Dec. 1, 1953 O. E. HILL 2,660,837

GRINDING MACHINE

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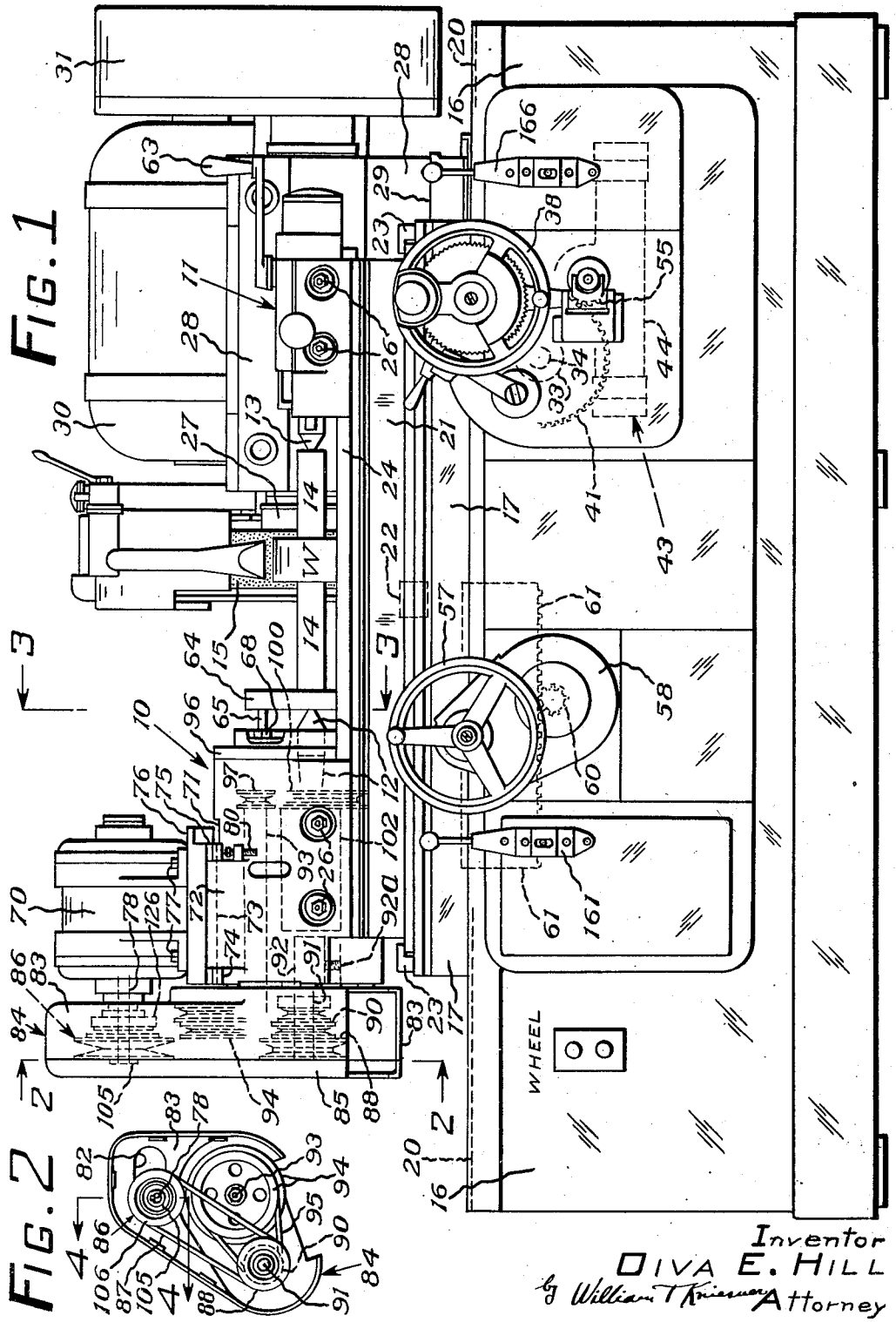


FIG. 1

FIG. 2

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GRINDING MACHINE

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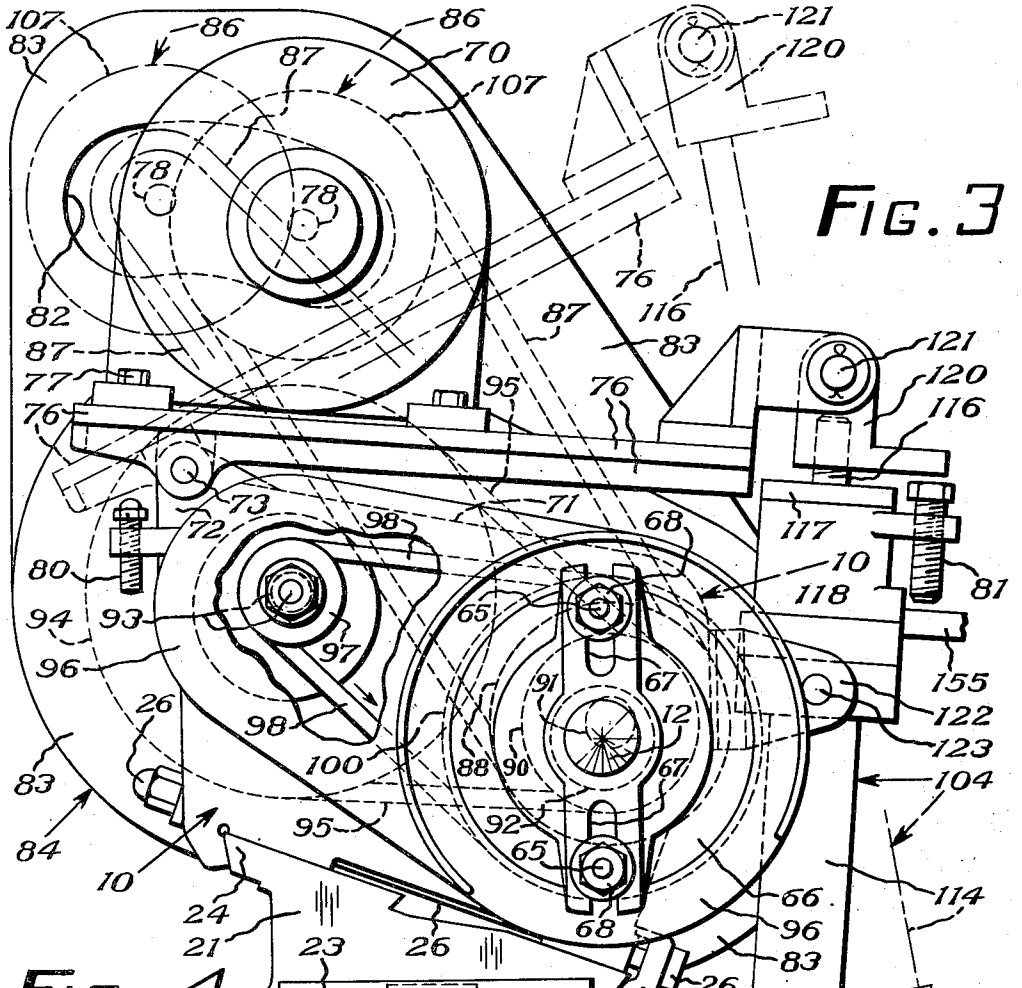


