United States Patent

Robillard et al.

[15] **3,634,979**

[45] **Jan. 18, 1972**

[54] **GRINDING MACHINE**

[72] Inventors: **Edward G. Robillard,** Cherry Valley; **Robert H. Lizotte,** Leominster; **Herbert R. Uhtenwoldt,** Worcester, all of Mass.

[73] Assignee: **The Heald Machine Company,** Worcester, Mass.

[22] Filed: **Nov. 25, 1969**

[21] Appl. No.: **879,785**

[52] **U.S. Cl.** **51/165.8**

[51] **Int. Cl.** **B24b 49/00**

[58] **Field of Search** 51/165.77, 165.8, 165.87, 165.9

[56] **References Cited**

UNITED STATES PATENTS

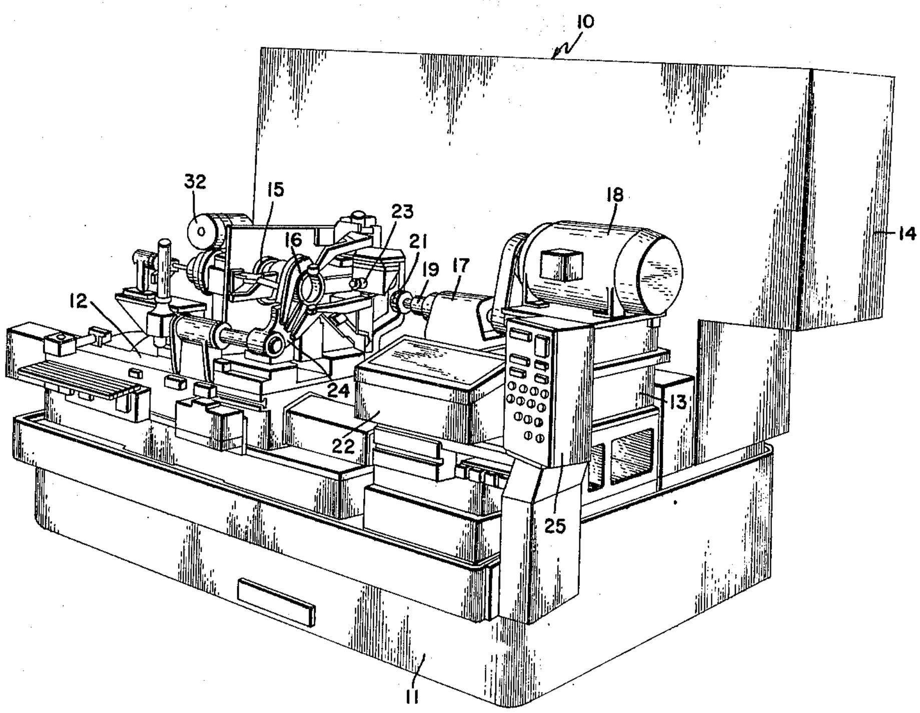
3,269,064	8/1966	Lockwood	51/165.9 X
3,327,432	6/1967	Lockwood	51/165.87
3,403,480	10/1968	Robillard	51/165.87
3,503,158	3/1970	Robillard et al.	51/165.8

Primary Examiner—Lester M. Swingle
Attorney—Norman S. Blodgett

[57] **ABSTRACT**

This invention relates to a grinding machine and, more particularly, to apparatus for generating a surface of revolution by the abrasive process, substantial portions of the grinding cycle being controlled by digital means.

