United States Patent [19]

Hagar et al.

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[45] **July 23, 1974**

[54] **AUTOMATIC DATA RETRIEVAL SYSTEM FOR PUMPING WELLS**

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[21] Appl. No.: **258,756**

[52] **U.S. Cl.** **73/151**

[51] **Int. Cl.** **E21b 47/00**

[58] **Field of Search** ..... 73/151, 133 R

[56] **References Cited**

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Attorney, Agent, or Firm—A. L. Gaboriault; George W. Hager, Jr.

[57] **ABSTRACT**

Measurements of the load conditions on a plurality of pumping wells are made by strain gauges mounted on the pumping wells. A field-located remote terminal unit is connected to each of the plurality of pumping wells. Upon command from a centrally located computer, the remote terminal unit stores the load condition measurements from a pumping well selected by the computer. At some later time the computer retrieves the load condition measurements stored in the remote terminal unit.

11 Claims, 15 Drawing Figures

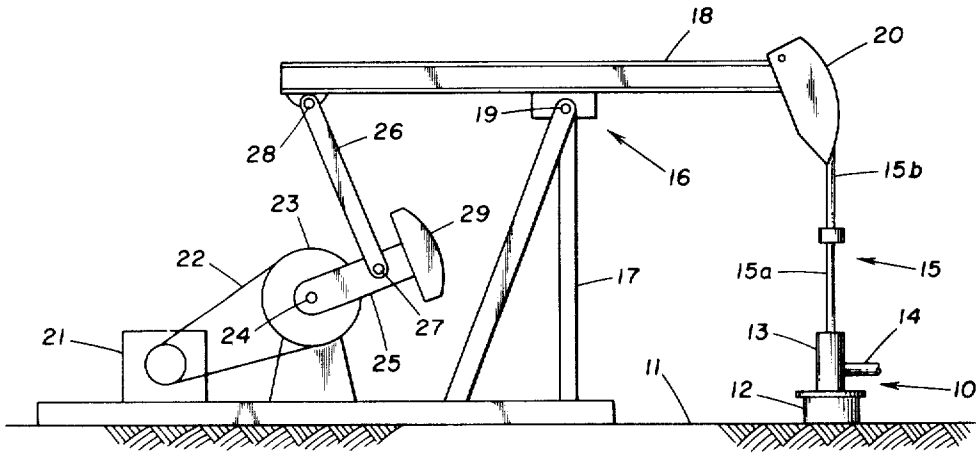


FIG. 1

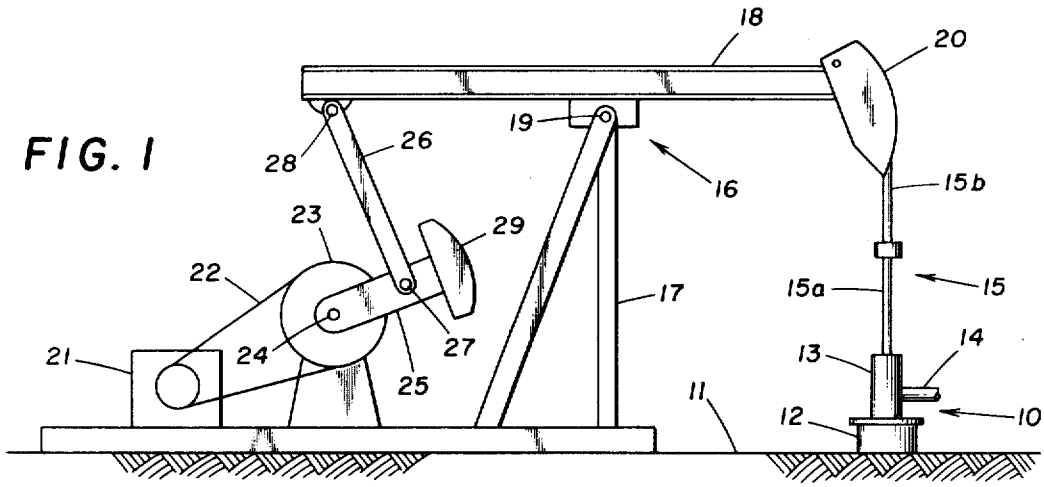

18
20
19
26
28
16
15b
23
29
22
17
15a
15
21
24
27
25
13
14
11
12
10

FIG. 5

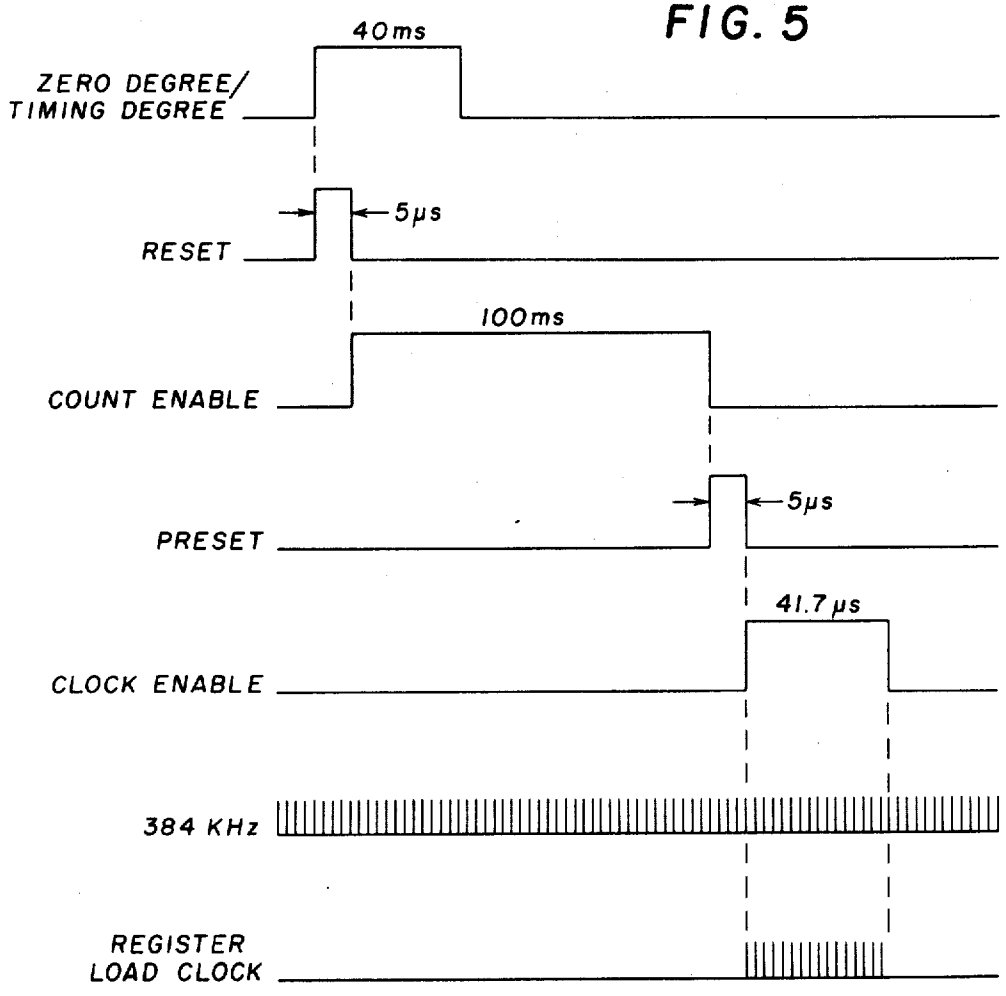
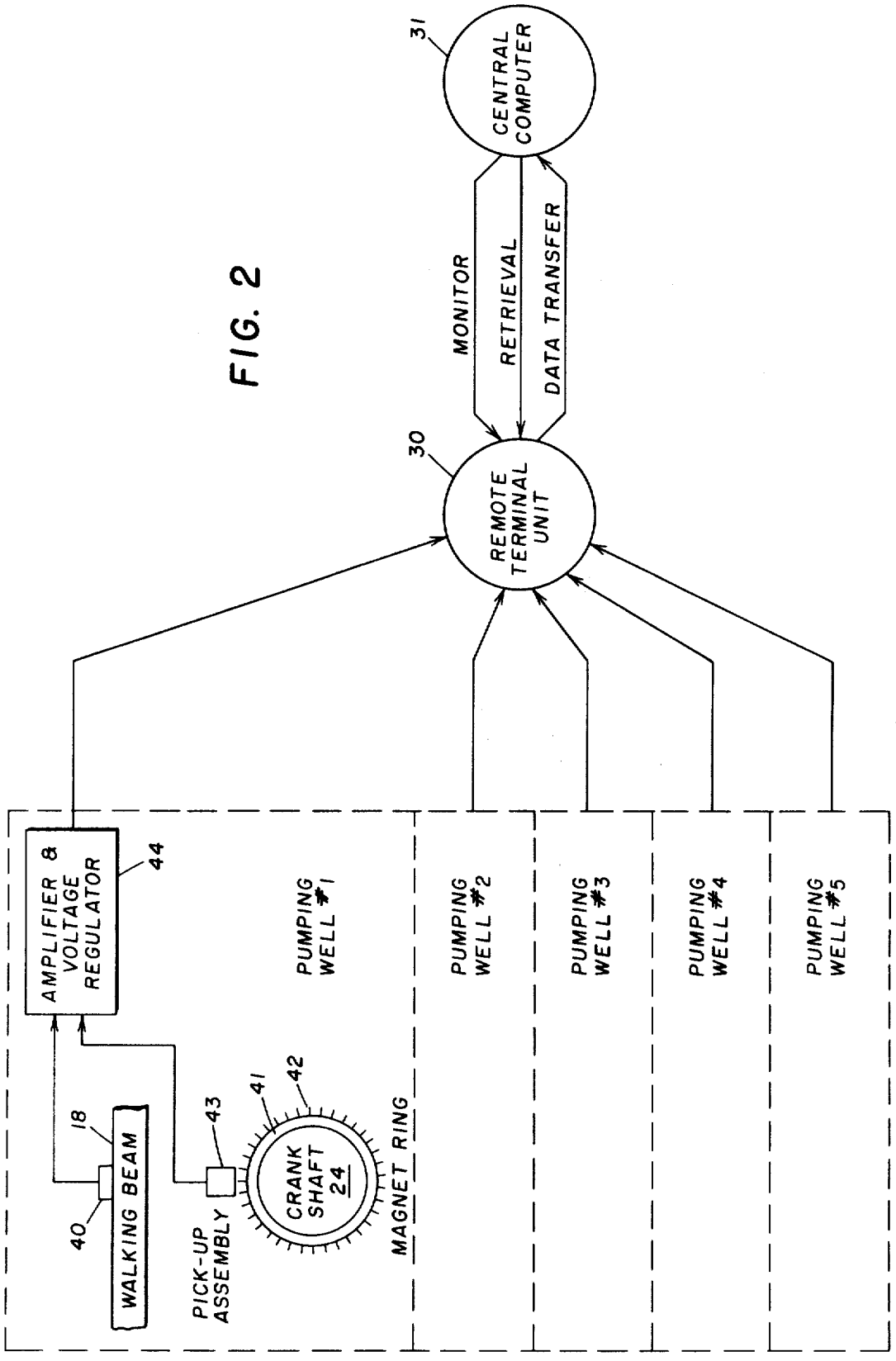

