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[45] Patented **Apr. 20, 1971**
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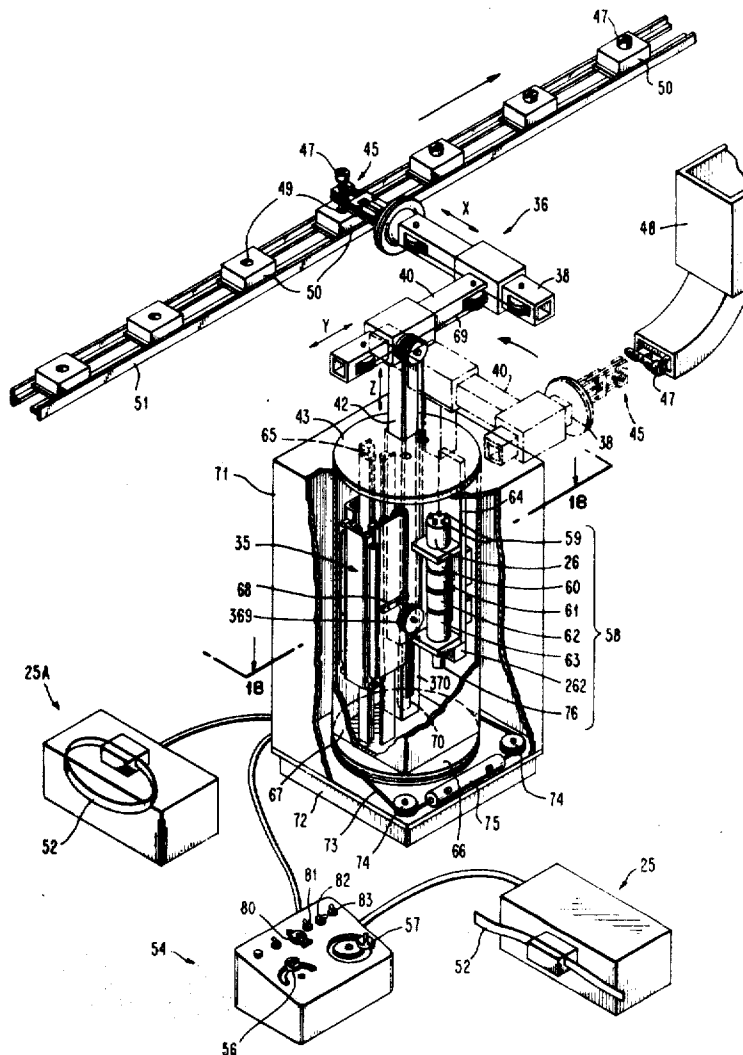
[54] **MANIPULATOR**
21 Claims, 48 Drawing Figs.

[52] U.S. Cl. **214/1,**
214/147, 74/89.2
[51] Int. Cl. **B25j 9/00**
[50] Field of Search. **214/1 (B),**
1 (B3), 1 (B4), 1 (RCM), 147, 147 (T), 650, 651,
653, 1 (B7); 74/110, 89. (Z)

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ABSTRACT: A hydraulically operated manipulator is controlled as an automatic assembly robot to grasp, position and join parts. A tape is perforated with coded instructions and dimensions to control the sequence and amount of displacement by means of incremental motions in several modes of movement of the manipulator. Such modes include grip, sweep, X, Y, Z, θ (arcuate gripper wrist motion) and search (vibratory parts matching such as inserting a pin in a hole). The main components of the manipulator are a tape reader, an electrically and hydraulically controlled hydraulic serial-to-parallel converter and memory and a hydraulic driver, integer and fraction hydraulic piston adders, an articulated series of X, Y, Z slide members with a gripper and a wrist member all driven by a common drive cable, and a vibratory hydraulic search mechanism.



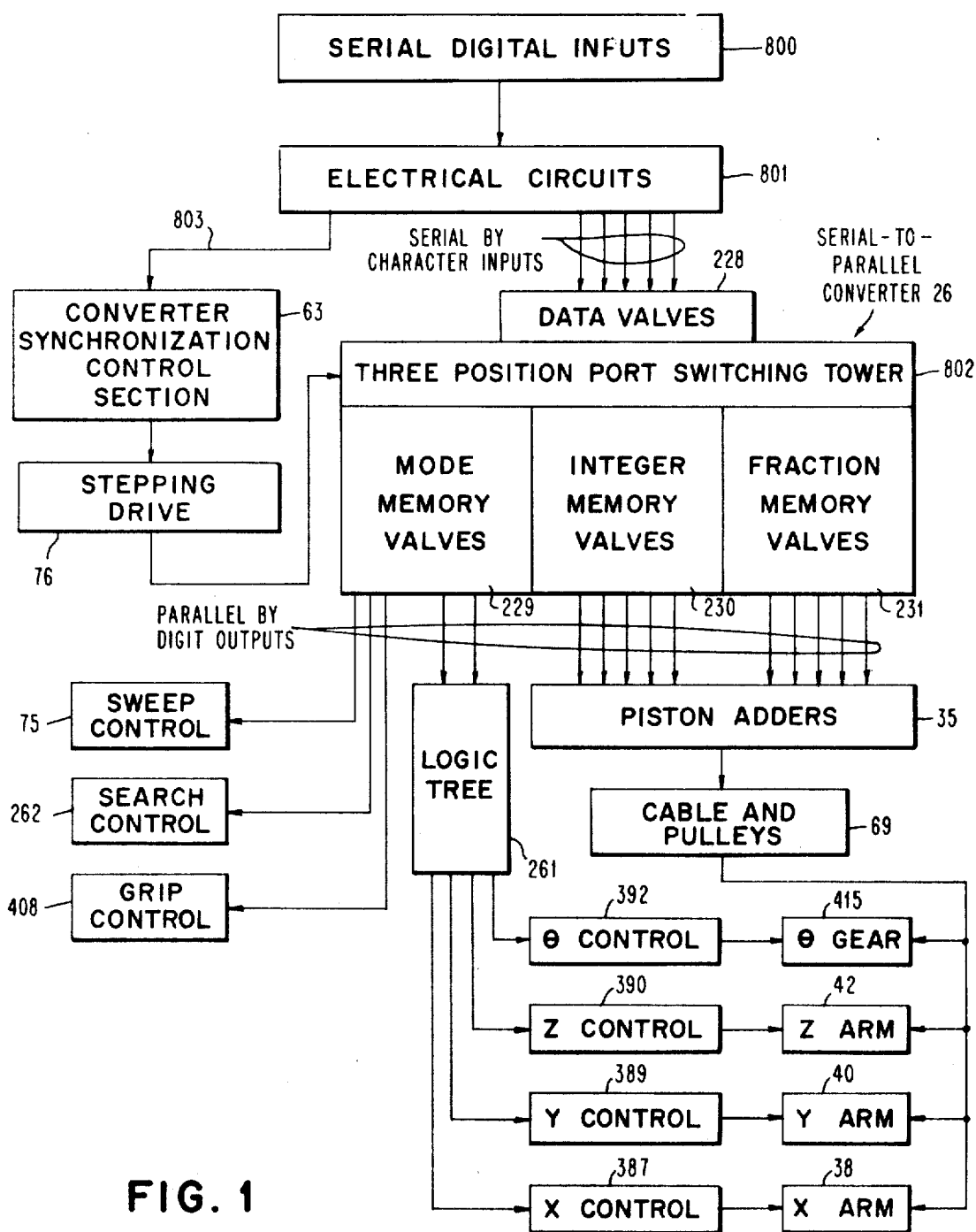


FIG. 1

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FIG. 2

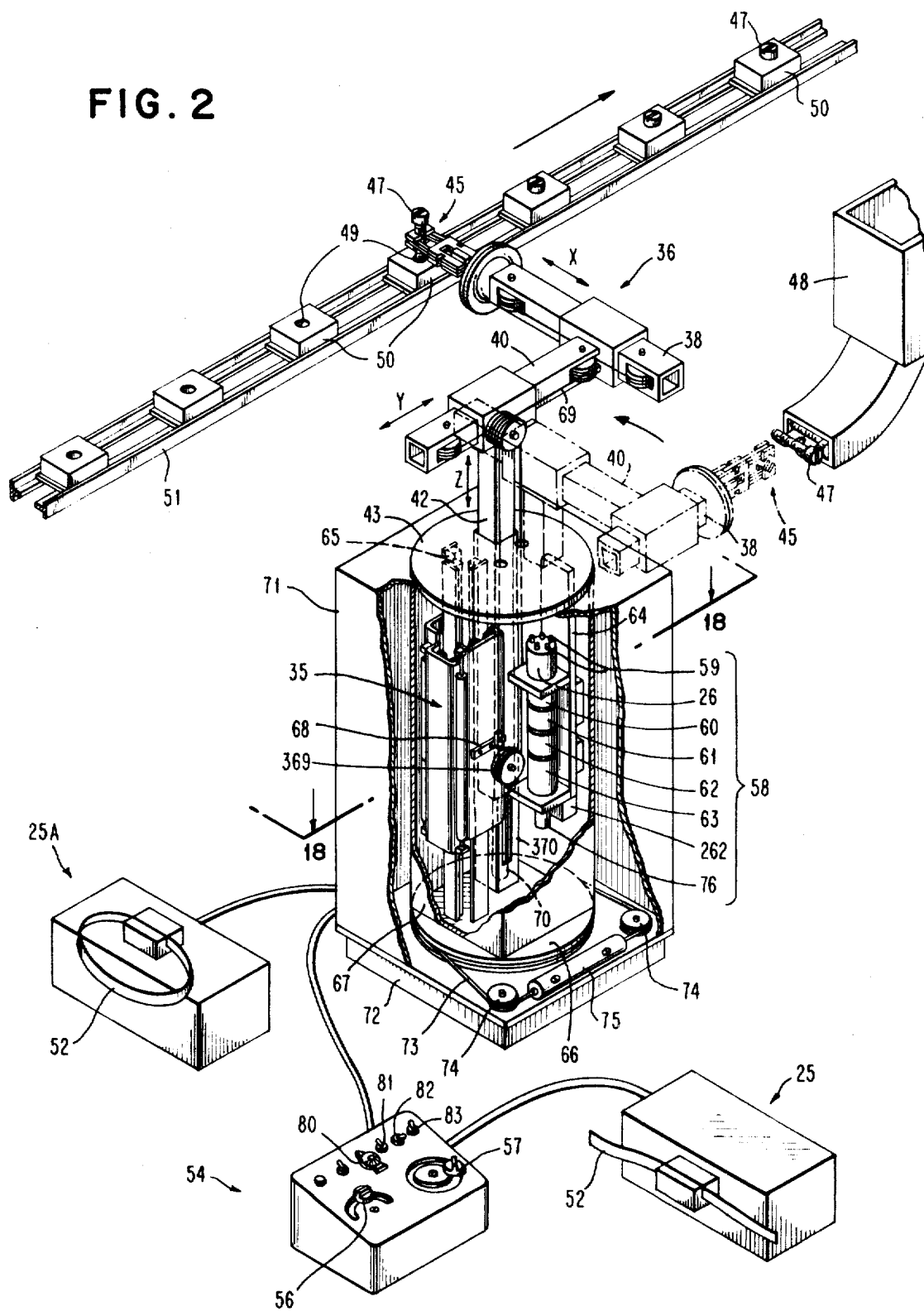


FIG. 3A

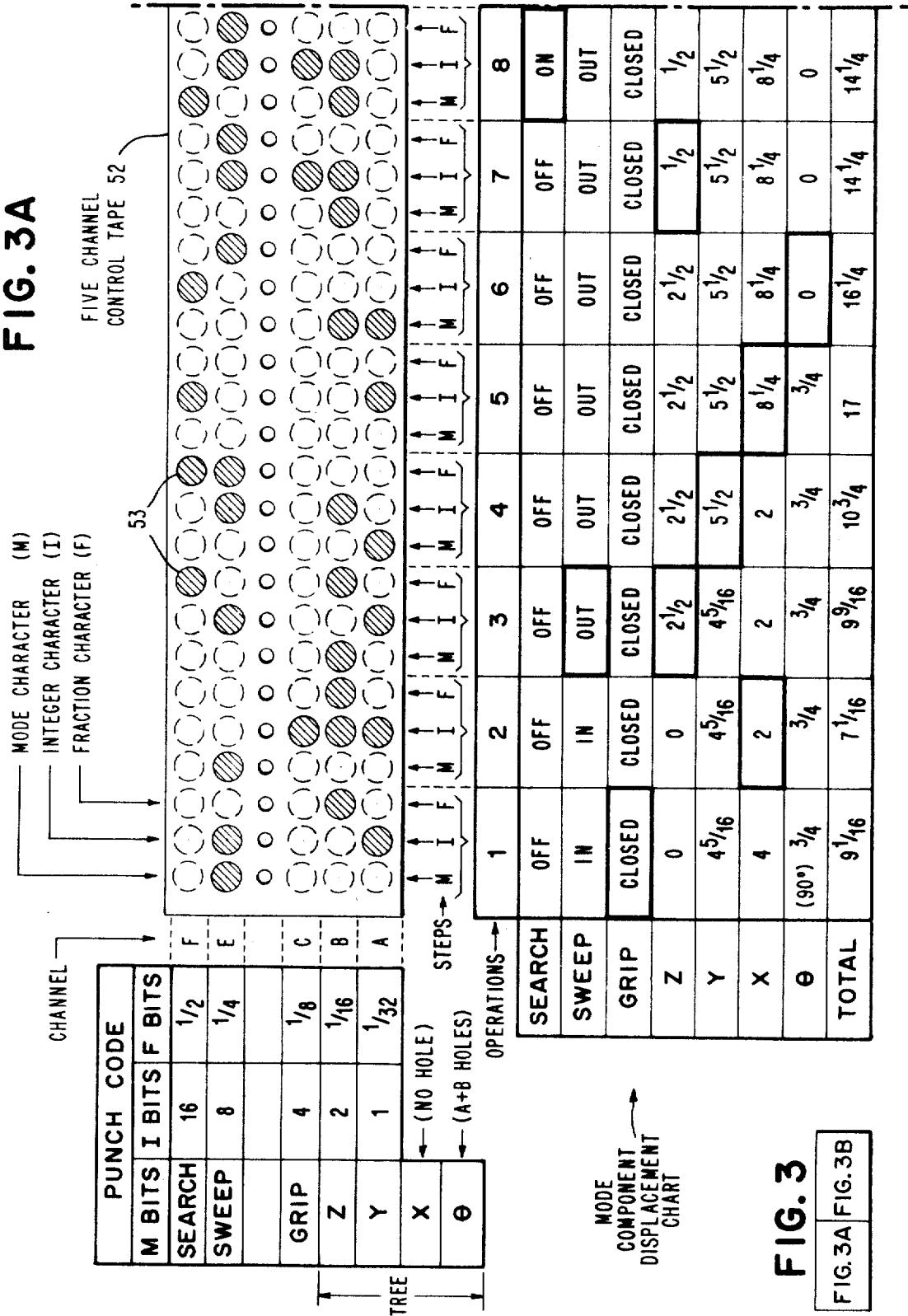


FIG. 6

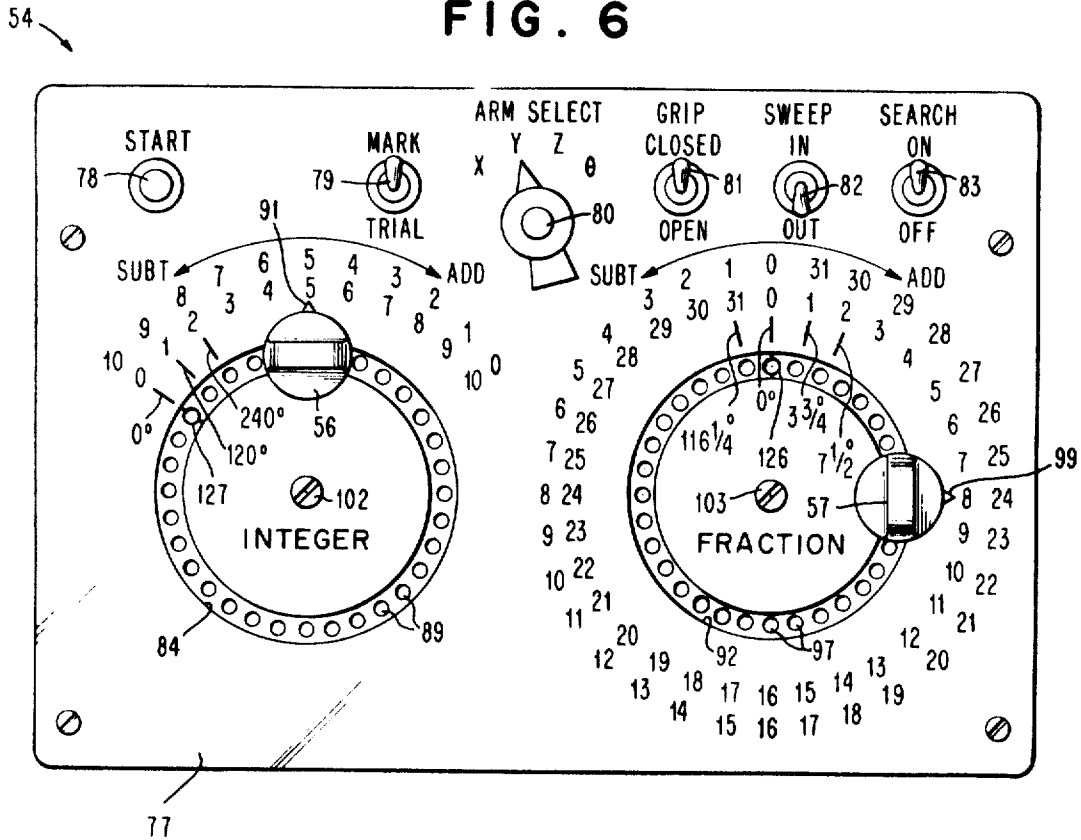


FIG. 7

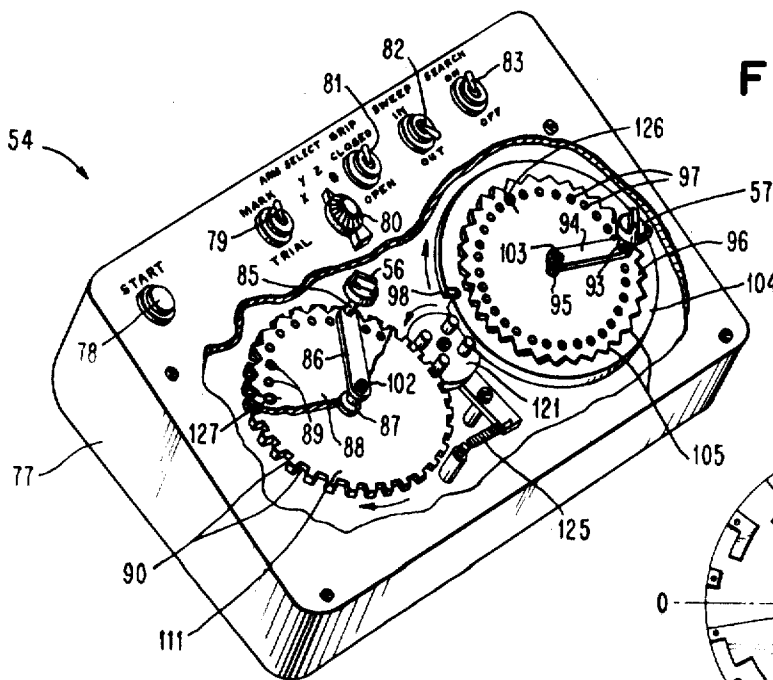
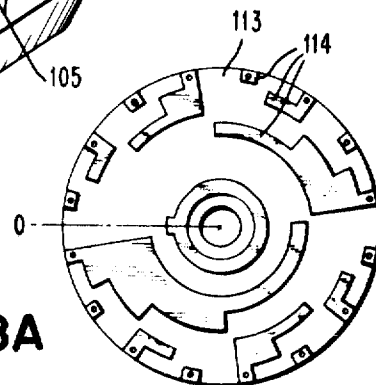


FIG. 8A



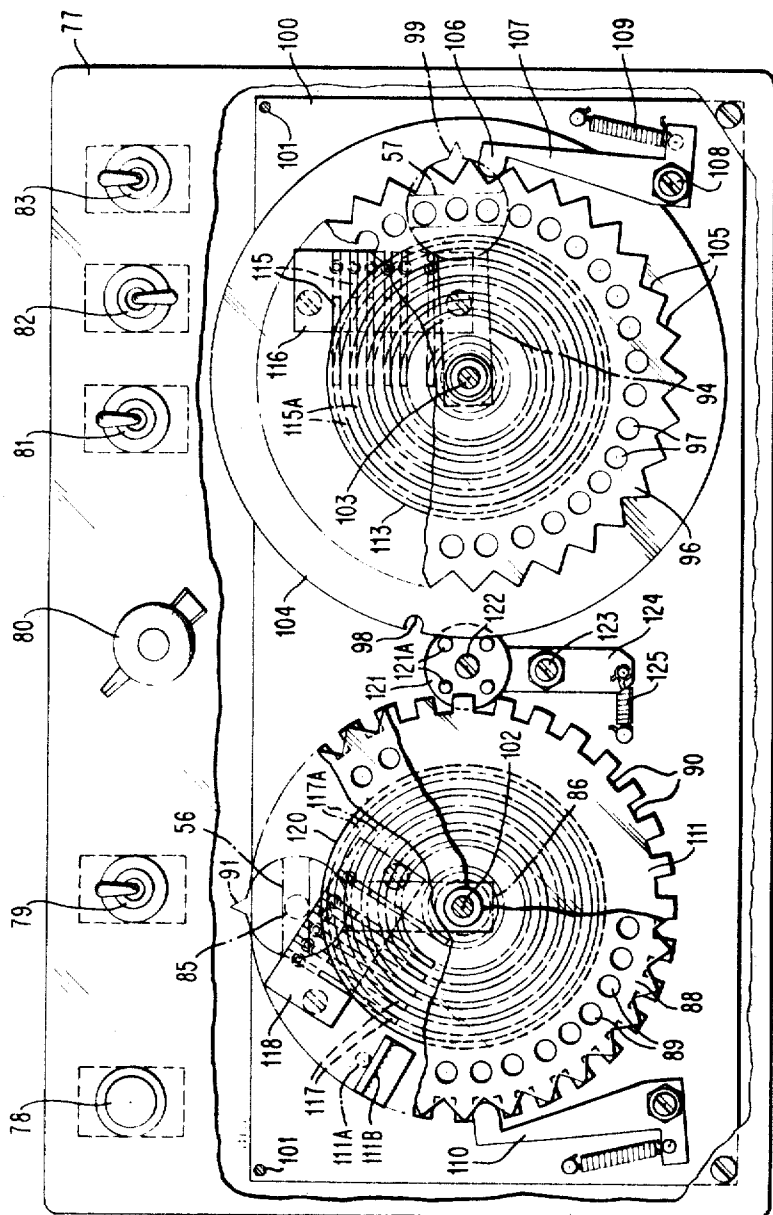


FIG. 8

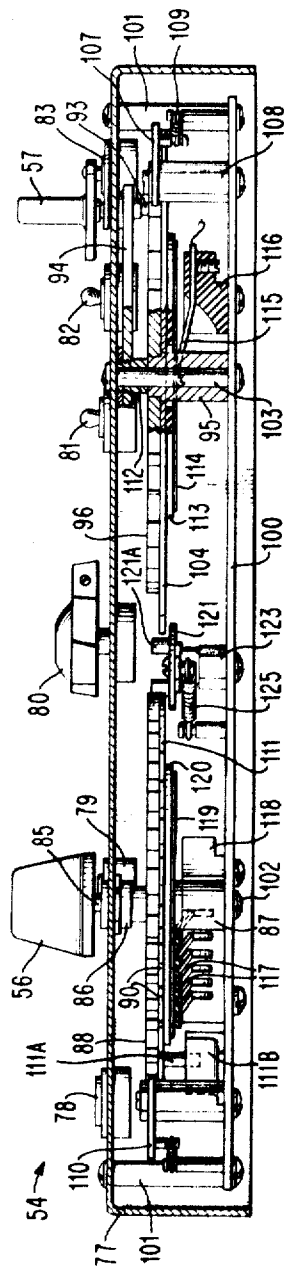
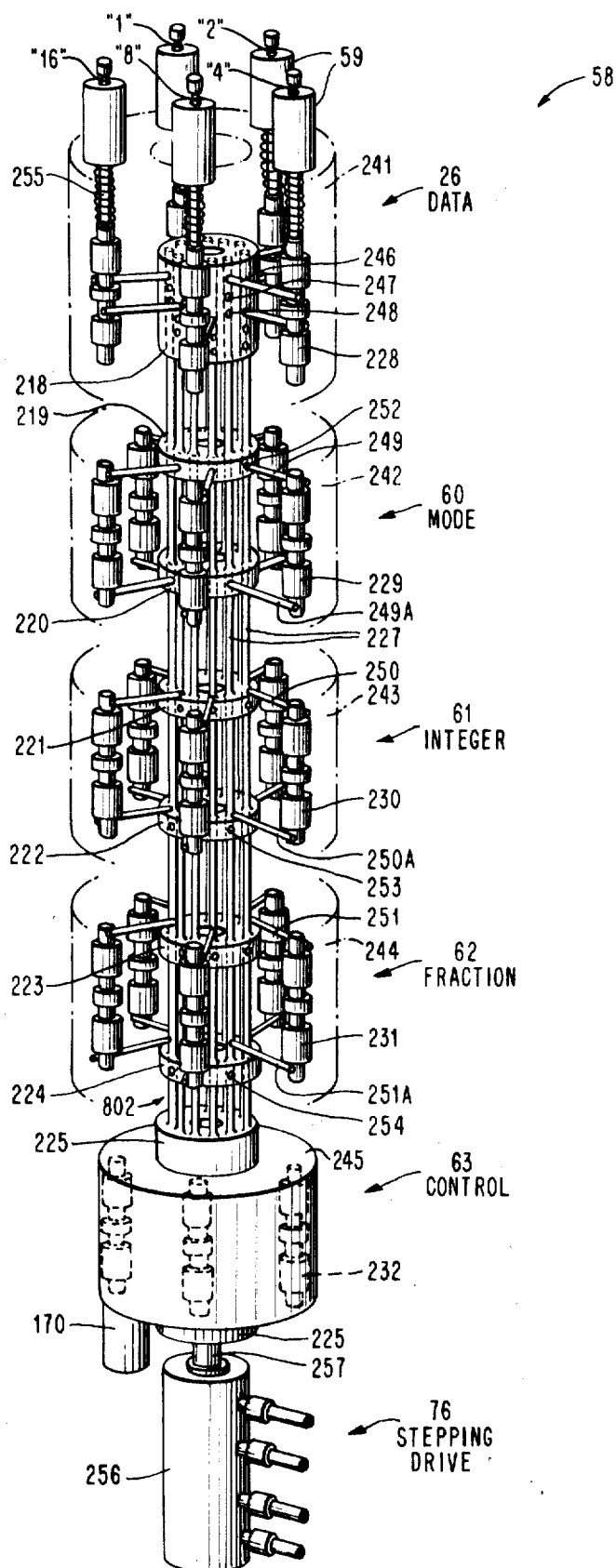