9 Claims, 37 Drawing Figures



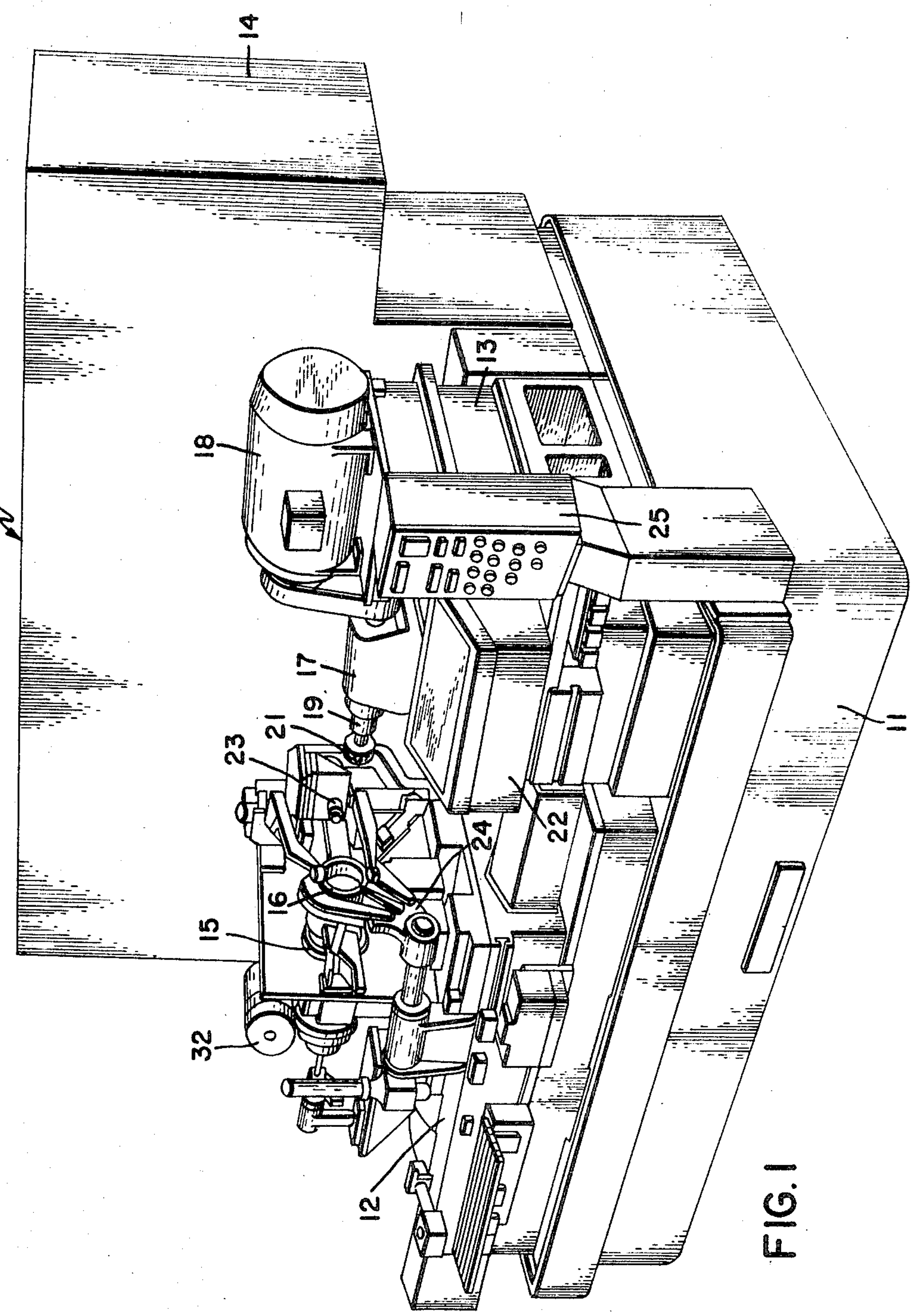


FIG. 1

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Donald S. Blodgett
ATTORNEY

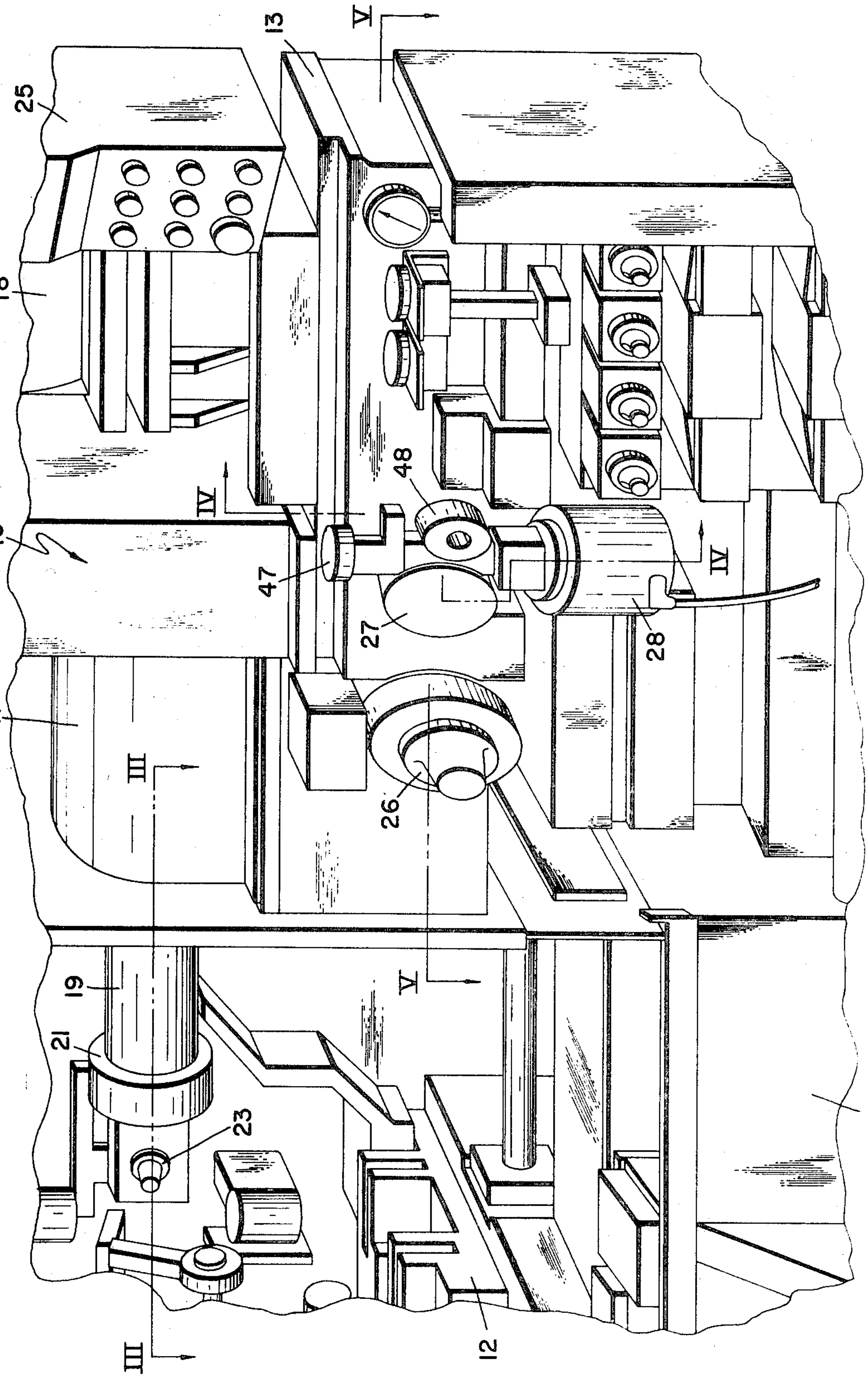


FIG. 2

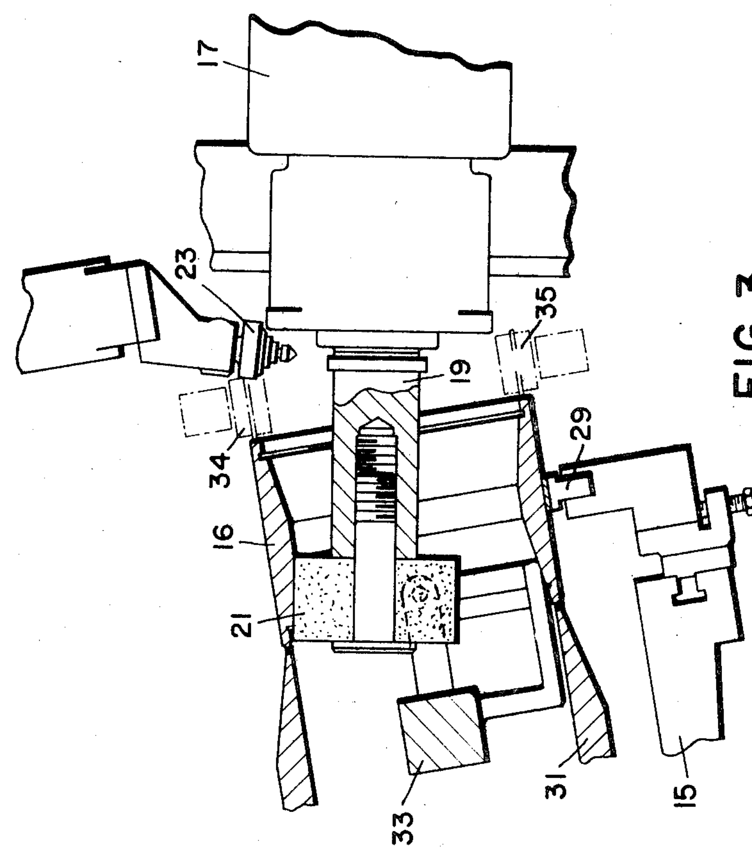


FIG. 3

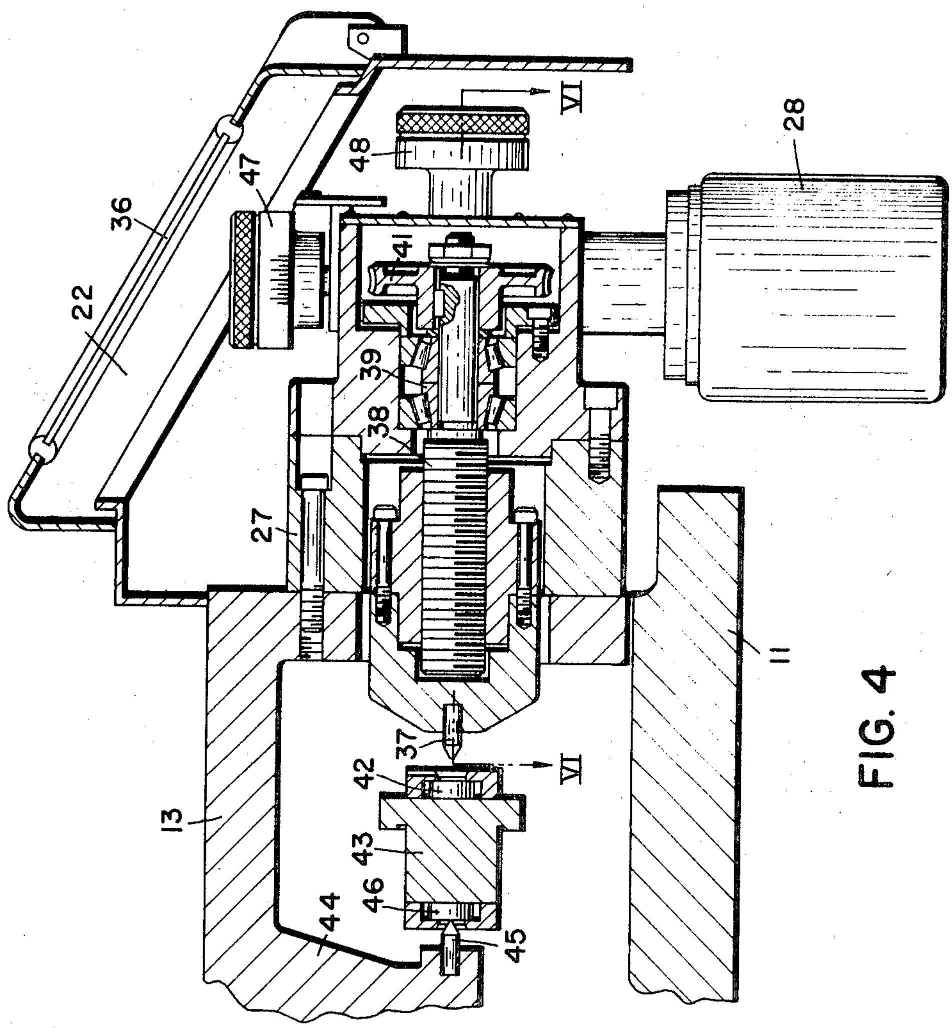


FIG. 4

PATENTED JAN 18 1972

3,634,979

SHEET 05 OF 36

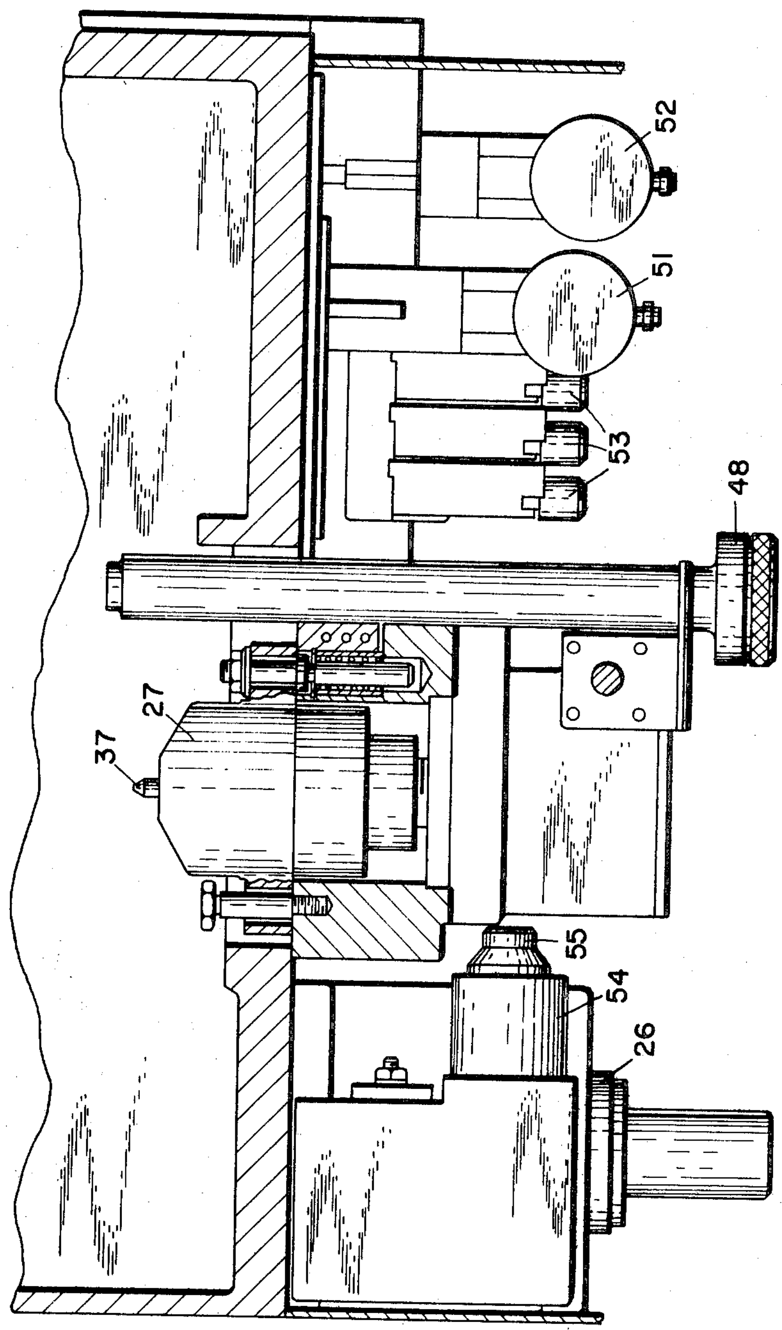


FIG. 5

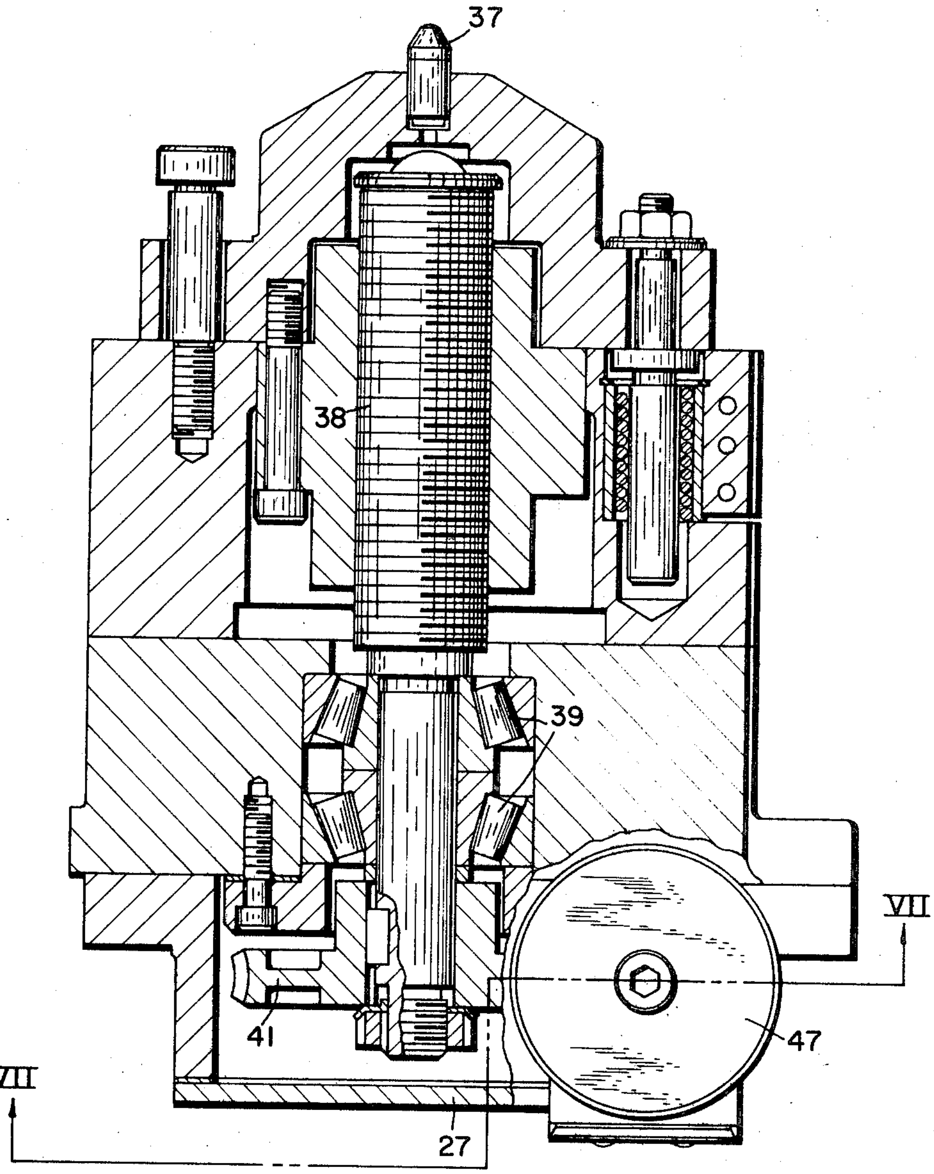


FIG. 6

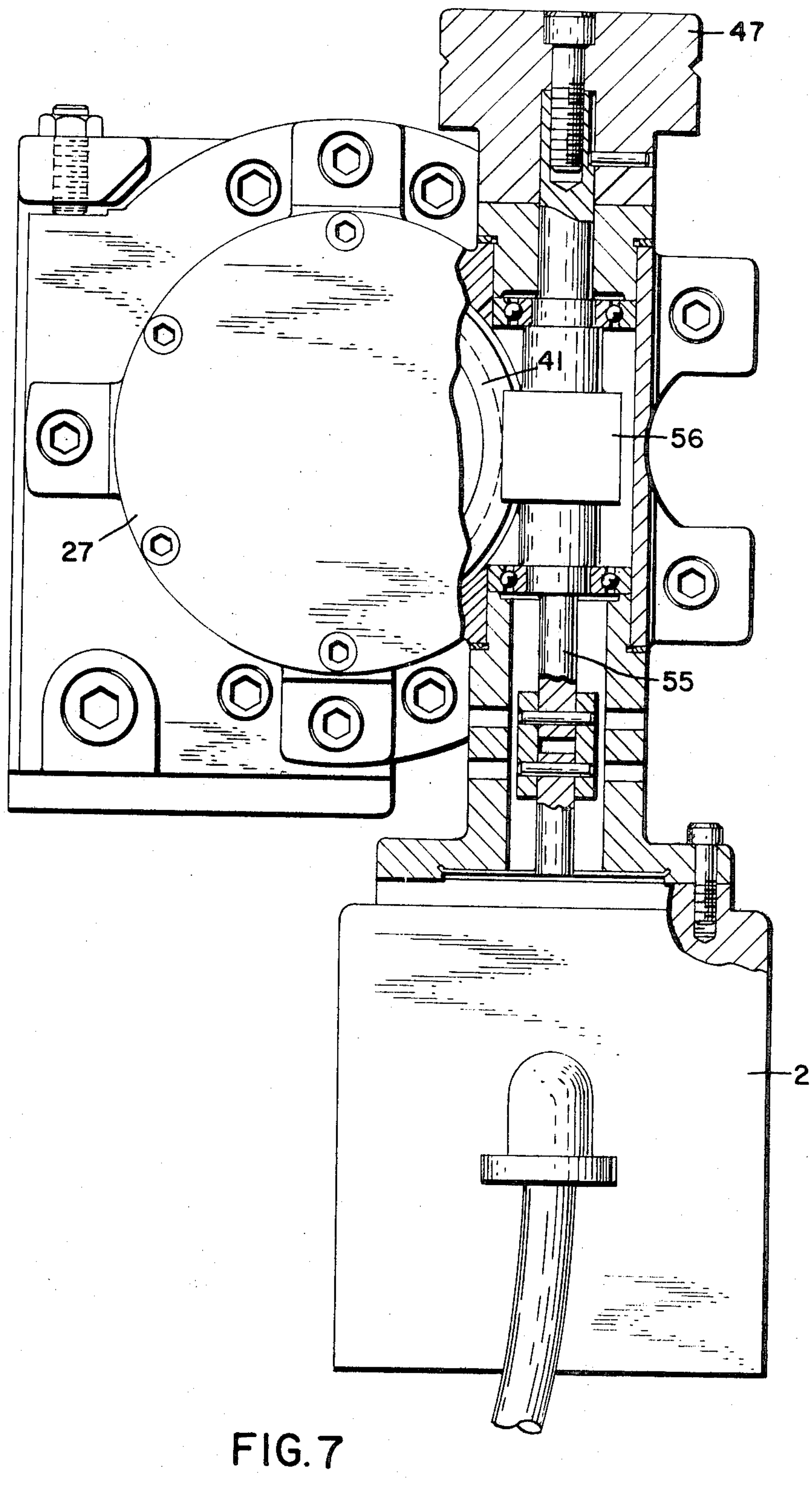


FIG. 7

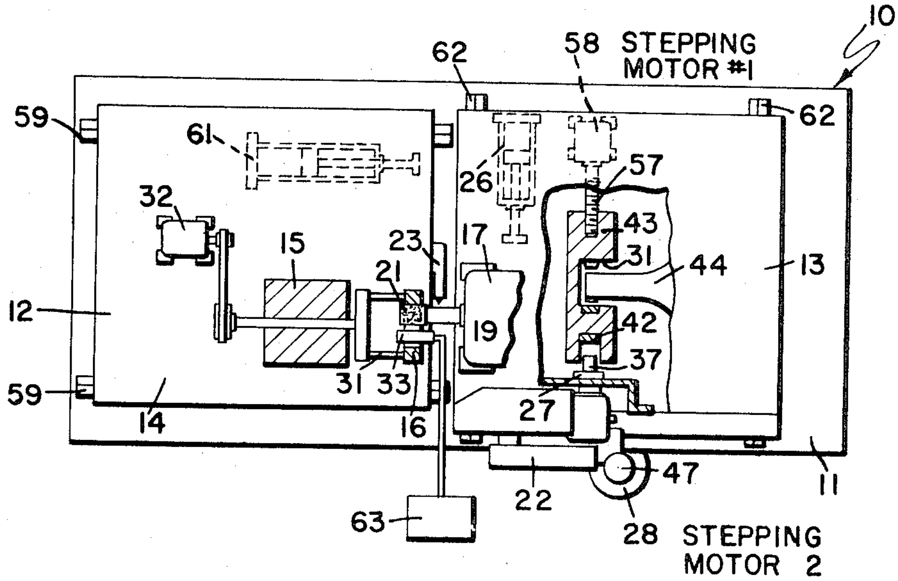

10
62
58 STEPPING MOTOR #1
62
59
61
57
26
32
15
23
17
43
31
44
13
12
21
19
42
37
59
31 33
27
14
16
22
47
11
63
28 STEPPING MOTOR 2

FIG. 8

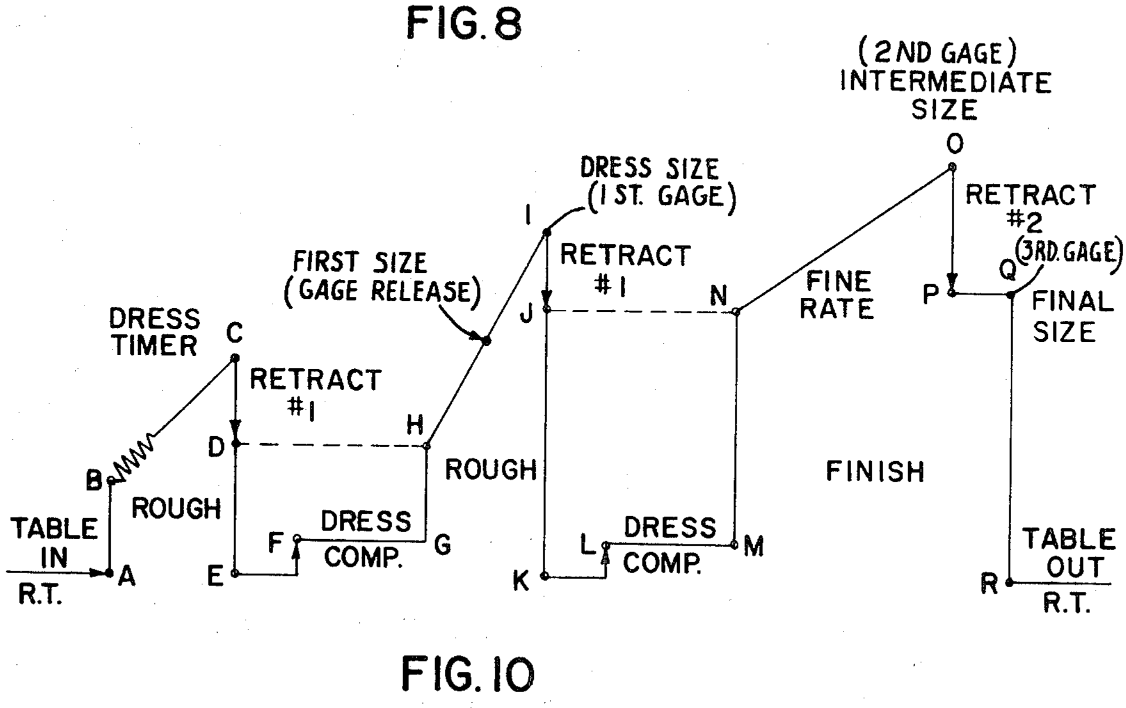

(2ND GAGE) INTERMEDIATE SIZE
O
DRESS SIZE (1 ST. GAGE)
I
RETRACT #2
(3RD. GAGE)
FIRST SIZE (GAGE RELEASE)
RETRACT #1
Q
P
FINAL SIZE
N
FINE RATE
J
DRESS TIMER
C
RETRACT #1
H
D
B
ROUGH
ROUGH
FINISH
TABLE IN
DRESS
DRESS
TABLE OUT
F
G
L
M
COMP.
COMP.
R.T.
A
E
K
R
R.T.

FIG. 10

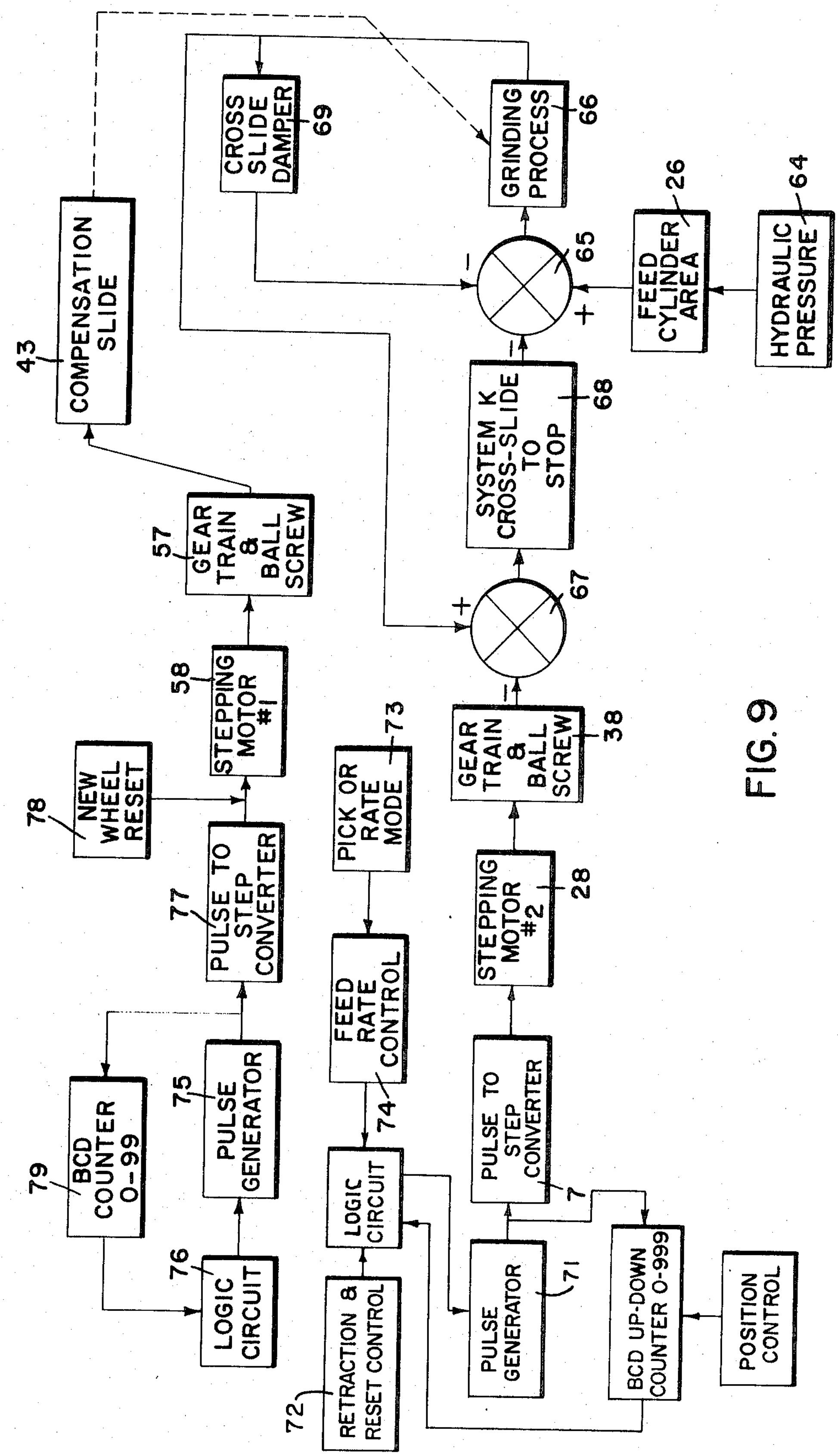

COMPENSATION SLIDE
43
CROSS SLIDE DAMPER
69
GRINDING PROCESS
66
FEED CYLINDER AREA
26
HYDRAULIC PRESSURE
64
65
SYSTEM K CROSS-SLIDE TO STOP
68
67
GEAR TRAIN & BALL SCREW
57
STEPPING MOTOR #1
58
NEW WHEEL RESET
78
PULSE TO STEP CONVERTER
77
PICK OR RATE MODE
73
GEAR TRAIN & BALL SCREW
38
STEPPING MOTOR #2
28
FEED RATE CONTROL
74
BCD COUNTER 0-99
79
PULSE GENERATOR
75
LOGIC CIRCUIT
76
LOGIC CIRCUIT
PULSE TO STEP CONVERTER
7
RETRACTION & RESET CONTROL
72
PULSE GENERATOR
71
BCD UP-DOWN COUNTER 0-999
POSITION CONTROL

FIG. 9

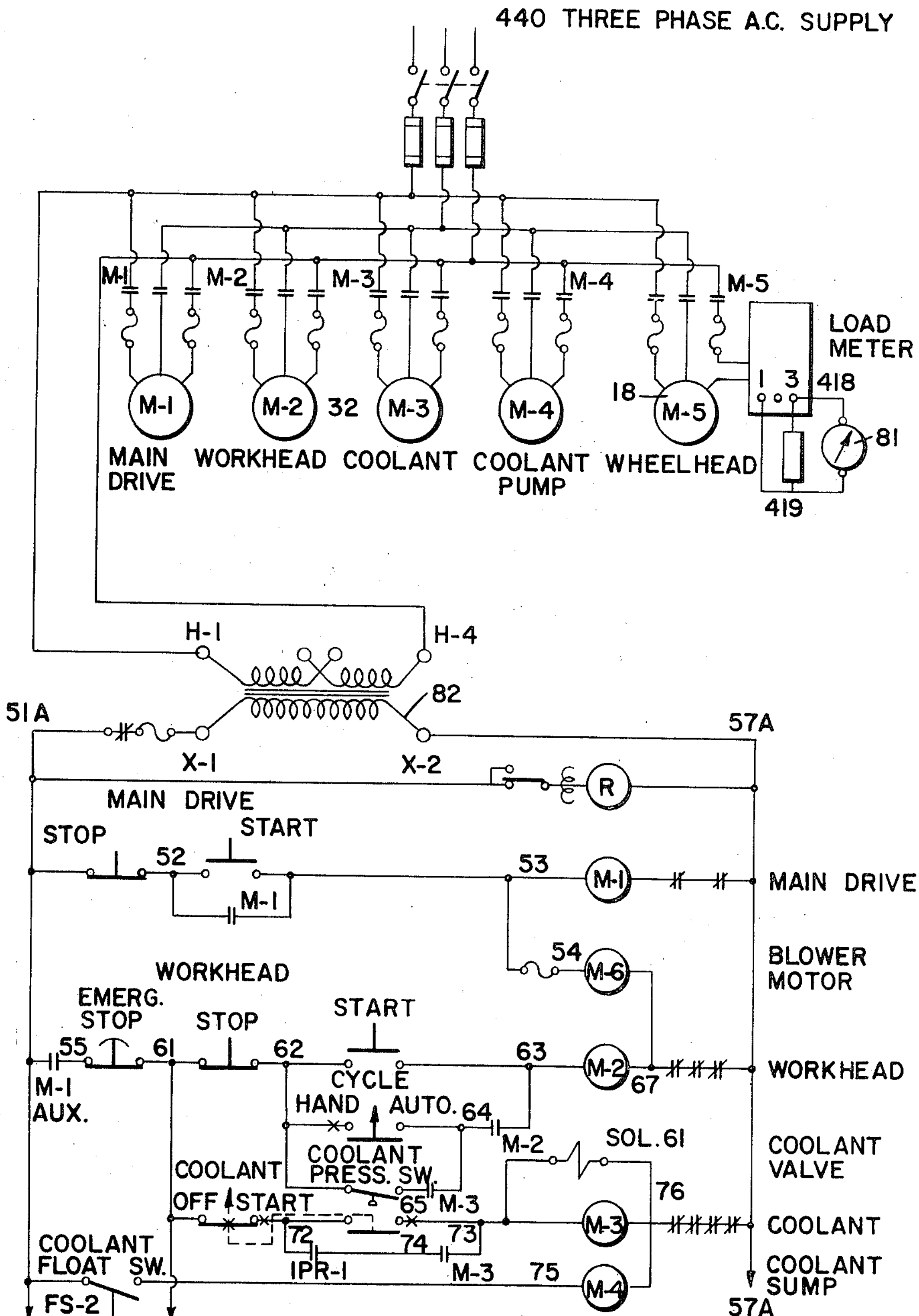

440 THREE PHASE A.C. SUPPLY
M-1
M-2
M-3
M-4
M-5
LOAD METER
1 3
418
81
419
18
M-1
M-2
32
M-3
M-4
M-5
MAIN DRIVE
WORKHEAD
COOLANT
COOLANT PUMP
WHEELHEAD
H-1
H-4
82
51A
X-1
X-2
57A
R
MAIN DRIVE
STOP
START
52
53
M-1
M-1
MAIN DRIVE
54
M-6
BLOWER MOTOR
WORKHEAD
EMERG. STOP
STOP
START
55
61
62
63
M-2
67
WORKHEAD
M-1 AUX.
CYCLE
HAND
AUTO.
64
M-2
SOL. 61
COOLANT VALVE
COOLANT
COOLANT PRESS. SW.
76
OFF
START
65
M-3
72
74
73
M-3
COOLANT
COOLANT FLOAT SW.
IPR-1
M-3
75
M-4
COOLANT SUMP
FS-2
57A
51A
61A

FIG. 11

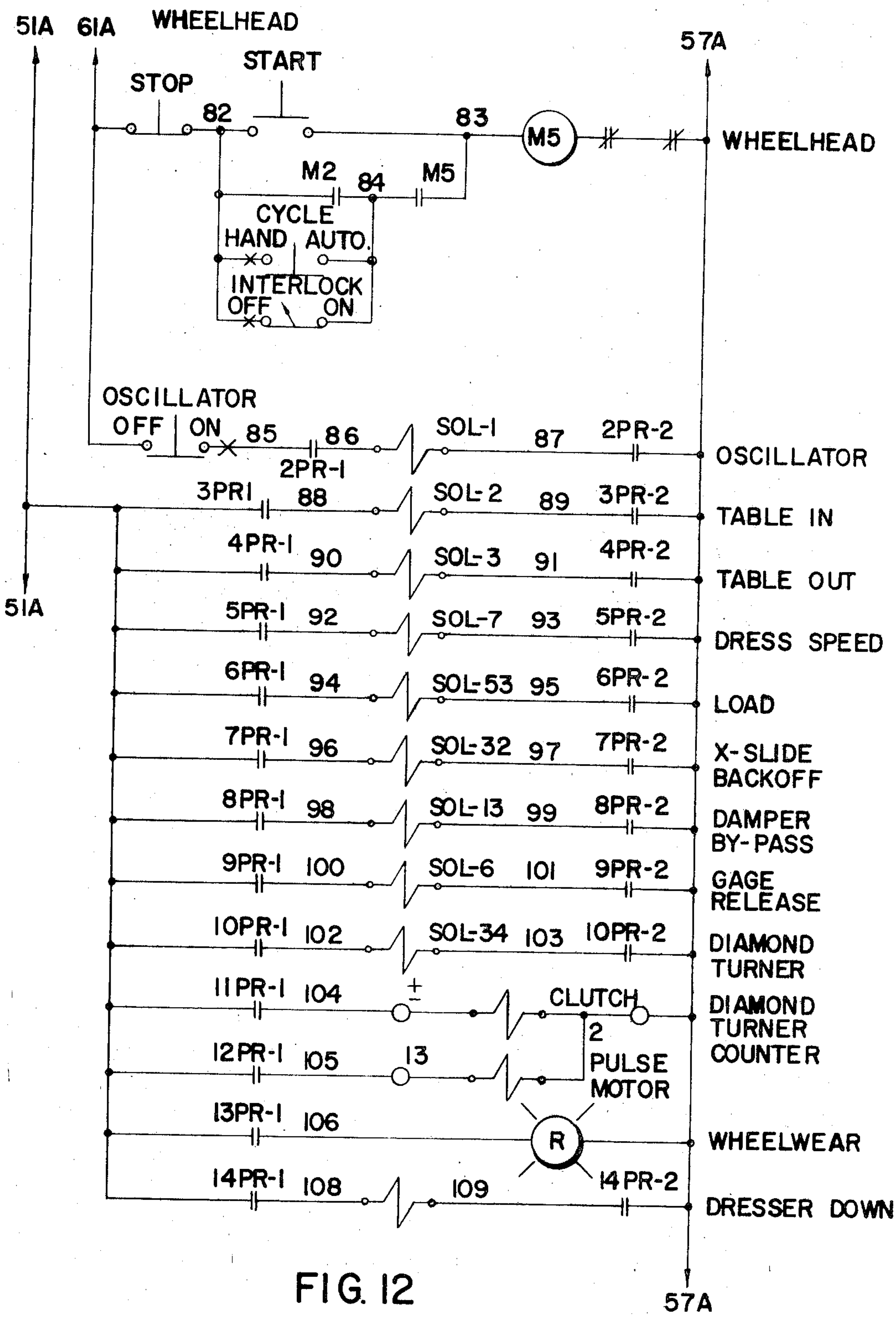

51A
61A
WHEELHEAD
STOP
START
82
83
M5
WHEELHEAD
57A
M2
84
M5
CYCLE
HAND
AUTO.
INTERLOCK
OFF
ON
OSCILLATOR
OFF
ON
85
86
2PR-1
SOL-1
87
2PR-2
OSCILLATOR
3PR1
88
SOL-2
89
3PR-2
TABLE IN
4PR-1
90
SOL-3
91
4PR-2
TABLE OUT
51A
5PR-1
92
SOL-7
93
5PR-2
DRESS SPEED
6PR-1
94
SOL-53
95
6PR-2
LOAD
7PR-1
96
SOL-32
97
7PR-2
X-SLIDE BACKOFF
8PR-1
98
SOL-13
99
8PR-2
DAMPER BY-PASS
9PR-1
100
SOL-6
101
9PR-2
GAGE RELEASE
10PR-1
102
SOL-34
103
10PR-2
DIAMOND TURNER
11PR-1
104
CLUTCH
2
DIAMOND TURNER COUNTER
12PR-1
105
13
PULSE MOTOR
13PR-1
106
R
WHEELWEAR
14PR-1
108
109
14PR-2
DRESSER DOWN
57A