FIG. 3

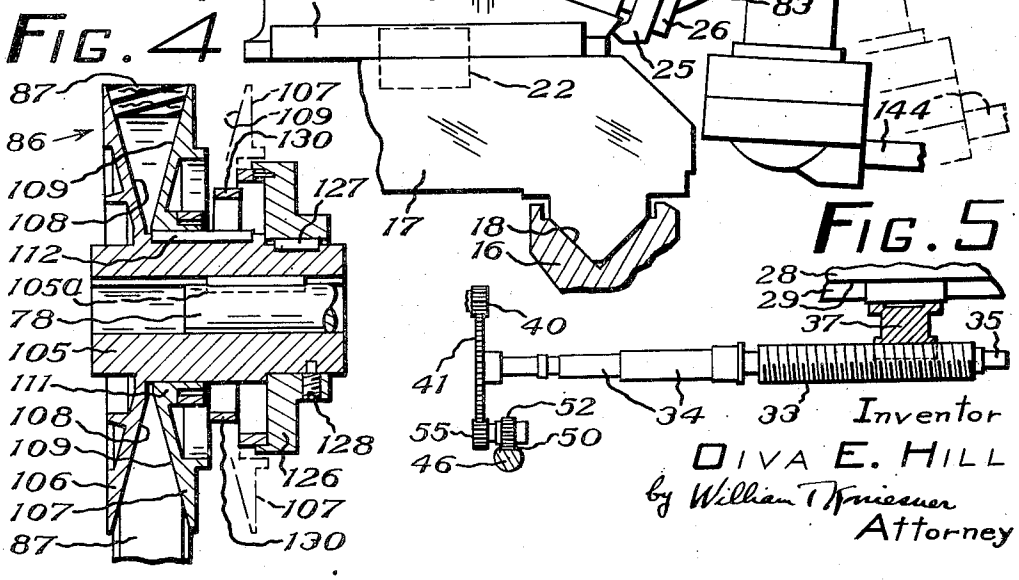


FIG. 4

FIG. 5

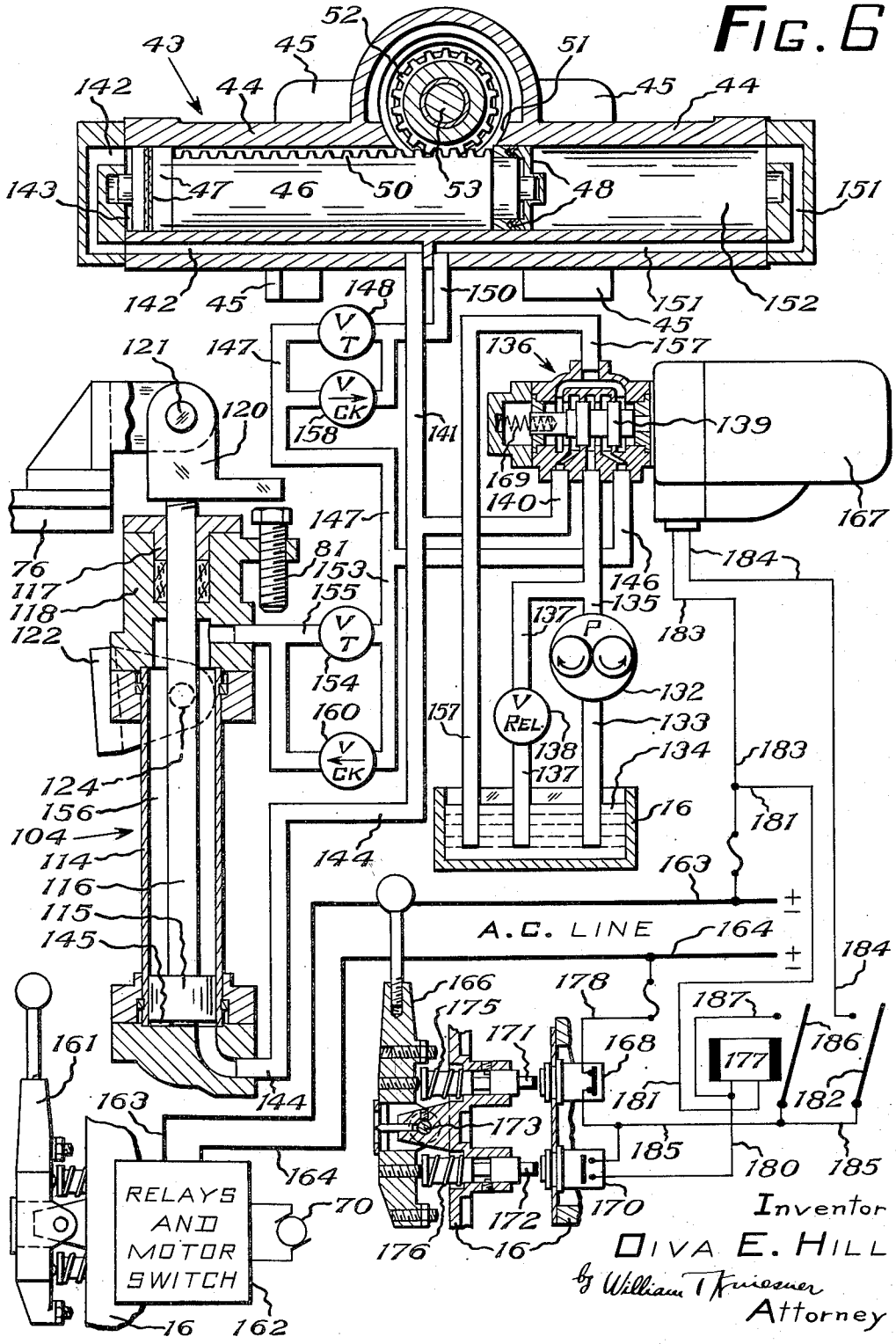
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GRINDING MACHINE

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FIG. 6



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GRINDING MACHINE

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17 Claims. (Cl. 51—95)

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This invention relates to grinding machines, and more particularly to a grinding machine for correlating surface speed of the work being ground and the cutting rate of the grinding wheel.

One of the objects of this invention is to provide a simple and practical grinding machine for dependably controlling and correlating work surface speed and cutting rate of the grinding wheel. Another object is to provide a grinding apparatus in which relative feeding movement of work surface to the grinding wheel may be controllably interrelated in a thoroughly practical and dependable manner; another object is to carry out the just stated objects by mechanisms and controls that will provide a suitable range of flexibility to meet not only the requirements for grinding a given work-piece, but also the varying requirements of other types or kinds of work-pieces to be ground. Another object is to provide a grinding apparatus of practical and inexpensive construction for controllably varying the surface speed of the work-piece during grinding operation thereon by the grinding wheel, and well adapted to meet the varying conditions of hard practical use. Another object is to provide a grinding apparatus in which relative feed movement between grinding wheel and work-piece may be dependably synchronized with change in surface speed of the work-piece. Another object is to provide a compact and efficient variable-speed drive for the work-piece and controls therefor that will be well adapted for controllable coaction with other elements of the grinding apparatus such, for example, as control of depth of cut of the grinding wheel.

Another object is to provide simple, practical, and efficient hydraulic controls for variably correlating surface speed of the work and depth of cut of the grinding wheel. Another object is to provide an apparatus of the just-mentioned character for performing a grinding operation commencing with high rate of stock removal and terminating in low rate of stock removal which may be efficiently carried out.

Another object is in general to provide an improved grinding apparatus of the above-mentioned character. Other objects will be in part obvious or in part pointed out hereinafter.

The invention accordingly consists in the features of construction, combinations of elements, and arrangements of parts as will be exemplified in the structure to be hereinafter described and the scope of the application of which will be indicated in the following claims.