FIG. 9

FIG. 10



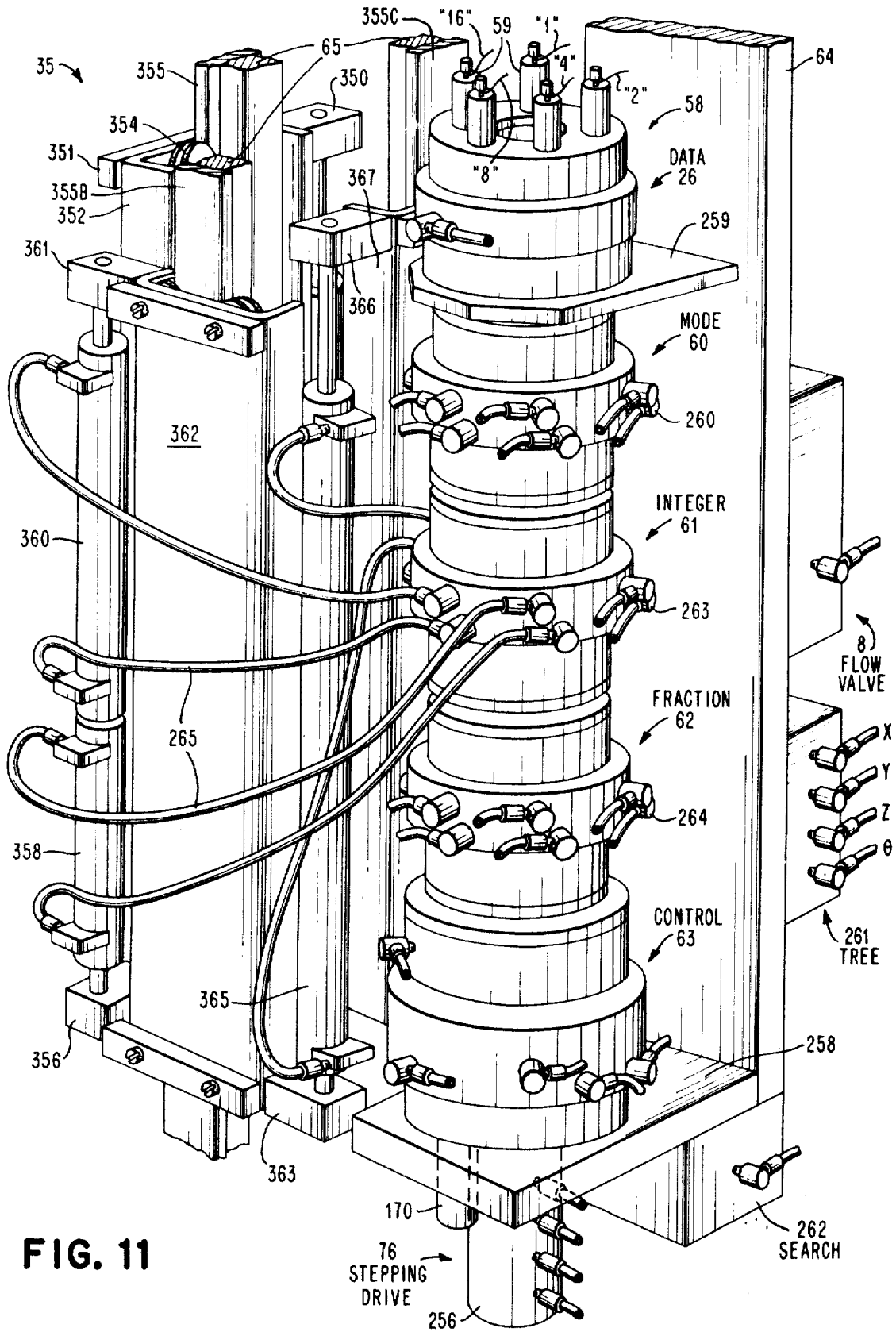


FIG. 12

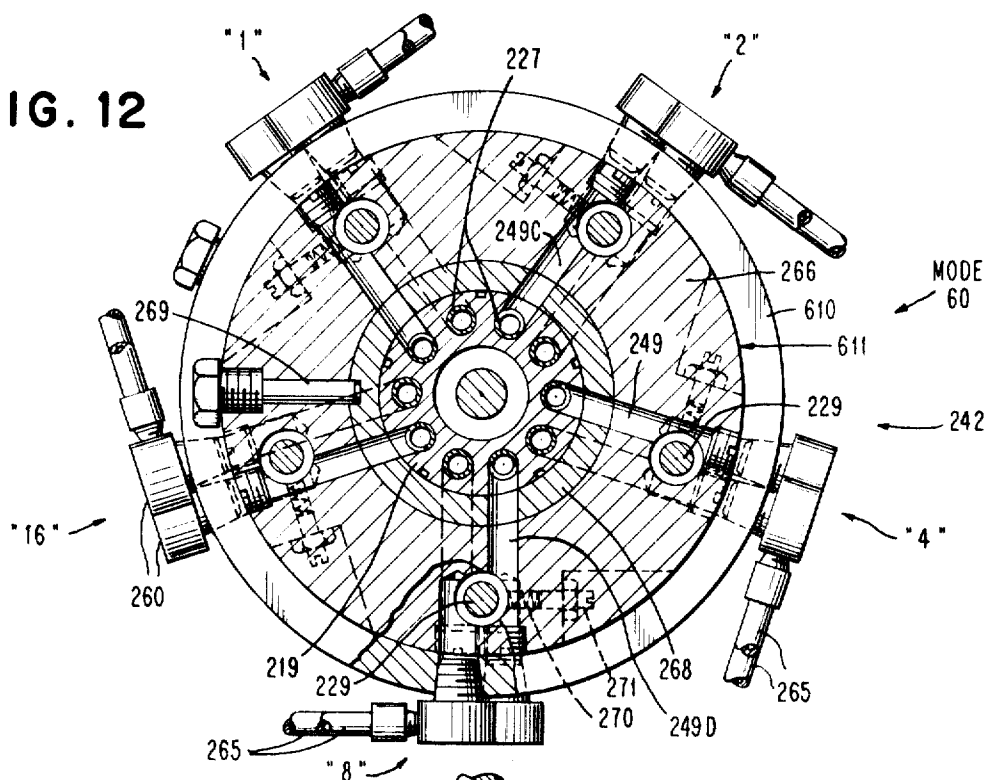


FIG. 13

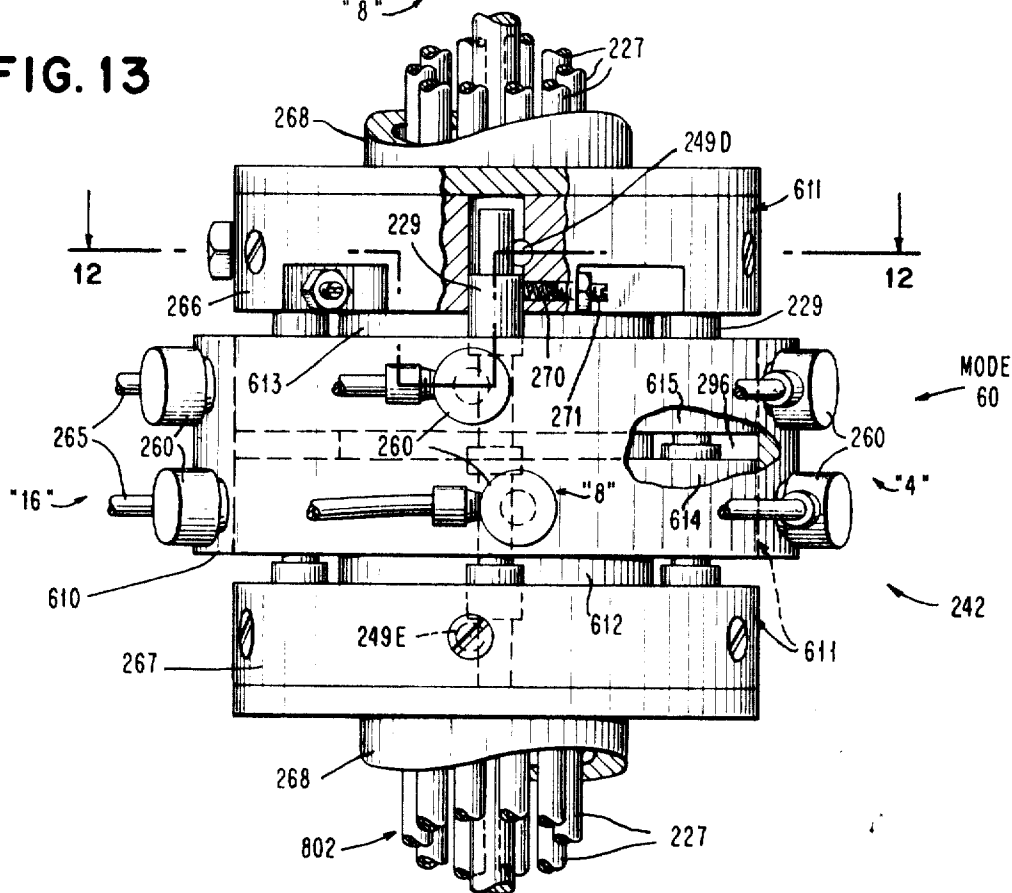


FIG. 14

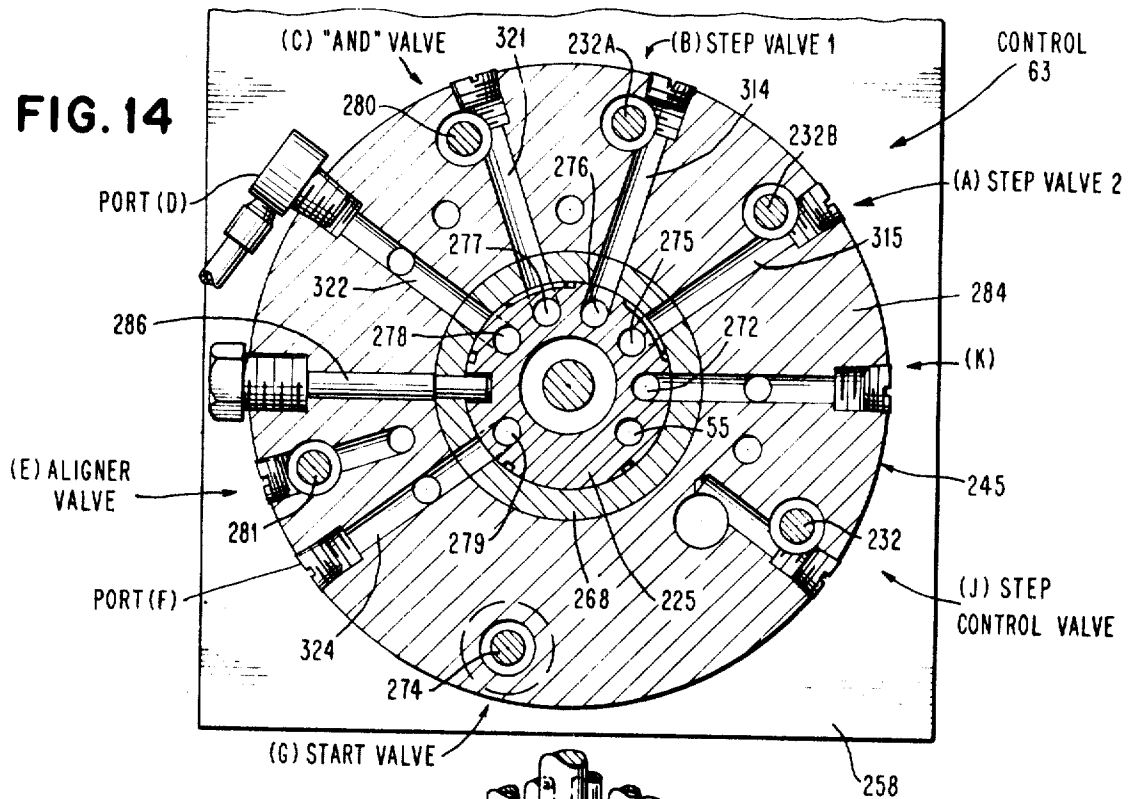


FIG. 15

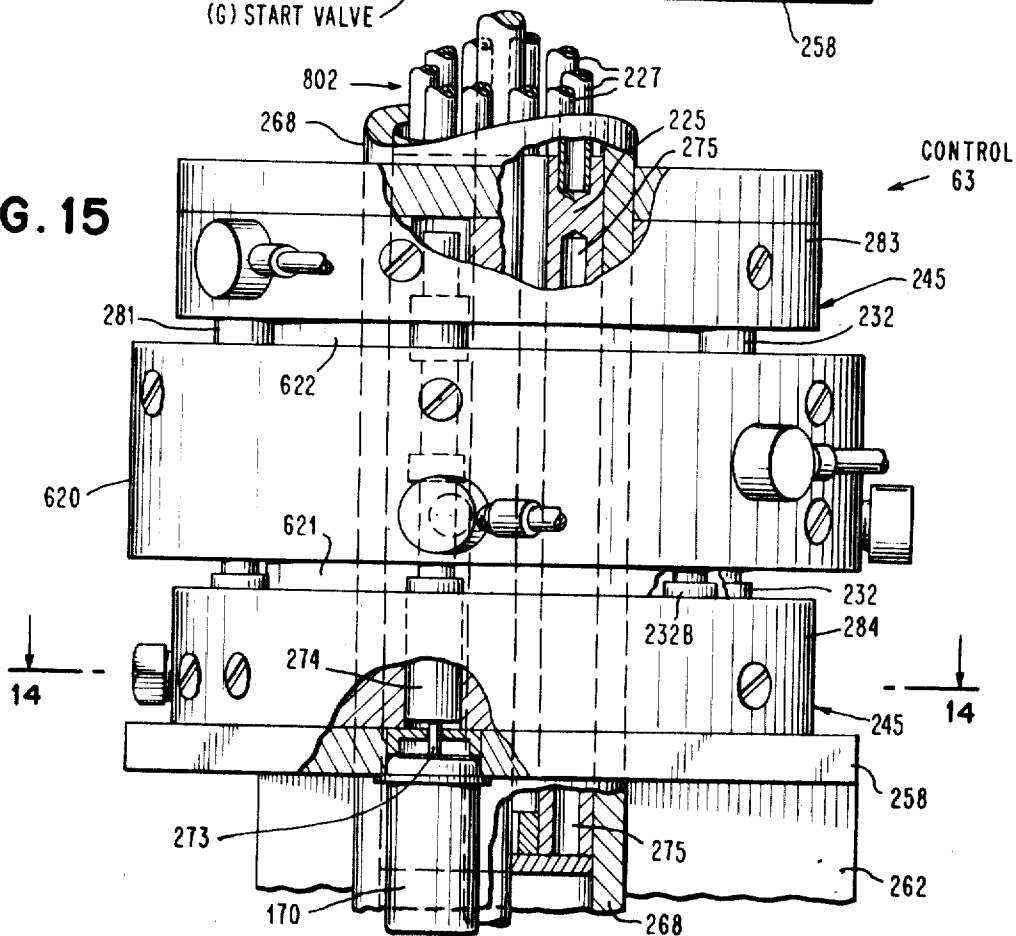


FIG. 17
PISTON ADDERS
AT $4\frac{5}{16}$ "

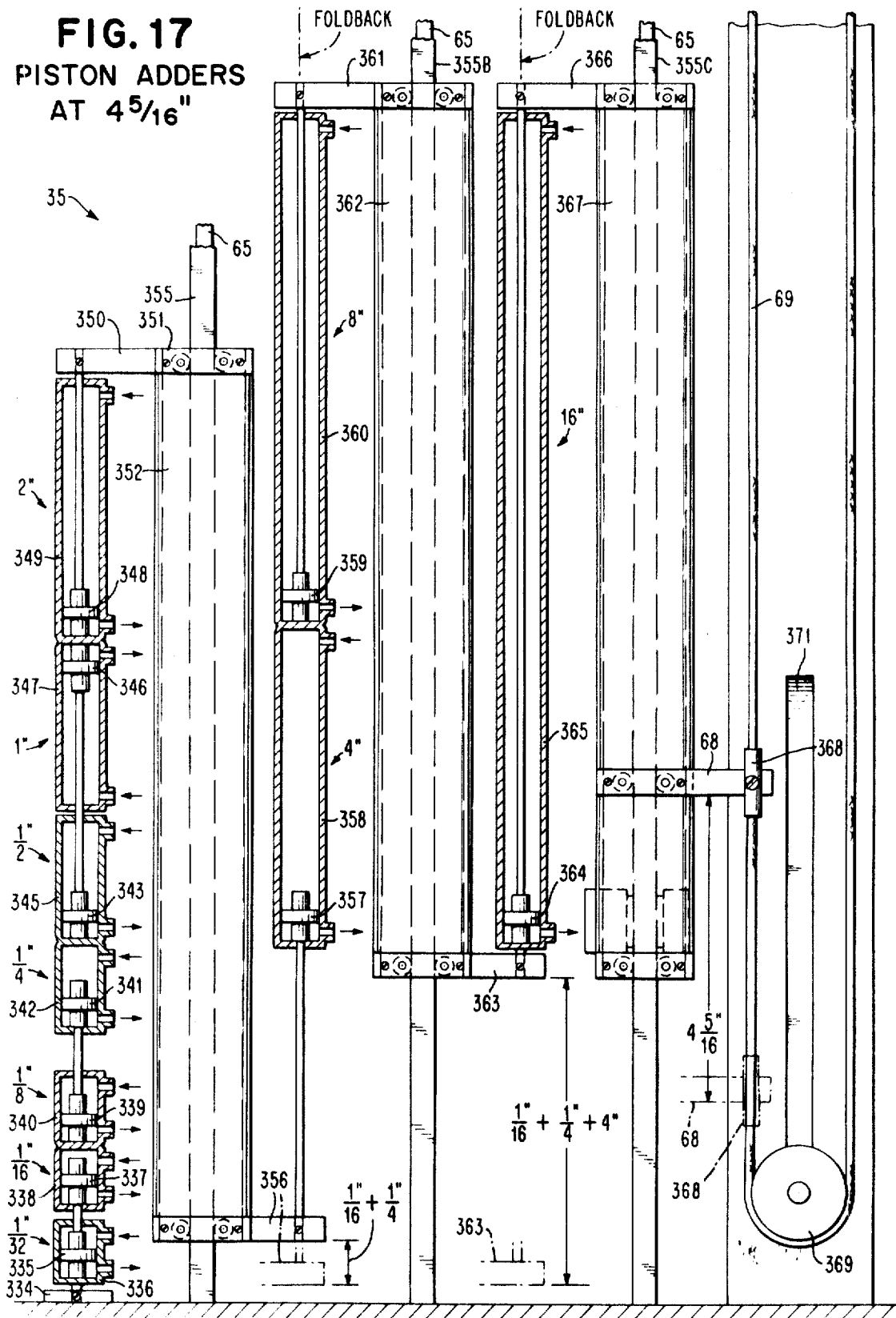


FIG. 18A

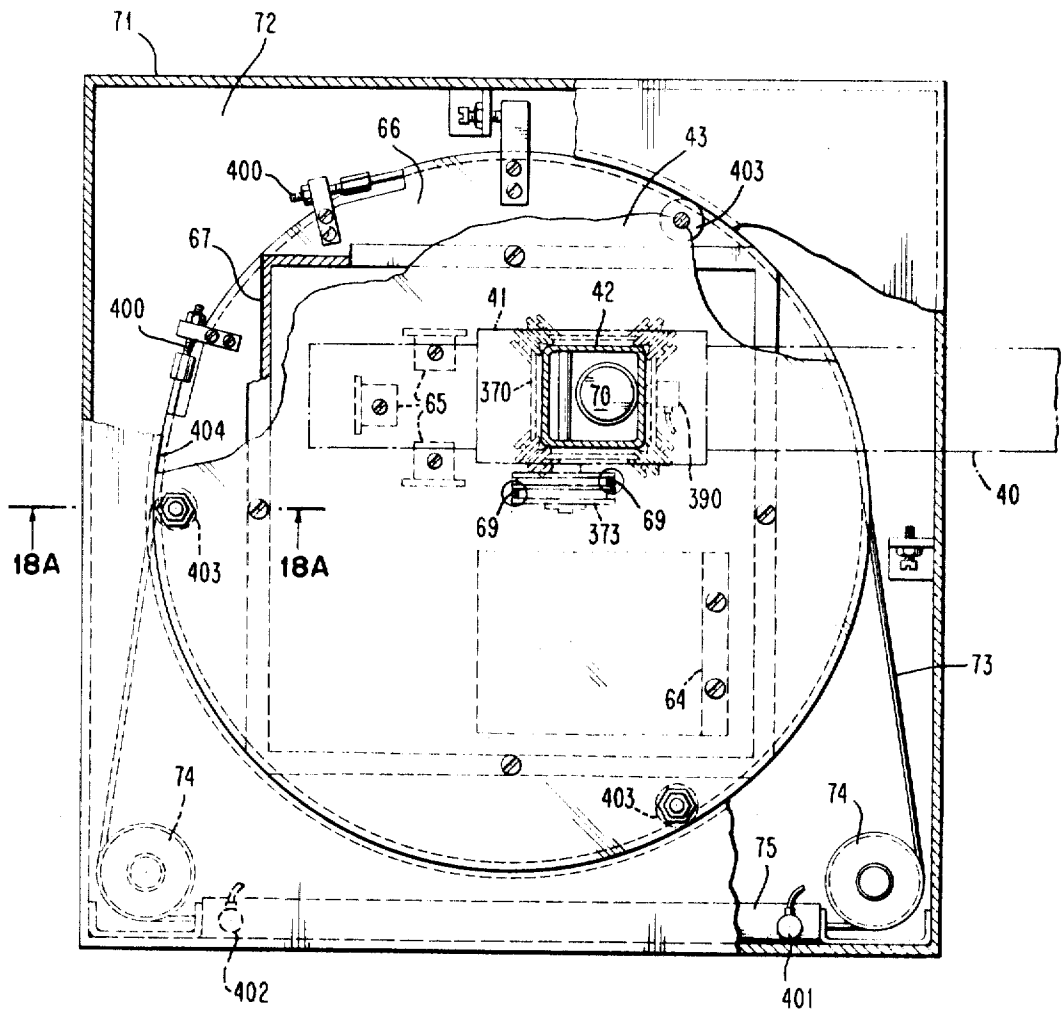
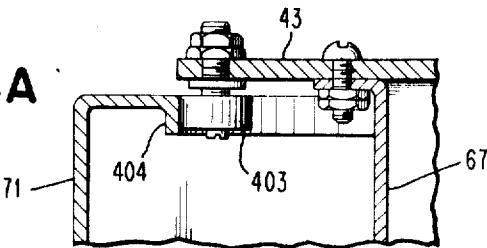
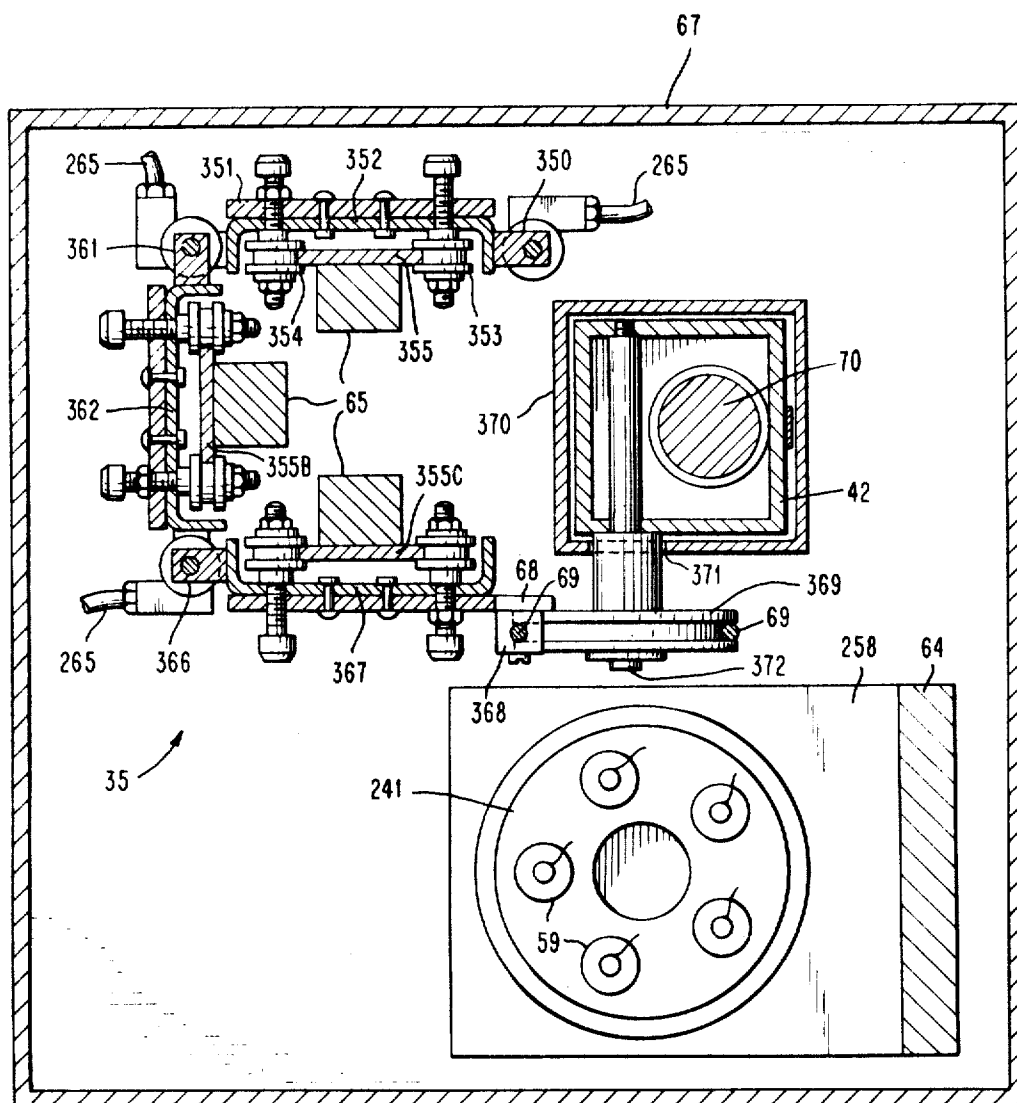