FIG. 12

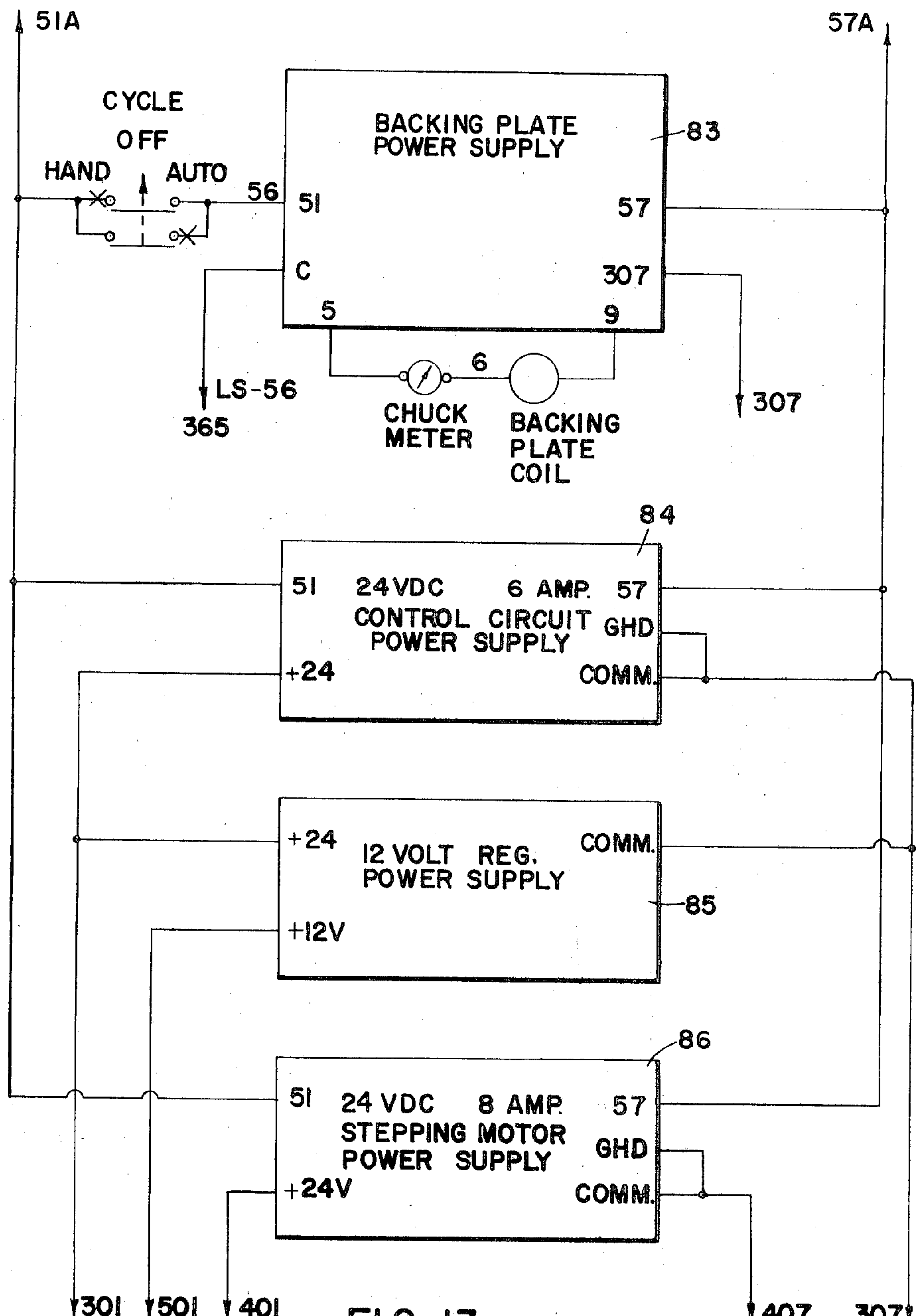

51A
57A
CYCLE
OFF
HAND
AUTO
56
BACKING PLATE POWER SUPPLY
83
51
57
C
307
5
9
6
LS-56
365
CHUCK METER
BACKING PLATE COIL
307
84
51
24VDC
6 AMP.
57
CONTROL CIRCUIT POWER SUPPLY
GHD
+24
COMM.
+24
12 VOLT REG. POWER SUPPLY
COMM.
85
+12V
86
51
24 VDC
8 AMP.
57
STEPPING MOTOR POWER SUPPLY
GHD
+24V
COMM.
301
501
401
407
307

FIG. 13

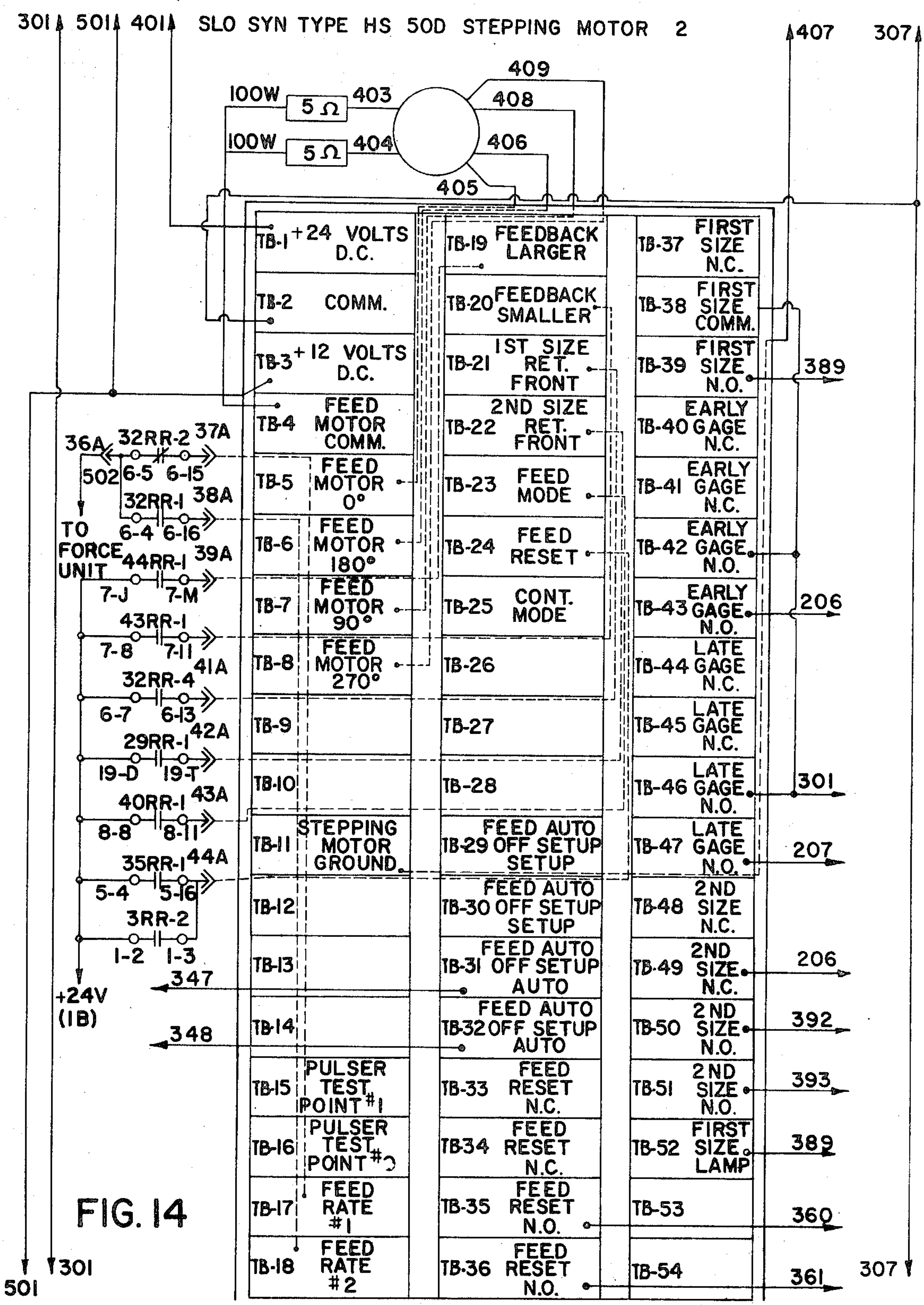


FIG. 14

I.C. FEED UNIT FOR FRONT STEPPING MOTOR CARD CAGE & TERMINAL STRIPS VIEWED FROM WIRING SIDE

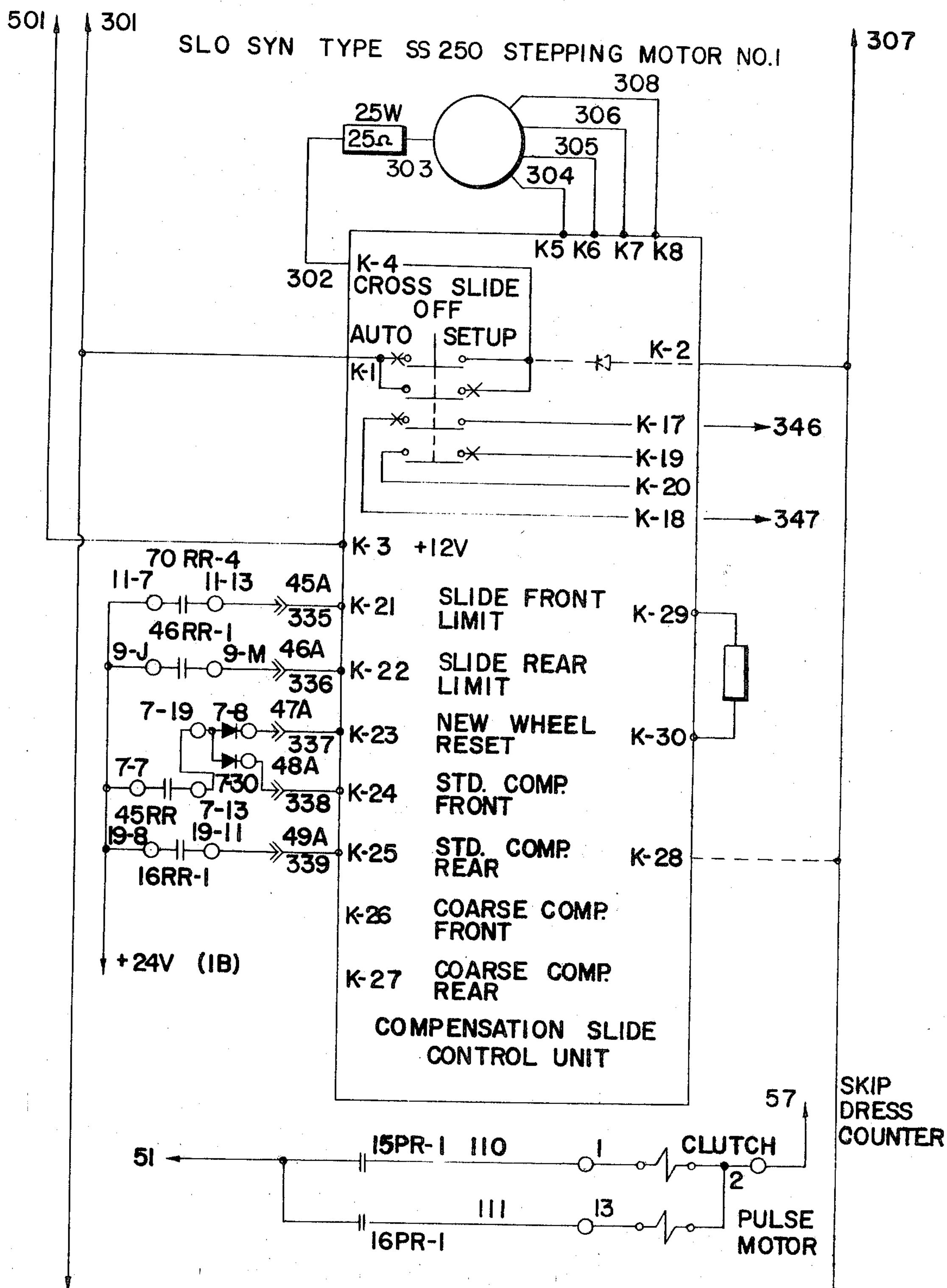

501
301
SLO SYN TYPE SS 250 STEPPING MOTOR NO. 1
307
308
306
305
304
25W
25Ω
303
302
K5 K6 K7 K8
K-4
CROSS SLIDE
OFF
AUTO
SETUP
K-1
K-2
K-17
346
K-19
K-20
K-18
347
K-3 +12V
70 RR-4
11-7
11-13
45A
335
K-21
SLIDE FRONT LIMIT
K-29
46RR-1
9-J
9-M
46A
336
K-22
SLIDE REAR LIMIT
7-19
7-8
47A
337
K-23
NEW WHEEL RESET
K-30
48A
7-7
7-30
338
K-24
STD. COMP. FRONT
45RR
7-13
19-8
19-11
49A
339
K-25
STD. COMP. REAR
K-28
16RR-1
K-26
COARSE COMP. FRONT
+24V (1B)
K-27
COARSE COMP. REAR
COMPENSATION SLIDE CONTROL UNIT
57
SKIP DRESS COUNTER
51
15PR-1
110
1
CLUTCH
2
111
13
16PR-1
PULSE MOTOR

FIG. 15

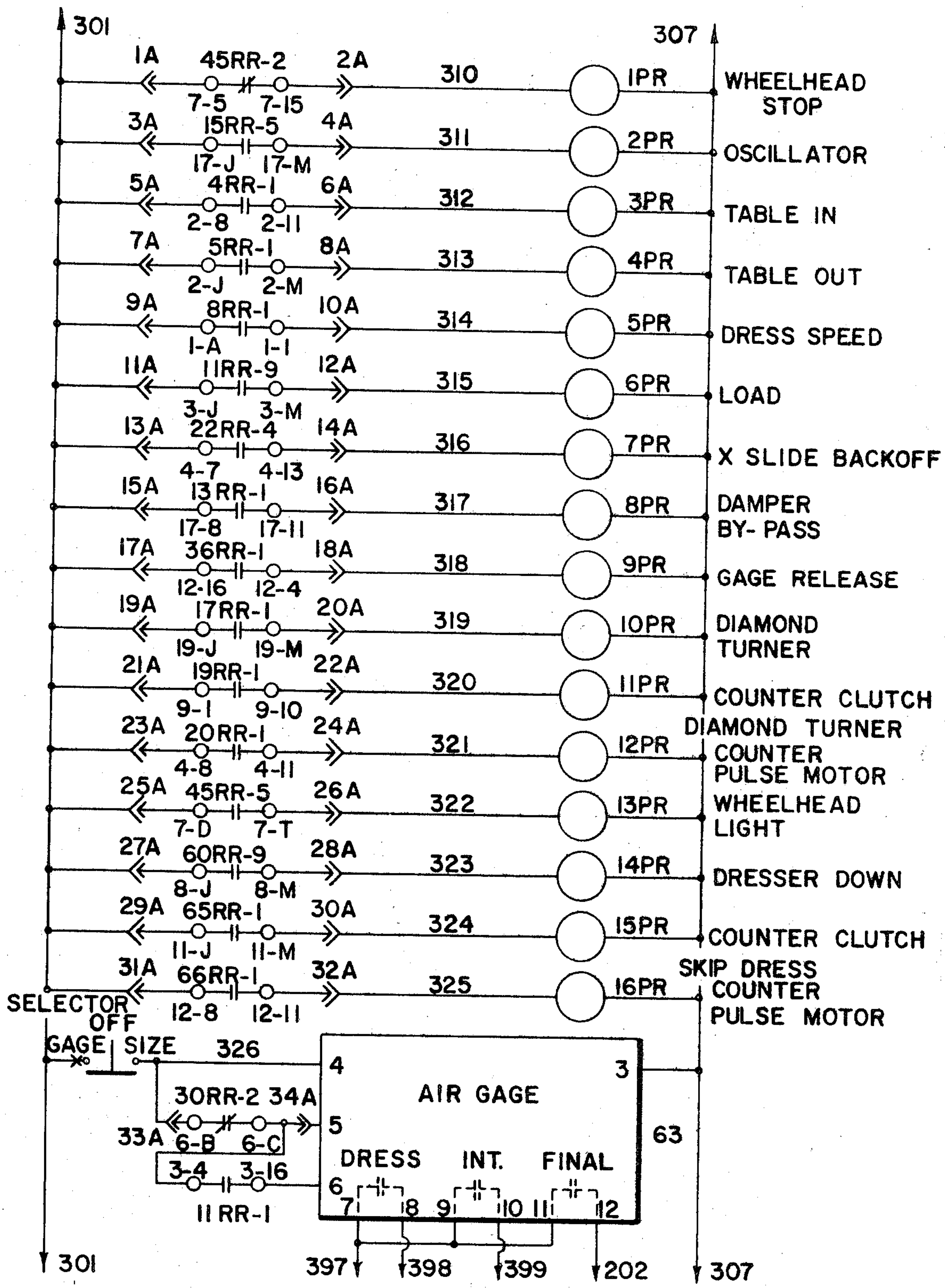

301
307
1A 45RR-2 2A 310 1PR WHEELHEAD STOP
7-5 7-15
3A 15RR-5 4A 311 2PR OSCILLATOR
17-J 17-M
5A 4RR-1 6A 312 3PR TABLE IN
2-8 2-11
7A 5RR-1 8A 313 4PR TABLE OUT
2-J 2-M
9A 8RR-1 10A 314 5PR DRESS SPEED
1-A 1-1
11A 11RR-9 12A 315 6PR LOAD
3-J 3-M
13A 22RR-4 14A 316 7PR X SLIDE BACKOFF
4-7 4-13
15A 13RR-1 16A 317 8PR DAMPER BY-PASS
17-8 17-11
17A 36RR-1 18A 318 9PR GAGE RELEASE
12-16 12-4
19A 17RR-1 20A 319 10PR DIAMOND TURNER
19-J 19-M
21A 19RR-1 22A 320 11PR COUNTER CLUTCH
9-1 9-10
23A 20RR-1 24A 321 12PR DIAMOND TURNER COUNTER PULSE MOTOR
4-8 4-11
25A 45RR-5 26A 322 13PR WHEELHEAD LIGHT
7-D 7-T
27A 60RR-9 28A 323 14PR DRESSER DOWN
8-J 8-M
29A 65RR-1 30A 324 15PR COUNTER CLUTCH
11-J 11-M
31A 66RR-1 32A 325 16PR SKIP DRESS COUNTER PULSE MOTOR
12-8 12-11
SELECTOR
OFF
GAGE SIZE
326
AIR GAGE
4 3 5 63
30RR-2 34A
33A 6-B 6-C
3-4 3-16
11RR-1
DRESS INT. FINAL
6 7 8 9 10 11 12
301 397 398 399 202 307

