

Nov. 20, 1945.

J. T. BOLAS

2,389,407

MILLING AND LIKE MACHINE FOR COPYING AND REPRODUCING

Filed Sept. 13, 1943

6 Sheets-Sheet 1

FIG. 1.

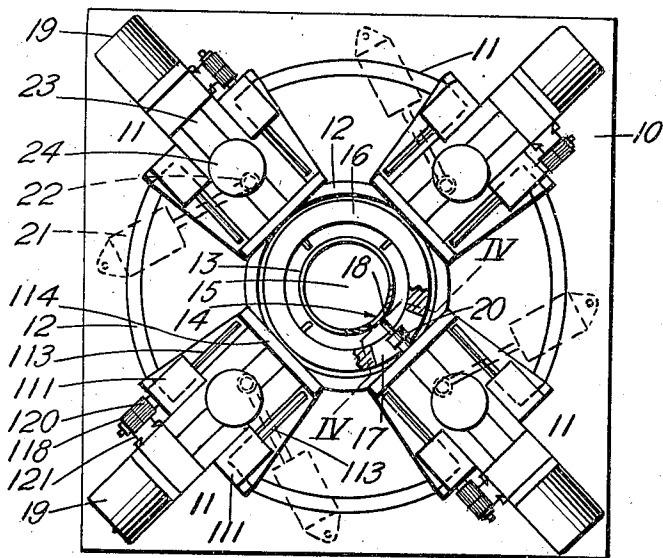
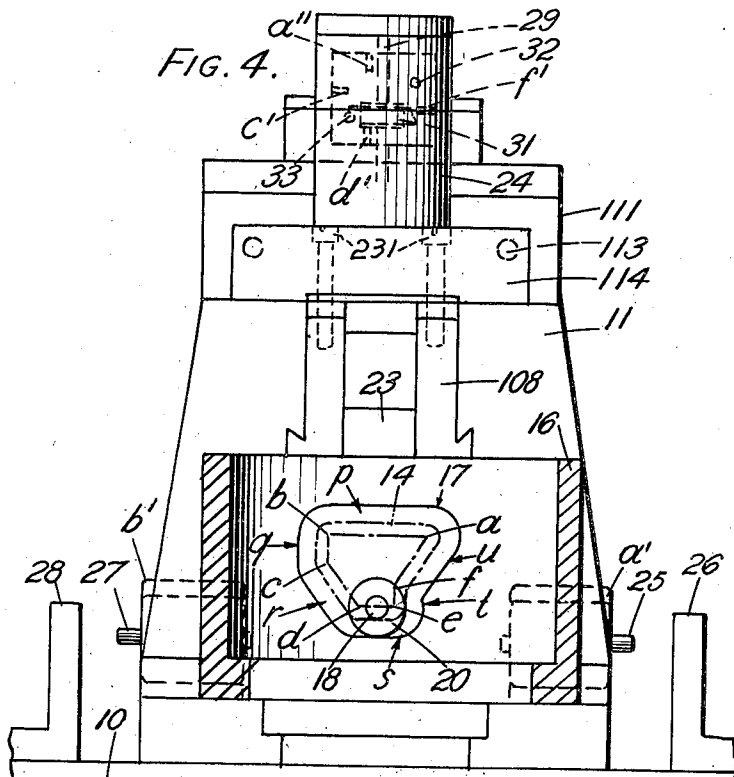


FIG. 4.



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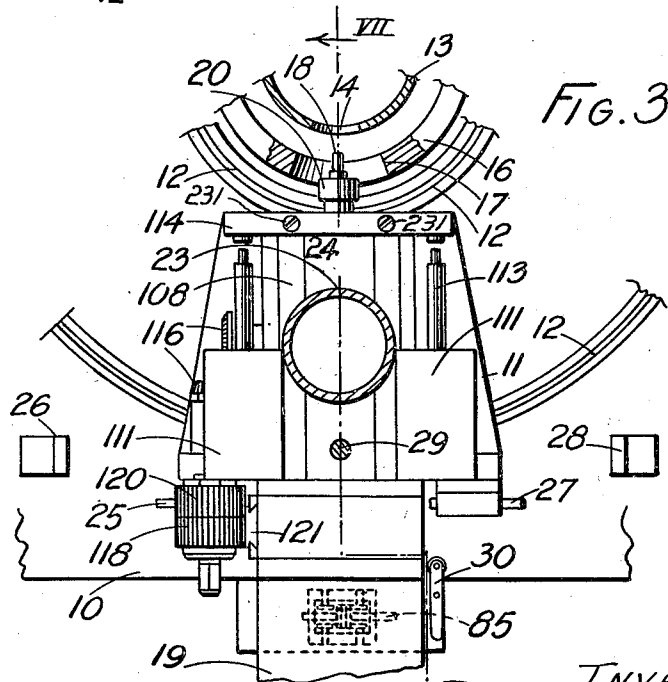
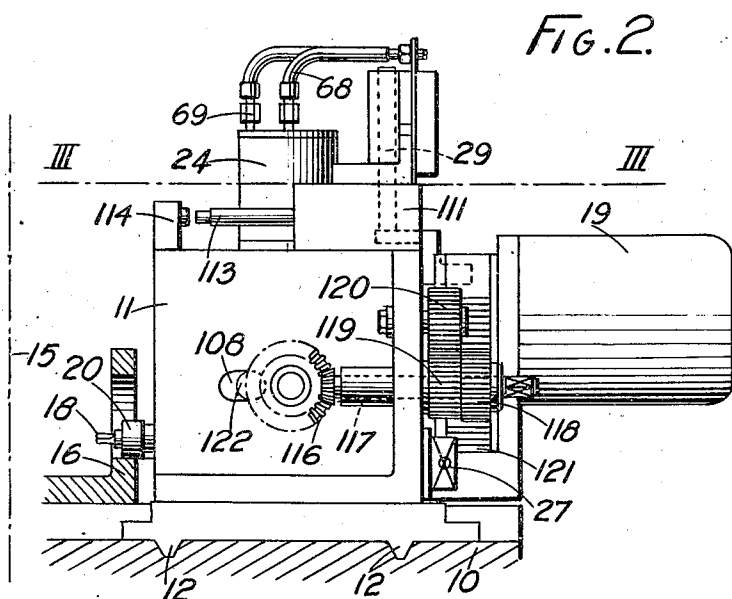
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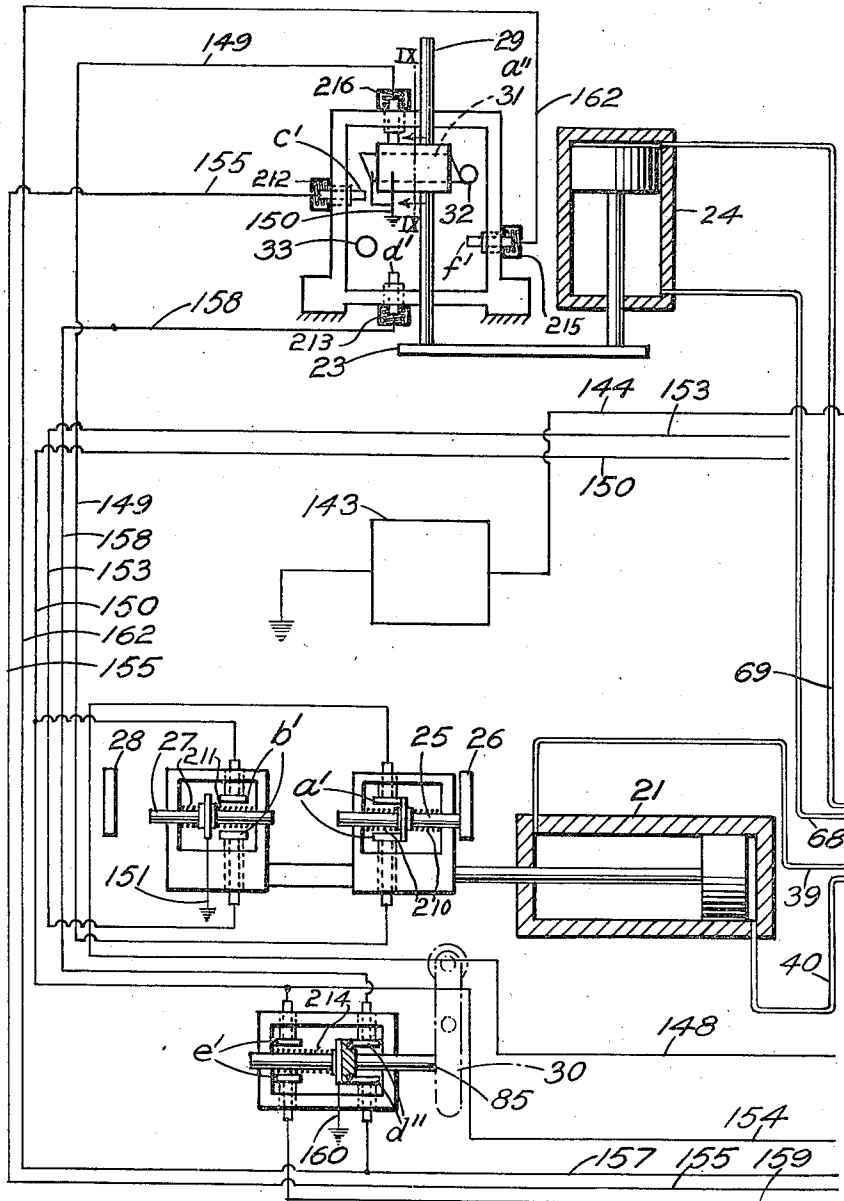
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FIG. 5.