FIG. 18

FIG. 19



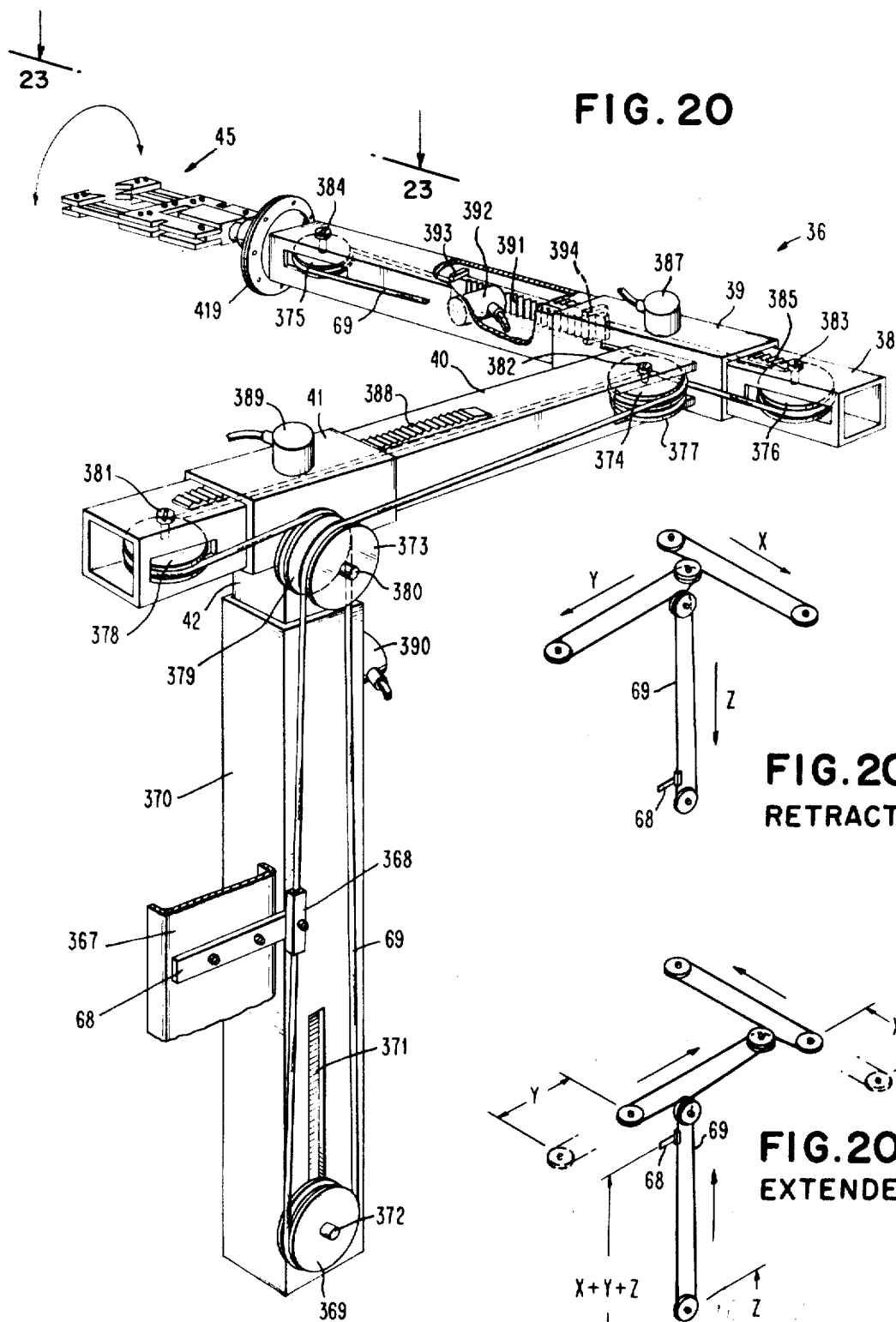


FIG. 20

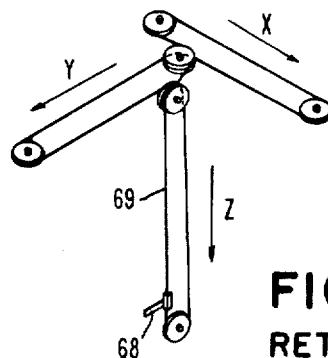


FIG. 20A
RETRACTED

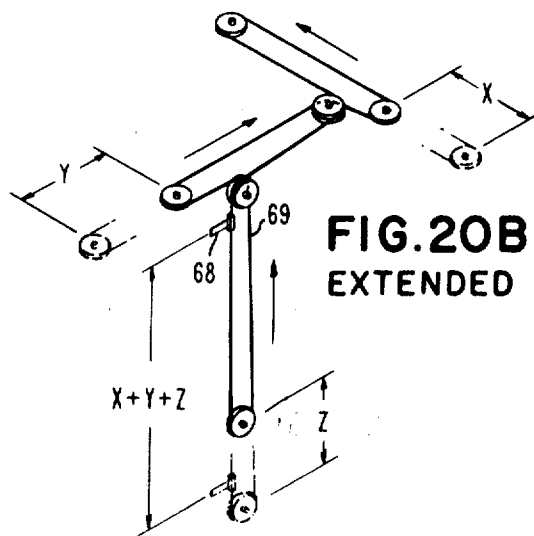


FIG. 20B
EXTENDED

FIG. 21

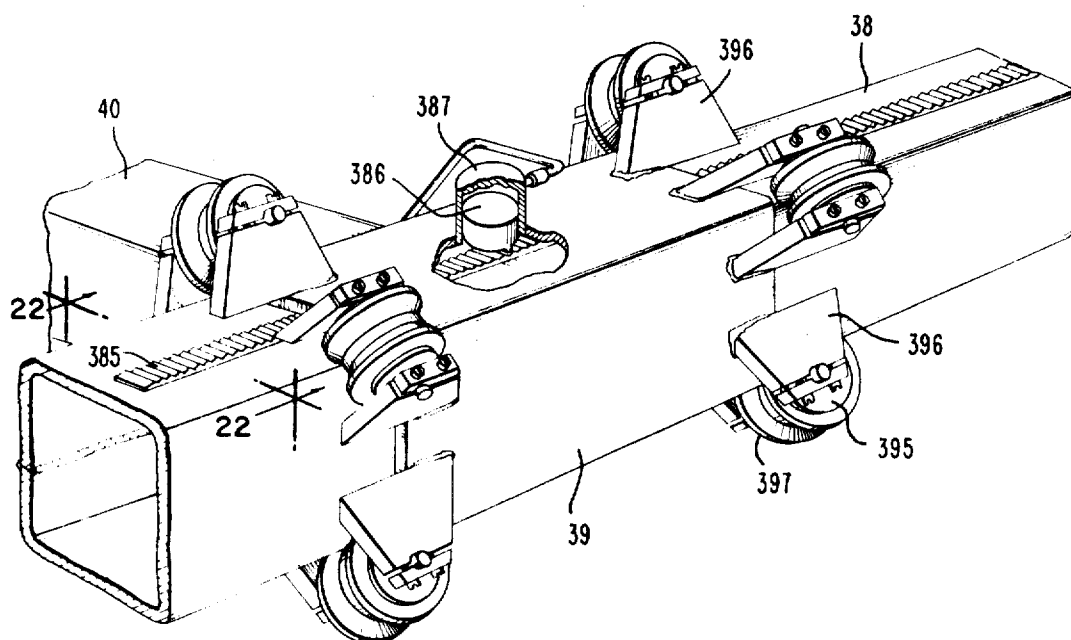


FIG. 22

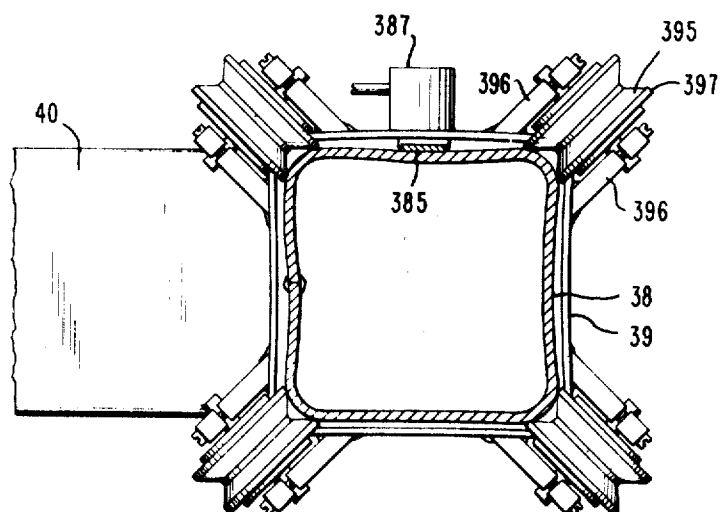


FIG. 23

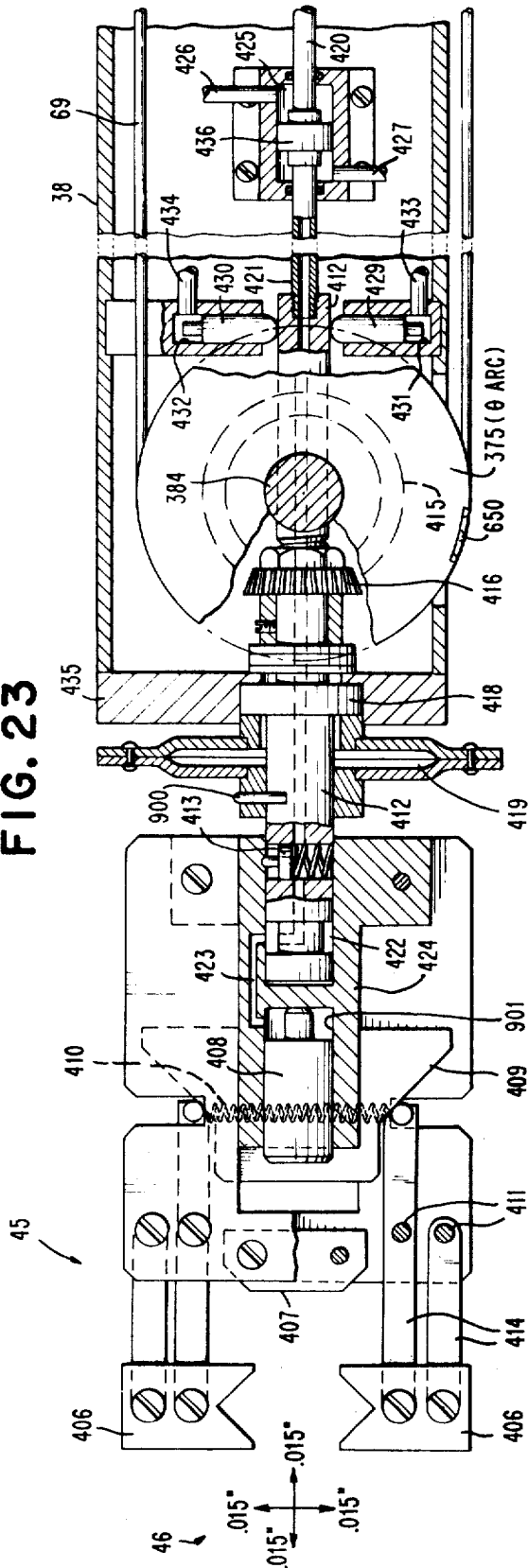


FIG. 24

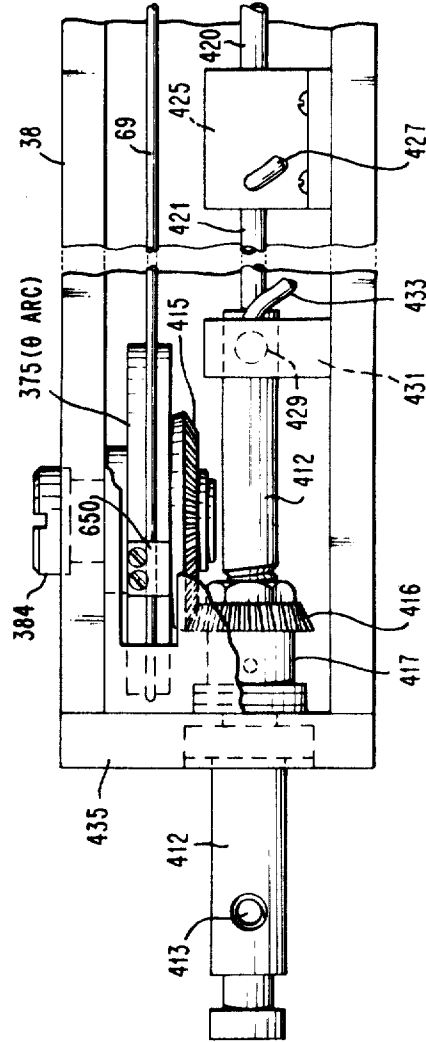
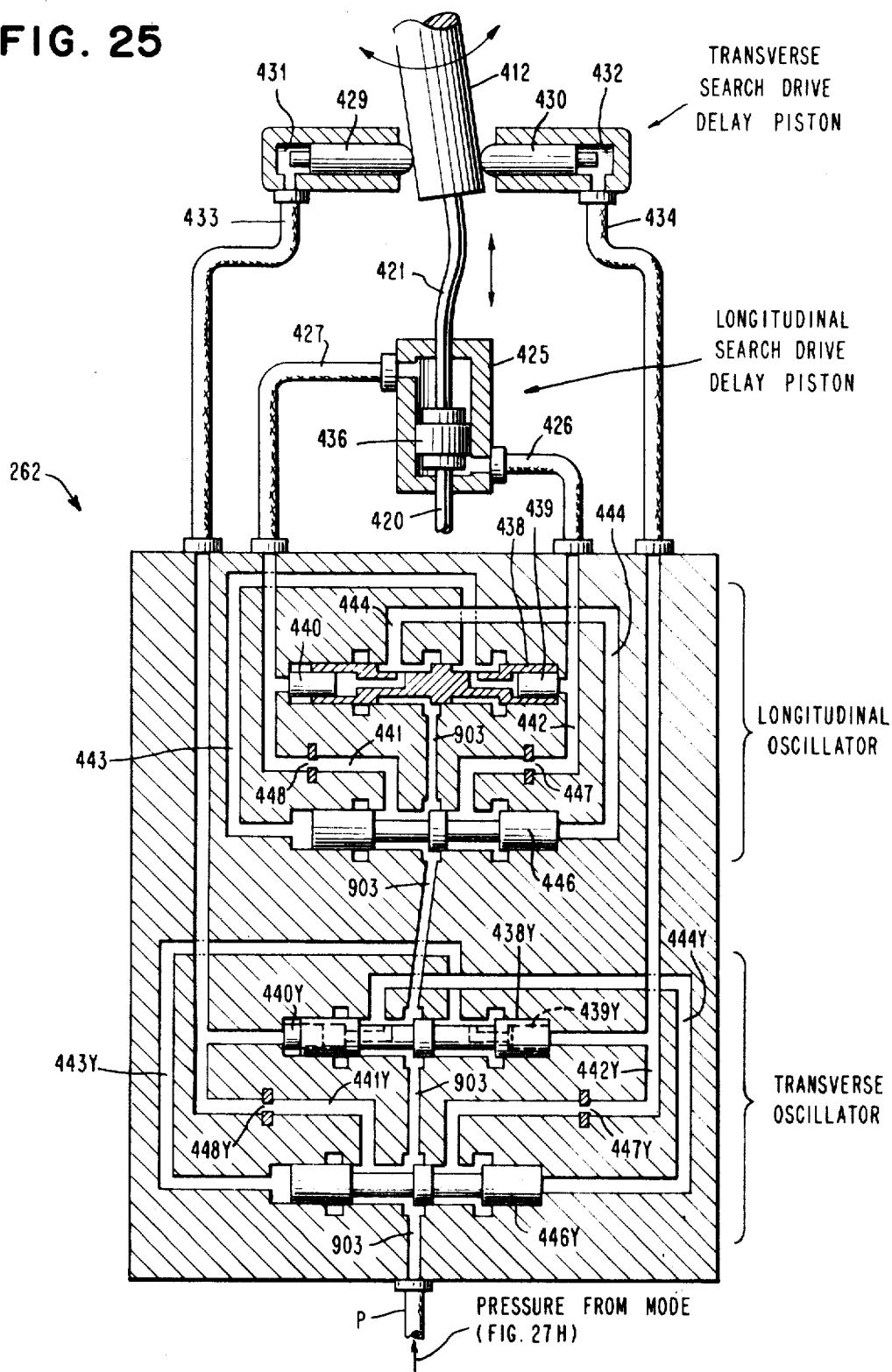
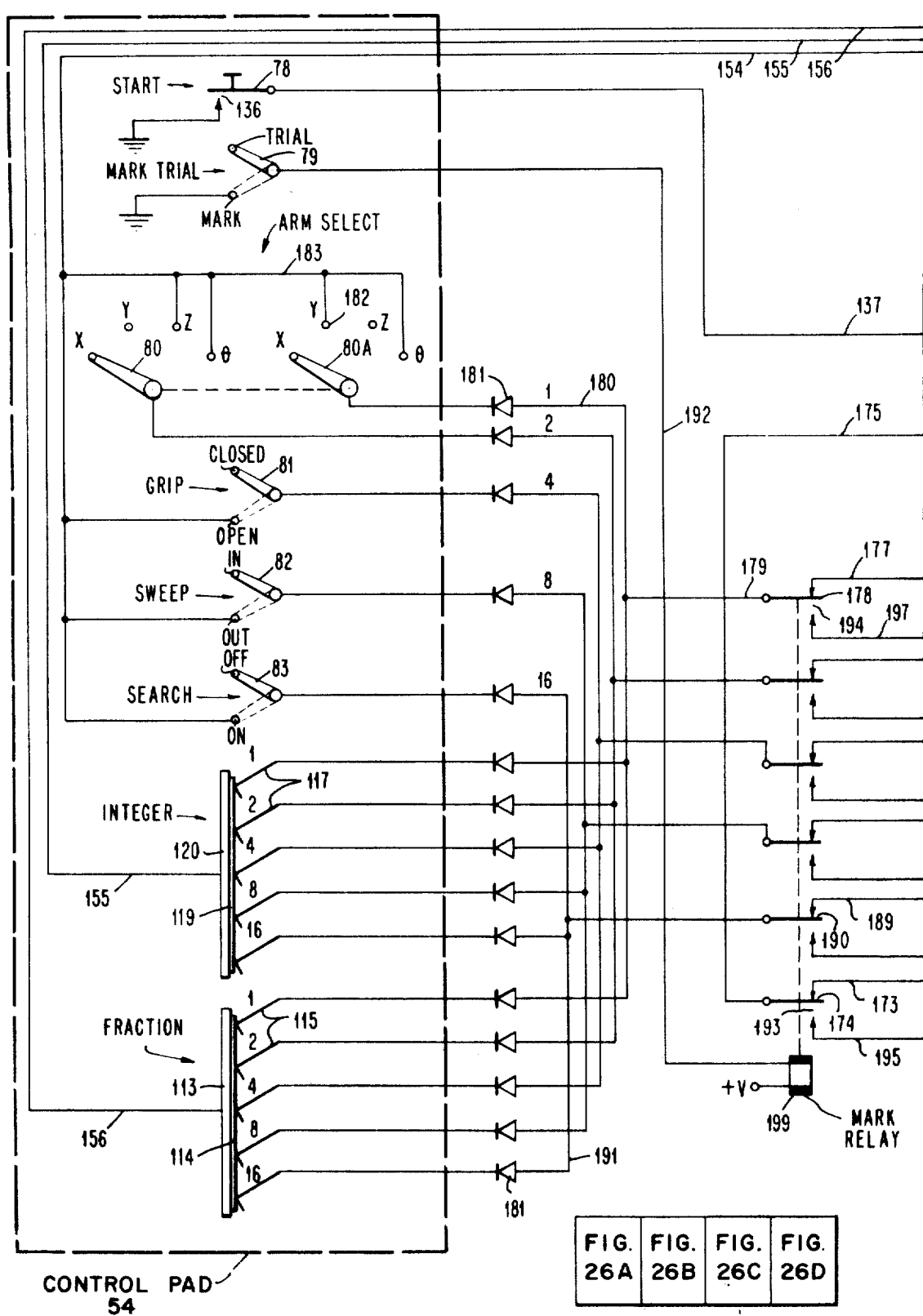


FIG. 25





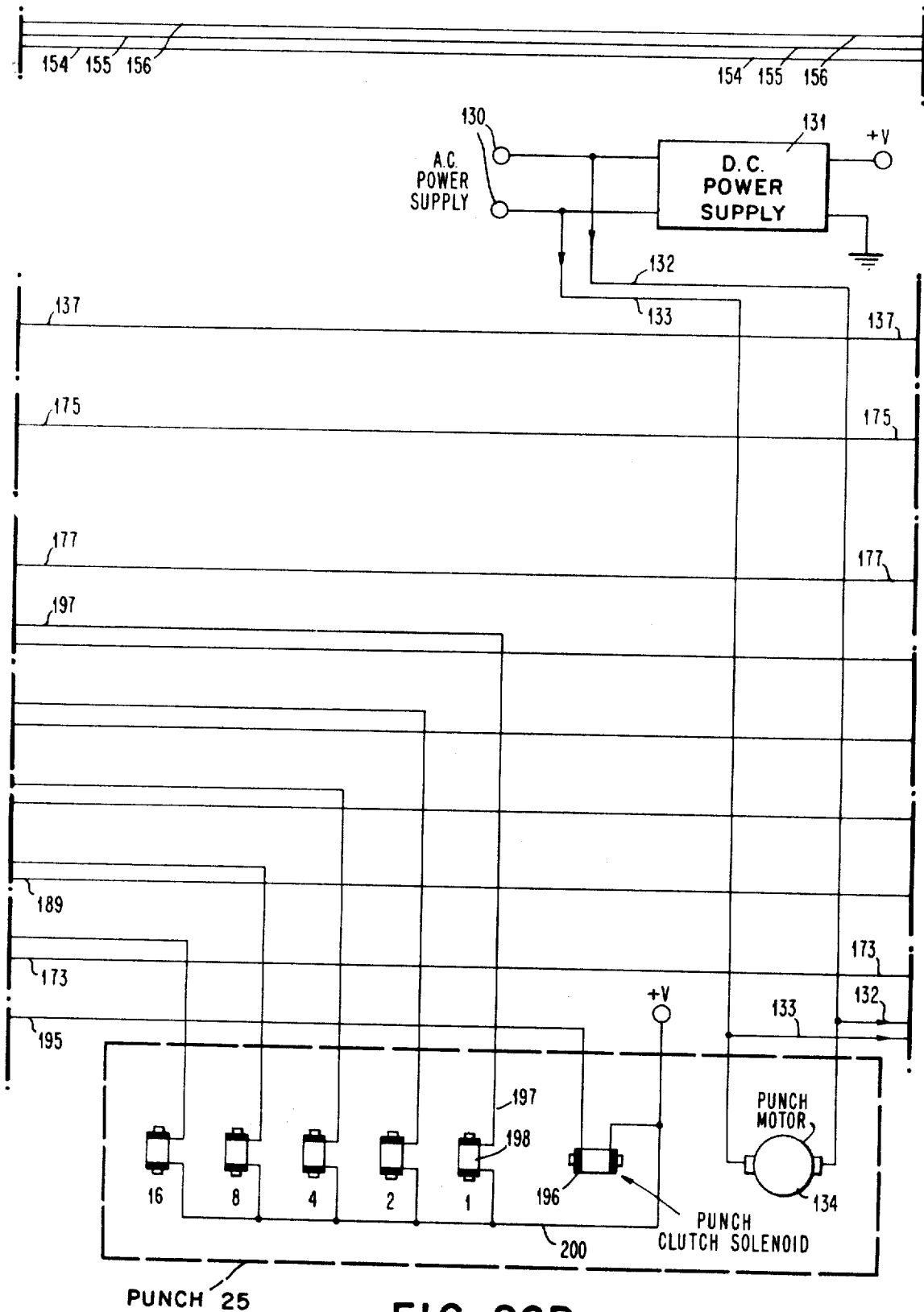
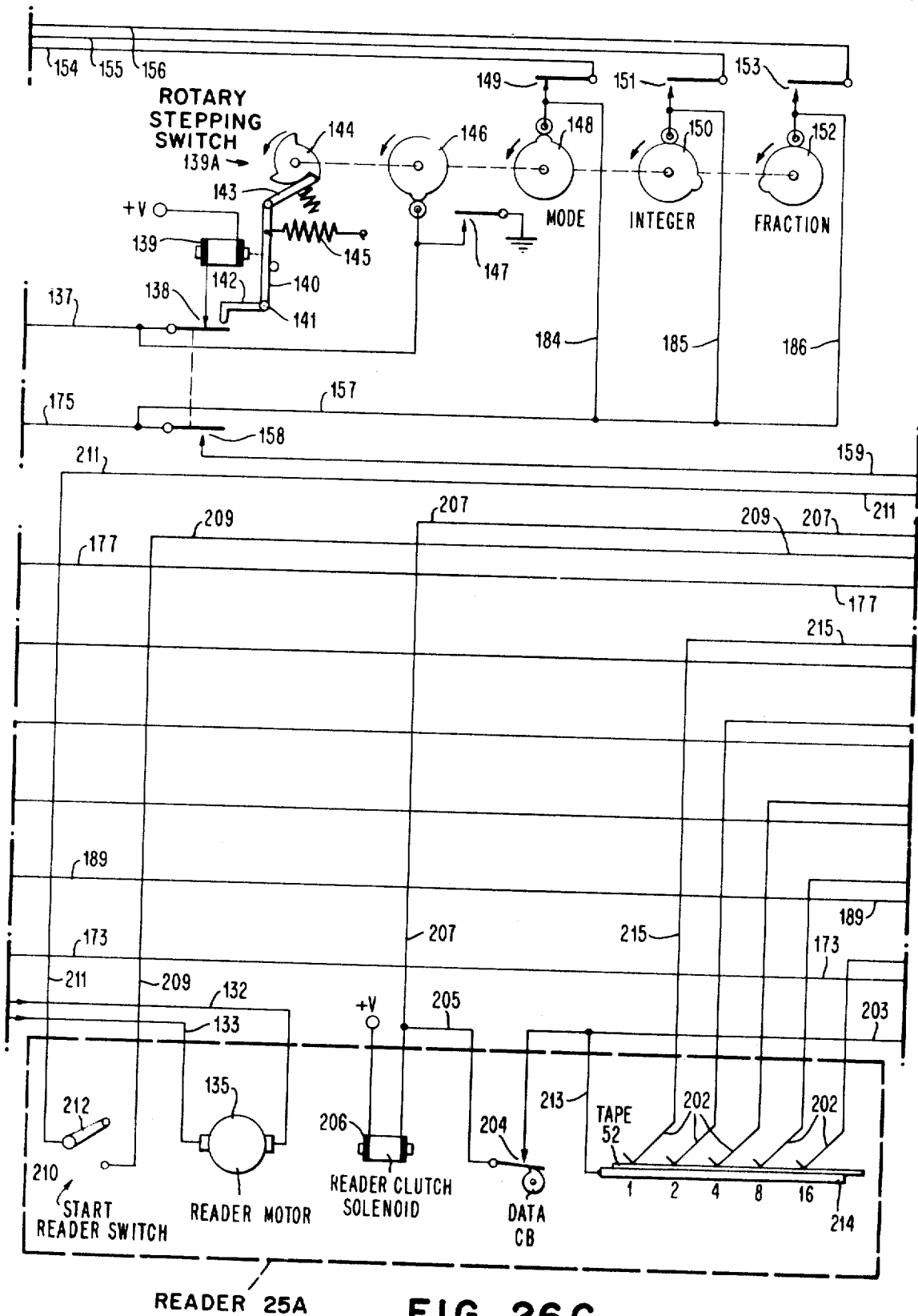


