United States Patent

[11] 3,550,630

[72] Inventor **Hugo A. Panissidi**
Peekskill, N.Y.

[21] Appl. No. **695,139**
[22] Filed **Jan. 2, 1968**
[45] Patented **Dec. 29, 1970**
[73] Assignee **International Business Machines Corporation**
Armonk, N.Y.
a corporation of New York

[54] **SERIAL-TO-PARALLEL HYDRAULIC DEVICE**
10 Claims, 27 Drawing Figs.

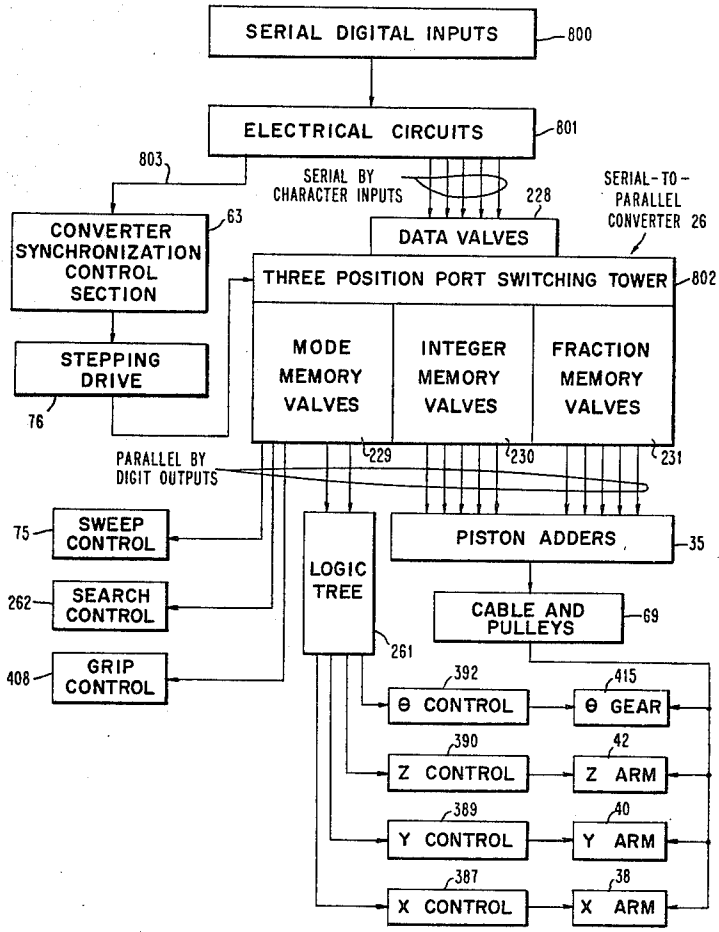
[52] **U.S. Cl.** **137/624.18,** 91/35
[51] **Int. Cl.** **F15b 21/02,** G05b 19/00
[50] **Field of Search** ..... 91/37(Cursory), 38, 35, 36, 37; 214/70, 1B, 1B2—4, 1BS1—4; 251/3; 137/624.11, 624.18, 624.2, 635

[56] **References Cited**
UNITED STATES PATENTS

3,072,146	1/1963	Gizeski	137/552
3,198,084	8/1965	Hague et al.	91/37X
3,156,157	11/1964	Smith	235/201X
3,198,084	8/1965	Hague	91/37

Primary Examiner—Alan Cohan
Attorneys—Hanifin and Jancin and Graham S. Jones II

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.



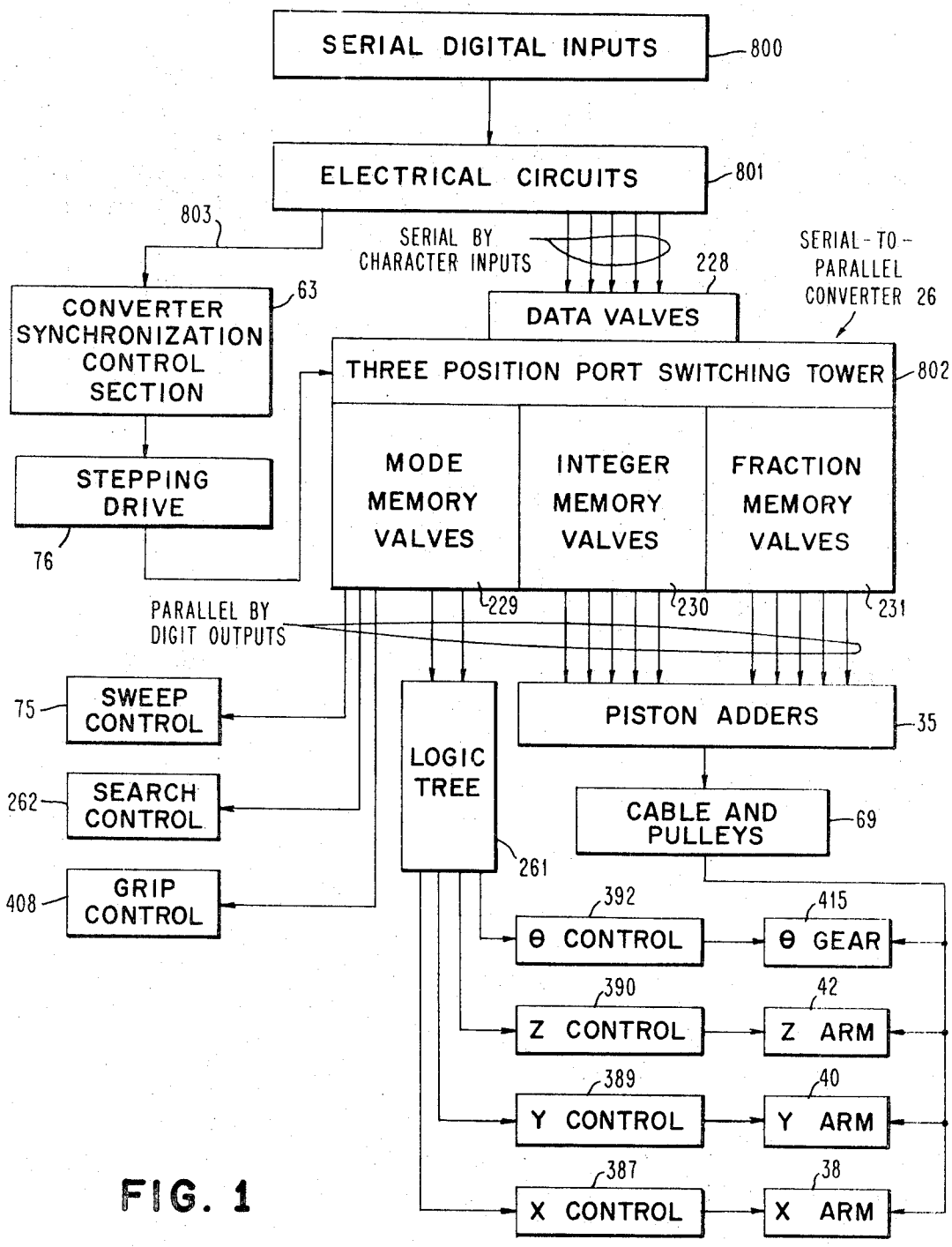


FIG. 1

INVENTOR
HUGO A. PANISSIDI

BY Graham S. Jones, II
ATTORNEY

FIG. 2

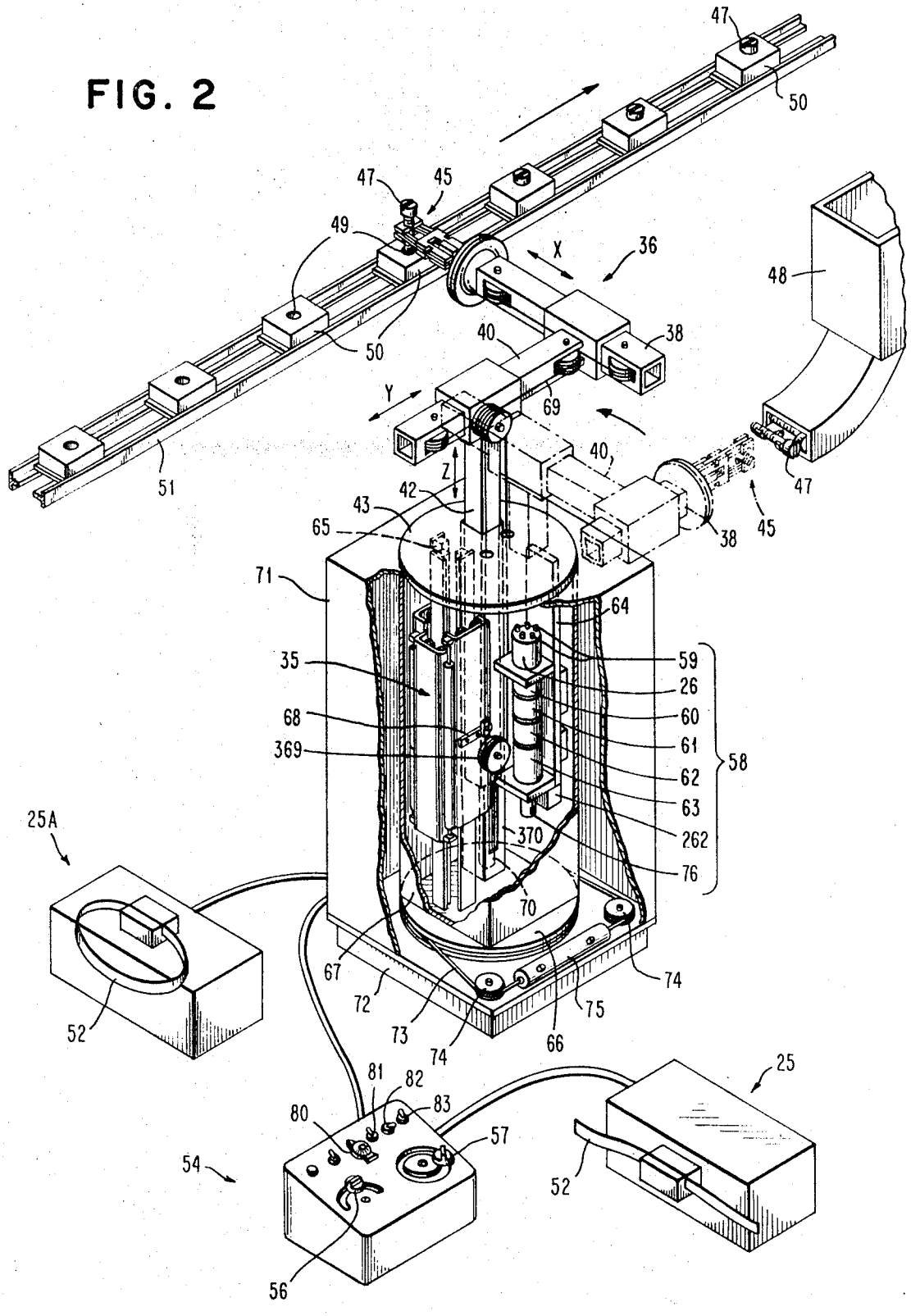
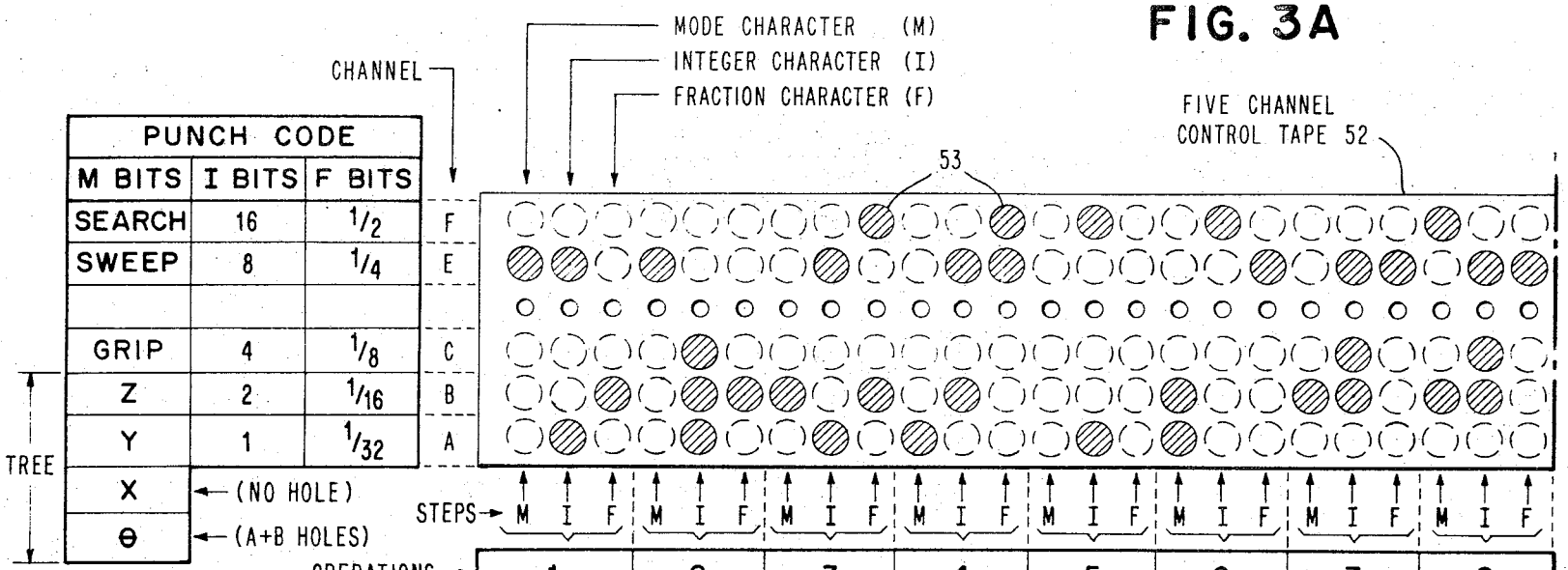