40ms
ZERO DEGREE/
TIMING DEGREE
5μs
RESET
100ms
COUNT ENABLE
5μs
PRESET
41.7μs
CLOCK ENABLE
384 KHz
REGISTER
LOAD CLOCK

FIG. 2


31
CENTRAL COMPUTER
MONITOR
RETRIEVAL
DATA TRANSFER
30
REMOTE TERMINAL UNIT
AMPLIFIER & VOLTAGE REGULATOR
44
PUMPING WELL #1
PUMPING WELL #2
PUMPING WELL #3
PUMPING WELL #4
PUMPING WELL #5
18
WALKING BEAM
40
PICK-UP ASSEMBLY
43
41
42
CRANK SHAFT 24
MAGNET RING

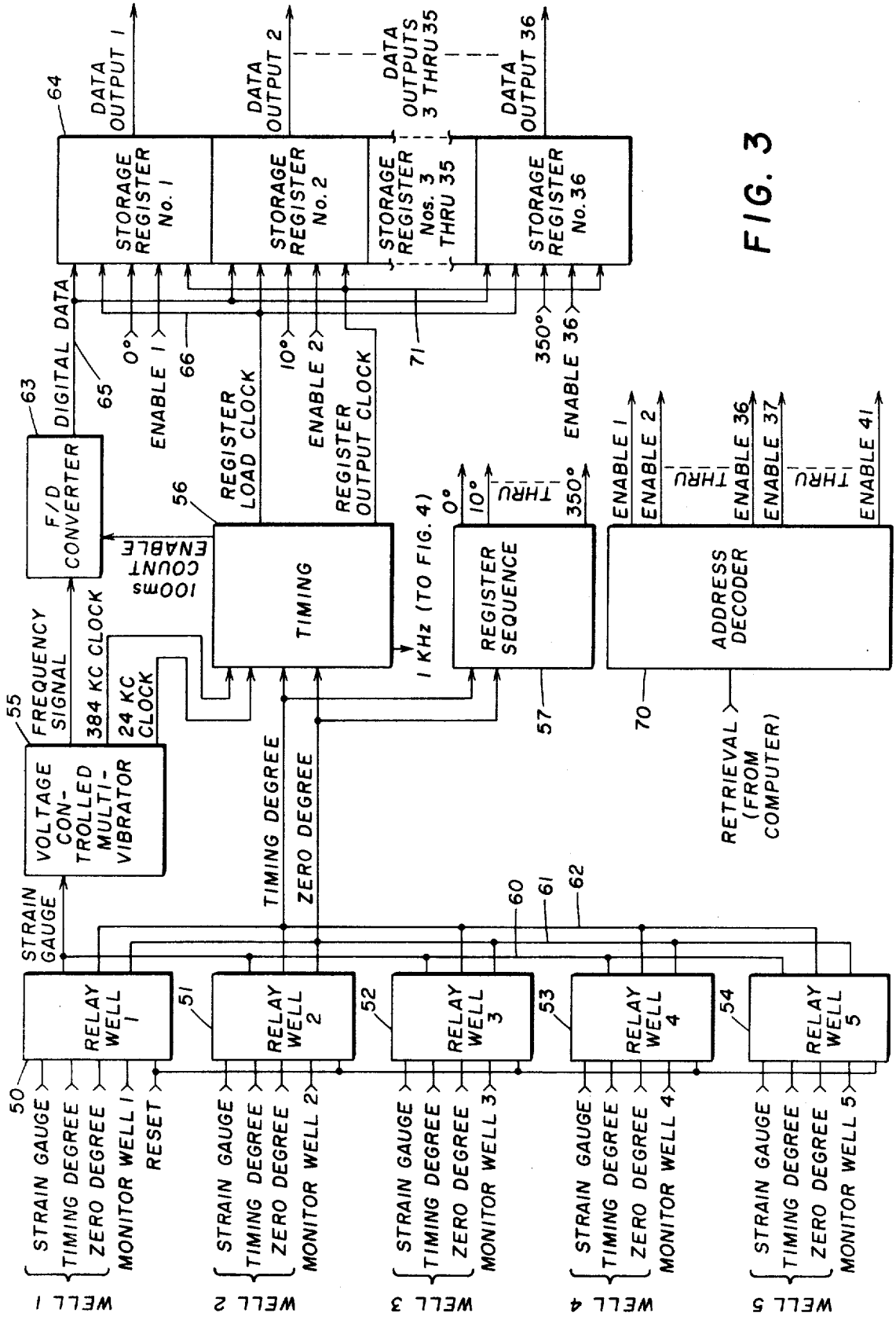

WELL 1
WELL 2
WELL 3
WELL 4
WELL 5
STRAIN GAUGE
TIMING DEGREE
ZERO DEGREE
MONITOR WELL 1
RESET
MONITOR WELL 2
MONITOR WELL 3
MONITOR WELL 4
MONITOR WELL 5
RELAY WELL 1
RELAY WELL 2
RELAY WELL 3
RELAY WELL 4
RELAY WELL 5
50
51
52
53
54
VOLTAGE CONTROLLED MULTIVIBRATOR
55
FREQUENCY SIGNAL
384 KC CLOCK
24 KC CLOCK
60
61
62
TIMING DEGREE
ZERO DEGREE
TIMING
100ms COUNT ENABLE
56
1 KHz (TO FIG. 4)
REGISTER SEQUENCE
57
0°
10°
THRU
350°
ADDRESS DECODER
70
RETRIEVAL (FROM COMPUTER)
ENABLE 1
ENABLE 2
ENABLE 36
ENABLE 37
ENABLE 41
F/D CONVERTER
63
DIGITAL DATA
65
REGISTER LOAD CLOCK
66
REGISTER OUTPUT CLOCK
71
64
STORAGE REGISTER No. 1
STORAGE REGISTER No. 2
STORAGE REGISTER Nos. 3 THRU 35
STORAGE REGISTER No. 36
DATA OUTPUT 1
DATA OUTPUT 2
DATA OUTPUTS 3 THRU 35
DATA OUTPUT 36

