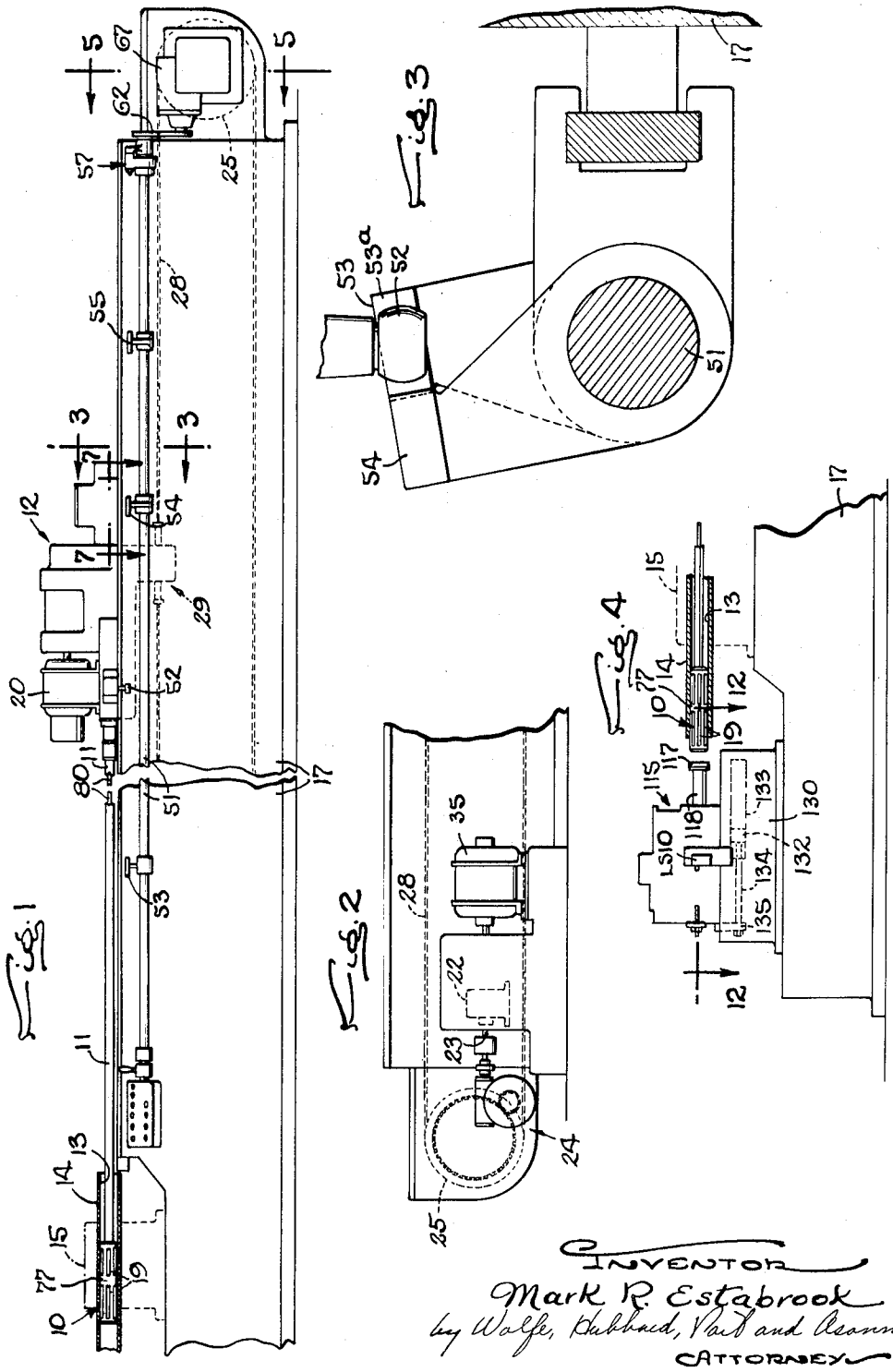
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AUTOMATIC HONING METHOD

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Fig. 5

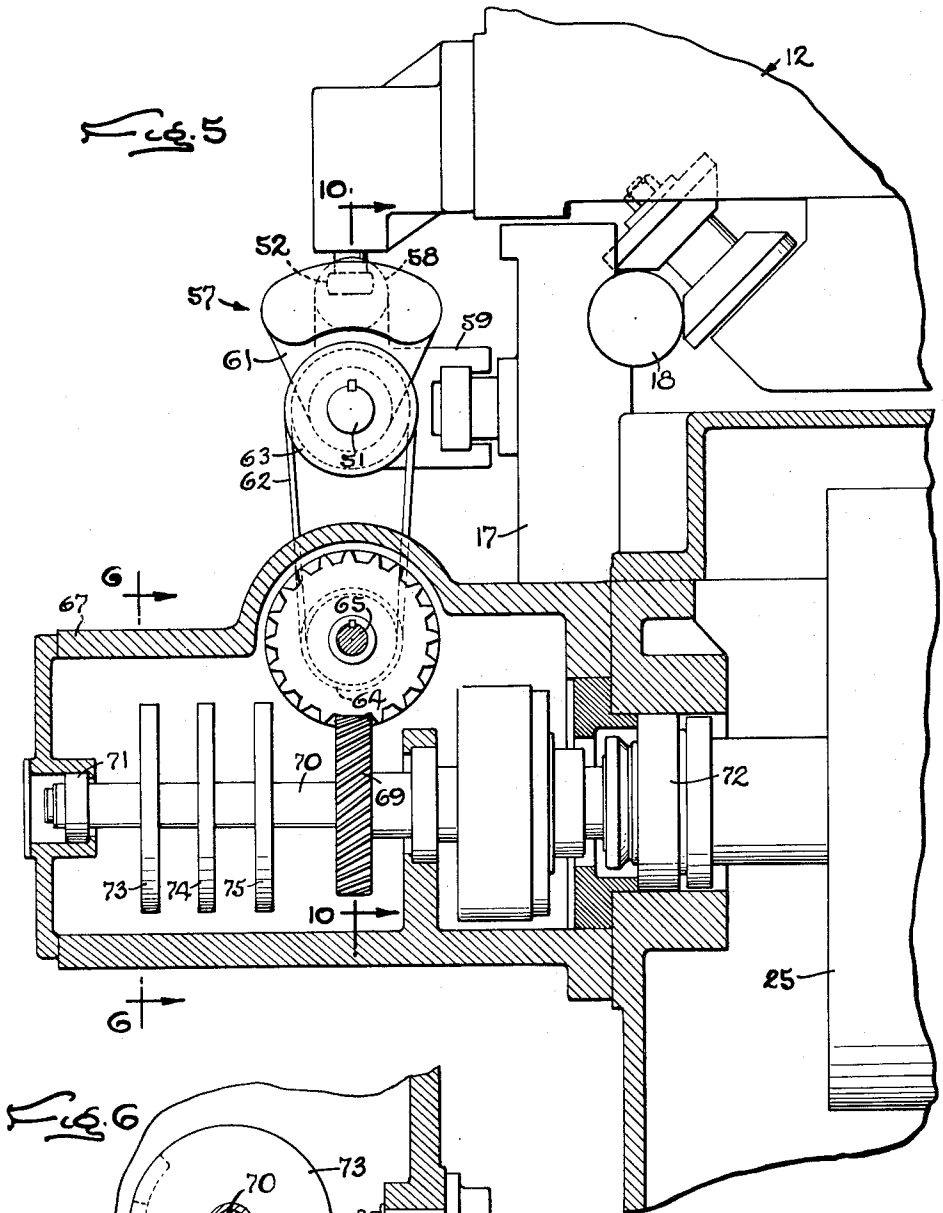
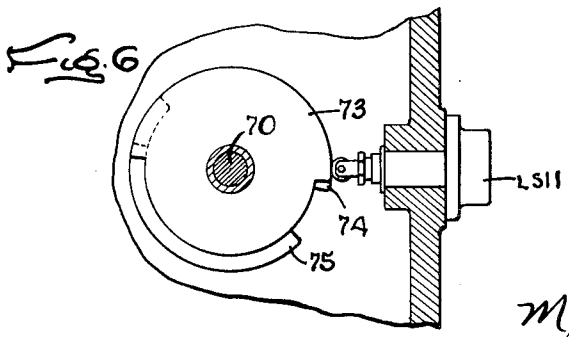