FIG. 16

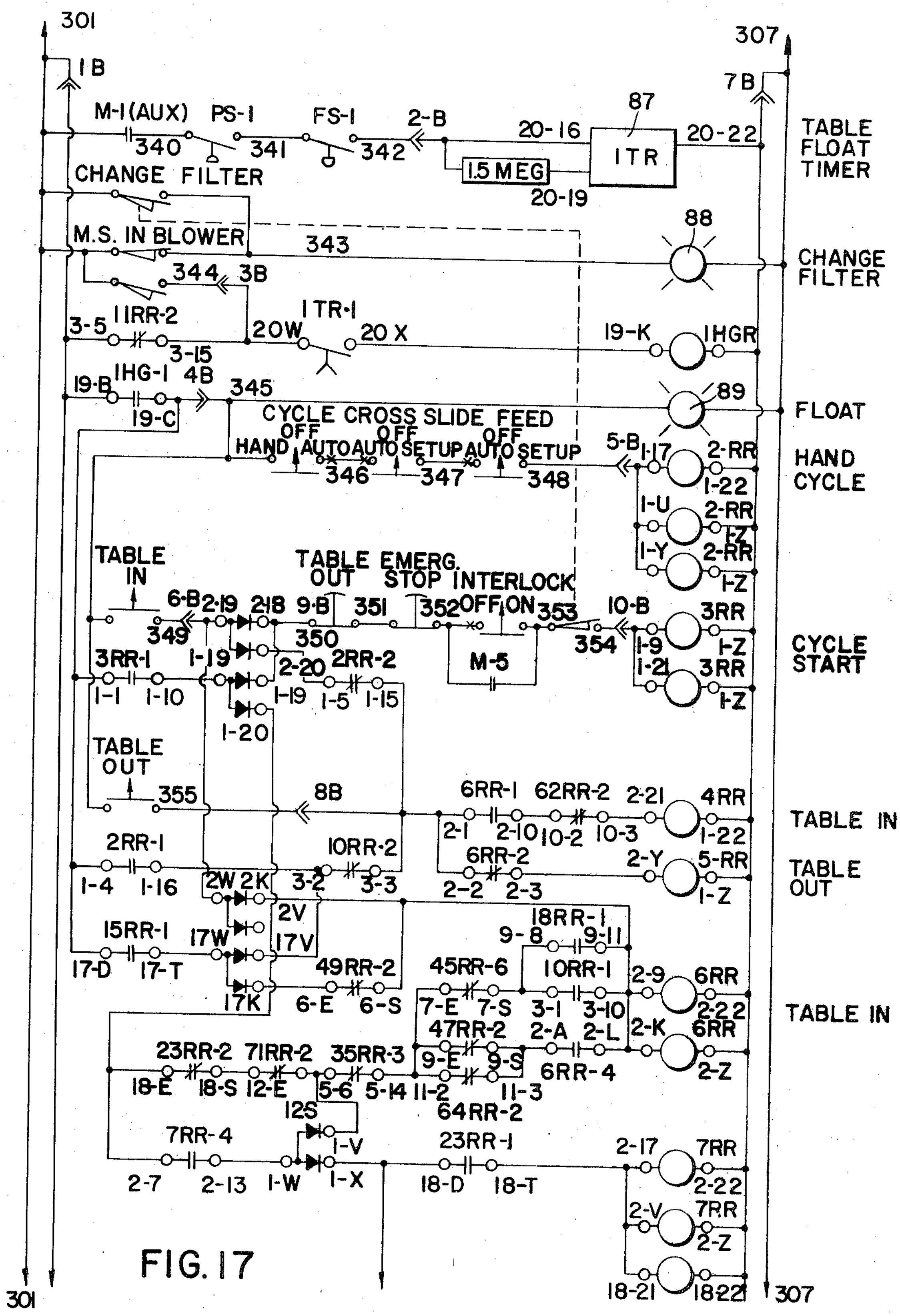

301
307
1B
7B
M-1 (AUX)
PS-1
FS-1
2-B
87
20-16
ITR
20-22
TABLE FLOAT TIMER
340
341
342
1.5 MEG
20-19
CHANGE FILTER
88
M.S. IN BLOWER
343
CHANGE FILTER
344
3B
3-5
11RR-2
ITR-1
20W
20X
19-K
1HGR
3-15
19-B
1HG-1
4B
345
89
FLOAT
19-C
CYCLE CROSS SLIDE FEED
OFF
OFF
OFF
HAND
AUTO
AUTO
SETUP
AUTO
SETUP
346
347
348
5-B
1-17
2-RR
1-22
HAND CYCLE
1-U
2-RR
1-Z
1-Y
2-RR
1-Z
TABLE IN
TABLE OUT
EMERG. STOP
INTERLOCK
OFF
ON
6-B
2-19
2-18
9-B
351
352
353
10-B
3RR
349
350
354
1-9
1-Z
CYCLE START
3RR-1
1-19
2-20
2RR-2
M-5
1-21
3RR
1-1
1-10
1-19
1-5
1-15
1-Z
1-20
TABLE OUT
355
8B
6RR-1
62RR-2
2-21
4RR
TABLE IN
2-1
2-10
10-2
10-3
1-22
2RR-1
10RR-2
6RR-2
2-Y
5-RR
TABLE OUT
1-4
1-16
2W
2K
3-2
3-3
2-2
2-3
1-Z
2V
18RR-1
15RR-1
17W
17V
9-8
9-11
17-D
17-T
49RR-2
45RR-6
10RR-1
2-9
6RR
17K
6-E
6-S
7-E
7-S
3-1
3-10
2-22
TABLE IN
47RR-2
2-A
2-L
2-K
6RR
23RR-2
71RR-2
35RR-3
9-E
9-S
6RR-4
2-Z
18-E
18-S
12-E
5-6
5-14
11-2
11-3
64RR-2
12S
7RR-4
1-V
23RR-1
2-17
7RR
2-7
2-13
1-W
1-X
18-D
18-T
2-22
2-V
7RR
2-Z
18-21
18-22
301
307

FIG. 17

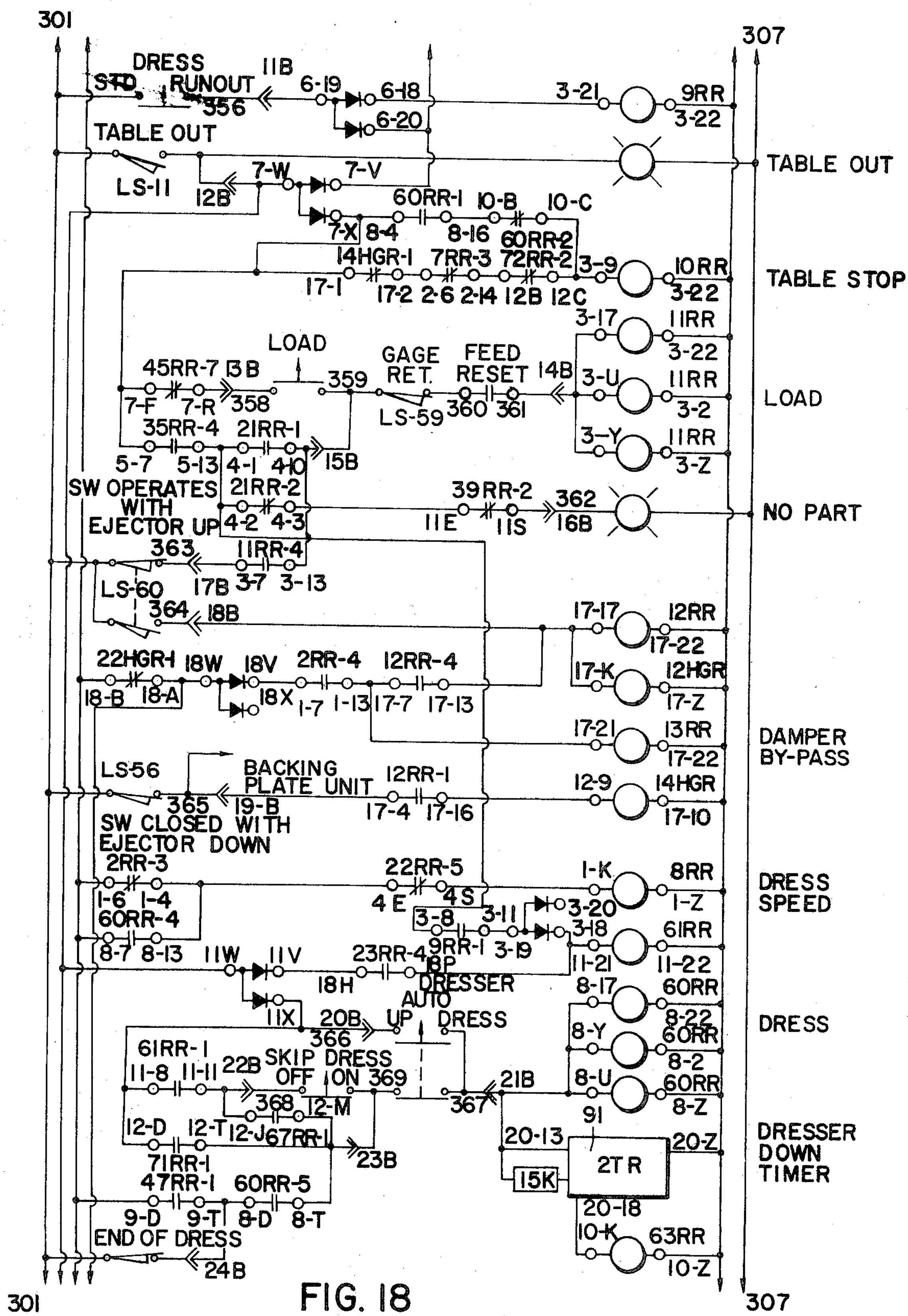

301
307
DRESS
STD. RUNOUT
356
11B
6-19
6-18
6-20
3-21
9RR
3-22
TABLE OUT
LS-11
12B
7-W
7-V
TABLE OUT
60RR-1
10-B
10-C
7-X
8-4
8-16
60RR-2
14HGR-1
7RR-3
72RR-2
3-9
10RR
17-1
17-2
2-6
2-14
12B
12C
3-22
TABLE STOP
3-17
11RR
3-22
LOAD
45RR-7
13B
359
GAGE RET.
FEED RESET
14B
3-U
11RR
7-F
7-R
358
LS-59
360
361
3-2
LOAD
35RR-4
21RR-1
3-Y
11RR
5-7
5-13
4-1
4-10
15B
3-Z
SW OPERATES WITH EJECTOR UP
21RR-2
39RR-2
362
4-2
4-3
11E
11S
16B
NO PART
363
11RR-4
LS-60
17B
3-7
3-13
364
18B
17-17
12RR
17-22
22HGR-1
18W
18V
2RR-4
12RR-4
17-K
12HGR
18-B
18-A
18X
1-7
1-13
17-7
17-13
17-Z
17-21
13RR
17-22
DAMPER BY-PASS
LS56
BACKING PLATE UNIT
12RR-1
12-9
14HGR
365
19-B
17-4
17-16
17-10
SW CLOSED WITH EJECTOR DOWN
2RR-3
22RR-5
1-K
8RR
DRESS SPEED
1-6
1-4
4E
4S
1-Z
60RR-4
3-8
3-11
3-20
3-18
61RR
8-7
8-13
11W
11V
23RR-4
9RR-1
3-19
11-21
11-22
18H
18P
DRESSER AUTO
8-17
60RR
11X
20B
UP
DRESS
8-22
DRESS
366
8-Y
60RR
61RR-1
22B
SKIP DRESS OFF ON
369
8-2
11-8
11-11
21B
8-U
60RR
368
12-M
367
8-Z
91
12-D
12-T
12-J
67RR-1
20-13
20-Z
DRESSER DOWN TIMER
23B
2TR
71RR-1
15K
47RR-1
60RR-5
20-18
9-D
9-T
8-D
8-T
10-K
63RR
END OF DRESS
24B
10-Z

FIG. 18

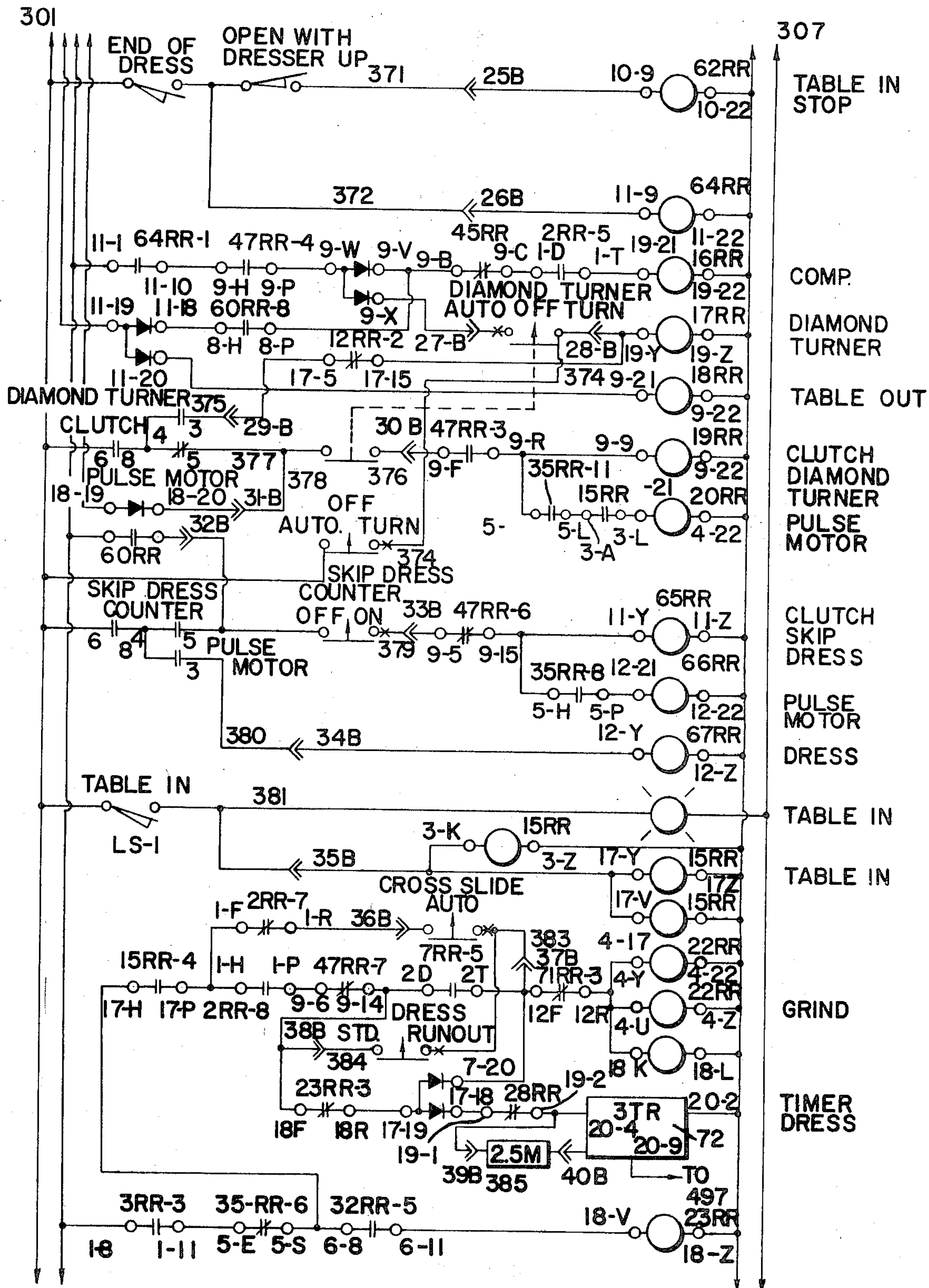

301
END OF DRESS
OPEN WITH DRESSER UP
371
25B
10-9
62RR
10-22
307
TABLE IN STOP
372
26B
11-9
64RR
11-22
11-1
64RR-1
47RR-4
9-W
9-V
9-B
45RR
9-C
2RR-5
1-D
1-T
19-21
16RR
19-22
COMP.
11-10
9-H
9-P
DIAMOND TURNER
AUTO OFF TURN
11-19
11-18
60RR-8
9-X
17RR
DIAMOND TURNER
8-H
8-P
12RR-2
27-B
28-B
19-Y
19-Z
11-20
17-5
17-15
374
9-21
18RR
9-22
TABLE OUT
DIAMOND TURNER
375
CLUTCH
4
3
29-B
30 B
47RR-3
9-R
9-9
19RR
9-22
CLUTCH DIAMOND TURNER
6
8
5
377
PULSE MOTOR
378
376
9-F
35RR-11
-21
18-19
18-20
31-B
OFF
15RR
20RR
PULSE MOTOR
32B
AUTO. TURN
5-
5-L
3-L
4-22
60RR
3-A
374
SKIP DRESS
SKIP DRESS COUNTER
COUNTER
OFF ON
33B
47RR-6
65RR
11-Y
11-Z
CLUTCH SKIP DRESS
6
8
4
5
PULSE MOTOR
3
379
9-5
9-15
35RR-8
12-21
66RR
5-H
5-P
12-22
PULSE MOTOR
380
34B
12-Y
67RR
12-Z
DRESS
TABLE IN
381
TABLE IN
LS-1
3-K
15RR
3-Z
35B
17-Y
15RR
17Z
TABLE IN
CROSS SLIDE AUTO
17-V
15RR
1-F
2RR-7
1-R
36B
383
4-17
22RR
37B
15RR-4
1-H
1-P
47RR-7
7RR-5
2D
2T
71RR-3
4-Y
4-22
22RR
17-H
17-P
2RR-8
9-6
9-14
DRESS
12F
12R
4-U
4-Z
GRIND
38B STD.
RUNOUT
384
7-20
18 K
18-L
23RR-3
19-2
17-18
28RR
3TR
20-2
TIMER DRESS
18F
18R
17-19
20-4
20-9
72
19-1
2.5M
40B
39B
385
TO
497
3RR-3
35-RR-6
32RR-5
18-V
23RR
1-8
1-11
5-E
5-S
6-8
6-11
18-Z
301
307

FIG. 19

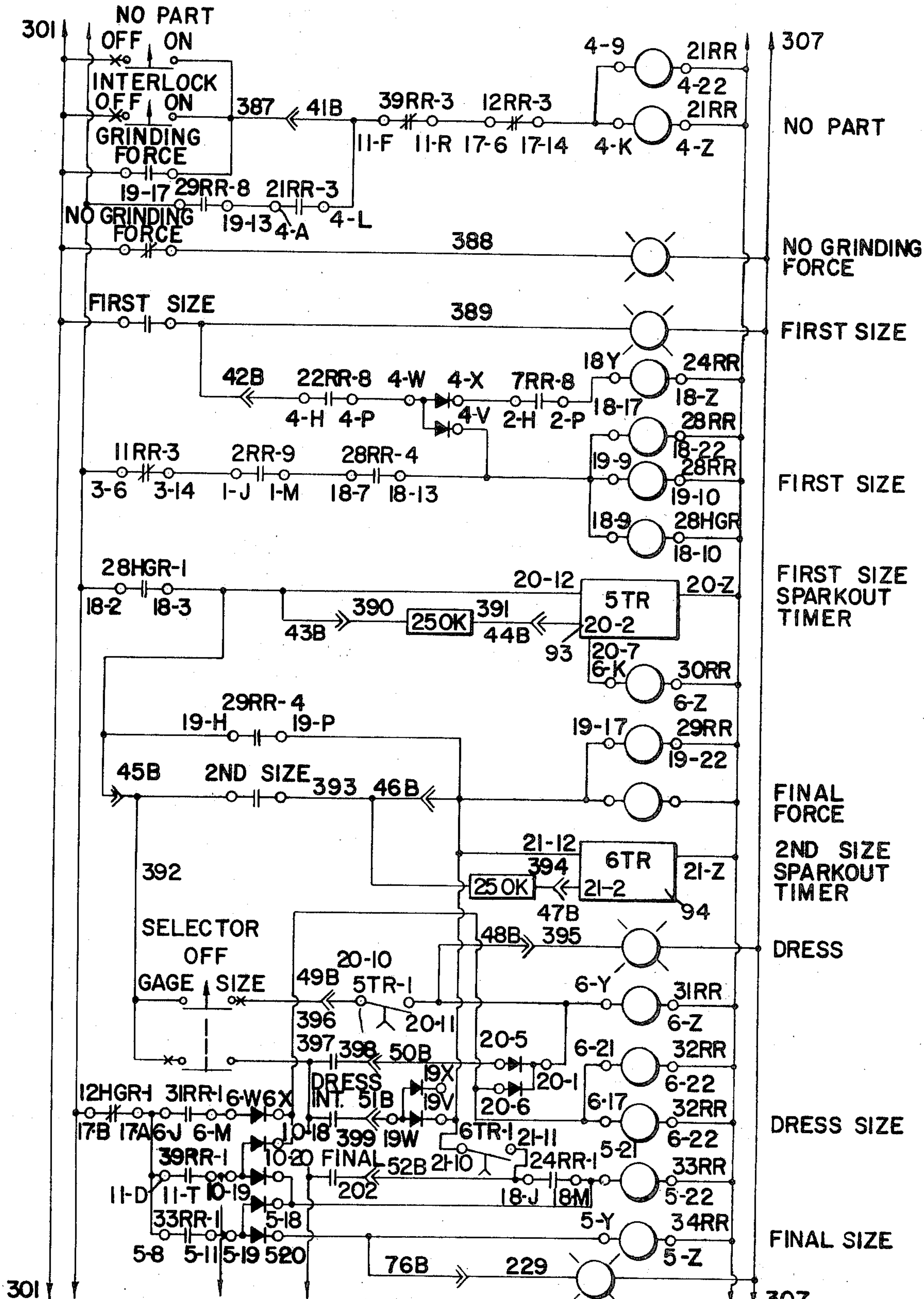

301
NO PART
OFF ON
INTERLOCK
OFF ON
GRINDING FORCE
NO GRINDING FORCE
387
41B
39RR-3
12RR-3
11-F 11-R 17-6 17-14
4-9
21RR
4-22
21RR
4-K 4-Z
307
NO PART
19-17 29RR-8 21RR-3
19-13 4-A 4-L
388
NO GRINDING FORCE
FIRST SIZE
389
FIRST SIZE
42B 22RR-8 4-W 4-X 7RR-8
4-H 4-P 4-V 2-H 2-P
18Y 24RR 18-Z 18-17
28RR 18-22 28RR 19-9 19-10
11RR-3 2RR-9 28RR-4
3-6 3-14 1-J 1-M 18-7 18-13
FIRST SIZE
18-9 28HGR 18-10
28HGR-1
18-2 18-3
20-12
5TR
20-Z
390 250K 391
43B 44B 20-2
93
FIRST SIZE SPARKOUT TIMER
20-7 6-K 30RR 6-Z
29RR-4
19-H 19-P
19-17 29RR 19-22
45B 2ND SIZE 393 46B
FINAL FORCE
21-12
394
6TR
21-Z
250K 21-2
94
2ND SIZE SPARKOUT TIMER
392
47B
48B 395
DRESS
SELECTOR
OFF
GAGE SIZE
20-10
49B 5TR-1
396 20-11
6-Y 31RR 6-Z
397 398 50B
20-5
6-21 32RR 6-22
DRESS INT. 51B
19X 19V
20-1
20-6
6-17 32RR 6-22
DRESS SIZE
12HGR-1 31RR-1 6-W 6X
17B 17A 6-J 6-M
10-18 399 19W
6TR-1 21-11
39RR-1
10-20 FINAL 52B 21-10
24RR-1
5-21 33RR 5-22
11-D 11-T 10-19
202
18-J 18M
33RR-1
5-18
5-Y 34RR 5-Z
FINAL SIZE
5-8 5-11 5-19 5-20
76B 229
301
307

