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Imhoff et al.

[11] **3,903,653**

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[54] LAPPING MACHINE

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[73] Assignee: **Harold J. Imhoff**, Stuart, Fla.

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[52] **U.S. Cl.** .... **51/59 R**; 51/165.92

[51] **Int. Cl.**[2] **B24B 19/00**

[58] **Field of Search** .... 51/34 D, 59 B, 165.92, 51/165.93, 34 R, 35; 29/76 A

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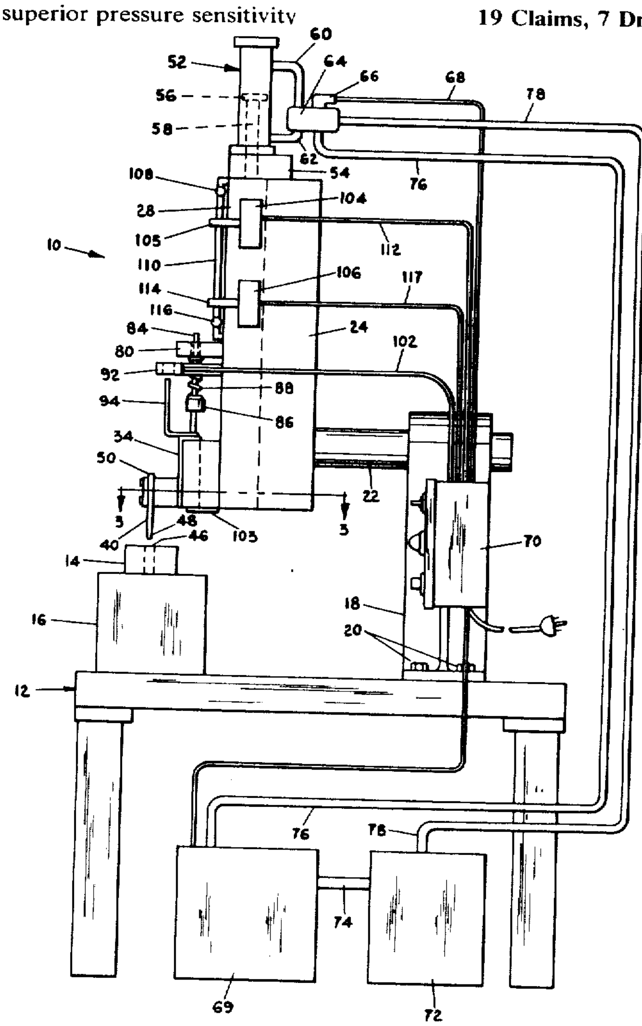
Attorney, Agent, or Firm—McGarry & Waters

[57] **ABSTRACT**

A lapping machine having superior pressure sensitivity and performance characteristics is driven by a double action hydraulic drive cylinder and controlled by electronic controls and an electro-hydraulic servo valve mechanism. Driving engagement between the drive cylinder and lapping tool is effected by a dual slide arrangement drivingly interconnected by a resilient biasing member, with the drive cylinder being connected to a primary slide and the lapping tool being mounted on a secondary slide. An electronic sensor in the form of an electric eye senses the pressure on the lapping tool and automatically causes the lapping tool to be withdrawn from the work piece when the pressure on the lapping tool reaches a predetermined level. The electronic eye is actuated by relative movement between the slides, and the relative movement is adjustable by varying the tension on the resilient biasing member. The electronic controls are adjustable to permit "lap" and "peck" modes of operation and to provide independent variation of stroke length, up speed, down speed, and the rate of progression of a lapping tool through a work piece. The electronic controls also cause the lapping machine to be turned off automatically when the lapping operation has been completed.