Fig. 6



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Fig. 7

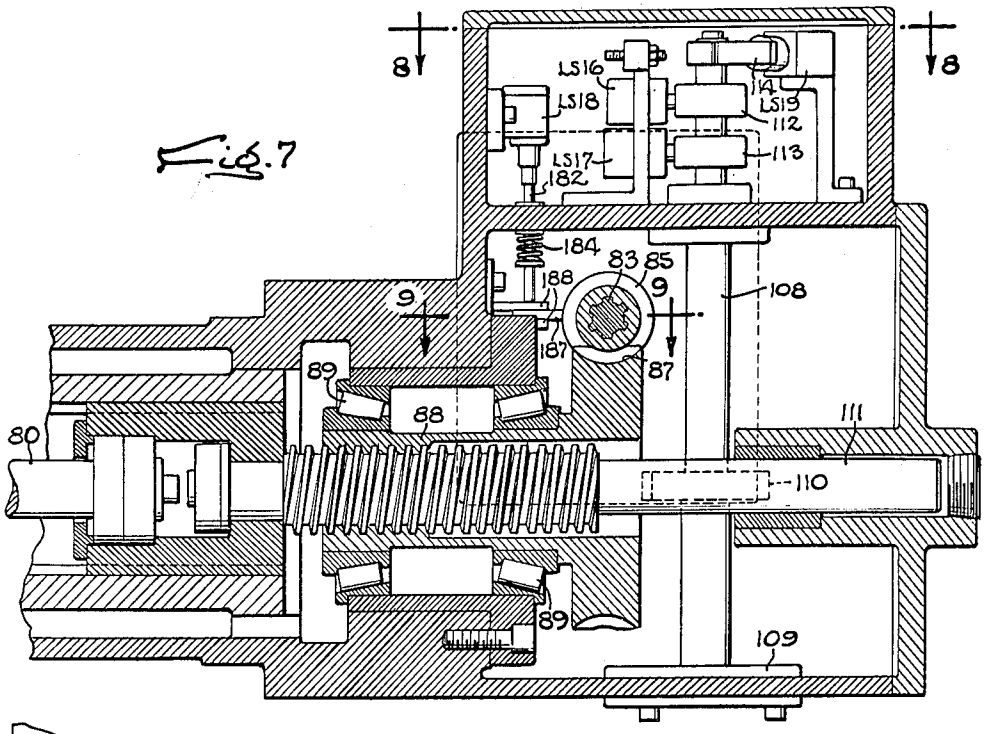


Fig. 8

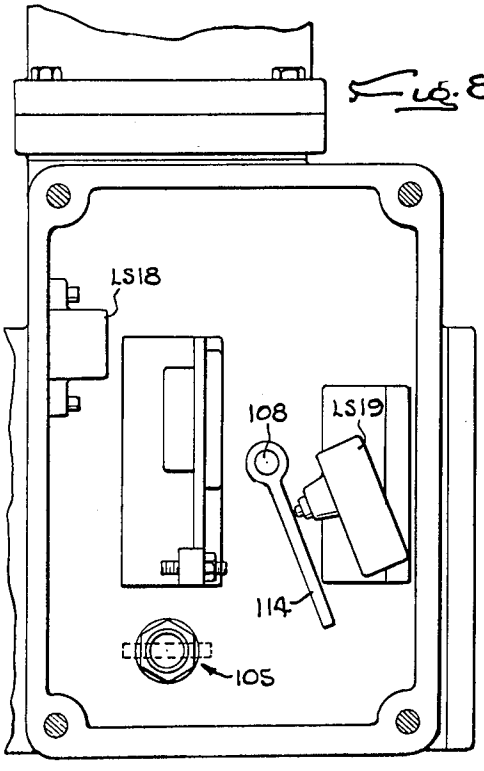
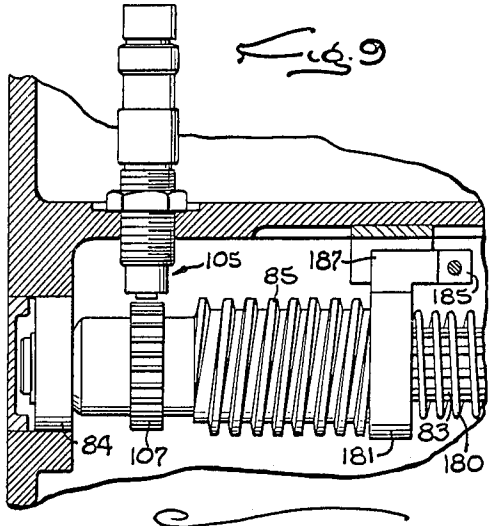


Fig. 9



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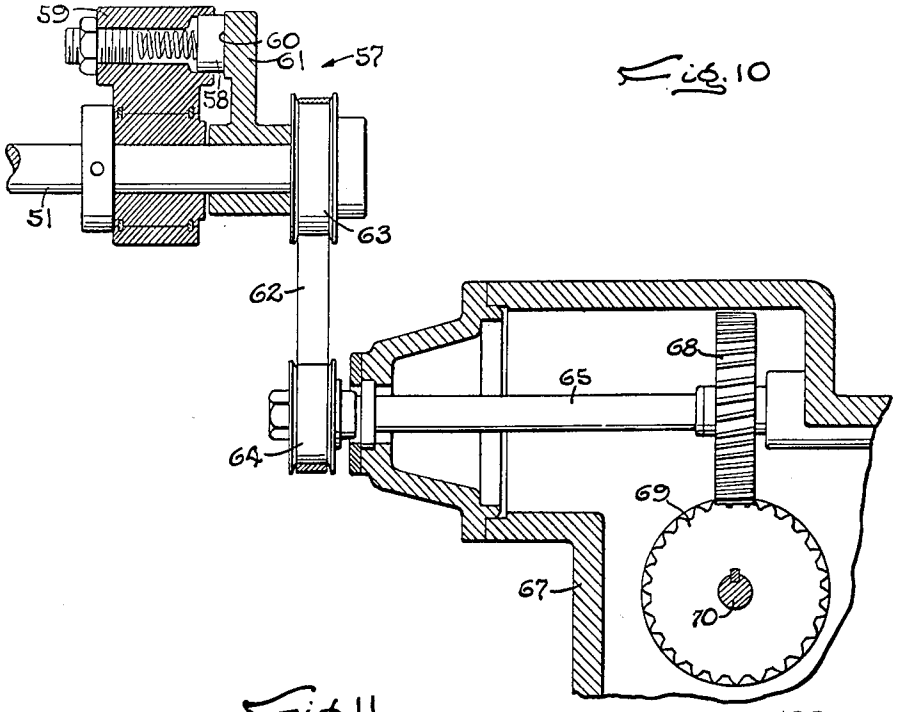


Fig. 10

Fig. 11

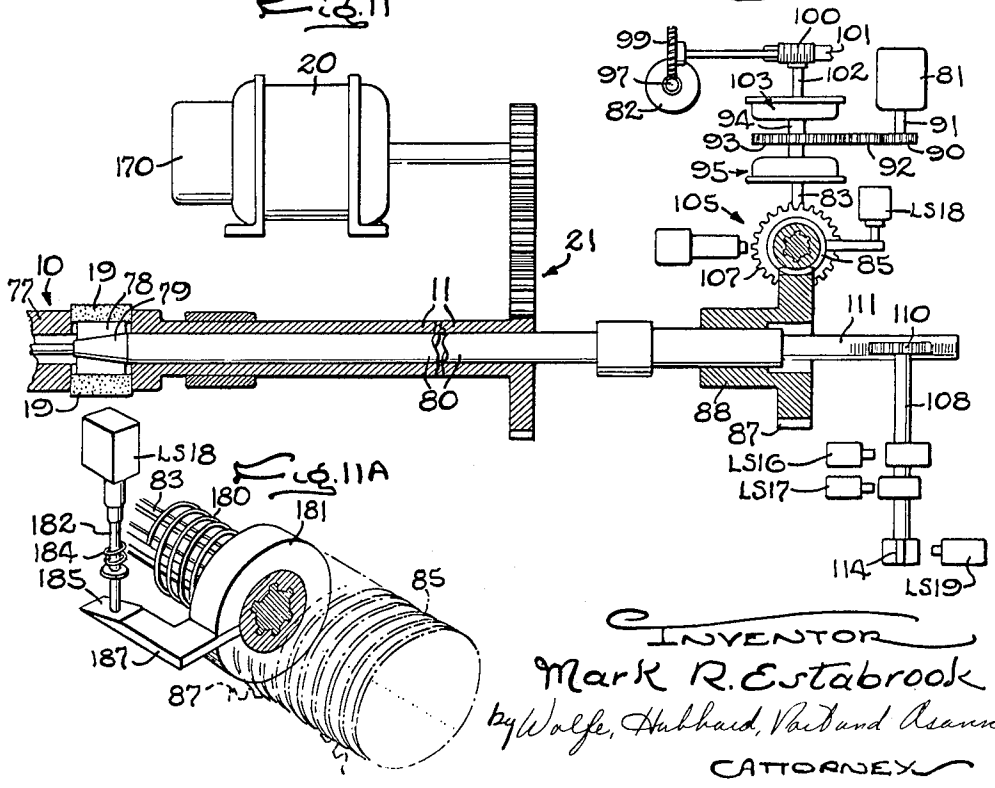


Fig. 11A

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Fig. 12

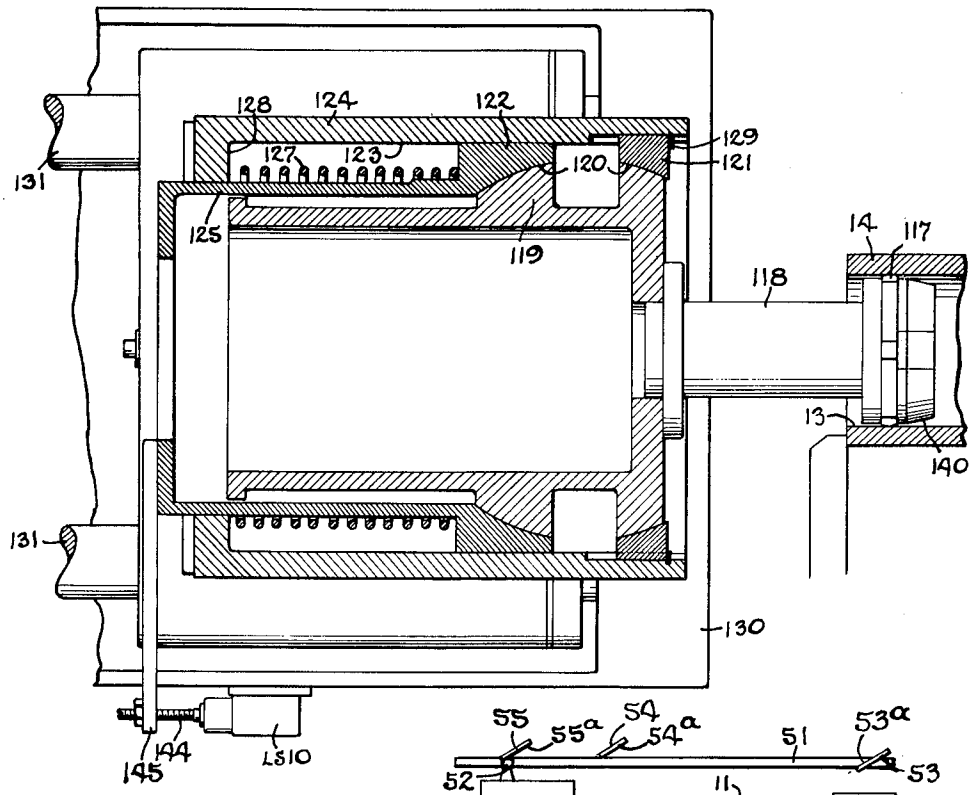
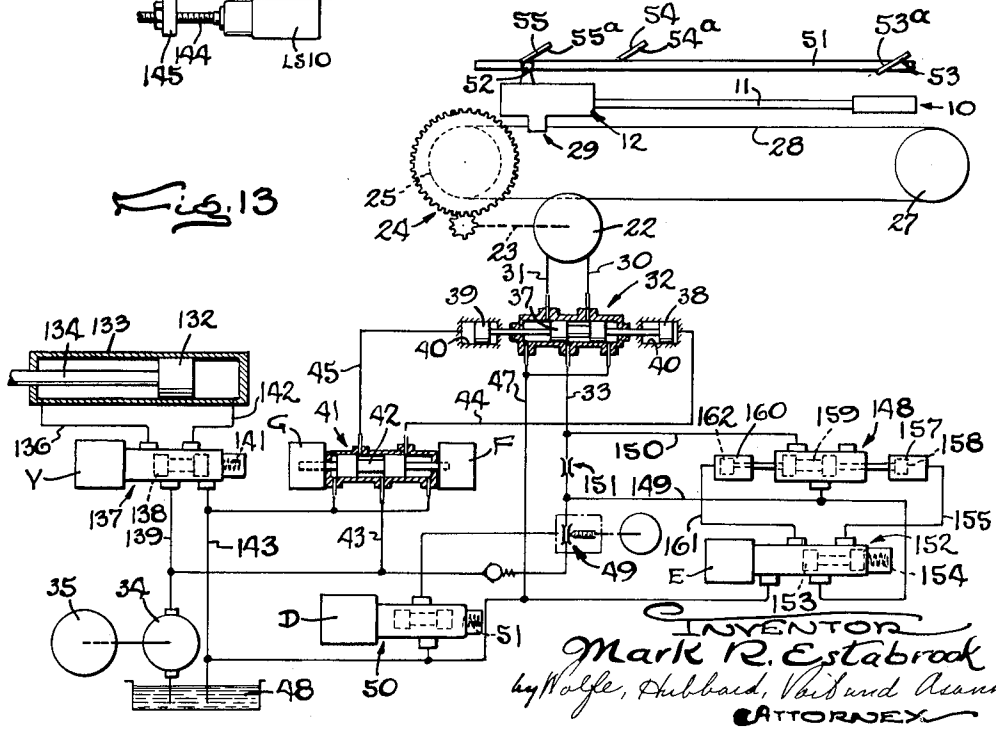