In the accompanying drawings in which similar reference characters refer to similar parts throughout the several views—

Figure 1 is a front elevation of the complete grinding machine, certain parts of the drive shafts and pulleys being shown in broken lines with the belting and bearing supports therefor purposely omitted to avoid confusion;

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Figure 2 is a detached fragmentary end elevation showing certain features of drive, as seen along the line 2—2 of Figure 1;

Figure 3 is a detached end elevation on a larger scale of the head stock unit, substantially as seen along the line 3—3 of Figure 1, certain parts being broken away;

Figure 4 is a detached enlarged vertical sectional view of a variable-pitch drive pulley substantially as seen along the line 4—4 of Figure 2;

Figure 5 is a fragmentary detached vertical sectional view through the grinding wheel slide and the wheel feeding mechanism to illustrate a possible form of mechanism for wheel feed;

Figure 6 shows in section several of the various hydraulic mechanisms and shows diagrammatically the piping and valve connections and controls therefor.

My invention is best illustrated in connection with so-called external cylindrical grinding, oftentimes referred to as center grinding, particularly where the work-piece to be ground is supported and rotated by and on centers; accordingly, for purposes of illustration, in Figure 1 I have shown a grinding apparatus provided with a head stock unit 10 and a tail stock unit 11 having centers 12 and 13, respectively, for supporting the work-piece W, as by an arbor 14, so as to present, upon rotation, successive portions of the surface of the work-piece W to a grinding wheel 15 to grind it to cylindrical form. Head stock 10 and tail stock 11 are supported on a box-like frame or base 16 through the intermediary of a longitudinally slidable or reciprocable table 17 supported and guided by a longitudinally extending V-way 18 (Figure 3) and a companion flatway 20, and an intermediate table 21 (Figures 1 and 3) which rests flatwise on table 17 and relative to which it may be swivelled about a vertical axis, an axis usually provided by a suitable pivotal connection between the two tables in the form, for example, of a heavy cylindrical block or stud indicated at 22 in Figure 1, there being clamping devices 23 at the respective ends of the two tables to fix the swivel table 21 in the desired relation to the sliding table 17. Head stock 10 and tail stock 11 rest directly upon the swivel table 21 by which they are aligned and along which they are adjustably positionable in any suitable manner.

For example and as is better shown in Figure 3, the upper face of swivel table 21 may slant downwardly and rearwardly, providing along its upper front edge a V-shaped guide-part 24 with which the front underside of the head stock and tail stock interfit, clamping dogs 25 at the rear of the stocks, controlled by bolts 26 and the nuts of which are operable from the front of the ma-

chine (Figure 1), coacting to clamp the stocks to the table.

By means of the swivel table 21 the axis of the centers 12, 13 or of the work-supporting arbor 14 may be tilted in the horizontal plane, relative to the horizontal axis of the grinding wheel 15 which is parallel to the path of longitudinal movement of the table 17 on the bed 16, so that the surface of a rotating work-piece may be ground to tapered form. The grinding wheel axis is provided by a spindle 27 (Figure 1) carried in suitable bearings in a grinding wheel slide 28 which is slidably mounted in usual manner on a pair of rearwardly and hence transversely extending flat and V-ways 29 (Figures 1 and 5) provided in a rearward extension of the machine base 16 so that the grinding wheel is movable toward and away from the longitudinal table 17 or toward and away from the observer viewing Figure 1, the axis of wheel spindle 27 being parallel to the line of longitudinal traverse of table 17. Grinding wheel 15 is mounted on one end of spindle 27 which is driven by an electric motor 30 through driving connections at its other end, such as pulleys and V-belts (not shown) enclosed in a belt guard or casing 31.

Wheel slide 28 may be fed toward or away from the axis of the work support and along its ways 29 by a feed screw 33 (Figure 5) having shaft extensions 34 and 35 rotatably carried in suitable bearings (not shown); wheel slide 28 has a depending half-nut 37 which meshes with feed screw 33 and accordingly wheel slide and grinding wheel partake of movement toward or away from the work axis if the feed screw 33 is bodily moved (hydraulically, for example) or if it is given a rotary movement by any suitable means; for example, apparatus and mechanism for both bodily moving the feed screw and rotating it, with accompanying controls, may be employed, such as are disclosed in Silven Patent No. 2,522,485. However, to simplify an understanding of my invention, for purposes of illustration I have selected to show herein a simple form of manual drive of the feed screw 33 and illustrative and preferred form of power drive therefor and control interrelated, as is later described, with the drive of the work-piece W through the head stock 10.

Thus, there is mounted at the front of the machine base 16 (Figure 1) a manually operable feed wheel 38 provided with suitable driving connections with the feed screw 33, such as a small gear 40 (Figure 5) coaxial with the wheel 38 and meshing with a large gear 41 on the front end of feed screw shaft 34, whereby transverse movement of the wheel slide and grinding wheel 15 may be manually effected. Power drive of feed screw 33 I preferably effect hydraulically, as by a hydraulic motor generally indicated in Figures 1, 5, and 6 by the reference character 43; it may comprise a cylinder 44 provided with suitable brackets 45 (Figure 6) by which it is secured at the front of the machine base 16 in a position substantially as indicated in Figure 1, with its axis horizontal and extending lengthwise of the apparatus. As better shown in Figure 6, cylinder 44 is double-acting, having a reciprocable double-ended piston 46 therein provided with piston rings 47 and 48 at its respective ends, the intervening portion of the piston 46 having a rack 50 formed thereon which is exposed to an opening 51 in the cylinder wall to mesh with a pinion 52 on a transverse shaft 53 that is supported in a suitable bearing in upward extensions of the cylinder 44 and that carries a gear 55 (Figure 5) that meshes with larger gear 41 on the feed screw shaft 34 (Figures 5 and 1). Depending on the direction of the stroke given the piston 46, feed screw 33 is rotated slowly in one direction or the other to feed the wheel slide and grinding wheel toward the axis of the work or to retract it from the work. In-feed movement of the grinding wheel is to take place during grinding action of the grinding wheel on the work-piece as, for example, where the width of the grinding wheel 15 is equal to or greater than the width of the work W to be ground, as is illustrated in Figure 1. Relative axial setting between grinding wheel and work-piece W may be effected by setting the position of table 17—21 lengthwise of the ways 18—20 of the machine base 16, by any suitable means; longitudinal movement, including reciprocation, of table 17—21 may be manually effected, as by a hand wheel 57 (Figure 1) mounted at the front of the base 16 which, through suitable gearing enclosed in the gear cover or case 58, may drive a pinion 60 that meshes with a rack 61 (Figures 1 and 3) that extends lengthwise along the underside of table 17, or movement of the table may be effected in suitable strokes or steps or stages by a power drive, such as the hydraulic drive and controls disclosed in the Silven Patent No. 2,522,485, and such movement correlated to other mechanisms of the apparatus, particularly the traverse and feed movements of the grinding wheel slide 28, also as disclosed in the said Silven patent, depending upon the character of work-piece to be operated upon.

The tail stock 11 (Figure 1) may be of any suitable construction and may have any suitable mechanism, illustratively a hand lever 63 (Figure 1), for controlling the center 13 to permit ready replacement and mounting of the work-supporting arbor 14 which is provided with a dog arm 64, preferably double-ended and extending to each side of the arbor 14 to engage with diametrically opposed dogs 65, 65 (Figures 1 and 3) which are carried by a driven face plate or head 66 (Figure 3) that is coaxial with the center 12; head 66 is provided with diametrically opposed radial slots 67, 67 through which the dogs 65, 65 project and along which they are adjustably positioned and fixed by clamping nuts 68, 68. As the head 66, with its driving dogs 65, 65, rotates at a suitable speed, the round work-piece W is correspondingly rotated for action thereon by the grinding wheel 15, and provision is made to controllably change or vary the speed of drive of the head 66 and hence the rate at which the surface of the work-piece W is progressively presented to the face of grinding wheel 15, preferably in correlation with change in rate of in-feed of the grinding wheel itself.