19 Claims, 7 Drawing Figures



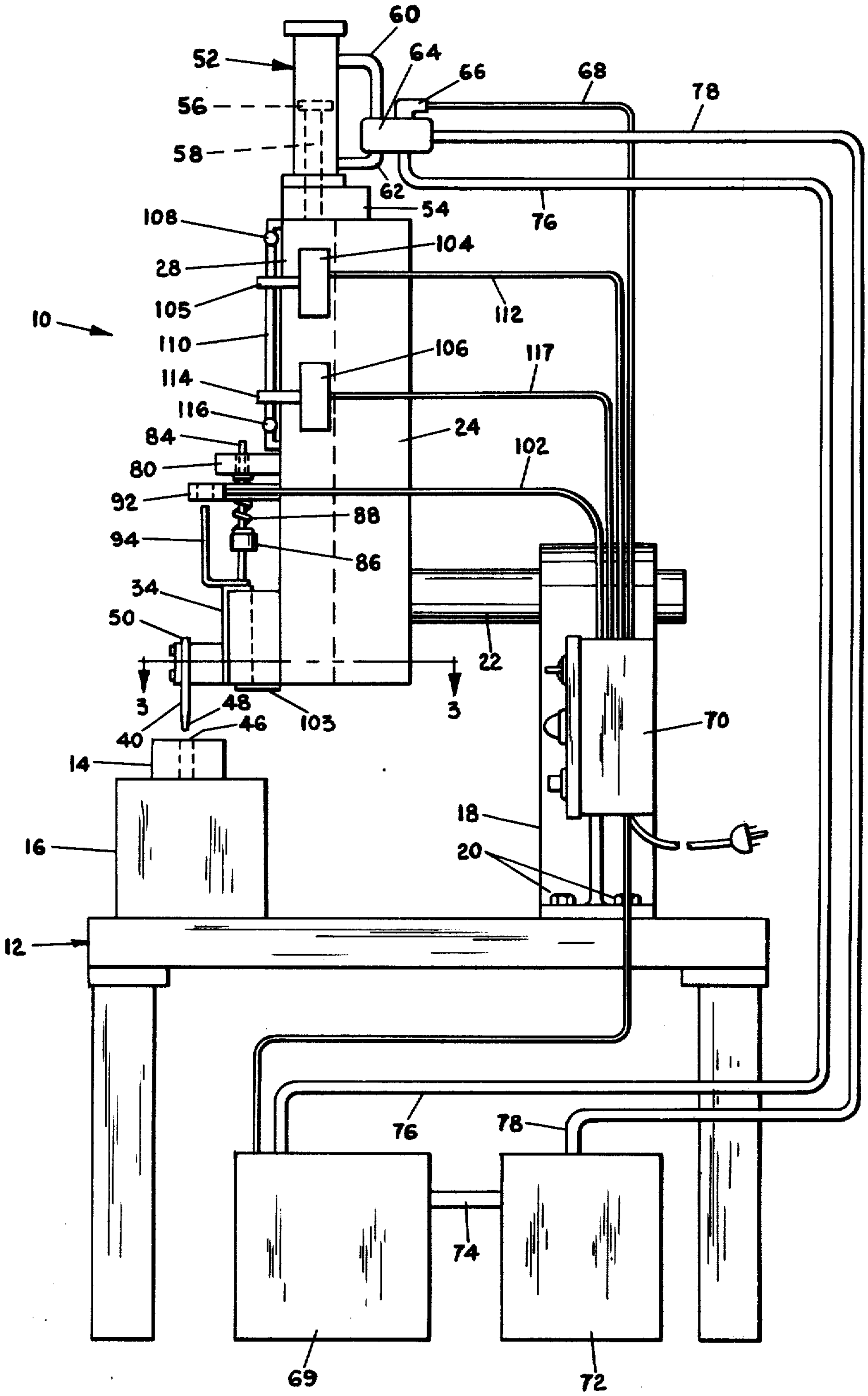

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FIG. 1

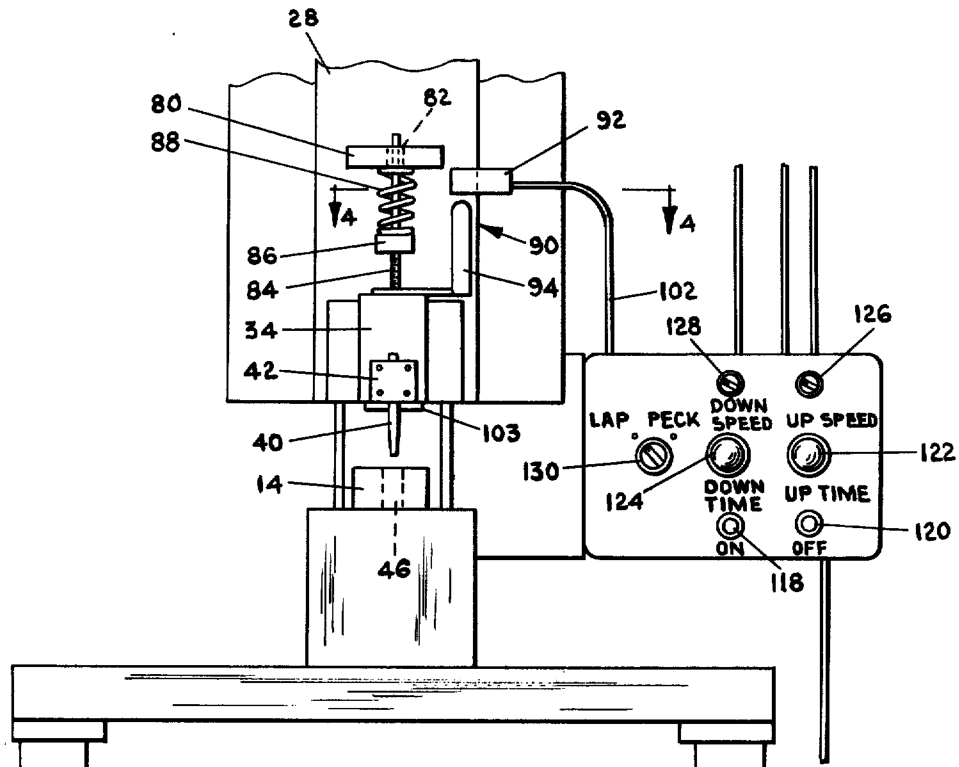

FIG. 2

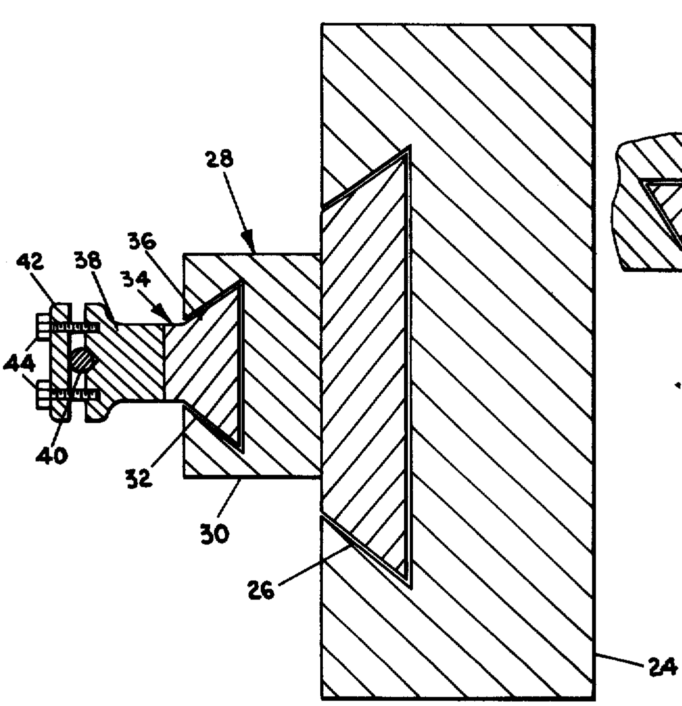

FIG. 3

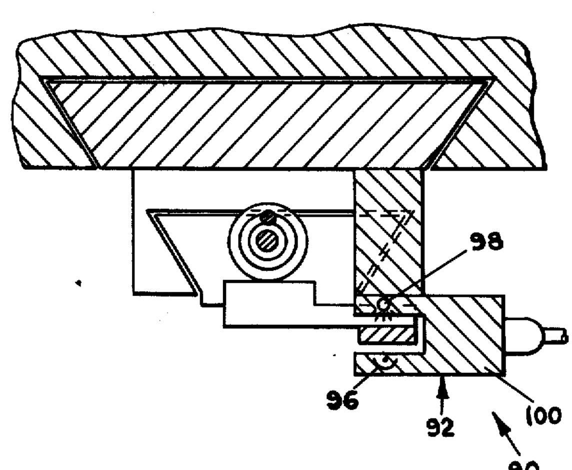

FIG. 4

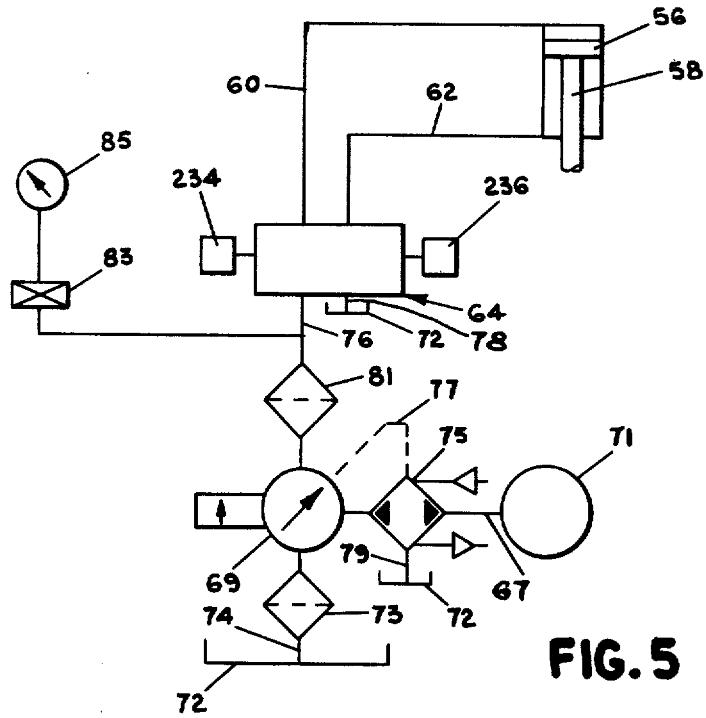
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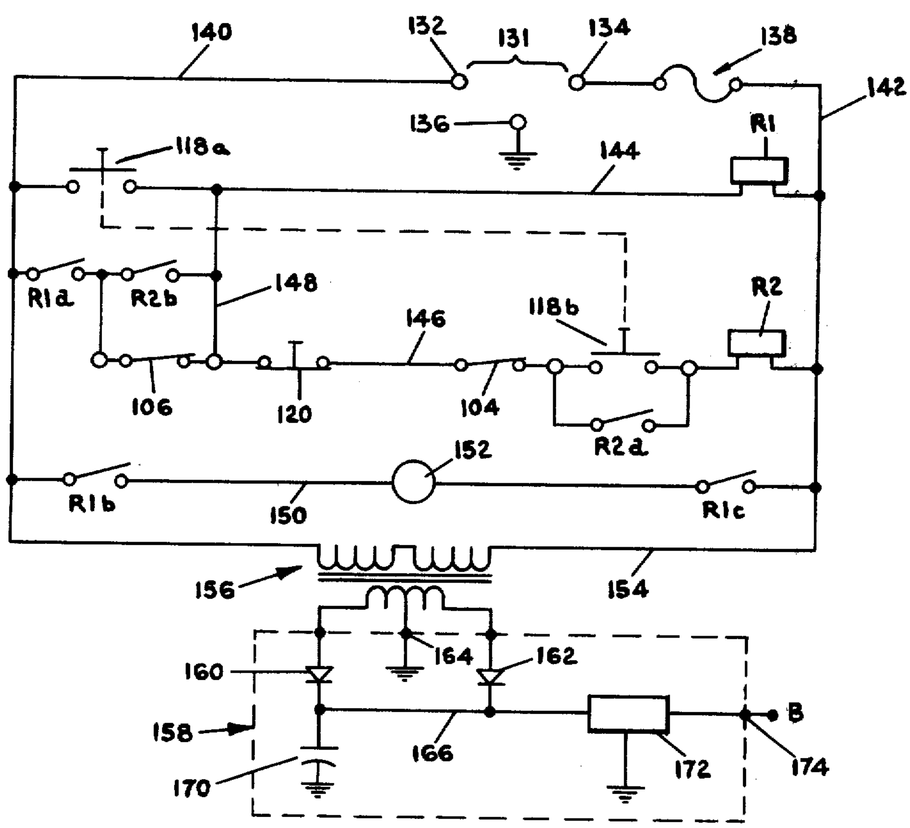
FIG. 5