Fig. 13



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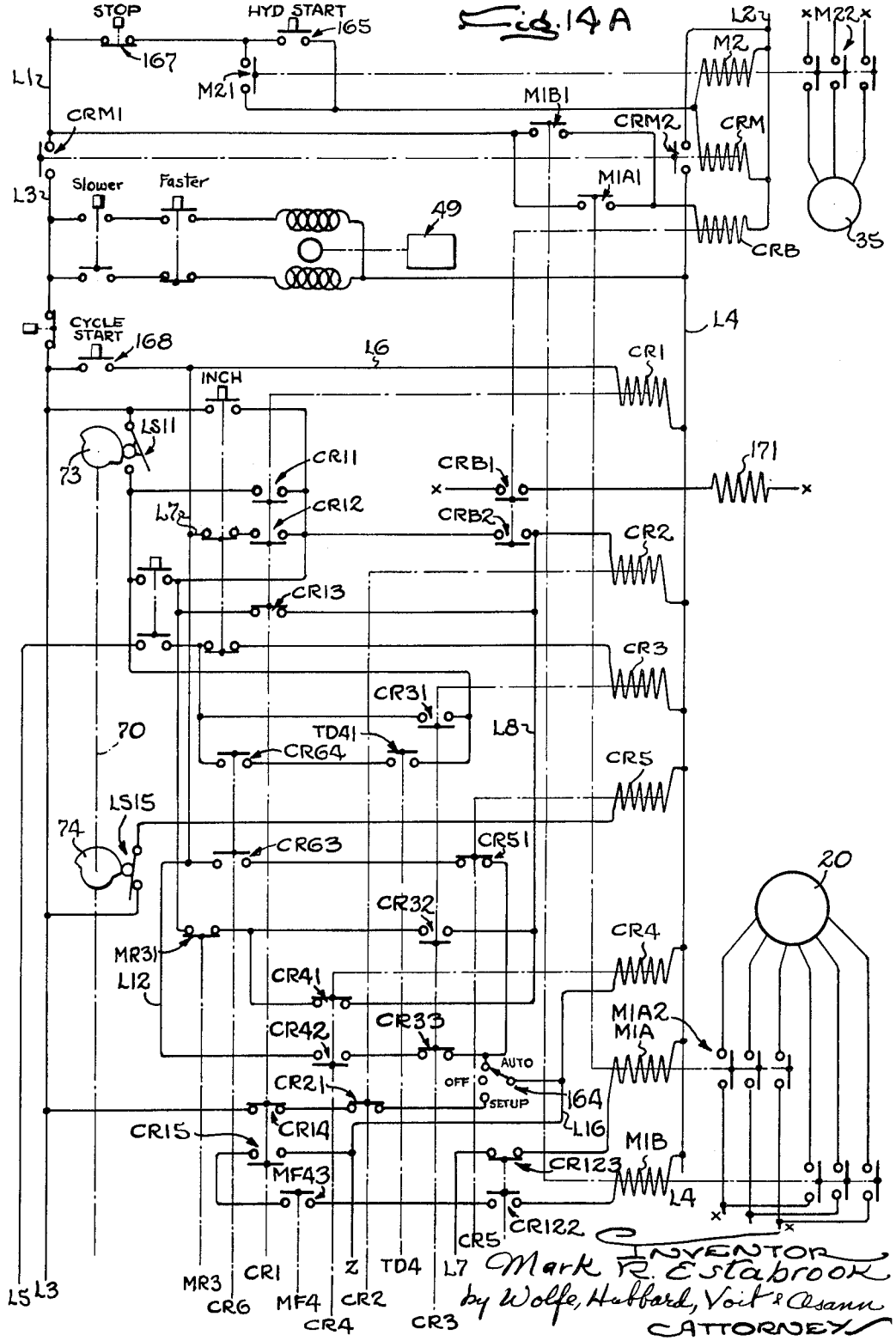