As a source of driving power I prefer to employ an electric motor, indicated at 70 in Figures 1 and 3; the head stock 10 is constructed substantially in the form of a casing-like housing having a more or less flat, rearwardly inclined top wall, indicated at 71 in Figure 3, and projecting upwardly from its front wall; it has a long boss 72 (Figures 1 and 3) that has a longitudinal bore to receive a long hinge pin 73 the ends of which extend into bored-out spaced bosses 74 and 75 that project downwardly from a heavy plate 76 which carries the motor 70, being secured thereto, as by cap screws 77, the pivoting axis provided by pin 73 and the axis of motor shaft 78 being parallel to each other and parallel to the axis of rotatable face plate or

head 66. The resultant hinged mounting of the motor 70 relative to the housing of head stock 10 permits bodily displacement of the motor and its shaft 78 relative to the head stock housing, throughout a suitable range and for a purpose later described, a range on the order of that indicated in Figure 3 by the full-line and broken-line positions of the motor-supporting plate 76. Suitable means may be provided to adjustably limit the range of swing of the motor support, such as, for example, a stop screw 80 (Figures 3 and 1) carried in a bracket extension at the front of the head stock housing and a screw 81 carried in a bracket at the rear of the housing, the motor support 76 being controllably shiftable in a manner later described.

Motor shaft 78 projects to the left as seen in Figure 1 through an arcuate slot 82 (Figures 2 and 3) formed in the wall 83 of a belt-and-pulley encasing guard 84, provided with a removable cover 85, which is secured in any suitable way to the left end wall of the head stock housing, and on the end of shaft 78 is secured a variable-pitch pulley 86 (Figures 1, 2, and 4) to take a so-called V-belt 87 which also runs over and drives a V-grooved pulley 88 (Figures 1 and 2) which has coaxially secured to it, or coaxially constructed therewith to form a single unit, a stepped or cone pulley 90 (Figure 1) which provides a suitable number of V-grooved pulleys of different pitch diameters. The pulley unit 88—90 is located in the lower forward part of the guard casing 84 and is rotatably supported on a stud shaft 91 projecting from the left wall of the head stock casing and rigidly secured in the latter by means of a cylindrical block 92 integrally formed with the stud shaft 91, but with the axis of the latter eccentric to the axis of the block 92 (see also Figure 3).

Extending lengthwise of the head stock casing 10 and in an upper portion thereof, and rotatably supported in suitable bearings (not shown) carried in the left and right end walls of the casing, is a shaft 93 (Figure 1) whose left end projects into the guard casing 84 where it carries a stepped or cone pulley 94 providing a suitable number of differently diametered V-shaped grooves that are complementary to those of the stepped pulley 90; by means of a V-belt 95 (Figures 2 and 3) pulley 94 and its shaft 93 are driven from pulley 90 on stud shaft 91 at a speed that is selectible according to which complementary pair of V-shaped grooves is selected for the belt. Any suitable number of speed changes may thus be provided, and to simplify the drawings and for purposes of illustration, two steps are shown in each of the pulleys 90 and 94, thus providing for two such speed changes. The block 92 which eccentrically carries the stud shaft 91 is seated in an appropriate cylindrical recess in the left wall of head stock casing 10 so that it is rotatably adjustable in order thereby to adjust the distance between shaft 91 and shaft 93, when necessary to take up stretch in the belt 95. At the same time, for the full-line or normal at-rest position of the tiltable motor 70 and its hinged support 76 as shown in Figure 3, such adjusting shift of stud shaft 91 effects a change in the distance between itself and the motor shaft 78, and while variable-pitch pulley 86 (Figures 1 and 3) is self-accommodating to such a shift, it is preferred to compensate therefor by adjusting the screw 81 (Figure 3) to raise or lower it and thus fix the normal at-rest position of motor shaft 78 and its distance from the shaft 91 so that variable-pitch pulley 86 is self-adjusting to one of its extremes of variable pitch diameters—in this case, maximum pitch diameter substantially as indicated in Figure 4. Adjusting screw 81 may thereafter be reset as needed to compensate for subsequent stretch in V-belt 87. Any suitable means may be provided to lock the eccentric mounting block 92 in its adjusted position such as, for example, set screw 92a (Figure 1).

The right end of shaft 93 (Figure 1) in head stock 10 projects through the right end wall into a guard casing 96 (Figures 1 and 3) suitably secured to the right end wall of the head stock casing, and there shaft 93 has secured to it a pulley 97 which by way of belt 98 (Figure 3) drives a larger pulley 100 that drives the face plate or head 66 that carries the driving dogs 65, 65 (Figures 1 and 3) coaxially with the head stock center 12. Pulley 100 may be constructed as a unit with the face plate 66 or the two may be secured together coaxially in any suitable manner and as a unit are rotatably supported on a heavy stud shaft 102 which is rigidly carried or supported within the head stock casing and which projects through the right end wall thereof and also through the face plate 66, and in that end it has a tapered hole in which the tapered shank of center 12, which need not rotate, fits. As indicated in Figure 1, the inner ends of the stud shaft 102 and the pulley-supporting part 91—92 are closely adjacent and, as indicated in Figure 3, they are very nearly coaxial; a hole extends axially through the stud shaft 91 and also through the mounting block 92, and a larger hole extends axially through the stud shaft 102; by removing the belt guard cover 85 (Figures 1 and 2), a rod may be extended through these holes to engage the inner end of center 12 when it is necessary to dislodge the same.

The described train of drive from motor shaft 78 to the face plate 66 provides a substantial speed reduction so that the work-piece W (Figure 1) may be rotated relatively slowly at substantially constant speed, a speed selectable by the cone or stepped pulleys 90 and 94 and belt 95, according to the diameter of the work W, to provide an appropriate maximum surface speed of presentation of the work to the grinding wheel, the pitch diameter of variable pulley 86 being the maximum as shown in Figure 4, with the movable motor 70 and its support 76 in normal or at-rest full-line position as shown in Figure 3. At such maximum work-surface speed, grinding wheel 15 commences to grind the rotating work-piece W and is fed toward the axis of the latter at preferably a substantial rate, as by the hydraulic motor 43 (Figures 6 and 5) above described, in order to achieve high rate of material removal from the work W, in effect accomplishing so-called "rough" grinding, whereupon, as is later described, the rate of feed of grinding wheel is lessened and rate of drive of the work W is reduced in correlation therewith so as to remove less and less stock from the work W and at diminishing surface speeds of the latter to conclude the grinding operation with "finish" grinding. According to my invention, I provide means for reducing the pitch diameter of pulley 86 on motor shaft 78 to diminish the surface speed of the work, and in the preferred form of my invention I employ a hydraulic motor 104 for that purpose and coacting with the hydraulic motor 43 that effects grinding wheel feed. Variable-pitch pulley 86 on the motor shaft 78 may be

constructed as shown in Figure 4; it has a hub 105 by which it may be keyed to motor shaft 78, as at 105a, and externally it carries two disc-like sheave parts 106 and 107 providing juxtaposed inclined faces 108 and 109, respectively, with inclinations, substantially as shown, appropriate to the inclined side faces of a so-called V-belt but which is more usually of trapezoidal cross-section, substantially as shown in Figure 4. While flexible, belt 87 made in known manner of rubber-bonded plies of fabric which extend transversely of its cross-section as shown in Figure 4, has substantial transverse rigidity and rides the pulley or sheave by engaging its inclined side faces respectively with the inclined faces 108, 109 of the sheave plates and at a radius which is changeable according as the axial spacing between these inclined faces 108, 109 is changed. Suitable provision is made for changing this axial spacing; sheave disc 106 may be integrally formed with the hub 105 and at one end of the latter, while sheave disc 107 is slidably carried by the hub 105, being itself formed with a hub 111 for that purpose and by which it is also splined to the hub 105, as at 112, so it will rotate with its companion disc 106 even though it changes its axial position relative thereto. Provision is made to control the shift of sheave disc 107 axially and thus change the pitch diameter of pulley 86 to vary the rate of drive of face plate 66 from that selected by means of the cone pulleys 90 and 94 and belt 95. Such means is under the control of the just-mentioned hydraulic motor 104 which functions, as above mentioned, in correlation with the hydraulic motor 43 that actuates the grinding wheel feed. Hydraulic motor 104 comprises a cylinder 114 (Figures 3 and 6) suitably mounted and provided with a piston 115 and piston rod 116 which extends through a stuffing box 117 in cylinder head 118 and which at its outer end has secured to it a bracket 120 which is pivotally connected by a pin 121 to a bracket extension at the rear (Figure 3) of the motor mounting plate 76 and at a point remote from the hinge pin 73 of the latter, and thus motor 70 and its shaft 78 with pulley 86 may be displaced, about hinge pin 73 as an axis, throughout the range earlier above mentioned and thus change the distance between shaft 91 (Figures 1 and 2) and its own shaft 78.