FIG. 26B



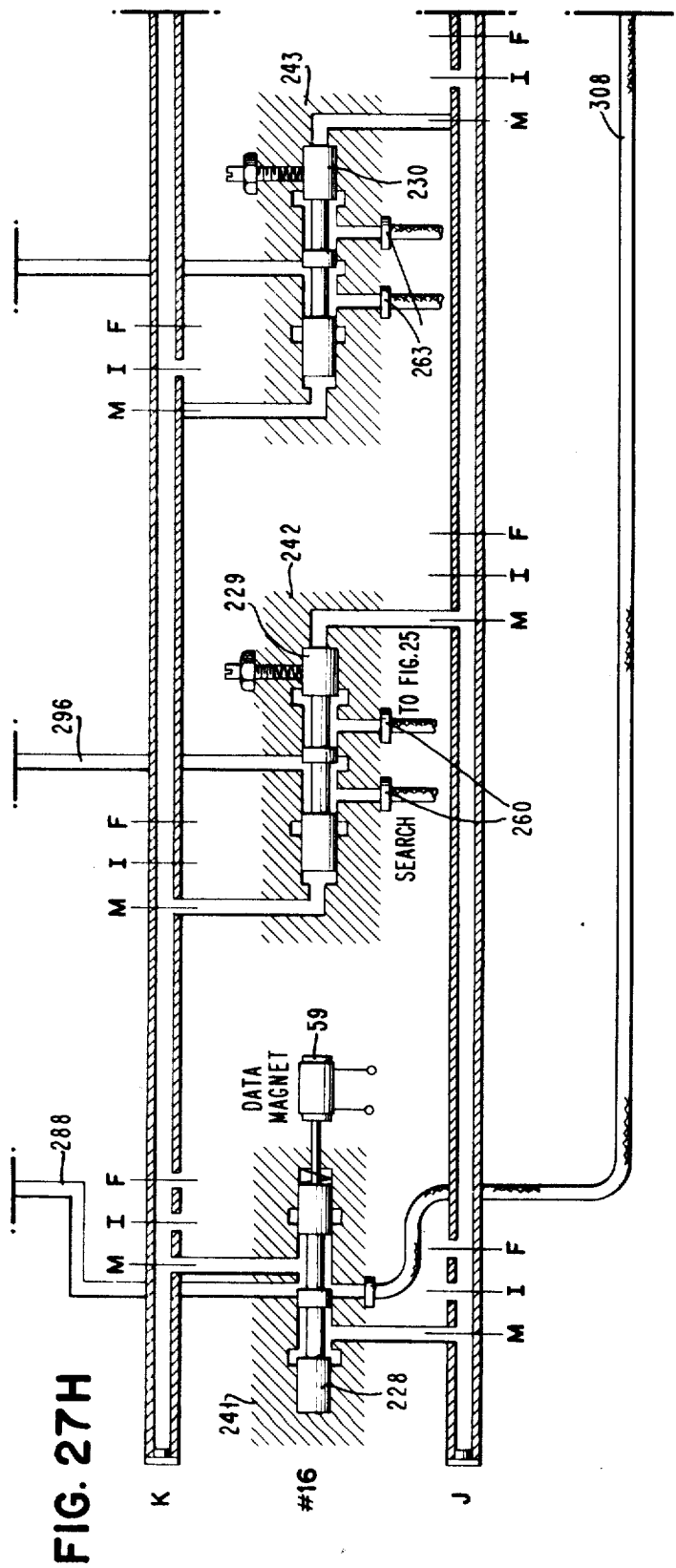


FIG. 27H

FIG. 27A	FIG. 27B	FIG. 27C	FIG. 27D
FIG. 27E	FIG. 27F	FIG. 27G	FIG. 27H FIG. 27J FIG. 27K
FIG. 27H	FIG. 27I	FIG. 27J	

FIG. 27

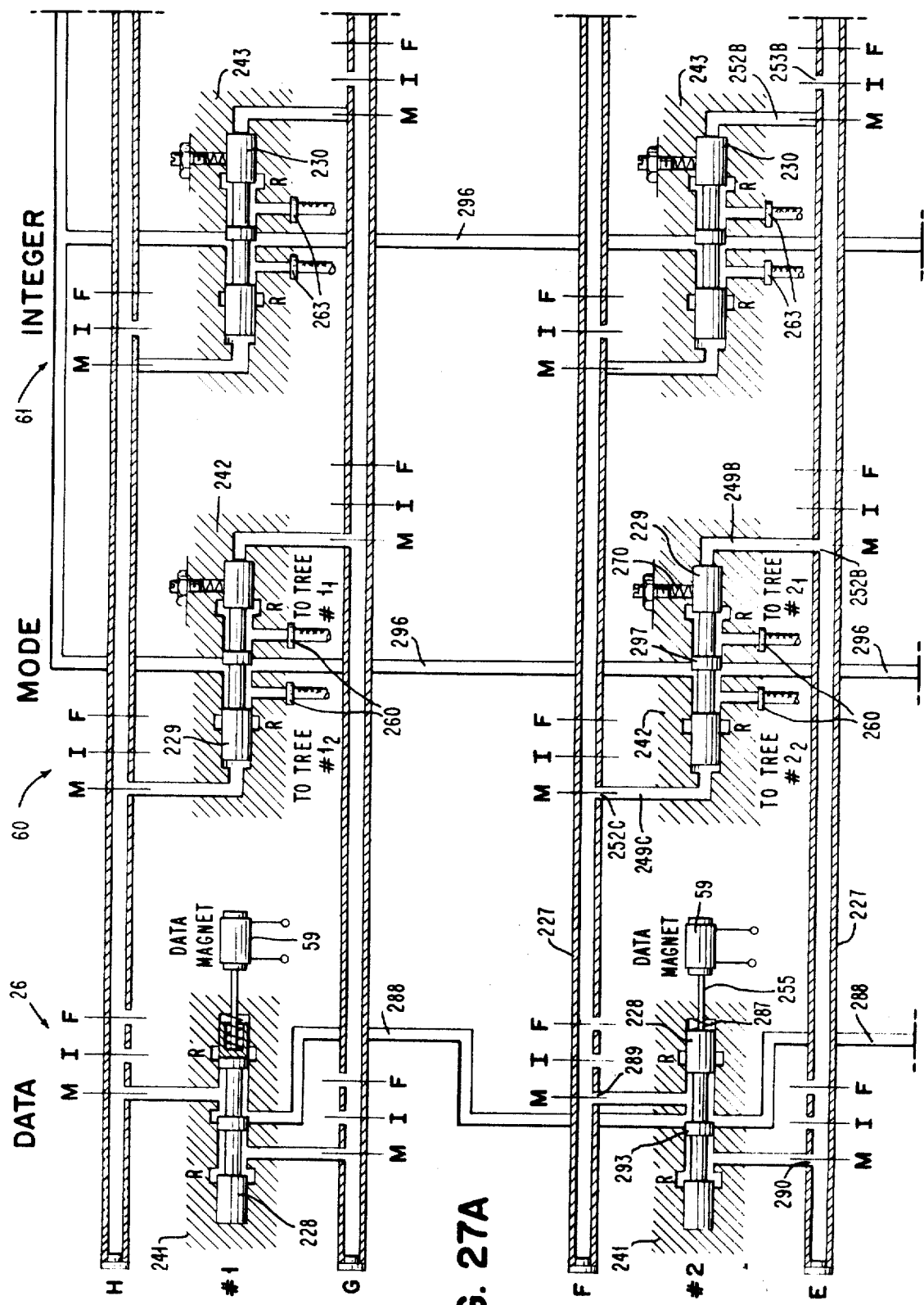
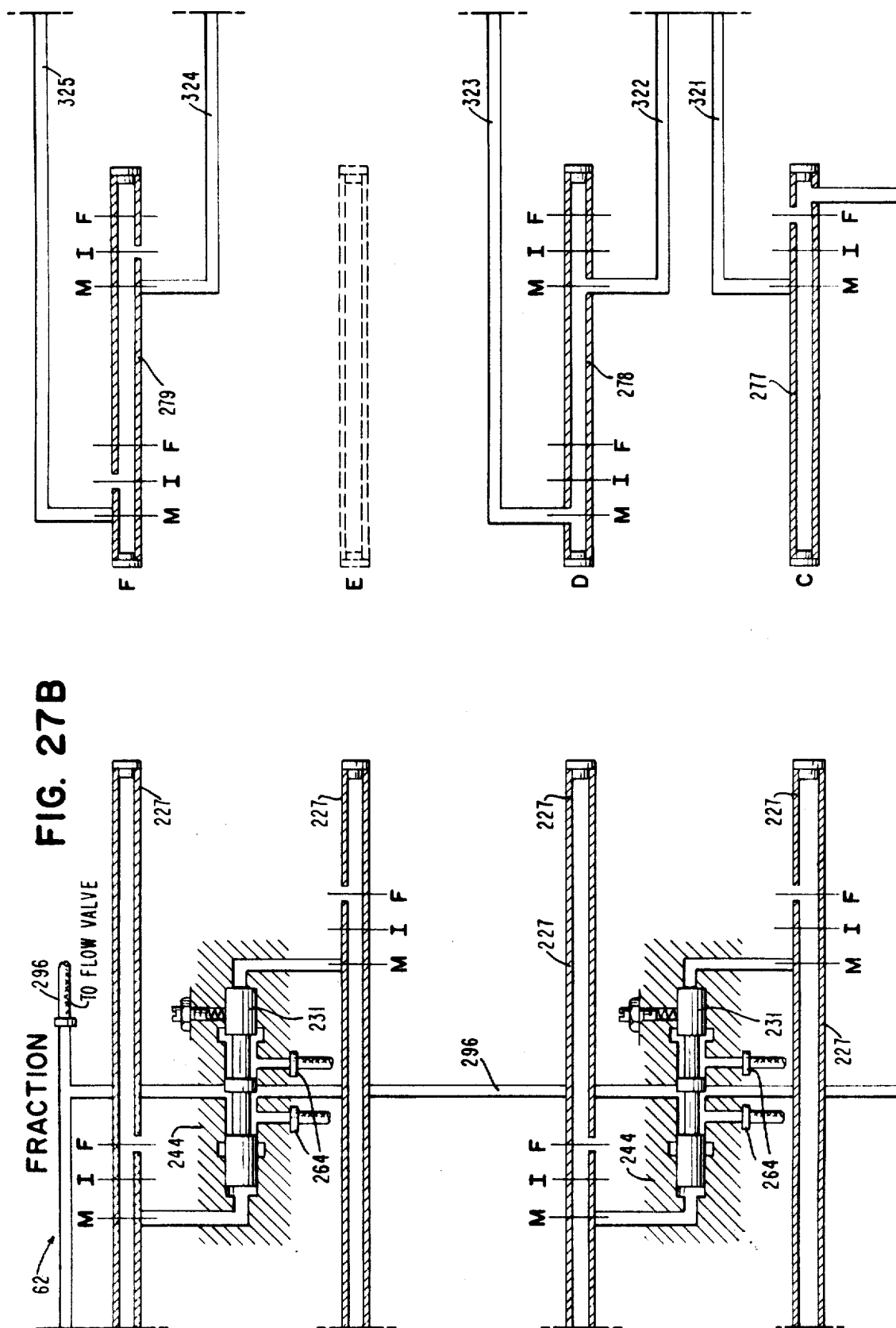


FIG. 27A

FIG. 27B



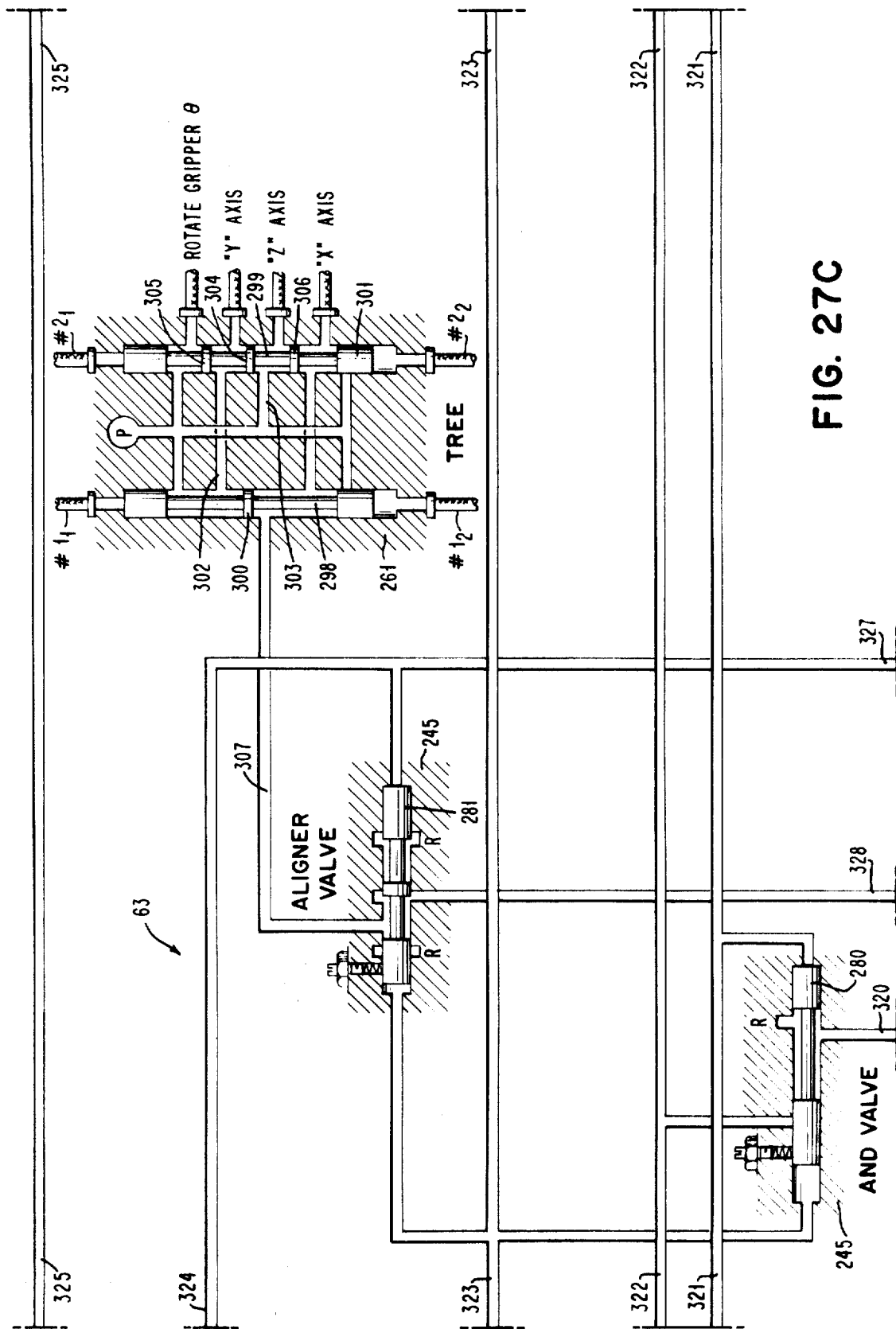


FIG. 27D

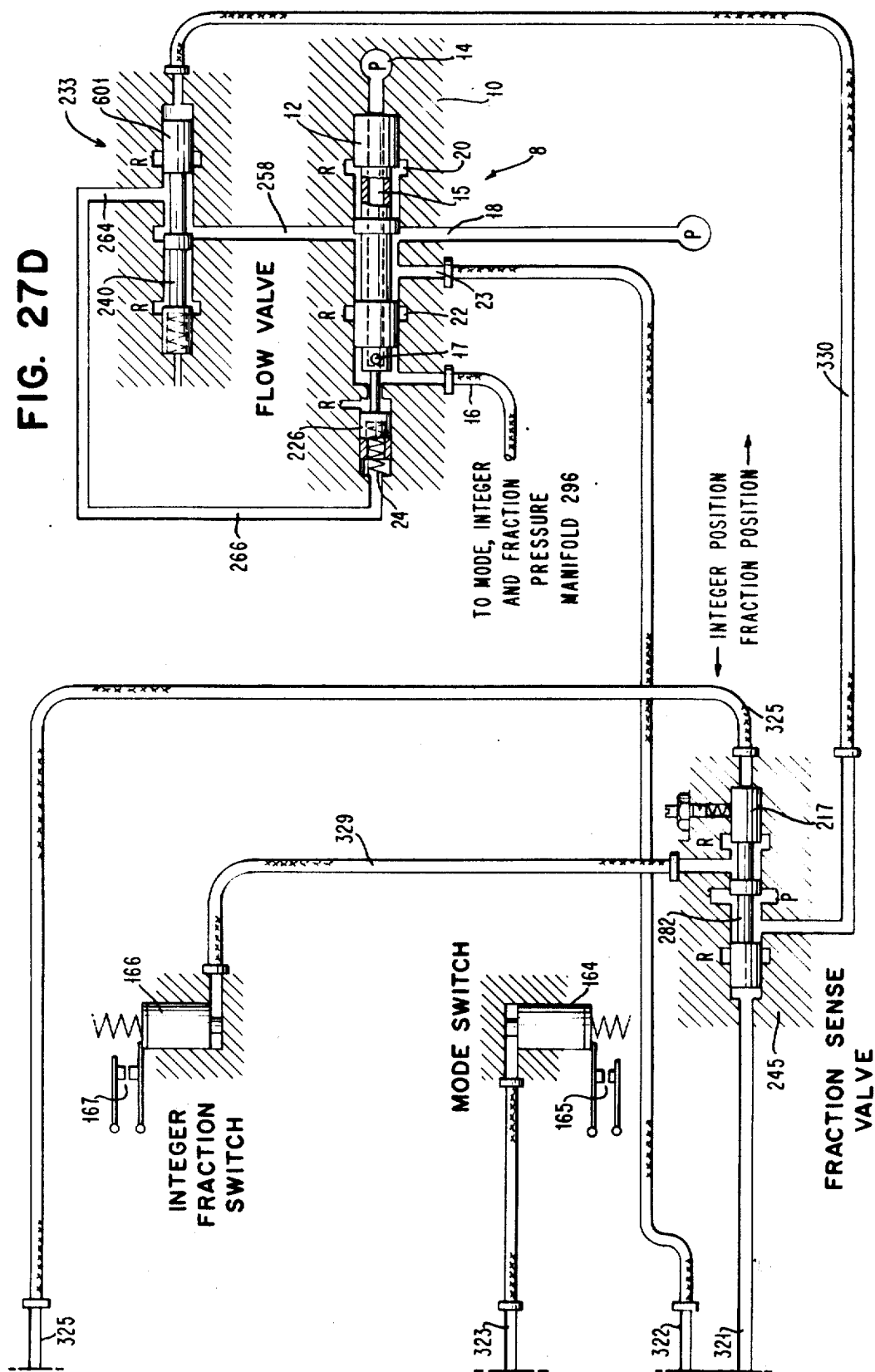
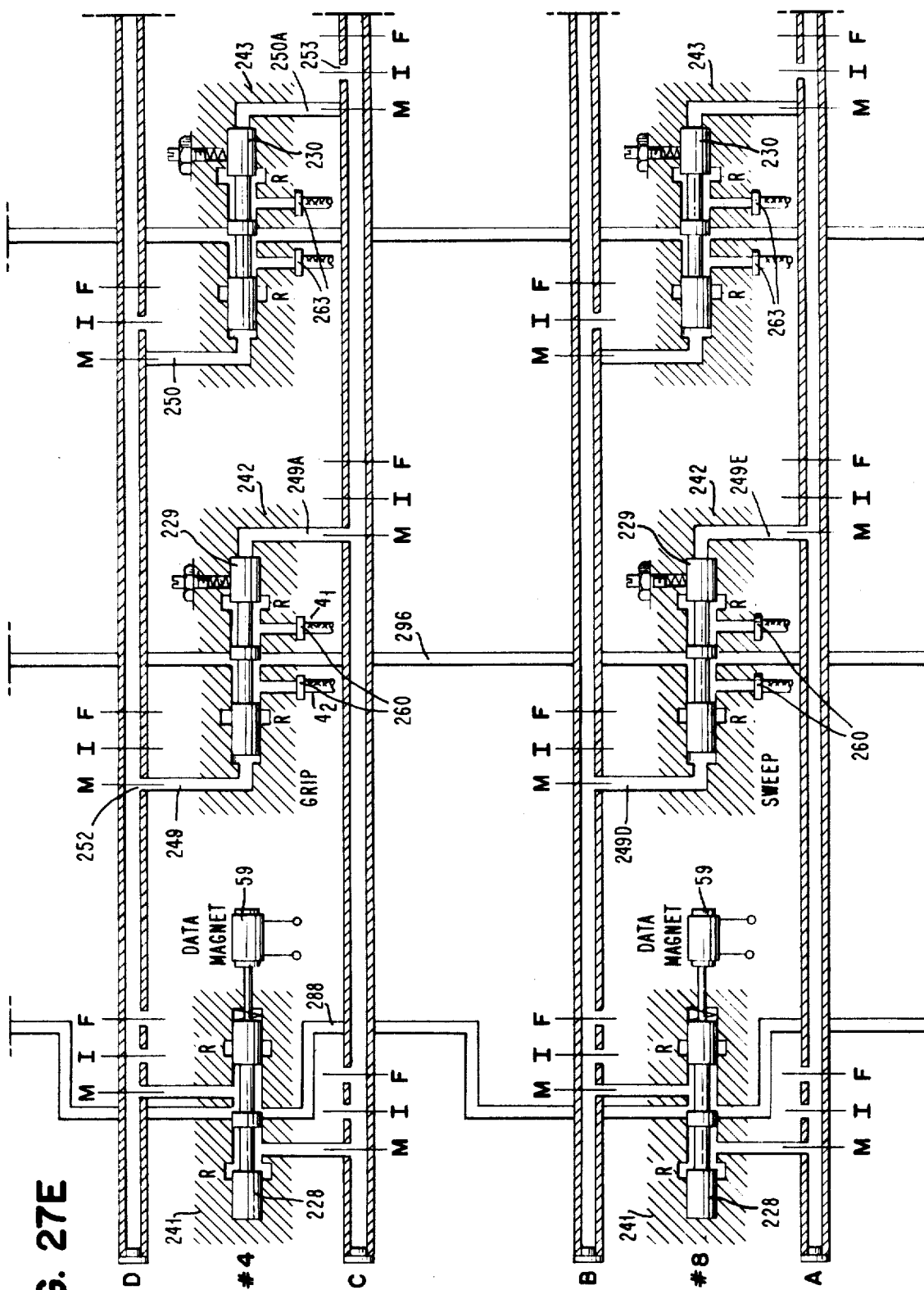
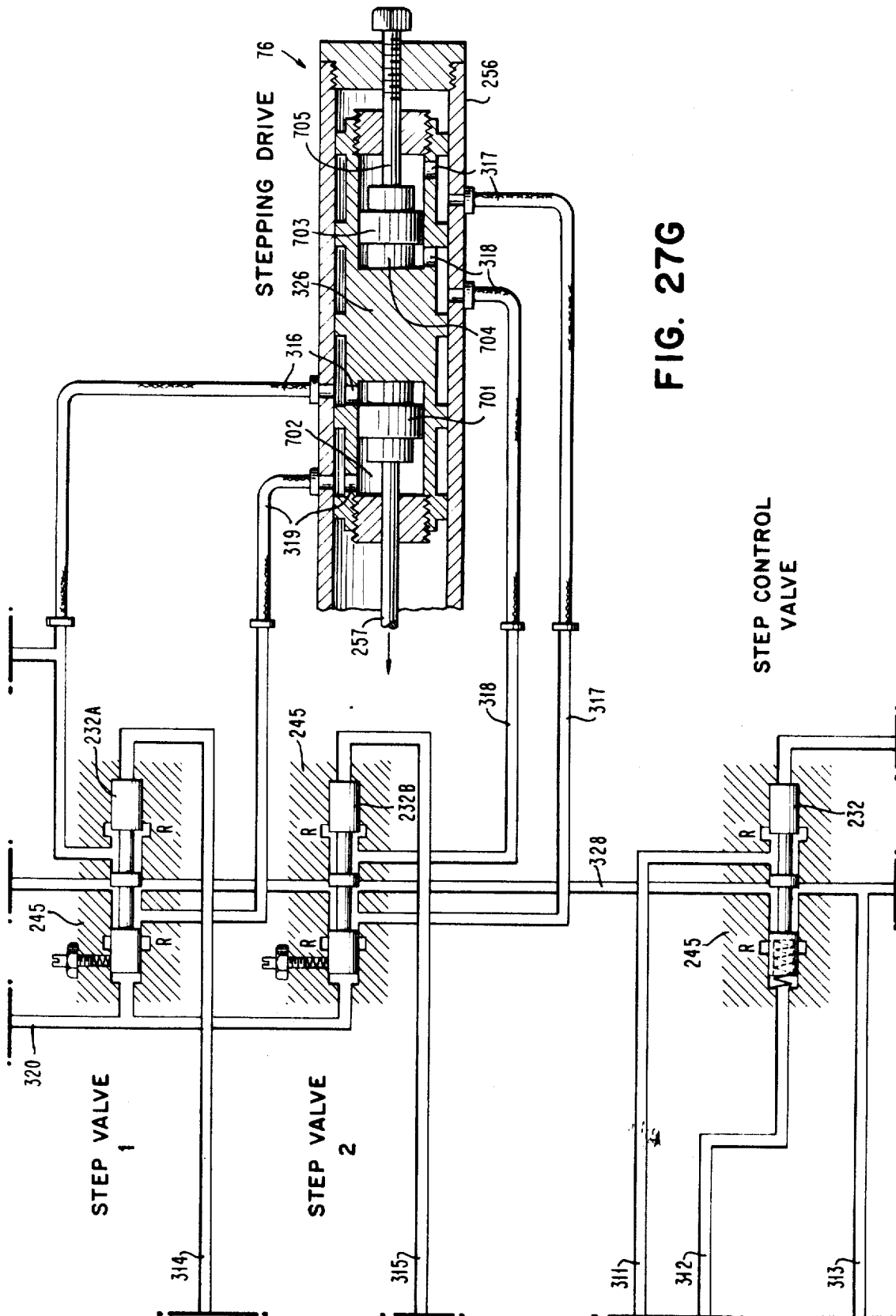