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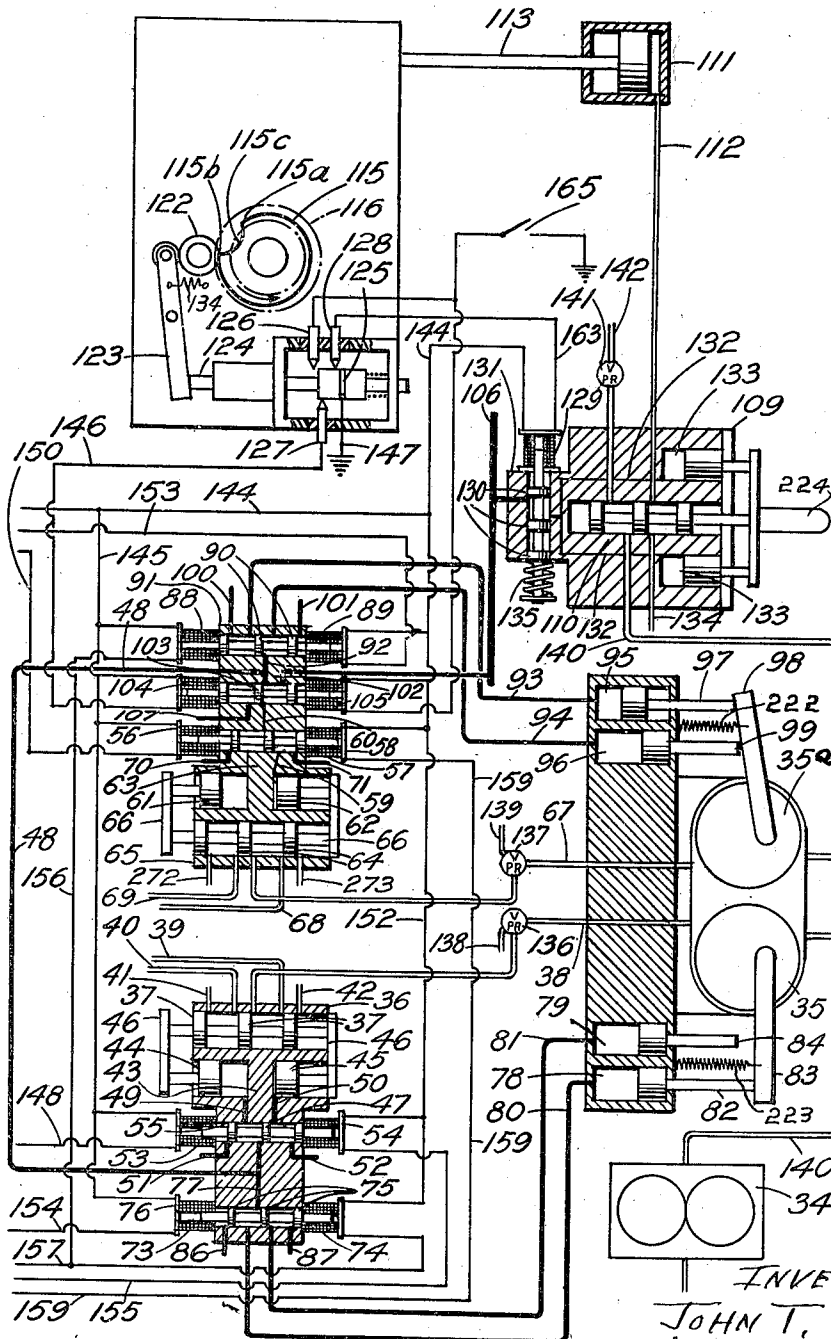
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FIG. 6.



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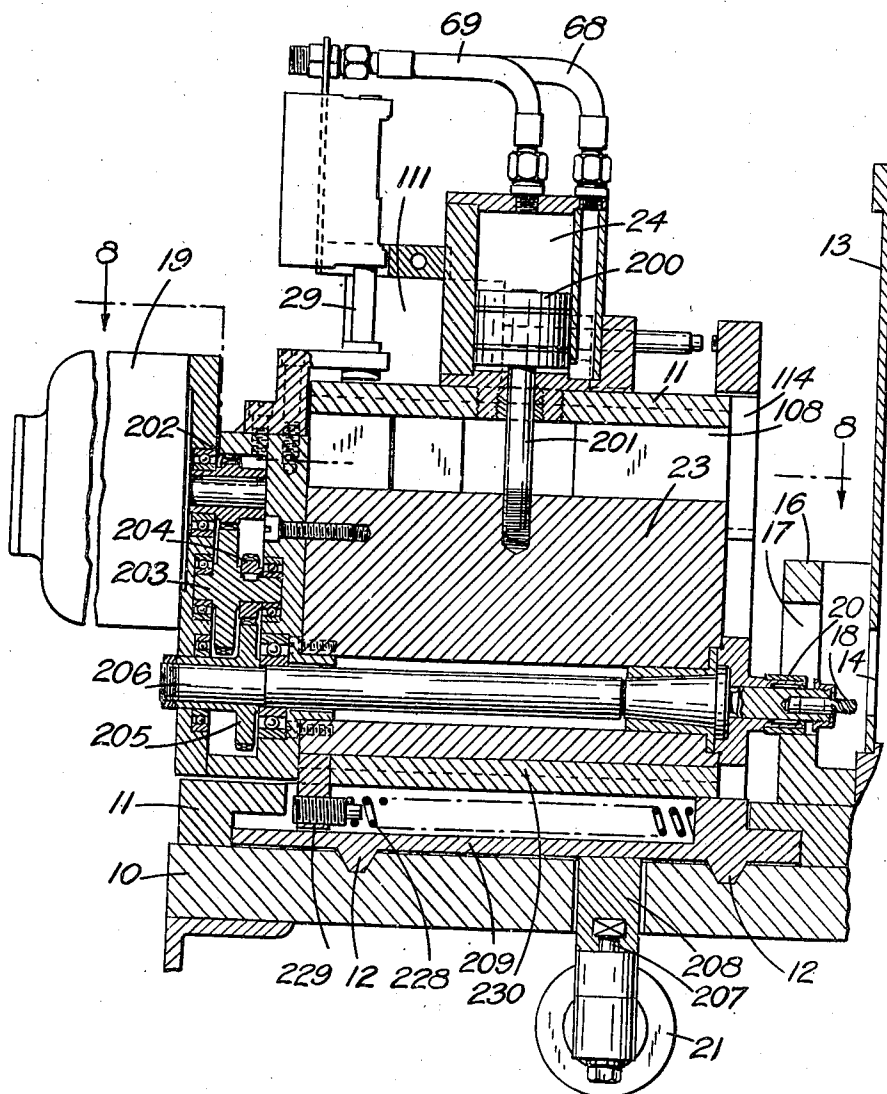
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FIG. 7.



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FIG. 8.