47
50
47
45
49
X
36
48
50
40
38
Y
69
40
Z
42
43
65
51
47
45
38
71
64
35
59
26
68
60
369
61
62
58
63
262
370
76
25A
70
67
74
72
75
73
66
74
52
81
82
25
80
83
57
54
52
56

FIG. 3A



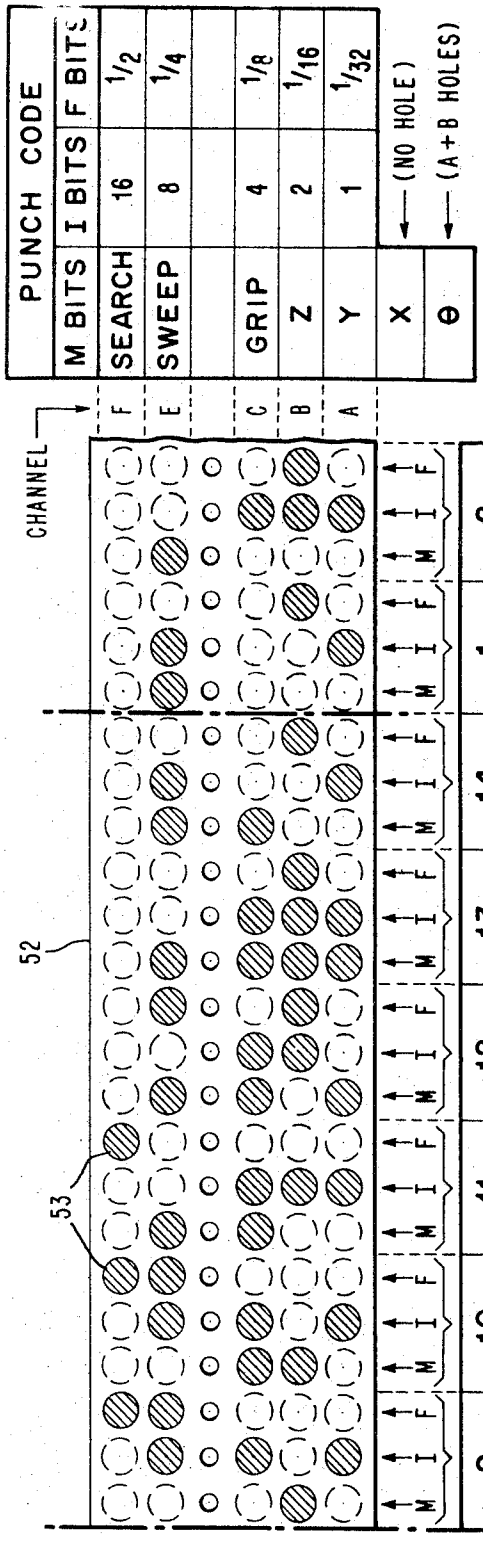
MODE COMPONENT DISPLACEMENT CHART

OPERATIONS →	1	2	3	4	5	6	7	8
SEARCH	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON
SWEEP	IN	IN	OUT	OUT	OUT	OUT	OUT	OUT
GRIP	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED
Z	0	0	$2\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
Y	$4\frac{5}{16}$	$4\frac{5}{16}$	$4\frac{5}{16}$	$5\frac{1}{2}$	$5\frac{1}{2}$	$5\frac{1}{2}$	$5\frac{1}{2}$	$5\frac{1}{2}$
X	4	2	2	2	$8\frac{1}{4}$	$8\frac{1}{4}$	$8\frac{1}{4}$	$8\frac{1}{4}$
Θ	(90°) $\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	0	0	0
TOTAL	$9\frac{1}{16}$	$7\frac{1}{16}$	$9\frac{9}{16}$	$10\frac{3}{4}$	17	$16\frac{1}{4}$	$14\frac{1}{4}$	$14\frac{1}{4}$

FIG. 3

FIG.3A	FIG.3B

FIG. 3B



9	10	11	12	13	14	1	2	SEARCH
OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	SEARCH
OUT	OUT	IN	IN	IN	IN	IN	IN	SWEEP
CLOSED	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSED	CLOSED	GRIP
0	0	0	0	0	0	0	0	Z
5 1/2	5 1/2	5 1/2	4 5/16	4 5/16	4 5/16	4 5/16	4 5/16	Y
8 1/4	8 1/4	2	2	2	4	4	2	X
0	0	0	0	3/4	3/4	3/4	3/4	Θ
13 3/4	13 3/4	7 1/2	6 5/16	7 1/16	9 1/16	9 1/16	7 1/16	TOTAL

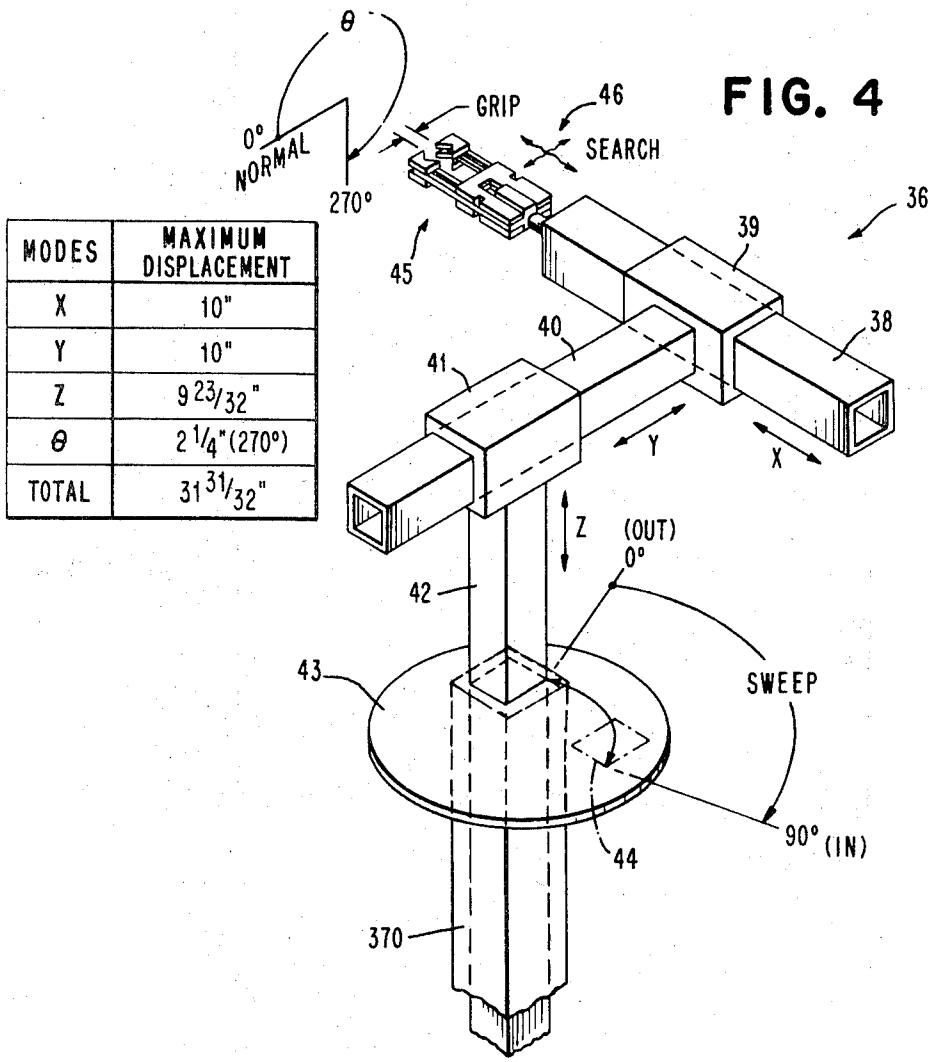


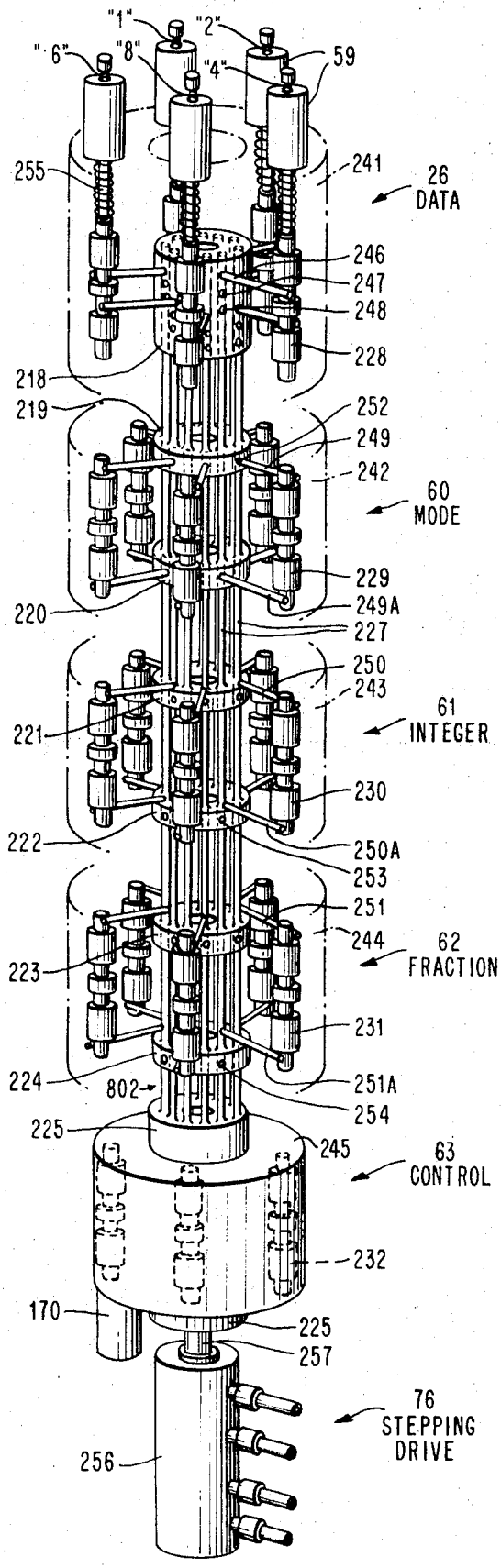
FIG. 4

MODES	MAXIMUM DISPLACEMENT
X	10"
Y	10"
Z	$9\frac{23}{32}$"
θ	$2\frac{1}{4}$"(270°)
TOTAL	$31\frac{31}{32}$"

FIG. 5

CONVERSION CHART FOR θ MODE (θ = Y + Z)	
θ DISPLACEMENT IN DEGREES	PUNCH CODE FOR I & F HOLES
$3\frac{3}{4}$°	$\frac{1}{32}$"
$7\frac{1}{2}$°	$\frac{1}{16}$"
$11\frac{1}{4}$°	$\frac{1}{32}$" + $\frac{1}{16}$"
$266\frac{1}{4}$°	2" + $\frac{1}{32}$" + $\frac{1}{16}$" + $\frac{1}{8}$"
270°	2" + $\frac{1}{4}$"

FIG. 6


"1"
"2"
"6"
"8"
"4"
59
58
255
241
26
DATA
246
247
248
228
218
219
252
249
242
60
MODE
229
220
249A
227
250
243
61
INTEGER
221
230
222
250A
253
251
244
62
FRACTION
223
231
224
802
251A
254
225
245
63
CONTROL
232
170
225
257
76
STEPPING
DRIVE
256

