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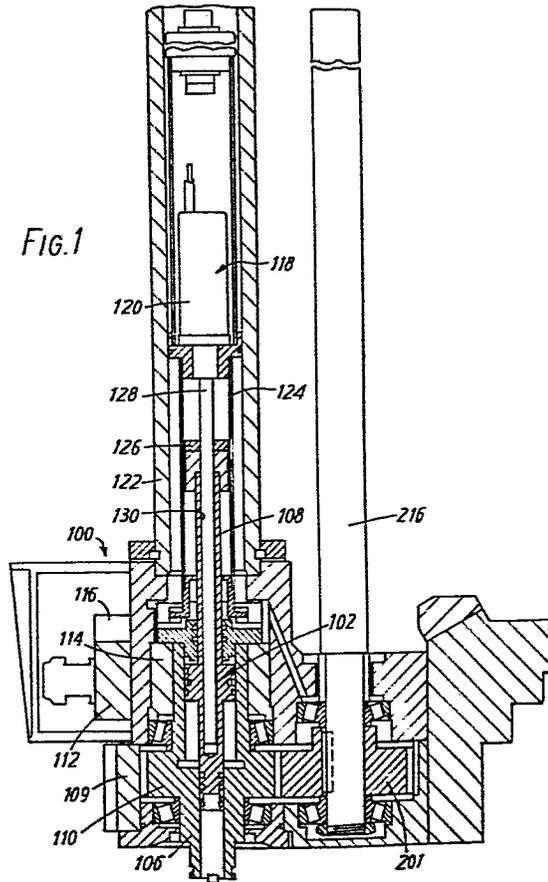
54 **Improvements relating to honing.**

57 A honing machine uses a honing tool of the type having two honing surfaces and a core for adjusting the lateral positions of the surface relative to the tool body. The machine has a piston feed mechanism for adjusting the honing diameter of the tool, a drive mechanism for rotationally driving the tool and a stroke mechanism for axially reciprocating the tool to effect a honing stroke. A control system monitors the position and velocity of the feed piston of the feed mechanism and reaction force applied to the feed piston by contact with a workpiece and in dependence thereon controls the operation of the mechanism in a preselected manner.

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FIG. 1



Title: Improvements relating to honing

The present invention relates to abrasive machining and in particular to honing.

Hitherto known honing machines are generally
5 restricted in the type of machining operations which they can effect.

The present invention seeks to provide an improved apparatus for machining a workpiece.

Accordingly, the present invention provides an
10 apparatus for machining a workpiece using a machining tool of the type having at least one machining surface and an adjustment means for adjusting the position of the surface relative to the tool body the apparatus comprising a feed mechanism for adjusting the machining
15 diameter of the machining tool, drive mechanism for rotationally driving the tool and a stroke mechanism for axially reciprocating the tool for effecting a machining stroke; means for monitoring
the position and velocity
20 of a feed member of the feed mechanism and reaction force applied to the feed member;
and means for controlling the operation of said mechanisms in a preselected manner and in dependence on said monitoring means.

The present invention is further described herein-
after, by way of example, with reference to the
accompanying drawings, in which:-

Figure 1 is a side elevation, partly in section of
5 a feed mechanism of a preferred form of apparatus
according to the present invention;

Figure 2 is a side elevation, partly in section, of
a drive mechanism for driving the feed unit of Figure 1;

Figure 3 is a partial section along the line III-III
10 of Figure 2 showing a clamping mechanism for the drive
mechanism of Figure 2;

Figures 4 to 6 are schematic block diagrams of
control systems for the feed, drive and stroke
mechanisms of Figures 1 to 3; and

15 Figures 7 and 8 illustrate feed profiles of two
possible honing operations.

The preferred form of apparatus shown in the drawings
is an abrasive machine tool of the type known as a
honing machine. Such machines are used generally for
20 the machining of bores in workpieces and are required

to provide three distinct tool movements which are:

- (a) axial reciprocation of the tool in the workpiece bore being machined;
- (b) rotation of the tool about its reciprocal axis; and
- 5 (c) movement of a feed cone within the tool itself along the reciprocal axis to expand or collapse the abrasive surface of the tool radially of its reciprocal axis to enable the workpiece bore to be machined to the required diameter and, for example,
10 to cater for wear of the abrasive surfaces.

In the described apparatus the above movements are provided respectively by a feed mechanism 100, a spindle drive mechanism 200 and a stroke drive mechanism 300 which are described in detail below. The apparatus is
15 hydraulically powered under control of a number of closed loop electronic control circuits which are also described in detail below. The above-mentioned mechanisms are all mounted on a typical base frame for honing machines and this is neither described nor shown
20 in the accompanying drawings for reasons of clarity.

The feed mechanism 100 is in the form of a unit

which can be removed, relatively easily, from the apparatus. The feed piston 102 is preferably integrally formed intermediate the ends of its piston rod 108 which extends through the upper and lower ends 5 of the spindle 106. The lower end of the piston rod 108 is detachably connectable to a cone rod of a feed cone of a honing tool, the body of which is detachably connectable to the lower end of the spindle 106. The spindle is rotatably supported in a housing 109 and 10 carries a coaxial gear wheel 110, preferably formed integrally with the spindle 106, which connects with the spindle drive mechanism and through which rotational drive is applied to the spindle 106 and the honing tool. The feed piston 102 and its piston rod 108 are rotatable 15 with the spindle 106. This particular configuration avoids the use of rotating thrust races and typical flexible joints used hitherto which are prone to wear and error. The direct connection of the honing tool cone rod to the feed piston rod also eliminates the 20 normally used flexible joints, thus avoiding the problems associated with these.

Movement of the feed piston 102 in the chamber 104 and thus changes in the effective diameter of the honing tool is controlled by the application of pressurised 25 hydraulic fluid, typically at a pressure of 70 bars, to

the chamber 104 with the piston 102 and spindle 106 serving as a double-acting-piston-cylinder unit. Fluid flows to and from the chamber 104 via a servo valve unit 112 which is mounted on the housing 109 and coupled 5 to the spindle chamber 104 by way of a rotary manifold 114 with hydrostatically controlled sealing for spindle rotational speeds of up to 4000 rpm. The differential fluid pressure across the piston 102 is measured by means of one or more differential pressure transducer 10 116 which is also mounted on the housing 109. The feed mechanism 100 is designed to resist deviations in piston position and differential pressure during high acceleration and edeceleration of the yousing 109 by the stroke drive mechanism 300 as described below, 15 positional and differential pressure accuracies of 1 μ and 0.1 bar being obtainable.

In order to control accurately the movement of the feed piston a transducer 118 is provided which measures both the position and the velocity of the feed piston 20 102 relative to the spindle 106. The transducer is preferably a magneto-restrictive transducer which comprises a unit 120 which is mounted coaxially above the piston rod 108 in a hollow upstanding extension 122 of the housing 109. The unit 120 is supported above the 25 spindle 106 by means of a tube 124 rigidly secured to the

unit 120 and connected at its lower end to the spindle 106 by way of a thrust race or similar coupling. The upper free end of the piston rod 108 projects into this tube and carries an annular permanent magnet 126

5 inductively coupled to a core 128 which extends from the unit 120 coaxially into an axial bore in piston rod 108, sufficient clearance being provided between the core 128 and the inner wall of the piston bore 130 to prevent the latter being fouled by the core. The

10 tube 124 is made of a material chosen such that its temperature coefficient of expansion compensates for dimensional changes in the piston feed unit as a result of changes in temperature to ensure that the accuracy of the spacing between the unit 120 and the spindle 106

15 is maintained. A temperature change of 50°C has been found to introduce a piston positional error of only 0.125μ .

On switch-on of the apparatus a self-calibration procedure for the feed piston position monitoring

20 transducer 118 is effected. The piston is fully withdrawn as far as possible and then dropped 1mm. This final position is then taken as the piston datum position for all future operations while the apparatus is switched on.