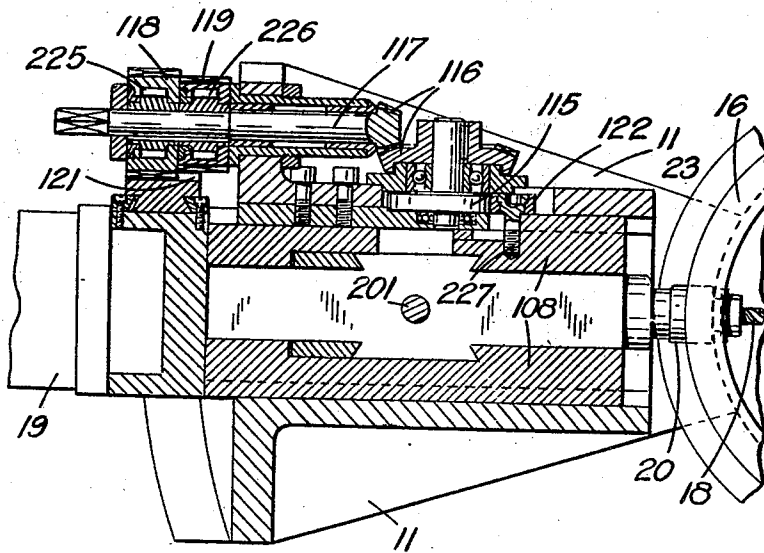
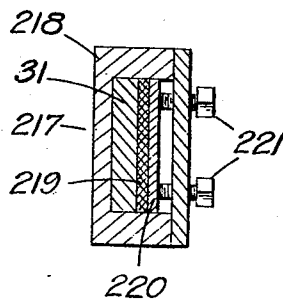


FIG. 9.



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UNITED STATES PATENT OFFICE

2,389,407

MILLING AND LIKE MACHINE FOR COPYING
AND REPRODUCING

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Application September 13, 1943, Serial No. 502,182
In Great Britain July 28, 1942

8 Claims. (Cl. 90—13.5)

This invention relates to milling or like machines of the kind comprising a cutter support and a work support, which cutter support is mounted for movement relatively to the work support along two substantially perpendicular paths, a pattern support and a follower to cooperate with a pattern on the pattern support, which follower is mounted for movement relatively to the pattern support along two paths parallel to the aforesaid paths and is so interconnected with the cutter support that their compounded relative movements are similar, two reversible hydraulic motors arranged one to impart the said relative movement in either direction to the cutter support and the follower along one pair of parallel paths and the other along the other pair of paths, and control means automatically operable to adjust the direction of operation of each motor in accordance with the configuration of a pattern on the pattern support and the position of the follower relatively to that pattern. In such a machine the follower follows the outline of the pattern and constrains the cutter support to move in a corresponding manner.

In prior machines of this kind, the control means brings the motors into action alternatively first in one direction and then in the other direction to feed the follower along a rectangular path relatively to the pattern. As either motor is thus operating as a feeding motor, the other is brought into action as a holding motor to feed the follower towards, and hold it against, the pattern so that the actual path traced by the follower relatively to the pattern is compounded by the relative movements given to it by the two motors as restricted by the outline of the pattern. The holding motor acts to hold the follower against the pattern to ensure that its outline is accurately followed but it will not do so satisfactorily if the feeding motor is feeding the follower along a path inclined away from the pattern at an angle in the order of 45° since the rate at which the holding motor feeds the follower towards the pattern may not be sufficient to ensure that it does not leave the pattern. It has been proposed to supply motive fluid to the motor which is acting as the holding motor at a lower pressure than that at which it is supplied to the other or feeding motor since a lower pressure can be used to hold the follower against the pattern than is needed to feed the cutter. This proposal would increase the risk of the follower leaving the pattern since the rate at which the follower is fed towards the pattern by the holding motor would be less than the rate at which it is fed by feeding

motor away from the pattern and the risk that the follower will leave the pattern is increased.

According to the present invention, a milling or like machine of the above kind is provided with means for supplying each motor with motive fluid at substantially constant pressure and at variable rate which means is adjusted by the control means to supply fluid to each motor at the appropriate rate for each position of the follower relatively to the pattern. With this arrangement the maximum rates at which the two motors can move the follower along its two paths relatively to the pattern are adjusted in accordance with the position of the follower in such manner that the follower is moved at all times towards the pattern. Thus the follower would be moved over a portion of the pattern that is inclined at 45° to both its paths by one motor operating to feed the follower at the high rate along one path towards the pattern and the other operating at the low rate to feed the follower along the other path away from the pattern, the resultant movement of the follower being thus directed towards the pattern.

A milling or the like machine according to the invention is particularly suitable for cutting holes in the wall of a hollow body. Thus in sleeve valve internal combustion engines the valve sleeve is formed with a plurality of ports which can be cut rapidly and to a high degree of accuracy by a milling machine constructed in accordance with the present invention. According to yet another feature of the invention this is provided for by compounding the movement of the follower and cutter of an arcuate motion described about the centre of the cylindrical element and a linear motion parallel with the long axis of the element.

A specific embodiment of the invention will now be described by way of example with reference to the accompanying drawings which illustrate a machine designed for the purpose of simultaneously cutting four ports in a valve sleeve for an internal combustion engine.

In the drawings—

Figure 1 is a plan view of the machine showing its general arrangement;

Figure 2 is a side elevation of a cutter head forming part of the machine;

Figure 3 is a plan view of the cutter head;

Figure 4 is a section on the line IV—IV of Figure 1 showing an outline of one of the patterns and of the means associated with the follower for initiating the changes in the direction and/or rate of movement of the follower as it traverses the pattern;

Figures 5 and 6 are diagrammatic views of the means for bringing about the changes in movement of the follower;

Figure 7 is a section of a cutter head taken on the line 7—7 of Figure 3;

Figure 8 is a section on the line 8—8 of Figure 7, and

Figure 9 is a section on the line 9—9 of Figure 5.

As shown in Figure 1 the machine generally comprises a table 10 which carries four cutter heads 11 each of which is capable of reciprocation on the circular slides 12. The sleeve 13 in which are to be cut ports 14 is clamped in position on table 10 so that it is centrally disposed about axis 15 and surrounding the sleeve is a ring 16 having patterns 17 formed in the walls thereof (see Figure 7). The slides 12, ring 16 and sleeve 13 are concentric. One cutter head 11 and its associated parts will now be described in detail.

The head 11 carries a cutter 18 which is in driving engagement with a spindle 206 (Figure 7) that extends through the head from the rear end thereof towards the axis 15. The head carries an electric motor 19 the spindle of which is provided with a gear 202 which forms part of a gear train 202, 203, 204 and 205, the latter being carried on the spindle 206. In this way the electric motor 19 transmits drive to the spindle 206 and hence to the cutter 18. The spindle 206 passes centrally through the roller 20 which constitutes the follower referred to above. This particular disposition of follower and cutter combined with the small extent which they protrude from the cutter head ensures that the cutter and follower reproduce the outline of the pattern 17 without variations due to deflections of the cutter and follower.

When each cutter 18 is advanced into cutting relationship with sleeve 13, follower 20 moves inwardly over pattern 17; if the follower is then moved around the periphery of the pattern to the cutter will produce on the outer face of the sleeve a groove of similar outline to that of the pattern. The path followed by the follower 20 and hence by the cutter 18 in moving around the pattern is compounded of two movements which are mutually at right angles, that is the reciprocating movement of the cutter head 11 on slides 12 and the vertical movement of slide 23. The reciprocating movement of the cutter head 11 on slides 12 is produced by a hydraulic motor 21 (see Figures 1 and 7) the ram of which is connected to a pin 207 carried by a lug 208. The latter is secured to a portion 209 of the head 11 so that when the ram is reciprocated its movement is transmitted to the head 11 through the agency described. The horizontal movements imparted to the head 11 will be applied to the cutter 18 and the follower 20 since these are carried by the head. It follows therefore that motor 21 will impart to the cutter and follower horizontal movements about the axis 15. It is to be understood that the motor 21 is suitably carried on the under face of the table 10. The vertical movements of the slide 23 are produced by a hydraulic motor 24 which is carried by the cutter head. The ram 200 of the hydraulic motor 24 is connected by rod 201 with the slide 23 so that when pressure fluid is admitted to the hydraulic motor ram 200 will reciprocate the slide 23 upwardly or downwardly in a vertical direction. Thus when pressure fluid passes by pipe 68 to motor 24 the slide will be raised and when

pressure fluid passes by pipe 69 to the hydraulic motor the slide will be lowered. As is clear from Figure 7 the spindle 206 is mounted for rotation in the slide 23 so that when the latter is raised and lowered the spindle 206, and hence the cutter 18 and follower 20, partake of a similar movement.