FIG. 27E





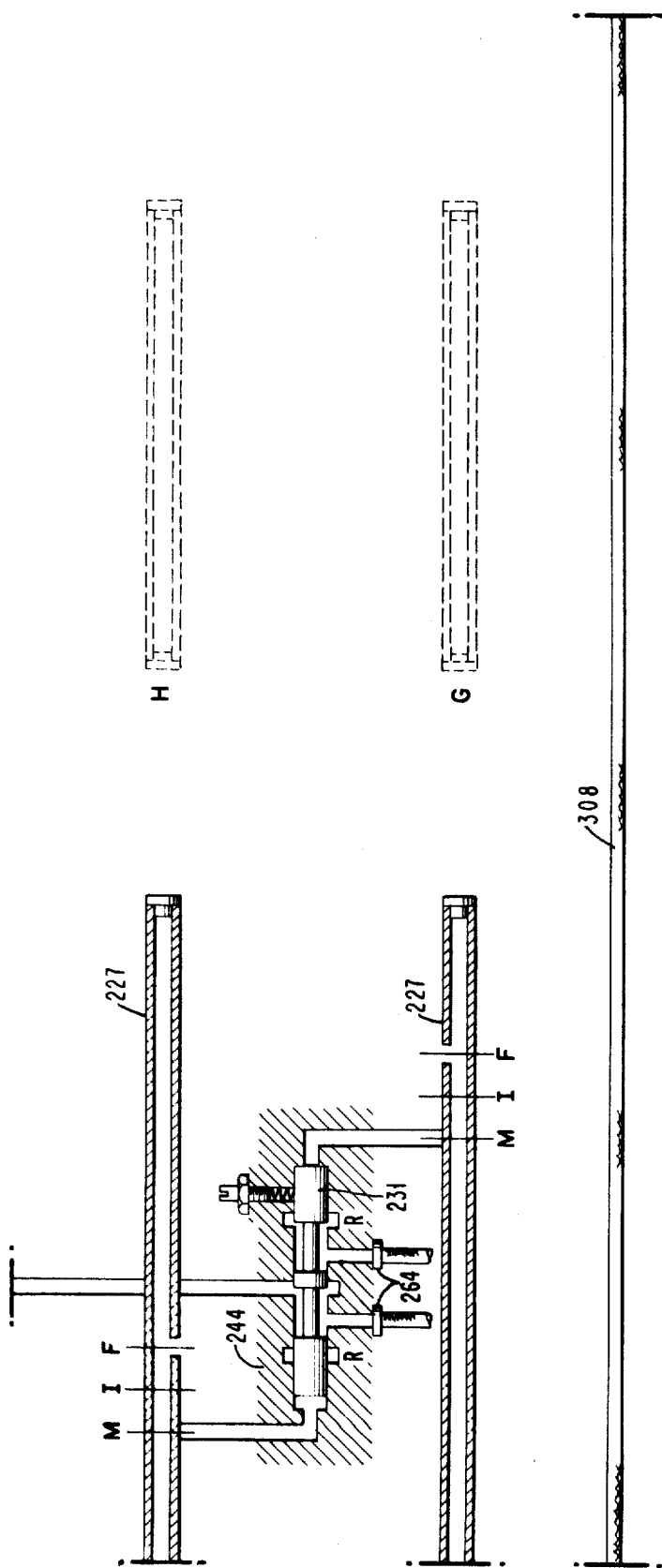


FIG. 27I

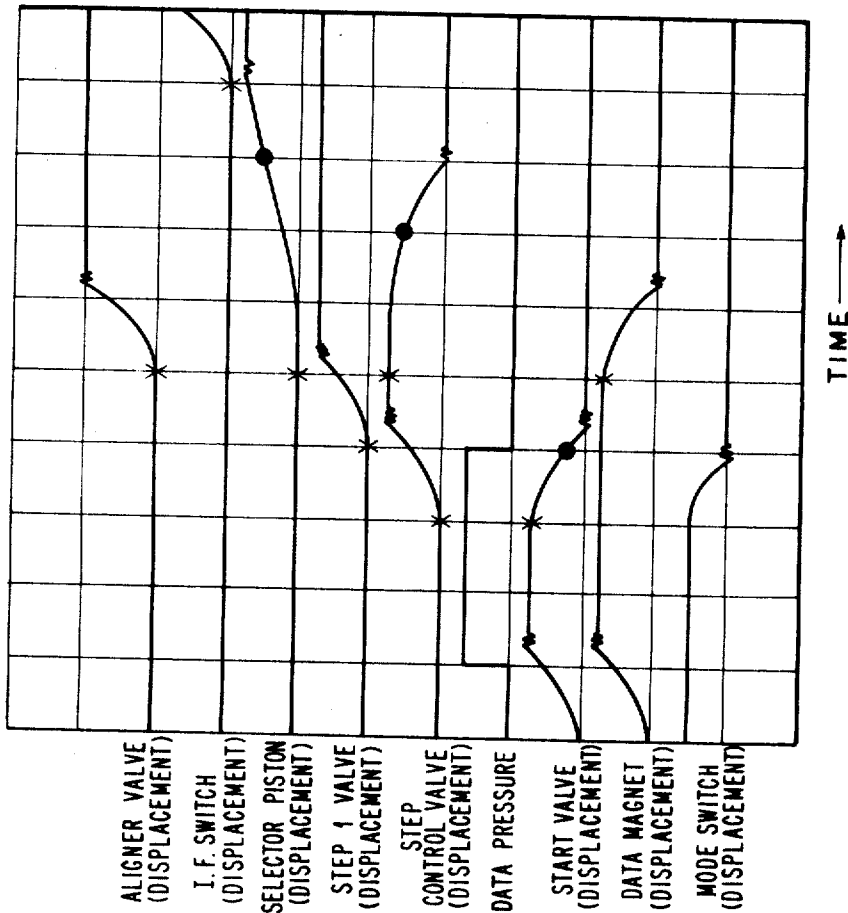
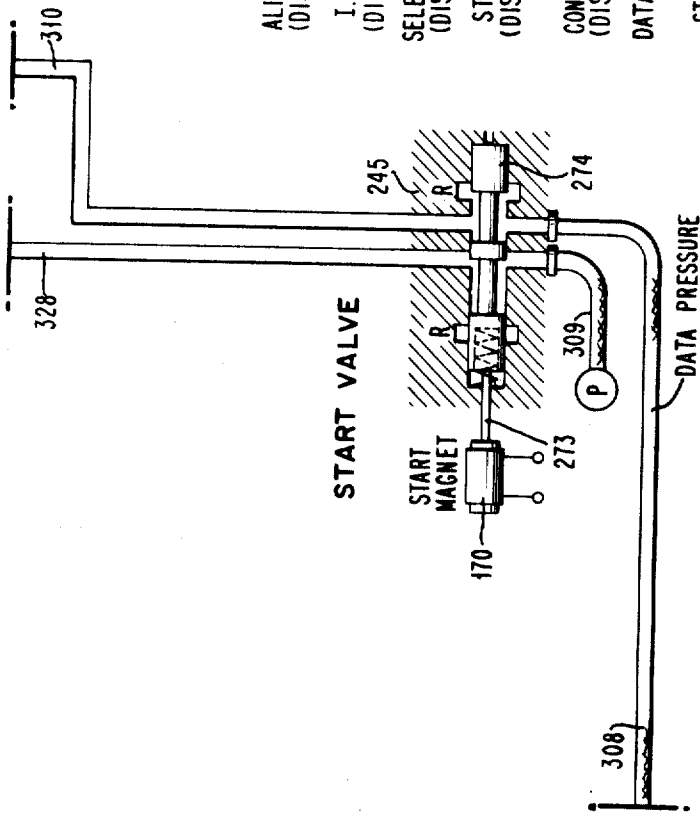


FIG. 27K

FIG. 27J

MANIPULATOR

BACKGROUND OF THE INVENTION

In the prior art there are many forms of mechanical, electrical, hydraulic and pneumatic types of assembly devices including manipulators and artificial arms. Use of radioactive substances for industrial and medical purposes has stimulated development of remote control and automatic manipulators. A U.S. Pat. No. 3,144,947 assigned to the assignee of this invention shows a pneumatically driven manipulator. In the prior art a master slave manipulator is shown providing seven types or modes of motion. All modes involve rotation and a plurality of drive cables is employed. Most automatic assembly devices are especially designed to perform a single, unique function. Furthermore, they frequently require expensive construction techniques, machined parts, a plurality of motor drives or elaborate controls.

The present invention provides a simple form of construction for an article handling device or manipulator. It incorporates in it capabilities which make it more universal in application. It is suitable for a wide variety of jobs such as grasping, moving, positioning and fitting. The present invention eliminates the indirectness and multiplicity of the controls of the prior art. A single piston adder is used instead of a plurality of individual arithmetic devices. No intermediate servos are needed. The present device employs a single serial-to-parallel digital converter, a single, common, piston adder and a common drive capable to operate the manipulator in a plurality of modes of operation. It can move distances in the order of one thirty-second of an inch up to several feet.

Consequently it is an object of this invention to provide a novel article.

Another object is to provide a novel manipulator.

An important object of this invention is to control article handling devices or manipulators directly from a perforated tape reader without employing analogue controls such as servomechanisms, feedback loops or complex analogue to digital converters.

Another object of this invention is to provide a single arithmetic drive unit for driving a plurality of elements selectively, in response to control data presented serially by character.

A further related object is to provide a simple encoder input which is compatible with the perforated paper tape input. Such an encoder might use simple contacts.

A further object is to avoid custom design of a control system to perform individual tasks and to provide a versatile manipulator which can operate in response to a limited amount of data.

A further object of this invention is to provide an end point programmed manipulator which can be programmed by a trial and error technique, which avoids the need for recording all trial and error steps.

Yet another object is to provide an article handling device or manipulator with members selectively movable in the X, Y, Z and Θ modes of operation by means of a common drive cable.

Another object is to furnish detenting means for accurately aligning and locating each articulated member at the end of each motion.

A further object is to provide a plurality of arm members with selective hydraulic detenting means for locking all arm members except a selected arm member. The selected member may then be driven by the drive cable to an extent determined by hydraulic piston adder, which may be either a long or short distance and exact fractions such as increments of one thirty-second of an inch.

Another object is to attain the design of a light weight, rapidly operating, accurate manipulator employing relatively few inexpensive components.

Still another object is to provide an economical form of construction for manipulators wherein the movable members comprise standard square tubing sections mounted to slide

between rollers situated to ride on lines adjacent the rounded corners of said tubing.

Yet another object is the provision of a compact multiple form of piston adder to drive several arm members of a manipulator.

Still another object is to provide a manipulator using only one drive cable connected to drive all three arm members and the turning of the gripper.

Another object is to so create an extensible arm assembly that will employ unmachined common structural steel tubing to provide accurate adjustment of an orthogonal arm.

It is an object to provide a highly accurate manipulator which does not depend upon a spherical coordinate system including servos and analogue drive systems.

A further object is to provide a novel guide roller slide means to provide joints between structural tubing supports whereby the longitudinal axial surfaces near the corners of otherwise irregular square cross section tubing may be utilized for building manipulator members which will not bind or seize and will permit motions to a fraction of an inch.

Another object is to provide between slidable arms and mountings an hydraulically driven aligner clamp detent cooperating with a toothed locating rack. With a cable system having inherent hysteresis, the final adjustment to an accurate position is assured by action of the detent which also serves as a lock preventing motion of the arm member on which it operates, according to the mode of manipulator operation selected.

SUMMARY OF THE INVENTION

A hydraulically operated manipulator is controlled as an automatic assembly robot to grasp, position and join parts. A tape is perforated with coded instructions and dimensions to control the sequence and amount of displacement by means of incremental motions in several modes of movement of the manipulator. Such modes include grip, sweep, X, Y, Z, Θ (arcuate gripper wrist motion) and search (vibratory parts matching such as inserting a pin in a hole). The main components of the manipulator are a tape reader, an electrically and hydraulically controlled hydraulic serial-to-parallel converter and memory and a hydraulic driver, integer and fraction hydraulic piston adders, an articulated series of X, Y, Z slide members with a gripper and a wrist member all driven by a common drive cable, and a vibratory hydraulic search mechanism.

The tape code used is a five channel binary code in response to which five solenoids operate selectively a serial-to-parallel converter for reading-in the mode, inch, and fraction, values successively, into the converter as a form of memory for subsequent control of the amount and mode of displacement by a hydraulic piston adder drive. The particular mode member and the piston adders drive the manipulator to an extent selected in increments of one thirty-second of an inch, up to a total of 31 and 31/32 inches. The common drive cable passes around all movable main mode members, X, Y, Z and Θ . In operation all mode members except one are clamped and locked for the moment. The only released member; i.e., the selected mode member is driven by the cable which is driven by the piston adders. The grip, sweep and search modes of operation are selected by operation of the converter, but are operated by actuators which are independent of the piston adders and the "common" drive cable. Common, square cross section, structural tubing is used to form X, Y and Z slidably articulated, arms. The wrist of the gripper is rotatable through an angle Θ between 0° and 270° . Once a part which is to be assembled is manipulated to a selected position, a search operation may be initiated in which the part may be oscillated along a plane. The part is driven in two directions out of phase so that an overall pattern of probing motions is followed until the two parts are aligned.

A dial control pad form of control board has switches and adjustable commutator arms which can be set to select a

desired mode of operation and a desired number of inches or fractions of inches of motion of the manipulator. The pad can be used to control a punch to make a control tape for the manipulator. This control pad can remember its "position" and can be used for "adding in" new position data.

The manipulator can be programmed by the control pad to perform a wide variety of repetitive assembly operations.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of a preferred embodiment of the invention, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic showing of a digital manipulator control system for this invention.

FIG. 2 is a perspective view of the entire manipulator system of the present invention shown performing an assembly operation of grasping a bolt and inserting it into an opening of a workpiece carried on a continuous conveyor line.

FIG. 3 shows a chart indicating how the two portions, FIG. 3A and FIG. 3B, of an illustration of a program tape are to be assembled.

FIG. 3A shows the first portion of a program tape and a chart of the operations controlled thereby.

FIG. 3B shows the trailing portion of the same program tape and the operations governed by the indicia thereon.

FIG. 4 is a schematic perspective view showing the manipulator arm and all motions provided by the seven modes of operation of the arm.

FIG. 5 is a conversion chart for the Θ mode of operation showing equivalent linear values in fractions for the same code holes. Such code values produce corresponding degrees of displacement of the gripper from $3\frac{3}{4}^\circ$ to 270° out of a normal horizontal position.

FIG. 6 is a plan view of the control pad showing the mode selection switches thereon and the integer and fraction dials.

FIG. 7 is a perspective view of the control pad with a portion of the top cover removed to show the Geneva fraction-to-integer carrying mechanism between the lower order fraction wheel and the higher order integer wheel.

FIG. 8 is a plan view partly in section showing the control pad with separate wheel mechanisms cooperating with the lower and higher order commutators and wheels and the Geneva transfer mechanism between the two wheels.

FIG. 8A shows the lower face of one of two discs controlled by the dials and the binary conductive position encoding paths thereon.

FIG. 9 is a sectional elevation of the control pad.

FIG. 10 is a schematic perspective view of the serial-to-parallel digital converter.

FIG. 11 is another perspective view of the serial-to-parallel digital converter showing the external hydraulic connections therefrom to a piston adder.

FIG. 12 is a sectional plan view taken along line 12-12 in FIG. 13 through a mode valve section of the hydraulic digital converter and showing the five control valves which are operated according to a binary code to select the several modes of manipulator movement.

FIG. 13 is an elevation view partly in section showing the mode section of the hydraulic converter.

FIG. 14 is a sectional plan view taken along line 14-14 in FIG. 15 showing the logic and control portion of the hydraulic digital converter.

FIG. 15 is an elevation partly in section showing the lowermost stepping control section of the hydraulic digital converter.

FIG. 16 is a diagrammatic unfolded sectional elevation view of the piston-adder mechanism in the normal position.

FIG. 17 is a diagrammatic unfolded sectional elevation view of the piston-adder mechanism shown adjusted to an extent representative of $4\frac{5}{16}$ inches of movement.

FIG. 18 is a plan view partly in section of the manipulator housing and sweep drive as seen along line 18-18 in FIG. 2.

FIG. 18A is a sectional elevation detail view taken along line 18A-18A in FIG. 18.

FIG. 19 is a sectional plan view of the manipulator sump showing the folded arrangement of the piston adder sections as associated with the cable and the vertical Z arm of the manipulator.

FIG. 20 is a perspective view of the manipulator showing the three arm portions, the gripper and the cable connections thereto.

FIG. 20A is a schematic view showing the relative locations of the cable and arm pulleys when all the arm members are retracted.

FIG. 20B is a schematic view showing the relative locations of the cable and arm pulleys when all the arm members are extended.

FIG. 21 is a perspective view of a manipulator arm support having roller guides, and a detenting and clamping means for a slidably articulated tubing arm section.

FIG. 22 is a transverse sectional view of an arm tube taken along line 22-22 in FIG. 21 showing how the rollers cooperate with surfaces along axial lines thereon adjacent the rounded corners of the tubing.

FIG. 23 is a partially sectional plan view of the gripper, generally as viewed from line 23-23 in FIG. 20 a showing of the drive cable pulley, and bevel gear and their relationship as well as the gripper cam actuator and the vibrating search mechanism.

FIG. 24 is an elevation view of the inner portion of the gripper drive mechanism with an arm plate wall partially broken away.

FIG. 25 is a schematic sectional view of the hydraulic circuit and output for the gripper vibrating search mechanism.

FIG. 26 is a chart showing how the wiring diagram is to be assembled.

FIGS. 26A-26D is a schematic diagram of the electrical circuit for the manipulator control system.

FIG. 27 is a chart showing how the hydraulic converter logic and control circuit diagram is to be assembled.

FIGS. 27A-27K is a hydraulic circuit diagram which includes a flat schematic interpretation of the control valve sections, the tubular connections of the serial-to-parallel converter, the logic and control sections, and the stepping cylinder.

Referring to FIG. 1, a schematic flow chart is shown which is intended to clarify the overall method of operation of the manipulator control system which is described below. The purpose of the manipulator system is to provide incremental motions which are controlled digitally. Thus, a manipulator arm may be driven in a single direction, then in a second direction. It may be turned around through a sweep angle, may grip or release an item, and may twist its gripper as selected on a step-by-step basis.

The system under consideration here is responsive to serial digital inputs 800 in which three characters are required in order to provide operation of the manipulator in a single mode of its operation. The output of the digital input section is passed through electrical circuits 801 which operate transducers, e.g. solenoids. The transducers operate data valves 228 in a serial-to-parallel converter 26. The information supplied to the data valves 228 at the input of the serial-to-parallel converter 26 is received serially by character. The data valves 228 provide inputs to mode, integer or fraction memory valves 229, 230, and 231 as selected by a three position port switching tower 802. The three position port switching tower 802 is driven by a stepping drive 76 controlled by a converter control section 63 which receives a solenoid input 803 from the electrical circuits. Thus, for the first character input from the digital inputs 800 transmitted to the data valves 228, the mode memory valves 229 will be connected by the switching tower 802 to receive read-in information from the data valves 228. At the end of reading in the first character, the converter control section 63 will be actuated to operate the stepping drive 76 to index the switching tower 802 to a second step position. In the second

position, the integer memory valves 230 will be coupled to the data valves 228 so that the data valves 228 may provide read-in information to the integer memory valves 230. Finally, the third character is read into the fraction memory valves 231 after the stepping drive 76 has moved the switching tower 802 to its third position. The mode memory valves 229 are connected to adjust the system through five outputs, three outputs to mode controls and two outputs to a logic tree 261. A sweep control 75 controls sweeping of the manipulator about a vertical axis or the like. A search control 262 provides for oscillation (preferably in a figure eight pattern) of the gripper. Grip control 408 provides gripping or releasing of an item. The search mode 262 of operation is basically used because the digital adjustments otherwise provided for the manipulator do not go below a predetermined fraction of an inch. The two remaining outputs of the mode memory valves are connected through a logic tree 261 which is operated on a binary basis to X, Y, Z and Θ controls 387, 389, 390 and 392 which will permit operation of a Θ gear 415 for turning the gripper through an angle, the Z arm 42 for sliding the Z arm 42 relative to the base of the manipulator and the Y arm 40 and the X arm 38 respectively for sliding them relative to the Z and Y arms respectively of the manipulator. The outputs of the integer memory valves 230 and the fraction memory valves 231 of the converter are connected to ten piston adders 35 which are connected in series so that the output of the piston adders 35 moves the distance which had been selected by the serial digital inputs and which was stored in the integer and fraction memory valves 230 and 231. The output of the piston adders 35 is connected to drive a cable 69 which is wound about eight pulleys which are secured to the manipulator arms. The pulleys are secured to the arms in such a way that when the Θ , Z, Y, and X controls 392, 390, 389 and 387 are appropriately adjusted, a single one of the Θ gear 415, the Z arm 42, the Y arm 40 or the X arm 38 will be operated to move the arm or the gripper, as desired. Such motion will provide the angular or linear displacement selected by the serial digital inputs 800.

The converter control section 63 operates rapidly and with great accuracy because hydraulic pulse techniques are employed for synchronization of the stepping drive. Thus, the switching tower 802 will not be stepped or indexed except at the appropriate time in synchronism with the reception of serial digital inputs from the electrical circuits 801. At the same time, the control section 63 includes safeguards to permit indexing only after the piston adders 35 have been adjusted to the appropriate position called for by the information stored in the integer and fraction memory valves 230 and 231.

Before studying the details of construction of the manipulator system as shown in FIG. 2, consider FIG. 4, illustrating seven modes of movement of the manipulator 36. In FIG. 4, three mutually perpendicular arms X, Y, and Z are shown slidably connected together to provide a manipulator arm. At the end of the arm is shown a gripper. The horizontal X arm 38 is slidable in a holder 39 at the end of the Y arm 40. The Y arm 40 is supported by a holder 41 at the top of the vertical Z arm 42. The Z arm 42 is slidable to telescope within a sleeve 370. The entire structure is rotatable about the center of a disc 43 to turn the manipulator 36 partially from the position shown, to the position of arm 42 indicated in phantom at 44. This sweep mode of operation of the entire manipulator 36 starts from a normal "out" position at 0° and sweeps as indicated through an angle of 90°, to turn the support 42 to the "in" position at 44. By sweeping, the manipulator may be turned 90° about a vertical center line.

It is obvious in FIG. 4 that the orthogonal modes of movement of the X, Y and Z arms provide three-dimensional positioning. Another mode of operation, Θ , provides a turning motion (wrist action) associated with the gripper 45 shown extending from the left end of the X arm 38. The gripper can turn through an angle between 0° and 270°. The gripper 45 is shown in the 0° position.

The conversion chart, FIG. 5, shows the relationship for identical punch code values punched in the tape between linear displacement and corresponding angular steps Θ through which the gripper turns. An angular step may be at minimum 3¼° of motion or at maximum 270° of motion.

Another mode of operation associated with the gripper 45 comprises the gripper motion which is effective to clamp a part between the jaws of the outwardly extending fingers. Gripping may be done either before or after turning the gripper through an angle Θ as required to accomplish the assembly operation. A final mode of operation is that of search, illustrated diagrammatically at 46. The search mode provides vibration of the gripper in two directions so that an article held therein may be jiggled into engagement with a mating part. The chart shown to the left of FIG. 4 sets forth an example of the assigned displacements of the three X, Y, Z arms, and the gripper rotation which displacements should provide a total movement of 31 31/32 inches. This is the maximum movement permitted by the piston adders described herein.

Thus, in summary, FIG. 4 illustrates the seven modes of motion of the manipulator members for displacement along axes X, Y, and Z, turning through angle Θ , gripping, sweeping and searching.

The perspective view of FIG. 2 shows the manipulator system as applied to perform a specific assembly operation. A bolt 47 supplied by a hopper 48 is grasped by the gripper 45 (dotted position). The manipulator is swept counterclockwise. The gripper is turned to hold the bolt erect and the bolt is deposited in a hole 49 in a workpiece 50. Workpieces may be advanced successively by a conveyor 51 in synchronism with the operations of the manipulator 36. The system may be used in many other environments than in connection with an assembly line.

The assembly operations shown in FIG. 2 may be controlled digitally. Preferably punched tape is used as a memory or program control. A typical sample loop of endless punched tape 52 is shown in FIGS. 3A and 3B. Such tape 52 is adapted to move the manipulator on a step-by-step basis. The tape includes five channels which will permit use of binary characters as large as 31. In addition, each "operation" of the manipulator is recorded in three steps represented by three characters. The first character M, indicates the mode of operation. The second character I represents the whole number, i.e., integer value of the motion selected for the mode. The final character F indicates the fractional value of motion to be performed during the particular operation.

Before the punched tape can be used to operate the manipulator automatically, the programming tape must be punched in accordance with a predetermined program. However, of course, the program must be developed. Such a program could be developed by employing conventional techniques. Elaborate calculations, drawings and the like could be used. However, I have found that the trial and error method of positioning and programming is most suitable for use in connection with the manipulator. By using the trial and error technique, the operator can look at the gripper and consider its position relative to the position in which he desires to have the gripper located. Then the operator can consider which modes of operation should be used and in which sequence those modes should be used in order to move the gripper into the desired position.

Then a control pad 54 is used to select each mode of operation. The control pad is also used to select the corresponding distance or angle of motion through which the operator considers that the manipulator should be moved in order to reach the objective. Such adjustment of the pad is made for each selective mode of operation, that is the mode is selected and the distance or angle is read into the pad by dialing.

If the value selected by the operator is correct, then the control pad 54 may be switched from connection with the manipulator to connection with the tape punch 25. The

control pad will store information as to the mode, which has been selected, and the distances which have been dialed in, which can be translated into digital information which then can be punched into the tape. Thus, the preceding trial operation and the resultant position of the gripper can be recorded on the punch tape.

In practice, the operator will select a mode, dial numerical information into the control pad, watch the arm move, decide whether the arm is in the correct position for operation in that mode. Then he will dial in any correction of the position to which the arm has been adjusted because of incorrect trial selection of numerals.

If the position reached is the one which is desired, then the succeeding mode of adjustment is used. For example, if the X arm had been extended, then the Z arm might be extended to raise the entire manipulator. In this way a series of unidirectional motions of the desired length or angular motions through the desired angle follow each other one by one, one at a time, except for the sweeping mode of operation which will often occur concurrently with the other motions. Each such unidirectional linear or angular motion will be referred to herein as an operation.

The controls which an operator must use to adjust the position of the manipulator by means of trial and error and a control pad 54 are shown in FIG. 2. The control pad 54 has several mode switches 80, 81, 82 and 83, adjustable integer and fraction knobs 56 and 57 respectively for manually selecting a desired mode of operation. The knobs 56 and 57 are used to indicate the amount of motion desired. Each operation tried on pad 54 during the trial and error period of control of the manipulator is recorded in the punch paper tape 52 by tape punch 25. After programming for the work to be done, for example the assembly job, the operator splices the tape 52 into a loop. Then it inserts the tape 52 into the tape reader 25A where it is read. The tape is used for controlling the sequence in which the modes of operation of the manipulator are actuated automatically.

The signals from the tape reader 25A are employed to read information into a serial-to-parallel converter. The serial-to-parallel converter comprises three sections, a data input section, a memory section, and a control section. The memory section is comprised of three sections which relate to the mode of operation, the integral or integer value of the displacement which is to be performed during a particular operation, and the fractional value of the displacement. The three memory units receive the characters of mode, integer and fraction values serially and provide outputs at their output ports in a parallel manner, simultaneously. The converter is a hydraulic unit which employs mechanisms and pulse techniques in order to provide input, memory storage and output information to the manipulator.

The output of the tape reader 25A is used to actuate a plurality of data magnets 59 secured to the top of the data section 26 of the converter. The data magnets 59 adjust valves in the data section 26. The fluid outputs of the valves are sequentially connected to the mode, integer and fraction valve sections 60, 61 and 62 respectively by means of a stepped porting system.

The porting system is operated on a step-by-step basis in synchronism with the steps represented by the perforated tape shown in FIG. 3A. Thus, for a single operation of the manipulator, the converter will be stepped twice from a low position in which the mode valves will be adjusted by the data valves, a second step in which the integer value will be read into the integer valves from the data valves; and a third step in which the fractional value will be read into the fraction valves by the data valves. The control logic employed in the system, with the exception of the tape reader, comprises hydraulic logic circuits which are located in portions of the converter as shown in FIG. 2.

The arms of the manipulator are moved in straight line paths by means of arithmetic drive units which in this case are piston adders 35. The piston adders 35 are 10 in number and

are connected in a modified series arrangement. Thus, motion of any one of the pistons in the cylinders associated therewith will cause the output of the series of piston adders to move to the same extent as the piston under consideration.

Each of the piston adders 35 is connected to the output of a single one of the corresponding valves in the memory unit, i.e., the integer section 61 and the fraction section 62. In other words five of the piston adders are connected to the five integer valves for the integers 1, 2, 4, 8 and 16 and the other five piston adders are connected to the five fraction valves for values from 1/32 of an inch up to $\frac{1}{2}$ inch.

In order to conserve space, the piston adder 35 is made in three sections supported on three T-bar tracks 65 extending between the top disc 43 and the lower disc 66, which forms the base of a sump tank or reservoir 67. Arrangement of the piston adder sections on the T-bar tracks 65 provides a compact folded structure.