A hydraulic accumulator (not shown) is preferably

provided to smooth hydraulic pressure fluctuations and accommodate feed piston collapse to datum on failure of supply, e.g. on emergency stop.

Turning now to the spindle drive mechanism 200,
5 shown in Figure 2 this comprises three preferably unity ratio gears 202, 204, and 206 arranged in line with their rotational axes parallel and coupling a gearbox 208 of a drive motor 210 to a shaft 216 to which the gear 202 is splined. A unity ratio gear 201 rotatably
10 mounted in a lateral extension of the housing 108 with its rotational axis parallel to that of the spindle gear 110, is splined onto the lower end of the shaft 216. The gear 201 meshes with the spindle gear 110. The gearbox 208 preferably provides a reduction ratio of
15 3.4:1 from the motor which is preferably a variable speed hydraulic motor. The gearbox itself can be omitted when the apparatus operates at high spindle r.p.m. and may in fact be a variable 1:1 gear selection possible. Hydraulic fluid is supplied in a closed-loop arrangement
20 to the hydraulic motor, the flow being controlled by an electro-hydraulic-servo system the electrical control for which is described in more detail below. The motor is controlled to provide an infinitely variable rpm drive to the spindle 110 between preselected limits of,
25 for example 100 to 1,000 rpm. Torque and speed control of the motor is effected to provide a constant 5 horse

power and enable speed accuracies of up to ± 2 rpm to be obtained, the pressure of the hydraulic fluid supplied to the motor being monitored by a pressure transducer 212 with a digital tachometer 214 being
5 provided to measure the motor rpm. The tachometer preferably is such as to provide an angular positional accuracy of the motor and thus the spindle 106 of up to 0.18 degree to enable, for example, an automatic tool changing mechanism to be used with the apparatus.
10 Pressure transducers 212 monitor the applied rotational cutting force. The drive to the spindle is reversible with a controlled rate of deceleration and acceleration to enable optimum performance to be achieved.

15 The stroke drive mechanism 300 is also shown in Figure 2 and comprises a hydraulic cylinder 302 coaxially surrounding a portion of the cylindrical housing extension 122 which serves as the stroke piston and rod assembly for the stroke drive mechanism. The
20 piston rod assembly 122 is detachably secured at its lower end to the feed mechanism 100. The piston rod assembly 122 and the cylinder 302 cooperate as a double-acting piston-cylinder unit with the piston rod assembly 122 being shown in Figure 2 in its fully
25 retracted position raising the feed mechanism 100 to its maximum height.

Expected accuracies throughout the speed range are as follows:-

Positional \pm .125mm, repeating to within \pm .025mm, the reverse point would normally be expected to change
5 within \pm .125 dependent on velocity but at any selected velocity, reverse point would be maintained within \pm .025mm.

Short Stroke - a movement provided at each reverse point, adjustable between 5 and 50mm in length, used to correct
10 inaccuracies of size and geometry, especially when honing blind end bores.

Subject to same positional accuracies as previous paragraph.

A Reverse Dwell - settable for time - is provided at the bottom reverse point, being capable of delaying the
15 change in direction of the main stroke piston, also to correct inaccuracies as before. The feature includes the ability to dwell on each reversal, or be programmed to dwell on every other, 3rd, 4th, 5th or 6th reversal. The reversal time is accurately 'ramped' to minimise
20 shock on reversal, the time being as short as possible (typically 50ms at a stroke speed of 500 mm/s) to enable the typical cross-hatch pattern and angle resulting from the honing process to be maintained accurately over the full bore surface area.

25 The flow and pressure of hydraulic fluid to the

cylinder 302 is controlled by means of an electro-hydraulic servovalve unit 304 mounted adjacent the cylinder. The total working stroke of the piston rod assembly 122 and thus the honing tool is typically 300
5 millimetres, the design principle readily and simply enabling changes in machine stroke capacity to be incorporated at the machine erection stage by the variation of a minimum number of machine components.

The hydraulic fluid pressure would typically be
10 70 bars. The stroke speed can be varied from a lower limit of 1 millimetre per second to an upper limit of 500 millimetres per second. During a honing operation the stroke drive mechanism reciprocates the piston rod assembly 122 and thus the honing tool between preset
15 limits at a constant velocity with reversal time of the stroke being as short as possible with controlled deceleration prior to reversal and acceleration after reversal of the stroke direction. In addition, accurate setting of the end stroke positions is desired,
20 especially when machining blind-end bores. To ensure accurate control a transducer 306 is provided to measure both the stroke velocity and position, the transducer conveniently being a magneto-restrictive type transducer.

The transducer comprises a stationary unit 308 which

is conveniently secured to the upper surface of the drive mechanism 200. The unit 308 has a rod 310 extending parallel with the piston rod assembly 122 upwardly of the stationary member 308 and passing
5 through an annular magnet 312 secured relatively to the piston rod assembly 122. The clearance between the rod 310 and magnet 312 is sufficient to ensure that neither fouls the other during reciprocation of the piston rod assembly 122.

10 Pressure tapping points are conveniently provided at each end of the cylinder 302 for pressure transducers to facilitate accurate measurement of the stroke cutting force applied to a honing tool, the pressure difference being a measure of the force.

15 When not in use there would be a tendency for the piston rod assembly 122 to drop as a result of the weight of the feed drive mechanism 100 and hydraulic fluid leakage in the cylinder 302. This can, in some circumstances, result in damage to a workpiece left in
20 position beneath the feed drive mechanism or a tool connected to the spindle 106. To overcome this problem and ensure that when the apparatus is switched off the piston rod assembly 122 is locked in position in a hydraulically actuated clamping mechanism 400 is provided.

As is best seen in Figure 3 the clamping mechanism comprises a split clamp ring 402 which is retained in an annular groove in a housing portion 404 which is secured relative to the cylinder 302 and surrounds a portion of the piston rod assembly 122 above the cylinder 302. The ring 402 is positioned in the groove 404 with that portion containing its gap 402 extending into a tangential bore 408 in the housing portion 404. One end portion of the ring 402 is retained in position by a cylindrical wedge 410 retained in the end of the blind bore 408 and engaging in a notch in the adjacent ring end portion. The opposing end portion of the ring also has a notch which engages with the end of an actuating rod 412 projecting into the bore 408 and being axially slidable in the bore. The end of the rod remote from the ring carries a piston 414 slidable in a cylinder 416, the piston dividing the cylinder into two chamber 418 and 420. The chamber 418 contains one or more clamping springs which urge the piston and thus the rod 412 into the bore 408 to compress the clamp ring 402 causing it to grip the piston rod assembly 122. The force applied by the clamping springs 422 is selected to provide sufficient friction between the clamp ring 402 and the piston cylinder assembly 122 to retain the latter in position against the action of gravity but is sufficiently low such that it is easily overcome by the reciprocating force applied to the piston rod

assembly 122 when the stroke drive is operating. This ensures that should the clamp mechanism 400 accidentally be left off during machine operation no damage will result.

5 The chamber 420 is connected to the hydraulic fluid supply for the apparatus such that when the apparatus is switched on pressurised fluid is supplied to the chamber 420 to release the clamp mechanism 400.

Referring now to Figures 4 to 6 these show schematic
10 block diagrams of the control circuits for the feed mechanism 100, spindle drive mechanism 200 and stroke drive mechanism 300.

Figure 4 shows the control circuit for the feed mechanism 100, the circuit comprising a microcomputer 400
15 which is microprocessor controlled and which controls the operation of the servovalve unit 112 which in turn controls the feed piston 102 coupled to the honing tool cone rod which is diagrammatically illustrated at 402.