FIG. 20

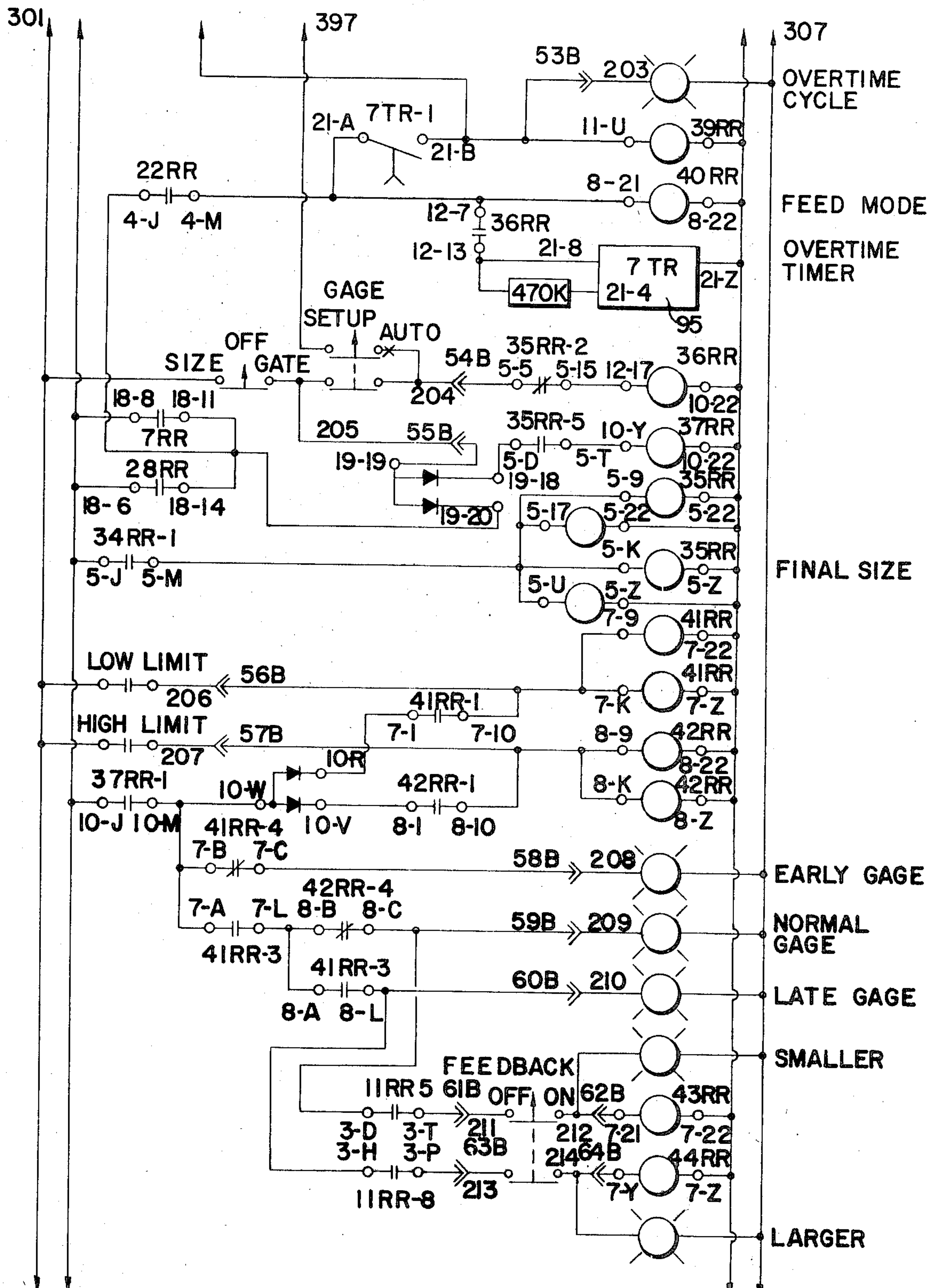

301
397
307
53B
203
OVERTIME CYCLE
21-A
7TR-1
21-B
11-U
39RR
22RR
4-J 4-M
8-21
40 RR
8-22
FEED MODE
12-7
36RR
12-13
21-8
7 TR
OVERTIME TIMER
470K
21-4
21-Z
95
GAGE SETUP
AUTO
OFF
SIZE
GATE
54B
35RR-2
5-5
5-15
12-17
36RR
10-22
204
18-8 18-11
7RR
205
55B
35RR-5
10-Y
37RR
5-D
5-T
10-22
19-19
19-18
5-9
35RR
28RR
18-6 18-14
19-20
5-17
5-22
5-22
34RR-1
5-K
35RR
5-J 5-M
5-U
5-Z
5-Z
FINAL SIZE
7-9
41RR
7-22
LOW LIMIT
56B
206
41RR
7-K
7-Z
41RR-1
HIGH LIMIT
57B
7-1
7-10
8-9
42RR
207
10R
8-22
37RR-1
10-W
42RR-1
8-K
42RR
10-J 10-M
41RR-4
10-V
8-1
8-10
8-Z
7-B 7-C
58B
208
EARLY GAGE
42RR-4
7-A 7-L 8-B 8-C
59B
209
NORMAL GAGE
41RR-3
41RR-3
60B
210
LATE GAGE
8-A 8-L
SMALLER
FEEDBACK
11RR5
61B
OFF ON
62B
43RR
3-D 3-T
211
212
7-21
7-22
3-H 3-P
63B
214
64B
44RR
11RR-8
213
7-Y
7-Z
LARGER

FIG. 21

PATENTED JAN 18 1972 3,634,979

SHEET 21 OF 36

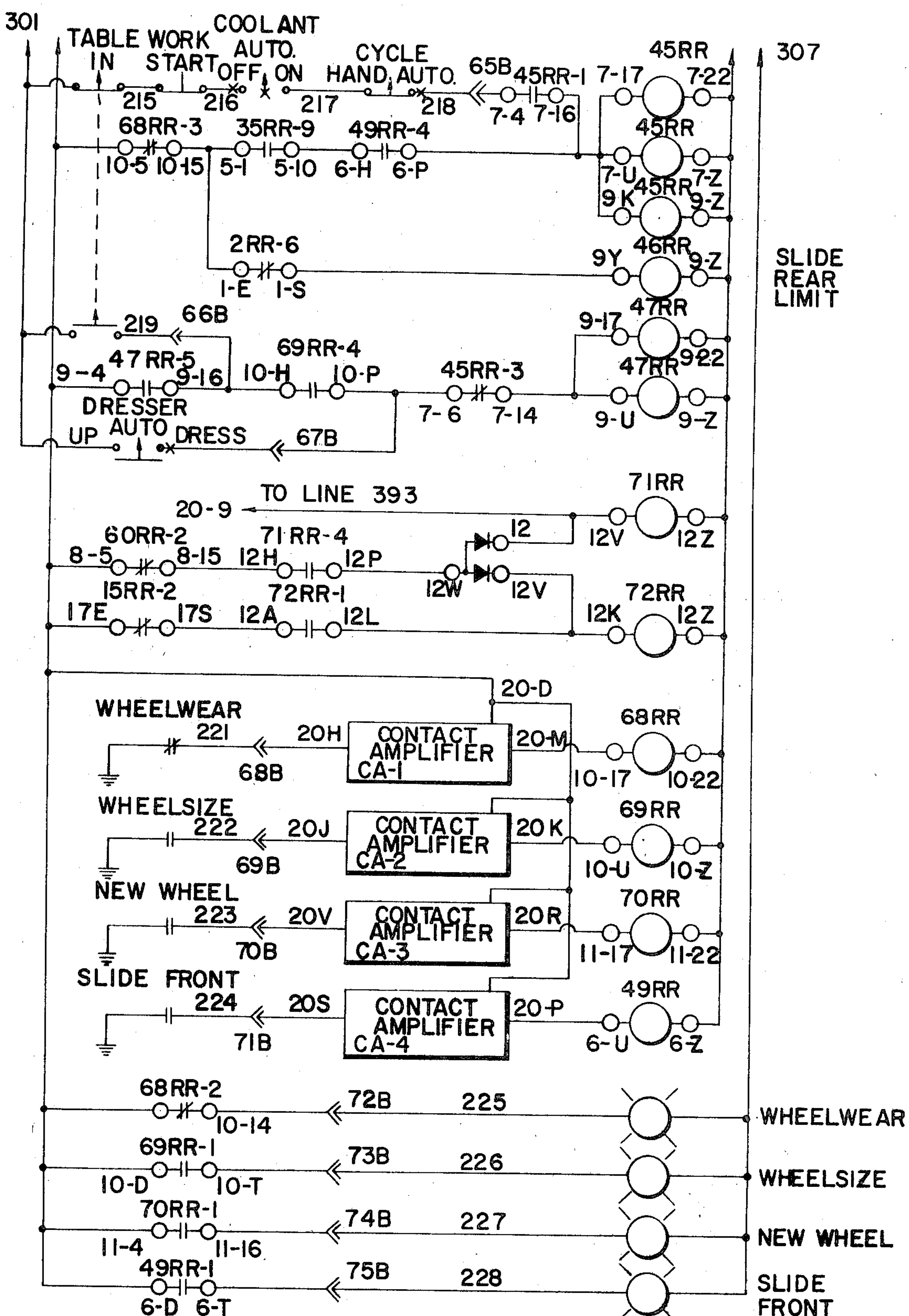
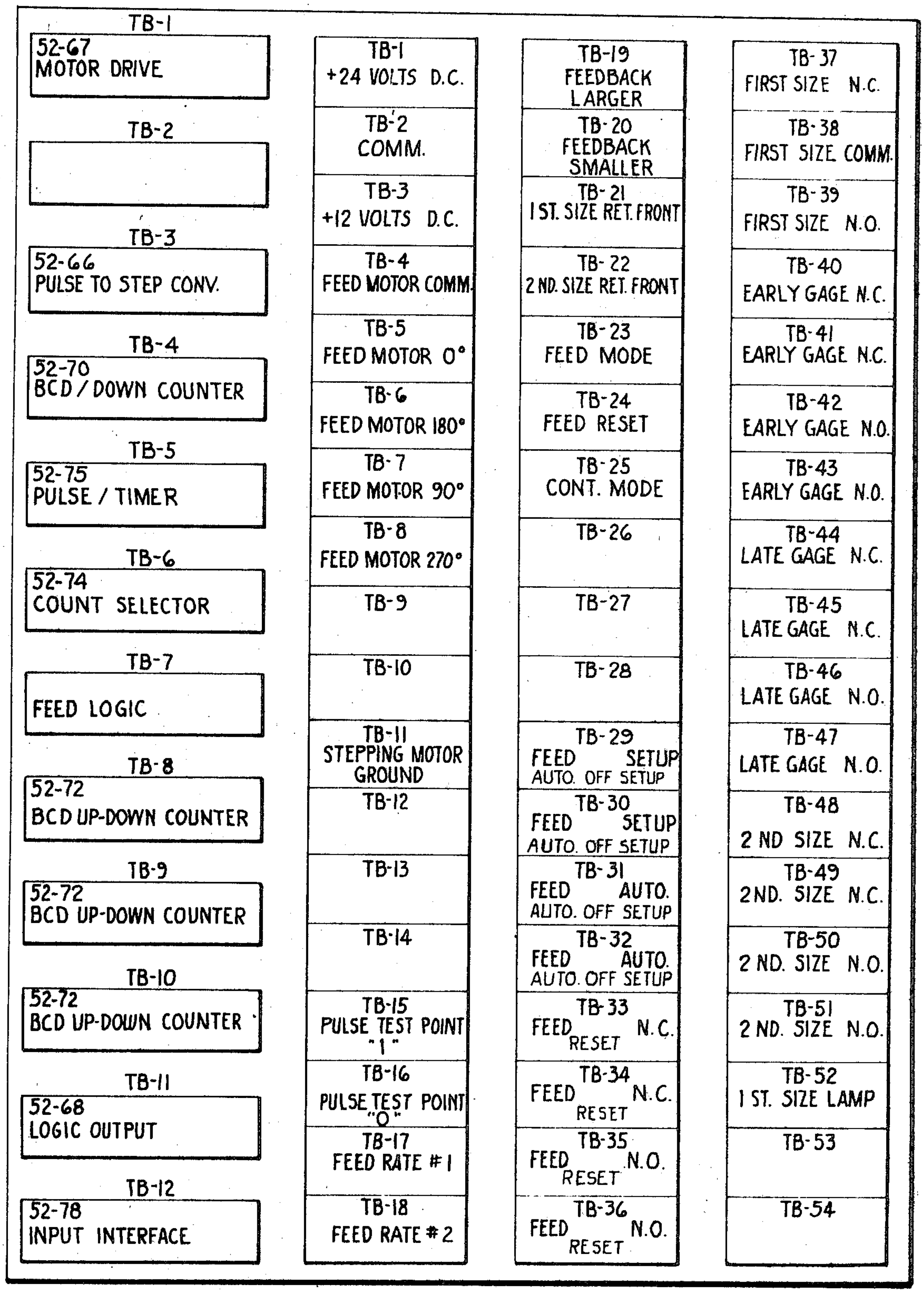


FIG. 22



I.C. FEED UNIT FOR FRONT STEPPING MOTOR
CARD CAGE & TERMINAL STRIPS VIEWED FROM WIRING SIDE

FIG. 23

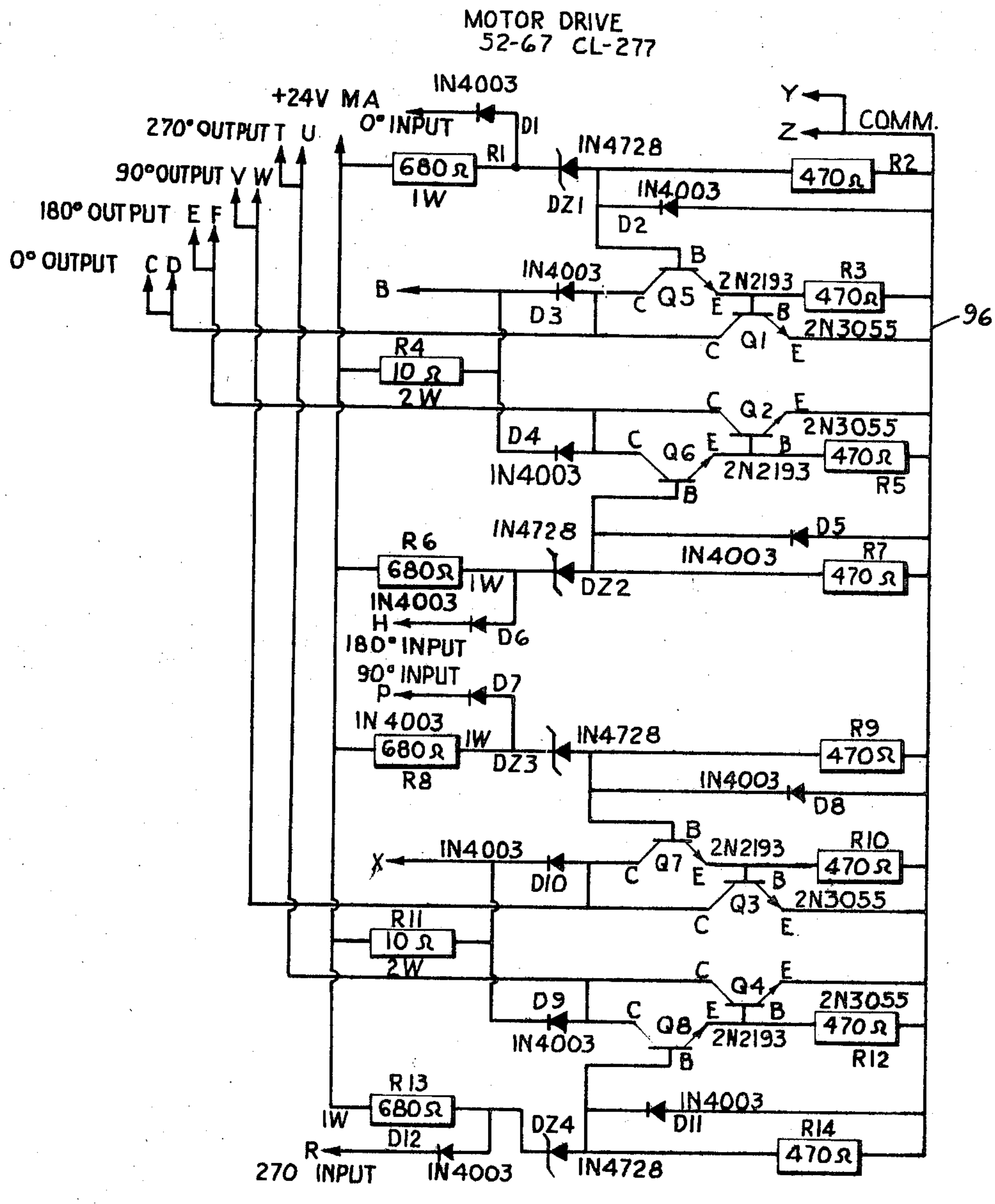

MOTOR DRIVE
52-67 CL-277
+24V MA
270° OUTPUT T U
90° OUTPUT V W
180° OUTPUT E F
0° OUTPUT C D
IN4003
0° INPUT
D1
R1
680Ω
1W
IN4728
DZ1
Y
Z
COMM.
470Ω
R2
IN4003
D2
B
IN4003
B
D3
Q5
2N2193
R3
470Ω
Q1
2N3055
96
R4
10Ω
2W
Q2
2N3055
D4
IN4003
Q6
2N2193
470Ω
R5
IN4728
D5
R6
680Ω
1W
IN4003
R7
470Ω
DZ2
IN4003
H
D6
180° INPUT
90° INPUT
D7
P
IN 4003
680Ω
1W
R8
DZ3
IN4728
R9
470Ω
IN4003
D8
X
IN4003
D10
Q7
2N2193
R10
470Ω
Q3
2N3055
R11
10Ω
2W
Q4
2N3055
D9
IN4003
Q8
2N2193
470Ω
R12
R13
680Ω
1W
D12
R
270 INPUT
IN4003
DZ4
IN4728
IN4003
D11
R14
470Ω

FIG. 24

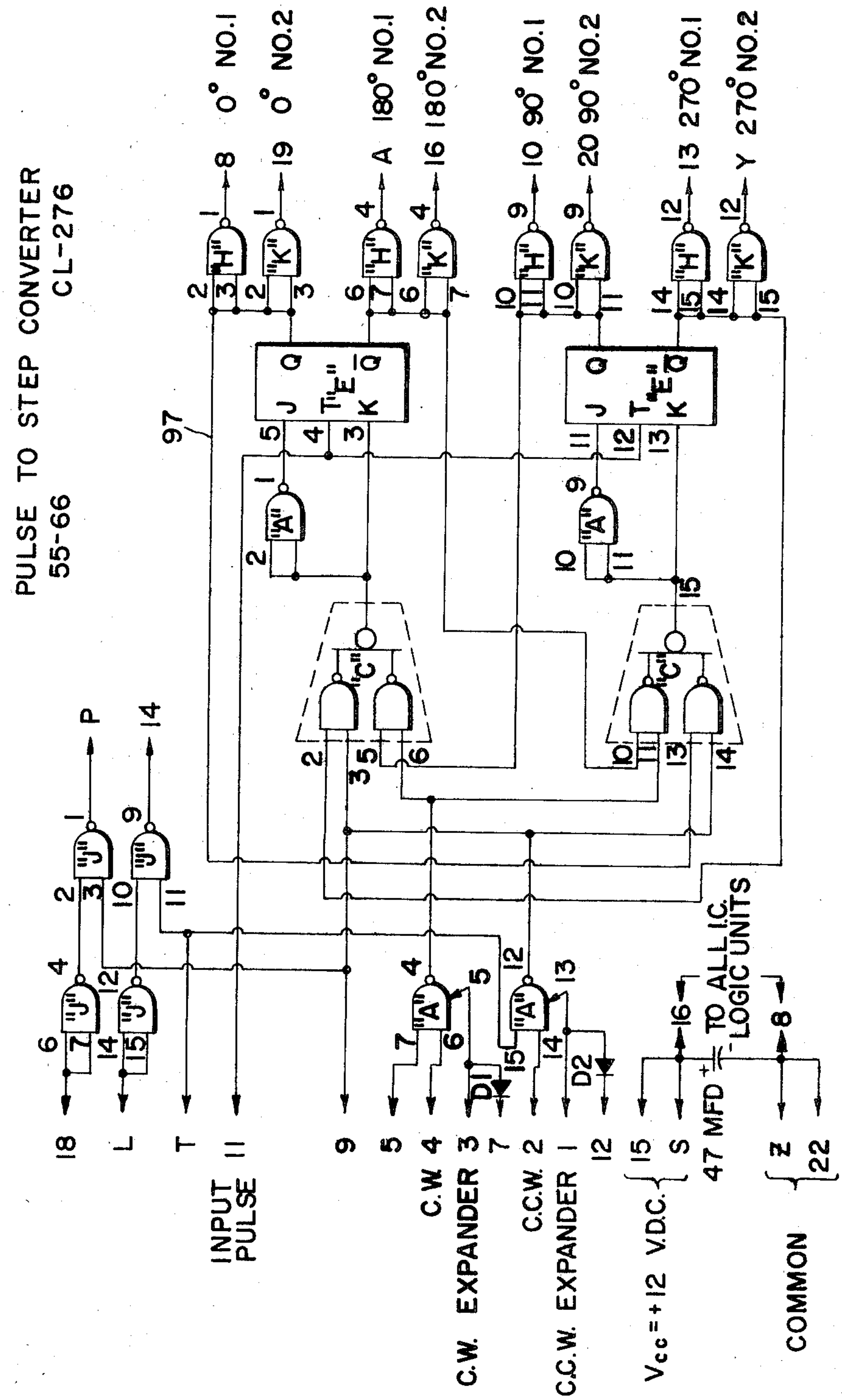
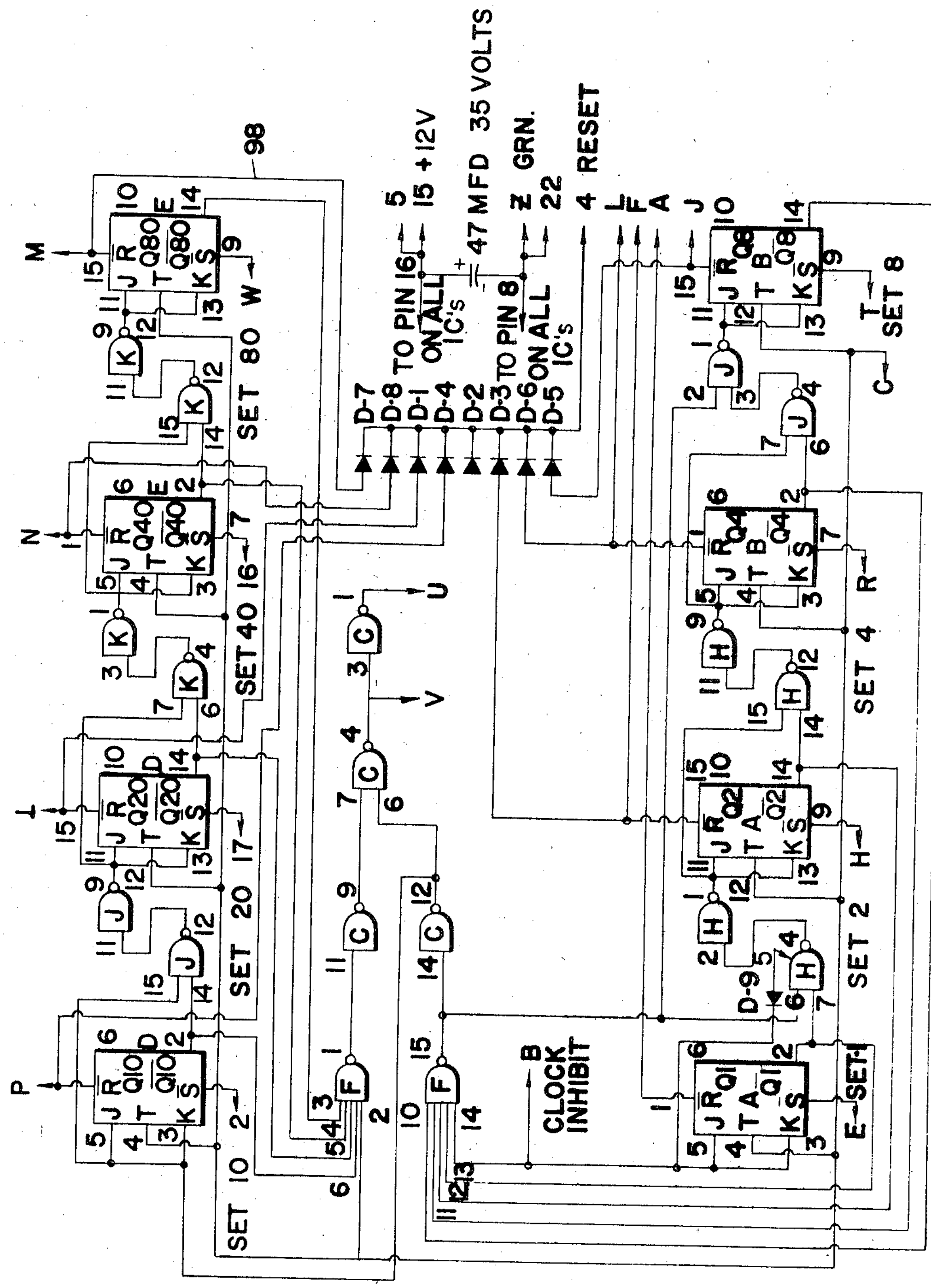