The piston adder is secured to a drive cable 69 by means of a clamp bar 68. The drive cable 69 is "endless" and runs around pulleys which cooperate to drive the X, Y, and Z arms 38, 40, and 42, and also around a pulley associated with the gears for turning the gripper 45. A single drive cable is employed for operating the three X, Y, and Z arms and turning the gripper through angle Θ .

Normally, the arms and the gripper are locked in position by means of toothed pistons which engage with racks located on the surface of the X, Y and Z arms. When the arms and the gripper are locked in that manner, they cannot slide, or turn, in response to a pull by the drive cable 69. By releasing any one of the toothed piston detents, the corresponding arm will move with respect to its support the same distance as the drive cable 69 is moved by the piston adder 35.

In the sweeping mode of operation, the vertical Z arm 42 of the manipulator rides on a vertical piston 70 which is the equivalent of a counter weight. The arm 42 also telescopes up from inside a sleeve 370 inside the sump tank 67.

The sump tank 67 includes a top disc 43 to which is attached a plate 64 supporting the serial-to-parallel converter 58 inside the tank. The top and lower discs 43 and 66 of the tank are secured together by the three T-bars 65 and the outer walls of the tank 67. The manipulator tank 67 is rotatable within a cabinet 71 relative to a fixed central pivot on the base 72 of the cabinet.

In order to turn the tank 67 to provide sweep motion, the lower disc is formed with a peripheral pulley groove. Around the pulley groove is drawn an operating cable 73 guided by pulleys 74. The cable is driven by a hydraulic cylinder 75 which turns the entire unit 90° as illustrated by the phantom position of the manipulator in FIG. 2.

Now that the general operation of the manipulator arm has been described, the way in which program control information is recorded on the perforated tape 52 will now be described with reference to FIGS. 3A and 3B. A representation of the tape is shown at the top of those FIGS. Below the tape is shown an operation chart which illustrates the changes in mode versus the 14 operations, two of which are repeated at the right-hand side of the chart in FIG. 3B. The search, sweep, grip, Z, Y, X, and Θ modes of operation are listed along the left hand margin of the chart and the numerical identification of the operation is listed at the top of each column.

As explained, each operation includes three steps of reading information into the memory of the serial-to-parallel converter. The first step is reading the mode character identified on the paper tape above the first operation as mode character, M. Secondly, the integer character, I, is read into the converter. The third step is to read the fraction character, F, into the converter. In the example shown, looking at the punch code chart to the left of the tape, we see that the search mode has no hole which means that it has not been selected. The sweep mode has a hole which means it is "in." Grip has no hole which indicates that it is closed.

The last two A and B channels to four the mode character also have no hole. This means as we can see from referring to

the lower portion of the punch code chart that the X mode of operation has also been selected, as is noted by the notation "no hole" next to X. To the left of Z, Y, X and Θ we note the identification "tree." This indicates that the first two A and B channels are used to control a logic tree which can be switched to four positions. Thus, if both of the first two channels of the mode character are punched, the Θ mode of operation is actuated as is noted by A+B holes next to Θ on the punch code chart. If only the A channel hole is punched, then the Z mode of operation will be selected and if only the B channel hole is punched, then the Y mode of operation will be selected.

Referring to the second character, (the integer character as indicated above the tape) for operation one, we see that the channel E, character I, bit 8 and the channel A, character I, bit 1 have been punched as identified by the punch code to the left of the tape. Looking at the third or fraction character, as indicated in FIG. 3A, for operation one, we note that the F bit value of 1/16 coincides with channel B, in which a hole is punched. Thus, the arm is to be extended to a total displacement of 9 1/16 inches. However, the value of X for the 14th operation was also 4. Accordingly, although the X mode of operation has been selected, the value 4 is retained and so the X arm will not move. For that reason, there is no heavy line placed around the position X on the chart under operation one, since the grip mode of operation actuator is to be actuated to close the gripper. The box adjacent to grip and under operation one is outlined by a heavy line, as it is closed.

The grid of blocks is accentuated with a heavier outline wherever changes occur. The bottom line of the chart states the total motion in inches and fractions of an inch.

In FIG. 2, the manipulator 36 is shown in phantom in a position called for by the 14th operation chart column, FIG. 3A, and the gripper 45 is not closed over bolt 47. The initial arm placements Y at 4 5/16 inches, X at 4 inches, and the gripper arc Θ at 90° (three-fourths inches) were produced first by trial adjustment of the control pad 54. The tape is prepared for operation one, in which the "grip" control is closed.

The "STEPS" row of identifications involve three successive characters M, I, F; i.e., mode memory read-in followed by integer memory read-in followed by fraction memory read-in. These steps establish successive hydraulic porting from data valves to memory valves in the three converter valve sections 60, 61 and 62. The first character M sensed by the tape reader 25A, FIG. 2, actuates a combination of the five data magnets 59 to adjust the data valve section 26 whose output is then ported to the mode memory valves in the mode valve section 60. The hydraulic converter 58 will then be stepped to a second position by operation of a stepping drive 76. The stepping drive 76 is actuated by a control section 63 which establishes hydraulic timing. Now, new port connections from the data valve section 26 to the integer memory valve section 61 are established for the second character I on the tape. Finally, the stepping converter 58 will be adjusted to the position for porting the output of the data magnet valve section 26 to the fraction memory valve section 62 for the third character F on the tape 52. Reading of each character from the tape triggers operation of a start valve which synchronizes operation of the hydraulic control section 63, which controls the stepping drive 76. The information secured by the three steps of data read-in is stored by the valves which are held as selected to serve as hydraulic memory.

After the motion of the arm or gripper has been completed, the stepping converter 58 will be automatically reset to its initial position by control section 63 ready for reading-in the next three characters for the next operation. This converter is fully described below with reference to FIGS. 10-15 and FIGS. 27A-27K.

In the tape controlled operations, FIGS. 3A and 3B, for the assembly job of FIG. 2, a sequence of 14 operations is included on the tape. At times, the presence of a bit such as the channel E hole in the mode character relating to "sweep,"

in operation one, does not effect a change. Conversely, it sustains a setting established earlier. The absence of a bit such as the absence of the Channel C mode character bit regarding "grip" in operation one, does effect a change to closure. Prior to operation one, the previous grip bit, as in operation 14 in FIG. 3B, had maintained the grip.

The second operation involves a -2 inch movement of the X arm i.e., withdrawal of bolt 47 from hopper 48, FIG. 2. This shows that position adjustments may be positive or negative in direction. Piston adder movement is effected directly from an existing setting to the new setting, which is set in the tape in absolute terms, i.e., from 9 1/16 inches to 7 1/16 inches and not back and forth from a normal position. In the third operation it is revealed that two modes of operation can be active concurrently. As shown, the manipulator sweeps to out while the Z arm rises 2 1/2 inches from zero. The heavily outlined blocks of the operations chart manifest the subsequent sequence of program steps and extents of operation necessary for assembly of the bolt in FIG. 2.

THE CONTROL PAD

The control pad 54 of FIGS. 6-9 is an electrical control board including switches for selecting mode, integer and fractional settings to move the manipulator 36 to trial positions and to provide corresponding digital inputs, when the trial positions are acceptable, to the tape punch 25. In a trial condition of pad operation, the pad settings effect adjustments of the manipulator 36 instead of reading into the tape 52. In the mark condition of pad operation, only the tape punch 25 is operated to punch a five bit binary code character representative of a pad setting. But usually the pad is set for several trial manipulator settings, until one mode of operation is performed as desired. Then that particular setting is punched by a mark switch transfer of pulses.

As shown in FIGS. 6 and 7, the control pad 54 comprises a casing 77 bearing a series of electrical switches 78-83 extending across the top portion. These switches are identified in a left to right order as the start button 78, mark or trial switch 79, arm select X, Y, Z or Θ switch 80, grip closed or open switch 81, sweep in or out switch 82, and search on or off switch 83.

Under the integer knob 56 at the left is an annular slot 84 through which a plunger pin 85 extends downwardly from knob 56. The pin is axially slidable in the end of an arm 86 pivoted on a shaft 10. A large saw-toothed, integer-encoding star wheel 88 is journaled on shaft 102. A ring of 32 openings 89 and a corresponding series of edge positioning teeth are formed around the periphery of the wheel 88. The circular openings 89 are adapted to receive the tapered end of pin 85 for cranking of wheel 88 thereby. A disc 111 under wheel 88 is formed with a corresponding set of edge notches 90. The notches 90 are part of a Geneva carry or transfer mechanism to be described.

Referring again to FIG. 6, associated with the annular slot 84 is a pair of numerical sequences 0-10 and 10-0 which represent integers of motion in inches which may be selected by cranking of wheel 88. Cranking is effected by grasping the knob 56, moving it arcuately to the add or subtract 0, mark. Then one may press the knob downwardly to insert pin 85 into an opening 89 to engage the wheel 88. Then he may crank the knob 56 and the arm 86 to turn the wheel 88 until the pointer 91 on knob 56 is opposite the desired number.

Three numerals 0°, 120° and 240° show the Θ settings for the turning mode Θ . As shown in FIG. 8, a stop pin 111A on disc 111, abuts against a fixed block 111B to prevent the integer disc from adjustment beyond 31 positions.

In a somewhat similar fashion, the fraction encoder is formed with a complete annular slot 92 through which projects a plunger pin 93, FIG. 7, extending down from a knob 57 and slidable through an arm 94 pivoted shaft 103. On a bearing 95 is the adjustable, fraction-encoding, star wheel 96 formed with a ring of 32 detent notches 105 and a similar

number of marginal holes 97 for receiving pin 93. A disc 104 is attached to the lower surface of star wheel 96. A single Geneva drive notch 98 is formed in the periphery of disc 104 for the purpose of carrying an integer secured by addition of two fractions.

FIG. 6 shows that two rings of fractional division markings 0—31 and 31—0 are arranged around slot 92. They indicate the additive and subtractive settings for the desired number of one thirty-second inch increments of movement to be selected by fraction knob 57. To make the desired fraction setting, knob 57 is swung to 0, and pressed down to insert pin 93 in a hole 97. Then the wheel 96 is cranked to the desired fractional setting such as eight thirty-seconds, as shown. The pointer 99 on knob 57 indicates the adjustment. Then knob 57 is released to its spring-biased outward position. The wheel 96 will remain where adjusted since both encoding wheels 88 and 96 are detented as commutator memory devices.

The interior construction of control pad 54 is best shown in FIGS. 8 and 9. A base plate 100 is supported in casing 77 by four corner posts 101. A shaft 102 rises to support the bearing 87 for wheel 88 and disc 111. A shaft 103 rises to support the bearing 95 for wheel 96 and disc 104.

Cooperating with the star wheel detent notches 105 is the rounded tip 106 of a detent arm 107 pivoted at support 108 and biased by a spring 109 to align and maintain a wheel setting. A similar form of detent 110 is provided to cooperate with the saw-toothed teeth or notches of the integer wheel 88.

Surrounding shaft 103, FIG. 9, is a sleeve 112 carrying the arm 94 loosely assembled on the shaft. The bearing 95 carries the fraction wheel 96 and disc 104. Disc 104 carries on its lower surface a layer of insulation 113 upon which conductive paths 114 are formed as shown in FIG. 8A. The paths 114 provide binary readout settings according to the adjusted position of the disc assembly relative to a set of brushes 115 extending from an insulation block 116 to press on the paths 114. In FIG. 8 it is shown how block 116 is situated on base 100 to direct brushes 115 forward to ride on brush paths 115A in contact with the paths 114 on the rotary disc for motions in both directions.

A similar set of brushes 117 is mounted on a block 118 and pressed upon conductive paths 119 in FIG. 9 formed on an insulation layer 120 fastened to the lower face of the integer disc 111. The brushes follow brush paths 117A shown in FIG. 8. The arrangement of parts on shaft 102, FIG. 9, for the integer settings is practically the same as the parts shown in sectional detail on fraction disc shaft 103. Arm 86 is loosely assembled on shaft 102 while wheel 88 and disc 111 are fastened to bearing 87 which is loosely rotatable on shaft 102. The integer setting is held in position as a readout memory device by the detent 110 cooperating with the sawteeth of the star wheel 88.

From the foregoing it is apparent that the control pad 54 of FIGS. 6—9, is an economical double-dialed form of switchboard for entering integers and fractions of inch settings for conversion to five bit binary characters. Such characters are used for controlling the extent of movement in modes of operation X, Y, Z, or Θ the perforation of a five place binary paper control tape 52.

The displacement data for controlling the manipulator arm from the control pad must be supplied serially in two binary characters representing an integer (1 inch to 31 inches) and a fraction (0 inch to thirty-one thirty-seconds of an inch, in one thirty-second intervals). Therefore, the encoding wheels 88 and 96 are both designed for adjustment to 32 positions representative of a different five bit binary character electrically readable therefrom. The wheels are adjustable clockwise or counterclockwise for additive or subtractive operations by the arms 86 and 94.

Should the fraction knob 57 be cranked to enter twenty-four thirty-seconds of an inch first and then again cranked additively to add sixteen thirty-seconds of an inch or to demand a total manipulator arm movement of $1\frac{1}{4}$ inches, then the fraction disc 104 has turned $1\frac{1}{2}$ revolutions and a 1 must be carried to and added to the integer wheel 88.

For carrying 1 a Geneva transfer wheel 121 is placed between the fraction and integer discs 104 and 111. As the fraction disc 104 turns one revolution, a single carry notch 98 therein engages one of four pins 121A on the transfer wheel 121. The transfer wheel 121 is loosely mounted on a pivot 122 carried by a lever 124 pivotally mounted at 123 and spring biased to press against the smooth outer surface of the fraction disc 104 by the spring 125. As the transfer wheel 121 is turned one-fourth turn during a carry by notch 98, one of its four pins 121A swings into one of the edge notches 90 of the integer disc 111 to turn it one step. This effects a carry and adds 1 inch to the integer setting. Subtractive carries are effected conversely.

It is important to note that the movement of the transfer wheel 121 during a carry is not simply a rotary motion. Rather it is a rocking motion whereby clearance is maintained for freedom of adjustment of the integer wheel 88 before and after a carry motion is effected. The rocking motion of the transfer wheel 121 is made possible because the carry notch 98 is shallow. Hence the motion towards disc 104 of the pin 121A when it becomes engaged in notch 98 is slight. During rotation about pivot screw 122 the engaged pin 121A becomes a pivot and is pushed slightly to the left in FIG. 8 as disc 104 turns counterclockwise. During turning of the fraction disc 104, the diametrically opposite pin 121A turns about shaft 122. The opposite pin 121A is also swept in a raised arc about the engaged pin 121A which carries it far into the notch 90 and cranks the integer disc 111 one step. Then, by rocking about pivot 123, the opposite pin retracts farther to the right than it would simply by turning on shaft 122. Accordingly, settings of the integer disc 111 may be selected without disturbing the fraction disc 104 because ordinarily the transfer wheel pins 121A are out of the path of the notches 90 on the integer disc 111.

General operation of the control pad is described below by reference to FIG. 6. If the operator wishes to extend the manipulator arm 5 inches he swings the pointer 91 of integer knob 56 to the numeral 0. There he depresses the knob until its pin engages a hole. He then cranks the pointer of the knob and the disc clockwise until the pointer is at 5. If the operator wishes to collapse the manipulator arms he will crank the encoder wheel 88 counterclockwise. The 0 positions of the two encoder wheels 88 and 96 are accentuated by a marking 126 adjacent a hole 97 of the fraction wheel 96 and a similar sort of marking 127 adjacent an opening 89 in the integer wheel 88.

In FIG. 6 angular measurements are noted at the left of the annular slot 84. The divisions for 0°, 120° and 240° are aligned with the 0, 1, and 2 inch markings.

THE WIRING DIAGRAM

The electrical controls to be exercised by tape 52, FIGS. 3A and 3B, and the electrical control arrangement including the commutators formed on insulation layers 113 and 120 of the control pad 54, FIGS. 8 and 9, are described above. Here the wiring connections from the pad and tape reader 25A to the five data control magnets, or solenoids 59, FIG. 2, of the serial-to-parallel converter 26 are described.

FIG. 26 shows how the four sections of the wiring diagram FIGS. 26A—26D are to be assembled and considered in left to right order.

FIG. 26A shows the circuit of the control pad, in a top to bottom order, including the switches 78—83, the conductive paths 119 and 114 on insulation layers 120 and 113. FIGS. 26B and 26C deal mainly with the tape punch 25 and tape reader 25A. The data magnets 59 are shown in FIG. 26D.

An AC power supply 130 is provided for motors and pumps and the DC power supply 131. Connected to the power supply 130 are lines 132, 133, FIG. 26B connected to the punch motor 134 and the reader motor 145.

There are generally three styles of electrical control of the manipulator, as follows: (1) trial operation of the manipulator arms directly from the control pad, (2) mark operation to

punch the tape with the settings of the control pad, and (3) automatic operation by the tape.

In trial, and mark operations, desired settings of mark or trial switch 79 and all mode control switches 80, 80A, 81, 82 and 83 and the integer and fraction wheel settings are made before the start button 78 is pressed to close contacts 136. Contacts 136 are connected to a line 137 to power a stepping solenoid 139 through normally-closed contacts 138 and a positive DC voltage source. Solenoid 139 operates a rotary stepping switch 139A to operate three cams for sequentially powering the mode, integer, and fraction switches in the control pad. Solenoid 139 is connected to a lever 140 which it pulls counterclockwise about a pivot 141. A spring 145 tends to hold the lever to the right. However, when the lever 140 is operated, its arm 142 moves down to break the circuit to the solenoid by opening contacts 138. However, before the contacts break the circuit, the arm 140 is attracted far enough to the left to index a pawl 143, supported by the lever 140, behind one tooth on a ratchet wheel 144. Ratchet wheel 144 is mounted on a shaft to drive cam discs 146, 148, 150 and 152. The first-mentioned cam disc 146 is moved initially to allow the closure of holding contacts 147 which set up a holding circuit for the solenoid 139 after the start button 78 is released.

The arm 142 also serves to close contacts 158 to provide a ground connection through I-F pressure switch contacts 167, or mode pressure switch contacts 165, if closed, for the circuits through the successive contact closures by the mode, integer and fraction cams. Referring to the mode cam disc 148, it is normally in a position to close contacts 149 for connecting the mode setting on the pad to the data magnets 59. Contacts 158 also close a circuit to the start magnet 170, FIG. 26D, which synchronizes the hydraulic control system. Tracing the circuit for the start magnet 170, at the right, line 171 connects from the positive DC voltage supply through the start magnet 170, line 172, normally-closed contacts 169, line 173, normally-closed contacts 174, line 175, closed contacts 158, line 159, closed contacts 160, line 161, closed contacts 162, line 163 and normally-open contacts 165 to ground. Contacts 165 are associated with a mode pressure switch 164 which is located in the control valve section 63 to prevent operation of the data magnets in the mode read-in step until the tower has been returned to the mode position. Along with operation of the start magnet 170, assume for example that the 1 bit data magnet 59 is also operated to move the Y arm as the first trial step. Tracing the circuit, positive voltage V is supplied through the line 171 to the 1 bit data magnet 59, to normally-closed contacts 176, line 177 to normally-closed contacts 178 in FIG. 27A, line 179, line 180, isolation diode 181, switch arm 80A (assumed to be positioned to contact Y) terminal 182, line 183, line 154 over to FIG. 26C and the closed mode contacts 149, line 184 to line 157, contacts 158, line 159, closed contacts 160, line 161, closed contacts 162, line 163, now closed, normally-opened mode contacts 165, and to ground.

The above-traced start and mode circuits are established before the ratchet pawl 143 engages ratchet wheel 144 to step discs 146 and 148 an initial 120°. However, an instant later ratchet wheel 144 is advanced, contacts 147 close, mode contacts 149 open, but integer contacts 151 are closed. The latter action makes line 155 active. Line 155 connects, FIG. 26A, to the integer paths on insulation layer 120, wherefrom a setting for 1 inch and activation of the 1 brush 117 will set up a circuit through line 179 and contacts 178 much the same as the Y mode 1 bit circuit already traced. One difference is that the hydraulic mode pressure switch 164 opens contacts 165 upon completion of the mode read-in step. This is timed with the operation of the I-F pressure switch 166 to close contacts 167 to ground signifying that the converter is ready for read-in of the desired movement in inches and fractions.

Stepping of ratchet 144 to cause the closure of fraction contacts 153 by disc 152 follows in the same fashion. Assuming that the fraction one-half inch is represented by a

16 bit pad setting, then the circuit includes the positive voltage V supply, line 171, the 16 bit data magnet 59, line 187, normally-closed contacts 188, line 189, normally-closed contacts FIG. 26A, line 191, isolation diode 181, the 16 brush 115 which rests on a path selected by adjustment of the disc carrying insulation layer 113, line 156 to fraction contacts 153, FIG. 26C, now closed; line 186, wire 157, closed contacts 158, wire 159, closed contacts 160, line 168, contacts 167 and then to ground.

For selection of the X arm mode, with both circuits open at the switch arms 80 and 80A, selection is accomplished by hydraulic tree controls. All other arm select (Y, Z, and Θ) mode selections of 1 and 2 alone or in combination are believed apparent by establishment of settings of the switch arms 80 and 80A in light of the circuitry already traced. For selection of the grip, sweep, and search modes of operation by switches 81, 82 and 83, respectively, the circuitry to the respective valve controlling data magnets 59 representing decimal values of .4, .8 and 16 are also thought obvious in light of the circuitry already traced.

In the above-trial operations, the control pad settings were used to position the manipulator after the operator set the switch 79 to trial. Subsequently, he observed the manipulator arm to determine whether it was positioned as desired or whether the gripper engaged an object in the best manner. If the manipulator motion produced was satisfactory for automatic operation, then the motion was to be established as part of a future program by punching holes into three character positions in the tape 52. To do this the first step is to preserve the prepared pad settings while shifting the switch 79 to mark. Upon closure of the mark or trial switch 79 a circuit is established from ground and through switch 79 through line 192, to actuate mark relay 199 connected to positive voltage V. The mark relay 199 operates a series of relay contacts from 178 to 174. The output lines from the control pad are shifted from the manipulator 36 and the converter and directed into the tape punch 25.

When the mark relay 199 is energized, contacts 174 open to break the circuit to the hydraulic start magnet 170 and establish via contacts 193 a circuit through the punch clutch solenoid 196. However, the circuit for the punch solenoid 196 must await the operation of the start and stepping switches 78 and 139A. The control circuit for the solenoid 196 includes the positive voltage V in FIG. 26B, the solenoid 196, line 195, contacts 193, wire 175 and the normally-open contacts 158 FIG. 26C which are subject to the operation of the start and stepping switches 78 and 139A.

After the punch 25 has been activated by the switch 79, the start button 78 may be depressed to initiate punching by a circuit including line 137, contacts 138 and stepping solenoid 139. This initiates the stepping switch operation for successive punching for mode, integer, and fraction settings in the control pad.

As an example of tape punching, assume that the mode selector switch arm 80A is set for the Y mode.

Then the circuit includes a connection from ground and contacts 165 in FIG. 26D, line 163, contacts 162 and 160, line 159, contacts 158 closed early, lines 157 and 184, mode contacts 149, line 154, wire 183, Y mode terminal 182, switch arm 80A, lines 180 and 179, contacts 194, line 197, punch magnet 198 and line 200 to plus V. This effects a perforation at 1 in the M character of a tape set as shown for the fourth operation in FIG. 3A.

Succeeding, I and F punchings follow, immediately under control of the stepping switch 139A. Tape punching is terminated after the third F punching step when the stepping switch 139A returns to the position shown.

Each such three-step punch setting cycle is usually followed by resetting the switch 79 to trial. Another control pad trial cycle ensues. Punching of the tape follows setting of the control pad for trial adjustments of the manipulator 36. The process continues until a complete program has been established for transporting and handling a part. The program

control punched tape 52 so created may then be formed into a loop to provide a repetitive program control means.

A third process of electrical operation is automatic control. The program tape 52 is the control over all the actions of the manipulator 36. To select automatic control, a control switch 79A on FIG. 26D is shifted to automatic. A mechanical connection 201 shifts an aligned set of contacts from 162 to 169 to establish connections between the tape sensing brushes 202 and the data magnets 59.

After the control switch 79A is set for automatic control, the start reader switch 212 is operated to close contacts 210 and actuate a reader clutch solenoid 206 for tape feeding. The circuit includes mode contacts 165, FIG. 26D, line 163, line 211, start switch contacts 210, wire 209, contacts 208 now closed, wire 207, reader clutch solenoid 206 and the positive source voltage V. Simultaneously, over line 207, a branch circuit is established to actuate the hydraulic start magnet 170. This branch circuit includes wire 205, the data circuit breaking contacts 204 (normally-open), which close 10-15 milliseconds after the clutch starts, a wire 203, contacts 169A (now closed), wire 172, start magnet 170 and line 171 to the positive voltage supply V. Two magnets are actuated by the reader start operation, i.e., the reader clutch solenoid 206 and the hydraulic start magnet 170. The reader clutch solenoid 206 controls advance and stepping of the tape 52. The start magnet 170 controls the stepping of the hydraulic serial-to-parallel converter. Other controls affecting the timing of the stepping controls are the pressure switches 164 and 166, FIG. 26D, in the hydraulic apparatus. For example, the mode pressure switch assures that mode read-in is delayed until the tower is in mode position. Another control over stepping is the data circuit breaker cam, which insures separation of the contacts 204 until perforations in the tape are aligned with the tape sensing brushes.

An example of automatic control of the circuit by the tape 52 resulting in adjustment of the hydraulic converter port opening settings will now be considered. It will be assumed again to involve the Y arm and a 1 bit sensed in the tape. Therefore, the circuit required to energize the 1 bit data magnet 59, involves the ground connection, FIG. 26D, and mode pressure switch contacts 165, now closed, wires 163 and 211, start reader switch contacts 210, wire 209, contacts 208 (now shifted), wire 207, wire 205, circuit breaker contacts 204 (closed for each row of perforations in the tape) wire 213 reader contact plate 214, a tape reader brush 202 projecting through a 1 bit tape perforation, wire 215, contacts 216 (now closed), the 1 data magnet 59 and line 171 to the positive voltage supply V.

After the initial automatic mode operation, the tape reader clutch solenoid 206 is cut off by mode pressure switch 165. The start magnet 170 was already cut off by circuit breaker contacts 204. They are both energized successively for integer and fraction tape reading operations after the I and F pressure switch contacts 167 close when operated by the hydraulic synchronizing control section. The tape 52, FIG. 3A, is then stepped along, not only to read the three successive characters controlling the three steps of one operation. Nor is stepping of the tape limited to a succession of 14 such operations of a complete assembly operation. Such complete cycles of operation continue without interruption, ad infinitum, until the operator opens the start reader switch 212.

From the foregoing explanation of the electrical circuit, it may be gathered that the primary purpose of the manual and tape controls is to energize combinations of the five data magnets 59 and the start magnet 170 to control hydraulic stepping and porting of pressure in the hydraulic converter. The operation of the serial-to-parallel, hydraulic stepping converter 26 is described below.

THE SERIAL-TO-PARALLEL, HYDRAULIC CONVERTER

The serial-to-parallel converter shown in FIGS. 10 and 11 reads and stores the information supplied to data magnets 59 from the tape 52 by the electrical system described above. For any given operation with reference to FIG. 3, the data magnets 59 will operate the valves in the data section 26 which will first adjust the valves in the mode section 60. Each of five data valves 228 can be connected by means of two of 10 axial tubes 227 one at a time to a valve in each one of the mode, integer and fraction sections 60, 61 and 62 respectively, only for a particular position of a central tower 802 of eight pistons and the 10 tubes.