Two feed back loops are provided, the first comprising
20 the differential pressure transducer 116 and the second comprising the position and velocity transducer 118. The circuit also includes a signal generator 404 which is capable of providing a number of preselected high frequency signals with which the normal control signal

effecting feed of the feed piston 102 can be modulated to provide, for example, a "staircase" signal which results in a pulsed forward feed of the feed piston. In addition to the generator 404 a gauging mechanism
5 406 is also included to enable measurement of the work-piece bore to be effected, the resulting measurement signal serving as an input control signal for the honing programme. Finally, a keyboard 408 enables piston
10 terminal position of the feed piston, the magnitude of feed increments and the maximum pressure differential to be allowed as measured by the differential pressure transducer 116, to be fed into the microcomputer by an operator.

15 Using the above-described control system a number of different types of feed of the feed piston 102 may be effected. Firstly, positive feed may be applied to the honing tool, this being a set amount of cone rod movement relative to time, but with a pressure override.
20 For example, if the differential pressure monitored by the transducer 116 exceeds a preselected value then the feed is , for example, terminated or another desired operation effected. This avoids problems such as broken honing tools which is a particular problem when small diameter honing tools are used.

25 Pressure feed, that is controlled movement of the

cone rod given by the pressure driven differential in the chamber 104, may also be effected with, for example, position and velocity control of the feed piston 102 effected through measurement of its position and
5 velocity by the transducer 118.

Pulse feed, that is the incremental step movement of the feed piston 102 and thus the honing tool cone rod taking place at set time periods during honing or applied at particular stroke positions, can also be
10 effected under the control of the signal generator 404. The shape of the signal generated by the generator 404 can be varied to provide optimum machining conditions. Such high frequency signals may also be used to modulate the signals controlling movement of the feed piston 102
15 when either positive feed or pressure feed are applied. Different feed systems can also be mixed during the machining of a component and the precise control which is effected over the honing tool enables calculation of the amount of abrasive wear and amount of component
20 material removed to be readily effected.

The variables controlling the type of feed applied to the honing tool may also be varied during the honing stroke. For example, when pressure feed is applied the hydraulic fluid pressure may be held at a relatively low
25 value at the end portions of the honing stroke and

adjusted to a relatively high value during the midportion of the stroke. This is particularly useful as at each end of the honing stroke when a portion of the honing tool abrasive projects from the workpiece bore if the same hydraulic fluid pressure is maintained then the interfaced pressure between the honing tool abrasive and the bore increases as the contact area of the abrasive reduces resulting in diametric and geometric innaccuracies especially when making components with a thin wall at either end.

Figure 5 shows the control system for the spindle drive mechanism in which the microcomputer controls the hydraulic motor 210 via a hydraulic pump 500 and servo valve 502. Three feed back loops are provided in this system, the first incorporating the pressure transducer 212 which serves to ensure a constant horsepower for the hydraulic motor 210. the second feedback loop has a differential pressure transducers 504 to monitor the fluid pressure for the motor drive and provide information to enable calculation of the rotational cutting force applied to the honing tool and which provides a control signal dependant thereon to enable cutout of the motor if the pressure exceeds certain preselected limits. The third feedback loop includes the tachometer 214 which also monitors the angular position of the hydraulic motor 210 and thus of the

honing tool 402 and enables the honing tool to be positioned in any desired preselected angular position.

Finally, a keyboard 506 enables an operator to feed in preselected spindle drive information such as the desired rotational speed of the honing tool and any changes, for example, speed, which are to be effected during the honing operation.

Referring now to Figure 6 this shows the control system for the stroke drive mechanism 300, the main control being effected via the servo valve unit 304, stroke piston 152 and feed mechanism 100. Two feedback loops are provided, the first including the differential pressure transducer 316. This feedback loop enable the stroke piston to be controlled dependance on the differential pressure existing in the cylinder 302 and can ensure, for example, that where a blind bore is being machined the stroke is immediately halted the moment the end of the honing tool touches the end of the blind bore minimising tool damage. The transducer 316 also provides information for calculation of the axial cutting force applied to the honing tool. Alternatively, the second feedback loop monitors the reverse point error (transducer 306) and if an error greater than or equal to 0.2mm in reverse position is detected an error condition will result and the machine will withdraw

and cease operation. Contact of the tool with the blind bore end is sensed as an increase in the hydraulic fluid differential pressure in the cylinder 302. The second feedback loop includes the position and velocity 5 transducer 306 which monitors the exact position and velocity of the piston rod assembly 122 and thus of the honing tool.

A keyboard 600 is provided to enable an operator to feed into the computer 400 information on the stroke, 10 for example, the desired stroke velocity and end positions and a gauging mechanism 602 provides information on the workpiece dimensions to enable automatic adjustment of the stroke and feed variables. The gauging mechanism 602 and the gauging mechanism 406 15 may in fact be combined in a single gauging mechanism and the three keyboards 408, 506 and 600 may be comprised by a single keyboard.

On hitherto known honing machines the feed, stroke and spindle drive mechanisms are all controlled 20 independently one another. With the present invention the feed stroke and spindle drive mechanisms can be controlled together with the variables of any one of the mechanisms being adjustable independance of change in the variables of the other mechanisms.

The following description of some of the operational options which are available using the above-described apparatus will provide an indication of the versatility of the apparatus.

5 It will be understood that all feed options can be controlled from in-process sizing equipment, feedback control from pre-and/or post-process sizing equipment, or feedback control from the final feed piston position.

10 Accurate control of bore 'parallelism' can be controlled by either in-process or post-process sizing by changing the stroke reversal position to correct taper, barrel or bell mount shaped bores.

By detecting the shape of the bore as defined above,
15 the reverse point can be incremented or decremented to produce a parallel condition or define geometrical requirements, it being possible to machine for example a taper using the present apparatus.

The described, preferred apparatus according to
20 the present invention divides a honing operation into four separate stages and some of the possible options for each stage are given below.

Stage 1

- In this stage of honing the feed piston 102 moves from a datum position to expand the honing tool to be preselected position. This is effected by one of the following:
- 5 following:
- (a) hydraulic fluid at a relatively low pressure is applied to the chamber 104 to drive the feed piston 102 downwardly as seen in Figure 1 to expand the honing tool abrasive until the abrasives
- 10 contact the bore wall of the workpiece to be honed, this position being sensed by an increase in the differential pressure in chamber 104 and a large change in piston velocity. The feed piston position is then monitored and stored in the microcomputer.
- 15 (b) the position of feed piston 102 for a preselected tool expansion is preset and overrides the low differential pressure sensing to enable hydraulic fluid pressure to be applied to the chamber 104. If the honing tool abrasives contact the workpiece
- 20 bore wall before the feed piston 102 reaches its preset position the differential pressure rised to its preset low override value monitored by the transducers 116 immediately halting movement of the feed piston. The feed piston position is then
- 25 monitored and stored in the microcomputer.
- (c) This is similar to (b) above but with the piston

being moved at a relatively high velocity, e.g. greater than 50 milimetres per second, to the initial expansion position. The abrasives would not now be expected to contact the workpiece bore on moving to the preset position.

Stage 2

In this stage the feed piston and thus the honing tool abrasives are moved to enable the abrasives to cut the workpiece bore wall.

- 10 (a) A preselected differential pressure for the hydraulic fluid in chamber 104 is set and the stroke mechanism 300 actuated. Maintaining the differential pressure in chamber 104 ensures that the abrasives continue to expand and hone the workpiece bore. A time limit can be set on the honing operation or a preselected end position for the feed piston 102 programmed into the micro-computer so that honing ceases once the piston attains this position. The option can only be used with Stage 1(a).
- 15
- 20
- (b) Here the feed piston velocity and differential pressure in chamber 104 are preselected with the honing operation terminated after a preset time interval or on feed piston 102 attaining a preselected position in the chamber 104.
- 25
- (c) Movement of the feed piston 102 is in discreet

steps effected by hydraulic fluid pressure pulses at preselected intervals with the honing operation being terminated after a preselected time or feed piston position is reached.