PULSE TO STEP CONVERTER CL-276
55-66
0° NO.1
0° NO.2
180° NO.1
180° NO.2
90° NO.1
90° NO.2
270° NO.1
270° NO.2
INPUT PULSE
C.W.
C.W. EXPANDER
C.C.W.
C.C.W. EXPANDER
V_{cc} = +12 V.D.C.
47 MFD
TO ALL I.C. LOGIC UNITS
COMMON

FIG. 25



BCD TWO DECADE DOWN COUNTER
52-70
CL-279

FIG. 26

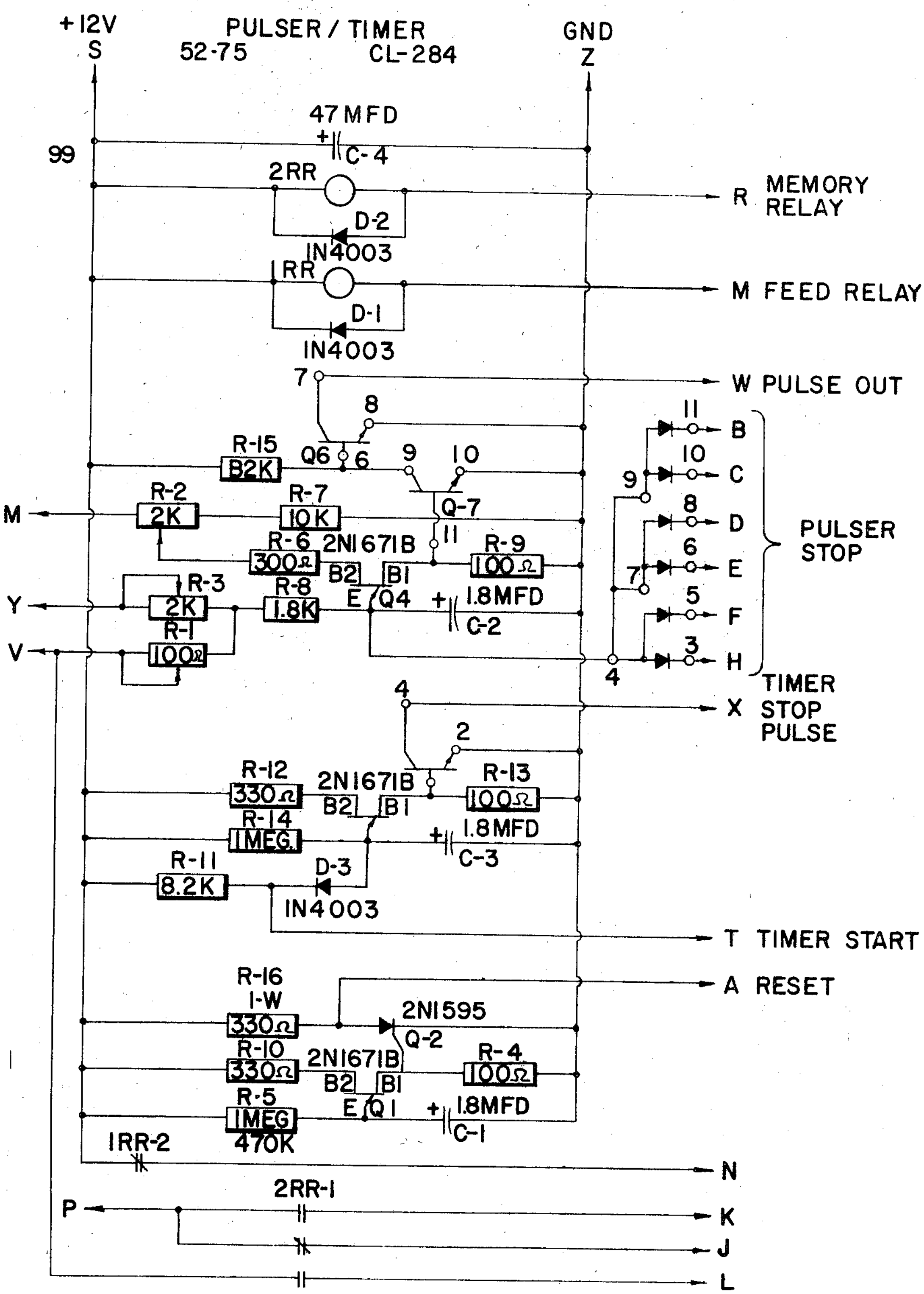

+12V
S
PULSER / TIMER
52-75
CL-284
GND
Z
47 MFD
C-4
99
2RR
R MEMORY RELAY
D-2
IN4003
1RR
M FEED RELAY
D-1
IN4003
W PULSE OUT
R-15
82K
Q6
R-2
2K
R-7
10K
Q-7
R-6
300Ω
2N1671B
R-9
100Ω
B2
B1
R-3
2K
R-8
1.8K
E
Q4
1.8MFD
C-2
R-1
100Ω
M
Y
V
B
C
D
E
F
H
PULSER STOP
TIMER STOP PULSE
X
R-12
330Ω
2N1671B
R-13
100Ω
R-14
1MEG.
1.8MFD
C-3
R-11
8.2K
D-3
IN4003
T TIMER START
A RESET
R-16
1-W
330Ω
2N1595
Q-2
R-10
330Ω
2N1671B
R-4
100Ω
R-5
1MEG
470K
Q1
1.8MFD
C-1
1RR-2
N
P
2RR-1
K
J
L

FIG. 27

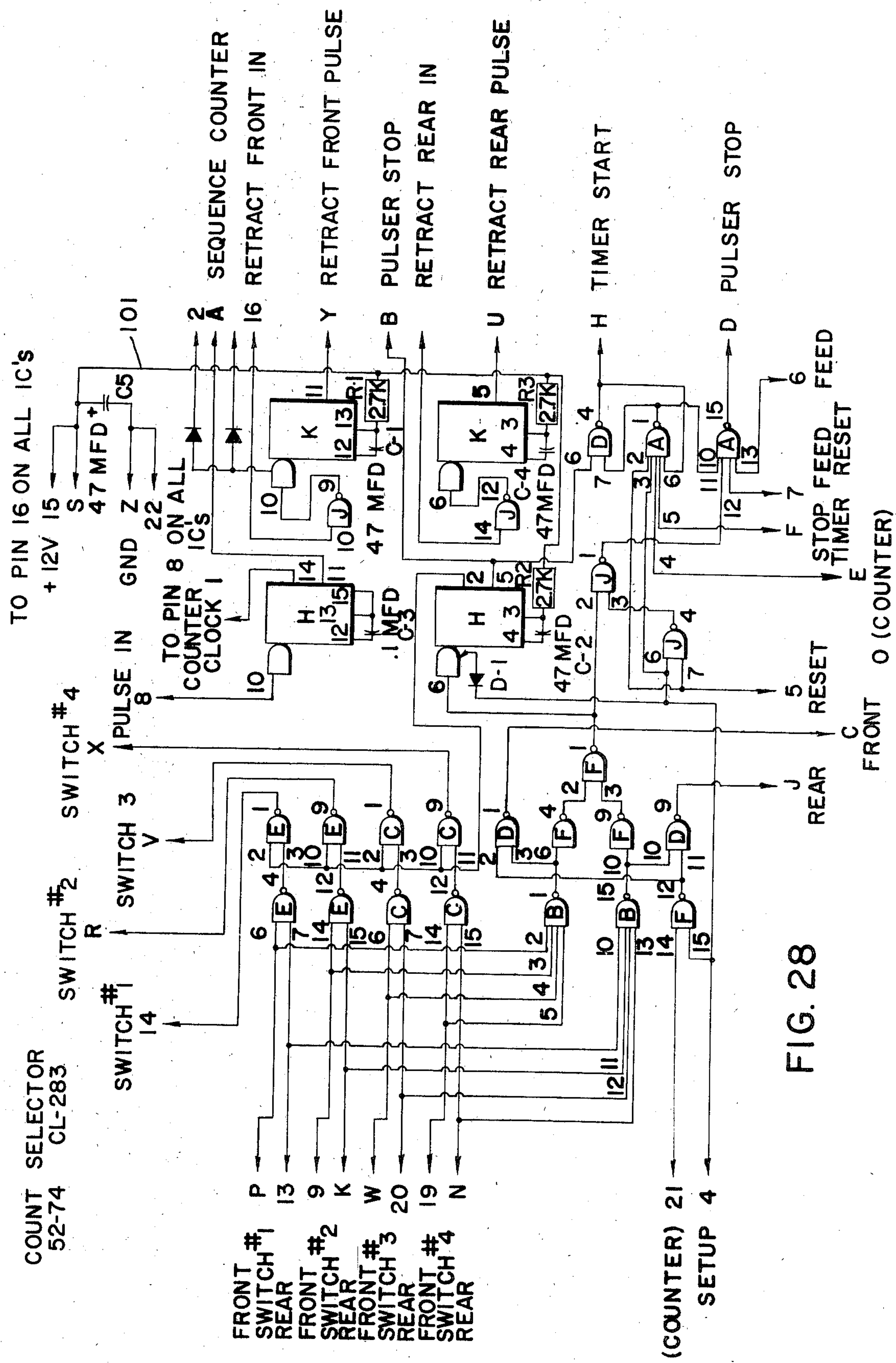

COUNT SELECTOR
52-74 CL-283
TO PIN 16 ON ALL IC's
+12V 15
S
47 MFD
C5
GND Z
22
TO PIN 8 ON ALL IC's
101
2 SEQUENCE COUNTER
A RETRACT FRONT IN
16
Y RETRACT FRONT PULSE
B PULSER STOP
RETRACT REAR IN
U RETRACT REAR PULSE
H TIMER START
D PULSER STOP
6 FEED
7 FEED RESET
F STOP TIMER
E
O (COUNTER)
5 RESET
C FRONT
J REAR
TO PIN COUNTER CLOCK 1
PULSE IN 8
SWITCH #4 X
SWITCH 3 V
SWITCH #2 R
SWITCH #1 14
.1 MFD C-3
47 MFD C-1
47 MFD C-4
47 MFD C-2
D-1
R1 2.7K
R2 2.7K
R3 2.7K
FRONT SWITCH #1 REAR P 13
FRONT SWITCH #2 REAR 9 K
FRONT SWITCH #3 REAR W 20
FRONT SWITCH #4 REAR 19 N
(COUNTER) 21
SETUP 4

FIG. 28

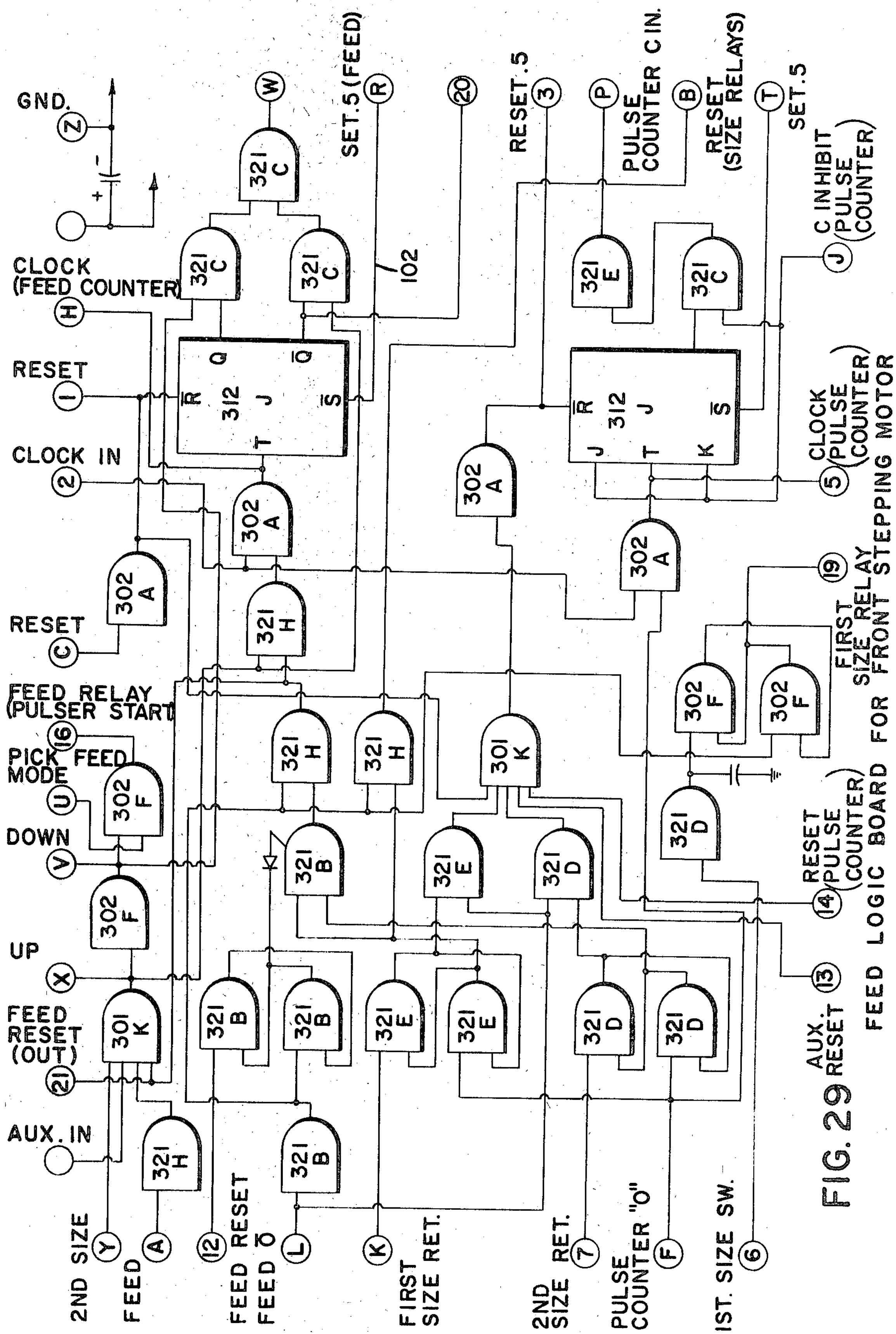


FIG. 29

FEED LOGIC BOARD FOR FRONT STEPPING MOTOR

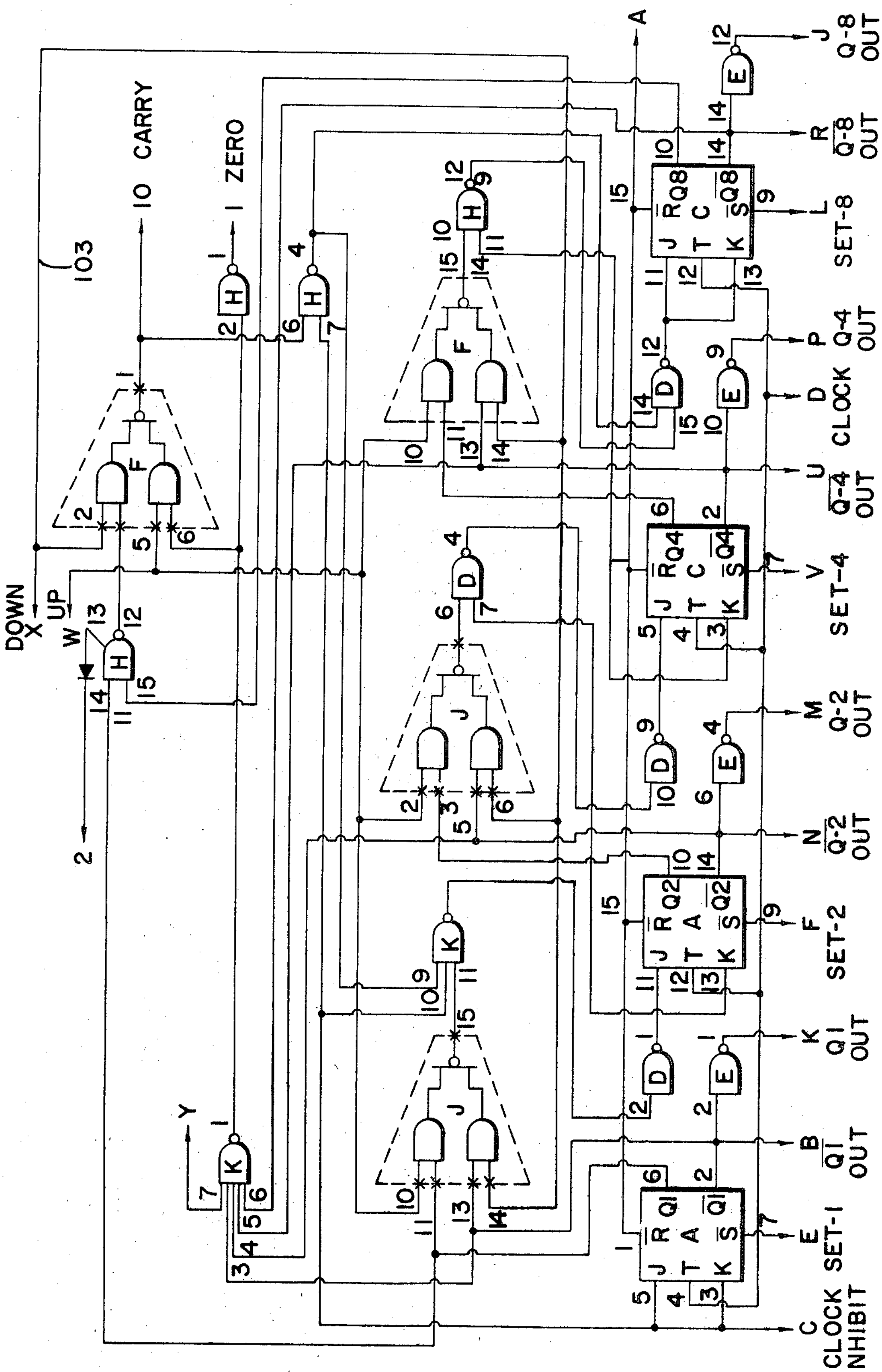
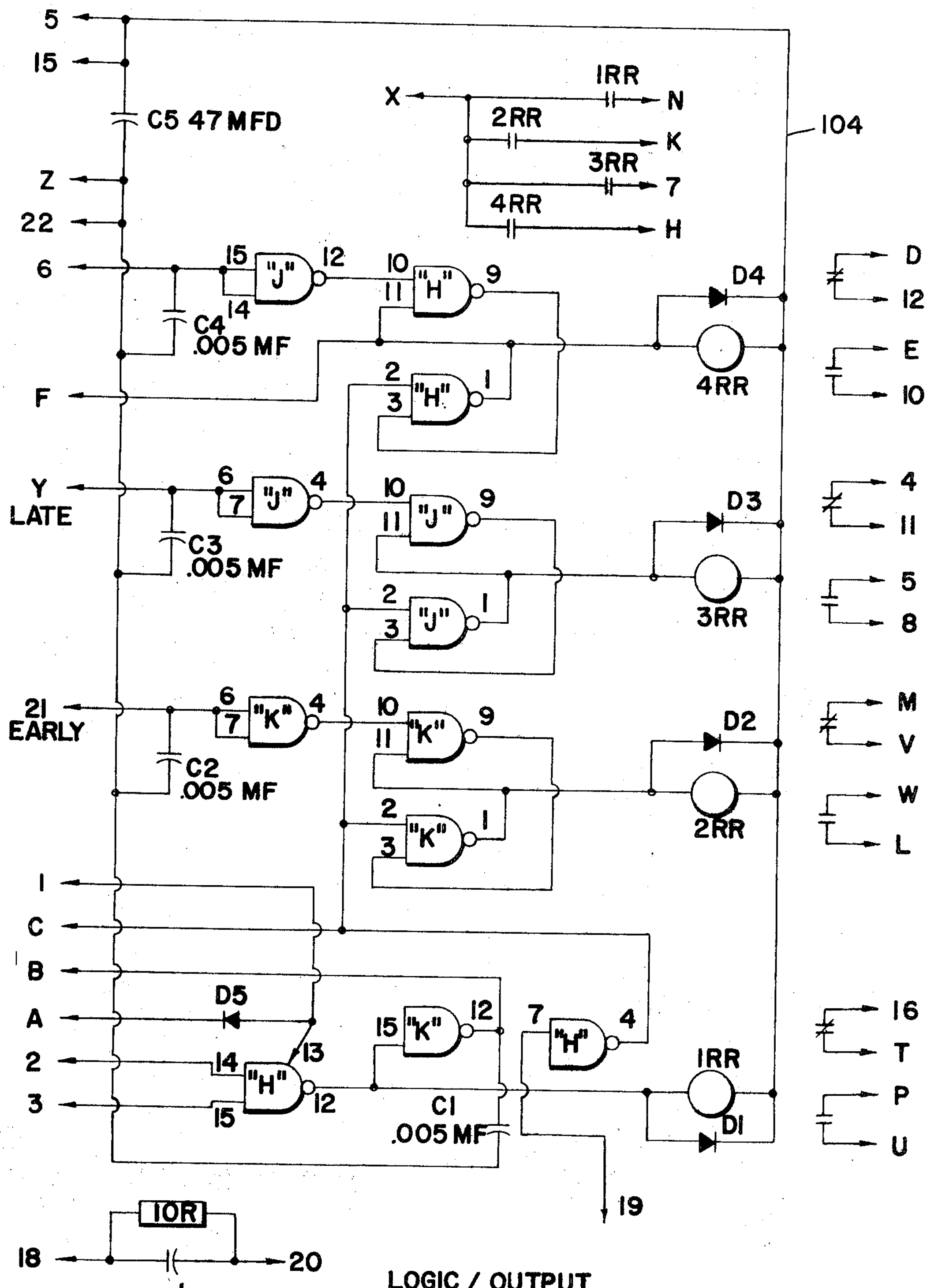