The central tower 802 has three positions. The first position is the mode position in which the data magnets 59 and the tubes 227 and radial channels in the valve sections and aligned ports for the data valve section 26 and mode valve section 60 are in communication. At such time as the mode valves 229 are connected to the data valves 228, the integer and fraction section valves are disconnected. After the mode valves 229 have been adjusted by the data section 26 in response to the operation of the data magnets 59, the central tower 802 comprising the eight pistons which are connected by the axial tubes 227 is moved up one position by the control section 63 and the stepping drive 76 as will be explained below.

After the central tower 802 has been moved up one step, then the integer valve section 61 will be actuated, as its five valves 230 will be in communication with the five valves in the data section 26. Accordingly, the integer valves will be adjusted by the tape character which operates the data magnets 59 during the second step of an operation, that is, in FIG. 3A, going from step M to step I.

As soon as the integer valves 230 in section 61 have been adjusted, then the tower is again stepped by the combination of the control section 63 and the stepping drive 76 to elevate the tower of pistons and tubes 227 a further step until the five valves 231 in the fraction section 62 are in communication with the five valves in the data section 226. At this time, the valves in mode section 60 and in integer section 61 and in fraction section 62 have been displaced or shifted to record and serve as a memory of the information which has been read-in from the perforated tape.

As can be seen from FIG. 11 a number of flexible tubes are connected from the mode, integer and fraction sections of the serial-to-parallel converter to the arithmetical drive units or piston adder 35. In the three memory sections, comprising mode section 60, integer section 61 and fraction section 62, there are a total of 15 spool valves each of which is positionable to two different positions. Each of these spool valves have two outputs so there is a total of 30 output lines which are connected from the converter to the piston adder 35.

The schematic perspective view in FIG. 10 provides a showing of the internal structure of the hydraulic memory converter to provide a general understanding of the construction of the converter. In the center is seen a tower 802 of eight pistons 218-225 which are spaced apart by and bonded to a central ring of 10 axial tubes 227. The axial tubes 227 are made from common steel tubing to provide a strong low mass design and to avoid the drilling of long holes. The tubes 227 are also used as pressure and fluid conduits, and they are ported through the pistons to connect the spool valves.

Spool valves are clustered inside the valve sections around the tower 802 in five groups of five spool valves. From top to bottom the groups of spool valves may be identified as the data entering valves 228 in the data section 26, mode selection valves 229 in the mode section 60, integer selection valves 230 in the integer section 61, fraction selection valves 231 in the fraction section 62, and stepping control valves 232 in control section 63.

A series of fixed, common, solid valve encasements 241-245 shown in phantom holds the clusters of valves 228-232 respectively. These encasements 241-245 house the valves in cylindrical bores therein, (shown in detail, FIGS. 27A-27J) and radial tubular fluid channels have been bored for connections between the pistons and the tubing ports and the valve ports. Such channels are shown diagrammatically in FIG. 10 by the channels such as channel 246 shown as tube rather than a bore for convenience of illustration, since the encasement is shown in phantom. Channel 246 is shown adjacent to data entering spool valve 228.

It will be noted that the channel 246 extends inwardly towards the piston 218 of the tower 802 in which there is a normally positioned mode opening aligned with its distal end. Beneath the distal end, and the mode port, are two other regularly spaced port openings in piston 218, integer port opening 247 and fraction port opening 248. This spaced relationship of channel 246 with the normal and stepped port openings 247 and 248 indicates the displacement of the tower required for channel 246 to communicate with those ports 247 and 248. The whole tower 802 must be elevated for such communication to occur.

In FIG. 10, glancing downwardly successively, we find mode channels 249 and 249A, spaced about pistons 219 and 220, integer channels 250 and 250A about pistons 221 and 222 and fraction channels 251 and 251A about pistons 223 and 224. The mode channels 249 are aligned with ports 252 in the piston 219, the integer channels 250A are spaced one step above port 253 and the fraction channels 251A are spaced two steps above port 254. As the piston tower is elevated step-by-step the channels will be aligned first with the mode section 60, secondly with the integer section 61, and then in the third step with the fraction section 62 as the pistons with their ports are carried up with the tower, while the channels remain affixed in the outer casings as can be seen.

The purpose of the upper data section 26 with data magnets 59 is to adjust in three steps the particular mode, integer and fraction valves 229, 230 and 231 to be shifted and held during a particular operation called for by the tape. The purpose of the lower, control valve section 63 is to synchronize and control successive upward stepping of the piston assembly by the stepping drive 76.

It was noted above how the data magnets 59 were energized in combinations by the control pad or tape. At the top of FIG. 10 it is seen that each of the data magnets 59 has an individual solenoid plunger 255 aligned to shift a corresponding data valve 228 when energized. A series of three such shifts by data magnets 59 for each of the three stepped positions of the tower provide the valve portings to shift the selected sets of M, I and F valves.

Interspersed between such selective portings between the data section and other sections are the operations of the control valve section 63 for starting, synchronizing, and stepping of the whole piston assembly. The START magnet 170 is associated with the control valve section 63. The drive section 76 contains two stepping drive pistons encased in a fixed case 256 above which extends therefrom the drive piston rod 257 for pushing the tower or piston assembly upward with two steps of motion, while the integer and fraction valves are ported to the data valves.

While FIG. 10 affords a good general picture of the converter and controls associated therewith, views of FIGS. 11-15 show more specific exterior and interior details, and composite schematic FIGS. 27A-27J shows particular hydraulic controls and the valving thereof.

FIG. 11 shows the exterior appearance of the converter 26 and how it is fixed on the vertical bar 64 by a shelf 258 and a tie piece 259. The mode valve section 60 has a series of output ports 260 with tubing which is connected to mode actuators for the grip, sweep and search 262 modes directly. The other ports 260 are connected to a logic tree section 261 for indirect control over X, Y, Z and Θ modes as may be seen in FIG. 27C. Out of the integer and fraction valve sections 61 and 62 are

extended the ports 263 and 264, respectively, with flexible tubing 265 to the corresponding valve chambers of the piston adder or arithmetic drive unit 35.

FIG. 13 is an enlarged elevational view of the mode valve section 60 of the converter partly sectioned to show the interior of one mode selector valve 229 (including its spool). FIG. 12 is a sectional plan view taken generally along line 12-12 in FIG. 13. The valve encasement 242, as seen in FIG. 13, includes a hollow cylindrical block 611 on which a ring 610 is thermally bonded. Three annular slots are cut on the outer face of the block 611. Two of those annular slots 612 and 613 provide openings for the return flow of hydraulic fluid from the spool valves 229. The third slot 296 is used to supply hydraulic fluid to the valves under pressure. The third slot 296 is also referred to as the mode memory manifold in connection with FIGS. 27A-27J. The block 611 has two end portions 266 and 267 and two central portions 614 and 615. In the upper end portion a radial bore has been made to provide a port and a mode channel 249D connecting the valve to piston 219. Mode channel 249D is used for shifting a spool of 8 valve 229 to its 0 position. The output ports 260 which are affected by the position of spool 229 are centrally located in the block 611. The block 611 is affixed to the sleeve 268 as shown in FIG. 12 where a pin 269 fits in a recess in the sleeve 268.

The mode pistons 219 and 220, FIG. 10 slide within the fixed sleeve 268 and the upper mode piston 219 is shown in section in FIG. 12. There it is shown that 10 tubes 227 are required in order to provide top and bottom connections to the two mode channels such as 249D and 249E from the ports for each of the five mode valves 229 in the mode valve section 60. These pairs of channels 249, 249A, 249B, 249C, 249D, 249E, etc., are seen to extend outwardly, radially from the tube pairs and to connect to the end chambers surrounding the opposite ends of each spool 229. Three mode actuators are driven directly from three outputs of the mode section valves. The other two valves are connected to the logic tree 261 to provide four other mode control outputs.

The five mode sets of tubes, valves, channels and ports, FIG. 12 are identified in a clockwise order from the upper left, as related respectively to the 1, 2, 4, 8 and 16 bits for the binary system.

In FIG. 13, the single revealed 8-bit mode valve 229 is shown with its spool in a depressed position where it is held to provide a hydraulic memory setting. A small compression spring 270 is housed in a hole and backed by an adjustment screw 271. The screw is adjusted to compress the spring against the spool surface with sufficient force to retain the spool in an adjusted position without interfering with hydraulic selection and restoration pulses or pressures.

FIG. 15 is an enlarged elevation showing of the control valve section 63 of the converter partly sectioned to show the ends of the 10 axial tubes 227 as distinguished from six interior channels provided for control, such as the tubular channel 275, shown for step valve 2 at position A. A bottom partial section shows the start magnet 170 with its plunger 273 pressing against downwardly spring-biased start valve 274. FIG. 14 shows a sectional plan view of the control section along line 14-14 in FIG. 15. Cylindrical valve block 245 has two end portions 283 and 284 for end ports for shifting the spool valves, while reading ports are located in the central portion of the block 245 under the thermally bonded ring 620. This block 245 has three slots also, and return slots 621 and 622 are shown. The valve block 245 rests on shelf 258. The axial piston 225 is secured to the lower and is slidable vertically within the control valve section 63. The piston 225 is shown in the normal M position and will assume the successive I and F upward stepped porting positions. A series of vertically shifting valve spools such as the spool of step control valve 232 are housed in much the same way as the code bit valves of the other four valve sections. However, in the control section, the valves are used mainly for synchronization, pulse generation and logic functions which are independent of the data inputs.

Referring to alphabetic notations A—K and reading in a counterclockwise direction, in FIG. 14, the main control functions of the valves can be outlined. Starting at the upper right corner and reading counterclockwise, the valves are as follows: A—step valve 2 232B; B—step valve 1 232A; C—an AND valve 280; D—a port from channel 278; E—an ALIGNER valve 281; F—a port from channel 279; G—the START valve 274, J—the STEP CONTROL valve 232, and K a port from commutator channel 272. To these valves and ports it is seen that a plurality of radial channels such as channel 315 to channel 275 extend outwardly from six central tubular channels 55, 272, 275, 276, 277, 278, and 279 extending vertically inside the piston 225. A key pin 286 holds the slotted piston 225 and sleeve 268 in alignment so the tower will not turn about its longitudinal axis. The many hydraulic connections to and from these valves, channels and ports are discussed more fully, with reference to the schematic FIGS. 27A—27K.

Before studying the details of the schematic view FIGS. 27A—27K, as arranged in FIG. 27, we will consider its relationship to FIG. 10 and how it may be most easily understood. If FIG. 10 is turned counterclockwise and placed on assembled FIGS. 27A—27K with the top of FIG. 10 at the left, then the horizontal and vertical correlation is evident. That is, the data, mode, integer, fraction, and control valves are aligned in a left to right order in both views. Vertically, FIGS. 27A, 27E, 27H, etc., the views of the valve clusters are unrolled or spread out from the circular arrays of FIG. 10 into a flat representation. The parts relating to the binary data bits are arranged from top to bottom in binary numerical order from 1, 2, 4, 8 to 16. Manifestly, the parts in the flat schematic are not in the correct physical positions. They are spread schematically and placed to explain the concepts of hydraulic porting, connection and control. The pistons of the tower are omitted. Ports are shown as openings in the ten axial tubes 227, which are now parallel and horizontal, and identified as A, B, C, D, E, F, G, H, J, K.

At the upper right corner, FIGS. 27C and 27D, there are several hydraulic controls including the flow valve control, now shown, in FIG. 10. At the lower right corner, FIG. 27K, a timing chart shows the sequence of control valve operations, some of which were explained above relative to electrical timing.

It is believed well to describe the data, mode, integer and fraction valve relationships, first, before explaining the nature of the controls at the right-hand side. At the extreme left, a data magnet 59, e.g. the 02 magnet 59 may actuate its plunger 255 to pull the spool of data entering valve 228 to the right in opposition to its biasing spring 287. Valve 228 has no peripheral holding spring for memory positioning of the operating because data entry is effected by a momentary, transient fluid signal. This transient signal is passed to the mode, integer, or fraction memory valve to which the data valve is connected by the axial tubes 227 to which they are ported, for the tower step position then prevailing. Because of the above shift to the right of the 2 valve 228, pressure from the transient source line 288, which would normally appear at port 289 and would be coupled through the upper axial tube 227, F, is blocked by the shifted land 293. Instead, pressure is diverted down to port 290 and from it through the lower axial tube 227, E, to a memory valve. Scanning along this particular (lower) axial tube 227, E, for an operating port to a memory valve opposite any of the three M, I, F read-in step positions for all modes, it is seen that only the mode port 252B is opposite a tube opening. Pressure there, and in aligned mode channel 249B, causes the spool of valve 229 to be shifted to the left. There the spool land 297 blocks the fluid pressure from source 296 to conduit tree 02₁ and instead diverts pressure through port 260 into conduit tree 02₁. This shifted position of mode valve 229 is held as a hydraulic memory, during a three step tape operation. The compression spring 270 prevents spool movement except in response to a hydraulic signal. Later, after all three steps cause read-in

settings to be established in memory valves 229, 230 and 231, and after the manipulator is actuated, restoration of 2 valve 229 is effected through left channel 249C as the piston and tube assembly is collapsed through read-in step positions F, and I to M. The valve construction including a lower right channel 249B between the right end of spool 229 and the lower axial tube 227, E, and an upper left channel 249C between the left end of mode memory spool 229 and the upper, axial tube 227 F, is common to all mode, integer and fraction valves. The style of operation is also the same.

After the adjustment of the mode 2 valve as noted, the stepping drive 76, FIG. 27G, pushes the drive piston rod 257 one step, and the tower 802 and all the axial tubes 227 are shifted one step to the left. Then, should the 2 data magnet 59 be energized again, the integer 2 valve 230 will shift to the left through axial tube 227, E, and the I port 253B then set to communicate through channel 252B with the lower tube 227E. A corresponding read-in step follows for an F setting of the tower.

As explained above, the five pairs of axial tubes 227 have only single ports such as 252C and 252B opposite the memory or mode, integer and fraction valves. However three ports are provided to the data valves 228. Successive settings and restoration of the data valves are made in all three stepped and collapsed positions of the tower.

The operation of the other mode valves 229 for 4, 8, and 16 bit values is similar, but the outputs are connected directly to the mode controls, i.e. grip, sweep, and search. The steps for 1 bit line of valves, the 4 bit line of valves, the 8 bit line of valves, and the 16 bit line of valves is similar to the steps of the 2 line of valves.

The 1 and 2 mode valves 229 are involved with the tree controls, FIG. 27C, where the four mode fluid ports X, Y, Z, Θ are seen at the upper right. As explained above, manipulator arm locking pressure is applied to all of the four mode actuators except the actuator for the one mode whose operation is selected. Combinations of 1 and 2 mode valve positions cause pressures applied at the tree to remove locking pressure from a selected mode member as follows for release of:

- X—no 1 or 2 bits
- Y—only a 1 bit
- Z—only a 2 bit
- Θ —both 1 and 2 bits

The tree 261 is operated as a mode selection control (FIG. 27C) in response to combinations of pressures at 02₁ or 02₂, and at 01₁ or 01₂. Normally, with neither a 1 or a 2 bit as data, the valves 298 and 299 in the tree are positioned as shown, so that line 307 can communicate with the X axis line so that pressure can be controlled by the aligner valve 281. All three other tree mode lines Y, Z and Θ are pressurized and the actuators in the manipulator clamped into inactive positions. The X arm will then be the only one free to be moved when pressure is removed on line 307 by aligner valve 281 in Step I. Should the 2-bit spool 299 in the tree 261 be shifted by selective pressure at the 02₁ line as already outlined, then land 301 lowers to permit a line to apply source P pressure to the X axis line and to cause clamping of the X axis. The Θ and Y axis lines are also pressured and the elements are clamped, the former through channel 302 and the latter through channel 303. The selected mode, i.e., the Z axis line, is not connected to source P to be pressurized and can be unclamped for action, by aligner valve 281 in Step I. In Step I, line 327 supplies pressure from step valve 232A to shift the aligner valve 281. Therefore, a 2-bit mode input will free the Z arm for adjustment of its position because it is the only arm unclamped.

Other combinations of selective pressures at 01₁ and 02₁ are controlling over valves 298 and 299 to position spool rings 305 and 306 as well as the other shoulders so that selective unclamping of the Y and Θ mode actuators are effected in a similar manner. Restoration and alignment of valves 298 and 299 in the positions shown is effected by pressure in channels 01₁ and 02₁ as regulated by the mode valves 229.

THE STEPPING CONTROLS

Referring to FIGS. 10 and 27A—27K, it will be recalled that the stepping piston assembly consists of a tower comprising eight pistons supported and bonded to the 10 axial tubes and also a series of central tubular channels 272, 275, etc. (FIG. 14) inside the control piston 225, FIG. 10, for effecting porting to the various control valves in the control valve section 63. It is also recalled that in FIG. 10, near the bottom of the view is a drive piston rod 257 extending through the fixed case 256 of the stepping drive section 76 to step the entire assembly upwardly for two successive positions, beyond the mode position. Now referring to the right side of the chart and FIG. 27G, there is shown the selector or drive piston rod 257 extending from the double cylinder 326, which is provided to furnish the stepping drive. The primary purpose of the controls about to be considered is that of stepping the piston rod 257 rapidly with two successive movements to elevate the entire tower or piston assembly 802 for making the three sets of serial-to-parallel hydraulic connections.

Each set of characters received from the tape reader is accompanied by a start signal, which through the already noted electrical circuit, actuates the start magnet 170, only if the mode switch 165 is closed through pressure in channel 323 FIG. 27J. This impulse operates plunger 273 and serves to shift the spring-biased spool of the start valve 274. The right-hand output 310 of the start valve 274 is connected to drive the spring-biased spool of the step control valve 232. Then valve 232 in turn has an output 311 which is connected by porting in the central tubular distribution channels 272 and 276 which are coupled by a manifold 600 and shift control channel 314 to the spool of step valve 232A. With the transfer of the step valve 232A, by a pulse channel 314, the output 316 therefrom is communicated to the double cylinder 326. The piston rod 257 secured to the piston 701 in chamber 702 of cylinder 326 will be moved to the left by one position. During the midposition movement of the tower 802 including the piston assembly, the shift control channel 312 for the tube 55 will be momentarily connected to reset tube 55 to apply a pulse of pressure to momentarily assist the spring of the step control valve 232 to return the step control valve 232 to its initial position. The mode switch 165 will have opened because of shifting of connections to tube 278 to disconnect pressure from channel 323. The start valve 274 will by then have been forced by its spring to return to its original position. Correct timing of operation of the control section will be assured since operation of step valve 232B will await the second operation of the start valve 274.

With the stepping piston assembly in the second I position, the second start signal of the tape reader accompanying read-in of a second tape character will actuate the start magnet 170. The integer fraction switch 167 will be closed at the second step because of pressure on channel 329 from fraction sense valve 282 which will be in its left position as a result of pressure in channel 325 and the position of tube 279.

Closure of circuit breaker contacts 201 and integer fraction contacts 167 will actuate the start magnet 170. Now, the step control valve 232 in response to shifting of the start valve 274, will conduct the step pulse which will effect the transfer of the spool of the step valve 232B through the selected porting of the position selecting pulse distribution tubes 275 and 272 connected by manifold 600 and via the I port of tube 275 through the channel 315. The step valve 232B output 318 will cause the double cylinder 326 to push the piston 701 and shaft 257 left as pressure in chamber 704 builds up on the left of piston 703 affixed to case 256 by shaft 705. Thus, the tower 802, or piston assembly is quickly urged to the third, fraction, position toward the left. The midposition porting of the reset tube 55 will again, through channel 312, momentarily pulse the step control valve 232 to ensure resetting of the valve 232 before reaching the third position. Thus, the timing of operation of the and valve 280 and fraction sense valve 245 to the fraction position will be deferred until the input tape requires operation.

With the tower or stepping piston assembly in the third, F, read-in position, the third start signal accompanying read-in of a character will again actuate the start magnet 170. However, the output of the step control valve 232 is connected through distribution tubes 272 and 277 via manifold 600 to the channel 321 through an F port for operating the spool of the valve 280 to the left. The and valve 280 in turn controls the porting to the channel 320 directed to the restoring ends of the stepping valve controls 232A and 232B, which in turn will cause the stepping drive 76 to lower the tower 802 due to the porting of the step controls through pressure in the restoration channels 317 and 319. Thus the piston 701 and the cylinder 326 are restored to the right. Now the piston rod 257 is in its start position ready for the next cycle of operation.

The timing chart, FIG. 27K, shows the timing of operation of valves in the converter during transfer of the converter from the mode position to the integer position. It also shows the timing of pulses for moving the aligner valve 281 to its left-hand position through channel 327 from step valve 232A. The aligner valve 281 is used to control the pressure in the tree 261. Pressure in the tree is released from the line to a selected mode piston when pressure is released from channel 307. This occurs when the aligner valve is in its left-hand position. The tree 261 will remain in this condition until the tower 802 is lowered to the mode position, when tube 278 will connect the channels 323 and 322 conducting pressure from the flow valve 8 via line 23. This assumes the flow valve 8 is off after completion of a piston adder positioning operation. The mode switch contacts 165 will close simultaneously as a result of pressure on line 323 to actuator 164.

When tube 277 is in the fraction read-in position, the channel 321 restores a fraction sense valve 282 to its right-hand position. It was shifted earlier at integer through the tube 279 from channel 324 and step valve 232A, port I, the channel 325 applied at the right end 217 of fraction sense valve 282. This end of first step indication at the fraction sense valve is communicated in position I up through channel 329 to the integer fraction I-F switch actuator 166 to close contacts 167. This occurs after the opening of mode contacts 165. Later, in the fraction position F, contacts 167 open, after the tube 277 conducts step control valve pressure to shift the fraction sense valve 282 to the right-hand position, to remove pressure from the integer fraction switch actuator 166.

Also directed out of fraction sense valve 245 is a channel 330 to the latch valve 233 for the flow valve 8, which channel is cut off from pressure by the leftward shift of the fraction sense valve 282 in the integer position. Consideration is given below to the way the flow valve 8 quickly detects change in flow and acts through the pressure source and channel 322 and tube 278 and line 323 to shift the mode switch valve 164 to initiate a second series of steps. The first set of characters from the tape reader actuate the magnet-controlled data-entering valves 228 (at the left), the output of which is initially ported to the first, mode, set of character memory valves. The stepping piston assembly will then step up one position, porting the output of the valves 228 to the second, integer, set of character memory valves for the second set of characters from the tape reader. And finally the stepping piston assembly will move up to the third position porting through the axial tubes from the outputs of the data valves to the third, fraction, set of character memory valves for the third set of characters from the tape reader, or pad.

Turning now to the upper right corner of the schematic showing at FIG. 27D, it is of note that a valve such as flow valve 8 is designed to include a spool which maintains a first position in the housing in the absence of flow of hydraulic fluid. When the hydraulic fluid begins to flow through the valve, the valve spool moves to a second position and stays there until the flow ceases at which time the valve spool returns to its first position.

It is desirable that such a flow valve be adapted to move at the earliest possible time, that is with a minimum of flow through the system and to return as rapidly as possible when

the flow ceases. For example, it should return rapidly when the piston adder is stalled by pressure of the manipulator on a fixed object or personnel. This is a safety feature.

Reference may be made to a detailed description of such a flow valve in the copending patent application of R. C. Herbert Ser. No. 548,291 now U.S. Pat. No. 3,399,692 filed on May 6, 1966 for Hydraulic Flow Valve System assigned to the assignee hereof.

The flow valve 8 is shown including a valve body 10 and a spool 12. The flow valve is included in the hydraulic system with an input port 14 and an output port 16 connected to the mode, integer, and fraction valve manifold system 296 which provides pressure to the output sections of the memory valves from flow valve 10. The hydraulic fluid controlling the flow valve travels from the pump 14 in through a channel 15 in hollow spool 12 through orifice 17 in spool 12 to output port 16. A second positive pressure port 18 is provided in the valve body 10 to introduce positive hydraulic pressure from the pump. Two annular return ports 20 and 22 are provided to return the hydraulic fluid to sump (not shown). When there is no flow of hydraulic fluid through the valve, that is, no flow from pump 14 through output port 16, the spool 12 is biased to be positioned normally to the right or input side of the valve body 10 by means of a bias spring 24 which is compressed against a return piston 226 which pushes on the valve spool 12. The bias force exerted by the spring 24 is minimal and is easily overcome as soon as hydraulic flow occurs through the valve. In the no-flow state, when the valve spool 12 is to the right of the valve body 10, the hydraulic fluid introduced through pressure port 18 is directed out through port 23. From port 23 it connects to tube 278 via line 322 for connection to mode switch actuator 164 to close the mode switch in position M when flow to the piston adders 35 from the flow valve 8 has ended. The output port 16 is hydraulically connected to apply pressure to the mode, integer, and fraction manifolds. When flow occurs in the system it builds up from a minimum to a maximum value over a finite period of time. At the moment flow begins from pump 14 and out through output port 16, a differential pressure is produced across the valve spool 12 by orifice 17. This differential pressure, at the moment of minimum flow, is sufficient to overcome the force of the bias spring 24 shifting the position of valve spool 12 to the left. The flow valve spool 12 will remain to the left while the maximum flow condition prevails in the system.

If no further structure were provided, the flow valve spool 12 would stay in the leftmost position until the hydraulic flow decreased below the minimum flow point to permit the relatively small force of bias spring 24 to urge the spool 12 to the right. However, in addition to moving the flow valve spool 12 to the left at the moment of minimum flow, it is also necessary that the valve spool 12 be returned to its initial position at the moment the maximum flow ends; that is, at the moment the flow rate begins to fall below a maximum, not after it has decreased to below the minimum flow point. When the flow through the spool 12 begins to decline from maximum there is still an almost maximum differential pressure forcing the spool 12 to the left. A force in addition to the force of bias spring 24 must be applied and this additional force must be applied only after the maximum flow has been reached and the spool 12 has moved to the left. This additional force will be applied to the return piston 226. A hydraulic valve 233 provides the additional force and applies it at the proper time.

When the fraction sensing valve 282 is positioned via line 321, as shown, after completion of the fraction read-in step, pressure is applied through line 330 to the right side 601 of the valve 233. The valve spool 240 is normally in its rightmost position so that pressure is normally cut off from the valve output port 264 and line 266. However, when the valve is shifted by the fraction sense valve, port 264 is pressurized. A hydraulic pressure pulse is directed through hydraulic line 266 to actuate the return piston 226. The exposed area of the return piston 226 is selected such that pressure on it, in

combination with the force of bias spring 24 provides a total force which is slightly less than the force due to the differential pressure across the flow valve 8 during the maximum flow. Thus the valve spool 12 of the flow valve 8 still remains in its leftmost position. As soon as flow through the flow valve 8 reduces below maximum, the differential pressure across the orifice 17 will decrease. Then the pressure of the bias spring 24 plus the force on the return piston 226 will be sufficient to move the valve spool 12 back to its initial rightmost position.

Then the next mode position read-in can begin when the flow valve permits closure of the mode switch contacts 165.