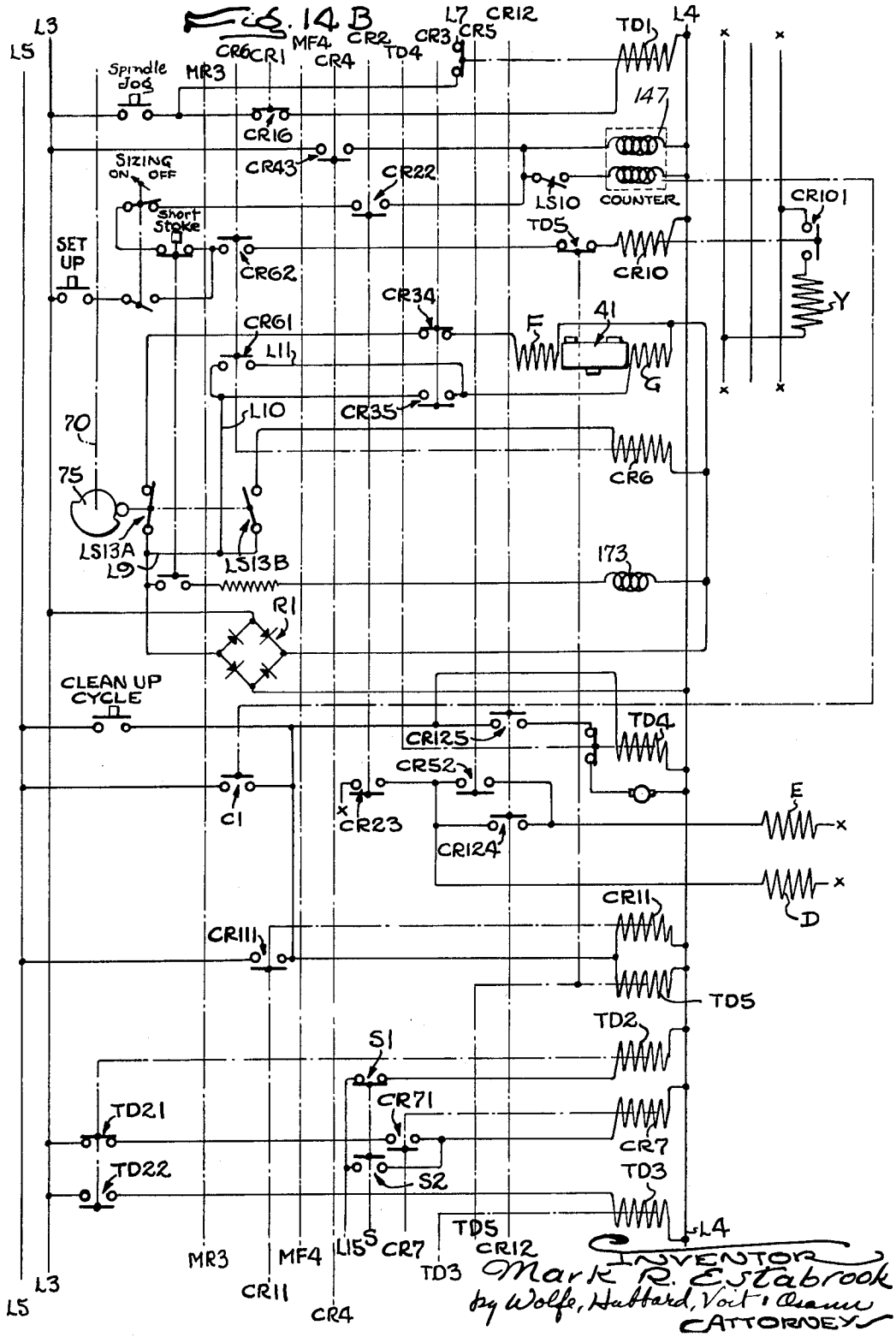
Fig. 14A

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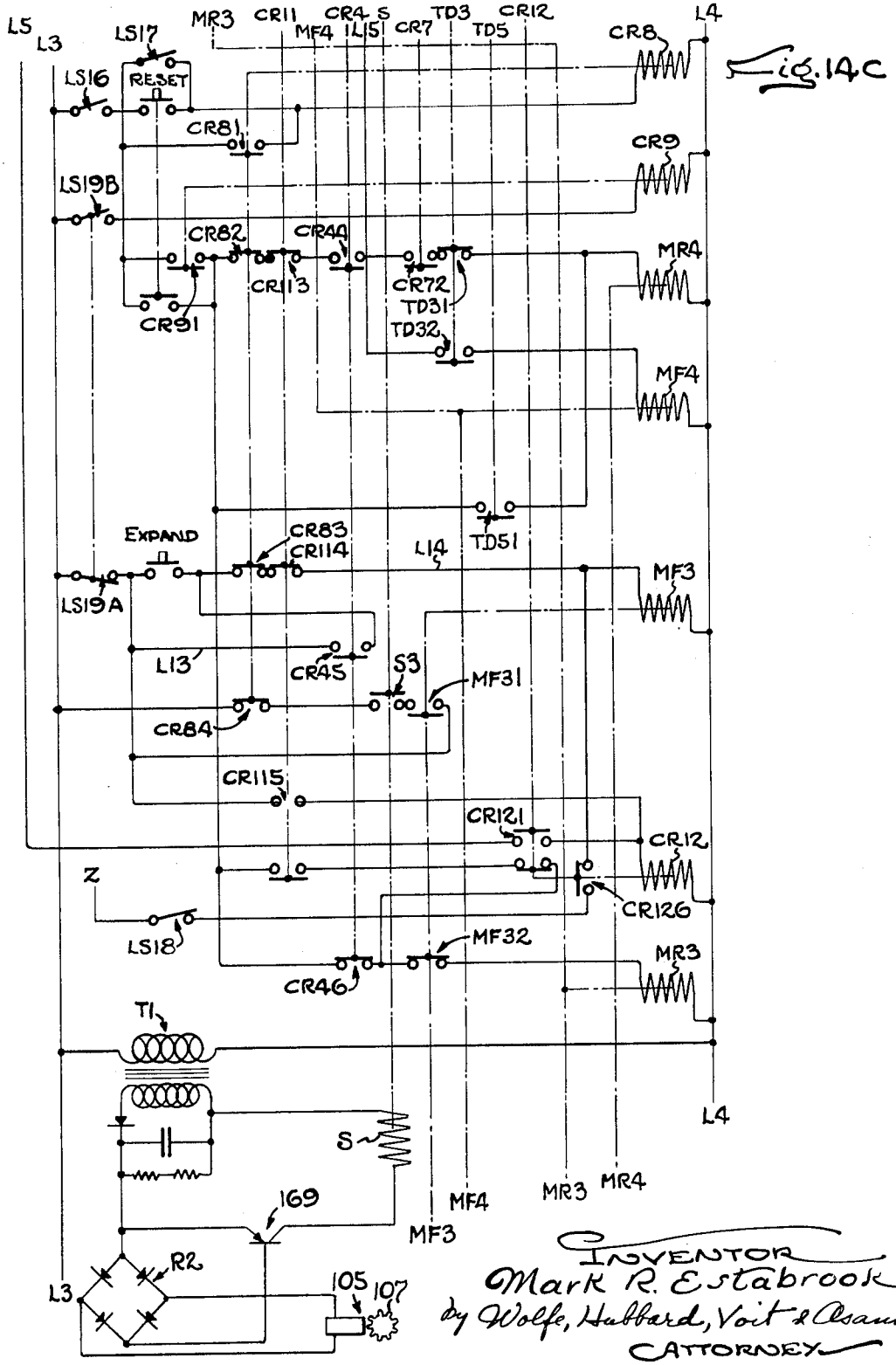


Fig. 14C

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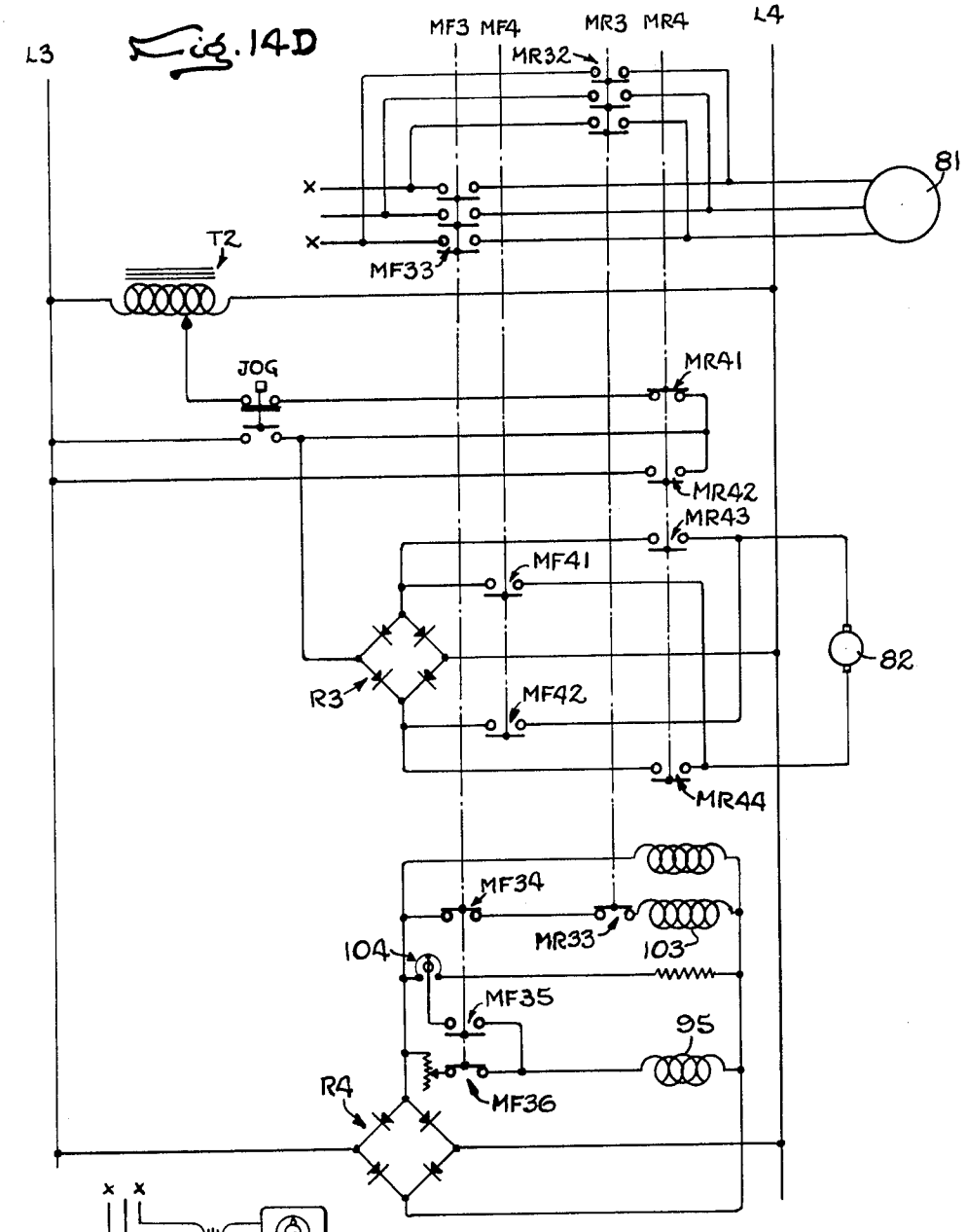


Fig. 14D

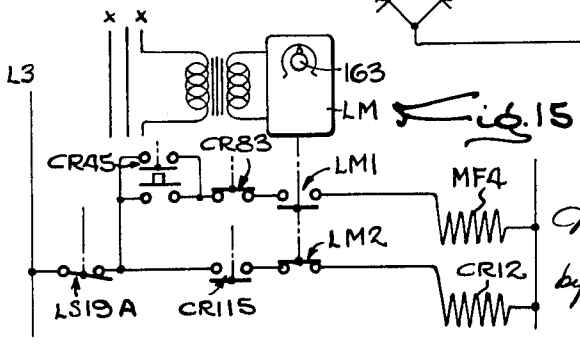


Fig. 15

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United States Patent Office

3,237,350

Patented Mar. 1, 1966

3,237,350

AUTOMATIC HONING METHOD

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Filed Mar. 4, 1965, Ser. No. 437,043
4 Claims. (Cl. 51—290)

This is a continuation-in-part of my copending application Serial No. 280,849, now abandoned.

This invention relates to the automatic honing of work bores by reciprocating a radially expansible and contractible honing tool back and forth within the bore while rotating the tool and slowly expanding the same within the bore to maintain relatively high honing pressure between the bore wall and the abrasive elements on the tool until the bore is enlarged to the desired size. The invention has more particular reference to honing operations including a supplemental or finishing cycle for polishing the bore wall after the latter has been rough honed to the desired size. Usually, such supplemental honing is performed under reduced pressure as compared to the pressure used during rough honing.

The primary object of the present invention is to improve the finish obtained by supplemental honing while reducing the finishing time required.

A more detailed object is to produce an improved finishing cycle by varying the rate of reciprocation as well as by the honing pressure used, and also by varying the rate of rotation.

Other objects and advantages of the present invention will become apparent from the following detailed description taken in connection with the accompanying drawings, in which

FIGURE 1 is a fragmentary side elevational view of a honing machine for practicing the present invention.

FIG. 2 is a fragmentary side elevational view taken from the opposite side of one end of the machine shown in FIG. 1.

FIG. 3 is an enlarged fragmentary sectional view taken along the line 3—3 of FIG. 1.

FIG. 4 is a fragmentary side elevation of the other end of the machine shown in FIG. 1 taken from the same side as FIG. 1 with the parts in different positions and with some parts broken away and shown in section.

FIG. 5 is an enlarged fragmentary section taken along the line 5—5 of FIG. 1.

FIG. 6 is a fragmentary sectional view taken along the line 6—6 of FIG. 5.

FIG. 7 is an enlarged fragmentary section taken along the line 7—7 of FIG. 1.

FIG. 8 is a fragmentary sectional view taken along the line 8—8 of FIG. 7.

FIG. 9 is an enlarged fragmentary sectional view taken along the line 9—9 of FIG. 7.

FIG. 10 is a fragmentary sectional view taken along the line 10—10 of FIG. 5.

FIG. 11 is a schematic illustration of the hone expanding and contracting mechanism.

FIG. 11A is an enlarged fragmentary perspective view schematically showing part of the expansion mechanism.

FIG. 12 is an enlarged fragmentary section taken along the line 12—12 of FIG. 4 with the parts in different positions.

FIG. 13 is a diagrammatic representation of the hydraulic control circuits of the machine.

FIG. 14 is a diagrammatic representation of the electrical control circuits of the machine and comprises four sheets, 14A through 14D which may be arranged end to end to form the full figure.