The drive from the motor 19 to the spindle 206 is in no way affected by the vertical movements which are imparted to the slide 23 since the motor and the gear train between the motor and the spindle 206 are all carried by the slide 23 and are moved vertically therewith.

The hydraulic motors 21 and 24 are each supplied with fluid under pressure (as will be more fully described hereinafter) by an associated variable delivery pump so that the rate of movement of the follower 20 and cutter 18 can be altered in both the horizontal and vertical directions by adjusting the pump delivery.

Let it be assumed that the follower (and hence the cutter) is about to trace out the port outline 14 shown in Figure 4: the follower is in engagement with pattern 17 and the common axis of follower and cutter coincides with point *a*. As the follower travels around the periphery of the pattern in an anti-clockwise direction the track which it describes is as follows:

(i) From *a* to *b* the horizontal hydraulic motor 21 is supplied by its pump at a high rate of delivery and consequently the rate of movement of the follower in a horizontal direction is correspondingly high. During this movement the hydraulic motor 24 is supplied with fluid at a low rate of delivery so that the follower remains in contact against surface *p* and accurately follows the pattern.

(ii) From *b* to *c* the horizontal hydraulic motor 21 is supplied with fluid at a low rate of delivery so that the follower accurately follows the pattern round the bend and down face *q*. The vertical hydraulic motor 24 is supplied by its pump at a high rate of delivery so that the follower moves downwardly at a correspondingly high rate.

(iii) From *c* to *d* the horizontal motor 21 is supplied at a low rate so that the follower tends to move slowly in a direction away from face *r* but to ensure that the follower is kept in contact with the face the vertical motor 24 is supplied with fluid at a high rate so as to move the follower downwardly at a correspondingly high rate.

(iv) From *d* to *e* the hydraulic motor 21 is supplied at a high rate so that the follower moves rapidly along the surface whilst being maintained in contact with the face *s* by fluid which is delivered at a low rate to the vertical motor 24 by its associated pump.

(v) From *e* to *f* the horizontal hydraulic motor 21 urges the follower against face *t* whilst the vertical motor 24 draws the follower along the face at a high rate of movement.

(vi) From *f* to *a* the horizontal hydraulic motor 21 is urging the follower against surface *u* for which purpose it is fed with fluid at a high rate of supply whilst the vertical motor 24 moves the follower along face *u* towards point *a* at a low rate of movement: this ensures that the follower is kept in contact with the face of the pattern.

It will have been appreciated that by suitably selecting the direction and rate of movement of the follower in a horizontal and vertical direction it accurately follows the contour of the pat-

tern, these factors being suitably preselected when a change in contour is immediately due to take place as the follower moves around the pattern.

The means for initiating these changes in direction and movement is shown in Figures 4 and 5. When the follower and cutter occupy position *a* the cutter head 11 is in its extreme right-hand position in moving to which it has brought switch rod 25 against stop 26 carried by table 10 so that electric switch *a'* is closed. The closing of this switch energises one or more solenoids (as will be more fully hereinafter described) which brings into operation the horizontal and/or vertical motors 21 and 24, the required direction and rate of movement in the horizontal and vertical directions of the follower and cutter during its movement along face *p* is produced. Similarly when follower and cutter occupy position *b* the cutter head 11 is in its extreme left-hand position in moving to which switch rod 27 has engaged stop 28 (which is carried by table 10) and electric switch *b'* is closed to select the feeds to the hydraulic motors 21, 24 which will result in the follower accurately following face *q* of the pattern. Whilst the follower is traversing face *q* the cutter head remains in the extreme left-hand position so that switch *b'* remains closed. The follower moves downwardly however until it reaches point *c* whereupon switch *c'* is closed and the feeds to the hydraulic motors selected for the follower to traverse face *r* of the pattern. Closing of switch *c'* as described is effected by switch arm 29 which is carried by slide 23 and is consequently reciprocated in the vertical direction when the slide is operated to move the follower upwardly and downwardly. Now when the slide has reached the bottom of its travel and consequently the follower has assumed position *d* switch *d'* is closed. This switch is in series with switch *d''* which is normally closed: accordingly when switch *d'* closes, the feeds from the pumps to the hydraulic motors are suitably selected for the follower to move across face *s* of the pattern. The vertical slide 23 in its lower extremity engages trigger arm 30 so that when the cutter head 11 moves to the right arm 30 is displaced firstly to open switch *d''* and then when the head has reached a position in which the follower coincides with point *e* to close switch *e'*. This again selects the desired feeds to the hydraulic motors so that the follower accurately traces the contour *t*; this involves an upward movement of the vertical slide which takes it out of engagement with arm 30. The latter is then spring urged to assume its normal position whereupon switches *d'* and *e'* are opened as switch *d''* is closed by the return springs of the switch. When the vertical slide has risen so that follower reaches point *f* the switch arm 29 has taken up a position to close switch *f'* thus selecting the feeds to the hydraulic motors which are required for the follower to move over part *u* of the pattern. This movement continues until the follower reaches point *a*: advantage being taken of the horizontal movement of the cutter head entailed so that switch *a'* is closed when the follower reaches this point. To ensure that the follower and cutter do not commence their travel along face *p* before the follower has completed its travel along face *u* to its highest position, switch *a''* is provided in series with switch *a'* so that the horizontal and vertical hydraulic motors are not fed with fluid to direct the fol-

lower along face *p* until switch arm 29 has taken up a position to close switch *a''*.

To ensure that switch arm 29 only engages switch *c'* in its downward travel and switch *f'* during its upward travel the switch arm carries a selector device generally indicated at 217 (Figure 9). The latter comprises a channel member 218 which is carried by the arm 29 and a contact piece 31 mounted therein. The contact piece 31 is maintained in frictional engagement with the member 218 by means of a plate 220 between which and the contact piece 31 there is disposed a friction plate 219. The friction plate 219 and the plate 220 are pressed into engagement with the contact piece 31 and the latter into engagement with the member 218 by bolts 221 which pass through a cover plate carried by the member 218. The contact piece 31 engages stationary pins 32 and 33 respectively during the upward and downward travel of the member 218 when the arm 29 is moved in the corresponding directions. Thus as the arm approaches the upper limit of its travel the contact piece 31 engages pin 32 and is moved to the left and in its downward travel it engages pin 33 and is urged to the right. The contact piece 31 is frictionally held in the member 218 in such a manner as to enable the pins 32 and 33 to move the contact piece as indicated. However, this frictional effect is of sufficient magnitude to ensure that when the contact piece 31 is brought into engagement with the switches *c'* and *f'* the latter are incapable of moving the contact piece relatively to the member 218 since the springs of these switches are not sufficiently strong for thus purpose. As a consequence when the arm approaches the upper limit of its travel the contact-piece engages pin 32 and is moved to the left so that in its subsequent downward movement it closes switch *c'* and clears switch *f'*. Having passed switch *f'*, contact-piece 31 engages pin 33 and is urged to the right so that in the subsequent upward movement of the arm 29 switch *f'* is closed and switch *c'* remains open. It will have been noted that when switches *a'* to *f'* are closed they are immediately opened again by their associated springs which are respectively indicated at 210 to 216 with the exception of switch *b'*, the reason being that if the solenoids associated with any one switch are maintained energised the next succeeding switch may energise solenoids which conflict in their effect with those that have been maintained energised. This circumstance does not arise in connection with switch *b'*.

Turning now to Figures 5 and 6: the train of events following the closing of the switches will now be described. Broadly the effect of closing any one of the switches is to energise one or more solenoids, each of which either adjusts a valve controlling the flow of pressure air to a pneumatic motor, which in turn adjusts a hydraulic valve to determine the direction of feed to the horizontal or vertical cylinder, or alternately adjusts the delivery of the feed pump. So as clearly to distinguish between the electric circuit, the pneumatic pipe lines and the hydraulic pipe lines in the drawings the first is shown as a thin single line, the second as a thick single line and the third as a thin double line.