FIG. 3

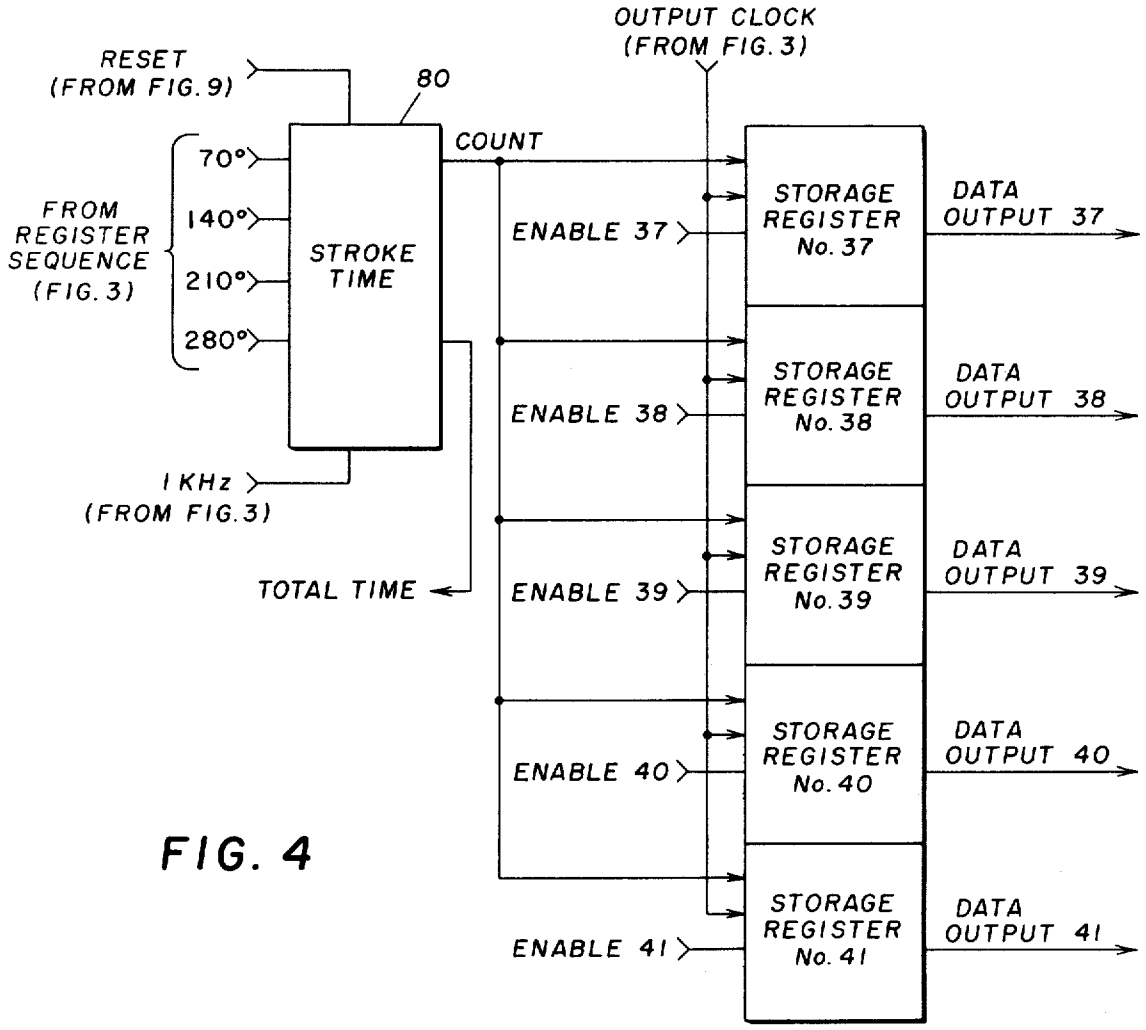

OUTPUT CLOCK
(FROM FIG. 3)
RESET
(FROM FIG. 9)
80
COUNT
70°
140°
210°
280°
FROM
REGISTER
SEQUENCE
(FIG. 3)
STROKE
TIME
1 KHz
(FROM FIG. 3)
TOTAL TIME
ENABLE 37
ENABLE 38
ENABLE 39
ENABLE 40
ENABLE 41
STORAGE
REGISTER
No. 37
STORAGE
REGISTER
No. 38
STORAGE
REGISTER
No. 39
STORAGE
REGISTER
No. 40
STORAGE
REGISTER
No. 41
DATA
OUTPUT 37
DATA
OUTPUT 38
DATA
OUTPUT 39
DATA
OUTPUT 40
DATA
OUTPUT 41

FIG. 4

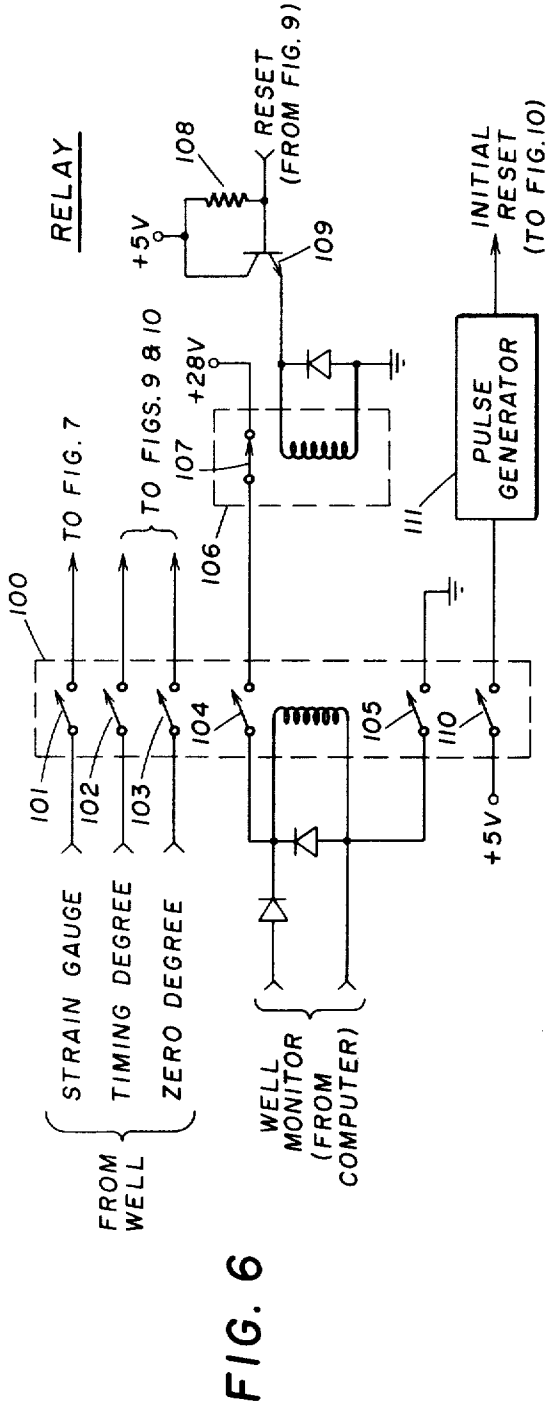

RELAY
TO FIG. 7
TO FIGS. 9 & 10
+28V
+5V
108
RESET
(FROM FIG. 9)
109
107
106
100
101
102
103
104
105
110
111
PULSE GENERATOR
INITIAL RESET
(TO FIG. 10)
+5V
STRAIN GAUGE
TIMING DEGREE
ZERO DEGREE
FROM WELL
WELL MONITOR
(FROM COMPUTER)

FIG. 6

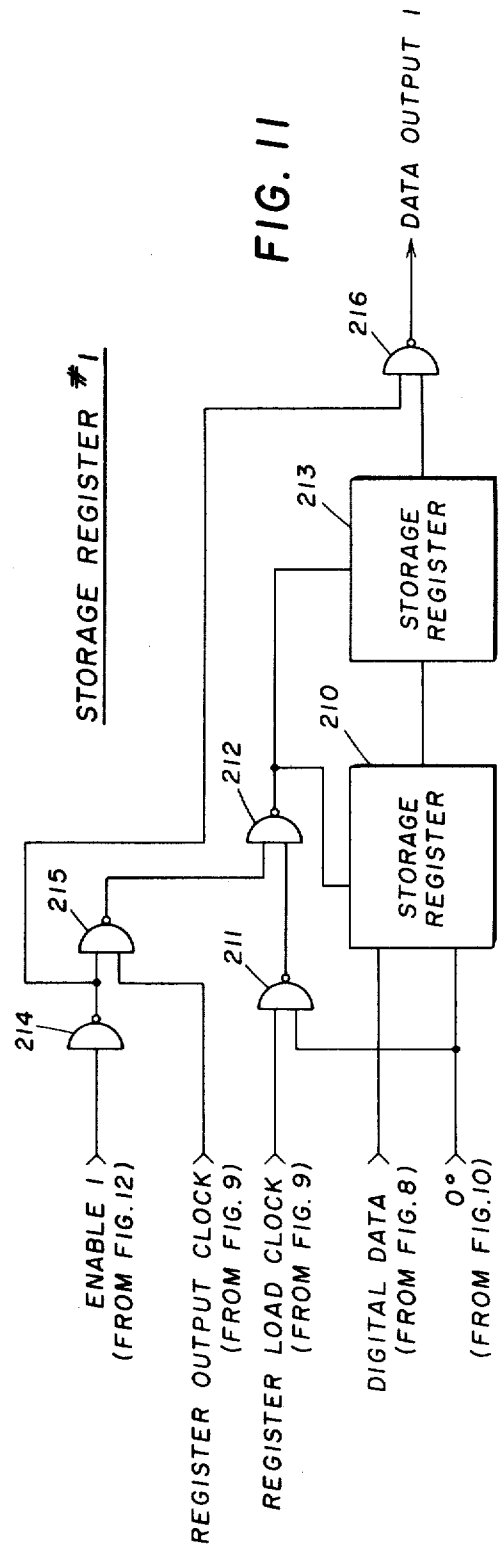

STORAGE REGISTER #1
216
DATA OUTPUT 1
213
STORAGE REGISTER
210
STORAGE REGISTER
212
215
211
214
ENABLE 1
(FROM FIG. 12)
REGISTER OUTPUT CLOCK
(FROM FIG. 9)
REGISTER LOAD CLOCK
(FROM FIG. 9)
DIGITAL DATA
(FROM FIG. 8)
0°
(FROM FIG. 10)