Suitable provision is made to compensate for the arcuate path of movement of the connecting pin 121 as motor support swings about its pivoting axis, and this may comprise a U-shaped yoke 122 (Figure 3) secured to the rear wall of the head stock casing and between the arms of which cylinder 114 is pivotally supported near its upper end by trunnions or pins 123, 124 (Figures 3 and 6) so that the hydraulic motor is self-adjusting to change in angularity of the motor support 76, as indicated in the full-line and broken-line positions shown in Figure 3. Bracket 120 conveniently serves to coact with the adjustable stop screw 81 which is preferably carried, as shown in Figures 3 and 4, by a bracket extension provided in the upper end of upper cylinder head 118 whereby they can more directly take up downward thrust (see Figure 6) caused by the piston 115 and thus limit its downward stroke of movement according to the setting of screw 81.

Variable-pitch sheave or pulley 86 (Figures 2 and 4) is made to change its pitch diameter according to the movement of piston 115 of hydraulic motor 104 and thus correspondingly to change the surface speed of the driven work-piece W. The left end of pulley hub 105 (Figure 4) carries a large diametered collar 126 keyed or splined, as at 127, and locked against axial movement by a set screw 128 and thus held in appropriate spacing from the slidable sheave disc 107. Collar 126 serves as an abutment or anchorage for one end of a spring 130, the other end of which abuts against sheave disc 107, yieldably forcing the latter to the left in Figure 4 away from collar 126 and toward the companion sheave disc 106.

Spring 130 may be of any suitable construction, illustratively it may be a spiral helix, so that as the spacing between collar 126 and disc 107 diminishes, the turns of the spring are accommodated one within another, thus to occupy a minimum of space when the spring is compressed to its maximum. Collar 126 and sheave disc 107 may be flanged toward each other and dimensioned so that the two may telescope as indicated in broken lines in Figure 4 when disc 107 reaches its extreme position to the right, a position in which the pitch diameter of the pulley 106—107 is smallest, and the belt 87 rides against the lower portions of the inclined faces 108—109, appropriately clearing the hub 105. Parts 126 and 107 are shaped to provide appropriate seats for the end turns of spring 130 which may be held therein in any suitable manner.

Spring 130 is relatively powerful and sufficiently so to maintain endless belt 87 taut, causing sheave plate 107 to move to the left in Figure 4 and the belt to ride at a larger radius should the belt be given any slack, as by decreasing the distance between motor shaft 78 and pulley 88 and, conversely, spring 130 yields and permits sheave plate 107 to move to the right and belt 87 to ride at a lesser radius when the distance between motor shaft 78 and pulley 88 is increased; in the former case the speed of drive of pulley 88 is decreased, as is also the drive of the face plate 66 and the work W, and in the latter case the drive of these parts is increased. Abovedescribed hydraulic motor 104, by shifting motor 70 relative to the axis of pulley 88 determines the spacing between motor shaft 78 and pulley 88 and the rate and direction in which that distance is changed, correspondingly to determine the rate of drive of the work W, in correlation to the rate at which grinding wheel feed takes place. Illustratively, for any selected ratio of drive by means of stepped pulleys 90 and 94, the speed of drive of the face plate may be diminished from a maximum value to one-half corresponding, respectively, to maximum pitch diameter of the variable-pitch drive pulley 86 and minimum pitch diameter thereof; where round work is being ground of a diameter on the order of two or three inches, that for illustrative purposes may represent a change in speed or drive of the work W from about 60 R. P. M. to 30 R. P. M.

Referring now to Figure 6, hydraulic motors 43 and 104 are included in a fluid pressure system which comprises a suitably driven pump 132 which draws liquid through pipe 133 from a reservoir 134 provided within the base 16 of the machine; its output is connected by pipe 135 to a control valve 136, pipe 135 also having a connection through pipe 137, and a suitable pressure relief valve 138 back to the reservoir 134. Valve 136, which may be of the piston type and provided with pistons and ports substantially as indicated in Figure 6, has an outlet port connected by pipe 140 and pipe 141, through cylinder pas-

sages 142 in hydraulic motor 43, to left-hand chamber 143 of motor 43, and connected by pipe 140 and pipe 144 to the lower chamber 145 of hydraulic motor 104. Valve 136 has another outlet connected by pipe 146, pipe 147, throttle valve 148, and pipe 150, through cylinder passages 151, to the right-hand chamber 152 of hydraulic motor 43 and connected by pipe 146, pipe 153, throttle valve 154, and pipe 155 to the upper chamber 156 of hydraulic motor 104. Valve 136 has another outlet connected by pipe 157 to discharge into the reservoir 134. Throttle valves 148 and 154 are unidirectionally shunted or bypassed by check valves 158 and 160, respectively, by respective pipe connections as indicated in Figure 6, the check valves permitting flow only in the respective directions of the arrows as shown.

Head stock driving motor 70 may be started and stopped by any suitable control, preferably at the front of the machine, as by a pivoted lever 161 (Figure 1); lever 161 is shown also in Figure 6, and through suitable relays and a main motor switch, diagrammatically indicated at 162, motor 70 may be connected or disconnected from the power line 163—164. Valve 136 is manually controllable in any suitable manner, preferably from the front of the machine, as by pivoted lever 166 (Figure 1). Valve 136 may be of the solenoid-actuated type, having an enclosed solenoid 167 which when de-energized permits a spring 169 to shift and hold valve piston 139 in an at-rest position shown in Figure 6, and which when energized shifts and holds the valve piston to the left, compressing spring 169; lever 166 accordingly controls the opening and closing of the circuit of solenoid 167 which receives its energy from the power line 163—164.

An illustrative control circuit is shown in Figure 6 and comprises a normally closed switch 168 and a normally open switch 170, either of which may be momentarily operated according as which one of two spring-opposed plungers 171 and 172 is actuated to the right by lever 166 which is pivoted at 173 to coact with the plungers so that only one or the other is moved to the right according to the direction in which lever 166 is tilted, the plunger springs 175, 176 normally holding lever 166 in neutral or mid-position.

With motor 30 (Figure 1) driving grinding wheel 15 and the circuit of head stock motor 70 closed in response to actuation of start-and-stop lever 161 so as to drive the work-holder or arbor 14 of the work-piece W thereon, grinding wheel slide 28 is given a position wherein grinding wheel 15 is just about ready to engage the rotating work W and is ready to be given an in-feed movement; wheel slide 28 may be so positioned by any suitable known means, illustratively by the above-mentioned hydraulic rapid traverse mechanism, as in Figure 5 of Silven Patent No. 2,522,485, by which the feed screw and wheel slide of half-nut are bodily shifted forwardly and halted, whereupon in-feed ensues by rotation of the feed screw. The piston 115 of hydraulic motor 104 (Figures 6 and 3) is in lowermost position as determined by the stop screw 81, fixing a spacing between variable-pitch pulley 86 and pulley 88 (Figures 2 and 3) that corresponds to maximum pitch diameter in pulley 86 and hence maximum speed of drive of the work W. The operator now momentarily shifts lever 166 counter-clockwise in Figure 6, momentarily closing switch 170, to energize relay 177 through a circuit from power line 164, conductor 178, switch 168, switch 170, conductor 180, relay 177, conductor 181, to power line 163. Relay 177 closes switch 182 to energize solenoid 167 in a circuit from line 163, conductor 183, solenoid 167, conductor 184, switch 182, conductor 185, switch 168, and by conductor 178 to line 164, thereby shifting the valve piston to the left where it is held until solenoid 167 is deenergized.