Figure 5 shows the electrical switches *a'*—*f'* and the horizontal and vertical hydraulic motors 21, 24 already described: the electrical connections leading from the switches to the solenoids of Figure 6 are also shown.

Referring now to Figure 6: a constant delivery pump 34 supplies oil under pressure to the variable delivery pumps 35, 35a so as to maintain these pumps flooded whether they be delivering fluid or not. Fluid under pressure from pump 35 passes to the horizontal hydraulic motor 21 (Figure 5) by way of valve 36. The latter comprises three spaced piston elements 37, which are coupled together to form a unit, longitudinal adjustment of which enables the fluid flowing from pump 35 into pipe 38 to be directed into either pipe 39 or 40. The arrangement is that if the piston unit 37 is in its left-hand positions (as shown in Figure 6) fluid is pumped along pipe 38, through valve 36, pipe 39 to the left-hand side of the hydraulic motor 21 to move the cutter head from left to right. Simultaneously fluid is forced out of the motor 21 through pipe 40, valve 36 and drain pipe 41. If the pistons are in their right-hand position fluid is pumped through pipe 38, valve 36, pipe 40 to motor 21, and the cutter head moves from right to left. Simultaneously fluid drains from the motor by way of pipe 39, valve 36, and drain pipe 42.

The hydraulic valve 36 is actuated by a pneumatic motor 43. The latter comprises a pair of pistons 44, 45, which are connected with the piston unit 37 by links 46. When air under pressure acts on piston 44, valve 36 is set to permit pressure fluid to reach motor 21 by pipe 39, similarly when air under pressure is admitted to piston 45 valve 36 is set to permit pressure fluid to flow along pipe 40 to motor 21. The admission of pressure air to pistons 44, 45 is controlled by valve 55 which comprises three spaced and coupled pistons 47 the position of which determines whether pressure air from the branch pipe line 48 enters by duct 49 to piston 44 or by duct 50 to piston 45: the air being permitted simultaneously to escape from the inert piston through valve 55 and by way of ducts 51 or 52. The position of the piston unit 47 is determined by the solenoids 53, 54, which are connected to one or more of the switches a'—f' already referred to. Thus in the position shown in Figure 6, solenoid 54 has been energised, the pneumatic piston unit 47 is in its right-hand position and air under pressure passes from pipe 48 through valve 55, and duct 49 to piston 44 to actuate the hydraulic valve 36 as described: at the same time air in the cylinder of piston 45 escapes by valve 55 and duct 52.

A similar arrangement of solenoids, pneumatic valve and motor and hydraulic valve is associated with vertical hydraulic motor 24 and variable delivery pump 35a. Hence solenoids 56, 57 actuate the pneumatic piston unit 58 of valve 59 to permit pressure air from pipe 60 to pass to piston 61 or 62 of pneumatic motor 63, said pistons being respectively coupled to the hydraulic piston unit 64 of valve 65 by links 66 so that pressure fluid from the pump 35a enters valve 65 by pipe 67 and passes by pipe 68 or 69 to the vertical hydraulic motor 24. As in the corresponding unit associated with the horizontal hydraulic motor 21, escape ducts 70, 71 are respectively associated with pistons 61, 62 of the pneumatic motor and drain pipes 272, 273 respectively with the hydraulic piston unit 64.

The hydraulic and vertical motors 21 and 24 are supplied with pressure fluid at either of two rates so that the motors produce a corresponding rate of movement of the follower and cutter. The rate of feed in the horizontal direction is selected by the switches a'—f' closing the circuits to solenoids 73 or 74 to displace the piston

unit 75 of valve 76 to the left or right and permit pressure air from line 77 to pass to cylinders 78 or 79 respectively by way of pipes 80, 81. When pressure air enters cylinder 78 piston rod 82 displaces lever 83 to its maximum extent and the variable delivery pump 35 delivers fluid at a high rate with consequent fast movement of the head in the horizontal direction whilst if pressure air is supplied to the cylinder 79 piston rod 84 displaces the lever 83 to its minimum operating extent and the pump delivers at a low rate: the cutter head then moves slowly. The lever 83 is spring urged against the piston rods. Air from the inert cylinders escapes through pipe 80 or 81, valve 76 and pipes 86 or 87 respectively. In the same way the rate of feed in the vertical direction is determined by switches a'—f' closing the circuit to solenoids 88, 89 associated with the piston unit 90 of valve 91 which regulates the admission of pressure air from pipe 92 to pipes 93 or 94 and thence to the cylinders 95, 96. The piston rod 97 of cylinder 95 displaces lever arm 98 of the variable delivery pump 35a to provide the high rate of delivery and consequently fast movement in the vertical direction; the piston rod 99 of cylinder 96 displaces arm 98 to ensure low rate of delivery from pump 35a. Air from the inert cylinder escapes by pipe 93 or 94, valve 91 and pipes 100, 101 respectively. The means just described determines the rate at which the cutter will move in each direction if it is not constrained by the pattern which will, however, prevent, or slow down, the movement in one or the other direction so that the associated motor will not take in fluid or will do so more slowly than it is delivered by the associated pump. The excess fluid is delivered to drain through relief valves 136 and 137, connected to the delivery pipes 38 and 67 of the pumps 35 and 35a, and drain pipes 138 and 139. The relief valves also limit the pressure at which the fluid is delivered so that it is delivered at substantially constant pressure at the full load on the motors.

It will be noted from Figure 6 that the air supply to pipe 48 (which is the supply for regulating the direction and rate of movement of the follower and cutter in a horizontal direction) and pipes 60 and 92 (which is the supply regulating direction and rate of feed in a vertical direction) passes through valve 102. This valve comprises a piston unit 103 which is actuated by solenoids 104, 105; energization of solenoid 104 sets valve 102 to permit pressure air from the main supply line 106 to pass to the valves 55, 59, 76 and 91 whilst energisation of solenoid 105 sets valve 102 to prevent admission of air to the valve and simultaneously to enable the air in these valves to escape to atmosphere by pipes 48, 60, 92, valve 102 and duct 107.

The apparatus described so far has been concerned with imparting movements in a vertical and horizontal direction to the follower and cutter so that the shape of the pattern is accurately reproduced. It is necessary to provide means for advancing the cutter towards the work, and for increasing the depth of the cut as the machining operation proceeds; it is also highly desirable to provide a single starting control for the four cutter heads so that they simultaneously commence work and to provide individual means associated with each head to operate solenoid 105 and valve 102 so that immediately a port has been formed in sleeve 13 the tracing operation of the follower and consequently the cutting operation associated with that port stops automatically. It

follows that although the four cutter heads start their cutting operations at the same time the shapes of the valve ports being different one may finish before the other.

The vertical slide 23 is carried by the cutter head 11 through the intermediary of a horizontal slide 108 (Figure 3) which is capable of being advanced to bring the cutter 18 against sleeve 13. Slide 108 is advanced by two agents against the action of a spring 228 (Figure 7) which at one end abuts the member 209 of the head 11 and the other end of which abuts a plate 229. The latter is secured to a plate 230 which is bolted to each of the slides 108 between which the slide 23 is carried. As a consequence when the slide 108 is moved towards the axis 15 by either of said two agents the spring 228 is compressed and tends to urge the slide 108 back to its initial position. Of the two agents referred to one is provided to advance the cutter up to the sleeve prior to the commencement of the cutting operation. Advantage is taken of this sequence of operations to provide a single master control which will firstly bring about the initial infeed of the four cutters and then will bring the electric-pneumatic-hydraulic apparatus above described into operation. In Figure 6 the master control is generally indicated at 109 and comprises a valve 110 which controls the delivery of pressure fluid from pump 34 to pipe 112, pipe 140 and to the pair of infeed cylinders 111 (Figures 1, 2, 3) and from these cylinders to drain (for convenience only one such cylinder is shown in Figure 6). The piston rods 113 of cylinders 111 engage a cross-member 114 (Figures 1, 2 and 3) secured to the slide 108 by bolts 231, so that when the handle 224 of control 109 is pushed inwardly valve 110 is set to allow pressure fluid from pump 34 to pass to the infeed cylinders 111 whereupon piston rods 113 advance to engage cross-member 114 and move slide 108 and cutter 18 towards sleeve 13.