FIG. 11

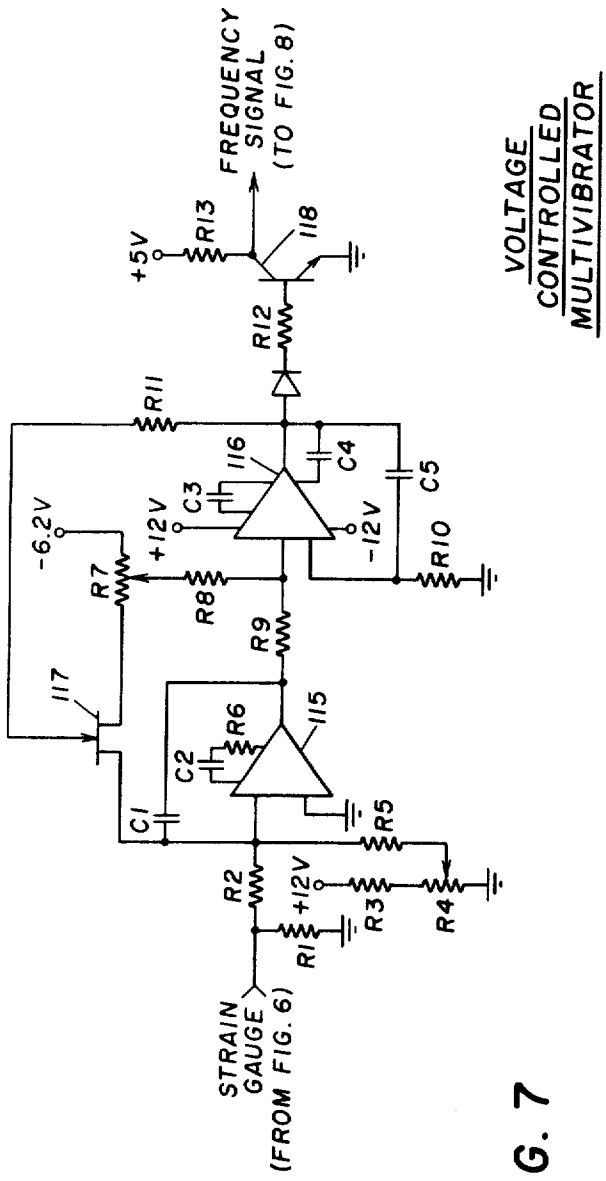

VOLTAGE CONTROLLED MULTIVIBRATOR
FREQUENCY SIGNAL (TO FIG. 8)
+5V
R13
118
R12
R11
116
C4
C5
C3
+12V
-12V
-6.2V
R10
R7
R8
R9
117
R6
115
C2
C1
R5
R2
+12V
R3
R4
R1
STRAIN GAUGE (FROM FIG. 6)

FIG. 7

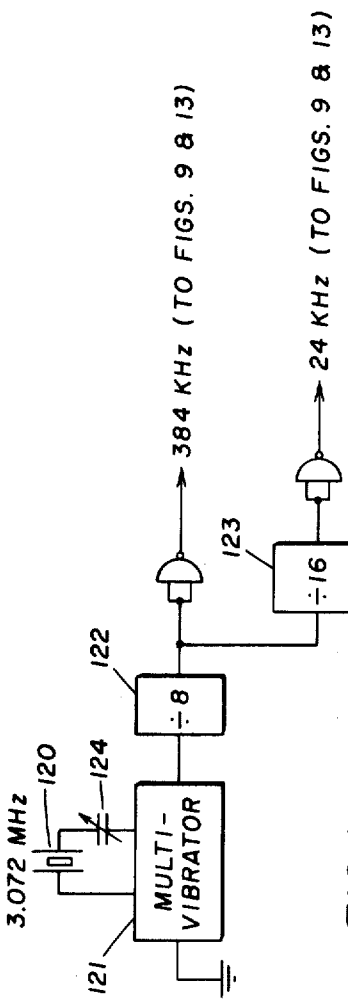
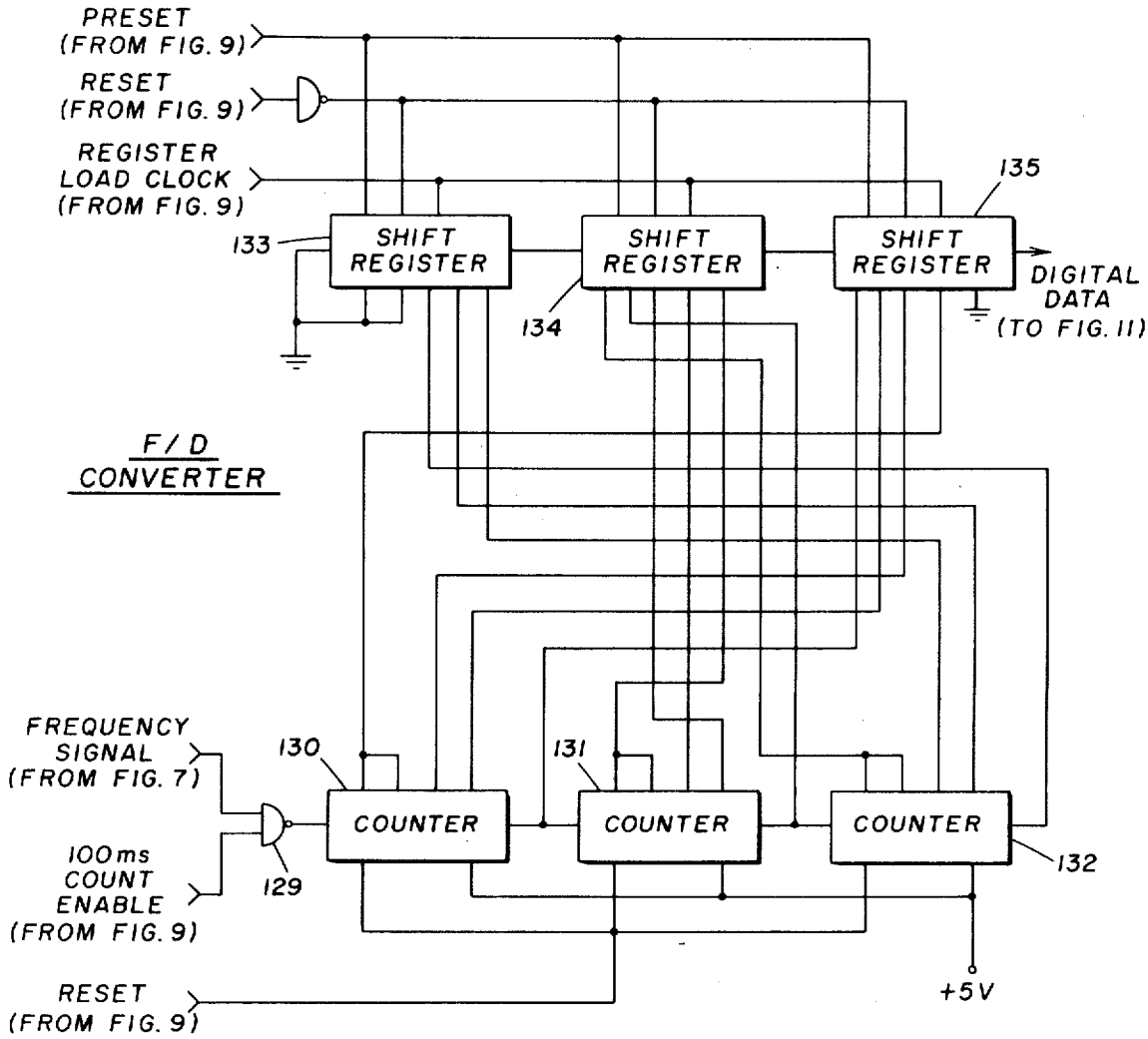