Relay 177 has an auxiliary switch 186 which is also closed to maintain the circuit of relay 177 closed even though starting switch 170 moves back to normally open position; the resultant holding circuit extends from line 164, conductor 178, normally closed stop switch 168, conductor 185, closed auxiliary switch 186, conductor 187, relay 177, conductor 181, to power line 163. Solenoid 167 thus remains energized until lever 166 is tilted, after conclusion of the grinding operation about to be described, in clockwise direction (Figure 6) to momentarily open switch 168, thus de-energizing relay 177 to restore its switches 182 and 186 to open position.

With valve piston 139 held in its left-hand position, the discharge of pump 132 is connected through the valve to pipe 140 from which pipe 141 supplies liquid under pressure to the left chamber 143 of grinding wheel feed hydraulic motor 43 and pipe 144 supplies it to lower chamber 145 of the speed-change control hydraulic motor 104; piston 46 of the former moves to the right in Figure 6, and piston 115 of the latter commences to move upwardly. Grinding commences, the grinding wheel being steadily fed toward the axis of the rotating work W, the moving piston 46 rotating the feed screw 33 in in-feed direction by the mechanism above described in connection with Figure 5; at the first grinding contact of grinding wheel with the work W, the latter is rotating at maximum speed, giving the work a high surface speed commensurate with maximum rate of material removal appropriate to the cutting characteristics of the grinding wheel and to the composition of the work-piece W. As grinding and wheel in-feed continue, rate of drive of the work W decreases, somewhat commensurately decreasing rate of material removal, and the decrease in surface speed continues until the work W is just about brought down to size by which time surface speed, with the illustrative figures earlier above given, may be reduced to half of its starting surface speed.

The respective rates of grinding wheel in-feed and of change in work surface speed, in the illustrative embodiment, are controllable by means of throttle valves 148 and 154 (Figure 6) which control the respective rates at which liquid is permitted to escape from the other sides of the motor pistons 46 and 115. The escape or discharge from chamber 152 of motor 43 is by way of cylinder channels 151, pipe 150, throttle valve 148, pipe 147, pipe 146 which stands connected, within the piston valve 136, to discharge pipe 157 leading back to reservoir 134; throttle valve 148 is adjustable or controllable in any suitable manner, illustratively manually, it being noted that check valve 158 blocks any by-passing of valve 148. The other chamber 156 of speed-control motor 104 discharges through pipe 155, throttle valve 154, pipe 153, pipe 146 which is connected by the valve 136 to discharge pipe 157 that leads to the reservoir 134; check valve 160 blocks by-passing of throttle valve 154, which is also ad-

justable or controllable in any suitable manner, preferably manually.

For example, throttle valves 148 and 154 may be set or controlled so that the two hydraulic motors 43 and 104 conclude their respective strokes at just the same time whereupon the operator may thus permit the grinding wheel to be held in a fixed position to "spark out" and conclude the finish grinding at the lowest work surface speed, the operator himself controlling the period of such a dwell. Or these throttle valves may be set so that piston 46 of feed motor 43 comes to rest at the end of its stroke in suitable time before piston 115 comes to the end of its upward stroke, and in such case there results a dwell or halting in the in-feed of the grinding wheel to conclude finish grinding and sparking out at continued diminishing work surface speed. Or throttle valves 148 and 154 may be set or controlled so that the speed-change motor piston 115 reaches the end of its stroke at any suitable time just prior to the conclusion of the in-feed stroke of feed-motor piston 46, in which case finish grinding at constant low surface speed of the work W at controlled wheel in-feed may be had, followed by sparking out during a suitable dwell after the feed-motor piston 46 comes to a halt.

The stage of finish grinding and sparking out having been concluded, the operator actuates lever 166 clockwise in Figure 6 to momentarily open stop switch 168, thus de-energizing solenoid 167, whereupon valve piston 139 assumes the at-rest position shown in Figure 6. As a result the pipe connections to the two hydraulic motors are changed and both are actuated in reverse direction at maximum speed, unaffected by the throttle valves 148 or 154. The output of pump 132 now stands connected to pipe 146 so that liquid under pressure flows to chamber 152 of feed-motor cylinder 44 through pipe 147, check valve 153 (by-passing valve 148), and pipe 150, rapidly moving piston 46 to the left and rapidly rotating feed screw 33 to retract the grinding wheel, and that liquid under pressure flows through pipe 153, check valve 160 (by-passing throttle valve 154), and pipe 155 to the upper chamber 156 of the speed-change motor, rapidly lessening the distance between motor shaft 78 and pulley 88 and causing the spring 130 (Figure 4) to increase the pitch diameter of pulley 86 and restore the initial high-speed ratio of drive of the head stock face plate 66. As piston 46 of motor 43 moves to the left, liquid is discharged from its left-hand chamber by way of passage 142, pipe 141, pipe 140 which, through the valve 136, is connected to the discharge pipe 157 that leads to reservoir 134; the downward movement of piston 115 of motor 104 causes discharge of liquid from chamber 145 through pipe 144 and pipe 140 which, through valve 136, is connected to the reservoir return pipe 157.

The quick return of the parts to starting position permits the operator to start removing the arbor 14 from the machine and replace it with an arbor carrying the next work-piece W to be ground, the cycle being recommenced by actuation of lever 166 in counter-clockwise direction in Figure 6 to actuate the start switch 170.

It will thus be seen that there has been provided in this invention a grinding machine in which the various objects above noted together with many thoroughly practical advantages are successfully achieved. It will be seen that the apparatus is of compact, rugged, and easily controllable construction and arrangement and is well adapted to meet the varying conditions of hard practical use. The apparatus is well adapted to achieve high efficiency of grinding action, being capable of high cutting rate as in initial or "rough" grinding stages of a grinding operation, and yet in the same grinding operation good precision and effective "finish" grinding are achievable.

As many possible embodiments may be made of the above invention and as many changes might be made in the embodiment above set forth, it is to be understood that all matter hereinbefore set forth, or shown in the accompanying drawing, is to be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In a grinding machine, in combination, a grinding wheel, means for rotatively supporting a work-piece to be ground and driving means therefor comprising motive means having a driving connection with said rotatable work-supporting means that includes two pulleys and a connecting drive belt, one of said pulleys having spring-biased coacting belt engaging members which are relatively movable in axial direction for changing the effective pitch diameter thereof whereby to change the ratio of drive between said two pulleys and thereby change the speed of drive of said work-supporting means, means movably mounting one of said pulleys for movement in a direction to change the distance between it and the other of said two pulleys and thereby effect change in the ratio of drive therebetween, means for effecting relative feeding movement between said grinding wheel and said rotatable work-supporting means during grinding action of the grinding wheel on the rotating work-piece and for effecting relative retracting movement between said grinding wheel and the work-supporting means, and reversible motor means operating at relatively low speed in one direction of drive and operating at relatively high speed in opposite direction of drive and having operating connections with said pulley mounting means to move it to change the aforesaid ratio of drive, with means for controlling the direction of drive of said motor means to effect low-speed movement of said pulley mounting means during relative feeding movement between said grinding wheel and said work-supporting means to move said pulley mounting means and thereby change the speed of drive of said work-supporting means and to effect high-speed movement thereof for resetting the machine for the next cut by the grinding wheel.