THE PISTON ADDER

The function of the piston adder is to translate the required values of displacement (of the manipulator), which have been stored as bits in the integer and fraction units of the converter, into actual displacement of the drive cable 69. Thus, each of the integer and fraction valves in the converter has its output lines connected to the piston adder 35. The basic concept underlying the operation of the piston adder 35 is that if several pistons and cylinders carrying those cylinders are connected in series, then the cumulative displacement of all of the pistons in all of the cylinders will be additive (or subtractive depending upon the initial positions of the pistons). In this case, the cylinders have lengths which permit values of displacement related according to the binary system of numbers, i.e., one thirty-second inch, one-sixteenth inch, one-eighth inch, one-fourth inch, one-half inch, 1 inch, 2 inches, 4 inches, 8 inches, and 16 inches. However, rather than employing a long tower of the 10 required pistons and cylinders stacked vertically, a folded arrangement is used including rails to slidably support the cylinders and pistons which might otherwise be misaligned.

The integer and fraction porting of pressure is directed into the piston adder or the arithmetic drive units 35 shown perspective in FIG. 2, in section at the upper left in FIG. 19, diagrammatically unfolded at 0 position in FIG. 16, and adjusted by 4 5/16 inch movement in FIG. 17. The piston adder apparatus 35 here is in three sections, FIG. 19, compactly arranged around or folded around three sides of a square on which the Z arm 42 occupies the fourth side. Such a piston adder apparatus, FIG. 16, is a fluid actuated assembly which may be linearly extended to a plurality of predetermined lengths. The piston adder shown consists of a plurality of interconnected pistons and cylinders each having either a single piston as in the case of the one thirty-second piston 335 in chamber 336, or containing two back-to-back pistons, such as the one-sixteenth inch and one-eighth inch pistons 337 and 339 located in two separate chambers 338 and 340 within a single piston cylinder.

In FIG. 16 the 10 piston chambers included in the piston adder mechanism 35 are indicated by the reference numbers 336, 338, 340, 342, 345, 347, 349, 358, 360 and 365. The first five of these chambers relate to the fraction control settings of the adder, i.e., one thirty-second, one-sixteenth, one-eighth, one-fourth and one-half and the additional five chambers relate to the integer controls, namely, 1, 2, 4, 8, 16 inches of movement. Each of these piston chambers is back-to-back with the exception of the two end chambers. Each of the piston chambers has associated therewith two ports through which fluid may be introduced and removed from the chamber by means of a valve, a pump and a reservoir arrangement. When fluid under pressure is introduced to any chamber the piston rod therein moves the length of the chamber and when the fluid pressure is released, the piston rod returns to its original position. The pump reservoir and connecting hoses are not shown in FIG. 16 because the structure and operation is otherwise indicated hereinbefore.

In the above order, each of the piston chambers permits twice the piston displacement of the preceding chamber. Thus, chamber 336 affords one thirty-second of an inch of piston movement, chamber 338 affords one-sixteenth of an

inch of piston movement, chamber 340 affords one-eighth of an inch of piston movement, etc.

When all the piston rods are in their retracted position, as in FIG. 16, the piston adder mechanism is at its 0 position. By causing the individual piston rods to move either singly or in combination (by input fluid pressure), the piston adder mechanism shown in FIG. 16 can be extended to a distance up to 31 31/32nd of an inch from a 0 position or any distance in between, in increments of one thirty-second of an inch. For example, as shown in FIG. 17, if the 4 inches, 1/4 inch and 1/16 inch pistons are actuated, then the entire piston adder mechanism is extended 4 5/16ths of an inch. The clamp 68, being connected to the end of the highest order piston adder member would therefore move 4 5/16ths of an inch beyond the normal position which is shown at the right. Combinations of the piston rods within the various piston chambers may be actuated at the same time providing for a total distance equal to the sum of the lengths of the piston chambers actuated, both fractions and integers. A piston adder mechanism is described in U.S. Pat. application Ser. No. 411,066 entitled "Piston Adder Apparatus," filed Nov. 13, 1964, now U.S. Pat. No. 3,266,377, of Hugo A. Panissidi and assigned to the assignee hereof.

In the unfolded view, FIG. 16, it is seen that the top piston 348 in this first adder tower is connected to a cross bar 350 which in turn is connected to a vertical slide connector 352, at the bottom of which a crossbar 356 is attached to the bottom of a rod connected to the 4 piston 357. At the top of the rod of 8 piston 359 is attached a third crossbar 361 secured to a second vertical slide connector 362, that has a crossbar 363 attached to the bottom of the rod of 16 cylinder 365, out of the top of which extends the rod of the piston 364. The rod of piston 364 is attached to the crossbar 366, attached to the third and final vertical slide connector 367. Extending from slide connector 367 is the clamp bar 68 and a clamp 368 attached to a common drive cable 69. This whole linkage, FIG. 19, rides upwardly on three rails, such as rail 355, secured to one of the bars 65 and rails 355B and C arranged on the other sides for the three piston towers. The purpose is to provide compact hydraulically controlled vertical movement and to impart such movement additively or subtractively to cable 69.

An example of slide construction, FIG. 19, shows that bar 351 has a U-frame 352 secured thereto and at the sides thereof, near top and bottom, there project roller standards with rollers 353 and 354 riding on the edges of the rail 355 fastened to one of the bars 65. It is obvious that the other two slides are mounted for vertical reciprocation in the same fashion.

From the discussion of the electrical controls of diagram FIGS. 26A—26D and the schematic controls of FIG. 27A—27K, it is apparent that the piston adder 35 is set after integer and fraction selection and after such a setting is immediately displaced according to the selected increments of additive or subtractive motion. It is held where placed until a subsequent mode and distance is selected.

THE MANIPULATOR

The manipulator 36 is described generally above relative to FIGS. 2 and 4. Here the cable drive to the manipulator is described in greater detail. Referring to FIG. 20, the endless drive cable 69 is shown passing from the piston adder clamp 368 around a series of 8 pulleys 369 and 373—379. The pulleys are rotatably secured to shafts carried by either the movable or fixed portions of the arm. The Θ pulley is carried on a shaft secured to the end of the X arm. Pulley 369 is carried by shaft 372 extending through slot 371 in the fixed frame 370 and secured to the movable Z arm 42. Pulleys 373 and 379 are coaxially, rotatably mounted on the shaft 380 extending from the Y arm holder 41 through which the Y arm 40 extends. Coaxial pulleys 374 and 377 are rotatably mounted on shaft 382 in the portion of Y arm 40 extending

from X arm holder 39 held adjacent the X arm 38. Within the X arm 38 are the pulleys 376 and 375, the former being on shaft 383 and the latter being on shaft 384 which shaft also carries the gear for Θ angular adjustment of the outer gripper. A pair of diagrammatic views, FIG. 20A and FIG. 20B, show the appearance of the endless drive cable 69 in both the retracted and extended positions, respectively. These views show that regardless of the mode of motion selected (additively or subtractively) there is no slack in the cable because the assembly, the pulleys and the cable are arranged to take up all slack. Because the movements are in pairs, the extent of motion of one end of the cable is compensated for by equal motion of the opposite end which is moved along therewith. The output motion of the piston adder 35 during any adjusting operation is mechanically connected to a single member, i.e., X arm 38, Y arm 40, Z arm 42 or the Θ rotation. The system clamps all X, Y, Z and Θ members except the one whose motion is desired and frees the one mode member selected. Clamping is effected hydraulically in response to the controls, as discussed.

In FIGS. 20 and 21 the X arm 38 carries a toothed rack 385 with a pitch of 32 teeth per inch. Above rack 385 is poised a toothed piston 386, FIG. 21, hydraulically driven downwardly within cylinder 387 by the X axis tree mode hydraulic control when X arm movement is not desired. A spring, not shown, tends to retract the piston 386 from the position shown with the rack 385 unclamped. Similar corresponding units are Y arm rack 388, FIG. 20, and cylinder 389, Z cylinder 390 (the rack is inside on arm 42) and Θ rack 391 and cylinder 392. All cylinders operate similarly to clamp and release the racks. The Θ drive requires an unusual clamp. Its rack 391 has the drive cable 69 attached to its ends and is supported by guides 393 and 394 extending inwardly from the inner surface of arm 38.

Referring to FIGS. 21 and 22 it is seen that Y arm 38 is of common structural steel tubing 38 which has usual irregularities of dimension and quality. However the design of the slide connection of the arm joints overcomes any disadvantage caused by the irregularities of the unmachined surfaces of such structural steel tubing. Advantage is taken of the economy of structural tubing with its high stiffness to weight ratio. A guide roller design used overcomes the irregular and distorted surfaces of the square tubing as received from the mill. I discovered that such tubing is unusually accurate only along axial lines adjacent to the rounded corners where the metal is folded square. Advantage is taken of this discovery by arranging the two sets of four guide rollers 395 mounted between pairs of bearing blocks 396 on holder 39, so that the roller flange edges 397 ride on the rounded corner of arm 38. The use of such structural grade tubing makes it economically practical to use a manipulator which moves along three orthogonal axes to provide arm motions instead of employing a costly cartesian or spherical coordinate system.

Since the drive cable of FIG. 20, will be affected by inherent hysteresis the accuracy with which the position of an arm is adjusted with respect to its supporting joint is accomplished by the rack and piston detent. Engagement of the aligner piston detent and the rack sets the relationships between the rack 388 and its detent.

Referring again briefly to FIG. 4, the manipulator 36 is swung bodily in the sweep mode of operation from the normal 0° out position to a 90° in position at 44 by clockwise movement. The top view in FIG. 18 is partly in section and illustrates this feature. The Z arm 42 is mounted within the fixed square sleeve 370 which is suspended in sump tank 67, between the top disc 43 and the lower disc 66. An operating cable 73 is attached at two points 400 to disc 66, the periphery of which is a pulley, and is wound around corner pulleys 74 with its ends secured within a hydraulic cylinder 75 to piston ends (not shown). A sweep in drive hydraulic port 401 is at the right end of cylinder 75, and a restoration drive out drive port 402 is at the opposite end of the cylinder.

A section detail of construction providing for easy understanding of sweep movement is illustrated in FIG. 18A.

A set of rollers 403 is mounted to depend from the top disc 43. The rollers 403 ride on the surface of an annular flange 404 extending downwardly from the upper surface of the cabinet 71.

As illustrated in FIG. 2 by use of the seep mode of operation, the entire manipulator can be rotated between two stations. For example, it can rotate to a pickup station illustrated in phantom to obtain a part. Then it can turn to a work station for the assembly of the part. This procedure can be performed repetitively.

THE GRIPPER ASSEMBLY

The gripper 45, FIG. 23, comprises a pair of jaws 406, an anvil 407 and a gripper piston 408 held within a housing 424. The size and shape of such parts will depend upon the nature of the object to be picked up by the manipulator.

The two jaws 406 are simultaneously closed when a wedge cam 409 is driven to the left by the hydraulic grip-mode piston 408, because of the pivot pins 411 for the parallel arms 414 spanning between the wedge cam 409 and the outer grip jaws 406. The jaws 406 pivot toward the anvil 407 as they close providing a three-point support for holding objects having many shapes such as square, rectangular, triangular, other polygonal and round shapes. The anvil 407 may be as shown or may be modified to provide additional holding force by either magnetic or vacuum operated means. For relatively small objects the jaws 406 may be V-grooved as are conventional grippers to grasp round, polygonal or square objects. Then the anvil may not be necessary. A spring 410 attached to the right ends of the longer two parallel arms 414 tends to hold the ends of those arms against the cam surfaces of the wedge cam 409.

The gripper assembly 45 is secured to the manipulator arm 38 by means of a spring loaded manipulator shaft 412 to be inserted in a cavity 422 in housing 424 and which also carries a spring loaded detent piston 413 designed to be detented against a wall of the cavity 422. The shape of the detent piston 413 and the walls of the cavity 422 with which it engages, permits easy replacement of the gripper 45 on the manipulator shaft 412, provided the gripper piston 408 is not pressurized. The pressurization of the gripper piston 408 by tube 420 as described below also pressurizes the detent piston 413 with a force effective for locking the gripper to the manipulator shaft 412 whenever an object is to be picked up or transported by the manipulator. The automatic locking of the gripper 45 to the manipulator only when the gripper jaws 406 are engaged provides a simple means of exchanging gripper assemblies during a program of operation in which the objects to be handled require several different types of grippers.

The gripper shaft 412 and the gripper mounted on it are adapted to be rotated as much as 270° about the axis of the manipulator shaft 412. Such rotation is referred to as the Θ mode of operation. The manipulator shaft 412 is turned by the drive cable 69 drawn around and attached by bar 650 to the pulley 375 journaled on the short shaft 384. It is explained above that the rack 391 (FIG. 20) for the Θ mode drive cooperates with the piston 392 for controlling the pulley 375. The rack 391 and piston 392 are clamped at times when the Θ mode is not desired. When the gripper 45 is to be rotated, the rack 391 is then unclamped and the drive cable 69 is effective to rotate pulley 375 and a bevel gear 415, FIG. 24, attached to the underside of the pulley. This gear 415 meshes with another bevel pinion 416 which is mounted on a bushing 417 having a left portion extending through the end 435 of the X arm 38 and there engages one-half of a bellows-type coupling 419, the left half of which is pinned to the gripper shaft 412 by a pin 900. This bellows coupling 419 has a high spring constant. It is used for the vibratory, search mode of operation of the gripper end, as described more fully hereinafter.

It is shown in FIG. 23 that the gripper shaft 412 is hollow and at its right end 421 is connected with a flexible thin hollow tube 420 which also enters into the vibratory search mode of

operation of the gripper. This hollow tube 420 provides a fluid conduit into the gripper shaft 412 and through it into the cavity 422 in the housing 424. From cavity 422 another channel 423 carries the hydraulic pressure to a cavity 901 in the housing 424 for grip piston 408 to drive the wedge cam to the left.

With reference to FIG. 4, when the Θ mode rack is unclamped, it is possible to rotate the gripper 45 as illustrated by the angle Θ from a normal horizontal position, i.e., 0° to any angle between 0° and 270°.

Also FIG. 4 shows the directions of motion during the search mode of operation by means of a pair of lines 46. Lines 46 show that the gripper may be vibrated in two orthogonal directions to search for a mating position of two engaged parts one of which is held by the gripper and another of which is in a work station.

Referring back to FIG. 23 such longitudinal and transverse movements are actuated by hydraulic pistons whose motions are coupled to the gripper shaft 412. At the right end of FIG. 23 it is seen that the flexible shaft 420 passes through and is attached to longitudinal piston 436 within a chamber 425 served by hydraulic lines 426 and 427. In the transverse direction, two hydraulic plungers 429 and 430 are shown pressing against opposite sides of the gripper shaft 412. The plungers 429 and 430 are held within chambers 431 and 432 and connected by hydraulic lines 433 and 434 through which they are alternately operated by a transverse oscillator described below.

THE SEARCH DEVICES

In order to facilitate the insertion of, for example, a fastener (screw, rivet or pin) into a part supported opposite the gripper assembly 45, the manipulator shaft 412, FIG. 25, is simultaneously oscillated longitudinally at one frequency and transversely at a different frequency, each with an amplitude of .031 inches. It is during the searching mode of operation that a part such as the bolt 47, FIG. 2, may be held above the hole 49 in the workpiece 50 on the conveyor and vibrated to find coincidence with the hole. Since a manipulator to which the gripper is attached may be driven by a digital drive having as its smallest or minimum increment of displacement .031 inches, (unlike an analog drive), to locate parts more accurately the gripper has been adapted to scan or search for the desired position within the area .015 inches on all sides of a position automatically reached by the digital drive.

In FIG. 25 the dimensions of the actuators for providing such hydraulic vibratory movements are exaggerated. Also the actuators are shown in a schematic fashion to emphasize the characteristics of the search mode of operation. As the vibrated article encounters resistance as when it engages a hole in a supported part, the additional loading of the transverse and longitudinal hydraulic drive shown in FIG. 25 will result in an increase of frequency with a corresponding reduction in amplitude. The transverse search drive involves the opposing pistons 429 and 430 alternately pushing against the opposite sides of the gripper shaft 412. The longitudinal search drive is applied by piston 436 to the end of the flexible tube 421 to oscillate the gripper shaft 412 along its longitudinal axis. Beneath the search drive pistons 429, 430, and 436 shown in FIG. 25 are the hydraulic lines for connection to the hydraulic oscillating means. The longitudinal oscillator is in the upper section and the transverse oscillator is in the lower section.

The search drive circuits comprise two hydraulic oscillators with their respective delay pistons used as the drive for the gripper when in the search mode of operation. Since the two oscillators are similar, only the X oscillator will be described.

Assuming that the manipulator is stationary and that the gripper has been pressurized, by application of pressure through manifold 903, fluid under pressure will be applied at the line P from the converter. With the positions of the spools of longitudinal oscillator valves 438 and 446 as shown, fluid

under pressure will be directed to the ports 441 and 444. With the latch valve 438 and the longitudinal search piston 436 as shown in FIG. 25, the fluid pressure at the port 444 of latch valve 438 will affect the transfer of valve 446 to the left. This transfer causes fluid under pressure to appear at port 442. The area of the surface of the longitudinal search drive piston 436 exposed to hydraulic pressure as compared to its load mass is selected to require approximately half the fluid pressure, to displace it .030 inches, as compared with the pressure required to displace the piston 439 of the latch valve 438. When the search drive piston 436 reaches its maximum displacement the pressure in the channel 442 (which had been reduced by orifice 447 during motion of piston 436) will build up to almost maximum pressure. This is so because the flow through the orifice 447 to displace the latch valve 438 will, by then, have been reduced appreciably. Thus the pressure between latch piston 440 and latch valve 438 will become comparable to that on the right side of latch valve 438. Because the area of the right hand end of latch valve 438 exposed to that pressure is large compared to the area of latch valve 438 confronting piston 440, the total force on latch valve 438 will be directed leftward and latch valve 438 will shift to the left. With the transfer of the latch valve 438, the latch piston 439 will be pressurized through the port 442 driving the latch valve 438 to the left. The fluid now under pressure in the port 443 because of the leftward shift of latch valve 438 will restore the valve 446 to the right in the position shown, causing fluid under pressure from manifold 903 to appear at channel 441, restoring the longitudinal search drive piston 436 to the lower position shown. Again, the sudden reduction of fluid flow through the orifice 448 will allow the pressure to build up on the latch piston 440 of latch valve 438 and to transfer latch valve 438 to the right into the position shown.

Should the fastener supported by the gripper mate with the hole in the stationary part on the conveyor belt before the search piston 436 completes its stroke, then the piston 436 will be stalled and transfer of the valve 438 will occur sooner, because pressure will build up on line 426 or 427 and at port 441 or 442.

From the foregoing it is apparent that the longitudinal drive search piston 436 will be vibrated (reciprocated rapidly) until a part finds a mating arrangement and the searching operation is terminated immediately, by reduction of the amplitude of vibration to a very slight motion.

It is also apparent that a similar style of operation is effected when the two transverse search drive pistons 429 and 430 are considered as a single unit to be controlled by ports 442Y and 441Y in much the same way as the single unit longitudinal piston 436. The sole difference between the oscillators is that orifice sizes 447Y and 448Y may be selected for particular rates of operation. Accordingly, the specific description of the longitudinal oscillator applies to the transverse oscillator.

While the invention has been particularly shown and described with reference to a preferred embodiment thereof, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention.

I claim:

1. An article handling device comprising a plurality of arms, each arm movably connected on at least one end thereof to one of a plurality of joints operable for permitting an arm associated with each said joint to be displaced relative to said joint, whereby said arms are articulated, each of said joints including arresting means, control means for releasing said arresting means for each of said joints selectively in any desired sequence, at will, a single common drive system for reversibly urging displacement of opposite ends of said article handling device towards extension and retraction, said drive system being connected to each of said arms to exert simultaneous forces on all said arms for driving an arm in a joint having its arresting means released.

2. An article handling device comprising a plurality of elements connected by selectively releasable slidable joints, means for selectively releasing said slidable joints one at a time in any desired sequence, at will, a single common drive cable and pulleys secured to said elements for extending and retracting said article handling device by operation of each of said slidable joints one at a time.

3. A manipulator comprising in combination a plurality of elongated elements, means for articulation of said elements orthogonally to form an arm, a gripper secured to said arm, common driving and transmission means for mechanically linking said elements and said gripper simultaneously to urge motion of said elements and turning said gripper joints between said elements and said gripper, each of said joints including arresting means, and means for controlling said arresting means for said elements and said gripper to select which of said elements and said gripper is to be operated by releasing the arresting means associated therewith one at a time, said common drive and transmission means driving the selected one of said elements and said gripper at the joint having its arrested means released.

4. The manipulator described in claim 3 wherein said elements are of a hollow, square cross section.

5. A manipulator comprising in combination a plurality of elongated elements, means for slidable articulation of said elements orthogonally to form an arm, gripper means at one end of said arm, common driving means for said elements and said gripper means, means for controlling said elements and gripper to select which of said elements and gripper means is to be operated, and means for controlling the extent of displacement of said driving means, said elements being made from segments of construction grade, square cross section, common tubing having rounded corners and slidable within roller bearings supported on another of said elements.

6. A manipulator as described in claim 5 wherein said means for slidable articulation of said elements includes sets of rollers riding on the surface of said tubing along longitudinal lines adjacent to the rounded corners of said tubing.

7. A manipulator comprising in combination a plurality of elongated elements, means for slidable articulation of said elements orthogonally to form an arm, gripper means at one end of said arm, common driving means for said elements and said gripper means, means for controlling said elements and gripper to select which of said elements and gripper means is to be operated, and means for controlling the extent of displacement of said driving means, pulley means being associated with all of said elements and said gripper means and wherein said common driving means is a common drive cable passing through all of said pulley means for driving a selected one of said elements and said gripper means.

8. A manipulator comprising in combination a plurality of elongated elements, means for slidable articulation of said elements orthogonally to form an arm, gripper means at one end of said arm, common driving means for said elements and said gripper means, means for controlling said elements and gripper to select which of said elements and gripper means is to be operated, and means for controlling the extent of displacement of said driving means, and a plurality of detenting means for holding each of said elements and said gripper means in an adjusted position whereby release of any single one of said detenting means permits the actuation of only the selected one of the elements and the gripper means, said driving means being numerically controlled.

9. The manipulator described in claim 8 including a programming means for determining by signal transmission the order in which said detenting means are released.

10. A manipulator as described in claim 9 wherein said programming means acts in cooperation with said means for controlling the extent of displacement of said driving means to determine the order in which said elements and gripper are to be operated and the extent to which each is to be displaced.

11. The manipulator described in claim 10 wherein said programming means comprises an endless control tape for producing continuous repetitions of the sequence of operation of the manipulator.

12. The manipulator described in claim 9 including a manual control means for preparing said programming means for operation.

13. A manipulator comprising in combination a plurality of elongated elements, means for slideable articulation of said elements orthogonally to form an arm, gripper means at one end of said arm, common driving means for said elements and said gripper means, means for controlling said elements and gripper to select which of said elements and gripper is to be operated, and means for controlling the extent of displacement of said driving means, a plurality of detenting means for holding each of said elements and said gripper means in an adjusted position whereby release of any single one of said detenting means permits the actuation of only the selected one of the elements and the gripper means, said driving means being numerically controlled, programming means for determining by signal transmission the order in which said detenting means are released, said programming means acting in cooperation with said means for controlling the extent of displacement of said driving means to determine the order in which said elements and gripper are to be operated and the extent to which each is to be displaced, said programming means comprising an endless control tape for producing continuous repetitions of the sequence of operation of the manipulator, said endless tape is a perforated paper tape perforated with a series of sets of three characters of perforations for selecting a mode of operation of the manipulator, the integral value of the extent of displacement and the fractional value of the extent of displacement.

14. The manipulator described in claim 13 including a manual control means with mode, integer, and fraction controls for preparing the program tape to receive a series of characters representing mode, integral and fractional binary values.

15. A manipulator comprising in combination a plurality of elongated elements, means for slidably articulation of said elements orthogonally to form an arm, gripper means at one end of said arm, common driving means for said elements and said gripper means, means for controlling said elements and gripper to select which of said elements and gripper means is to be operated, and means for controlling the extent of displacement of said driving means, and a vibrating means connected to vibrate said gripper means longitudinally and transversely until an object held by said gripper is located in a position of engagement thereby restraining said vibration.

16. A manipulator for grasping and positioning a part for parts assembly purposes, said manipulator being adapted to shift the grasped part along three orthogonal axes to sweep about a base and to twist,

said manipulator having a plurality of adjustably related arm elements, with the distal one of said elements terminating in a gripper pivotally joined thereto,

means for selectively adjusting the position of any of said elements and the gripper;

means for operating the gripper to grasp a part;

means for controlling the extent of movement of a selected element and the twisting movement of said gripper;

means for sweeping said manipulator in its entirety;

means for vibrating said gripper in a transverse plane;

each of said arm elements being slidably carried in one of a plurality of joints having a hollow opening and a plurality of rollers secured thereto for providing a slidable, stable longitudinal degree of freedom for each of said arm elements,

each of said joints including finely machined detent members having a plurality of machined positions for

providing highly accurate final location of each said element in its corresponding one of said joints, at least one of said joints being secured to the end of an arm element.

17. An articulated manipulator for conveying and positioning workpieces, a vertical support with a vertically movable Z arm, a horizontally oriented support on said Z arm movably supporting a Y arm, a support on said Y arm movably supporting an X arm, a gripper rotatably supported on the end of said X arm, a detent means for each of said supports and said gripper and means for operating and releasing the same, a single common cable and pulley mechanism for displacing any of said arm sections and said rotatable gripper, when the detent means associated therewith is released, and a numerically controlled arithmetic drive means for driving the cable and pulley mechanism.

18. An articulated manipulator for conveying and positioning workpieces, a vertical support with a vertically movable Z arm, a horizontally oriented support on said Z arm movably supporting a Y arm, a support on said Y arm movably supporting an X arm, a gripper rotatably supported on the end of said X arm, a detent means for each of said supports and said gripper and means for operating and releasing the same, cable and pulley mechanism for displacing any of said arm sections and said rotatable gripper, when the detent means associated therewith is released, and an arithmetic drive means for driving the cable and pulley mechanism, each of said arms comprising:

a length of standard square hollow tubing and said supports therefor comprise,

sets of rollers riding on the surface of axial lines adjacent the rounded tubing corners.

19. A manipulator for grasping and positioning characterized by having:

a plurality of adjustably related arm elements with one of said elements having a gripper which is pivotally mounted thereon;

joints between said elements and said gripper, each of said joints including arresting means,

means for operating said gripper to grasp;

means for selecting which of said arm elements and the gripper is to be adjusted one at a time; and

common drive and transmission means mechanically linking all of said elements and said gripper for concurrently urging motion of all of said elements and said gripper and means for controlling said arresting means for allowing the driving of the selected one of said elements and said gripper one at a time in the joint associated with said selected one.

20. A manipulator comprising a plurality of elongated elements,

means for slidably relating said elements to form an arm adjustable in three orthogonally related planes,

a gripper means on one element of said arm,

means for selecting among said elements and gripper which one thereof is to be operated, and

a numerically controlled endless drive cable common to all of said elements and said gripper for reversibly adjusting each selected one of said elements and said gripper.

21. A positioner including a plurality of elements, joints between said elements, each of said joints including arresting means and means for controlling said arresting means for selectively releasing said arresting means one at a time, an arithmetic drive unit, a transmission means, connected to said drive unit, said transmission means mechanically linking said elements to concurrently urge motion of said elements for selective operation upon each of said elements one at a time driving release of the arresting means in the joint associated therewith.