384 KHz (TO FIGS. 9 & 13)
24 KHz (TO FIGS. 9 & 13)
123
÷16
122
÷8
3.072 MHz
120
124
MULTI-VIBRATOR
121

FIG. 14

FIG. 8


PRESET
(FROM FIG. 9)
RESET
(FROM FIG. 9)
REGISTER
LOAD CLOCK
(FROM FIG. 9)
133
SHIFT
REGISTER
SHIFT
REGISTER
SHIFT
REGISTER
135
134
DIGITAL
DATA
(TO FIG. 11)
F/D
CONVERTER
FREQUENCY
SIGNAL
(FROM FIG. 7)
100ms
COUNT
ENABLE
(FROM FIG. 9)
129
130
131
COUNTER
COUNTER
COUNTER
132
RESET
(FROM FIG. 9)
+5V

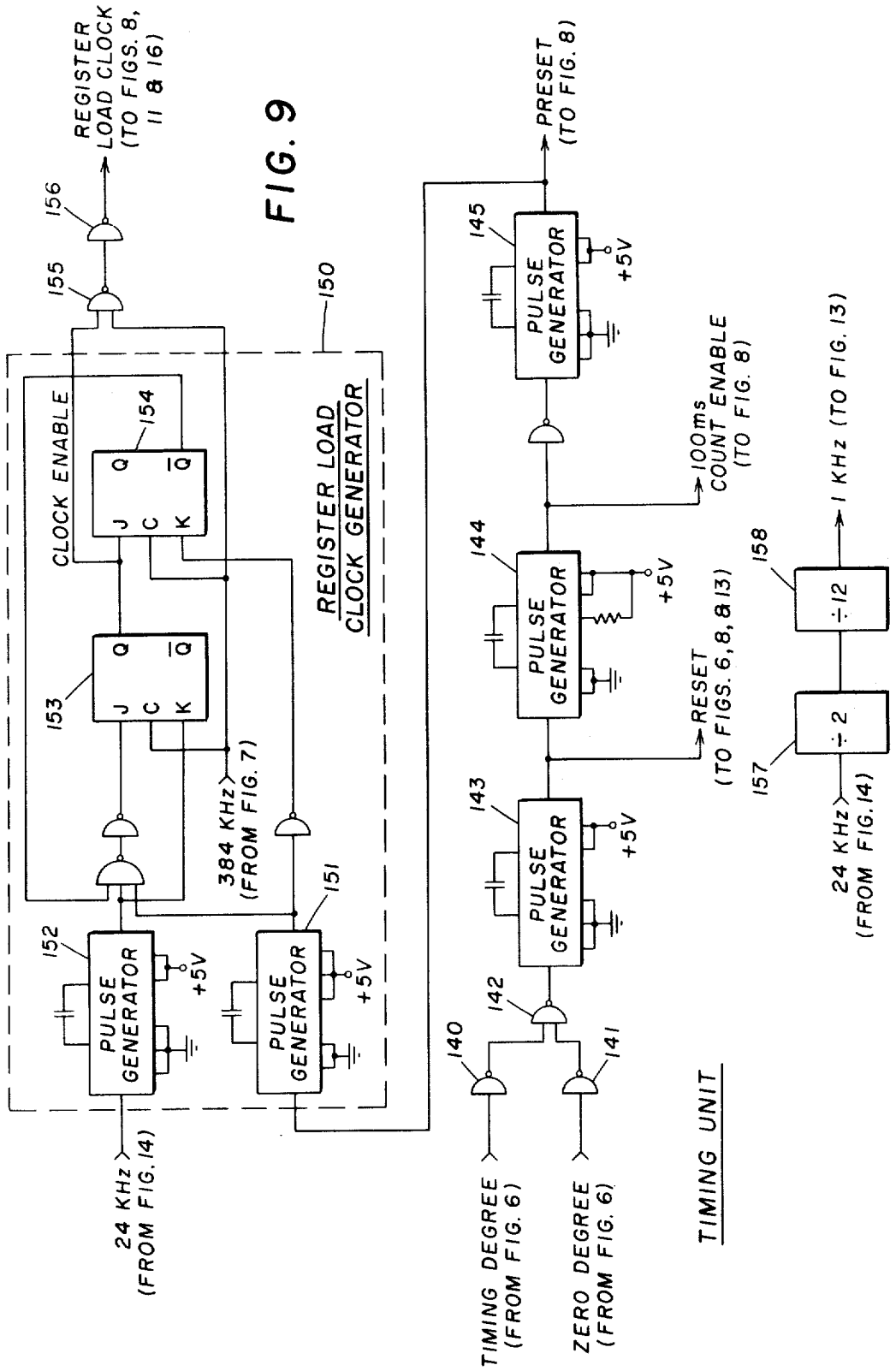
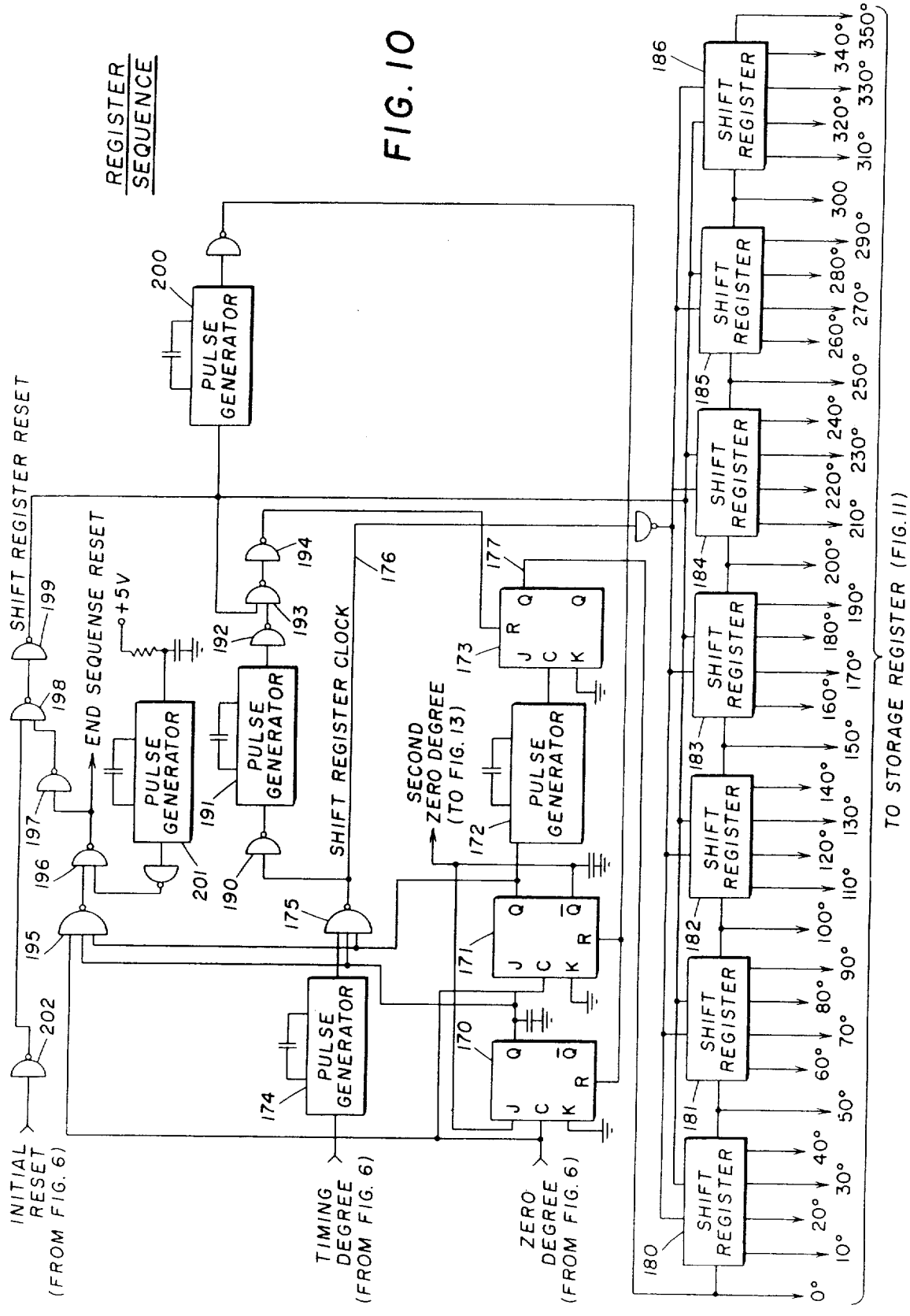