140
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131
134
138
142
136
R1
118a
144
R1a
R2b
148
146
118b
R2
106
120
104
R2a
152
R1b
150
R1c
156
154
164
162
160
158
166
170
172
174
B

FIG. 6

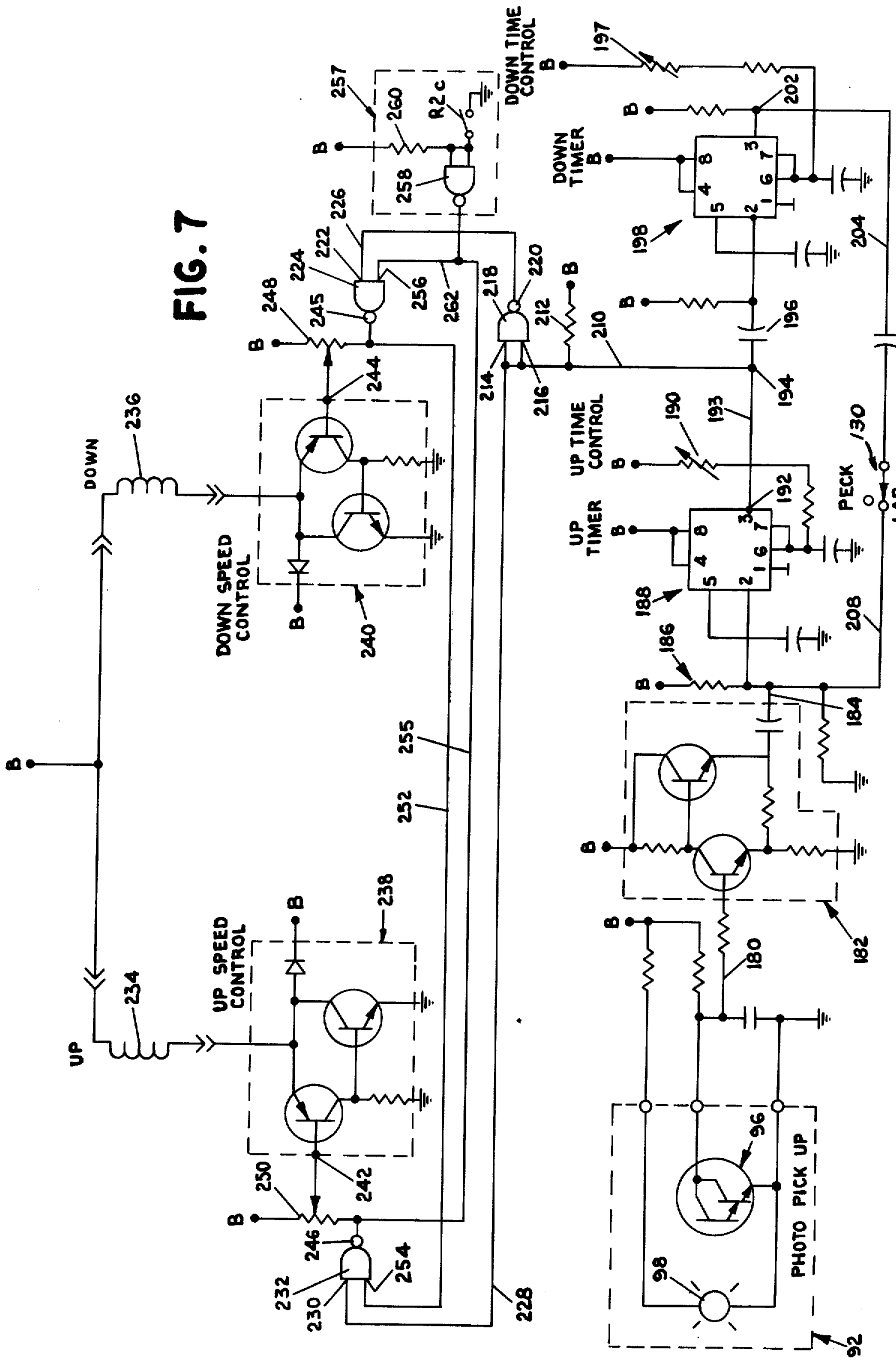
DOWN TIME CONTROL
DOWN TIMER
UP TIME CONTROL
UP TIMER
PECK
LAP
DOWN SPEED CONTROL
UP SPEED CONTROL
PHOTO PICK UP
UP
DOWN

FIG. 7

LAPPING MACHINE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to lapping machines and more particularly to lapping machines having an electrohydraulic control mechanism and improved pressure sensor.

2. Description of the Prior Art

In machine-tool manufacturing, lapping machines are used primarily for surfacing non-circular internal surfaces in a workpiece where a rotary grinding tool or honing tool cannot be used. In a lapping operation, a lapping tool or lap is supplied with a cutting medium such as a liquid slurry containing diamond, Norbide, or other cutting grit and is reciprocated in rubbing engagement with the surface to be finished to produce a surface cutting action. The reciprocating lapping tool is progressively fed along the surface until the entire surface has been finished.

In lapping a non-circular interior surface of a workpiece, the lapping tool generally is slightly tapered so that as the lapping tool is fed progressively into the opening, the fit between the lapping tool and the surface of the workpiece becomes tighter. As the lap cuts away the surface of the workpiece, the lapping tool is fed progressively into the opening until the entire surface has been finished.