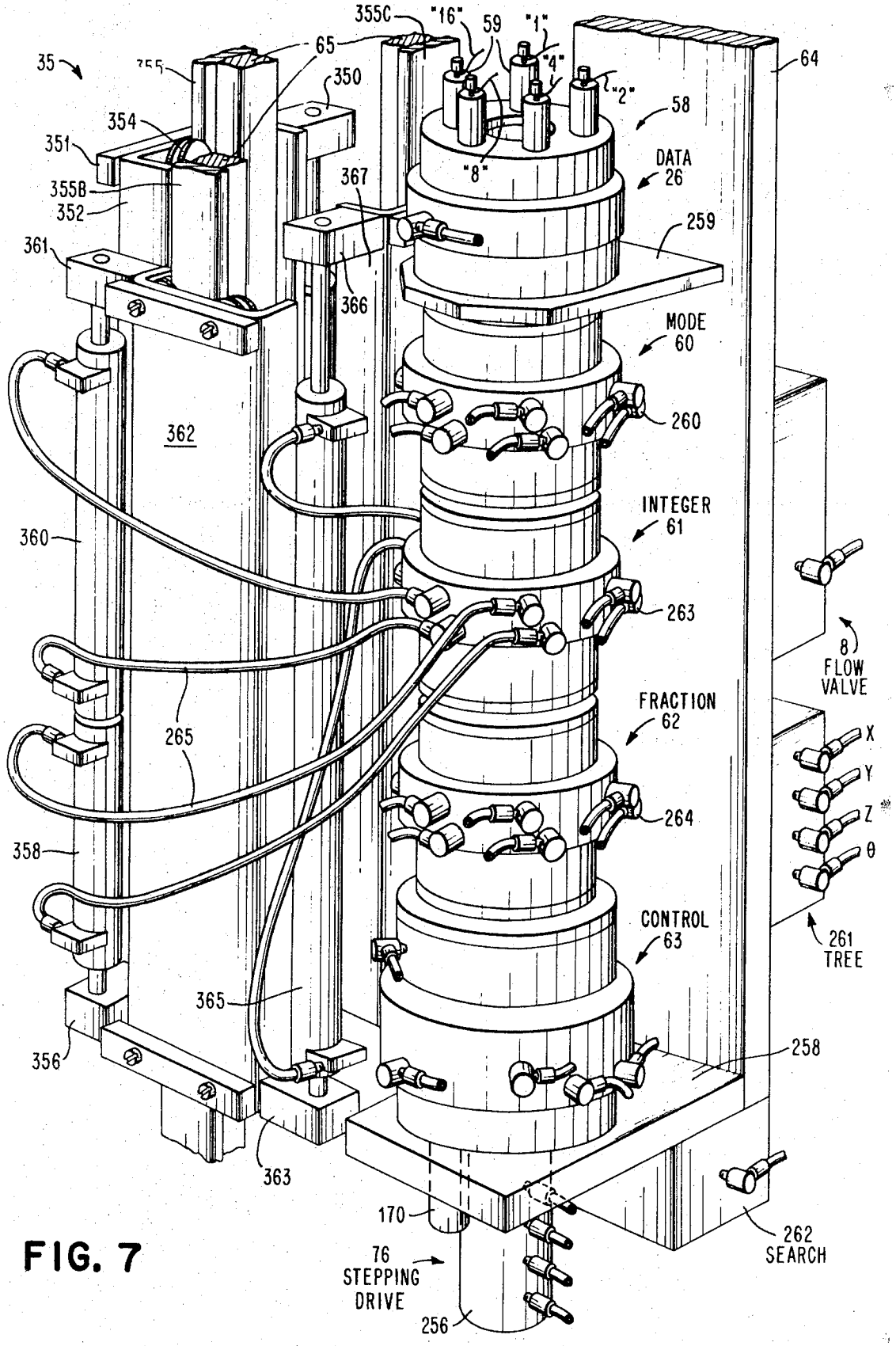

355C
"16"
59
"1"
"4"
"2"
"8"
65
35
350
354
351
355B
352
361
367
366
362
360
265
358
365
356
363
170
76
STEPPING
DRIVE
256
64
58
DATA
26
259
MODE
60
260
INTEGER
61
263
FRACTION
62
264
CONTROL
63
258
262
SEARCH
8
FLOW
VALVE
X
Y
Z
θ
261
TREE

FIG. 7

FIG. 8

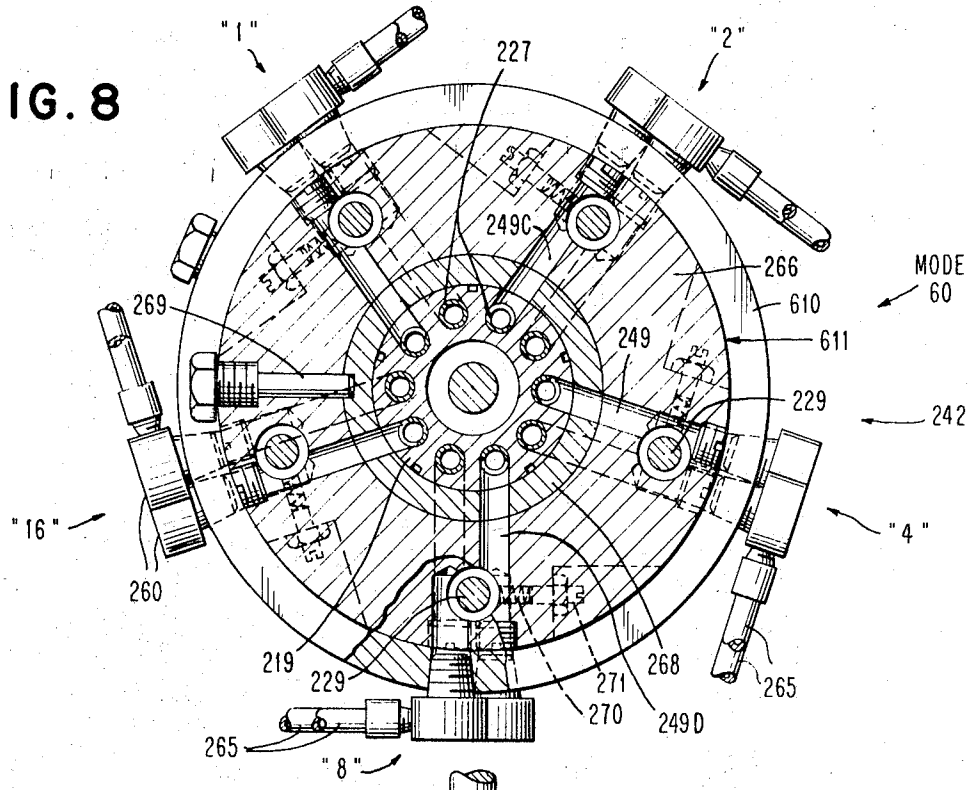

"1"
227
"2"
249C
266
MODE
60
610
611
269
249
229
242
"16"
"4"
260
219
229
271
268
265
270
249D
265
"8"

FIG. 9

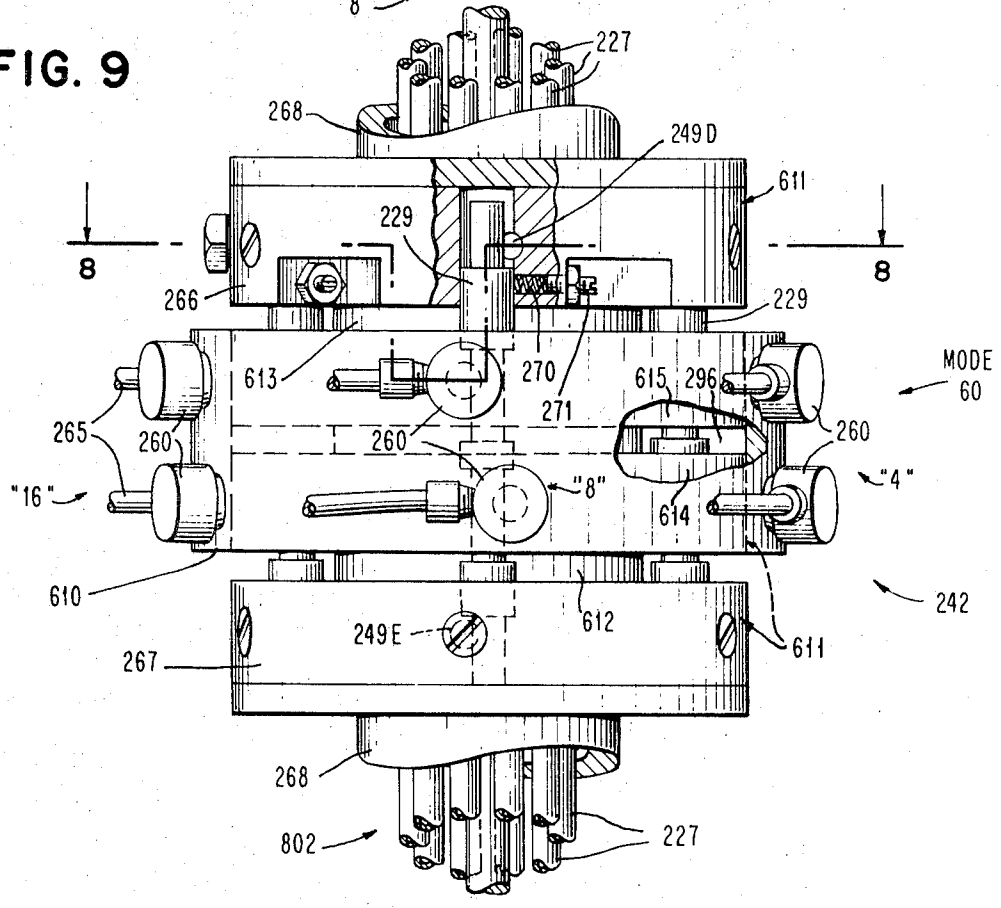

227
268
249D
611
229
8
8
266
229
MODE
60
613
270
615
296
271
265
260
260
260
"16"
"8"
"4"
614
610
242
612
249E
611
267
268
802
227

FIG. 10

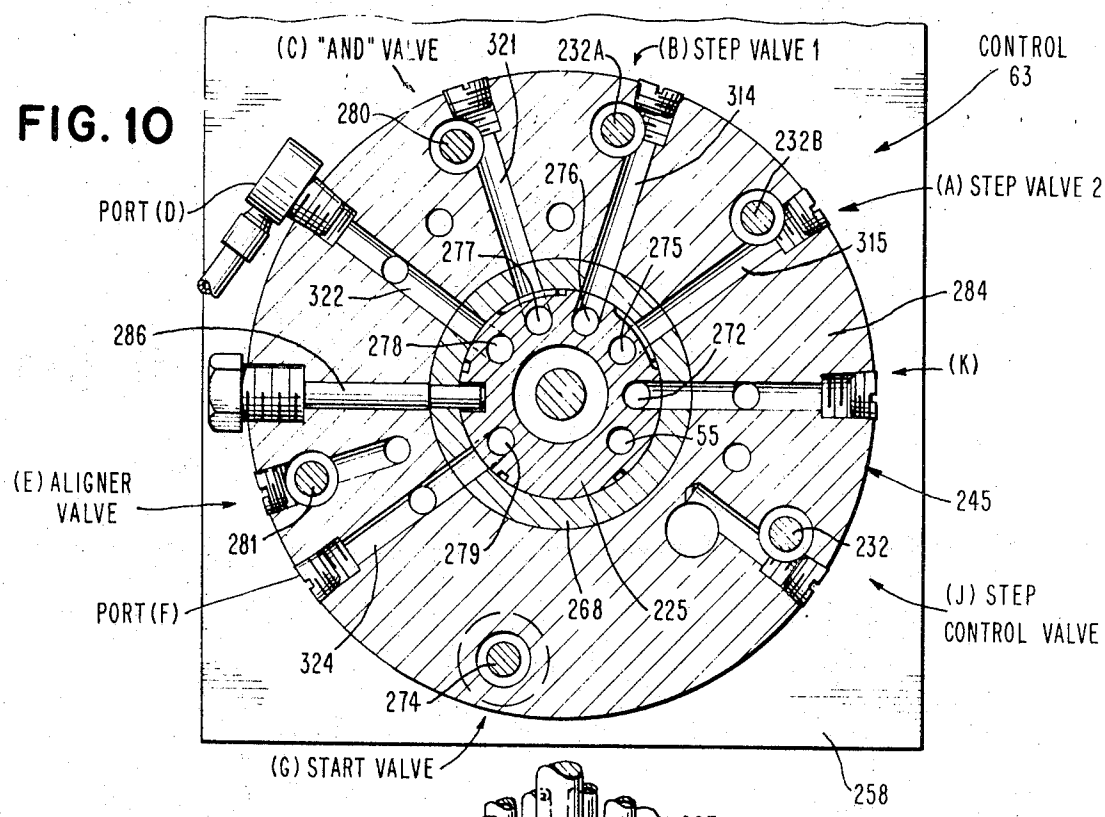

(C) "AND" VALVE
321
232A
(B) STEP VALVE 1
CONTROL
63
280
314
232B
276
(A) STEP VALVE 2
PORT (D)
277
275
315
322
284
286
278
272
(K)
55
(E) ALIGNER
VALVE
245
281
279
232
(J) STEP
CONTROL VALVE
PORT (F)
268
225
324
274
(G) START VALVE
258