FIG. 15 is a fragmentary digrammatic representative of an alternate form of a portion of the control circuits.

THE HONING MACHINE

Shown in the drawings for purposes of illustration is a horizontal honing machine in which a radially expansible and contractible honing tool 10 is carried by the outer end of a hollow spindle 11 journaled in a tool head 12 and projecting horizontally from the head along the axis of the bore 13 of a workpiece 14 to be honed. The workpiece is clamped in a fixture 15 on the machine base 17 and the tool head is guided on the base for reciprocation along the guide rods 18 (FIG. 5) toward and away from the workpiece to reciprocate the tool back and forth within the bore.

During such reciprocation, the usual abrasive sticks or stones 19 on the hone are pressed against the bore wall 13 while the spindle 11 is rotated by an electric motor 20 mounted on the tool head 12 and connected to the spindle through suitable gearing 21 (FIG. 11). Reciprocation of the head along the guide rods 18 is effected by a reversible power actuator which herein comprises a rotary hydraulic motor 22 suitably coupled to the head to slide the latter back and forth as the direction of rotation of the motor is reversed. For this purpose, the shaft 23 of the motor is connected by gearing 24 (FIG. 13) to a drum 25 journaled on the rear portion of the machine base 17 and cooperating with an idler drum 27 (FIG. 13) spaced forwardly along the base to support a cable 28 trained around the two drums and connected to the tool head at 29 (FIGS. 1 and 13) in a well-known manner to slide the head back and forth as the drums oscillate.

Control of tool head reciprocation

To produce the reciprocation of the tool head 12, fluid under pressure is supplied alternately to opposite sides of the motor 22 through lines 30 and 31 (FIG. 13), the flow through these lines being controlled by a pilot actuated valve 32 receiving pressure fluid through a line 33 communicating with the outlet of a pump 34 driven by a motor 35 (FIGS. 13 and 14A). By shifting the spool 37 of the valve back and forth, the flow through the lines 30 and 31 and through the motor 22 is reversed.

Herein, the spool 37 is shifted back and forth by two single acting pistons 38 and 39 (FIG. 13) fast on opposite ends of the spool and fitted in cylinders 40. Pilot pressure is applied to one end or the other of the spool 37 under the control of a solenoid operated valve 41 including a spool 42 movable back and forth to establish communication between a branch line 43 of the supply line 33 and one of two lines 44 and 45 leading to the cylinders 40.

When a solenoid F is energized, the spool 42 is shifted to the right in FIG. 13 to pressurize the line 44 and thereby shift the piston 38 and the spool 37 to the left to supply fluid to the motor 22 through line 31 while fluid exhausts from the motor through the line 30, the valve 32, and a drain line 47 leading back to the sump 48. Thus, the motor is driven in a direction to advance the tool head 12 toward the workpiece 14. When a solenoid G is energized, the spool 42 is shifted to the left to admit pressure fluid into the line 45 and move the piston 39 and the spool 37 to the right. Accordingly, fluid flows into the motor 22 from the supply line 33 through the line 30 and out through the line 31 to the drain line 47 thereby rotating the motor in a direction to retract the tool head.

The rate of reciprocation of the tool head during rough honing is controlled by adjusting the size of a variable orifice 49 (FIG. 13) in the supply line 33 and thereby increasing or decreasing the rate of flow through the supply line and the motor. A by-pass valve 50 operated by a solenoid D is operable when open to return the pump output from the supply line to the sump 48. The valve is opened by a spring 51 when the solenoid is deen-

ergized and thereby provides an on-off control for the motor 22 by preventing operation of the motor unless the solenoid is energized.

To energize the appropriate solenoid F, G and reverse the direction of rotation of the motor 22 at the end of each forward and return stroke of the tool head 12, an elongated control rod 51 is disposed below the head and journaled on the machine base 17 for back and forth rocking about an axis paralleling the path of reciprocation of the head. Such rocking is produced by a dog 52 (FIGS. 1 and 13) movable with and depending from the tool head and engageable with followers 53, 54 and 55 spaced longitudinally along the rod and projecting upwardly therefrom into the path followed by the dog. The forward follower 53 is positioned to be engaged by the dog when the hone reaches the forward end of the work bore 13 and is formed with a face 53A (see FIGS. 3 and 13) inclined across the path of the dog in a direction to rock the rod clockwise (FIG. 3) as the dog engages the follower. The intermediate follower 54 is formed with an oppositely inclined face 54A and is angularly spaced from the forward follower (see FIG. 3) to be rocked into the return path of the dog when the latter engages the forward follower. As the tool head moves rearwardly, the dog engages the intermediate follower and rocks the rod counterclockwise, such engagement occurring when the hone reaches the rear end of the work bore.

The rear follower 55 is formed with a face 55A inclined in the same direction as the face of intermediate follower 54 but angularly spaced from the latter to lie in the path of the dog 52 after the latter engages the intermediate follower. The rear follower is fast on the control rod 51 adjacent the rear end of the latter and cooperates with the dog to rock the rod farther in a counterclockwise direction when the tool head is fully retracted. The angular relation of the forward and rear followers is such that engagement of the dog with the rear follower rocks the face of the forward follower back into the path of the dog.

Adjacent the rear end of the control rod 51 is a device 57 (see FIG. 10) for preventing free rotation of the rod and holding the rod releasably in different angular positions. Herein, this device comprises a plunger 58 slidably guided in a housing 59 fast on the machine base 17 and spring-pressed against a friction face 60 on a lug 61 fast on and projecting radially to one side of the rod. Thus, the plunger and the friction face exert a friction drag for resisting turning of the rod.

Back and forth rocking of the control rod 51 by the dog 52 is utilized to acutate the solenoids F and G of the reversing valve 41 at the appropriate times. For this purpose, an endless belt 62 is trained around a pulley 63 (FIGS. 5 and 10) fast on the rear end of the rod and around a second pulley 64 on a parallel shaft 65 journaled in and projecting from a housing 67 on the machine base. A helical gear 68 keyed to the shaft 65 meshes with a similar gear 69 keyed to a cam shaft 70 journaled in bearings 71 and 72 (FIG. 5) in the housing 67. Thus, the cam shaft is rocked back and forth in unison with the control rod.

Three cams 73, 74 and 75 (FIGS. 5 and 14) spaced longitudinally along the cam shaft 70 are formed with angularly spaced rises for operating switches LS11 and LS15 and companion switches LS13A and LS13B in response to rocking of the control rod 51. During automatic honing, back and forth rocking of the cam shaft 70 with the control rod oscillates the cam 75 back and forth to actuate the companion switches LS13A and LS13B, opening switch LS13A and closing switch LS13B at the end of each forward stroke, and reversing the condition of the switches at the end of each rearward stroke. For purposes to appear later, the angular spacing of the rises of the cams 73 and 74 from the rise of the cam 75 is correlated with the amount of rocking of the control rod 51 and the cam shaft 70 so that the switches LS11 and LS15 are operated only when the tool head 12 is fully retracted and at the end of the first forward stroke of the head thereafter.

Hone structure and expanding mechanism

The hone 10 is of a conventional type comprising two series of abrasive stones 19 angularly spaced around and frictionally held in a body 77 and normally engaging followers 78 of conical cams 79 (FIG. 11). The latter are fast on a rod 80 which extends rearwardly through and is slidable in the spindle 11. When the rod is moved forwardly relative to the spindle, the stones are cammed outwardly and, as the rod is shifted rearwardly, the outward force on the stones is reduced to permit the stones to shift inwardly and reduce the pressure on the bore wall.

While the expander rod 80 may be moved back and forth by various kinds of power actuators, the actuator (FIGS. 7 and 11) shown herein is of the type comprising two reversible electric motors 81 and 82 whose motions are converted into reciprocatory movement of the rod by the mechanism shown schematically in FIG. 11. This mechanism includes a drive shaft 83 (see FIGS. 7, 9 and 11) journaled in bearings 84 (FIG. 9) in the tool head and carrying a worm 85 meshing with teeth 87 formed on the periphery of a nut 88 internally threaded onto the rear end portion of the expander rod. The nut is journaled in thrust bearings 89 (FIG. 7) and is held by the bearings in an axially fixed position relative to the head. Thus, rotation of the drive shaft turns the nut to shift the rod relative to the head and the spindle 11.

In this instance, the motor 81 for producing rapid expansion of the hone 10 is an A.C. motor drivingly connected to the drive shaft 83 through a pinion 90 (FIG. 11) on the motor shaft 91 and an idler gear 92 meshing on one side with the pinion and on the other side with a gear fast on a shaft 94. The latter is journaled in the head and normally is coupled to the drive shaft by a magnetic clutch 95. The speed of the feed motor 82, which herein is a D.C. motor, is reduced through a worm 97 on the motor shaft turning a wheel 99 which, in turn, turns a worm 100 and a wheel 101 fast on a shaft 102. A second magnetic clutch 103, when energized, couples the shaft 102 to the shaft 94.

The gear ratios are such that when the rapid traverse motor 81 is operating in a direction to move the expander rod 80 forwardly to the left in FIGS. 7 and 11, the diameter of the hone increases at a comparatively rapid rate. For example, the expander rod may be shifted longitudinally at a rapid rate on the order of eight and one-half inches per minute. On the other hand, when the feed motor 82 is operating alone, the expander rod moves at a much slower rate, for example, a maximum of .028 of an inch per minute. The rate of slow expansion of the hone is selected to correspond approximately to the rate of wearing away of the abrasive plus the rate of stock removal in a particular work material. In order to permit selective variation of the rate of slow expansion, the feed motor is energized through a variable transformer T2 (FIG. 14D) which controls the input voltage and speed of the motor. It will be evident that reverse operation of the respective motors results in rapid and slow contraction of the hone.

To avoid wasted time, it is desirable to expand the hone 10 within the work bore at the rapid rate preparatory to a honing operation to bring the stones 19 quickly into position close to the bore wall 13, and then to expand the hone slowly into high pressure engagement with the wall as the hone begins to rotate and reciprocate. By avoiding full, high pressure engagement with the rough bore at the beginning of the honing operation, the possibility of excessive loading of the hone because of irregularities in the bore size is eliminated. In the past, control of the motors 81 and 82 for such rapid and slow expansion without full engagement at the beginning of honing

has required rather complex mechanism for stopping the stones short of the bore wall while adjusting the amount of expansion during service use of a set of stones to compensate for prior wear on the stones.