One of the principal problems in lapping operations is that the lapping tool tends to wedge or bind into the cavity if the lapping tool is fed into the cavity with excessive pressure. To overcome this problem, in early lapping machines, the forward progress of the lapping tool was controlled manually, with an operator regulating the feed by feel. Such manual operation, however, was expensive and required many manhours of a skilled operator.

In order to avoid the necessity for manual operation of the lapping tool, several attempts have been made to devise lapping machines which more or less automatically regulate the inward progress of the lapping tool in response to increases in pressure on the lapping tool. In one such type of apparatus, the forward or inward pressure on the lapping tool is provided by a source of resilient pressure (e.g. air pressure or a spring), and the reciprocation of the lapping tool is achieved by means of mechanical cam that operates against this forward pressure to reciprocate the lapping tool away from engagement with the work piece. The forward pressure is crudely adjustable so that after the reverse movement of the lapping too caused by the cam, the lapping tool progresses in a forward direction until the friction between the lapping tool and the work piece overcomes the forward pressure and causes the lapping tool to stop its forward progress. As the lapping tool cuts away the surface of the work piece, the stroke of the lapping tool increases gradually until a switch mechanism sensitive to the length of the stroke of the lapping tool actuates a mechanical drive mechanism that moves the work piece into closer contact with the lapping tool, thus again shortening the stroke of the lapping tool until further cutting action is achieved.

One of the principal drawbacks of this type of apparatus is that the operation of the apparatus is dependent upon the wedging of the lapping tool in the work piece upon each reciprocation, and the mechanism by which the pressure of the lapping tool into the work piece is regulated is crude and imprecise. Accordingly, with this type of apparatus, the binding of the lapping tool in the work piece is a recurrent problem.

Another deficiency with this type of apparatus is that the apparatus requires a first source of forward pressure and separate drive means for reciprocating the lapping tool and moving the lapping tool progressively forward into the internal surface of the work piece. Further, the separate drive mechanisms for this apparatus are complex and expensive. Accordingly, lapping machines of this design are extremely expensive and not particularly effective.

Still another drawback with the foregoing lapping machines wherein a mechanical cam is employed to produce reverse reciprocation against a forward pressure is that such machines do not permit a wide range of variation in lapping conditions. The crude pressure controls of the prior devices permit only limited adjustment of pressure on the lapping tool, and the mechanical cam drive does not permit regulation of the distance of the reciprocal stroke of the lapping tool. Further, no independent adjustment of the forward and reverse reciprocation or progression of the lapping tool are possible. Also, it is not possible to operate such lapping machines in more than one mode, such as the lap and peck modes described below.

In order to overcome the deficiencies in lapping machines having the mechanical cam controls of the apparatus described above, some attempts have been made to produce lapping machines wherein the reciprocation and the forward progress of the lapping tool are both controlled by a combination of air and hydraulic drive mechanisms. Such drive mechanisms are preferable to mechanical cam reciprocation mechanisms and are less expensive, but, heretofore, they still have encountered problems with limited control over the pressure on the lapping tool and a lack of flexibility for a wide variety of uses. With these types of lapping machines, adjustment of pressure on the lapping tool is an inaccurate, time-consuming, and difficult job of manually adjusting air and hydraulic valves. Consequently, even though such apparatus is superior to a mechanical cam reciprocation apparatus, recurrent problems of tools binding in the work pieces are still encountered. Further, heretofore it has not been feasible to regulate the speed of reciprocation of the lapping tool or the rate at which the lapping tool is fed into the work piece. In this type of apparatus, the reciprocation speed is about 144 rpm, with the rate of progression of the tool into the work piece being relatively constant.

In order to overcome the deficiencies in the prior lapping machines, the present invention was evolved.

SUMMARY OF THE INVENTION

In accordance with the present invention, a lapping machine having superior prussure-sensitivity characteristics and performance characteristics comprises a hydraulic drive means adapted to control the movement of the lapping tool. An electro-hydraulic servo valve mechanism controls the operation of the hydraulic drive, and electronic controls connected to the electrohydraulic valve control the reciprocation of the lapping tool and the movement of the lapping tool into and out of the work piece. An electronic sensor generates an electrical signal whenever the pressure on the lapping tool reaches a predetermined level. Responsive to the electronic signal received from the sensor, the electronic controls cause the automatic withdrawl of the lapping tool from the work piece. After the lapping tool has been withdrawn from the work piece, the controls cause the lapping tool to be reinserted into the work piece and the cycle repeated.

Improved pressure sensitivity of the present invention is provided by connecting the hydraulic drive cylinder to a primary or master slide, and mounting the lapping tool on a secondary slide, both of which are mounted for independent linear motion in the same direction in the lapping machine. Resilient baising means in the form of a compression spring interconnects the two slides so that the forward motion of the primary slide urges the secondary slide also to move in the first direction.

An electronic sensor in the form of an electric eye is responsive to relative movement between the two slides (and, hence, pressure on the lapping tool) and generates an electrical signal triggering the withdrawal of the lapping tool from the work piece whenever the relative movement of the two slides in a forward direction reaches a predetermined level. The relative movement of the slides (and pressure on the lapping tool) is adjustable by varying the tension on the resilient biasing means.

The electronic controls of the present invention are adjustable to permit lap and peck modes of operation and to provide independent and wide variation of stroke length, up speed, down speed, and the rate of progression of a lapping tool through the work peice. The electronic controls also cause the lapping machine to be turned off automatically when the lapping operation has been completed.

Because of the variation and reciprocation speeds available with the lapping machine of the present invention, the machine also may be used as a filing machine.

These and other advantages and features of the present invention will hereinafter appear and for purposes of illustration, but not of limitation, a preferred embodiment of the subject of this invention is described in detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side plan view of the apparatus of the present invention.

FIG. 2 is a fragmentary front view of the apparatus of the present invention, showing the electronic sensor.

FIG. 3 is a sectional view taken along lines 3—3 of FIG. 1.

FIG. 4 is a fragmentary sectional view taken along lines 4—4 of FIG. 2.

FIG. 5 is a block diagram of the hydraulic system of the present invention.

FIG. 6 is an electrical wiring diagram showing the power supply and control relay circuitry of the present invention.

FIG. 7 is an electrical wiring diagram showing the electronic controls of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings, and more particularly to FIG. 1, a lapping machine **10** embodying the principles of the present invention is shown mounted on a table **12**, in position to perform a surfacing function on a workpiece **14**. Workpiece **14** is mounted immediately below the lapping machine on a set-up block or plate **16** which may be raised or lowered by an appropriate lifting mechanism (not shown) in order to move the workpiece into proper position with respect to the lapping tool.

Lapping machine **10** comprises a support bracket **18** which is securely fastened to the table by means of bolts or other suitable fasteners **20**. An adjustable mounting shaft **22** in the form of a horizontally disposed cylinder is mounted in the upper portion of support bracket **18** and extends outwardly therefrom. A vertically disposed frame **24** is mounted on the other end of mounting shaft **22** and extends upwardly therefrom in a line perpendicular to the plane of the table. When the lapping machine is in position for operation, frame **24** is held rigidly in position with respect to the table.

A vertically disposed wedge-shaped channel **26** is formed in the front surface of frame **24** (FIG. **2** orientation), and a master slide **28** is fitted in the channel for slideable motion in a linear direction along the frame. For reference purposes, movement of the master slide in a downward direction, according to FIG. **1** orientation, will sometimes be referred to as movement in a "forward" direction and movement in an upward direction will sometimes be referred to as movement in a "reverse" direction.