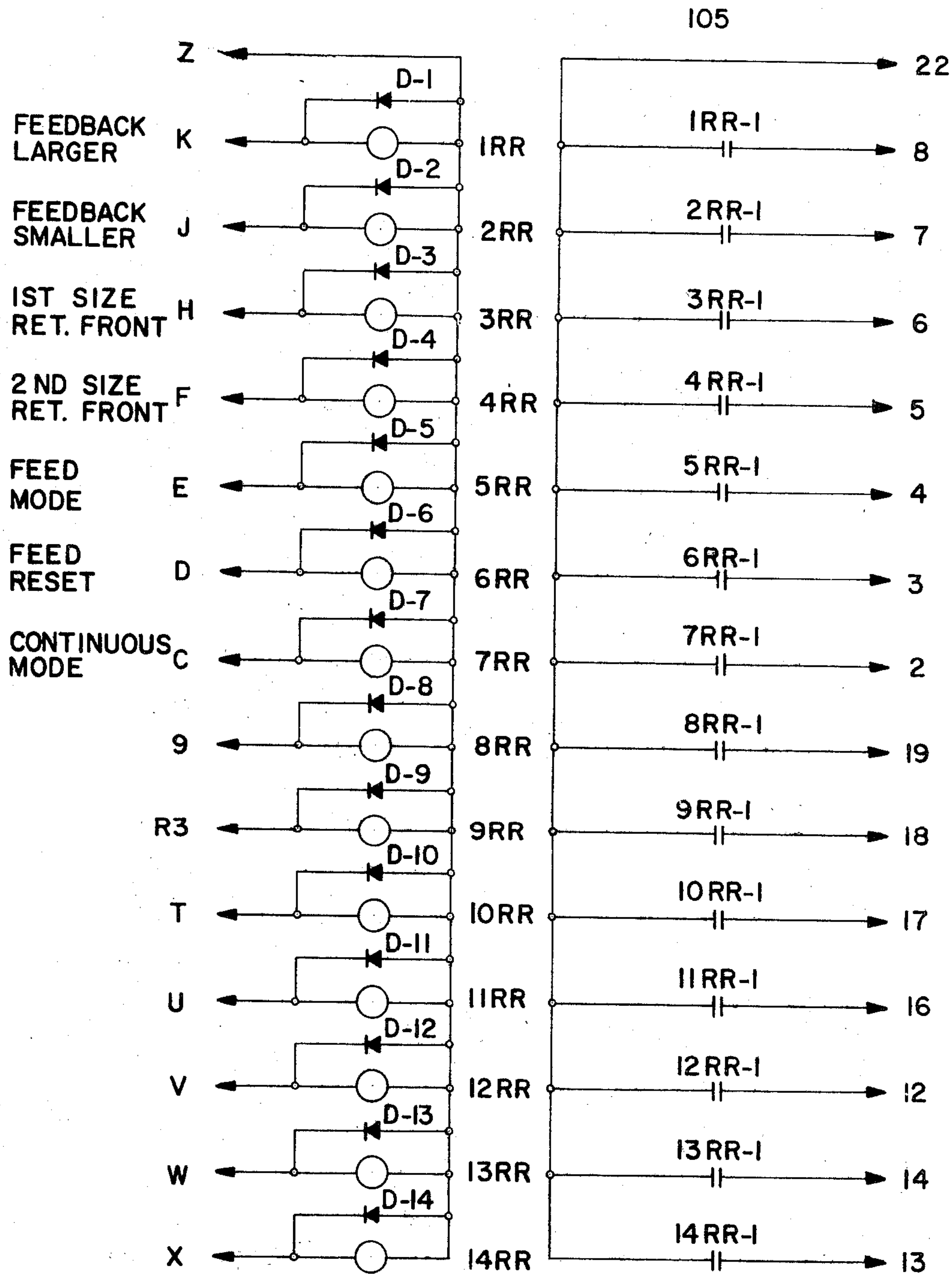
FIG. 30

BCD UP-DOWN DECADE COUNTER
CL-281
52-72



LOGIC / OUTPUT
52·68 CL·278

FIG. 31



— INPUT INTERFACE —

FIG. 32

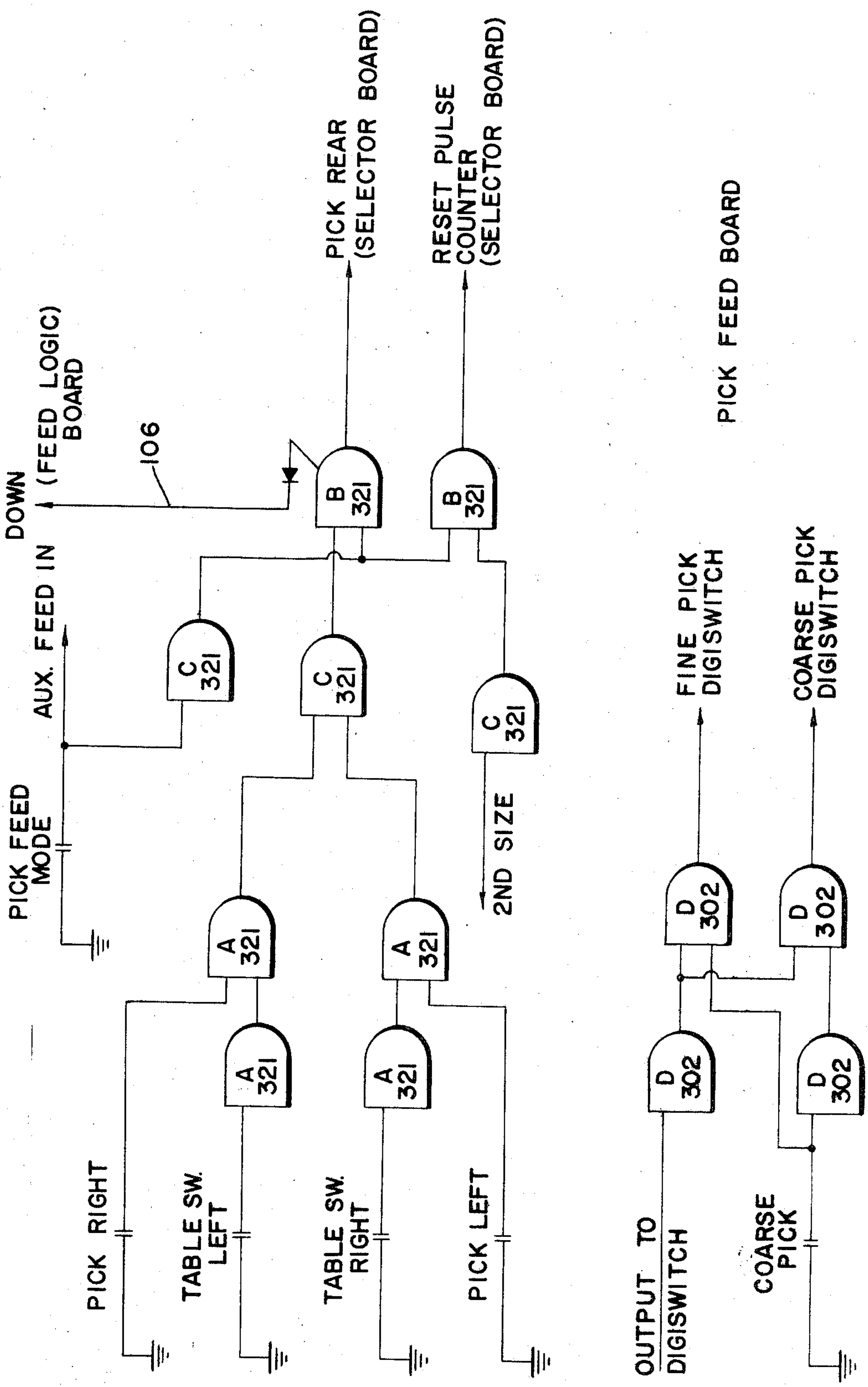

PICK REAR (SELECTOR BOARD)
RESET PULSE COUNTER (SELECTOR BOARD)
PICK FEED BOARD
DOWN
(FEED LOGIC) BOARD
106
B 321
B 321
AUX. FEED IN
C 321
C 321
C 321
PICK FEED MODE
2ND SIZE
A 321
A 321
A 321
A 321
FINE PICK DIGISWITCH
COARSE PICK DIGISWITCH
D 302
D 302
D 302
D 302
PICK RIGHT
TABLE SW. LEFT
TABLE SW. RIGHT
PICK LEFT
OUTPUT TO DIGISWITCH
COARSE PICK

FIG. 33

CHART FOR STEPPING MOTOR #2 CONNECTIONS

TERMINAL	CONNECT TO
TB-1	(SW1-1),(SW1-3),(SW2-1),(SW2-3),(SW2-5),(RL1-C),(RL2-C),(RL3-C),(J1-M),(J11-X),(RS1-1),(RS2-1),(RS3-1)
TB-2	(J1-Z),(J1-Y),(J3-Z),(J3-22),(J4-Z),(J4-22),(J5-Z),(J5-22),(J6-Z),(J6-22),(J7-Z),(J7-22),(J8-Z),(J8-22),(J9-Z),(J9-22),(J10-Z),(J10-22),(J11-Z),(J11-22),(J12-Z),(J12-22),(L1-2),(L2-2),(L3-2),(L4-2)(RS1-8),(RS2-8)
TB-3	(J3-S),(J3-15),(J4-S),(J4-15),(J5-S),(J5-15),(J6-S),(J6-15),(J7-S),(J7-15),(J8-S),(J8-15),(J9-S),(J9-15),(J10-S),(J10-15),(J11-S),(J11-15),(J12-S),(J12-15),(J7-R),(J7-T),(J8-E),(J8-F),(J8-V),(J8-L),(J9-E),(J9-F),(J9-V),(J9-L),(J10-E),(J10-F),(J10-V),(J10-L)
TB-4 (a)	(SW2-2),(SW2-4)
(b)	INSTALL 1N3253 DIODE (CATHODE TO J-4) (ANODE TO J-2)
TB-5	(J1-C),(J1-D)
TB-6	(J1-E),(J1-F)
TB-7	(J1-V),(J1-W)
TB-8	(J1-T),(J1-U)
TB-15	(J6-1),(J7-2)
TB-16	(J3-11),(J6-A)
TB-17	(E1-C)
TB-18	(F1-C)
TB-19	(J12-K),(SW1-2)
TB-20	(J12-J),(SW1-4)
TB-21	(J12-H)
TB-22	(J12-F)
TB-23	(J12-E)

TERMINAL	CONNECT TO
TB-24	(J12-D)
TB-25	(J12-C)
TB-29	(SW2-9)
TB-30	(SW2-10)
TB-31	(SW2-7)
TB-32	(SW2-8)
TB-33	(J11-16)
TB-34	(J11-T)
TB-35	(J11-P)
TB-36	(J11-U)
TB-37	(J5-J)
TB-38	(J5-P)
TB-39	(J5-K)
TB-40	(J11-M)
TB-41	(J11-V)
TB-42	(J11-W)
TB-43	(J11-L)
TB-44	(J11-4)
TB-45	(J11-11)
TB-46	(J11-5)
TB-47	(J11-8)
TB-48	(J11-D)
TB-49	(J11-12)
TB-50	(J11-E)
TB-51	(J11-10)
J1-A	(J3-8)
J1-H	(J3-A)
J1-P	(J3-10)
J1-R	(J3-13)
J3-9	(J3-5)
J3-P	(J5-B)
J3-14	(J5-C)

FIG. 34

CHART FOR STEPPING MOTOR #2 CONNECTIONS

TERMINAL	CONNECT TO
J3-4	(J6-C)
J3-2	(J6-J)
J3-7	(J7-16),(J6-6),(J5-M)
J3-12	(J7-21),(J6-7)
J4-P	(J4-1),(J4-N),(J4-M),(J4-A) (J4-F),(J4-L),(J4-J),(J7-3)
J4-B	(J7-P)
J4-C	(J7-5)
J4-V	(J6-E),(J7-F)
J4-E	(M3-1),(K3-1),(H3-1)
J4-H	(M3-2),(K3-2),(H3-2)
J4-R	(M3-4),(K3-4),(H3-4)
J4-T	(M3-8),(K3-8),(H3-8)
J4-2	(K2-1)
J4-17	(K2-2)
J4-16	(K2-4)
J4-W	(K2-8)
J5-D	(J6-D)
J5-E	(J6-B),(J11-18),(J7-J)
J5-A	(J7-C)
J5-T	(J6-H)
J5-N	(J5-Y)
J5-X	(J6-F)
J5-W	(J6-8)
J5-R	(J7-19)
J5-L	(E2-C),(F2-C)
F2-9	(F1-9)
E2-9	(E1-9)
J6-19	(J12-8)
J6-N	(J12-7)
J6-W	(J12-6)
J6-9	(J12-5)

TERMINAL	CONNECT TO
J6-4	(J12-2),(J7-14),(J11-20)
J6-21	(J4-U)
J6-5	(J7-1),(J8-A),(J9-A),(J10-A)
J6-X	(H3-C)
J6-V	(K3-C),(K2-C)
J6-R	(M3-C)
J6-16	(J12-6)
J6-Y	(J7-K)
J6-T	(J12-5)
J6-U	(J7-7)
J7-L	(J11-B)
J7-12	(J12-3)
J7-2	(J12-4)
J7-Y	(J11-F)
J7-X	(J8-W),(J9-W),(J10-W)
J7-V	(J8-X),(J9-X),(J10-X)
J7-H	(J8-D),(J9-D),(J10-D)
J7-W	(J8-C),(J8-2)
J7-20	(J8-Y)
J7-B	(J11-19)
J7-6	(A1-C),(A2-C),(A3-C)
J8-1	(J11-3)
J8-K	(RS3-2),(A3-1),(B3-1) (D3-1)
J8-M	(RS3-3),(A3-2),(B3-2) (C3-2),(D3-2)
J8-P	(RS3-4),(A3-4),(B3-4) (C3-4),(D3-4)
J8-12	(RS3-5),(A3-8),(B3-8) (C3-8),(D3-8)
J8-10	(J9-C),(J9-2)
J9-1	(J11-2)
J9-K	(RS2-2),(A2-1),(B2-1) (C2-1),(D2-1)

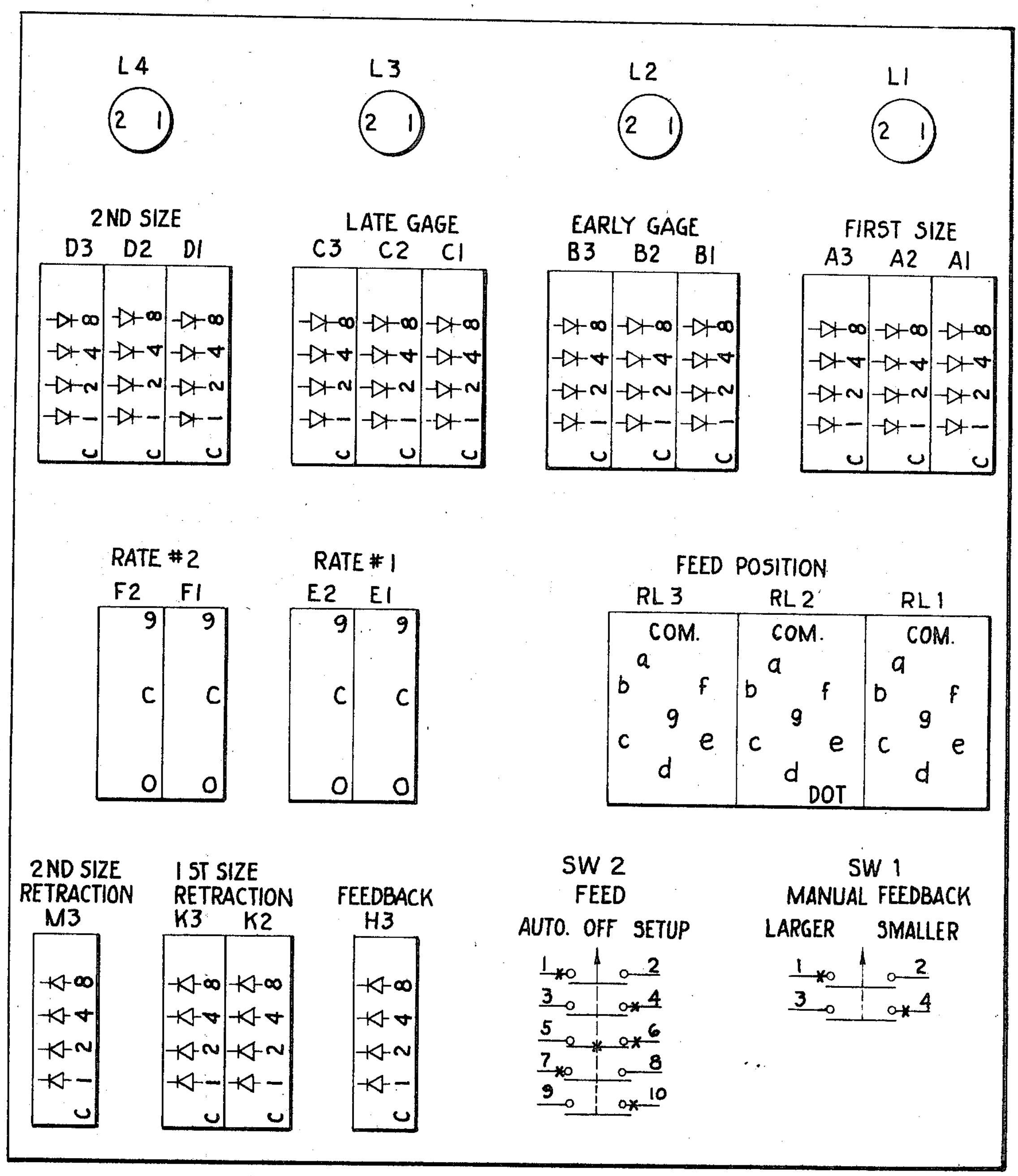
FIG. 35

CHART FOR STEPPING MOTOR #2 CONNECTIONS

TERMINAL	CONNECT TO
J9-M	(RS2-3),(A2-2),(B2-2),(C2-2) (D2-2)
J9-P	(RS2-4),(A2-4),(B2-4) (C2-4),(D2-4)
J9-12	(RS2-5),(A2-8),(B2-8) (C2-8),(D2-8)
J9-10	(J10-C),(J10-2)
J10-K	(RS1-2),(A1-1),(B1-1),(C1-1) (D1-1)
J10-M	(RS1-3),(A1-2),(B1-2),(C1-2) (D1-2)
J10-P	(RS1-4),(A1-4),(B1-4),(C1-4) (D1-4)
J10-12	(RS1-5),(A1-8),(B1-8),(C1-8) (D1-8)
J10-1	(J11-A)
J11-6	(D1-C),(D2-C),(D3-C)
J11-Y	(C1-C),(C2-C),(C3-C)
J11-21	(B1-C),(B2-C),(B3-C)
J11-K	(L2-1)
J11-7	(L3-1)
J11-11	(L3-1)
F2-9	(F1-9)
E2-9	(E1-9)
RL1-a	(RS1-9)
RL1-b	(RS1-10)
RL1-c	(RS1-11)

TERMINAL	CONNECT TO
RL1-d	(RS1-12)
RL1-e	(RS1-13)
RL1-f	(RS1-14)
RL1-g	(RS1-15)
RS1-6	(RS2-6),(RS3-6)
	INSTALL 1N3253(ANODE TO RS1-8)(CATHODE TO RS1-6)
RL2-DOT	(RS2-7)
	INSTALL RESISTOR BETWEEN RS2-7 & RS2-8
RL2-a	(RS2-9)
RL2-b	(RS2-10)
RL2-c	(RS2-11)
RL2-d	(RS2-12)
RL2-e	(RS2-13)
RL2-f	(RS2-14)
RL2-g	(RS2-15)
RL3-a	(RS3-9)
RL3-b	(RS3-10)
RL3-c	(RS3-11)
RL3-d	(RS3-12)
RL3-e	(RS3-13)
RL3-f	(RS3-14)
RL3-g	(RS3-15)
J-52	(L1-1)

FIG. 36



FRONT PANEL VIEWED FROM WIRING SIDE

FIG. 37

GRINDING MACHINE

BACKGROUND OF THE INVENTION

In the operation of grinding machines and, particularly, those for generating internal surfaces of revolution, it has been suggested that the crossfeed movements be brought about by the use of a stepping motor. Such a grinding machine is shown in the patent application of Robillard, et al. Ser. No. 672,222, filed Oct. 2, 1967, now U.S. Pat. No. 3,503,158 dated Mar. 31, 1970. Among the advantages of such a system is the fact that the control of the movements of the cross-slide can be controlled very accurately by the use of pulses, making use of modern logic circuitry. Among the disadvantages of this basic system, however, is the fact that, when used with a complex grinding cycle, certain problems arise when a single stepping motor is used for producing the compensation motion as well as the reset and retraction motions. Among other things, it makes it impossible to carry on some of the various crossfeed motions at the same time, and it has become difficult also to keep track of the position to which the cross-slide is returned for dress. These and other difficulties experienced with the prior art devices have been obviated in a novel manner by the present invention.