The motors **81** and **82** are controlled to produce the initial rapid expansion of the hone followed by gradual expansion into high pressure engagement. To these ends, the hone first is expanded into full engagement with the bore wall until a predetermined pressure between the stones and the wall is obtained, and means responsive to such engagement is provided to terminate operation of the rapid traverse motor and initiate reverse or contacting operation of the feed motor for a timed interval long enough to insure that the pressure is reduced to a sufficiently low level before starting continuous slow expansion of the hone along with rotation and reciprocation of the hone.

In this instance, the means responsive to full engagement of the stones **19** with the bore wall **13** includes the clutch **95** (FIGS. 11 and 14D) normally coupling the shaft **94** to the drive shaft **83**. Through a potentiometer **104** (FIG. 14D), the energization of the clutch and the torque the clutch is capable of transmitting are adjustable to obtain slipping of the clutch when the pressure between the stones and the bore wall reaches a selected value. Further, the turning of the shaft **83** during rapid expansion is utilized to condition the control circuits (FIG. 14) for operation of the feed motor. For these purposes turning of the shaft is sensed by a proximity generator **105** (FIGS. 9 and 14C) energized by the turning of a gear **107** fast on the shaft and operable when energized to generate an electrical signal. As will appear later, a sensitive relay S (FIG. 14) is energized in response to this signal, and starts the feed motor in a direction to contract the hone.

When the stones **19** engage the bore wall and the clutch **95** slips to stop the turning of the worm **85** and the shaft **83**, the sensitive relay is deenergized, stopping the rapid traverse motor **81** and energizing the feed clutch **103** to couple the shafts **94** and **102** together whereby the feed motor **82** begins to contract the hone. After a short interval of contraction determined by a timer TD2 energized in response to slipping of the clutch, the direction of operation of the feed motor is reversed to initiate slow hone expansion which continues throughout the rough honing operation.

Control switches LS**16**, LS**17**, LS19A and LS19B are operated as the expander rod **80** moves forwardly to condition the circuits for energization of the various relays at the appropriate times. For this purpose, the switches are arranged along an upright shaft **108** (FIGS. 7, 8 and 11) disposed on one side of the expander rod and journaled in bearings **109** (FIG. 7) in the head. A pinion **110** fast on the shaft meshes with the teeth of a rack **111** formed on the expander rod whereby the shaft is rotated as the rod moves and turns the pinion. Operator arms **112**, **113** and **114** mounted on the pinion shaft for rotation therewith operate the switches LS**16**, LS**17**, LS19A and LS19B at different times during the expansion of the hone to control the circuits of the feed and rapid traverse motors as the hone is expanded.

In this instance, switch LS**16** is closed by the arm **112** as the rod **80** starts to move forwardly, and companion switches LS19A and LS19B are operated by the arm **114** after a small amount of rod movement. Switch LS**17** is closed by the arm **113** only after the hone **10** has been expanded fully and thereby provides a safety control preventing further operation of the hone. For a purpose to appear later, the arm **114** is mounted to slip on the shaft as the latter continues to rotate after closure of switch LS19B.

The construction and manner of operation of the proximity generator **105** and sensitive relay S are well known to those skilled in the art. For example, the generator may be of the type sold by Electro Products, Inc., Chicago, Illinois, as Model No. 3040, and the relay may be of the type sold by Cutler Hammer under Bulletin 13535H2.

It will be seen that the stones **19** are shifted rapidly into engagement with the bore wall **13** before rotation and reciprocation are started and are protected against excessive initial pressure by the slipping of the clutch **95**. Moreover, such slipping is sensed and utilized to terminate rapid expansion and initiate slow contraction for a timed interval sufficient to reduce the pressure between the stones and the work bore to the desired amount for starting of the homing. Thus, excessive working pressure is avoided in a relatively simple manner and without undue delay.

Rough honing cycle

Through the circuitry to be described, the energization of the hydraulic motor **22**, the spindle motor **20**, and the hone expanding and contracting motors **81** and **82** is controlled to produce a cycle of machine operation including the steps of advancing the collapsed hone **10** into the bore of a workpiece **14** clamped in the fixture **15**, rapidly expanding the hone into engagement with the bore wall **13**, slowly contracting the hone to reduce the starting pressure, and then slowly expanding the hone while reciprocating the same at a rapid rate throughout the length of the bore and rotating the hone at a relatively slow, rough honing speed. In this manner, relatively high pressure is maintained between the abrasive stones **19** and the bore wall until the bore is enlarged to the desired size.

In the present instance, rough honing is terminated by a sizing device **115** (FIGS. 4 and 12) which gages the work bore **13** during the course of the honing operation and produces a suitable signal such as the closure of a switch LS**10** when the bore attains the desired size. Herein, the sizing device includes a plug **117** fast on one end of a rod **118** mounted on the machine base **17** adjacent the forward end of the workpiece for reciprocation along the axis of the bore toward and away from the workpiece, the plug having an external diameter equal to the desired bore diameter.

To support the plug **117** on the base, a ball **119** (FIG. 12) of spherical contour is fast on the end of the rod **118** opposite the plug and is fitted closely in mating surfaces **120** formed on two rings **121** and **122** telescoped into a bore **123** in a housing **124** slidably guided on the base. The ring **122** is formed integrally with a sleeve **125** smaller than the bore **123** and projecting outwardly through the left end thereof. A coiled spring **127** telescoped over the sleeve and compressed between the ring **122** and an internal annular shoulder **128** encircling the left end (FIG. 12) of the bore urges the ring **122** and the ball toward the right and into the position shown in FIG. 12 where the ball presses the ring **121** against a snap ring **129** seated in a groove encircling the right end of the bore. In this position, the rod projects outwardly toward the adjacent end of the workpiece.

The housing **124** is guided for sliding back and forth on a pedestal **130** along horizontal guide rods **131** to carry the plug toward and away from the workpiece. Such sliding is effected in timed relation with the hone reciprocation to advance the plug toward the work during each return stroke of the hone. This is accomplished by a suitable power actuator herein comprising a piston **132** (FIGS. 4 and 13) fitted in a cylinder **133** formed in the pedestal **130** with its axis paralleling the work axis, the piston rod **134** being secured to a lug **135** fast on the housing.

Pressure fluid from the pump **34** is delivered to the rod end of the cylinder **133** during each return stroke of the hone **10** through a valve **137** (FIG. 13) operated by a solenoid Y which is energized along with the return solenoid G of the valve **41**. When the solenoid Y is energized, the spool **138** of the valve establishes communica-

tion between a line **136** leading to the rod end of the cylinder **133** and a fluid supply line **139** communicating with the pump. Accordingly, the housing **124** and the plug **117** are advanced toward the workpiece.

As the housing slides toward the work, the leading end of the plug, which preferably is tapered at **140** (FIG. 12), enters thte bore **13**. The rings **121** and **122** cooperate to define a socket for the ball **119** permitting the plug to swivel and aline itself precisely with the bore. If the bore is undersize, the plug enters only partially and stops as the housing continues toward the work, the ball, the ring **122**, and the sleeve **125** yielding relative to the housing as permitted by the spring **127**. Then, as the head begins its forward stroke, the solenoid Y is deenergized with the return solenoid G and the spool **138** is returned to the position shown in FIG. 13 by a spring **141** so that fluid flows from the line **139** to a line **142** and thence to the head end of the cylinder **133** while the fluid in the rod end of the cylinder is exhausted through the line **136** and a drain line **143**. Thus, the plug is withdrawn.

When the work bore finally attains full size, the plug slides completely into the bore **13**. The signal switch **LS10** is mounted on the pedestal **130** alongside the housing **124** and is operated by an adjustable dog **144** (FIG. 4) carried by a bracket **145** fast on and projecting laterally from the left end of the sleeve **125**. The dog engages the switch only when the plug is fully inserted, and the signal produced by closure of the switch is utilized to control the machine circuits and terminate rough honing. Herein, a stroke counter **147** (FIG. 14) is provided to count a number of additional strokes after the plug first enters the bore, the number of additional strokes being preselected to compensate for wear on the sizing plug in service use.

THE FINISHING CYCLE

Heretofore, rough honed work bores have been finish honed in several ways, for example, by terminating expansion of the hone and allowing the pressure on the bore wall to "play out," by collapsing the hone and then re-expanding it into relatively low pressure engagement with the bore wall for a supplementary honing cycle, and by substituting a finer grit abrasive for the relatively coarse abrasive used in rough honing.

I have discovered that the performance of abrasive stones **19** of a given coarseness rating varies with the speeds of rotation and reciprocation of the hone as well as with the pressure with which the stones are pressed against the bore wall. Specifically, with a relatively coarse abrasive such as C180L grit suitable for rough honing, a reduction in the usual rough honing pressure and an accompanying reduction in the rate of reciprocation make is possible to polish a bore to a finer finish and in a shorter period of time than previously has been possible. It is believed that both the reduction in honing pressure and the reduction in the rate of reciprocation reduce the shearing forces on the exposed grit and the tendency to pull the grit from the stones. Accordingly, instead of shearing off or pulling out of the stones to expose new grit, the exposed grit is worn away and the sharp edges thereof are dulled or rounded to polish the wall rather than scratch it. I also have discovered that, contrary to what might be expected, a moderate increase in the speed of rotation of the hone can result in improved polishing and further reduce the time required for polishing.

In putting these discoveries into practice, I have provided a method of honing by controlling the actuators for reciprocating, rotating, expanding and collapsing the hone **10** to initiate and carry out an improved finish honing or polishing cycle, with the same abrasive used to rough hone the work bore **13** and automatically in response to attainment of the desired finished bore size, by reducing both the honing pressure on the bore wall and the rate of reciprocation of the hone. To obtain a further reduction in the amount of finishing time required and improve the finish obtained, the speed of rotation of the spindle **11** may be increased.

In this instance, the electric motor **20** for rotating the spindle is of the type having both high-speed and low-speed windings so as to be capable of rotating the hone **10** at different speeds during the roughing cycle and the finishing cycle. Preferably, the higher speed of the motor is adjustable to obtain a finishing speed on the order of ten to fifteen percent faster than the lower speed. For example, the lower roughing speed may be 1800 r.p.m. while the higher finishing speed is approximately 2000 r.p.m.