A mounting block **30** extends outwardly from the lower portion of master slide **28** and a wedge-shaped channel **32** is formed in the outer face of the mounting block.

A V-block or secondary slide **34** fits within the wedge-shaped channel in the face of mounting block **30** and is slideable with respect to mounting block **30** in the same linear direction as the master slide. V-block **34** comprises a wedge-shaped base **36** that rides within channel **32** and a tool holding portion **38** that extends outwardly therefrom over work piece **14.** Tool holding portion **38** is provided with a flat front surface having a V-shaped indentation therein. A lapping tool **40** comprising a tapered head **48** and a shank **50** is received in the V-shaped indentation in the tool holding portion, and a mounting plate **42** is fastened securely over lapping tool **40** by means of fasteners **44** and holds the lapping tool securely in place. When thus positioned, lapping tool **40** is in vertical axial alignment with a non-circular opening **46** in work piece **14,** such that movement of the lapping tool in a forward direction will cause the lapping tool to engage the internal surfaces of opening **46.**

Movement of the slides with respect to the frame is achieved by means of a hydraulic drive cylinder **52,** which is mounted on the top of the frame by means of a mounting block **54.** Hydraulic drive cylinder **52** comprises an internally slideable piston **56** and an extendable drive shaft **58,** the outer end of which is attached to master slide **28.** Hydraulic cylinder **52** is a conventional double-action cylinder, wherein the piston is moved in a downward direction by the injection of hydraulic fluid into the cylinder above the piston through an upper inlet conduit **60** and is moved in an upward direction by the injection of hydraulic fluid into the cylinder below the piston through a lower inlet conduit **62,** while at the same time withdrawing hydraulic fluid from upper conduit **60.**

Conduits **60** and **62** both lead from hydraulic cylinder **52** to an electro-hydraulic servo valve **64,** which, in response to appropriate electrical control signals, is adapted to closely and accurately regulate the operation of hydraulic cylinder **52**. The electro-hydraulic servo valve employed in the preferred practice of the present invention is commercially available and may be purchased from Hydratech, Pegasus Division, Troy, Mich. **48084**. This valve comprises a movable hydraulic spool valve, which is controlled by a pair of electrically operated solenoids (referred to as "up" and "down" solenoids) mounted in an electrical control element **66** on top of the valve. These solenoids position the spool valve to cause upward or downward movement or reciprocation of the piston in the hydraulic cylinder. By appropriate electronic monitoring, this valve is capable of producing variable rates of linear reciprocation of piston **56** at speeds of **0** to at least **250** rpm, while at the same time causing the gradual progression of piston **56** in a forward or reverse direction at any given rate of speed.

The operation of the servo valve is monitored or controlled by electrical controls **70**, which are connected to the servo valve by means of an electrical conductor **68**.

Hydraulic pressure is provided to the hydraulic cylinder by means of a hydraulic pump **69**, shown in block form on the floor underneath the table. Pump **69** withdraws oil from an oil tank **72** by means of a conduit **74** and pumps the oil through another conduit **76** to an inlet in the electro-hydraulic servo valve. A return conduit **78** leads from the servo valve back to the oil tank **72.**

The connection between master slide **28** and secondary slide **34** is best shown in FIG. **2**. A driving plate **80** is attached to the master slide and extends outwardly therefrom at a point above mounting block **30** and secondary slide **34.** Driving plate **80** is provided with a vertically disposed opening **82** therethrough. A threaded guide rod **84** is mounted on the top of secondary slide **34** and extends vertically upwardly therefrom through opening **82** in driving plate **80.** A collar **86** threadably engages guide rod **84,** and a resilient biasing means in the form of a compression spring **88** is interposed between collar **86** and driving plate **80.**

Movement of master slide **28** in a forward or reverse direction as a result of the reciprocation of piston **56** within hydraulic cylinder **52** is translated to secondary slide **34** in the following manner. As drive plate **80** moves downwardly in a forward direction it engages the upper end of compression spring **88.** As compression spring **88** is compressed, it exerts a corresponding force against the upper side of collar **86.** The pressure of spring **88** on collar **86** urges secondary slide **34** to move along with master slide **28** in a forward direction and causes lapping tool **40** to move forwardly into the opening in work piece **14.** Since the force exerted by a spring of this nature is linearly proportional to the amount that the spring is compressed, the force exerted by spring **88** on lapping tool **40** will be proportional to any relative movement of slide **28** with respect to the secondary slide **34.** Conversely also, relative movement of the slides will be proportional to the pressure on the lapping tool.

In order to adjust the amount of pressure necessary to trigger the withdrawal of the lapping tool from the work piece, an electronic sensor **90** is incorporated into the drive structure. Sensor **90** comprises an electronic eye **92** mounted on master slide **28** and a flag **94** mounted on secondary slide **34.** Electronic eye **92** comprises a photocell **96** and a light source **98** which are spaced apart on opposite legs of a U-shaped mounting bracket **100.** The space between the legs on mounting bracket **100** comprises a vertically oriented slot disposed above flag **94.** Electric eye **92** and flag **94** are spaced slightly apart so that when the master slide and primary slide are not in movement, flag **94** does not interrupt the light beam passing between light source **98** and photocell **96.** After relative movement between master slide **28** and secondary slide **34** has progressed a predetermined distance, flag **94** interrupts the light beam between light source **98** and photocell **96.** This causes the generation of an electrical signal, which is received by control mechanism **70** through line **102.** The control mechanism then causes the electro-hydraulic servo valve to reverse the direction of piston **56** and hydraulic cylinder **52.** As master slide **28** moves in an upward direction a stop plate **103** mounted on the bottom of the master slide engages the secondary slide and raises the lapping tool.

In order to adjust the forward pressure required on lapping tool **40** before the automatic withdrawal of the lapping tool is effected by the actuation of electric eye **92,** it is only necessary to adjust the position of threaded collar **86** on guide rod **84.** If collar **86** is moved upwardly on guide rod **84** so as to precompress the spring before reciprocation of drive plate **80,** a greater amount of pressure will be required on lapping tool **40** before there will be relative movement between slide **28** and secondary slide **34.** On the other hand, if collar **88** is lowered all the way to the bottom of guide rod **84,** a smaller amount of pressure will be required before there is relative movement between master slide **28** and secondary slide **34.** Thus, by controlling position of collar **86** on guide rod **84,** precise adjustment of the pressure on lapping tool **40** may be achieved.

The structure and details of operation of control mechanism **70** will first be explained in connection with the functions that it achieves and thereafter in connection with the electronic circuitry shown in FIGS. **6** and **7.** Referring to the control panel of the control mechanism shown in FIG. **2,** the control mechanism is provided with an "on" button **118** and an "off" button **120** of conventional design. The control mechanism is also provided with separate manually adjustable controls to control the lapping tool. These controls include an adjustable "up time" control **122** and an adjustable "down time" control **124,** which control the amount of time that the lapping tool is permitted to move in up and down (or reverse and forward) directions, respectively, before the direction of movement is automatically reversed. It is an important feature of this invention that, since the drive mechanism of the present invention is a double-action hydraulic cylinder and not a mere mechanical cam, it is possible to reciprocate the lapping tool with different forward and reverse speeds. This feature provides advantages for certain types of lapping operations.