5 (d) An incremental pulse feed is used, as in (c) above, this being applied after the first complete stroke cycle and thereafter at each end stroke reversal point or upper or lower reversed points until a preselected time or feed piston position is reached.

10 (e) Here, the feed piston 102 is fed at a preselected velocity until the honing tool abrasives contact the workpiece bore wall when the feed is then switched to hydraulic fluid pressure controlled feed and the instantaneous feed position is monitored
15 and stored in the microcomputer. This operation used only with options (b) and (c) of Stage 1.

Stage 3

Here the feed piston is moved under pressure feed or preselected velocity feed to its final position or again
20 an incremental hydraulic pressure pulse feed can be applied to the piston. In addition, stroke and spindle parameters can be changed. This stage can be bypassed, moving directly from stage 2 to stage 4.

Stage 4

25 This operating stage is effected after the workpiece bore

has been honed to the desired final size.

(a) The feed piston 102 is retained in its preselected final position for a set time interval and then retracted to collapse the honing tool. The honing
5 tool is rotated continuously during this operation until the stroke piston moves to its upper removal point. The spindle stops and the stroke piston moves to its intermediate withdrawal position.

(b) This is similar to (a) but with the rotation of the
10 honing tool ceasing before withdrawal of the honing tool.

(c) After the bore has been honed to its final preselected size the withdrawal of the honing tool rotation of the tool and retraction of the feed
15 piston 102 are effected at preselected timings.

Preselected size conditions can be achieved using preselected feed piston positions or by using signals from a gauging system. In all cases the position of the feed piston at its final size condition is monitored and
20 stored in the microcomputer. Within stages 2 and 3 the amounts of compensation for wear of the two abrasive surfaces can be preset. This compensation value can be initiated manually or automatically by use of external gauging.

25 As will be appreciated, certain of the above stages may be bypassed and functions within individual stages can

be activated individually and at all times the honing operation can be terminated if any fault signal is received, for example via the differential pressure transducers or position and velocity transducers.

5 To enable correct geometry to be achieved stages 2 and 3 can accommodate programmed short stroking, stroke dwell and spindle speed changes and reversals (the term "stroke dwell" refers to the situation where a zero length stroke is applied with spindle rotation for machining,
10 for example, blind bore ends).

Figure 7 and 8 illustrate the feed profiles of two honing operations with the changes in the hydraulic fluid feed pressure, piston velocity and position with respect to time being shown.

15 Referring to Figure 7, the honing tool is rapidly expanded under low pressure feed until the honing tool abrasives contact the workpiece bore. Honing is then effected at a preselected pressure feed until a preselected position of the feed piston 102 is attained
20 at the end of stage 2. Pulsed feed is then applied to finish the workpiece bore during the stage 3 operation until the feed piston attains its final position when the honing tool is collapsed by rapid retraction of the feed piston. In Figure 8 a rapid initial expansion of

the honing tool is effected until the abrasives attain a preselected position clear of the workpiece bore wall. The movement of the feed piston continues at a slower rate until the workpiece bore is contacted by the honing
5 tool abrasives. Honing then continues as in Figure 7 until the feed piston attains a further preselected position after which honing continues at a reduced pressure and velocity feed of the piston 102 until the latter attains its final preselected position. After a
10 preselected time delay the honing tool is then collapsed by retraction of the feed piston 102.

In addition to the above described operations the computer will additionally log:-

1. The amount of abrasive wear per machining cycle.
- 15 2. The amount of metal removal per machining cycle.
3. The total amount of abrasive wear thus enabling the machine to detect when to shut down to allow abrasives to be replaced.
4. Knowing items 1, and 2, calculate the 'G' ratio, a
20 term normally applied to grinding, now also applied to honing, which = $\frac{\text{Vol of metal removed}}{\text{Vol of abrasive used}}$ per cycle.

Knowing the optimum 'G' ratio for a set of particular machining conditions, the computer will, by varying various parameters, e.g. feed rate, maintain the optimum
25 'G' ratio and thus the most economical use of abrasive.

Although the invention is particularly described with reference to honing it will be appreciated that it is applicable to other types of machining operations such as reaming, diamond reaming, boring and drilling
5 and other abrasive or cutting operations.

CLAIMS:

1. An apparatus for machining a workpiece using a machining tool of the type having at least one machining surface and an adjustment means for adjusting the position of the surface relative to the tool body,
5 characterised in that the apparatus comprises a feed mechanism for adjusting the machining diameter of the machining tool, a drive mechanism for rotationally driving the tool and a stroke mechanism for axially reciprocating the tool for effecting a machining
10 stroke; means for monitoring the position and velocity of a feed member of the feed mechanism and reaction force applied to the feed member; and means for controlling the operation of said mechanism in a preselected manner and in dependence on said monitoring means.

- 15 2. Apparatus as claimed in claim 1 wherein said feed mechanism comprises first means to which the body of the tool is detachably securable and second means for coupling to said tool machining surface adjustment means, said first and second means being displaceable
20 relative to one another for adjusting said surface position relative to said tool body and said second means comprising said feed member.

3. Apparatus as claimed in claim 1 wherein said first and second means are displaceable along their common axis.

4. Apparatus as claimed in claim 2 or 3 wherein said feed member comprises a feed piston axially reciprocably
5 in a chamber in said first means and having a piston rod projecting through one, lower end of said cylinder for coupling to said tool surface adjustment means.

5. Apparatus as claimed in claim 4 wherein said feed piston and said chamber form part of a double-acting
10 piston-cylinder unit.

6. Apparatus as claimed in claim 4 or 5 wherein said first means comprises a spindle coupled to said drive mechanism so as to be rotatably drivable thereby.

7. Apparatus as claimed in any of claims 4 to 6 further
15 comprising a control system comprising a control loop having a valve means for controlling flow of fluid to said chamber, means for monitoring the differential pressure across said piston, means for monitoring the position and velocity of said piston relative to said chamber and a
20 control circuit operable to control said valve means in dependence on said differential pressure and said piston position and velocity to cause said piston to move relative to said chamber and adjust said tool machining

diameter in a preselected manner.

8. Apparatus as claimed in claim 7 wherein said control circuit is operable to inhibit movement of said feed piston when said differential pressure exceeds a preselected
5 value.

9. Apparatus as claimed in claim 7 or 8 wherein said control circuit further comprises a signal generator coupled to said control circuit for generating a number of preselectable high frequency signals for modulating
10 movement of said feed piston.

10. Apparatus as claimed in any of claims 1 to 9 wherein said drive mechanism comprises a hydraulic drive motor and a control system comprising a means for monitoring fluid pressure applied to said motor, a means for
15 monitoring differential pressure across said motor and a control circuit for controlling rotational drive applied to said feed mechanism by said motor in dependence on said pressure and differential pressure.

11. Apparatus as claimed in claim 10 wherein said control
20 system includes a control loop comprising a means, coupled to said control circuit, for monitoring the angular position of said feed mechanism.