FIG. 11

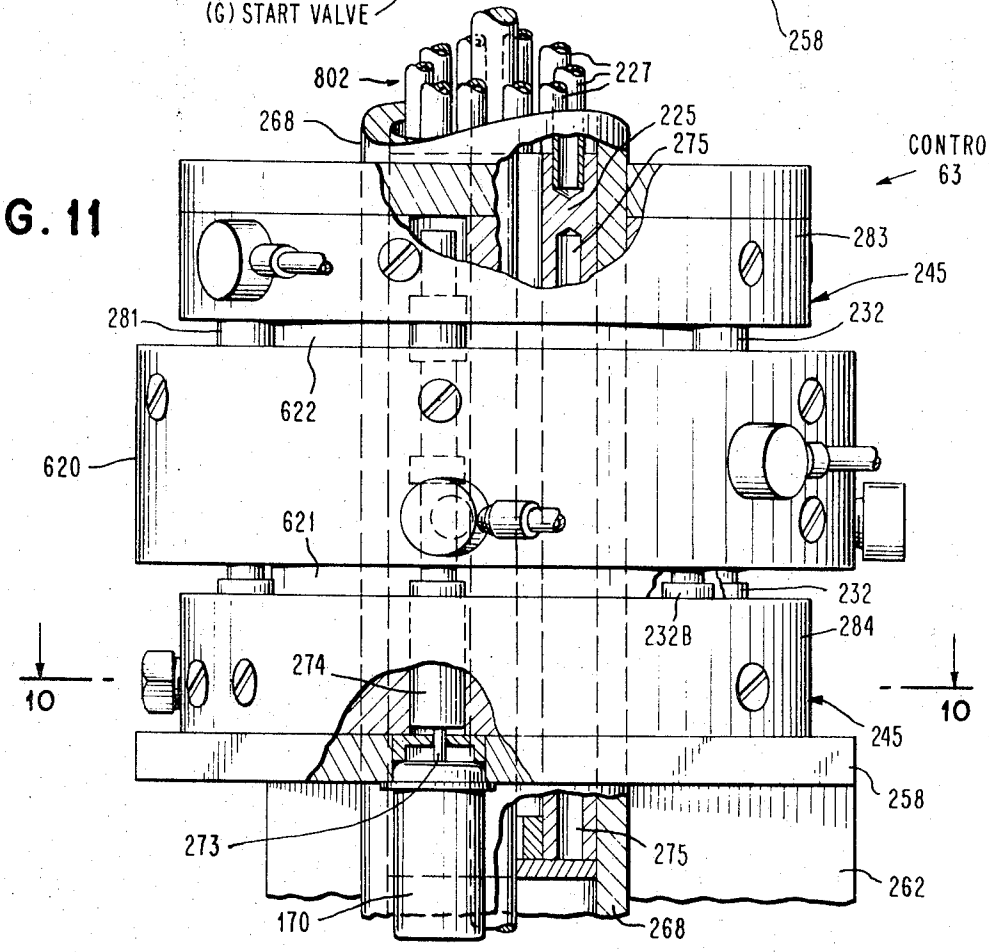

802
227
268
225
275
CONTROL
63
283
245
281
232
622
620
621
232
232B
284
274
10
10
245
258
273
275
262
170
268

FIG. 12

PISTON ADDERS AT ZERO

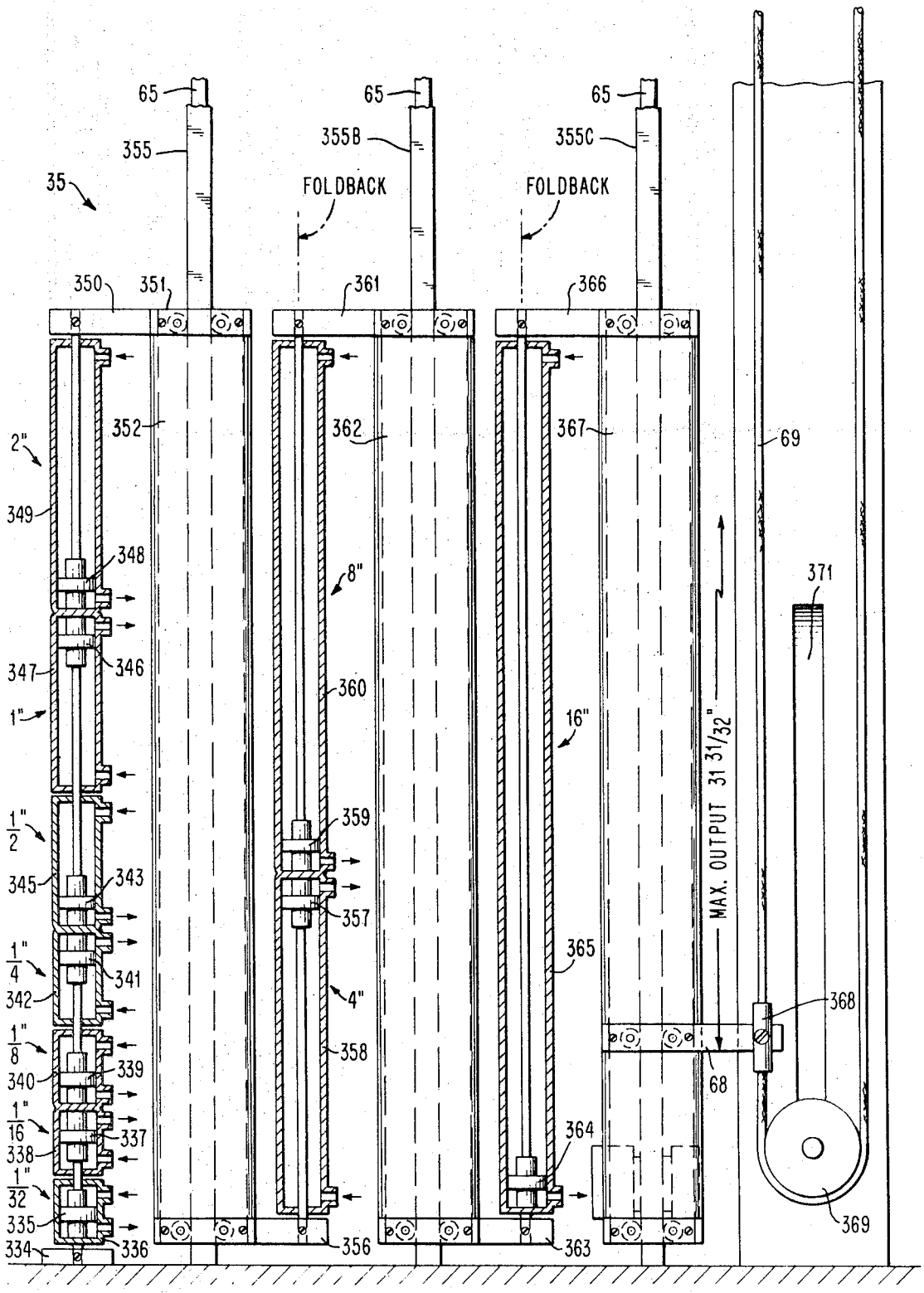
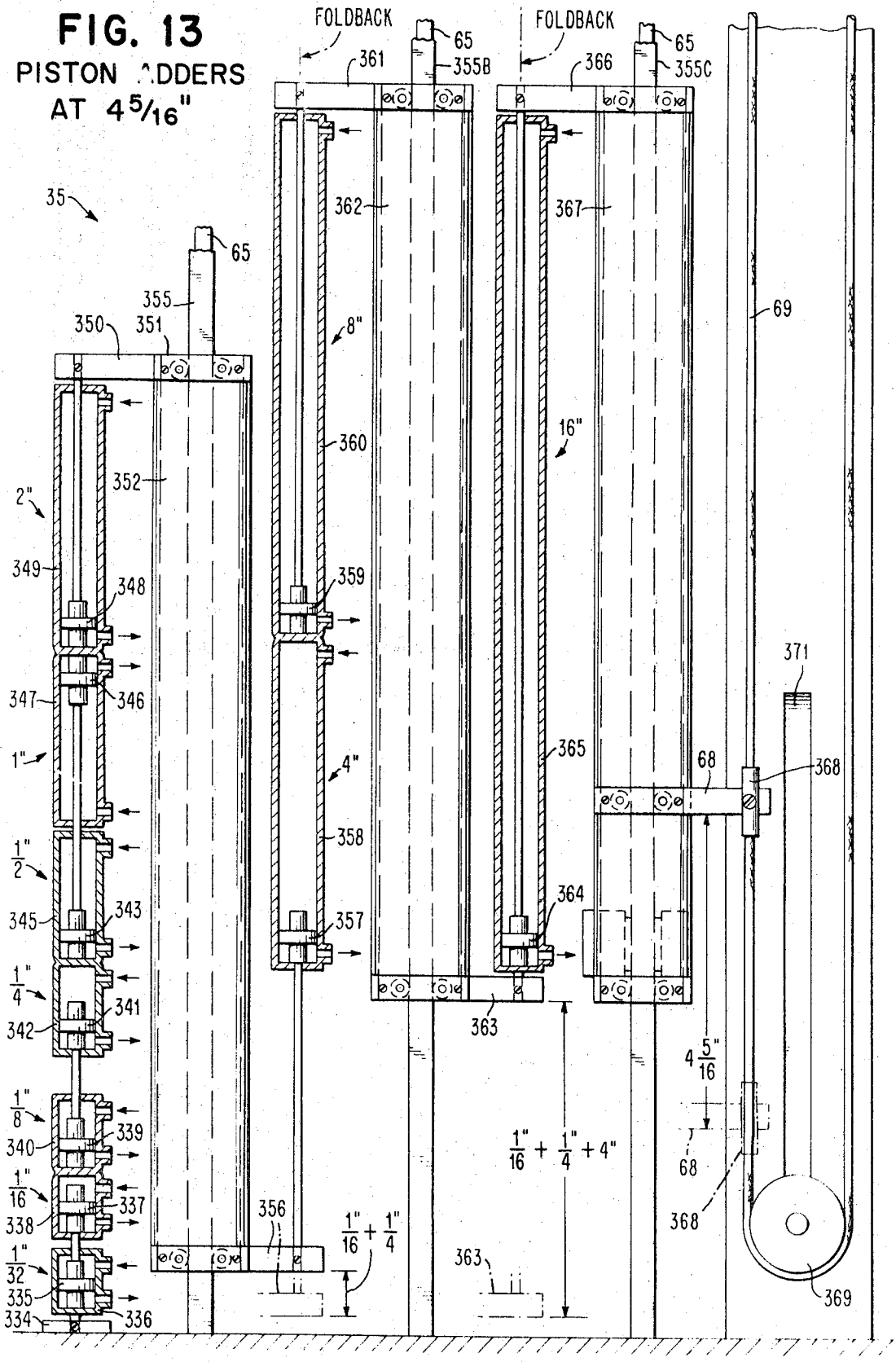


FIG. 13
PISTON ADDERS AT 4 5/16"