2. In a grinding machine, in combination, a grinding wheel, means for rotatively supporting a work-piece to be ground and driving means therefor comprising motive means having a driving connection with said rotatable work-supporting means that includes two pulleys and a connecting drive belt, one of said pulleys having spring-biased coacting belt engaging members which are relatively movable in axial direction for changing the effective pitch diameter thereof whereby to change the ratio of drive between said two pulleys and thereby change the speed of drive of said work-supporting means, means comprising a reversible piston-and-cylinder fluid motor for effecting relative feeding movement between said grinding wheel and said rotatable work-supporting means during grinding action for effecting separating movement therebetween, and means comprising a reversible piston-and-

cylinder fluid motor for controlling said belt-engaging members of said one pulley, a source of fluid under pressure, and valve means for controlling the effective fluid flow to said two motors to drive said first motor at a relatively low speed for feeding movement and to drive said second motor at relatively low speed for effecting relative axial movement of said belt-engaging members of said one pulley in a direction to diminish the speed of drive of said work-supporting means to drive both motors in reverse direction at relatively high speed for, respectively, relatively rapid movement of separation between the grinding wheel and the work-supporting means and relatively rapid axial movement between said belt-engaging members in a direction to increase the speed of drive of said work-supporting means.

3. In a grinding machine, in combination, a grinding wheel, means for rotatably supporting a work-piece to be ground and driving means therefor comprising a driven pulley and a motor having a drive pulley connected by a driving belt with said driven pulley, one of said pulleys having coacting belt engaging members which are relatively movable in axial direction for changing the effective pitch diameter thereof whereby the ratio of drive between said two pulleys is changeable, means for supporting said motor and its drive pulley for movement toward and away from the other pulley, means operating in response to said last-mentioned movement for effecting relative axial movement between said belt engaging members of said one pulley to change its effective pitch diameter, means for effecting relative feeding movement between said grinding wheel and said work-supporting means during grinding action, a fluid motor having a cylinder element and a coacting piston element and having operating connections with said motor supporting means and operable during said relative feeding movement to effect movement of said motor-supporting means and thereby control the spacing and the ratio of drive between said two pulleys, and means operating to control the action of said fluid motor comprising valve means for the motor-operating fluid and means for selecting the range of movement of said motor-supporting means toward and away from said other pulley.

4. A grinding machine as claimed in claim 3 in which said motor supporting means comprises a pivoted support for the motor with the axis of pivoting parallel to and offset from the axis of said drive pulley whereby shifting of the support about its axis shifts the motor and said drive pulley toward or away from the other pulley and said range-selecting means comprising adjustable stop means coacting with said motor-supporting means and in which said operating connections between said fluid motor and said pivoted motor-support comprise an articulated connection between the latter at a point spaced from its pivoting axis and one of said fluid motor elements and means pivotally supporting the other of said motor elements for self-accommodation of the fluid motor to the swing of said motor support as it pivots in response to relative movement between the piston-and-cylinder elements.

5. In a grinding machine, in combination, a grinding wheel, means for supporting a work-piece to be ground, power-driven means driving said work-supporting means to traverse the surface of a supported work-piece relative to said grinding wheel, said power-driven means including motive means having a driving connection with said work-supporting means that includes two pulleys and a connecting drive belt, one of said pulleys having coacting relatively movable parts for changing the effective pitch diameter thereof and for thereby changing the ratio of drive between said two pulleys, means for effecting a controllable amount of relative feeding movement between said grinding wheel and said work-supporting means, and means operable in timed relation to said relative feeding movement, said last-mentioned means comprising a piston-and-cylinder fluid motor having connections effective during a stroke of said motor for operating upon said relatively movable members of said pulley and upon said belt to change the effective pitch diameter of the former and to maintain driving tension of the belt with change in pitch diameter and control means for timing the conclusion of the stroke of said piston-and-cylinder motor in relation to said controllable amount of relative feeding movement.

6. In a grinding machine, in combination, a grinding wheel, means for supporting a work-piece to be ground, power-driven means driving said work-supporting means to traverse the surface of a supported work-piece relative to said grinding wheel, said power-driven means including motive means having a driving connnection with said work-supporting means that includes two pulleys and a connecting drive belt, one of said pulleys comprising two members having adjacent frusto-conical faces for engaging the belt with spring means axially biasing one of said members toward the other to increase the effective pitch diameter thereof, reversible fluid motor means operating in reversible strokes for effecting relative feeding movement between said grinding wheel and said work-supporting means and for effecting separating movement therebetween, and means operable during said relative movement and affecting the pitch diameter of said one pulley and affecting said belt to change the ratio of drive between said two pulleys, said last-mentioned means comprising means mounting one of said pulleys for movement in a direction toward and away from the other and reversible fluid motor means operating in reversible strokes for operating upon said pulley mounting means to change the distance between said two pulleys, a source of pressure fluid for said two fluid motor means, main control valve means, which in one position connects said source to both of said fluid motor means to actuate each in one stroke and in another position connects them to actuate each in its reverse stroke, and valve means for affecting the time period of the strokes of said two motors in relation to one another.

7. In a grinding machine, in combination, a grinding wheel, means for supporting a work-piece to be ground, power-driven means driving said work-supporting means to present the surface of a supported work-piece to said grinding wheel, said power-driven means having a variable-speed driving connection with said work-supporting means for changing the surface speed of the work-piece, said driving connection including two pulleys and a driving belt, one of said pulleys having coacting relatively shiftable belt-engaging parts which change the effective pitch diameter of the pulley according to the position of one of said parts relative to the other, means for effecting a controllable amount of relative feeding movement between said grinding wheel and said work-supporting means, means for con-

trolling the relative positions of said relatively shiftable members of said pulley and for controlling the relation of said belt to said two members and to the other pulley to change the effetcive pitch diameter of the pulley and to maintain driving tension of the belt with change in pitch diameter, means to actuate said controlling means in a direction to decrease the rate of drive of said work-supporting means and thereby decrease the surface speed of the work-piece as the grinding action of said grinding wheel thereon progresses, and controllable means for setting the relation between the time period of operation of said actuating means and the time period of the means for effecting said controllable amount of relative feed movement between the grinding wheel and the work-supporting means.

8. In a grinding machine, in combination, a grinding wheel, means for supporting a work-piece to be ground, power-driven means driving said work-supporting means to present the surface of a supported work-piece to said grinding wheel, said power-driven means having a variable-speed driving connetcion with said work-supporting means for changing the surface speed of the work-piece, said driving connection including two pulleys and a driving belt, one of said pulleys having coacting relatively shiftable belt-engaging parts which change the effective pitch diameter of the pulley according to the position of one of said parts relative to the other, means for effecting relative feeding movement between said grinding wheel and said work-supporting means and thereby control depth of cut of the grinding wheel on the work-piece and for effecting relative separating movement therebetween, means for controlling the relative position of said shiftable members of said pulley and for controlling the relation of said belt to said two members and to the other pulley to change the effective pitch diameter of the pulley and to maintain driving tension of the belt with change in pitch diameter, and means operating in timed relation to said feeding movement to actuate said controlling means at a relatively slow rate in a direction to decrease the rate of drive of said work-supporting means and thereby decrease the surface speed of the work-piece during grinding and operable during relative separating movement between said grinding wheel and said work-supporting means to actuate said controlling means at a relatively high rate in a direction to increase the rate of drive of said work-supporting means.