12. Apparatus as claimed in any of claims 1 to 11 wherein said stroke mechanism comprises a first means reciprocally coupled to a second means and adapted detachably to receive said feed mechanism.
- 5 13. Apparatus as claimed in claim 12 wherein said first and second means comprise respective elongate members telescopically interconnected, one of said members serving as a piston assembly for the other.
14. Apparatus as claimed in claim 12 or 13 wherein said
10 first and second means comprise a double-acting piston-cylinder unit.
15. Apparatus as claimed in claim 12, 13 or 14 wherein said second means is detachably connectible to a housing of said feed mechanism.
- 15 16. Apparatus as claimed in any of claims 12 to 15 comprising a control system for controlling operation of said stroke mechanism, the control system having means for monitoring the differential fluid pressure applied to said stroke mechanism and a control circuit for
20 controlling the stroke in dependence thereon.
17. Apparatus as claimed in claim 16 wherein said control system has means for monitoring the position and velocity

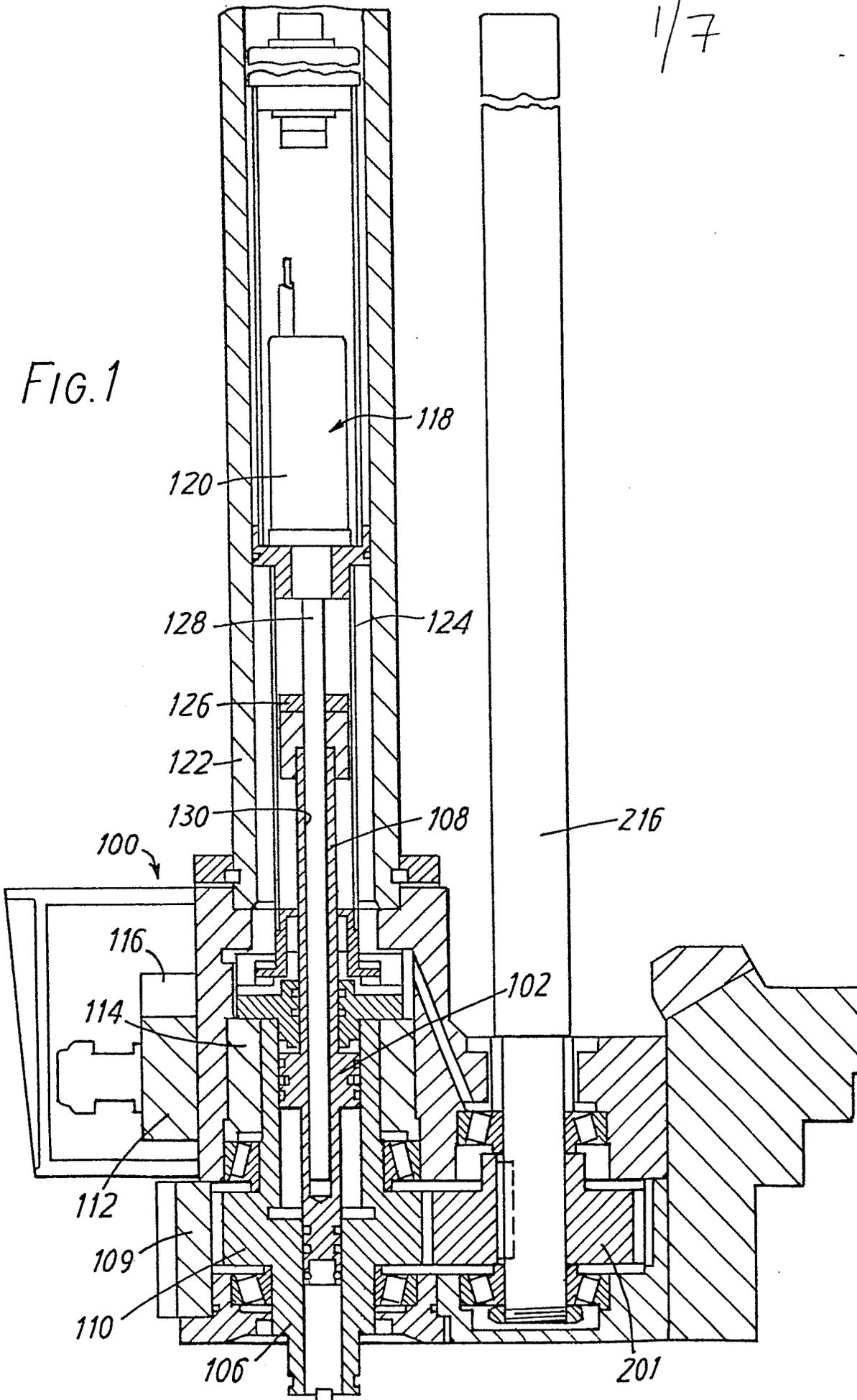
of said feed mechanism and said control circuit is operable to control the stroke in dependence thereon.

18. Apparatus as claimed in any of claims 12 to 17 further comprising a clamping mechanism actuatable to clamp the stroke mechanism first means relative to the second means.

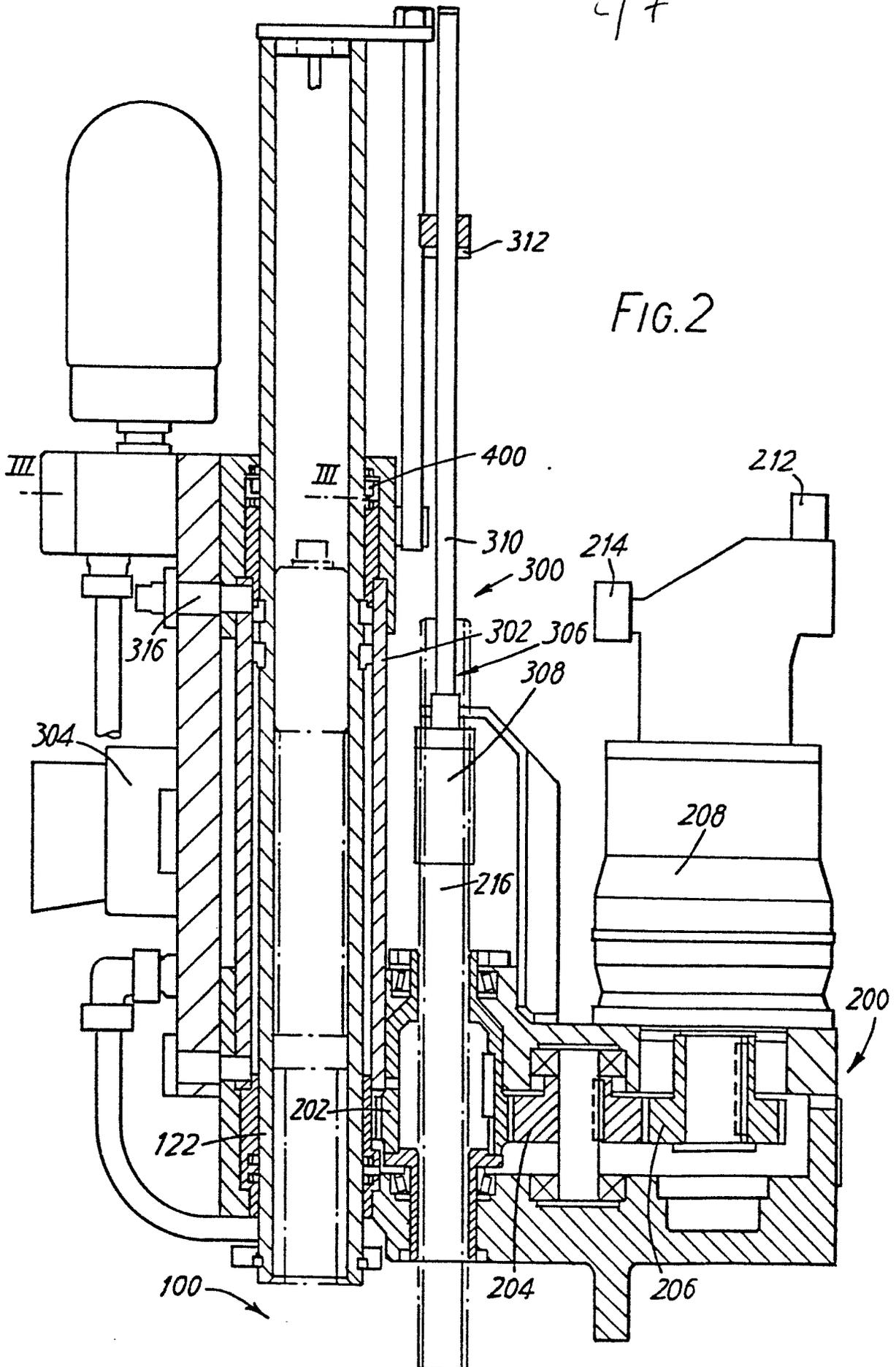
19. Apparatus as claimed in claim 18 wherein said clamping mechanism is hydraulically operable and has a clamp connected to a piston-cylinder unit coupled to a pressurised fluid supply for said apparatus, the arrangement being such that on supply of pressurised fluid to said apparatus said clamp is moved from a clamping position to an open position to allow operation of said stroke mechanism.