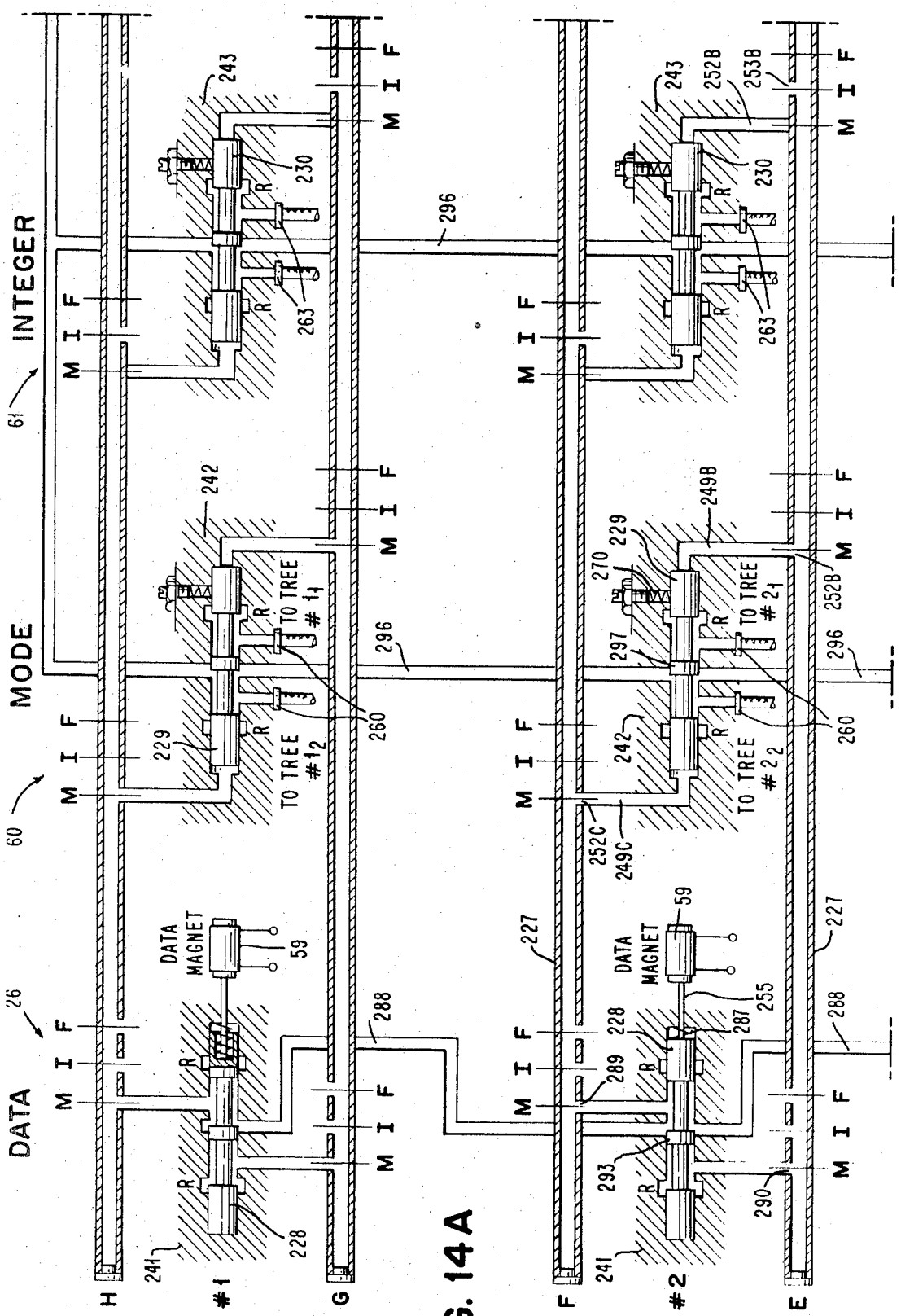

DATA
INTEGER
MODE
MIF
TO TREE #11
TO TREE #12
TO TREE #21
TO TREE #22
DATA MAGNET
#1
#2
H
G
F
E

FIG. 14A

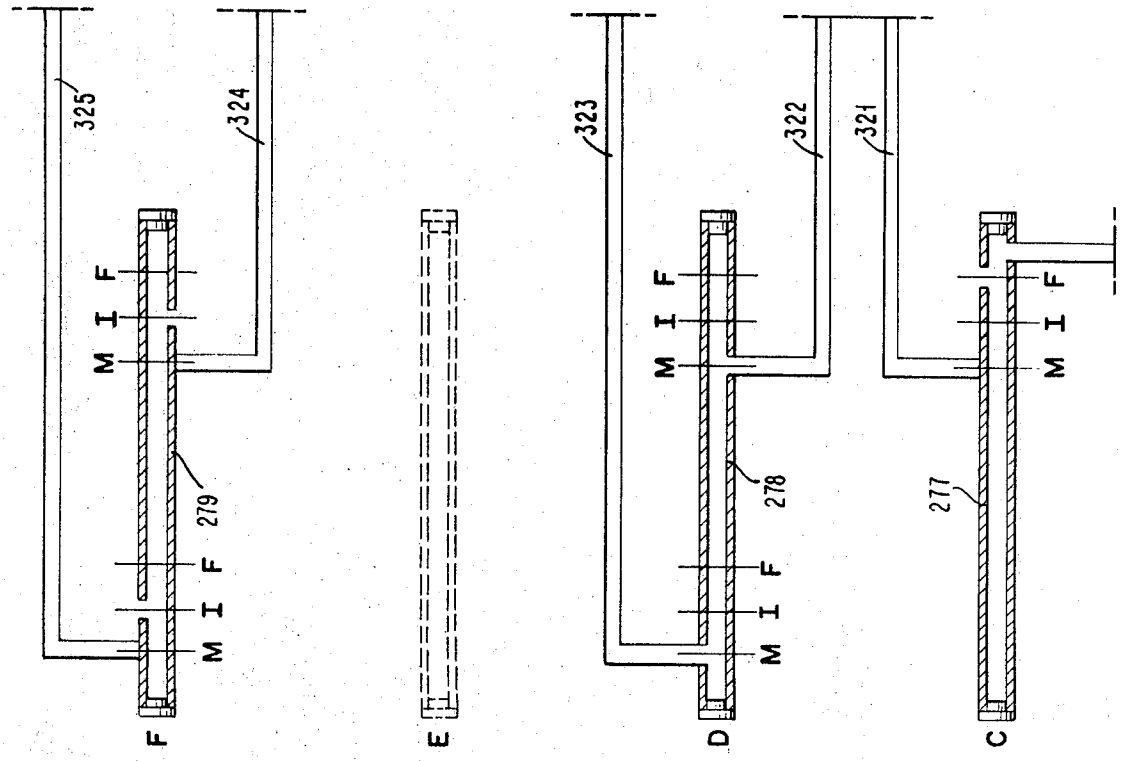
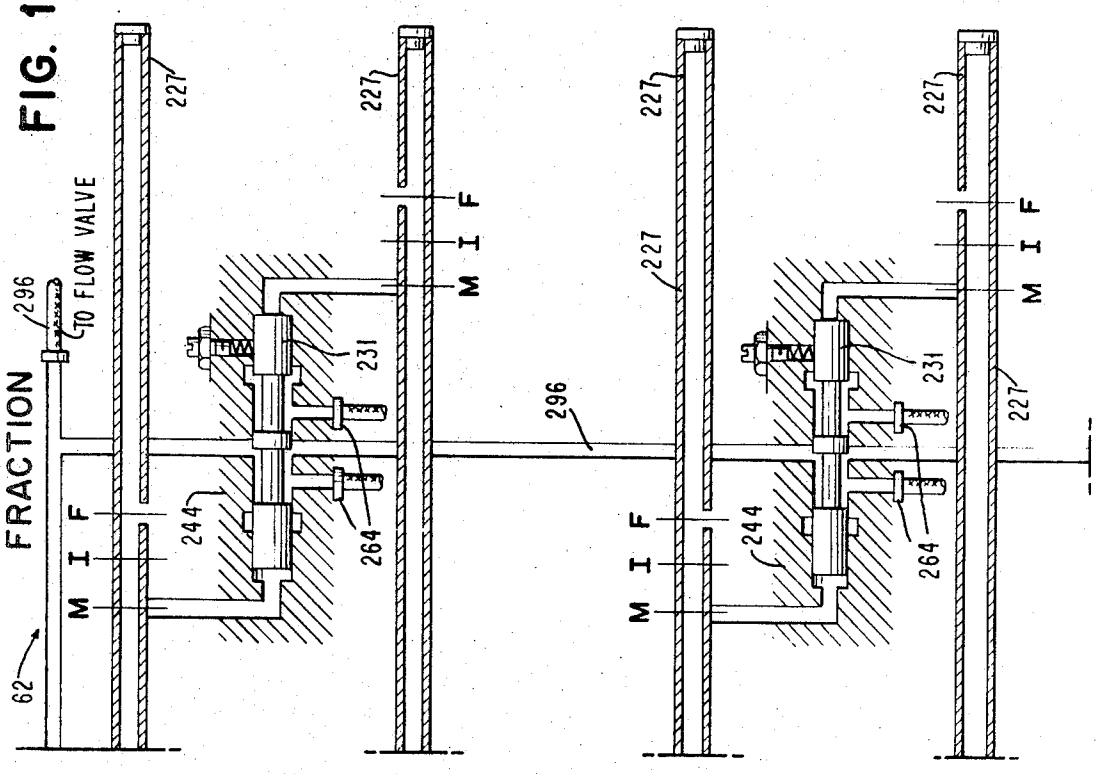

325
324
M I F
279
M I F
F
E
323
322
321
M I F
278
M I F
D
277
C
M I F

FIG. 14B


FRACTION
296
TO FLOW VALVE
227
227
227
227
227
M I F
M I F
M I F
231
231
244
244
264
264
296
62

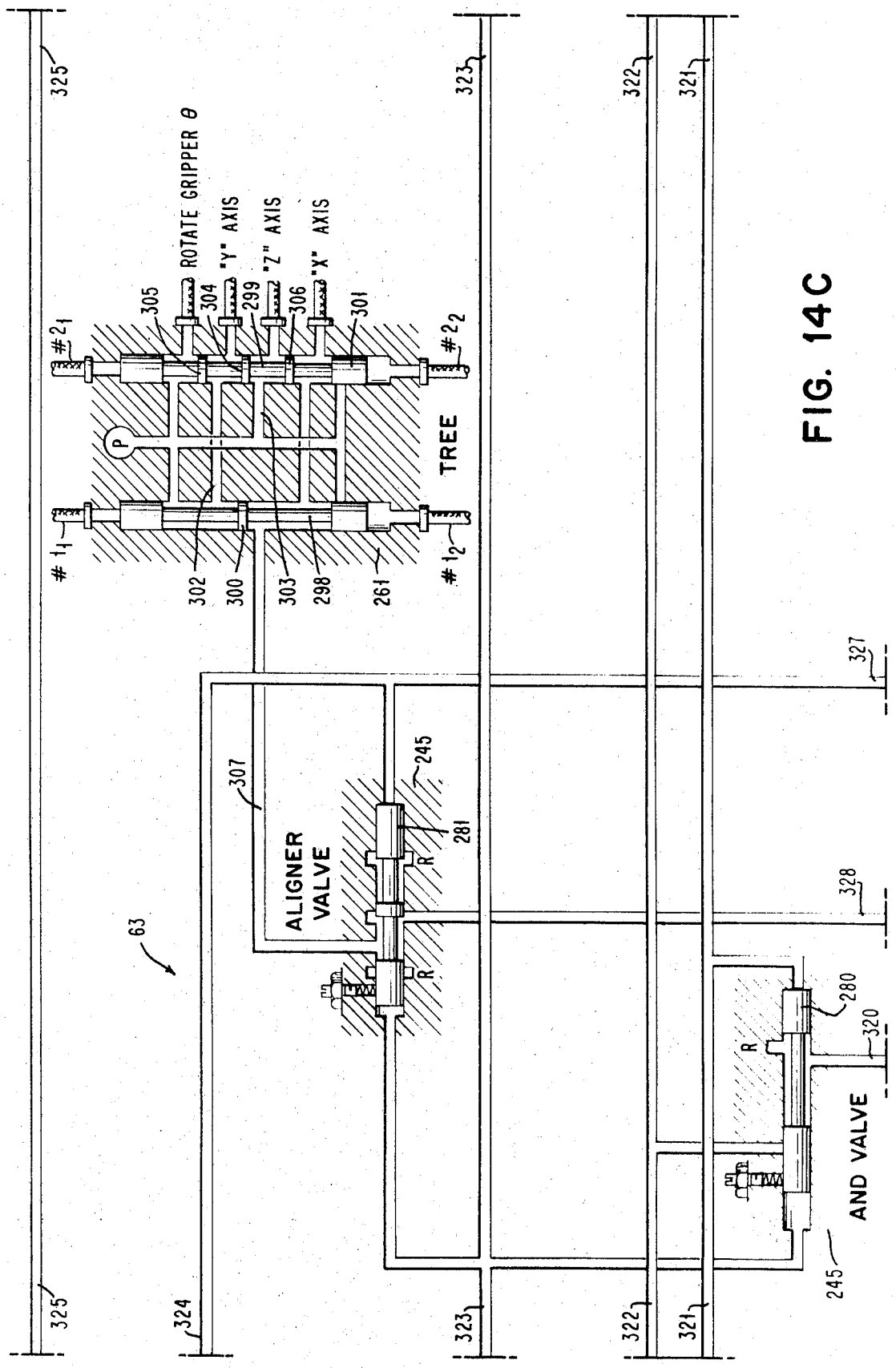
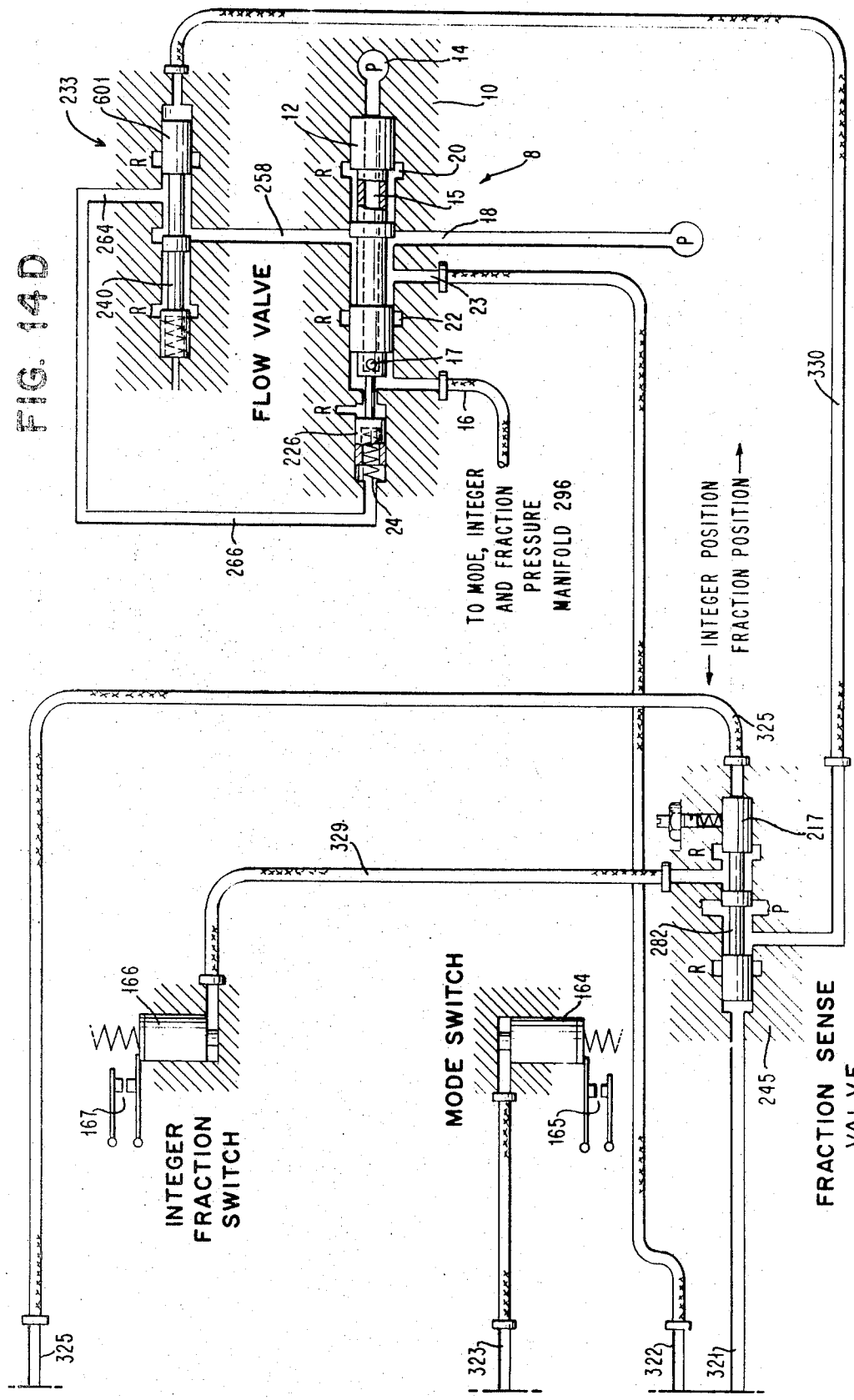