Similarly, the control mechanism includes separately adjustable controls **126** and **128** for regulating the "up speed" and "down speed" of the lapping tool, respectively. These controls control the rate at which the lapping tool is moved upwardly and downwardly. The ability to separately control the up speed and down speed of the lapping tool is advantageous, because it is sometimes desirable to move the reciprocating lapping tool very slowly in a downward direction into contact with the work piece, whereas it may be desirable to withdraw the lapping tool rapidly from the work piece once the downward cutting cycle has been completed, so that the cycle may be commenced again as quickly as possible.

Separate controls for both speed and time permit accurate adjustment of another characteristic movement of the lapping tool, namely, the stroke of the lapping tool. Since the distance traveled by the lapping tool is a function of both the speed of the tool and the time of movement of the tool is a given direction, the stroke of the tool may be adjusted by varying either the time or the speed control.

Likewise, the mean position of the lapping tool may be adjusted by varying the lengths of the upward and downward strokes of the lapping tool. By adjusting the speed and/or time controls so that the downward stroke is longer than the upward stroke, the lapping tool follows a gradual move in a downward direction along the workpiece as it follows a reciprocating path.

The down times may effectively be disconnected by means of a separate two-position switch **130** on the control mechanism in order to operate the lapping machine in either a lap or a peck mode.

When switch **130** is switched to a peck mode, the down timer is effectively disconnected, so the lapping tool proceeds in a forward or downward direction until either the electric eye causes automatic withdrawal of the lapping tool or the lapping tool progresses all the way through the work piece and trips a limit switch **104** which commences a cycle that automatically turns off the lapping machine.

In the operation of the lapping machine of the present invention in a peck mode, the operator first presses the on button, which starts the downward movement of master slide **28.** The action of drive plate **80** on compression spring **88** effects a corresponding movement in secondary slide **34** and lapping tool **40.** As lapping tool **40** progresses into the opening in work piece **14,** the frictional pressure between the lapping tool and the internal surface of the work piece gradually increases. This frictional pressure resists to a certain extent the movement of the lapping tool into the opening in the work piece. This frictional resistance is translated to an upward pressure on collar **86** against compression spring **88.** This force causes the compression of spring **88** and the consequent relative movement between master slide **28** and secondary slide **34.** When this relative movement has proceeded to a distance sufficient to permit flag **94** to interrupt the light beam in electric eye **92,** a control signal is generated which causes the hydraulic drive cylinder to reverse the direction and move master slide **28** in a reverse direction. As master slide **28** moves in an upward direction, stop plate **103** on the bottom of the master slide engages secondary slide **34** and pulls it along with the master slide in an upward direction. After the upward or reverse movement has proceeded for a predetermined time, which is determined by adjustment of the up timer, the control mechanism automatically causes the drive means to reverse directions and commence moving in a forward direction, so that the lapping tool is moved back into engagement with the internal surface of the work piece.

The downward movement of the work piece continues again until the pressure of the lapping tool again exceeds the predetermined cut-off pressure, at which time the lapping tool is again withdrawn from the work piece. This procedure is carried on automatically until the lapping tool removes enough of the material on the internal surface of the work piece so that the lapping tool may proceed all the way through the surface to be finished without interruption by electric eye **92.**

After the lapping tool has progressed all the way through the opening to be finished, the lapping machine trips upper limit switch **104** in the following manner. Toggle **105** extends outwardly from limit switch **104** and extends into the path of a projection **108** which is slidably mounted on the vertical rod **110,** which is in turn mounted on the master slide. The position of projection **108** on rod **110** may be adjusted by means of an adjustable fastener means (not shown). The position of projection **108** is adjusted so that when the lapping tool is moved all the way through the work piece **14,** projection **108** contacts toggle **105,** thereby actuating limit switch **104.** Limit switch **104** then sends an appropriate electric signal through lead **112** to the control mechanism, which then causes the lapping tool to be withdrawn from the work piece. The master slide moves upwardly until it trips a lower limit switch **106** mounted on the frame at the lower end of rod **110,** which turns the machine off. Limit switch **106** is substantially the same as limit switch **104** and comprises a toggle **114** that extends into the path of a projection **116** slideably mounted on rod **110** below toggle **114.** The position of projection **116** is adjusted to effect the disconnection of the lapping machine whenever the drive piston has raised the master slide to a predetermined point. Lead **117** connects switch **106** to controls **70.**

The operation of the machine in a lap mode is substantially the same as the peck mode, except that the down timer **122** is placed in operative condition. Thus, rather than simply proceeding downward until the tool hits resistance or reaches the end of the cycle, the tool proceeds downwardly until the down timer times out, whereupon the direction of the tool is automatically reversed and the up timer is automatically actuated. This produces a reciprocating motion, which, as pointd out above, may be adjusted to cause the gradual downward movement of the tool through the work piece. When the tool has proceeded through the workpiece, limit switch **104** is tripped and the stop cycle described above is repeated.

The electrical circuitry of the present invention is shown in FIGS. **6** and **7,** with FIG. **6** showing the power supply and relay circuitry and FIG. **7** showing the control circuitry. Preferably, the control circuitry of FIG. **7** and certain diode rectifier circuitry shown in FIG. **6** are employed in the form of electronic cards.

As shown in FIG. **6,** a conventional two-phase **115** volt, **60** hz. alternating current power source **131** is applied to terminals **132** and **134** and is grounded at terminal **136.** For larger operations, it might of course be necessary to employ **220** three-phase power to provide sufficient power for the machine.

Power source **131** is protected by a suitable circuit breaker **138** and powers the control and drive elements of the circuit through leads **140** and **142.**

A first branch **144** connected across leads **140** and **142** includes start switch **118*a*** and a motor control relay **R1.** Start switch **118*a*** also comprises a second pair of contacts **118*b*** in a second branch **146** extending across leads **140** and **142.** A lead **148** extends between leads 144 and 146 at a point between switch 118 and relay R1.

Branch 146 includes in series, in addition to switch 118*b*, a control relay R2, a relay switch R2*a* (controlled by control relay R2) connected in parallel with switch 118*b*; limit switch 104; stop switch 120; relay switch R2*b* (controlled by control relay R2) connected in parallel with limit switch 106; and a relay switch R1*a* (controlled by motor relay R1).

A third branch 150 connected across leads 140 and 142 comprises a drive motor 152 and relay switches R1*b* and R1*c* (both controlled by relay R1).

A fourth branch 154 connected across leads 140 and 142 includes transformer 156 and rectifier 158. Rectifier 158 includes diodes 160 and 162 and a center tap ground 164. An output lead 166 connected across the outputs of diodes 160 and 162 contains a filter 170 in the form of a grounded capacitor. Precise voltage regulation is provided by an integrated circuit voltage regulator 172, shown in block form. Acceptable units are available commercially from either Fairchild or Motorola.

The output B of rectifier 158 appears at terminal 174. Preferably this voltage is 5 volts D.C. This voltage powers the control elements set forth in FIG. 7.

Starting from the lower left hand corner of FIG. 7, electric eye 92 comprises light source 98 connected in parallel with a normally conductive photocell 96, and powered by power source B. The output of photocell 96 is connected by lead 180 to a conventional Schmitt trigger, 182, which shapes the wave from the photocell and transforms it to a proper voltage level compatible with the timing mechanism of the present invention.

When the flag interrupts the light beam received by photocell 96, the photocell becomes non-conductive and this causes the Schmitt trigger to generate a control pulse, which is transmitted to the timing mechanism by lead 184.