The second agent which is provided to advance the cutter is an infeed cam 115 which is carried by the cutter head 11 and which is driven (Figures 2, 3, 6 and 8) through bevel gears 116, shaft 117 and either pinion 118 or pinions 119, 120 from rack 121 when the vertical slide 23 which carries the rack moves upwardly and downwardly respectively. Pinions 118 and 119 each incorporate a pawl and ratchet free wheel device 225, 226 respectively so that in the upward movement of vertical slide 23 the drive from rack 121 is transmitted to cam 115 by gears 118, 116 whilst pinions 119, 120 are driven idly since the pawl and ratchet device 226 is then designed to free wheel, and in the downward movement the drive is transmitted by gears 120, 119, 116 whilst pinion 118 is driven idly since the pawl and ratchet device 225 is then designed to free wheel. The cam is thus always rotated in an anti-clockwise direction (see Figure 6) each time the vertical slide is operated and, engaging with a roller 122 carried by a pin 227 which is threaded into slide 108 advances the latter and the cutter as it rotates. The apparatus is designed so that the port is completely cut when the follower has traced around the pattern three times during which time it is necessary to advance the cutter from the initial to the final cut. This requirement is met by ensuring that the cam 115 rotates once during the three circuits of the pattern described by the follower the number of times the follower traces around the pattern to complete the cutting operation is determined by the material of the sleeve

13, its wall thickness, the cutting speed of the cutter 18 and the surface finish which is required for the wall of the ports 14. The machine being described has been designed with these factors in mind and the number of tracing movements referred to was selected to ensure accuracy and good finish for each port opening. When other considerations prevail the number of tracing movements may be varied to accord.

The cam profile is clearly seen in Figure 6 and it will be noted that it is of gradually increasing radius from points 115a to 115b which represents the advance to which the cutter is subjected by the cam. At 115b the cutting operation is about to stop and actually does so when roller 122 drops into step 115c. This it automatically does on passing 115b as the slide 108 is spring returned to move the cutter 18 away from the sleeve 13, and consequently the roller 122 towards the cam.

Actuation of the infeed cylinders 111 as described advances cross-member 114 and hence slide 108 sufficiently for the roller 122 to be lifted out of step 115c so that thereafter on the first vertical movement of slide 23 the cam 115 will be rotated as described above to bring part of the cam lying between 115a-115b into engagement with the roller 122. The function of the infeed cylinders is fulfilled when they bring cutter 18 up to sleeve 13 and raise roller 122 out of step 115c as indicated. At any time after the cutting operation has been commenced (that is after slide 23 has been moved vertically to bring cam 115 into engagement with roller 122 to perform the infeed movement of the cutter 18) the control 109 may be returned to its non-operative position. This will not result in an interruption of the cutting operation but only in the cylinders 111 being connected to drain by pipe 112, valve 110 and pipe 134 as hereinafter explained.

The roller 122 engages a lever 123 which is pivotally carried by the cutter head so that as the slide 108 is advanced by the infeed cylinders 111 and the cam 115 the lever is continuously displaced by the roller in one direction; upon the roller dropping into step 115c (the infeed cylinders having previously been drained so that slide 108 can be spring returned to its full extent) the lever 123 is returned by spring 234 to its initial position. This lever engages a switch rod 124 carrying upon an insulating block a contact piece 125, said rod 124 being reciprocated as the lever is displaced when the cutter is advanced and returned as above described. Co-operating with contact piece 125 are three contacts 126, 127 and 128 the first of which when it is engaged by 125 closes a circuit which energises solenoid 105 to close valve 102 and thus cut-off the pressure air supply to the various pneumatic valves and motors so that the electric-pneumatic-hydraulic apparatus is rendered inoperative, the second (127) energises solenoid 104 to open valve 102 and thus bring said apparatus into operation, and the third (128) energises solenoid 129 thereby to displace the piston unit 130 of pneumatic valve 131 to permit pressure air from main pipe line 106 to pass by branched pipe 132 to pneumatic motors 133 and simultaneously return control 109 to its "off" position and thereby place valve 110 so that pressure fluid drains from the infeed cylinders 111 through drain pipe 134. The piston unit 130 is returned by spring 135 to a position to cut-off pressure air from pneumatic motor 133, when the contact piece 125 passes beyond the contact 128.

When the infeed cylinders 111 advance the cutter to the cutting position, lever 123 moves switch

rod 124 to bring contacts 125, 127 into engagement to energise solenoid 104 thereby bringing the apparatus into operation, and cam 115 continues the displacement of switch rod 124 until contacts 125, 128 engage and solenoid 129 is energised with the effects described in the preceding paragraph. When the cutter has traced around the pattern three times and the cutter has completed its cutting operation and has returned to point *a* (Figure 4) the roller drops into step 115c, the switch rod 124 is spring-moved to bring contacts 125, 126 into engagement to energise solenoid 105 and thereby stop the apparatus.

The operation of the machine will now be described it being understood that the master control 109 simultaneously brings all four cutter heads into cutting operations but that each head then performs the cutting operation independently. Accordingly the description will commence with the actuation of the master control 109 simultaneously to start the cutting operation in the four cutter heads and will then be concerned with the sequence of operations entailed in cutting one of the four ports, namely that shown in Figure 4.

The general state of the mechanism is that the follower and cutter occupy position *a*, switch *a'* is therefore closed, but in completing the last of the preceding sequence of operations contacts 125, 126 were engaged thereby energising solenoid 105 and adjusting valve 102 to render the apparatus inoperative: accordingly switch *a'* being closed has no effect. The infeed cylinders 111 have been drained permitting slide 108 to be spring-returned to its retracted position and cutter 18 to be withdrawn from its cutting position: roller 122 is engaging step 115c and accordingly switch arm 124 is in its outer position with contact 125 to the left of contact 126. The handle 224 of master control 109 is in its "off" position (as shown in Figure 6) so that valve 110 is set to prevent flow of pressure fluid from pump 34 and pipe 140 to pipe 112 and hence to the infeed cylinders 111.

Pumps 34, 35, 35a are delivering fluid but as the last operation performed by the hydraulic motors 21, 24 was that of moving the follower 20 along face *u* of the pattern, valves 36, 65 (Figure 6) remain set in a position to enable this operation still to be performed. The follower is therefore pressed inwardly to the corner formed between faces *p* and *u*, and switch arm 29 will be in its highest position so that switch *a''* is closed. As the fluid being circulated by pumps 35, 35a cannot drive the hydraulic motors 21, 24 their action being merely to press the follower against faces *p* and *u* of the pattern 17 the fluid under pressure is delivered to drain through relief valves 136, 137 and drain pipes 138, 139 respectively. Similarly the fluid under pressure from pump 34 passes to the closed valve 110 by pipe 140 and is delivered to drain by way of relief valve 141 and drain pipe 142.

From the disposition of the various parts referred to above, the cutter heads 11 are simultaneously brought into operation upon the operator pushing the handle 224 of the master control 109 inwardly to set valve 110 so that pressure fluid from pump 34 passes by pipe 140 to the valve and therefrom to each pair of infeed cylinders 111 associated with each cutter head by a pipe 112 leading to each such cylinder, whereby piston rod 113 is advanced, engages bar 114, and moves slide 108 forward so that cutter 18 is brought up to sleeve 13. The cutter is now in a

position ready to commence the cutting operation which will result in the formation of port 14, motor 19 having previously been started to drive the cutter 18. Simultaneously with the advance of cutter 18 roller 122 carried by slide 108 is raised clear of step 115c.

In performing the operation of advancing slide 108 lever 123 is displaced to move switch rod 124 downwardly so that contact 125 is moved to engage contact 127.

Engagement of contacts 125, 127 completes the circuit from the source of electrical supply 143 (in the present instance a transformer) to solenoid 104 by conductors 144, 145, 146 and the earth return 147 so that the piston unit 103 of valve 102 takes up the position shown in Figure 6. Pressure air from the main supply line 106 is then free to pass to pneumatic valve 91 by pipe 92, to valve 59 by pipe 60, to valve 55 by pipe 48, and to valve 76 by pipe 77; the electric-pneumatic-hydraulic apparatus is accordingly brought into operation.

