contacts, one of said sets operable to deenergize said second means and stop movement of the grinding wheel when the workpiece reaches a first intermediate size, another of said sets operable to energize said third means and resume incremental movement of the grinding wheel when the workpiece reaches a second intermediate size, another of said sets operable to energize said third means and resume incremental movement of the grinding wheel when the workpiece reaches a second intermediate size, and yet another of said sets operable to reverse the operation of said first and third means to withdraw the grinding wheel.

22. In a precision grinding machine, a grinding wheel feed mechanism operable to move the grinding wheel forward from a retracted position through an automatic cycle for grinding a workpiece to a predetermined final size, the feed mechanism comprising:

(a) first means to move the grinding wheel forward from the retracted position to an advanced position adjacent the workpiece at a rapid rate,

(b) second means to move the grinding wheel forward from said advanced position initially at a fast grinding rate and subsequently at a fine grinding rate upon application of a speed change signal,

(c) third means to move the grinding wheel forward at an ultra fine grinding rate, and

(d) an automatic gauging mechanism having a plurality of sets of size contacts, one of said sets operable to apply a speed change signal to said second means and effect a reduction in movement of the grinding wheel from the fast to the fine rate when the workpiece reaches a first intermediate size, another of said sets operable to deenergize said second means and stop movement of said grinding wheel when the workpiece reaches a second intermediate size, another of said sets operable to energize said third means and resume movement of the grinding wheel when the workpiece reaches a third smaller intermediate size, and yet another of said sets to effect reverse operation of said first, second, and third means when the workpiece reaches the predetermined final size to return the grinding wheel to its retracted position.

23. In a precision grinding machine having a grinding wheel and a worktable adapted to support a workpiece and reciprocally movable between reversing points to traverse the workpiece across the cutting surface of the grinding wheel during a grinding operation, a feed mechanism operable to move the grinding wheel forward from a retracted position through an automatic cycle for grinding the workpiece to a predetermined final size, the feed mechanism comprising:

(a) first means to move the grinding wheel forward from a retracted position to an advanced position adjacent the workpiece at a rapid rate,

(b) second means to move the grinding wheel forward from said advanced position in a series of coarse increments,

(c) third means to move the grinding wheel forward in a series of ultra fine increments,

(d) a control mechanism operable to signal said second and third means to produce an increment of movement of the grinding wheel when the worktable reaches a selected reversing point, and

(e) an automatic gauging mechanism having a plurality of sets of size contacts, one of said sets operable to deenergize said second means and stop incremental movement of the grinding wheel whereby when the workpiece reaches a first intermediate size, another of said sets operable to energize said third means and resume incremental movement of the grinding wheel when the workpiece reaches a second intermediate size, and yet another of said sets operable to reverse the operation of said first and third means to withdraw the grinding wheel.

24. In a precision grinding machine, a grinding wheel feed mechanism operable to move the grinding wheel forward from a retracted position through an automatic cycle for grinding a workpiece to a predetermined final size, the feed mechanism comprising:

(a) means to move the grinding wheel from the retracted position to an advanced position adjacent the workpiece at a rapid rate,

(b) means to move the grinding wheel forward from the advanced position at a plurality of feed speeds, and

(c) an automatic gauging mechanism having a plurality of sets of contacts, one of said sets operable to stop feed movement of the grinding wheel when the workpiece reaches a first intermediate size, another of said sets operable to resume feed movement of said grinding wheel when the workpiece reaches a second intermediate size, and yet another of said sets operable to reverse the operation of both of said means to return the grinding wheel to its retracted position when the workpiece reaches the predetermined final size.

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