For different rates of reciprocation, control means is provided for controlling the energization of the hydraulic motor **22** to produce both rapid and slow reciprocation of the head **12**. Herein, this control means includes a valve **148** (FIG. 13) which opens and closes a passage through lines **149** and **150** by-passing a second restrictive orifice **151** in the fluid supply line **33**. During normal, rapid reciprocation of the head, the valve **148** is open and fluid from the pump **34** flows to the motor **22** through the variable orifice **49** which determines the rapid rate of fluid flow, through the valve and the by-pass lines, and then through supply line **33** and the reversing valve **32**. When the valve **148** is closed, however, the fluid must pass through the second orifice **151** which reduces the rate of flow into the supply line and thereby reduces the speed of rotation of the motor **22**.

Opening and closing of the valve **148** is controlled by a valve **152** operated by a solenoid E. When the solenoid is deenergized, the spool **153** of the valve is positioned by a spring **154** as shown in FIG. 13 to establish communication between a branch line **155** and a cylinder **157** fitted with a piston **158** fast on the spool **159** of the valve **148**. The piston and the spool are shifted to the left (FIG. 13) to open the valve for normal, rapid reciprocation of the head. When the solenoid E is energized, however, the spool **153** is shifted to the left to establish communication between the pump and a cylinder **160** through a branch line **161**. The piston **162** in this cylinder shifts the spool **159** to the right to close the valve **148** and block the by-pass lines. Thus, fluid can flow to the motor only through the second orifice **151** at the reduced rate. The rate of rapid reciprocation is on the order of 80 to 85 feet per minute while the slow rate of reciprocation is on the order of 20 to 25 feet per minute.

The reduction in honing pressure may be achieved in various ways, for example, by first contracting the hone to shift the stones **19** away from the bore wall and then reexpanding the hone into engagement with the bore wall with a selected reduced pressure. To terminate rapid expansion when the selected reduced honing pressure is obtained, the worm **85** is splined on the drive shaft **83** and is urged toward and held against a stop adjacent the bearing **84** by a spring **180** coiled around the drive shaft and acting between an adjustable collar (not shown) thereon and a sleeve **181** journaled on one end of the worm. The stress of the spring may be adjusted by adjusting the collar to vary the torque or expanding force at which the worm and the sleeve yield along the drive shaft after engagement of the stones and the bore wall.

Yielding of the worm **85** is sensed by a control switch **LS18** (see FIGS. 7, 9, 11A and 14C) whose contacts are housed within a casing supported on a wall of the head **12** (see FIG. 7) for engagement of the switch actuator with a plunger **182** slidable vertically in a partition **183** and urged by a spring **184** downwardly and against a cam surface **185** on a horizontal finger **187** carried by and movable with the sleeve **181**. Guides **188** (FIG. 7) above and below the finger prevent turning of the latter and the sleeve. When the worm is in its normal axial position against the stop collar, the plunger **182** engages a low point on the cam, thus allowing the switch **LS18** to re-

main closed. In the initial yielding of the sleeve following engagement of the stones and the bore wall, the finger is shifted to the left (FIG. 11A) to lift the plunger and open the switch which deenergizes the motor **81** with the stones **19** pressed against the bore wall with a pressure determined by the stress of the spring **180**. For additional details of such a control device, reference is made to Seborg et al. Patent No. 2,780,893.

An alternative device for effecting the honing pressure reduction, shown in FIG. 15, senses the contraction of the hone and terminates such contraction when the selected reduced pressure is obtained. In this instance, the pressure between the stones **19** and the bore wall **13** is sensed by a load meter LM (FIG. 15) which measures the current drawn by the spindle motor **20** and stops the feed motor when the current falls to a preselected value. Such load meters are well-known in construction and operation and for this reason the meter LM is shown only diagrammatically herein. Generally, the meter chosen for purposes of illustration includes a relay (not shown) which is energized when the current drawn by the spindle motor passes the level selected by the adjustment of a knob **163**, the relay then closing switches LM1 and LM2 which prepare the control circuits for the eventual finishing cycle. Then, when the current falls back to the selected value as the feed motor contracts the hone, the relay is deenergized and its switches open to deenergize the feed motor with the stones pressed against the bore wall with the desired reduced pressure. One suitable load meter relay for this purpose is that sold by Assembly Products, Inc., of Chesterland, Ohio, as Part No. 461-CMR.

THE CONTROL CIRCUITS AND AUTOMATIC OPERATION

Typical circuitry for controlling the honing operation in the practice of the novel method is shown in FIG. 14. When all the control circuits are deenergized, the various relays will be deenergized and the switches thereof positioned as shown in FIG. 14. With the tool head **12** fully retracted, the hone **10** collapsed, the spindle drive motor **20** stopped, a workpiece **14** to be honed clamped in the work fixture **15**, and a switch **164** set for automatic operation as shown in FIG. 14A, the machine is started by manually closing a start switch **165** which completes a circuit through a normally closed stop switch **167** and two relays M2 and CRM across two electric power lines L1 and L2 connected to a suitable power source (not shown). Relay M2 closes its switches M22 for energizing the hydraulic pump motor **35** and also closes a switch M21 to complete a holding circuit. Relay CRM closes its switches CRM1 and CRM2 to connect the power lines to lines L3 and L4 thereby completing circuits through rectifiers R1 (FIG. 14B), and R3 and R4 (FIG. 14D), and through a transformer T1 (FIG. 14C) for the sensitive relay S, and the variable transformer T2 (FIG. 14D) controlling the forward speed of the fed motor **82**. Through the rectifier R4, the slip clutch **95** and the feed clutch **103** are energized.

Advancing the hone into the workpiece

With the tool head **12** fully retracted, the dog **52** thereon is in engagement with the rear follower **55** on the control rod **51** thereby positioning the cams **73**, **74** and **75** and holding the switches LS11, LS13A, LS13B and LS15 in the positions shown in FIG. 14B, switches LS11 and LS13B being open and switches LS13A and LS15 being closed. Switch LS13A completes a circuit from the rectifier R1 through a switch CR34 and the forward solenoid F of the valve **41** thereby conditioning the latter to produce a forward stroke of the tool head when reciprocate solenoid D is energized to close the by-pass valve **50** (FIG. 13). When switch LS15 is closed, a relay CR5 (FIG. 14A) is energized and closes its switch CR52 in the circuit of the slow reciprocate solenoid E which remains deenergized until the circuit is completed by a closure of a presently open switch CR23.

To start the tool head toward the workpiece, a cycle start switch **168** is closed manually to energize a relay CR1 through line L6 and a second relay CR2 through line L7, presently closed switches CR12, MR31 and CR41, and line L8. Relay CR2 closes its switch CR23 to energize the slow reciprocate solenoid E through switch CR52, and also energizes reciprocate solenoid D to close the by-pass valve **50**. Accordingly, fluid flows to the hydraulic motor **22** at the slow rate determined by both the orifices **49** and **151** and flows through the motor in a direction to advance the tool head slowly toward the workpiece.

The start switch **168** is held closed as the hone enters the bore and slides along the latter toward the extreme forward position shown in FIG. 4. As the hone enters the work bore, the dog **52** passes the intermediate follower **54** which is positioned as shown in FIG. 3 out of the path of the dog. When the hone reaches the extreme forward position, the dog engages the forward follower **53** and rocks the control rod clockwise (FIG. 3) to turn the cam shaft **70** counterclockwise as viewed in FIGS. 6 and 14 far enough to open the switches LS13A and LS15 and close switches LS11 and LS13B. The intermediate follower rocks back into the return path of the dog to be engaged thereby during the next rearward stroke of the tool head.

Closure of switch LS11 completes a holding circuit for relay CR1 through now closed switches CR11, CR12, and lines L7 and L6, and closure of switch LS13B completes a circuit to energize relay CR6 (FIG. 14B) which closes its switch CR61 and thereby completes a circuit from the rectifier R1 through lines L9, L10 and L11 to the return solenoid G of the valve **41** to condition the latter for reverse rotation of the hydraulic motor **22**. Opening of switch LS13A simultaneously deenergizes the forward solenoid F.

At the same time, closure of a switch CR63 (FIG. 14A) by relay CR6 completes a circuit to a relay CR4 through line L7, switch CR51, and the automatic cycle switch **164**. Relay CR4 opens its switch CR41 thereby deenergizing relay CR2 which opens its switch CR23 to deenergize the reciprocate solenoid D and stop the tool head with the hone **10** positioned as shown in FIG. 4. Closure of a switch CR43 conditions the stroke counter **147** (FIG. 14B) for later operation.

Expanding the hone

To initiate rapid expansion of the hone **10**, a switch CR45 is closed by relay CR4 to energize a relay MF3 through switch LS19A and lines L13 and L14 as the tool head **12** stops. A switch CR42 closes to hold relay CR4 through lines L12 and L7, and relay MF3 closes its switch MF31 to complete a holding circuit and closes its switches MF33 (FIG. 14D) to energize the rapid traverse motor **81** in a direction to expand the hone rapidly into engagement with the bore wall. Opening of a switch MF34 as the motor is energized simultaneously deenergizes the feed clutch **103** to uncouple the feed motor **82** from the shaft **94**.

As the shaft **83** and gear **107** begin to rotate, the sensitive relay S is energized by the transformer T1 in response to the signal generated by the magnetic pickup **105** and applied to a transistor **169** which completes a circuit to the relay S. The latter opens a switch S1 while closing switches S2 and S3. As the expander rod **80** is shifted forwardly and the rack **111** rotates the pinion **110** and the shaft **108**, switch LS16 (FIGS. 11 and 14C) closes and, after a short delay, switch LS19A is opened as its companion switch LS19B is closed to energize a relay CR9 and close its switch CR91. The latter completes a circuit to relay CR7 through now closed switches LS16, CR82, CR11–3, CR44 and line L15, and relay CR7 closes its switches CR71 and CR72.

Switch CR71 completes a holding circuit and switch CR72 energizes a relay MR4 through switch LS16, there-

by starting the feed motor 82 reversely upon closing of switches MR43 and MR44 (FIG. 14D). Simultaneous opening of switch MR41 and closing of switch MR42 disconnects the rectifier R3 from the variable transformer T2 and connects the rectifier across lines L3 and L4 whereby the speed of the fed motor is determined by the voltage input from line L3 rather than from the transformer T2. Since the feed clutch 103 is deenergized, the feed motor runs idly as rapid hone expansion continues.