325
323
322
321
ROTATE GRIPPER θ
"Y" AXIS
"Z" AXIS
"X" AXIS
305
304
299
306
301
#2₁
#2₂
#1₁
#1₂
TREE
302
300
303
298
261
307
ALIGNER VALVE
245
281
63
327
328
280
320
AND VALVE
324

FIG. 14C

FIG. 14D


233
601
258
264
240
FLOW VALVE
266
226
24
12
14
10
20
8
15
18
22
23
17
16
TO MODE, INTEGER AND FRACTION PRESSURE MANIFOLD 296
330
INTEGER POSITION
FRACTION POSITION
325
329
217
282
245
FRACTION SENSE VALVE
166
167
INTEGER FRACTION SWITCH
164
165
MODE SWITCH
323
322
324
325

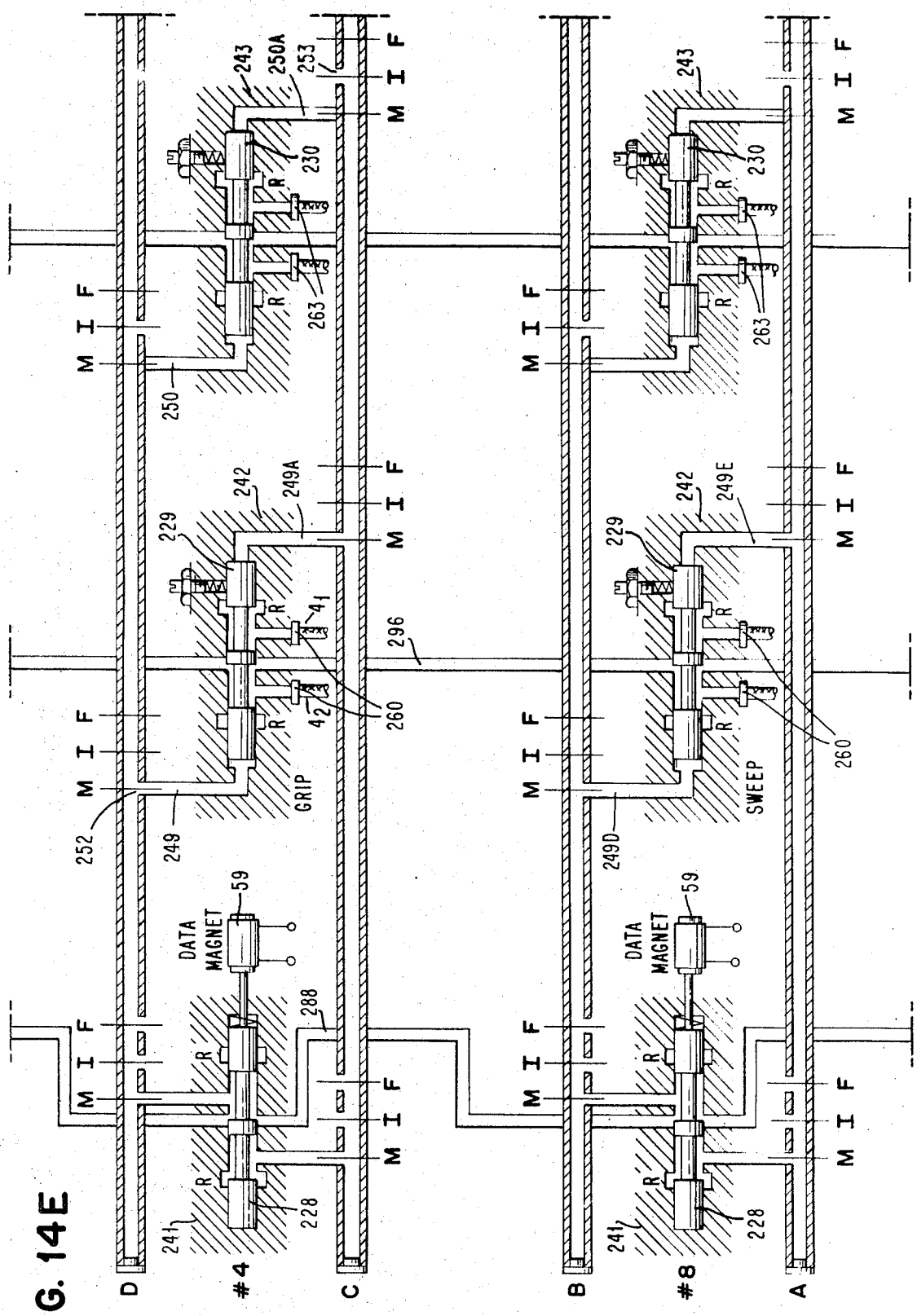

M I F
243
250A
253
230
R
263
250
242
249A
229
41
42
260
296
GRIP
252
249
DATA MAGNET
59
288
241
228
#4
D
C
249E
SWEEP
249D
#8
B
A

FIG. 14E

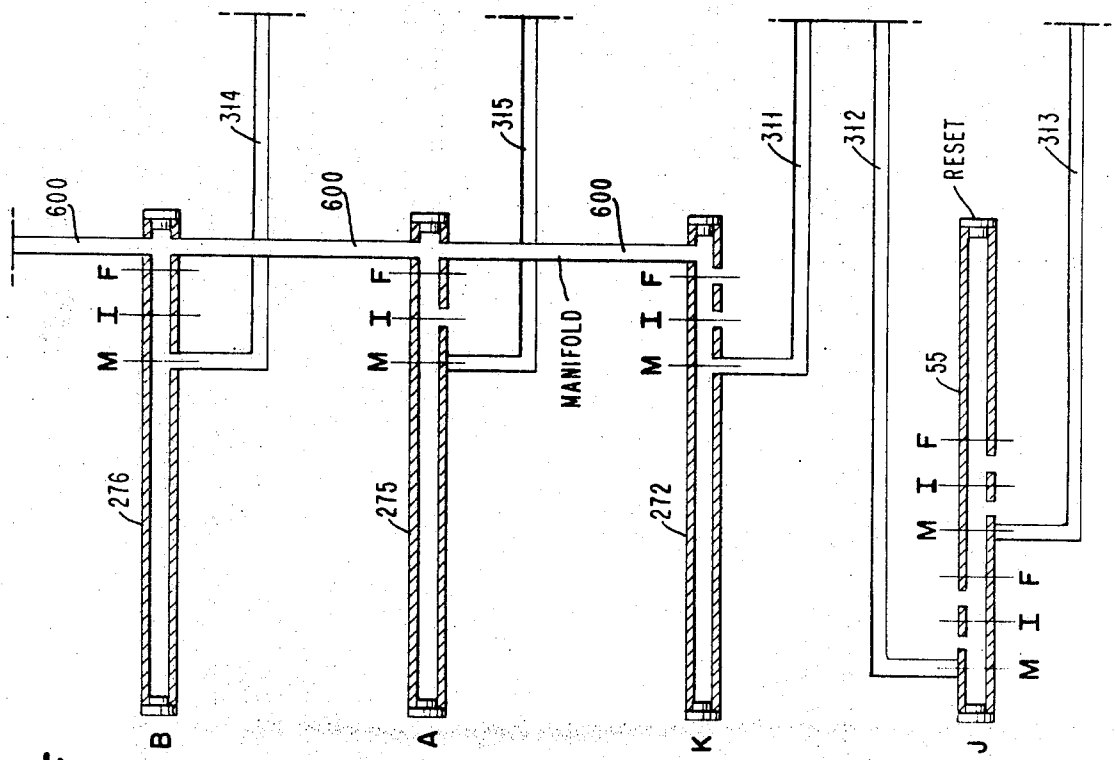
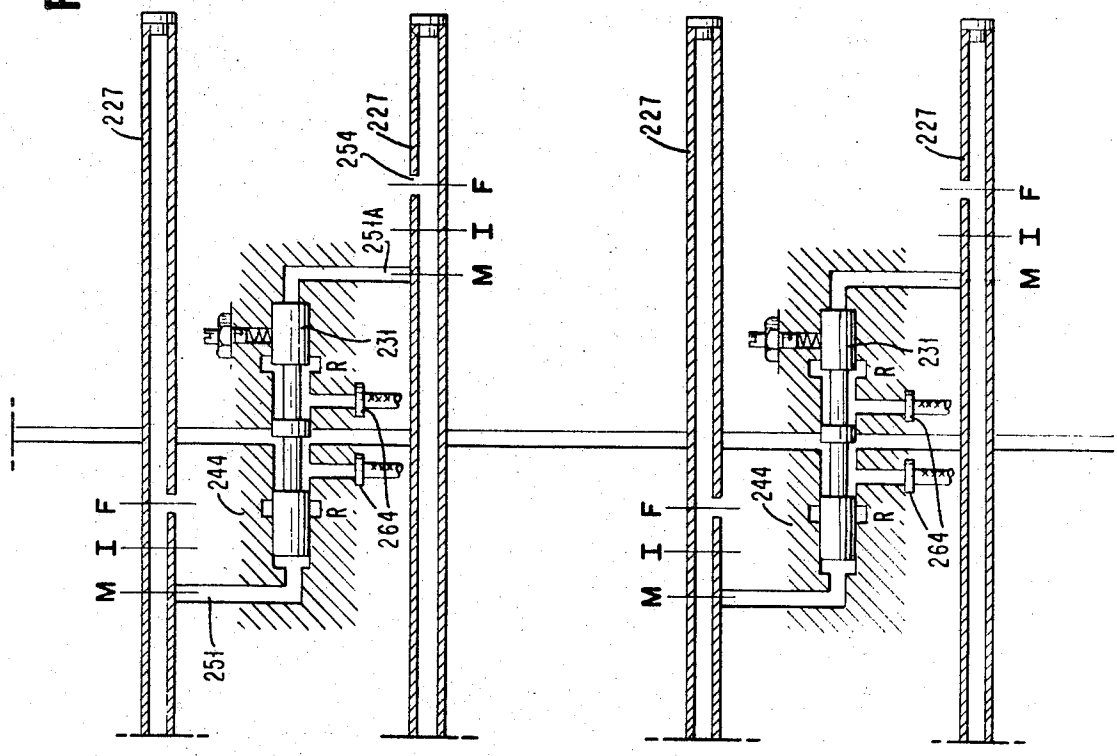