9. In a grinding machine, in combination, a grinding wheel, means for supporting a work-piece to be ground, power-driven means driving said work-supporting means to present the surface of a supported work-piece to said grinding wheel, said power-driven means having a variable-speed driving connection with said work-supporting means for changing the surface speed of the work-piece, said driving connection including two pulleys and a driving belt, one of said pulleys having coacting relatively shiftable belt-engaging parts which change the effective pitch diameter of the pulley according to the position of one of said parts relative to the other, means for effecting relative feeding movement between said grinding wheel and said work-supporting means and thereby control depth of cut of the grinding wheel on the work-piece and for effecting relative separating movement therebetween, means comprising a reversible motor for controlling the relative position of said relatively shiftable members of said pulley and for controlling the relation of said belt to said two members and to the other pulley to change the effective pitch diameter of the pulley and to maintain driving tension of the belt with change in pitch diameter, and means operable during said relative feeding movement to actuate said motor at relatively low speed in a direction to decrease the rate of drive of said work-supporting means and thereby decrease the surface speed of the work-piece during grinding and operable during said relative separating movement to actuate said motor at relatively high speed in a direction to increase the rate of drive of said work-supporting means.

10. In a grinding machine, in combination, a grinding wheel, means for supporting a work-piece to be ground, power-driven means driving said work-supporting means to present the surface of a supported work-piece to said grinding wheel, said power-driven means having a variable-speed driving connection with said work-supporting means for changing the surface speed of the work-piece, said driving connection including two pulleys and a driving belt, one of said pulleys having coacting relatively shiftable belt-engaging parts which change the effective pitch diameter of the pulley according to the position of one of said parts relative to the other, means for effecting relative feeding movement between said grinding wheel and said work-supporting means and thereby control depth of cut of the grinding wheel on the work-piece and for effecting relative separating movement therebetween, means comprising a reversible motor for controlling the relative shift between said shiftable members of said pulley and for controlling the relation of said belt to said two members and to the other pulley to change the effective pitch diameter of the pulley and to maintain driving tension of the belt with change in pitch diameter, a source of fluid under pressure for actuating said motor, and means operable during said feeding movement to supply said motor at a low rate with fluid from said source for actuating it in a direction to decrease the rate of drive of said work-supporting means and thereby decrease the surface speed of the work during grinding and operable during said relative separating movement to supply said motor with fluid at a relative high rate to drive the motor in reverse direction.

11. In a grinding machine, in combination, a grinding wheel, means for supporting a work-piece to be ground, power-driven means driving said work-supporting means to present the surface of a supported work-piece to said grinding wheel, said power-driven means having a variable-speed driving connection with said work-supporting means for changing the surface speed of the work-piece, said driving connection including two pulleys and a driving belt, one of said pulleys having coacting relatively shiftable belt-engaging parts which change the effective pitch diameter of the pulley according to the position of one of said parts relative to the other, reversible motive means operable in one direction to effect relative feeding movement between said grinding wheel and said work-supporting means and operable in reverse direction to effect relative separating movement therebetween, means including a reversible motor for controlling the relative shift between said relatively shiftable members of said pulley and for controlling the relation of said belt to said two members and to

the other pulley to change the effective pitch diameter of the pulley and to maintain driving tension of the belt with change in pitch diameter, said reversible motor operating at a low rate in the direction to decrease the rate of drive of said work-supporting means and operating at a high rate in the direction to increase the rate of drive of said work-supporting means, and interdependent controls for said reversible motive means and said reversible motor for substantially synchronizing the low-speed drive in said direction of said reversible motor with said first-mentioned direction of drive of said reversible motive means and the relatively high-speed drive of said reversible motor with the drive in reverse direction of said reversible motive means.

12. A grinding machine having a longitudinally extending table and a transverse slide supporting a grinding wheel, said table having thereon means for rotatably supporting and driving a work-piece for action thereon by said grinding wheel, said means comprising a head-stock unit having a driving motor and driving connections that include a drive pulley driven by said motor and a driven pulley and a connecting belt therebetween, said drive pulley comprising two coaxial relatively shiftable belt-engaging parts with spring means coacting therewith to bias one toward the other to increase the effective pitch diameter thereof, means mounting said drive pulley for movement in a direction to increase the distance between it and said driven pulley and thereby cause the belt to oppose said spring means and lessen the pitch diameter thereof, thereby decreasing the rate of drive of said driven pulley, means operating upon said wheel slide to effect feeding movement of the grinding wheel toward a work-piece supported in said work-supporting and rotating means and to determine the depth of cut of the grinding wheel on the work-piece, and means for diminishing the rate of cutting action of the grinding wheel on the work-piece comprising means operable during the feeding movement of the grinding wheel slide to move said driving pulley mounting means in a direction to increase the distance between said two pulleys and thereby diminish the rate of drive of the work-piece.

13. A grinding machine as claimed in claim 12 in which there are provided stop means coacting with said pulley mounting means to limit the range of movement thereof and the range of change of speed of drive of the work-piece.

14. A grinding machine as claimed in claim 12 in which said means for mounting said drive pulley for movement in the opposite direction comprises said motor and a movable carrier therefor associated with said head-stock unit, said drive pulley being carried by the motor shaft and said means for moving said pulley mounting means operating upon said carrier.

15. A grinding machine as claimed in claim 14 in which said carrier is movably associated with said head-stock unit by a pivotal connection therebetween the axis of which is parallel to and displaced from the axis of said driving pulley.

16. A grinding machine having a longitudinally extending table and a transverse slide supporting a grinding wheel, said table having thereon means for rotatably supporting and driving a work-piece for action thereon by said grinding wheel, said means comprising a head-stock unit having a driving motor and driving connections that include a drive pulley driven by said motor and a driven pulley and a connecting belt therebetween, said drive pulley comprising two coaxial relatively shiftable belt-engaging parts with spring means coacting therewith to bias one toward the other to increase the effective pitch diameter thereof, means movably supporting said motor from said head-stock unit for reversible movement in directions to increase and decrease the distance between said two pulleys whereby, upon increase in said distance, said belt opposes said spring means and the pitch diameter of said drive pulley is decreased and, upon decrease in said distance, said spring means is effective to increase the pitch diameter of said drive pulley, means operating upon said wheel slide to feed the grinding wheel toward said work-supporting and rotating means to determine the depth of cut and operable to retract the wheel slide and grinding wheel, and means for diminishing the rate of cutting action of the grinding wheel comprising means operable at a relatively low rate and during feeding movement of the grinding wheel slide to slowly shift said motor in a direction to increase the distance between said two pulleys and thereby relatively slowly diminish the surface speed of the work.

17. A grinding machine having a longitudinally extending table and a transverse slide supporting a grinding wheel, said table having thereon means for rotatably supporting and driving a work-piece for action thereon by said grinding wheel, said means comprising a head-stock unit having a driving motor and driving connections that include a drive pulley driven by said motor and a driven pulley and a connecting belt therebetween, said drive pulley comprising two coaxial relatively shiftable belt-engaging parts with spring means coacting therewith to bias one toward the other to increase the effective pitch diameter thereof, means movably supporting said motor from said head-stock unit for reversible movement in directions to increase and decrease the distance between said two pulleys whereby, upon increase in said distance, said belt opposes said spring means and the pitch diameter of said drive pulley is decreased and, upon decrease in said distance, said spring means is effective to increase the pitch diameter of said drive pulley, means operating upon said wheel slide to feed the grinding wheel toward said work-supporting and rotating means to determine the depth of cut and operable to retract the wheel slide and grinding wheel, and means operable during feeding movement of said grinding wheel slide for relatively slowly shifting said motor in a direction to increase said distance between said pulleys to relatively slowly diminish the surface speed of the work and operable at a relatively high rate of speed to shift said motor in opposite direction during retracting movement of said wheel slide to restore the rate of drive to its initial relatively high value.

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