REGISTER LOAD CLOCK (TO FIGS. 8, 11 & 16)
156
155
150
CLOCK ENABLE
154
153
Q
J
C
K
REGISTER LOAD CLOCK GENERATOR
384 KHz (FROM FIG. 7)
151
152
PULSE GENERATOR
+5V
24 KHz (FROM FIG. 14)
PRESET (TO FIG. 8)
145
100ms COUNT ENABLE (TO FIG. 8)
144
RESET (TO FIGS. 6, 8, & 13)
143
142
140
141
TIMING DEGREE (FROM FIG. 6)
ZERO DEGREE (FROM FIG. 6)
TIMING UNIT
158
÷12
÷2
157
1 KHz (TO FIG. 13)
24 KHz (FROM FIG. 14)

FIG. 9

FIG. 15

FIG. 10


REGISTER SEQUENCE
SHIFT REGISTER RESET
END SEQUENSE RESET
+5V
SHIFT REGISTER CLOCK
SECOND ZERO DEGREE (TO FIG. 13)
INITIAL RESET (FROM FIG. 6)
TIMING DEGREE (FROM FIG. 6)
ZERO DEGREE (FROM FIG. 6)
PULSE GENERATOR
SHIFT REGISTER
TO STORAGE REGISTER (FIG. 11)
0° 10° 20° 30° 40° 50° 60° 70° 80° 90° 100° 110° 120° 130° 140° 150° 160° 170° 180° 190° 200° 210° 220° 230° 240° 250° 260° 270° 280° 290° 300 310° 320° 330° 340° 350°

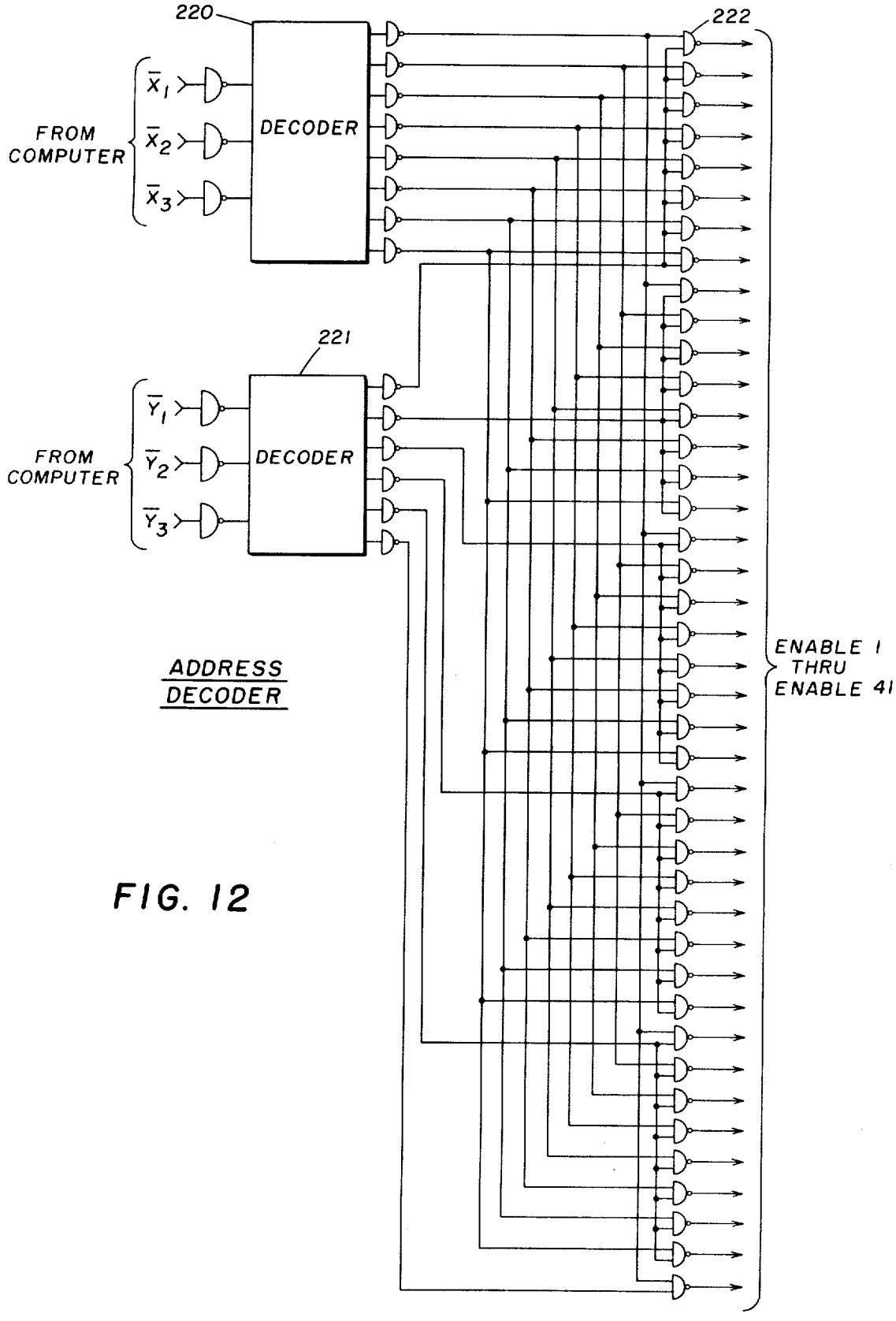
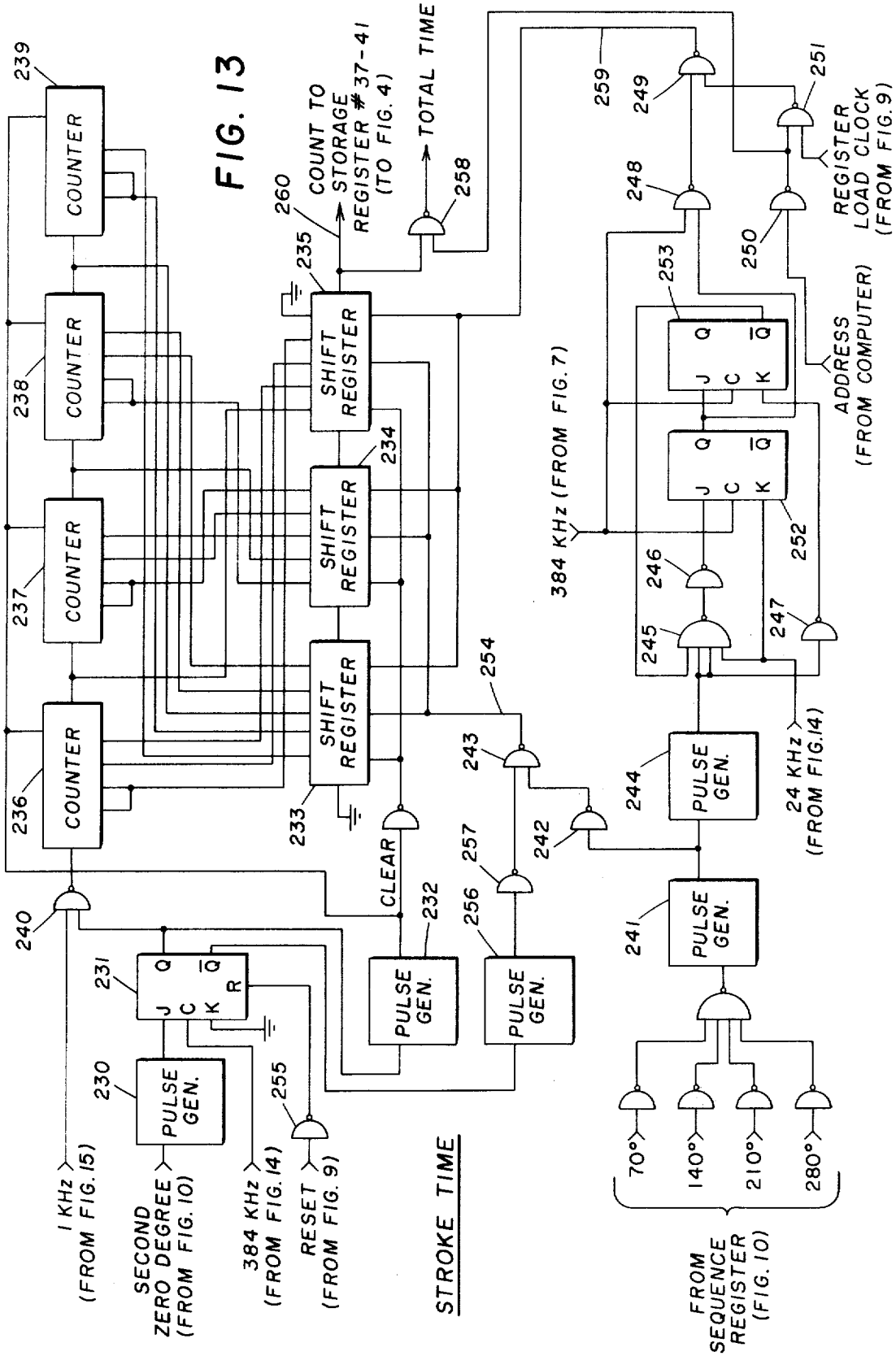