600
600
600
314
315
311
312
313
RESET
MANIFOLD
MIF
MIF
MIF
MIF
MIF
276
275
272
55
B
A
K
J

FIG. 14F


227
227
254
251A
MIF
231
R
244
264
251
MIF
227
MIF
227
MIF

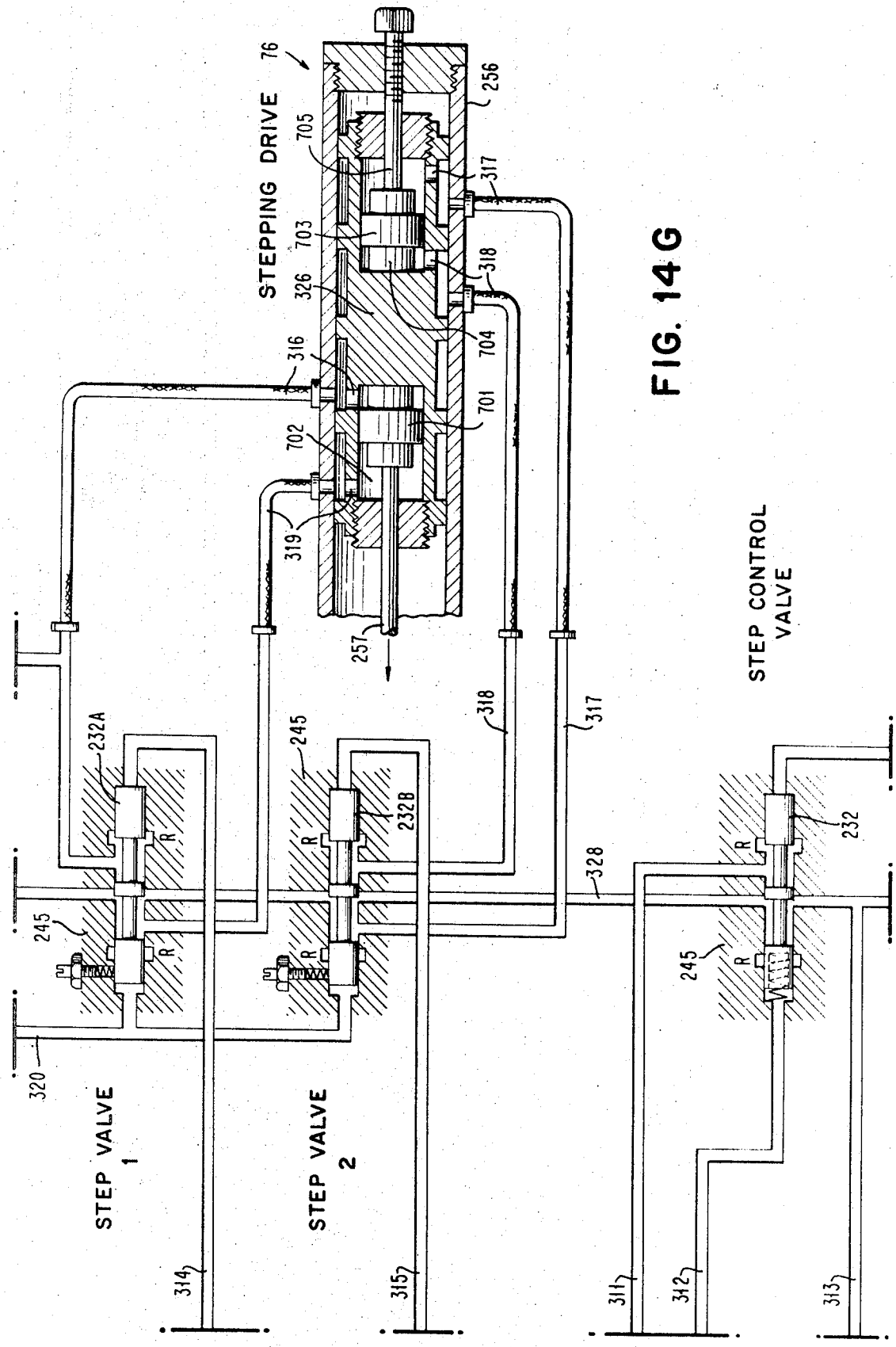

STEPPING DRIVE
76
256
705
317
703
318
326
704
316
701
702
319
257
318
317
232A
245
232B
328
232
245
245
320
STEP VALVE 1
STEP VALVE 2
STEP CONTROL VALVE
314
315
311
312
313
R

FIG. 14G

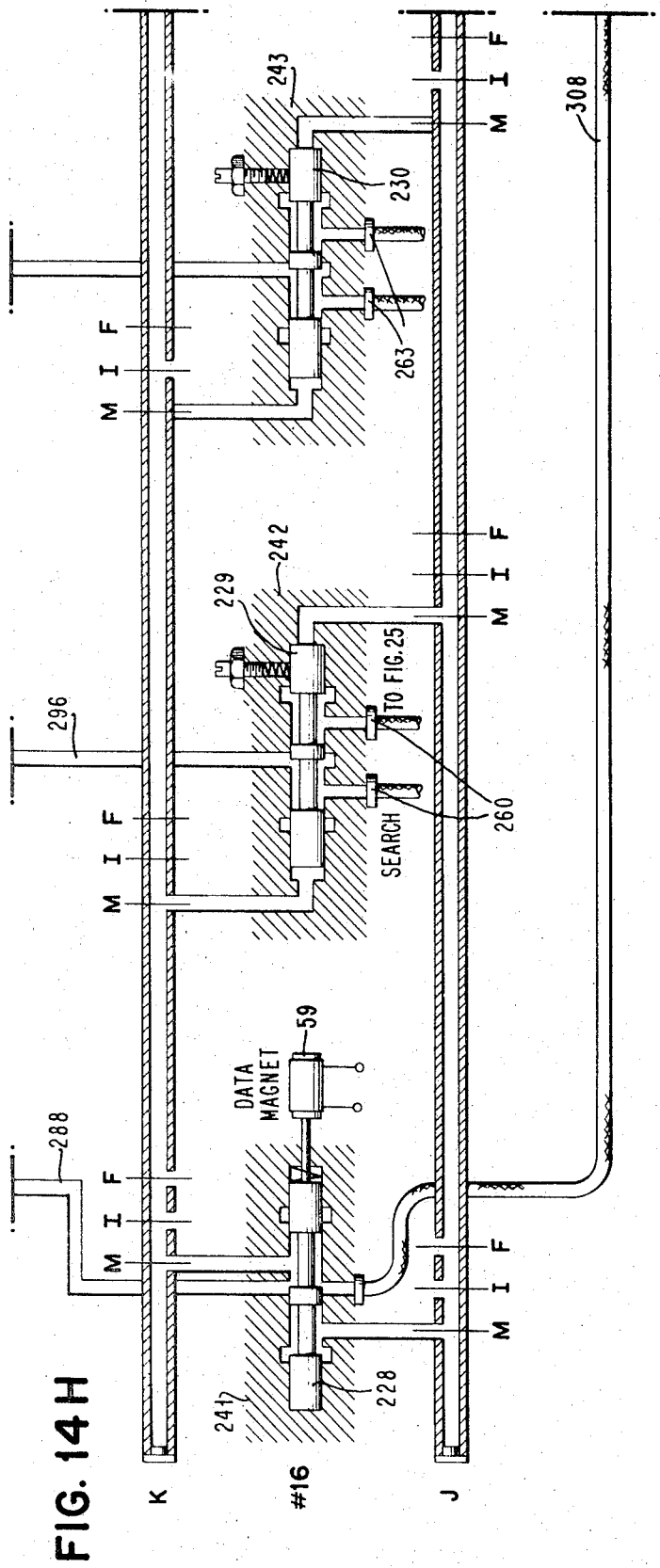


FIG. 14H

FIG. 14A	FIG. 14B	FIG. 14C	FIG. 14D
FIG. 14E	FIG. 14F	FIG. 14G	FIG. 14J FIG. 14K
		FIG. 14H	FIG. 14I

FIG. 14

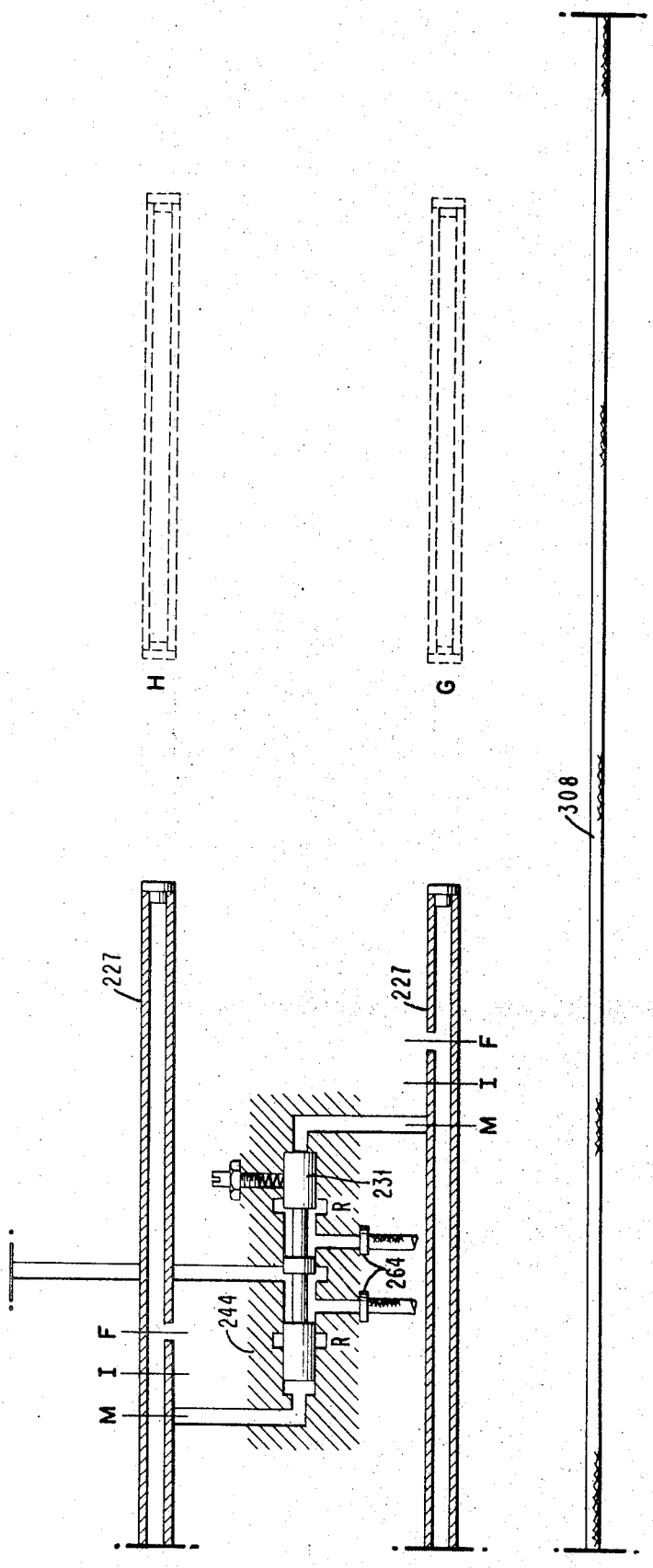


FIG. 14I

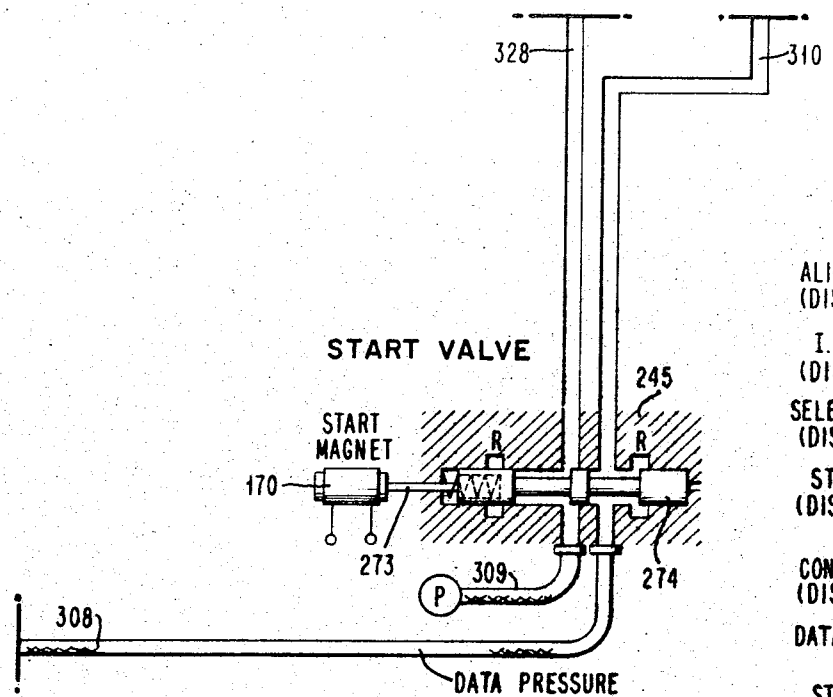


FIG. 14J

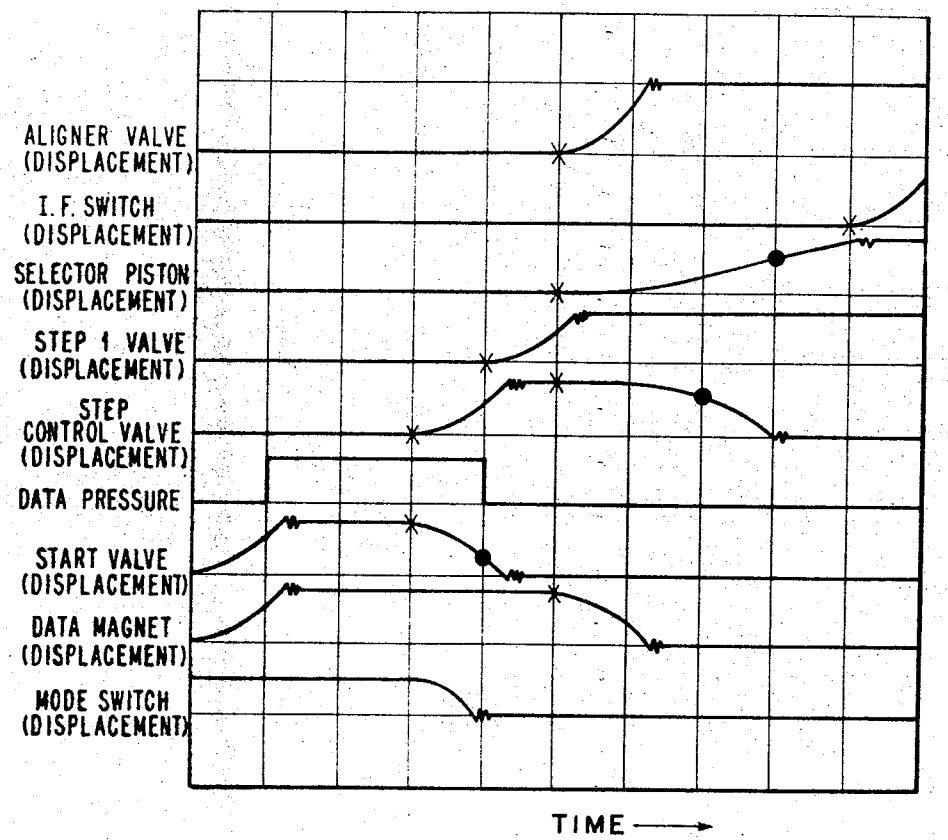


FIG. 14K

SERIAL-TO-PARALLEL HYDRAULIC DEVICE

CROSS REFERENCE TO RELATED APPLICATION

In a related copending application Ser. No. 694,941, filed Jan. 2, 1968 on my behalf entitled "Manipulator," and assigned to the assignee hereof, there is set forth a manipulator and the controls therefor including a description of the subject matter of this invention.