As already stated electric switches *a'* and *a''* are closed so that a circuit from the transformer 143 by conductors 144, 145, solenoid 53, conductors 148, switch *a'*, conductor 149, switch *a''* to the earth return conductor 150 is completed and solenoid 53 is energised. The piston unit 47 of valve 55 assumes its left-hand position so that pressure air from pipe 48 flows through duct 50 and acting on piston 45 of pneumatic motor 43 moves piston unit 37 of valve 36 to the right-hand position. Simultaneously air is expelled through duct 49 by piston 44 and escapes through valve 55 and escape pipe 51. Movement of the hydraulic valve 36 permits pressure fluid from pipe 38 to pass along pipe 40 to hydraulic motor 21 which thereupon operates to move the cutter head 11 over slides 12 from right to left. Fluid in the hydraulic motor 21 is simultaneously expelled through pipe 39, valve 36, and escape pipe 42. It is necessary that the follower move over face *p* of pattern 17 in the direction indicated, at a high rate of movement and that simultaneously the vertical motor is supplied by pump 35a with pressure fluid at the low rate of delivery so that vertical slide 23 is directed upwardly and follower 20 engages face *p* of the pattern. This vertical movement has already been selected by switch *b'* when the follower was at point *b* as will appear hereinafter and accordingly no change in the operation of the vertical motor 21 is required at point *a*.

The horizontal motor 21 moves the cutter head 11 from its right-hand position towards the left (Figure 3): when this motion commences, switch rod 25 disengages stop 26 and switch *a'* is opened thereby breaking the circuit to solenoid 53. As the head approaches its left-hand position and the follower reaches point *b*, switch rod 27 engages stop 28 and closes switch *b'*, whereupon the circuit from transformer 143 by conductors 144, 145, solenoid 56, conductor 150 and earth return 151 is completed: solenoid 56 is energised and piston unit 58 of valve 59 is displaced to permit pressure-air from pipe 60 to pass to piston 62 which is thereupon displaced to move piston unit 64 of hydraulic valve 65 to the right and permit pressure fluid from pipe 67 and pump 35a to enter hydraulic motor 24 by pipe 69, whereupon the motor operates to move slide 23 downwardly with simultaneous draining of fluid from the motor by pipe 68, valve 65, and drain pipe 73. This will direct the follower 20 downwardly along face *g*. A high rate of feed in this direction should

be provided: this is also effected by switch *b'* closing a circuit incorporating transformer 143, conductors 144, 152, solenoid 89, conductor 153, switch *b'* and earth return 151. Solenoid 89 is thus energised, piston unit 90 is drawn towards the solenoid and pressure air from pipe 92 passes by pipe 93, to cylinder 95 to displace piston rod 97 and lever 98 to set pump 35a to deliver to the hydraulic motor 24 at the higher rate. Simultaneously air escapes from cylinder 96 by pipe 94, valve 91 and escape pipe 101. The direction of movement of the follower in the horizontal direction as it traverses face *q* of the pattern is to be maintained the same as for face *p*; as however it is only required to press the follower against face *q* the rate of fluid supply to motor 21 is to be changed from the higher to the lower value. Accordingly switch *b'* also completes a third circuit including transformer 143, conductors 144, 145, solenoid 73, conductor 154, switch *b'* and earth return 151: solenoid 73 is thereby energised and piston unit 75 moves toward the solenoid to permit air under pressure from pipe 77 to pass through valve 76 to pipe 81 and cylinder 79 to displace piston rod 84 and lever 83 to select the low rate of feed from the pump 35a. At the same time air escapes from cylinder 78 by pipe 80, valve 76, and escape pipe 86.

Slide 23 is moved downwardly and the follower traverses face *q*, the cutter head 11 being maintained in its left-hand position by hydraulic motor 21 and accordingly switch *b'* remains closed. As slide 23 moves downwardly it carries rack 121 with it and drives cam 115 through gear 118, shaft 117, and bevel gears 116 so that the cam is rotated anti-clockwise and advances the cutter 18 into cutting engagement with sleeve 13. The cutting operation then commences. Rack 121 also rotates the gears 119, 120 but the free-wheel device incorporated in gear 119 permits this rotation to be of an idling nature. At point *c* the follower has moved downwardly until the vertical slide 23 draws switch rod 29 to a position where contact piece 31 engages contact *c'* to complete the circuit including transformer 143, conductors 144, 152, solenoid 54, conductor 155, switch *c'* and earth return 150: solenoid 54 is energised and draws piston unit 47 of valve 55 towards it and pressure air from pipe 48 is passed by duct 49 to piston 44 which it displaces to move the piston unit 37 of hydraulic valve 36 to the left. This permits the fluid which is being supplied by pump 35 at a low rate of feed to pass from pipe 38 to pipe 39 and hydraulic motor 21 which thereupon moves the cutter head 11 away from stop 28 towards the right.

The head 11 moves toward the right and simultaneously slide 23 is moved downwardly at a high rate of movement so that the follower remains in contact with face *r* of pattern 17. When the follower leaves point *c* in its movement along face *r* the horizontal movement enables switch *b* to open and the downward vertical movement permits switch *c'* to open.

Further downward movement of switch rod 29 carries contact piece 31 past switch contact *f'* without however closing the circuit incorporating this switch. As contact piece 31 passes pin 33 it engages therewith and the contact piece is moved to the right so that on the subsequent upward movement of rod 29 switch *f'* only will be closed.

When the follower and cutter reach their lowest extremity (which occurs when the follower reaches point *d*) switch *d'* is closed (and as al-

ready stated switch *d''* is normally closed) so that a circuit including transformer 143, conductors 144, 145, solenoid 88, conductors 156, 157, switch *d''*, conductor 158, switch *d'* and earth return 150 is completed to energise solenoid 88 whereupon piston unit 90 of valve 91 moves towards the solenoid and pressure air passes from pipe 92 through valve 91 to pipe 94 and cylinder 96 to set pump 35a for the low rate of fluid delivery. At the same time air escapes from cylinder 95 by pipe 93, valve 91, and escape pipe 100. When switch *d'* is closed it also completes a circuit containing transformer 143, conductors 144, 152, solenoid 74, conductor 157, switch *d''*, conductor 158, switch *d'* and earth return conductor 150. This effects energisation of solenoid 74 with consequent movement of piston unit 75 of valve 76 towards the solenoid. Pressure air from pipe 77 passes through the valve to pipe 80 and cylinder 78, which results in the high rate of feed to hydraulic motor 21. When valve 76 is set as described it enables air in cylinder 79 to escape by pipes 81 and 86. Follower 20 will consequently move across face *s* at a high rate of movement in the horizontal direction and with a low rate of feed to vertical motor 24 to keep the follower against this face.

As the cutter head 11 commences to move to the right, the vertical slide 23 which is at its lowest extremity engages arm 30 and brings it initially into engagement with switch rod 85 and then moves the latter to open switch *d''*. As the sleeve continues its movement arm 30 continues to displace switch rod 85 towards the left until when the follower 20 has reached position *e*, the switch rod has been so displaced that switch *e'* closes. This brings into operation three circuits, one comprising transformer 143, conductors 144, 152, solenoid 57, conductor 159, switch *e'* and earth return 160, the second comprising transformer 143, conductors 144, 152, solenoid 89, conductors 153, 161, switch *E₂* and earth return 160, whilst the third comprises transformer 143, conductors 144, 145, solenoid 73, conductor 154, switch *e'* and earth return 160. It will be noted that earth return 160 is associated only with switch *e'* and not with switch *d''*.

The effect of energising solenoid 89 is to draw piston unit 90 towards the solenoid and permit pressure air to pass from pipe 92 by way of valve 91 to pipe 93 and cylinder 95 so as to select the high rate of fluid supply by pump 35a to hydraulic motor 24, whilst the effect of energising solenoid 57 is to draw piston unit 58 of valve 59 towards the solenoid thereby permitting pressure air to pass to piston 61 to displace it and piston unit 64 of hydraulic valve 65 whereby fluid from pump 35a flows by pipes 67, 68 to motor 24 which thereupon operates to raise slide 23 and cutter 18 carried thereby. The effect of energising solenoid 73 is to displace piston unit 75 to the left to permit pressure air from pipe 77 to pass by way of pipe 81 to cylinder 79 whereupon the slow rate of fluid delivery is selected for pump 35. Simultaneously with the operation of the hydraulic motors and rate-selector cylinders as above described, escape of air and drainage of hydraulic fluid is effected through the various valves as already described hereinbefore.