220
222
FROM COMPUTER
$\overline{X}_1$
$\overline{X}_2$
$\overline{X}_3$
DECODER
221
FROM COMPUTER
$\overline{Y}_1$
$\overline{Y}_2$
$\overline{Y}_3$
DECODER
ADDRESS DECODER
ENABLE 1 THRU ENABLE 41

FIG. 12

FIG. 13


239
COUNTER
238
COUNTER
237
COUNTER
236
COUNTER
240
231
Q
Q
R
J
C
K
230
PULSE GEN.
1 KHz (FROM FIG. 15)
SECOND ZERO DEGREE (FROM FIG. 10)
384 KHz (FROM FIG. 14)
255
RESET (FROM FIG. 9)
260
COUNT TO STORAGE REGISTER #37-41 (TO FIG. 4)
TOTAL TIME
258
235
SHIFT REGISTER
234
SHIFT REGISTER
233
SHIFT REGISTER
CLEAR
232
PULSE GEN.
256
PULSE GEN.
257
242
243
254
STROKE TIME
259
249
251
REGISTER LOAD CLOCK (FROM FIG. 9)
248
250
253
ADDRESS (FROM COMPUTER)
384 KHz (FROM FIG. 7)
246
245
247
252
244
PULSE GEN.
24 KHz (FROM FIG. 14)
241
PULSE GEN.
70°
140°
210°
280°
FROM SEQUENCE REGISTER (FIG. 10)

AUTOMATIC DATA RETRIEVAL SYSTEM FOR PUMPING WELLS

BACKGROUND OF THE INVENTION

This invention relates to monitoring of sucker-rod-type well pumping units and more particularly to a system for monitoring the operation of such units by operating on a transducer signal representative of load changes in the units.

Sucker-rod-type pumping units are widely used in the petroleum industry to recover fluids from wells extended into subsurface formations. Such units include a sucker rod string extending into the well and means at the surface of the well for reciprocating the sucker rod string in order to operate a downhole pump. Typical of such units are the so-called "beam-type" pumping units. In a beam-type pumping unit the sucker rod string is suspended at the surface of the well from structure comprising a sampson post and a walking beam pivotally mounted on the sampson post. The sucker rod string normally is connected at one end of the walking beam. The walking beam is also connected to a prime mover through a suitable crank, crank shaft, and pitman connection. By this arrangement, the walking beam and sucker rod string are driven in a reciprocal movement by the prime mover.

In order to monitor the performance of a well produced by means of a rod-type pumping unit, it is a conventional practice to measure, either directly or indirectly, the load on the sucker rod string during each pumping stroke of the pumping operation. One particularly useful system by which this may be accomplished is disclosed in U.S. Pat. application Ser. No. 58,439, filed July 27, 1970, entitled WELL MONITORING PROCESS AND APPARATUS by Richard C. Montgomery and Jacque R. Stoltz. In this system, a transducer secured to the walking beam of a beam pumping unit generates a signal representative of the load in the beam as the beam is reciprocated during each pumping stroke. The load changes in the beam are representative of the load changes in the sucker rod string such that the information derived from the transducer may be utilized to analyze and/or control the performance of the well.

Another conventional technique for obtaining an indication of load measurements in the sucker rod string is to employ a transducer commonly termed a pump dynamometer which is attached directly to the sucker rod string, normally in the polished rod section thereof, to monitor variations in the stress in the sucker rod string. For example, U.S. Pat. No. 3,359,791, issued Dec. 26, 1967, to Rodney A Pantages, discloses a dynamometer which is mounted on the polished rod and which functions to generate an alarm or to initiate control action such as shut down of the prime mover in response to abnormally high or low loads on the polished rod.

Several methods have been employed to record these load measurements in the walking beam or the sucker rod string. One such method has been to record the load measurements directly onto a chart recording located at the well site. Another method has been to utilize an on-site computer to record the load measurements, with a large portion of the computer time dedicated to monitoring these load measurements. It has also been proposed that the recording of pumping well load measurements be controlled from a central data center. For example, as described by C. C. Boggus in "Let's Weigh Those Wells Automatically," THE OIL AND GAS JOURNAL, Vol. 62, No. 5, Feb. 3, 1964, p. 78, the output from a large number of pump dynamometers can be applied to a central computer where the information will be analyzed and appropriate control action taken.

SUMMARY OF THE INVENTION

This invention provides new apparatus for monitoring the operation of a number of remotely located well pumping units and for subsequently transmitting information as to the load characteristics of the pumping units to a centrally located computer for analyzation and for the control of the well pumping units. In carrying out the invention, there is provided a remote terminal unit which links a plurality of pumping wells to a central computer. The remote terminal unit includes a plurality of relays, one for each of the pumping wells. The central computer, upon appropriate command to the remote terminal unit, may couple a desired pumping well to the remote terminal unit by energizing the appropriate relay. A storage unit, located in the remote terminal unit, will monitor and store load measurements from the pumping well which is coupled to the remote terminal unit at the data rate for which the load measurements are being made, such data rate being dependent upon the stroke time of the pumping well. After load measurements from the particular pumping well have been stored in the storage unit of the remote terminal unit for a complete pumping stroke, the central computer may thereafter initiate a command to retrieve the data stored in the storage unit at a data rate faster than the rate at which the load measurements were transferred from the pumping well to the remote terminal unit. In this manner, the computer, after initiating a command to the remote terminal unit to monitor well pumping data, is free to carry out other data processing activities while the data from the pumping unit is being monitored and stored in the remote terminal unit at a data rate which is slower than the data rate at which the computer is capable of receiving data. The computer can then at a later time retrieve the data in a fast read cycle, thereby permitting more economic utilization of the central computer.

In another aspect, there is provided a transducer for generating a load signal representative of the changing load conditions on the sucker rod string during pumping operations. Timing pulses are generated at periodic intervals during each pumping stroke of the sucker rod string. The load signals are stored in a plurality of storge registers, one register being provided for each of the periodic intervals during the pumping stroke. The timing pulses strobe the load signals into the storage registers for the periodic intervals of the pumping stroke during which the load signals were generated.

In yet another aspect of the invention, the transducer is a strain gauge which generates a variable-current signal representative of the changing load conditions during the pumping stroke. The variable-current signal is utilized to generate a variable-frequency signal which varies linearly with the current signal. The variable-frequency signal is converted to a digital signal for storage in the storage registers.

In a further aspect of the invention, a ring is mounted around the crank shaft, the ring having a plurality of

magnets located around its periphery. A pickup assembly is mounted adjacent the crank shaft and produces the timing pulses as each of the magnets passes by the assembly as the crank shaft is rotated.

In still a further aspect of the invention, the stroke time of the pumping well is determined. A counter is provided for accumulating a count of a number of clock pulses which are produced after the start of the pumping stroke. Upon the occurrence of each of selected ones of the timing pulses generated for the periodic intervals of the pumping stroke, the count stored in the counter is shifted into one of plurality of storage registers. That is, at the end of a first selected number of periodic intervals, the accumulated count is shifted into one of a plurality of storage registers. Likewise, at the end of a second selected number of periodic intervals, the accumulated count is shifted into a second of the plurality of storage registers. This accumulation of count pulses and shifting of the counts into storage registers continues during the entire pumping stroke.

In a yet more specific aspect of the invention, 1-KHz clock pulses are applied to the counter. The accumulated counts are shifted into the storage registers at the 1-KHz clock rate. The stored counts thereby represent the stroke time of the pumping well for each of the selected number of periodic intervals in milliseconds.

In a still further aspect of the invention, each revolution of the crank shaft corresponds to one pumping stroke of the sucker rod string, timing pulses are produced for each 10° of rotation of the crank shaft, and the accumulated count is shifted into the storage registers at intervals of 70°, 140°, 210°, 280°, and 360°.

It is to be understood that the foregoing disclosure relates to only a preferred embodiment of the invention. Various modifications may be contemplated and resorted to by those skilled in the art without departing from the spirit and scope of the invention as hereinafter defined by the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a pumping well equipped with a sucker-rod-type pumping unit.

FIG. **2** illustrates a system for retrieving load data from a pumping well such as illustrated in FIG. **1.**

FIGS. **3** and **4** illustrate in block diagram a portion of the system of FIG. **2.**

FIG. **5** illustrates, in time relationship, graphs of the various signals resulting from the operation of the system of FIGS. **2–4.**

FIGS. **6–15** are circuit schematics of various portions of the units illustrated in FIGS. **3** and **4.**

DESCRIPTION OF A SPECIFIC EMBODIMENT

With reference to FIG. **1**, there is illustrated the wellhead **10** of a well which extends from the earth's surface **11** into a subsurface oil producing formation (not shown). The wellhead comprises the upper portions of a casing string **12** and a tubing string **13.** Liquid from the well is produced through the tubing string **13** by means of a downhole pump (not shown) to the surface where it passes into a flow line **14.** The downhole pump is actuated by reciprocal movement of a sucker rod string **15.** Sucker rod string **15** is suspended in the well from a support unit **16** consisting of a sampson post **17** and a walking beam **18** which is pivotally mounted on the sampson post by a pin connection **19.** The sucker rod string includes a polished rod section **15***a* which extends through a stuffing box (not shown) at the top of the tubing string and the section **15b** formed of flexible cable. The cable section **15b** is connected to the walking beam **18** by means of a "horsehead" **20.**

The walking beam is reciprocated by a prime mover **21** such as an electric motor. The prime mover drives the walking beam through a drive system which includes drive belt **22,** crank **23,** crank shaft **24,** crank arm **25,** and a pitman **26** which is pivotally connected between the crank arm and walking beam by means of pin connections **27** and **28.** The outer end of crank arm **25** is provided with a counterweight **29** which balances a portion of the load on the sucker rod string in order to provide for a fairly constant load on the prime mover.