BACKGROUND OF INVENTION

This invention relates to fluid data processing apparatus. This invention also relates to serial coupling between parallel arrays of fluid memory elements. More particularly, this invention relates to a hydraulic serial-to-parallel converter for serially connecting a bank of input valves to a plurality of banks of memory valves, one bank at a time. This invention also relates to means for selectively interconnecting valves rapidly and in synchronization with external controls.

Equipment for use in digital control of apparatus having a plurality of controls can require a large number of parallel inputs in order to communicate a single command or word to a control unit. In the prior art, hydraulic devices have been developed for accepting data serially by character until an entire word has been transmitted. Such serial-to-parallel arrangements require a transducer, e.g. a solenoid, for each bit of a character. When, for example, 15 such solenoids are required, the cost of solenoids is high. Furthermore, serial inputs are time consuming.

Perforated paper tape-reading devices which contain more than eight parallel channels are not readily available. Magnetic tape control is extremely expensive. Generally, hydraulic porting devices are relatively massive and accordingly they must be operated slowly to avoid excessive impact. Electronic serial-to-parallel converters and memories are expensive to operate for actuating hydraulic valves, because power supplies and isolation circuits are required.

It is desirable that the system should operate in hazardous environments including areas of high radiation levels, high temperatures, and under water, whereas electronic devices will not operate well in such environments. Furthermore, devices which permit serial-to-parallel conversion with minimal electric circuit making and breaking equipment are desirable.

Accordingly, it is an object of this invention to provide a novel serial-to-parallel hydraulic porting device.

Another object is to provide a novel serial-to-parallel converter.

An important object is to provide a fast acting converter employing a unitary movable structure which is light weight to provide low mass and low impact between parts in operation.

A principal object is to provide a porting structure permitting connection of a bank of several valves to a plurality of banks of valves seriatim.

An important object is to provide a movable porting structure for reciprocation within an elongated central cylindrical space in a fixed hydraulic porting structure. Such a structure should obviate the necessity for machining an elongated cylindrical bore and should provide a flexible movable porting tower of low mass and simple construction. The tower should be sufficiently flexible to avoid jamming in a long cylindrical space although the tower is long and thin.

A further object is to provide a converter for changing digital inputs comprising a plurality of multidigit characters into parallel outputs comprising a word which commands an operation.

An important object of this invention is to control displacement 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 control and memory device for actuating a plurality of elements selectively, in response to control data presented serially by character.

Another object is to attain the design of a lightweight, rapidly operating, accurate converter employing relatively few inexpensive components.

SUMMARY OF THE INVENTION

A hydraulic serial-to-parallel converter is employed to convert tape input into control of a hydraulic drive. A control tape is perforated with coded instructions and dimensions to control an output device.

The main components of the system are a tape reader, an electrically and hydraulically controlled hydraulic serial-to-parallel converter and memory and a hydraulic driver for operating integer and fraction hydraulic piston adders.

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 three characters serially such as the mode, inch, and fraction, values successively. The converter can be used as a form of memory for subsequent control of the amount and mode of displacement by a hydraulic piston-adder drive.

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 3¾° to 270° out of a normal horizontal position.

FIG. 6 is a schematic perspective view of the serial-to-parallel digital converter.

FIG. 7 is another perspective view of the serial-to-parallel digital converter showing the external hydraulic connections therefrom to a piston adder.

FIG. 8 is a sectional plan view taken along line 8–8 in FIG. 9 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. 9 is an elevation view partly in section showing the mode section of the hydraulic converter.

FIG. 10 is a sectional plan view taken along line 10–10 in FIG. 11 showing the logic and control portion of the hydraulic digital converter.

FIG. 11 is an elevation partly in section showing the lowermost stepping control section of the hydraulic digital converter.

FIG. 12 is a diagrammatic unfolded sectional elevation view of the piston-adder mechanism in the normal position.

FIG. 13 is a diagrammatic unfolded sectional elevation view of the piston-adder mechanism shown adjusted to an extent representative of 4 5/16 inches of movement.

FIG. 14 is a chart showing how the hydraulic converter logic and control circuit diagram is to be assembled.

FIGS. 14A—14K 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 10 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 3¾° 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 adder **35** 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 values 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 one-thirty second of an inch up to one-half 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 counterweight. 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 figures. 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 of 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 1, 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 1, 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 14 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 1, since the grip mode of operation actuator is to be actuated to close the gripper. The box adjacent to grip and under operation 1 is outlined by a heavy line, as it is closed.

The grip 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-quarter inch) were produced first by trial adjustment of the control pad 54. The tape is prepared for operation 1, 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. 6—11 and FIGS. 14A—14K.

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 1, 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 1, does effect a change to closure. Prior to operation 1, 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 2½ 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 is described in greater detail in my above-referenced copending application Ser. No. 694,941.

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. 6 and 7 reads and stores the information supplied to data magnets 59 from the tape 52. 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 26. 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. 7 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. 6 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. 14A—14J) 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. 6 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. 6 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 date 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 explained above how the data magnets 59 were energized in combinations by the control pad or tape. At the top of FIG. 6 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. 6 affords a good general picture of the converter and controls associated therewith, views of FIGS. 7—11 show more specific exterior and interior details, and composite schematic FIGS. 14A—14J shows particular hydraulic controls and the valving thereof.

FIG. 7 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. 14C. 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. 8 is a sectional plan view taken generally along line 8–8 in FIG. 9. The valve encasement 242, as seen in FIG. 9, 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. 14A—14J. 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 chan-

nel 249D is used for shifting a spool of 8-valve 229 to its O 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. 8 where a pin 269 fits in a recess in the sleeve 268.

The mode pistons 219 and 220, FIG. 6 slide within the fixed sleeve 268 and the upper mode piston 219 is shown in section in FIG. 8. 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. 8, 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. 9, 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. 11 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. 10 shows a sectional plan view of the control section along line 10–10 in FIG. 11. 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 tower 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. 10, 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. 14A—14K.

Before studying the details of the schematic view FIGS. 14A—14K, as arranged in FIG. 14, we will consider its relationship to FIG. 6 and how it may be most easily understood. If FIG. 6 is turned counterclockwise and placed on assembled FIGS. 14A—14K with the top of FIG. 6 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. 14A, 14E, 14H, etc., the views of the valve clusters are unrolled or spread out from the circular arrays of FIG. 6 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 10 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. 14C and 14D, there are several hydraulic controls including the flow valve control, not shown, in FIG. 6. At the lower right corner, FIG. 14K, 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 spool, 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 02_2 and instead diverts pressure through port 260 into conduit tree 02_1. 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. 14G, 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. **14C**, 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.
for release of Y, only a 1 bit.
for release of Z, only a 2 bit.
for release of θ, both 1 and 2 bits.

The tree **261** is operated as a mode selection control (FIG. **14C**) in response to combinations of pressures at 02_1 or 02_2, and at 01_1 or 01_2. 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 02_1 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 01_1 and 02_1 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 position shown is effected by pressure in channels 01_2 and 02_2 as regulated by the mode valves **229**.

THE STEPPING CONTROLS

Referring to FIGS. **6** and **14A—14K**, it will be recalled that the stepping piston assembly consists of a tower **802** comprising eight pistons supported and bonded to the 10 axial tubes **227** and also a series of central tubular channels **272**, **275**, etc. (FIG. **10**) inside the control piston **225**, FIG. **6**, for effecting porting to the various control valves in the control valve section **63**. It is also recalled that in FIG. **6**, 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. **14G**, 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. **14J**. 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 reader circuit breaker contacts and integer fraction contacts **167** actuates 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 and 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. **14K**, 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. **14D**, 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 inch, 4 inch, 8 inch, and 16 inch. 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 by misaligned.

The integer and fraction porting of pressure is directed into the piston adder or the arithmetic drive units **35** shown perspectively in FIG. **2**, diagrammatically unfolded at O position in FIG. **12**, and adjusted by 4 5/16 inches movement in FIG. **13**. The piston adder apparatus **35** here is in three sections, 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. **12**, 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 "1/16-inch" and "⅛-inch" pistons **337** and **339** located in two separate chambers **338** and **340** within a single piston cylinder.

In FIG. **12** 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. **12** 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. **12**, the piston adder mechanism is at its O 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. **12** can be extended to a distance up to 31 31/32 of an inch from a O position or any distance in between, in increments of one thirty-seconds of an inch. For example, as shown in FIG. **13**, if the 4 inch, **one-fourth inch and one-sixteenth** inch pistons are actuated, then the entire piston adder mechanism is extended 4 5/16 of an inch. The clamp **68**, being connected to the end of the highest order piston adder member would therefore move 4 5/16 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 in the name of Hugo A. Panissidi and assigned to the assignee hereof.

In the unfolded view, FIG. **12**, 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 "**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 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, FIGS. **7** and **13**, 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 control tape **52** and the schematic controls of FIGS. **14A—14K**, 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.

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. A serial-to-parallel hydraulic porting device comprising a plurality of input actuators, an input valve section including:

a plurality of input valves for operation serially by character in response to said actuators;

a plurality of memory valve sections providing outputs in parallel by word, each said memory valve section including a plurality of memory valves for adjustment by transfer of digital data to said memory valves through the inputs thereto; and

a porting structure for connecting the outputs of said input valve section selectively to the inputs of one of said memory valve section, seriatim, to adjust the positions of the valves in the connected one of said memory valve sections to correspond to the positions of said input valves.

2. Apparatus in accordance with claim **1** including a control section including means for regulating the position of said porting structure, actuating means having an input connected to the output of said control section, for adjusting the position of said porting structure, said actuating means including a drive means connected to said porting structure.

3. Apparatus in accordance with claim **1** including a data-reading device wherein said input actuators are connected to the output of said data-reading device, said hydraulic porting device comprising a serial-to-parallel converter.

4. A fluid converter including a plurality of input valves for sequential connection to a plurality of banks of memory valves, said converter including a movable porting structure for interconnecting said input valves and said memory valves, said porting structure including a plurality of sections of tubing providing structural support and fluid passageways.

5. Apparatus in accordance with claim 4 wherein said input valves and said memory valves are contained in valve blocks each having a central cylindrical bore with radial passageways to said valves from said bore, said porting structure including a plurality of pistons having longitudinal bores for connection with said tubing and said pistons having radial bores for coupling with said radial bores in said valve blocks in valve interconnection positions.

6. A fluid converter in accordance with claim 4 wherein said converter includes a hydraulic control valve section, said control valve section including a valve block containing a plurality of valves and passageways and a piston having a plurality of longitudinal and transverse bores for sequentially interconnecting said plurality of valves included in said valve block.

7. Apparatus in accordance with claim 6 wherein said converter includes a stepping drive including an interconnected pair of drive cylinders for stepping said piston and said sections of tubing connected to the output of said control section.

8. A serial-to-parallel digital converter comprising:

a plurality of data input actuators all responsive to digital characters, a data input valve section including a plurality of input valves for operation serially by character in response to said actuators;

a plurality of memory valve sections providing outputs in parallel by word each including a plurality of memory valves for adjustment by transfer of digital characters from corresponding input valves;

a central input valve section to memory valve section switching mechanism for connecting said input valve section successively to operate each of said memory valve sections seriatim; and

a control valve section including means for regulating the operation of said switching mechanism, actuating means connected to be operated by said control valve section.

9. A hydraulic serial-to-parallel digital converter including a serial input binary valve section, a plurality of parallel output binary valve sections, said input valve section having outputs adapted to be coupled to a plurality of channels in a plurality of character read-in positions, said channels being adapted to be selectively coupled to the inputs of said output valve sections, seriatim, in response to displacement of said channels relative to said output valve sections, control and driving means for selectively displacing said output valve section relative to said channels.

10. A fluid serial-to-parallel digital converter comprising:

a plurality of serial input transducers;

an input section comprising a plurality of binary input responsive fluid elements;

a plurality of output sections comprising a plurality of binary output producing fluid elements;

a coupling matrix comprising a plurality of channels and apertures; and

said channels being movable to a plurality of coupling positions relative to said output sections.