When the abrasive stones 19 engage the bore wall 13, however, the worm 85 shifts along the shaft 83 to open switch LS18, followed closely by slipping of the clutch 95 which stops turning of the gear 107 and thereby deenergizes relay S. Accordingly, switch S1 recloses to complete a circuit to a timer TD2 through line L15 and switches CR44, CR11–3, CR82, CR91 and LS16. At the same time, switch S3 opens to deenergize relay MF3 and stop the rapid traverse motor 81 by opening switches MF33 while closing switch MF34 to energize the feed clutch 103 and couple the feed motor 82 to the shaft 94. Thus, the feed motor immediately begins to contract the hone and reduce the initial high pressure engagement between the stones and the bore wall. Switch LS18 closes idly as contraction begins and remains closed until the finishing portion of the cycle is started. The circuit to relay MF3 through switch LS18 remains open until switch CR12–6 closes at the end of rough honing.

After the preselected timer interval, the timer TD2 times out and opens its switch TD21 to deenergize relay CR7 which opens switch CR72 to deenergize relay MR4 and stop the reverse operation of the feed motor. The timer TD2 also closes switch TD22 to energize another timer TD3. The latter times out after a short interval such as one-half second and closes its switch TD32 to energize a relay MF4 which closes its switches MF41 and MF42 to complete a circuit from the rectifier R3 to the feed motor 82 to run the latter forwardly and initiate slow expansion of the hone, the input to the rectifier being through the transformer T2 and now closed switch MR41 so that the feed motor runs at a speed determined by the setting of the variable transformer.

Reciprocating and rotating the hone

In addition to starting the hone expansion, relay MF4 closes its switch MF43 (FIG. 14A) to energize a relay M1A through a normally closed switch CR123, switch CR15, line L16, automatic cycle switch 164, and lines L12 and L7. Relay M1A closes a switch M1A1 to energize a relay CRB which releases a spindle brake 170 (FIGS. 1 and 11) by energizing the brake solenoid 171 (FIG. 14A) through a switch CRB1, and renergizes relay CR2 by closing a switch CRB2. Relay CR2 closes the switch CR23 in the circuit of the reciprocate solenoid D to start the hydraulic motor 22 to shift the tool head 12 rearwardly. At the same time, closure of switches M1A2 starts the spindle motor 20.

Accordingly, the hone 10 is moved rearwardly through the work bore 13 while being expanded gradually and rotated at slow speed. Since the relay CR5 and slow reciprocate solenoid E remain deenergized, fluid flows to the hydraulic motor 22 through the by-pass lines 149 and 150 to reciprocate the tool head at the rapid rate. When the dog 52 engages the intermediate follower 54 and rocks the control rod 51 counterclockwise (FIG. 3), the cam 75 returns the switches LS13A and LS13B to the condition shown in FIG. 14 to energize the forward solenoid F and start another forward stroke of the tool head. Thus, the latter reciprocates back and forth under the control of the forward and intermediate followers and the expander rod 80 is shifted slowly forwardly to maintain the honing pressure on the bore wall. As the shaft 108 turns, the arm 114 slips thereon to remain stationary relative to switch LS19B while holding the latter closed.

Initiation of the finishing cycle

Each time relay CR6 is energized by closure of switch LS13B at the end of a forward stroke of the tool head 12, a switch CR62 closes to energize a relay CR10 which closes its switch CR10–1 to energize solenoid Y (FIGS. 13 and 14B) and admit fluid to the sizing plug cylinder 133 through the hydraulic line 136. Thus, the plug 117 is advanced toward the end of the workpiece and attempts to enter the bore 13. When switch CR62 reopens during the next forward stroke of the tool head, relay CR10 and solenoid Y are deenergized and the sizing plug is retracted to the out-of-the-way position as the hone is moved forwardly.

When the work bore finally attains the size of the outer diameter of the sizing plug 117, the latter enters the bore and the dog 144 closes the signal switch LS10. This completes a circuit to the solenoid of the stroke counter 147 to begin counting the number of additional strokes selected to compensate for wear on the sizing plug. When these additional strokes are completed, the counter closes its switch C1 to energize relay CR11 and timer TD5. A switch CR11–1 is closed by the relay CR11 to maintain the energization of circuits to the relay and the timer and another switch CR11–3 is opened to deenergize relay MF4 and stop the expansion of the hone.

Another switch CR116 is also closed, completing a circuit through CR127 to the relay MR3 which is energized. The switches MR32 are thereby closed to run the rapid traverse motor 81 reversely and collapse the hones until the switch LS19B is engaged and opened.

Closure of LS19A completes a circuit to a relay CR12 through now closed switch CR11–5, and relay CR12 closes its switch CR12–6 in the circuit of relay MF3 through switch LS18, starting the traverse motor 81 to expand the hone until the worm 85 shifts, opening LS18 and stopping expansion with the stones pressed lightly against the wall. CR12 also closes a holding switch CR12–1 and opens a switch CR12–3 (FIG. 14A) to deenergize relay M1A and open switches M1A2 in the low-speed circuit of the spindle motor 20. At the same time, relay CR12 closes its switch CR12–2 to energize a relay M1B whose switches M1B2 energize the high-speed winding of the spindle motor to accelerate the spindle. Further, a switch CR12–4 (FIG. 14B) closes to energize the slow reciprocate solenoid E and a switch CR12–5 closes to energize the timer TD4 which times the finishing cycle.

Thus, the tool head 12 begins to reciprocate the hone 10 slowly through the bore with the abrasive stones 19 pressed only lightly against the bore wall and rotating at an increased speed. As a result, the stones polish the bore wall quickly to a fine, even finish while removing very little stock. The timer TD4 is set to time out after the interval of time selected for the finishing cycle. The length of the cycle, of course, will vary with the length and diameter of the bore and the fineness of finish required. When the timer times out, it closes a switch TD41 in the circuit of a withdraw relay CR3 which is energized at the beginning of the next rearward stroke of the tool head upon the closure of switch CR64 by the relay CR6 energized through switch LS13B.

Relay CR3 closes a switch CR31 to complete a holding circuit and also closes a switch CR32 to maintain the energization of the reciprocate relay CR2 as switch CR33 opens to deenergize the hone expansion relay CR4. The latter recloses a switch CR46 to energize the hone collapsing relay MR3 and initiate the rapid collapse of the hone by the traverse motor 81, at the same time opening switch MR33 to deenergize the feed clutch 103 and uncouple the feed motor 82 from the shaft 94. When switch LS19B is opened by the arm 114 as the expander rod 80 moves rearwardly, the motor is deenergized with the hone collapsed sufficiently to slide out of the work bore.

To maintain the energization of the return solenoid G as the dog **52** passes the intermediate follower **54** and opens the switch **LS13B**, relay **CR3** also closes a switch **CR35** which completes a holding circuit for the return solenoid through line **L10**, and opens a switch **CR34** to prevent the energization of the forward solenoid F. Thus, the tool head **12** continues rearwardly until the dog engages the rear follower **55** and rocks the control rod **51** counterclockwise (FIG. 3) to return the cam shaft **70** and the cams **73**, **74** and **75** to the positions shown in FIG. 14. Accordingly, the cam **73** opens switch **LS11** to stop the machine.

With the modified control using the load meter LM shown in the fragmentary circuit in FIG. 15 in place of the shiftable worm **85** and control switch **LS18**, the relay of the meter is energized to close its switch **LM1** in the circuit of relay **MR4** as long as the stones **19** are in high pressure engagement with the bore wall during rough honing. A second switch **LM2** is open in the circuit of relay **CR12**. When switch **CR11-3** is opened at the end of rough honing, and the honing pressure drops off as a result of deenergization of the feed motor **82**, the load meter relay is deenergized at a preselected reduced pressure indicated by the reduced current drawn by the spindle motor, thereby closing the switch **LM2** to energize the relay **CR12** to initiate the finishing cycle.

Appropriate manual controls are provided for terminating or varying the automatic cycle when desired. These controls include a short-stroking switch **172** for actuating a clutch **173** (FIGS. 5 and 14B) operable to couple the drum shaft directly to the cam shaft **70** so that the latter is rocked back and forth with the drum to effect short stroking of selected areas of the work bore **13**.

I claim as my invention:

1. The method of rough and finish honing a work bore wall by reciprocating a radially expansible and contractible honing tool back and forth through the bore while the tool is being rotated, said method including the steps of, expanding the tool into contact with the bore wall, gradually expanding the tool to maintain high pressure engagement with the wall while reciprocating the tool at a relatively rapid rate and rotating the tool to rough hone the wall until the latter attains the desired size, contracting the tool away from the wall, then expanding the tool back into engagement with the wall at a reduced honing pressure, and reciprocating the tool at a slower rate to polish the wall.

2. The method of rough and finish honing a work bore wall by reciprocating a radially expansible and contractible honing tool back and forth through the bore while the tool is being rotated, said method including the steps of, expanding the tool into contact with the bore wall, gradually expanding the tool to maintain high pressure engagement with the wall while reciprocating the tool at a relatively rapid rate and rotating the tool to rough hone the wall until the latter attains the desired size, contracting the tool until a reduced honing pressure is obtained, and then reciprocating the tool at a slower rate to polish the wall.

3. The method of rough and finish honing a work bore wall by reciprocating a radially expansible and contractible honing tool back and forth along the wall while the tool is being rotated, said method including the steps of, expanding the tool into contact with the bore wall preparatory to rough honing of the bore, gradually expanding the tool to maintain high pressure engagement with the wall while reciprocating the tool at a relatively rapid rate and rotating the tool relatively slowly to rough hone the wall until the latter attains the desired size, and then reducing the pressure between the tool and the wall, rotating the tool at an increased speed, and reciprocaing the tool along the wall at a slower rate to polish the wall.

4. The method of rough and finish honing a work bore wall by reciprocating a radially expansible and contractible honing tool back and forth along the wall while the tool is being rotated, said method including the steps of, bringing the tool into contact with the bore wall, gradually expanding the tool within the bore to maintain high pressure engagement with the bore while reciprocating the tool at a relatively rapid rate and rotating the tool to rough hone the wall until the latter attains the desired size, and then reducing the pressure between the tool and the wall and reciprocating the tool at a slower rate to polish the wall.

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