The signal transmitted by lead 184 is biased by voltage divider 186 and then is fed to up time circuit 188, which is a conventional integrated circuit timer. The up time circuit is controlled by adjustable potentiometer 190, which is connected in parallel with up time circuit 188. The output of up time circuit 188 appears at output terminal 192 (corresponding to position 3 in the block diagram of the up time control circuit). In operation, the output is high (i.e. 5 volts) when the timer is running and goes to zero volts when the timer has run out.

A lead 193 extends from terminal 192 to a speed control terminal 194 and then through a capacitor 196 to down time circuit 198, which is substantially identical to up time control circuit. Down time circuit is adjustable by means of potentiometer 197. This circuit is triggered when up time control times out and the voltage at terminal 192 drops to zero.

The output voltage of down time circuit appears at terminal 202, which is connected by lead 204 to lap-peck switch 130. When the switch is in its lap position (as shown in FIG. 7) the output signal at terminal 202 is conveyed through switch 130 and thereafter by lead 208 to the input terminal of up time circuit 188. When the output voltage a terminal 202 drops to zero this automatically triggers up time circuit 188. Thus, with switch 130 in its lap position, up time circuit 188 and down time circuit 198 each trigger the actuation of the other when each circuit times out, which results in a reciprocal action of the separate time control circuits.

When switch 130 is in its peck position, an open circuit exists between leads 204 and 208. Accordingly, the output signal of down time circuit 198 is not transmitted to the input terminal of up time circuit 188 and, therefore, up time circuit 188 is not triggered when the down time control times out. In either a lap or a peck position, up time circuit is triggered by the actuation of electric eye 92.

The timing controls are connected to the speed controls by means of a lead 210 which connects to the timing controls at terminal 194. The signal impressed on lead 210 is biased by resistance 212 and thereafter impressed upon input terminal 214 and 216 of a NAND gate 218. NAND gate 218 has an output terminal 220 and functions as follows: if the input voltage at both input terminals is high, the voltage at the output terminal is low. Conversely, if the voltage at either input terminal is low, the voltage at the output terminal is high. Output terminal 220 of NAND gate 218 is connected to the input terminal 222 of a down speed control NAND gate 224 by means of a lead 226. Input terminal 214 of NAND gate 218 is connected by means of a lead 228 to an input terminal 230 of an up speed control NAND gate 232.

The up and down motion of the lapping tool is controlled by means of an up solenoid 234 and a down solenoid 236 each of which is connected in series with a conventional two stage amplifier 238 and 240, respectively. Amplifiers 238 and 240 are normally non-conducting and are rendered conducting only when the voltage at the output terminals 246 and 245 of NAND gates 232 and 224, respectively, are low (i.e. zero volts). This occurs only when both input terminals are high.

Output terminals 245 and 246 of NAND gates 224 and 232, are connected by potentiometers 248 and 250 respectively to power source B and, a variable tap on these potentiometers is connected to input terminals 242 and 244 of the respective amplifiers. These potentiometers are the variable controls for the up and down speed circuits.

Further describing the electric circuitry, the output of NAND gate 224 is connected by lead 252 to an input terminal 254 and NAND gate 232. Conversely the output of NAND gate 232 is connected by means of a lead 255 to an input terminal 256 of NAND gate 224.

One other circuit control element in this circuit is a wired OR gate 257, comprising NAND gate 258, resistance 260 and a relay switch R2*c* (controlled by control relay R2), the operation of which is described below.

The operation of the timer circuitry is as follows: When the up timer is running and the output voltage at terminals 192 and 194 is high, the voltage at both input terminals of NAND gate 218 is high, so the voltage at terminal 220 is low. Thus, the voltage at input terminal 222 of down speed control NAND gate 224 is low. This makes the voltage at down speed control output terminal high. This makes amplifier 240 stay non-conducting and thereby prevents down solenoid 236 from operating.

At the same time, input terminals 230 and 234 of up speed control NAND gate 232 are both high, so ouput terminal 246 is low. This makes amplifier 238 conduct and renders up speed solenoid operative.

When the up speed timer times out, the voltage at terminals **192** and **194** goes low and the opposite voltage signals appear at output terminals **246** and **245** of the NAND gates **232** and **224**, Thus, amplifier **238** is rendered non-conducting, and amplifier **240** is rendered conducting. Accordingly, up solenoid is deenergized and down solenoid is energized.

With the circuitry being set up in this manner, it is evident that actuation of the start button will energize only the down solenoid (the up timer not being operative), and when the photocell or the down timer actuates the up timer, the down solenoid is de-energized and the up solenoid is energized. This cycle repeats itself automatically until the machine operation is terminated.

When the workpiece is finished, wired OR gate **257** overrides the timer circuit and shuts off the machine. When either stop button **120** or limit switch **104** is tripped, control relay R2 is broken, thereby opening relay switch R2*c*. This makes the input voltage of NAND gate **258** high and the output voltage low. This low voltage is transmitted by line **255** to the output terminal **246** of NAND gate **232**, thereby energizing the up solenoid. This same voltage is impressed on input terminal **256** of NAND gate **224** by means of line **262**, thereby de-energizing the down solenoid. When the master slide is returned to its original position, limit switch **106** is tripped, thereby de-energizing motor relay R1 and the hydraulic pump motor.

Additional details of the hydraulic circuitry are shown schematically in FIG. **5**. Tank **72** is connected to pump **69** through conduit **74**, via filter **73**. Pump **69** is driven by an electric pump motor **71** through a drive shaft **67**. Slip oil produced in pump (i.e. oil that slips by the pump) is conducted to a heat exchanger **75** through conduit **77**, and the cooled oil is thereafter returned to tank **72** by conduit **79**.

Oil pumped by pump **69** is first filtered by filter **81** and then pumped to electro-hydraulic servo valve **64** through conduit **76**. An insolator **83** and a pressure gauge **85** are connected into conduit **76** for purposes of measuring line pressure.

Electro-hydraulic servo valve **64** is provided with inlet conduit **76**, outlet conduits **60** and **62**, and a return conduit **78**, which leads back to tank **72**. Conduits **60** and **62** lead to hydraulic drive cylinder **52** and control the upward and downward motion of piston **56** and drive shaft **58** slidably mounted therein. Up and down solenoids **234** and **236** control the operation of electro-hydraulic servo valve **64**.

It should be understood that the embodiments described herein are merely exemplary of the preferred practice of the present invention and that various changes, modifications, and variations may be made in the arrangements, operations, and details of construction of the elements disclosed herein within departing from the spirit and scops of the present invention, as set forth in the appended claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A lapping machine for finishing a surface in a workpiece by means of a linearly reciprocating, nonrotating lapping tool comprising:

a frame;

a secondary slide member slidably mounted in the lapping machine for linear reciprocation movement with respect to the frame in a direction toward and away from the workpiece, said secondary slide member including means for mounting the lapping tool thereon such that reciprocation of the secondary slide member brings the lapping tool into abrading engagement with the surface of the workpiece;

drive means mounted on the frame for reciprocating the secondary slide member so as to move the lapping tool into and out of abrading engagement with the surface of the workpiece, said drive means being connected to the secondary slide member by means of a resilient biasing means, said resilient biasing means urging the lapping tool into engagement with the workpiece in response to movement by the drive means toward the workpiece, said resilient biasing means urging the lapping tool against the surface of the workpiece with a pressure that increases in proportion to the amount of relative movement between the secondary slide member and the drive means when the drive means is moved toward the workpiece;

sensor means for sensing the relative movement of the drive means and secondary slide member in the direction toward the workpiece, said sensor means generating a control signal when the distance moved by the drive means exceeds the distance moved by the secondary slide member by a predetermined amount; and

control means for reversing the direction of the drive means so as to withdraw the lapping tool from the workpiece whenever said control signal is generated, said control means thereafter causing the drive means to commence another reciprocation toward the workpiece.