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FIG. 1



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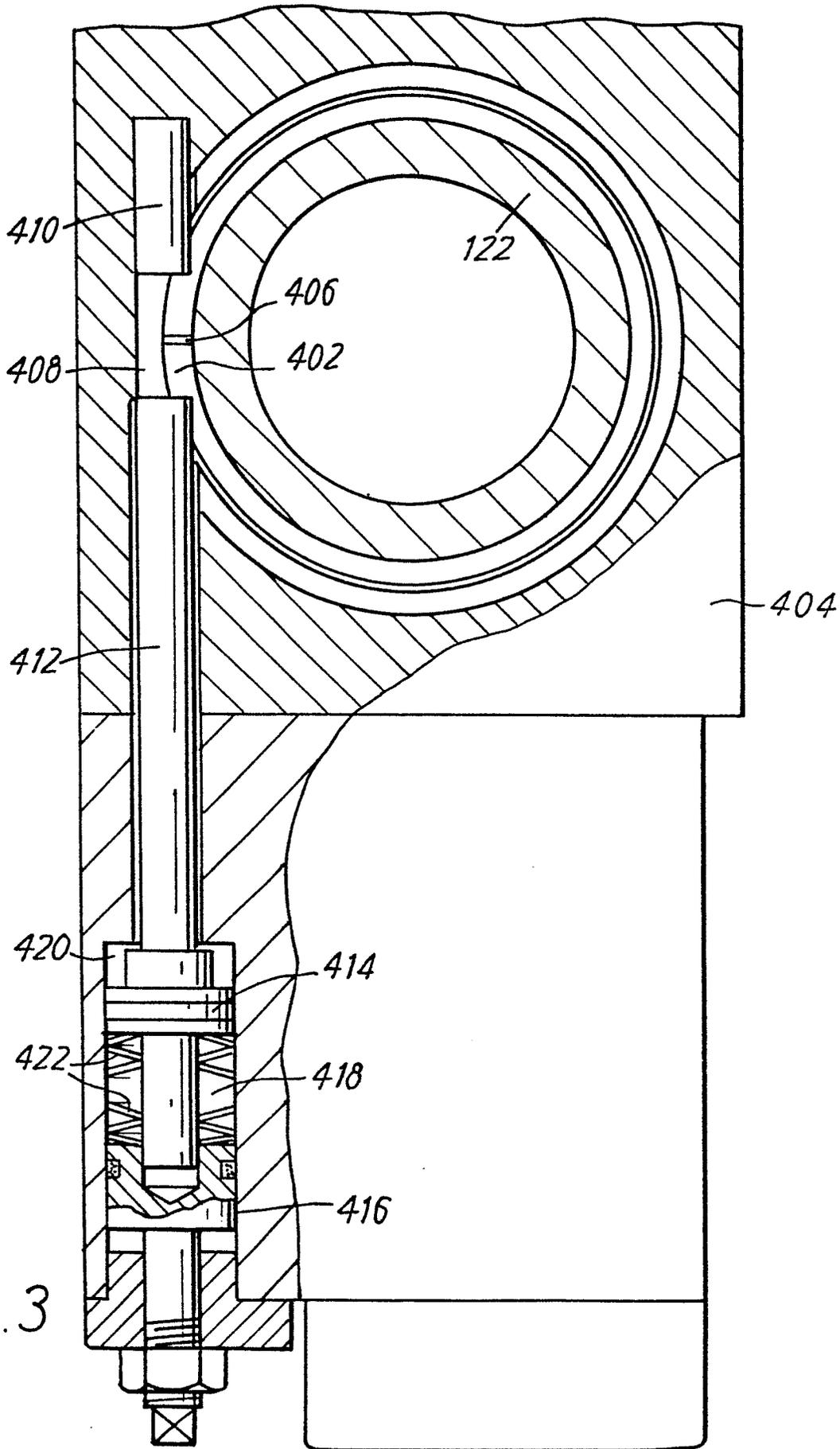


FIG. 3

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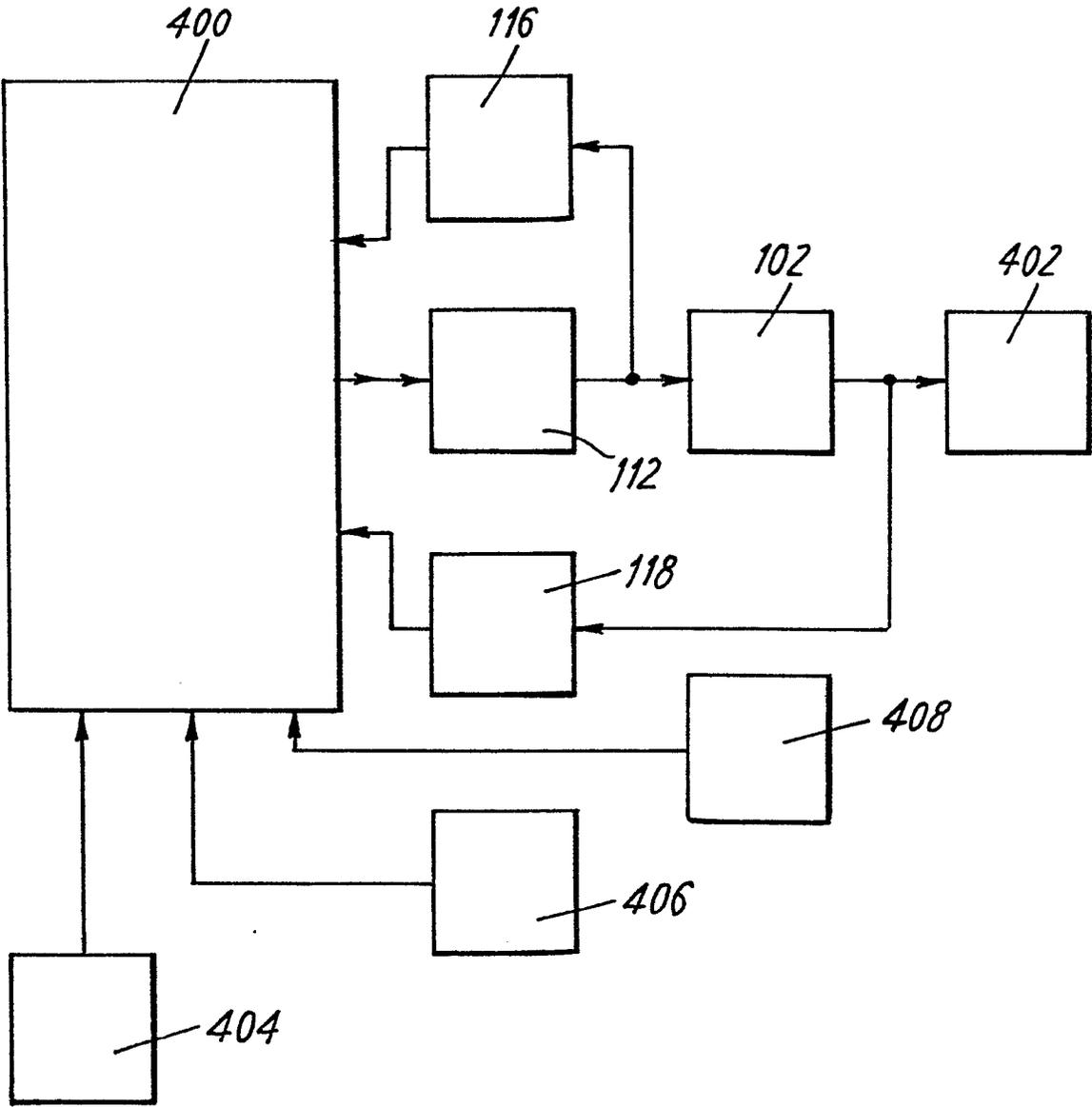