As slide 23 moves upwardly it disengages arm 30 which moves to its normal position away from switch rod 85, switch *e'* is spring-opened and switch *d''* closed. Due to the upward movement of sleeve 23, switch arm 29 ascends and switch

d' opens so that no train of events follows this closing of switch d'' .

When the follower has moved over face t and reached point f , switch f' is closed completing two circuits, one including transformer 143, conductors 144, 145, solenoid 88, conductors 156, 157, 162, switch f' and earth return 150, the other including transformer 144, 152, solenoid 74, conductors 157, 162, switch f' and earth return 150.

By thus energising solenoid 88, piston unit 90 of valve 91 is drawn towards the solenoid and permits pressure air to reach cylinder 96 by pipe 94 whereby a slow rate of fluid feed to motor 24 results. Air is simultaneously drained from cylinder 95 as has already been described. Solenoid 74 is energised to set valve 76 to allow pressure air to pass to cylinder 78 thereby selecting the high rate of feed to hydraulic motor 21. The follower traverses face u of the pattern and on reaching point a switch a' is closed with the results already described.

After switch f' is closed the further upward movement of switch rod 29 carries contact piece 31 past switch contact c' without however closing the circuit incorporating this switch. As contact piece 31 passes pin 32 it engages therewith and the contact piece is moved to the left so that on the subsequent downward movement of rod 29 switch c' only will be closed.

During the upward movement of slide 23 as the follower traverses the pattern from position e to a rack 121 drives cam 115 through gears 120, 119, shaft 117 and bevel gears 116 so that rotation of the cam advances cutter 18 and increases the depth of cut. Rack 121 also drives gear 118, however the free-wheel device incorporated in this gear enables the gear to rotate idly.

The sequence of operations outlined above is repeated until the follower has traversed the pattern three times and returned to position a' . The cutting operation is then complete, the port having been formed in sleeve 13.

As the follower moves along face u in its last circuit around the pattern, cam 115 is advancing roller 122 and hence cutter 18 to the limit of their travel. Switch rod 124 is therefore approaching its lowest extremity and in so doing brings contacts 125, 128 into engagement whereby a circuit including transformer 143, conductor 144, solenoid 129, conductor 163, contacts 125, 128 and earth return 147 is completed. Solenoid 129 on being thus energised draws piston 130 of valve 131 towards the right against the pressure of spring 135 to permit pressure air from main pipe line 106 to reach pneumatic motor 133 by way of ducts 132. Valve 110 is consequently moved to the right to place the handle 224 of the master control 109 in the "off" position and to permit fluid to drain from infeed cylinders 111 by way of pipe 112, valve 110 and drain pipe 134. Although the infeed cylinders are thus drained cam 115 maintains the cutter forward in its cutting position.

When follower 20 has reached position a and the cutting operation has been completed roller 122 has passed point 115b of cam 115. Slide 108 is then spring urged to retract the cutter from its working position. Roller 122 thereupon drops into step 115c and as a consequence switch rod 124 is spring returned upwardly and contacts 125, 126 engage. The circuit incorporating transformer 143, connectors 144, 145, solenoid 105, conductor 164, contacts 125, 126 and earth return 147 is thereby completed. Solenoid 105 when thus energised draws piston unit 103 of valve 102 towards it and thereby cuts off the supply

of pressure air from main pipe 106 to pipes 48, 60, 77 and 92 thus rendering the electric-pneumatic-hydraulic apparatus inoperative.

In the event that the operator wishes to stop any one of the four cutter heads an emergency stop switch 165 (Figure 6) is provided in the electric circuit associated with each cutter head. This switch on being closed completes a circuit incorporating transformer 143, conductors 144, 152, solenoid 105, conductors 164, 166 and earth return 167. The effect of energising solenoid 105 as already explained is to cut off the supply of compressed air to the pneumatic valves and motors.

It will be appreciated that the switches $a'-f'$ are selected to close at such times that it will be ensured the follower is always maintained in contact with the pattern. As the outline of the port or other hole which is to be cut varies so will the disposition of the switches relative to the peripheral path of the follower. Although in the above description a total of six switches was referred to it is to be understood that a greater or in certain limited cases a lesser number may be provided.

The machine forming the basis of the invention is also capable of being used for producing irregular shapes in plane bodies for instance in forming the scallops commonly found around the periphery of the articulated-rod carrier of a radial engine connecting-rod. The apparatus may be also used for the accurate production of positive cams, in which case the cutter forms a cam groove in the cam plate the cutter being advanced towards the plate as it moves along the groove until the required depth of groove is produced whereupon the cutter is retracted from the cutting position.

I claim:

1. A milling or like machine comprising a cutter support and a work support, which cutter support is mounted for movement relatively to the work support along two substantially perpendicular paths, a pattern support and a follower to co-operate with a pattern on the pattern support, which follower is mounted for movement relatively to the pattern support along two paths parallel to the aforesaid paths and is so interconnected with the cutter support that their compounded relative movements are similar, two reversible hydraulic motors arranged one to impart the said relative movement to the cutter support and the follower along one pair of parallel paths and the other along the other pair of paths, a separate variable delivery pump and relief valve for supplying each motor with motive fluid at constant pressure, means for independently varying the delivery of each pump, and control means automatically operable to adjust the direction of operation of each motor and the rate at which motive fluid is supplied to it in accordance with the configuration of a pattern on the pattern support and the position of the follower relatively to that pattern.

2. A milling machine according to claim 1 comprising a separate reversing valve for each motor for controlling its direction of operation, and a separate pneumatic motor for adjusting the setting of each valve, and a separate pneumatic valve for each pneumatic motor, which pneumatic valves are actuated by electric means constituting the control means.

3. A milling or like machine according to claim 1, comprising a separate pneumatic motor for adjusting each variable-delivery pump, and a

separate pneumatic valve for each said pneumatic motor which valves are actuated by the electrical means.

4. A milling or like machine according to claim 1, wherein the follower is constituted by a roller through the centre of which a milling cutter or its driving spindle passes.

5. A milling or like machine according to claim 1, wherein the cutter support is movable towards the work support, and means is provided for automatically advancing the cutter support towards the work support when the follower has completed its travel over a pattern in the pattern support to increase the depth of cut.

6. A milling or the machine according to claim 8 wherein the machine is brought into operation by a master control, said control opening a hydraulic valve to allow fluid to pass to a hydraulic motor which is provided for the purpose of advancing the cutter to the working position at a high rate of movement and simultaneously closing an electric switch associated with a solenoid which is adapted to open a valve and permit air to pass to said pneumatic valves.

7. A milling or like machine according to claim 1 in which the cutter cuts a hole in a hollow cylindrical member and in which the motion of the follower and cutter is compounded of an arcuate motion described about the centre of the cylinder and a linear motion parallel with the long axis of the cylinder.

8. A milling or like machine comprising a cutter support and a work support, which cutter sup-

port is mounted for movement relatively to the work support along two substantially perpendicular paths, a pattern support and a follower to cooperate with a pattern on the pattern support, which follower is mounted for movement relative to the pattern support along two paths parallel to the aforesaid paths and is so interconnected with the cutter support that their compounded relative movements are similar, two reversible hydraulic motors arranged one to impart the said relative movement to the cutter support and the follower along one pair of parallel paths and the other along the other pair of paths, a separate variable delivery pump and relief valve for supplying each motor with motive fluid at constant pressure, means for independently varying the delivery of each pump, and control means automatically operable to adjust the direction of operation of each motor and the rate at which motive fluid is supplied to it in accordance with the configuration of a pattern on the pattern support and the position of the follower relatively to that pattern, a separate pneumatic motor for adjusting each variable pump, a separate pneumatic valve for each said pneumatic motors, said valves actuated by electrical means, and a plurality of electrical switches, said switches being brought successively into operation as the follower travels around a pattern on the pattern support, each of said switches being connected with solenoids which actuate said pneumatic valves.

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