2. An improvement as claimed in claim **1** wherein the electronic control means comprise manually adjustable speed control means to control independently the speed at which the lapping tool is moved in said forward and reverse directions.

3. An improvement as claimed in claim **1** wherein the electronic control means further comprises manually adjustable up time control means to control independently the amount of time the lapping tool is moved in said reverse direction before commencement of another reciprocation in a forward direction.

4. An improvement as claimed in claim **3** wherein the electronic control means further comprises manually adjustable down time control means to control independently the amount of time the lapping tool is moved in said forward direction before movement is reversed to a reverse direction.

5. An improvement as claimed in claim **4** wherein the up time control means is adapted to cause forward movement of the lapping tool and the actuation of the down time control means when the predetermined up time elapses, and the down time control means is adapted to cause reverse movement of the lapping tool and the actuation of the up time control means when the predetermined down time elapses.

6. An improvement as claimed in claim **5** and further comprising switch means for selective disengagement of the down time control means so as to prevent the down time control means from causing reverse movement of the lapping tool and actuation of the up time control means when the predetermined down time elapses.

7. An improvement as claimed in claim 6 and further comprising limit switch means adapted to override the up and down controls and cause the movement of the lapping tool in a reverse direction out of contact with the workpiece after the lapping tool has moved a predetermined distance in said forward direction relative to the workpiece, said limit switch means being further adapted to turn off the lapping machine automatically after the lapping tool has moved a predetermined distance in said reverse direction.

8. An improvement as claimed in claim 1 wherein the sensor means is adjustable to adjust the pressure at which the sensor means triggers the withdrawal of the lapping tool from the workpiece.

9. A lapping machine according to claim 1 wherein the sensor means comprises:

photocell means mounted for movement in response to the movement of either the drive means or the secondary slide member, said photocell means generating said control signal when actuated;

photocell actuating means mounted for movement in response to the movement of the other of the drive means or the secondary slide member, whichever the movement of the photocell means is not responsive to, said photocell means actuating the photocell means whenever the forward movement of the drive means exceeds the forward movement of the secondary slide member by said predetermined amount.

10. A lapping machine according to claim 1 wherein:

the photocell means comprises a photocell and light source mounted in fixed positions relative to each other, with the light source positioned such that it directs light on the photocell when the photocell is not actuated, the control signal from the photocell being produced by the interruption of the light directed on the photocell by the light source; and

the photocell actuating means is a flag mounted such that the flag moves relative to the photocell and light source and interrups the light directed on the photocell by the light source when the forward movement of the drive means exceeds the forward movement of the secondary slide member by said predetermined amount.

11. A lapping machine according to claim 10 wherein:

the drive means comprises a hydraulic cylinder mounted on the frame and having an extendible drive shaft protruding therefrom;

the control means are electronically operated and include electro-hydraulic servo valve means for controlling the operation of the hydraulic cylinder;

a primary slide is mounted for linear motion along the frame and is drivingly attached to the extendible drive shaft;

the resilient biasing means interconnects the primary and secondary slides;

the light source and photocell are mounted for movement with the primary slide; and

the flag is mounted for movement with the secondary slide.

12. A lapping machine as claimed in claim 11 wherein the secondary slide is slidably mounted on the primary slide, and the primary slide is slidably mounted on the frame.

13. A lapping machine for surfacing a surface in a workpiece with a lapping tool comprising:

a frame;

a primary slide member mounted for slidable movement along a linear path in forward and reverse directions with respect to the frame;

a secondary slide member mounted for slidable movement along a linear path in said forward and reverse directions with respect to the frame, said secondary slide member including means for mounting the lapping tool such that the lapping tool will contact the surface of the workpiece upon movement of the secondary slide member in its forward direction;

resilient biasing means interconnecting the primary and secondary slide members, said biasing means urging the secondary slide member to travel along its path in the forward direction in response to the movement of the primary slide in the forward direction;

return means for moving the secondary slide member in the reverse direction in response to movement of the primary slide member in the reverse direction;

drive means for moving the primary slide member in either direction on its linear path, said drive means comprising a double-action hydraulic cylinder; and

control means for controlling the operation of the drive means so as to produce reciprocal motion of the primary slide member and cause a resultant reciprocation of the secondary slide member, said control means comprising:

electro-hydraulic servo valve means for controlling the operation of the hydraulic cylinder in response to electronic controls;

sensor means for causing the drive means to reverse the direction of movement of the primary slide from the forward direction to the reverse direction whenever the distance moved by the primary slide in the forward direction exceeds the distance moved by the secondary slide in the forward dirrection by a predetermined amount, the relative forward movement of the primary and secondary slide members through said predetermined distance being sensed by photocell means mounted in the lapping machine for movement responsive to the movement of one slide, said photocell means being actuated to trigger withdrawal of the lapping tool from the workpiece by photocell actuating means mounted for movement in response to the movement of the other slide, said photocell means and photocell actuating means being positioned so that the photocell actuating means actuates the photocell after said predetermined relative movement between the slides;

means for causing the drive means to re-reverse the direction of the primary slide member after predeternined movement of the primary slide member in the reverse direction; and

electronic control means for controlling independently the forward and reverse speeds of the lapping tool and the amount of time the lapping tool moves in its reverse direction before movement is switched to the forward direction, said control means being manually adjustabe to vary separately forward speed, reverse speed, and reverse time.

14. A lapping machine as claimed in claim 13 wherein the control means further comprises:

manually adjustable forward time control means for controlling the amount of time the lapping tool is permitted to move in a forward direction before the movement is switched to a reverse direction, if the movement is not otherwise reversed by the control means or sensor.

15. A lapping machine as claimed in claim **14** and further comprising limit switch means adapted to reverse the movement of the lapping tool to the reverse direction after the lapping tool has proceeded a predetermined distance through the workpiece and thereafter turn off the lapping machine after the lapping tool has been moved for a predetermined distance in the reverse direction.

16. A lapping machine according to claim **13** wherein the primary slide is slidably mounted on the frame for linear movement in said forward and reverse direction and the secondary slide is slidably mounted on the primary slide for linear movement in said forward and reverse directions with respect to the frame and the primary slide.

17. A lapping machine according to claim **16** wherein the secondary slide is mounted on the primary slide by means of a dovetail protrusion on the secondary slide member and a mating dovetail slot in the primary slide, in which the dovetail protrusion rides.

18. A lapping machine according to claim **16** wherein the resiliency of the resilient biasing means is adjustable so as to vary the pressure required on the lapping tool before the sensor means triggers the withdrawal of the lapping tool from the workpiece.

19. A lapping machine according to claim **18** wherein the resilient biasing means is a compression spring interconnecting the primary and secondary slide members, the resiliency adjustment in said resilient biasing means comprising adjustment means for varying the length of the spring so as to apply a variable initial compression load on the spring, such adjustment serving to change the lapping tool pressure necessary to cause said predetermined relative movement between the primary and secondary slide members.

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