FIG.4

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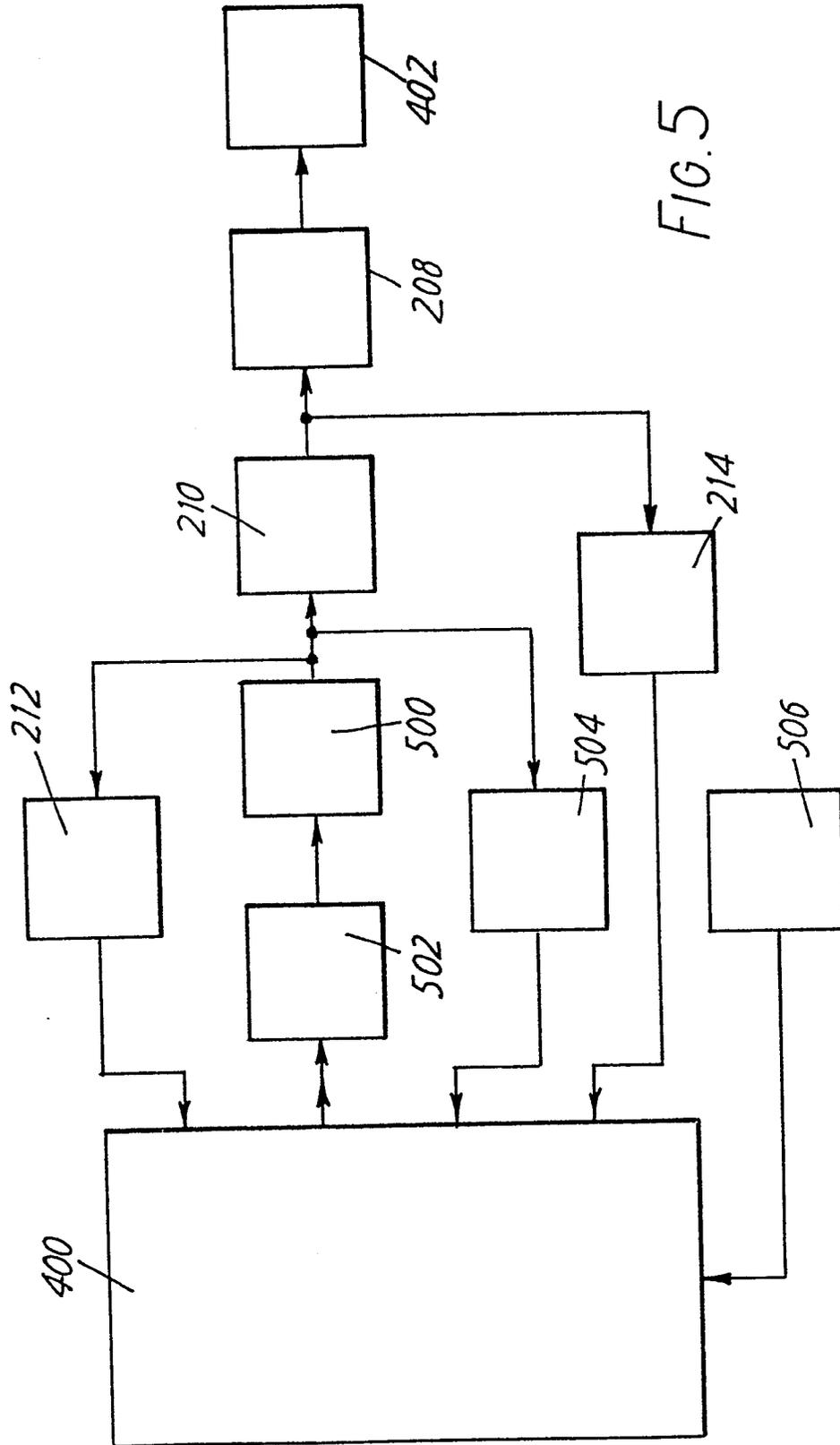