It is, therefore, an outstanding object of the invention to provide a grinding machine using digital control which is capable of being used for a large variety of grinding cycles.

Another object of this invention is the provision of a grinding machine in which certain movements of the crossfeed mechanism can take place simultaneously.

A further object of the present invention is the provision of a grinding machine using stepping motors for crossfeed action wherein there is no need for reset motion following retraction.

It is another object of the instant invention to provide a grinding machine operated by the use of electrical pulses wherein the crossfeed motions of feed rate motion, retraction, and compensation can be automatically and instantaneously changed within a wide range of duration and rate.

A still further object of the invention is the provision of a grinding machine having crossfeed mechanism which permits a combination of controlled force and controlled rate grinding to give the optimum geometry and quality to the finished surface.

Another object of the invention is the provision of means whereby a grinding machine cycle can be readily interrupted for dress more than once during a given cycle.

With these and other objects in view, as will be apparent to those skilled in the art, the invention resides in the combination of parts set forth in the specification and covered by the claims appended hereto.

SUMMARY OF THE INVENTION

In general, the invention consists of a grinding machine for finishing the surface of rotation of a workpiece, the machine having a base, having a workhead table mounted on the base adapted to support the workpiece, and having a wheelhead table mounted on the base adapted to support a rotatable spindle carrying an abrasive wheel. Means is provided for supporting one of the tables for sliding motion transversely of the axis of the surface of revolution and a secondary slide is associated with the said one of the tables and mounted for transverse sliding motion independently of the said one of the tables. A first stepping motor connects the base to the secondary slide for bringing about its sliding motion, and a second stepping motor is connected, on occasion, between the said one of the tables and the secondary slide to produce a sliding motion of the table.

More specifically, a control is provided to actuate the stepping motors so that the first stepping motor is used for dress compensation movements, and the second stepping motor is used for feed rate grinding movements and retraction movements. The control presents electrical pulses to the stepping motors, and the pulse frequency and the total number of pulses presented during a given movement are adjustable.

BRIEF DESCRIPTION OF THE DRAWINGS

The character of the invention, however, may be best understood by reference to one of its structural forms, as illustrated by the accompanying drawings, in which:

FIG. 1 is a perspective view of a grinding machine embodying the principles of the present invention,

FIG. 2 is an enlarged front elevation of the machine,

FIG. 3 is a partial sectional view of the machine taken on the line III—III of FIG. 2,

FIG. 4 is a vertical sectional view of the machine taken on the line IV—IV of FIG. 2,

FIG. 5 is a horizontal sectional view of the invention taken on the line V—V of FIG. 2,

FIG. 6 is a horizontal sectional view of a portion of the invention taken on the line VI—VI of FIG. 4,

FIG. 7 is a vertical sectional view of the invention taken on the line VII—VII of FIG. 6,

FIG. 8 is a plan view in schematic form of the grinding machine,

FIG. 9 is a schematic flow chart of the control scheme used in the machine,

FIG. 10 is a cycle diagram showing the operation of the machine,

FIGS. 11–22 are schematic electrical diagrams of the main electrical control features of the machine,

FIG. 23 is a schematic view showing the arrangements of logic circuits in the controls of the machine,

FIG. 24 is a schematic drawing of a motor driver,

FIG. 25 is a schematic diagram of a pulse-to-step converter,

FIG. 26 is a schematic diagram of a two-decade down counter,

FIG. 27 is a schematic diagram of a pulser-timer,

FIG. 28 is a schematic diagram of a count selector,

FIG. 29 is a schematic diagram of a feed logic board,

FIG. 30 is a schematic diagram of an up-down decade counter,

FIG. 31 is a schematic diagram of a logic output,

FIG. 32 is a schematic diagram of an input interface,

FIG. 33 is a schematic diagram of a pick feedboard,

FIGS. 34–36 are charts showing various stepping motor control connections, and

FIG. 37 is a schematic view of a front panel of the control as viewed from the wiring side.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring first to FIG. 1, wherein are best shown the general features of the invention, the grinding machine, indicated generally by the reference numeral **10**, is shown as consisting of a base **11** on which is mounted a workhead table **12** and a wheelhead table **13**. Also mounted on the base **11** behind the tables is a control cabinet **14**. Mounted on the table **12** is a workhead **15** carrying a workpiece **15** which, for the purpose of illustration, is shown as the outer race of a tapered roller bearing whose bore is to be finished. Mounted on the table **13** is a wheelhead **17** driven by a motor **18** and carrying a rotatable spindle **19**, the outer end of which carries an abrasive wheel **21**. At the front of the table **13** is mounted a feedbox **22**, while mounted on the workhead table **12** is a diamond dressing unit **23** as well as loading mechanism **24**. At the front of the base is mounted a control box **25** carrying pushbutton switches and the like for the operation of the machine.

FIG. 2 shows particularly well the front of a crossfeed hydraulic cylinder **26**, the front of a retractable stop mechanism **27** operated by a stepping motor **28**, and various other controls associated with the machine.

In FIG. 3 the manner in which the abrasive wheel **21** and the workpiece **16** are related is clearly shown, as well as their association with the dressing unit **23**. The workhead **15** is shown as having support shoes **29** which engage and support the outer surface of the workpiece. One end of the workpiece is engaged and driven by a tubular drive platen **31** which is suitably rotated by a motor **32** (see FIG. **17**. Located internally of the platen is a gage **33** which takes a continuous reading of the size of the bore and the workpiece that is being ground. The other end of the workpiece is engaged by clamping rollers **34** and **35** in the usual way.

FIG. **4** shows the interior of the retractable stop mechanism **27** and it also shows the manner in which the feedbox **22** is provided with an observation window **36**. The stop mechanism **27** is bolted to the front of the wheelhead table **13** which, in turn, is mounted for transverse sliding motion over the base **11**. The contact element **37** is slidably mounted in the housing of the stop and is propelled transversely by rotation of a ball screw **38**. The ball screw is, in turn, mounted in bearings **39** and is driven by a worm gear **41**.

The contact element is positioned to engage, on occasion, with a hardened element **42** mounted on a forwardly facing surface of a secondary or compensating slide **43**. A horn **44** extends downwardly from the wheelhead table **13** and is provided with a contact element **45** adapted on occasion to engage a hardened metal element **46** mounted on a rearwardly directed surface of the compensating slide **43**.

The worm gear **41** and, therefore, the ball screw **38**, is driven by the stepping motor **28** and is manually adjustable by means of a knob **47**. A manual compensating knob **48** extends from the front of the machine for a purpose to be explained hereinafter.

FIG. **5** shows a plan view of the apparatus described above showing that the knob **48** is attached to a horizontally disposed shaft **49** which extends inwardly of the machine under the table **13**. To the right of the table is mounted a feed indicator **51** and a cross-slide indicator **52**. Also extending from the front of the table are wheel wear switches **53**. Associated with the hydraulic crossfeed cylinder **26** is a throttle **54** controlled by a knob **55**.

FIGS. **6** and **7** show the details of the retractable stop mechanism **27**, particularly showing the manner in which the stepping motor **28** drives a vertical shaft **55** on which is mounted a worm **56**. This worm engages the worm gear **41** for the operation of the contact element in the transverse direction.

FIG. **8** shows the general layout of the machine for ease in understanding its operation. It can be seen that the compensation slide **43** is engaged at the rear by a ball screw **57** operated by a stepping motor **58**. In the description that follows, the stepping motor **58** will be spoken of as stepping motor No. **1**, while the stepping motor **28** will be considered as stepping motor No. 2. The workhead table **12** is mounted on ways **59** for movement longitudinally of the axis of the workpiece, and this motion is brought about by the operation of a hydraulic cylinder **61**. By means of the usual controls, the table can be reciprocated also during grinding in the usual way. The wheelhead table **13** is mounted on ways **62** for transverse motion. The gage **33** is shown as being of the pneumatic type having a lead extending outwardly to a control box **63**.

FIG. **9** is helpful in understanding the operation of the invention. Hydraulic pressure originating in a source **64** is passed on to the feed cylinder **26** which operates through a mixer **65** to produce the controlled force grinding process **66**. These forces make themselves felt at a mixer **67** which operates through the spring constant, K, of the system (indicated by the box **68**) which, in turn, feeds a force signal into the mixer **65**. The grinding process also is affected by a cross-slide damper **69** receiving force in the grinding process **66** and entering into the mixer **65**. At the same time, a pulse generator **71** operates the stepping motor No. 2 through the gear train and ball screw to operate through the mixer **67** on the system spring constant box **68**. Retraction and reset control **72** controls the flow of pulses from the pulse generator **71** to the stepping motor No. 2. Similarly, a pick or rate mode selection **73** operates through a feed rate control **74** to also regulate the flow of pulses from the generator **71** to the stepping motor No 2. The grinding process **66** is effected by the compensation slide **43** which, in turn, is regulated by the stepping motor No. 1 operating through a gear train and ball screw. A pulse generator **75** is controlled by a logic circuit **76** which, in turn, operates through a pulse-to-step converter **77** in the stepping motor control, a variation in operation being possible by means of the "new wheel" reset control **78**. Feedback takes place between the output of the pulse generator **75** and the input of the logic circuit **76** through a binary code decimal counter **79** (BCD counter).

The general operation of the machine can be best understood by referring to FIG. **10**. The workhead table **12** moves inwardly on rapid traverse to the point A, so that the abrasive wheel **21** lies within the workpiece **16**. The hydraulic crossfeed cylinder **26** is actuated to cause the wheelhead table **13** to move transversely to bring the wheel into engagement with the surface to be finished. Engagement takes place at the point B, and the workhead table begins reciprocation, while the wheel is advanced laterally into the workpiece under the hydraulic pressure in the cylinder **26** on a controlled force grinding operation. This is a rough grind that consists in rounding up the bore in the workpiece and removing substantial amounts of material from the surface. Eventually, a point C is reached as determined by a dress timer which had started at the point A. A retraction of the wheelhead table rearwardly to the point D takes place to relieve the deflection in the spindle **19** and a further action by means of the cylinder **26** carries the wheelhead back to the point E where the horn **44** engages the rearwardly facing surface of the compensation slide **43**. The compensation slide is then moved rearwardly by introducing a suitable number of pulses in to stepping motor No. **1** which has the effect of carrying the wheelhead table **13** rearwardly a short compensating distance. The workhead table **12** is then operated by the cylinder **61** to cause the wheel **21** to move past the diamond dressing unit **23** to dress the wheel, at which time the point G is reached. The wheelhead **13** is then moved inwardly by the cylinder **26** to the point H, so that the wheel engages the workpiece at the point H which, because of the retraction from point C to point D that previously took place, means that the wheel begins grinding without "cutting air." Another rough grind takes place to the point I where a second dress timer times out and calls for another dress. Retraction takes place to the point J, which retraction is the same as from the point C to the point D. Then, the wheelhead table **13** is moved back to the point K, compensation takes place to the point L, and a traversing of the workhead table **12** causes a dress to take place to the point M. The wheelhead table moves inwardly again, engaging the workpiece at the point N, and a grind takes place at a low force controlled force process to the point O. The point O is indicated by the gage **33** as having arrived, and a signal takes place stopping the grinding operation and introducing a retraction movement to the point P. This retraction is considerably less than the retraction from the point C to the point D, or from the point I to the point J because the low force cutting during this finish portion of the cycle has caused a smaller deflection of the spindle **19**. After the retraction takes place, the wheel is allowed to "spark out" grind the workpiece to the point Q where the gage indicates that final size is reached. The wheelhead is then backed off to the point R where the workpiece is removed and a new workpiece is inserted during the loading portion of the cycle.

The electrical controls which make this operation possible by the introduction of definite numbers of pulses at a given rate into the first stepping motor No. **1** and the stepping motor No. 2 are shown in FIGS. **11** through **34**.

FIG. **11** shows the three-phase main power supply during the machining and serving to operate the various large motors in the grinding machine through the conventional main switches. The load meter **81** indicates the torque load in the wheelhead at any given time. One phase of the main power source is converted through a transformer **82** and applies 440 volts to the main lines **51**_a_ and **57**_a_.

In FIG. **12**, the main power lines are shown as connected by means of relay contacts to solenoids which operate various hydraulic valves concerned with the operation of the grinding machine. From these solenoids are the oscillator solenoid

SOL–1, the table-in solenoid SOL–2, the table-out solenoid SOL–3, the dress speed solenoid SOL–7, the load solenoid SOL–53, the cross-slide backoff solenoid SOL–32, the damper bypass solenoid SOL–13, the gage release solenoid SOL–6, and diamond turner solenoid SOL–34, and solenoids associated with the diamond turner counter, as well as a dresser-down solenoid.

In FIG. 13, the main powerlines **51***a* and **57***a* are shown as connected to a power supply **83** which is used for magnetizing the backing platen **31** on occasion. It is also connected to a 24 volt DC power supply **84** whose output lines are designated as **301** and **307**. The powerlines **301** and **307** are connected to a 12 volt power supply **85** which supplies its output voltage on a line **501**. The main powerlines also are connected to a 24 volt DC stepping motor power supply **86**, and the output of this unit comes onto the lines **401** and **407**.

FIG. **14** shows the controls associated with stepping motor No. 2 and includes an integrated circuit feed unit showing the card cage and terminal strips as viewed from the wiring side of the control box.

FIG. **15** shows the arrangement of the controls for the stepping motor No. **1**. It can be seen in this view that the compensation slide and the stepping motor No. **1** are also used for the new wheel reset; that is to say, when the abrasive wheel **21** is worn down to the point where it is no longer useful, it is replaced by a new wheel and, of course, it is necessary to move the slide, particularly the compensation slide, well forward to begin the series of compensating and dressing cycles all over again. This movement takes place by use of the stepping motor No. **1** operating on the compensation slide **43**.

In FIG. **16** are shown the relay coils which operate some of the solenoids described above. More specifically, the wheelhead stop relay **1PR**, the oscillator relay **2PR**, the table-in relay **3PR**, the table-out relay **4PR**, the dress speed relay **5PR**, the load relay **6PR**, the cross-slide backoff relay **7PR**, the damper bypass relay **8PR**, the gage release relay **9PR**, the diamond turner relay **10PR**, the clutch relay **11PR** for the diamond turner counter, and the pulse motor relay **12PR** also associated with the diamond turner counter, the wheelhead light relay **13PR**, the dresser down relay **14PR**, and the counter clutch relay **15PR** for skip dress, as well as the pulse motor relay **16PR** also for the skip dress counter. At the bottom of the figure are shown the air gage control **63** having the various contacts for dress, intermediate size, and final size, these contacts closing (referring to FIG. **10**) at the points I, O, and Q, respectively.

FIG. **17** contains many control elements of the machine; among other things, it contains a timer **87** which assures that the table ways have been provided with hydrostatic fluid for a long enough time so that they are clearly "floating" on a hydrostatic film before any operation of the machine can take place. A light **88** is provided to assure that the oil filter is changed in time and a lamp **89** gives a continuous indication of the floating of the tables on their ways. The cycle start relays **3PR** are shown in place, as well as relays associated with manual cycle start of automatic cycle table-in and table-out movement.

FIG. **18** also shows a number of control elements including regulating relays associated with table stop, load, no-part indication, damper bypass, dress, speed, dresser down, and dresser down timer, this latter being the timer **91**.

FIG. **19** shows various parts of the controls for portions of the cycle, including the timer **92** which signals for the dress to take place at the point C.

FIG. **20** shows various regulating relays and their associated switches including the first size sparkout timer **93** and the second size sparkout timer **94**.

FIG. **21** shows various other portions of the controls including the overtime timer **95** and including the various controls for feedback when the cycle is taking longer or shorter than a predetermined range and it seems to be desirable to make a wheel slide adjustment.

FIG. **22** shows the various parts of the control which have to do with the size of the abrasive wheel, including the new wheel controls.

FIG. **23** shows somewhat schematically the various circuit boards that are used in the regulation of the motion of the stepping motor No. **2**, including the motor driver **96**, and pulse-to-step converter **97**, the BCD down counter **98**, the pulser-timer **99**, the count selector **101**, the feed logic **102**, the BCD up-down counters **103**, the logic output **104**, and the input interface **105**.

In FIG. **24** is shown the motor driver **96**, while FIG. **25** shows the pulse-to-step converter **97**. FIG. **26** shows the BCD two-decade down counter **98**, and FIG. **27** shows the circuitry used in the pulser-timer **99**. FIG. **28** shows the circuitry used in the count selector **101**. FIG. **29** shows the feed logic board **102** for the front stepping motor or stepping motor No. **2**. FIG. **30** shows the details of the BCD up-down decade counter **103** of which there are three in the control scheme. In FIG. **31** are shown the details of the logic output **104**. FIG. **32** shows the specific connections between the elements in the input interface **105** and shows the exact connections to the larger feedback, the smaller feedback, the first size front retraction, the second size front retraction, the feed mode, the feed reset, and the continuous mode method of operation of the stepping motor No. **2**. FIG. **33** shows the details of the pick feedboard **106** which enables the motor No. **2** to feed only at the ends of the reciprocation stroke. Finally, in FIG. **34** are shown the connections within the various parts of the control for the stepping motor No. **2**.

The study of the construction and operation of the machine will show why the use of retraction in the front stepping motor No. **2** is better than using retraction in the compensation slide stepping motion. In successively feeding and retracting in a given cycle, the stepping motor No. **2** uses a "dead reckoning" method of keeping track of its position. It is only necessary after the cycle is finished to retract back to a "zero" count. If one were to impose the retraction steps on the compensation slide, however, one would never know where to go to get the next dress, unless additional logic circuits calculated this for use. The point of dress would be a different figure after each cycle. Furthermore, it is not necessary to feed a reverse retraction of reset into the front retractable stop as would have to be done with the compensation slide retraction. Retractions do not interact with compensations in the present machine.

It is obvious that minor changes may be made in the form and construction of the invention without departing from the material spirit thereof. It is not, however, desired to confine the invention to the exact form herein shown and described, but it is desired to include all such as properly come within the scope claimed.

The invention having been thus described, what is claimed as new and desired to secure by Letters Patent is:

1. A grinding machine for finishing a surface of rotation of a workpiece, comprising

a. a base,

b. a workhead table mounted on the base and adapted to support the workpiece,

c. a wheelhead table mounted on the base and adapted to support a rotatable spindle with the abrasive wheel,

d. means for supporting one of the tables for sliding motion transversely of the axis of the surface of revolution,

e. a secondary slide associated with the said one of the tables and mounted for sliding transverse motion independently of the said one of the tables,

f. a first stepping motor connecting the base to the secondary slide for bringing about its sliding motion, and

g. a second stepping motor connected on occasion between the said one of the tables and the secondary slide to produce the sliding motion of the table.

2. A grinding machine as recited in claim **1**, wherein the surface of revolution which is to be finished is an internal surface, wherein the spindle is mounted as a cantilever with the abrasive wheel mounted at the free end, and wherein a dressing apparatus is mounted so as to be free of the movement of the said one of the tables and of the secondary slide.

3. A grinding machine as recited in claim **2**, wherein the said one of the tables is the wheelhead table, wherein the workhead table is mounted for longitudinal movement relative to the wheelhead table, and wherein the secondary slide is a compensation slide.

4. A grinding machine as recited in claim **3**, wherein a control is provided to actuate the stepping motors so that the first stepping motor is used for dress compensation movements and the second stepping motor is used for feed rate grinding movements and retraction movements.

5. A grinding machine as recited in claim **4**, wherein the control presents electrical pulses to the stepping motors, and wherein the pulse frequency and the total number of pulses presented during a given movement are adjustable.

6. A grinding machine as recited in claim **5**, wherein a hydraulic cylinder connects the wheelhead table to the base to produce a controlled force grinding movement, wherein a retractable stop extends from the wheelhead table for engagement with the compensation slide on occasion to restrict the said grinding movement, and wherein the second stepping motor is connected to retract the stop relative to the wheelhead table at a controlled rate.

7. A grinding machine as recited in claim **6**, wherein the control contains means for introducing a first predetermined number of pulses to the second stepping motor at one point in the grinding cycle for a retraction movement and introducing a second different predetermined number of pulses to the second stepping motor at another point in the grinding cycle for another retraction movement.

8. A grinding machine as recited in claim **4**, wherein means is provided to bring about longitudinal reciprocatory movement between the workhead table and the wheelhead table during the grinding cycle, and wherein the control contains means to introduce the pulses to the second stepping motor at the ends only of the reciprocatory motion for feed rate grinding movement at that time.

9. A grinding machine as recited in claim **4**, wherein the control contains means for introducing to the second stepping motor feedback pulses to compensate for long-range variations in the quality of the finished surfaces of successive workpieces.

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