FIG. 5

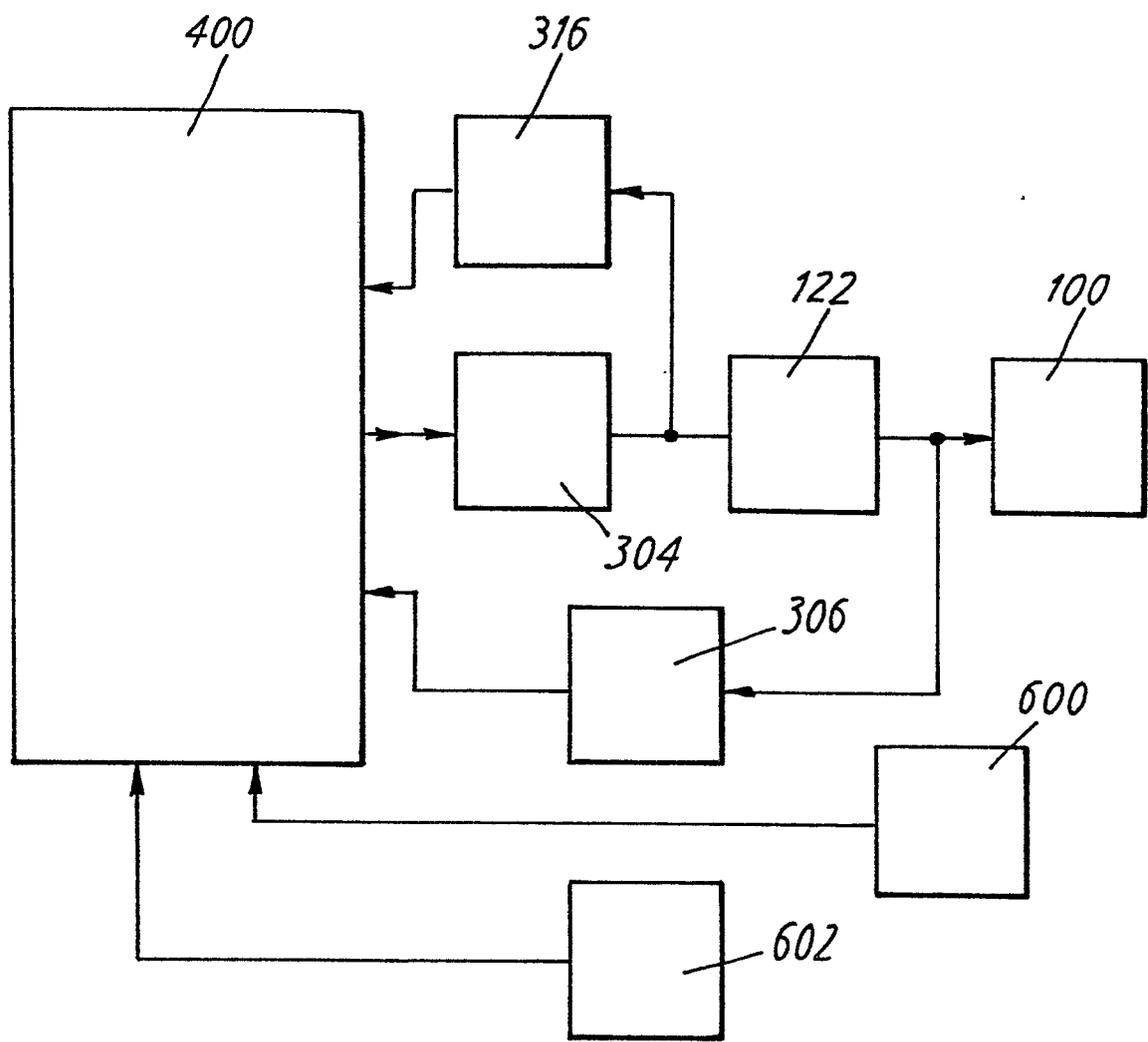


FIG. 6

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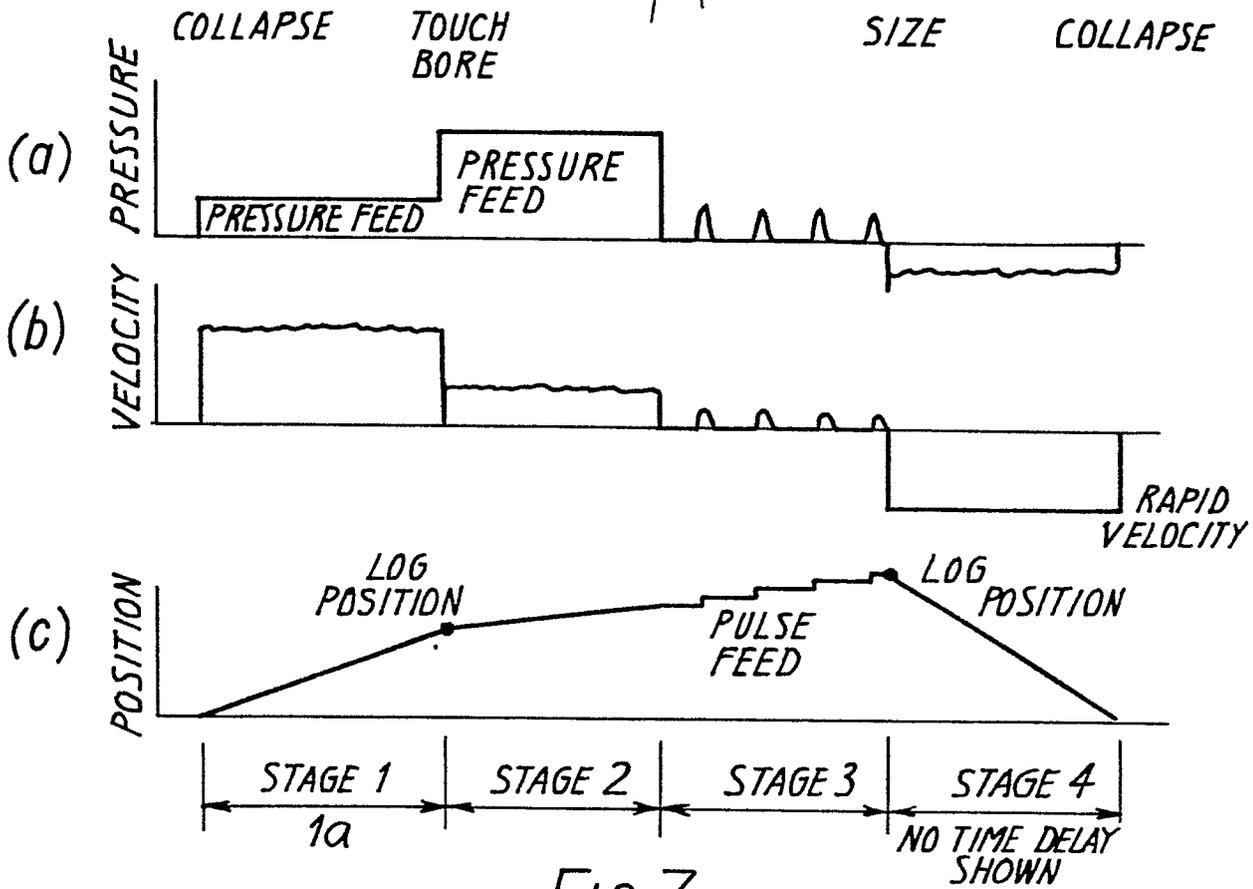


FIG. 7

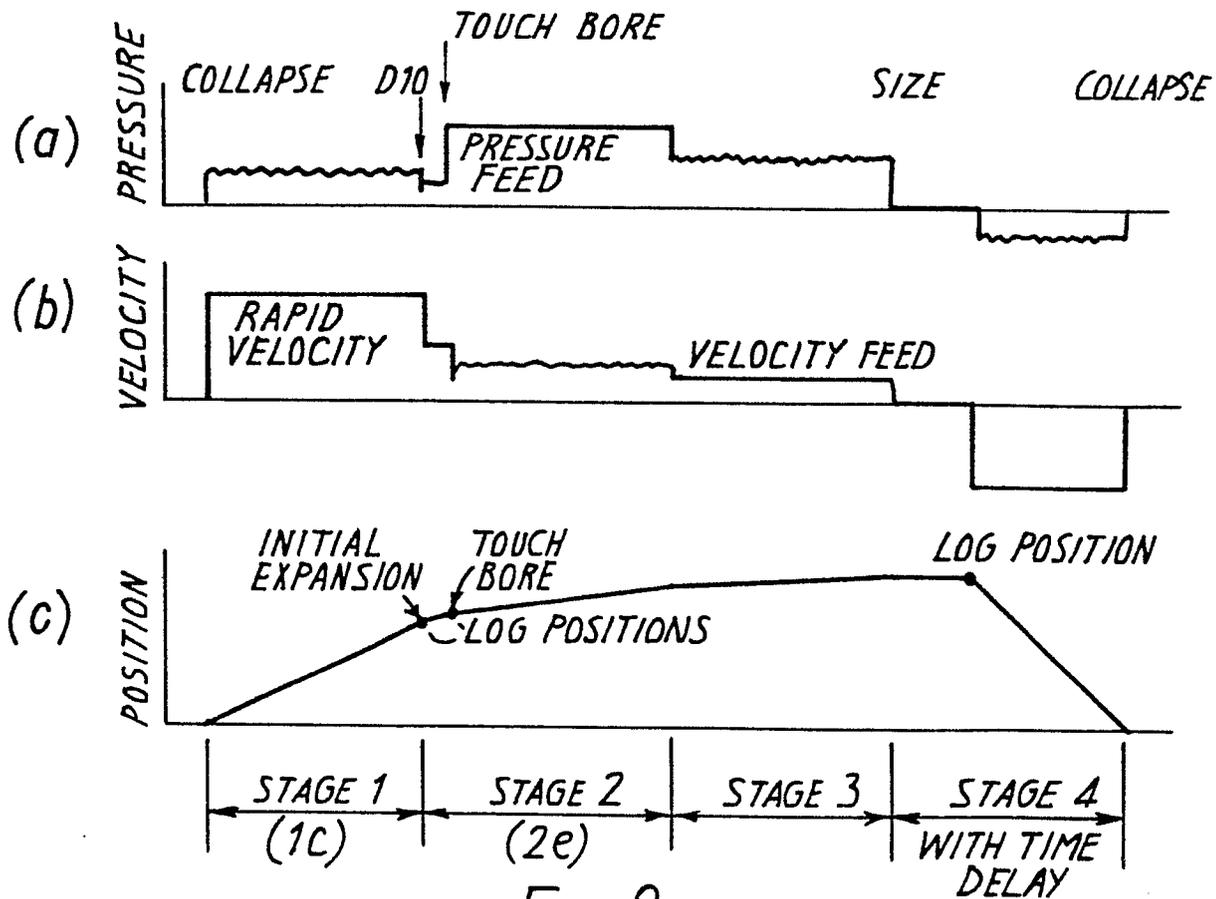


FIG. 8