The well pumping unit thus far described is conventional and merely exemplary of a specific embodiment which may be utilized in carrying out the present invention. For a more detailed description of other suitable beam pumping units which may also be utilized in carrying out the present invention, reference is made to PETROLEUM PRODUCTION ENGINEERING-OIL FIELD EXPLOITATION, Third Edition, McGraw-Hill Book Company, Inc., New York, Toronto, and London, 1953, Uren, L. C., and more particularly to the description of beam pumping units appearing in Chapter 6 thereof.

As the beam pumping unit is operated, the loading on the sucker rod string varies greatly. By analyzing this variance in sucker rod loading, a determination can be made as to the operating characteristics of the pumping unit. In accordance with the present invention, there is provided a system for monitoring the operation of a beam pumping unit by measuring load changes induced in the support unit as the sucker rod string is reciprocated. This is accomplished by locating on the support unit a load transducer which generates a signal representative of load changes induced in the support unit during operaton of the pump. While the support unit loading may not be directly proportional to the sucker rod loading during pumping operations, the relationship between the two loads is predictable. For example, when the transducer is mounted on the top of the walking beam, as is preferred, the beam loading is directly proportional to the sucker rod loading when the beam is horizontal and departs from such direct relationship by a predictable function as the beam moves from the horizontal position during an upstroke or a downstroke.

Referring now to FIG. **2,** there is shown a plurality of pumping wells which are coupled by means of a remote terminal unit **30** to a central computer **31.** On each well there is installed a strain gauge **40,** a magnet-carrying ring **41,** a pickup assembly **43,** and an amplifier and voltage regulator **44.** Strain gauge **40** is mounted on walking beam **18** and provides an ouptut current which is proportional to the load on the walking beam. This output current is applied to amplifier and voltage regulator **44.** The strain gauge **40** may be of any suitable type adapted for positioning on the pumping unit or any component in which the load changes are representative of the load changes in the rod string. A particularly suitable transducer is disclosed in U.S. Pat. application Ser. No. 58,439, entitled WELL MONITORING APPARATUS, filed July 27, 1970, by Richard C. Montgomery and Jacque R. Stoltz. The magnet ring **41**

is mounted around the crank shaft **24,** The magent-carrying ring contains a plurality of magnets **42** around the circumference of the ring. A particularly suitable magnet ring, for example, contains 36 magnets around the circumference of the ring at 10° intervals. The pickup assembly **43** provides a timing pulse every time a magnet is revolved past the pickup assembly. For example, with a magnet ring of 36 magnets, the pickup assembly provides a timing pulse for every 10° of rotation of the crank shaft **24.** A particularly suitable pickup assembly contains two Hall-effect solid state switches. The voltage regulator portion of amplifier and voltage regulator **44** provides the proper voltage for the Hall-effect switches. In the specific embodiment disclosed herein the pumping well makes one pumping stroke for each revolution of the crank shaft **24.** Therefore, 36 timing pulses are provided by the pickup assembly during each pumping stroke. It is these timing pulses from the pickup assembly **43** which are applied by the amplifier and voltage regulator **44** to the remote terminal unit **30.**

One of the 36 magnets **42** on the magnet ring **41** is offset to provide a zero pulse. The zero pulse magnet may be installed at any one of the 36 positions to allow the beginning of the operation to occur at any point desired on the pump stroke.

Any number of pumping wells may be coupled to the remote terminal unit **30.** For purposes of example herein, five pumping wells have been illustrated. System operation is initiated by a monitor command from computer **31.** The monitor command energizes a relay in the remote terminal unit **30** so as to couple the pumping well to be monitored to the remote terminal unit. Starting at a zero point as determined by the zero pulse magnet, strain gauge readings are recorded in the remote terminal unit at 10° intervals around the complete stroke of the pumping unit. At each 10° point, the current output from the strain gauge **40** is converted to digital form and stored in the remote terminal unit, resulting in 36 words of digital data being recorded at 10° intervals around the pumping stroke. At any time after the strain gauge data for one complete pumping stroke has been recorded and stored in the remote terminal unit **30,** the computer may address the remote terminal unit with a retrieval command and transfer the data from the remote terminal unit to the computer.

It can be particularly noted that the computer **31** is not tied up during the data recording cycle of each pumping stroke. After the computer issues the monitor command, it can continue with other activities until such time as the data from one complete pump stroke has been stored in the remote terminal unit **30.** Then, at some later time, the computer can retrieve the data for analyzation or further storage.

For further details of the operation of remote terminal unit **30,** reference may now be made to FIG. **3.** The outputs of the amplifier and voltage regulator **44** of each of the pumping wells **1–5** of FIG. **2** are connected respectively to the relays **50–54.** Each of the pumping wells provides three signals. The strain gauge **40** provides a current signal as one input to each of the relays. The pickup assembly **43** at each of the pumping wells provides two signals. The first, a timing degree signal, is provided by the pickup assembly **43** for each 10° of revolution of the crank shaft **24.** The second, a zero degree signal, is provided by the pickup assembly when the zero offset magnet passes the pickup assembly to initiate operation. Also applied to each of the relays **50–54** is a well address signal. This signal is a command directly from the central computer **31** and energizes the particular relay coupled to the pumping well for which the central computer desires to monitor and retrieve strain gauge data. For example, a monitor command from central computer **31** to monitor well No. **1** is coupled to relay **50.** This command energizes relay **50** to couple the strain gauge signal to voltage controlled multivibrator **55** and to couple the timing degree and zero degree signals to the timing unit **56** and to the register sequence **57.** The outputs of each of the relays **50–54** are tied together on common buses **60–62** so that data from the pumping well which is to be monitored is applied to voltage controlled multivibrator **55,** timing unit **56,** and register sequence **57.** The frequency of the voltage controlled multivibrator **55** is controlled by the strain gauge current. This relationship is a linear function, with the frequency increasing as the current increases. Output of the voltage controlled multivibrator is coupled to an F/D converter **63** where the strain gauge data is converted to digital data for storage in a bank of storage registers **64.**

Voltage controlled multivibrator **55** also provides a 24-KHz clock and a 384-KHz clock as inputs to timing unit **56.** Timing unit **56** in response to its four input signals (zero degree, timing degree, 24-KHz clock, and 384-KHz clock) provides a **100-ms** count enable signal for each 10° interval of crank shaft rotation. This 100-ms count enable signal synchronizes the strain gauge frequency sampling of the F/D converter and the storage of the digital data in the storage registers **64.** That is, the strain gauge frequency signal is sampled for a 100-ms count period and converted to digital data for shifting into storage registers **64.**

The register sequence **57** controls the shifting of the digital data from F/D converter **63** into the proper one of the thirty-six storage registers **64.** As each of the timing degree signals is applied to the register sequence **57,** an output is generated on one of the lines indicated by the legends "0°" through "350°." These 36 outputs are selectively coupled to the 36 storage registers **64.** For example, the 0° output of register sequence **57** is coupled as a strobe input to storage register No. **1.** The 10° output is connected as the strobe input signal to storage register No. **2,** etc., until the 350° output signal is coupled as the strobe input to storage register No. **36.** Such strobe signals enable the proper storage register to receive the digital data from the F/D converter by way of common bus **65.** For example, the storage register No. **1** is enabled by the 0° strobe signal to receive and store digital data from F/D converter **63** at the end of the 100-ms sampling period following the zero timing degree pulse. The storage register No. **2** is enabled by the 10° strobe input signal to receive and store the digital data following the 100-ms sampling period immediately after the 10° timing pulse. This sequence of storage of digital data continues until storage register No. **36** receives and stores the digital data sampled during the 100-ms period after the 350° timing pulse. The digital data which is shifted into the 36 storage registers **64** is shifted into the respective registers in response to the register load clock from timing unit **56.** The clock pulses are coupled to each of the 36 shift registers by means of common bus **66** and are generated by the timing unit **56** subsequent to the 100-ms sampling period and prior to the occurrence of the next 10 timing

pulse. This relationship of the register load clock to the 100-ms count enable pulse and the timing degree pulse is illustrated in the timing chart of FIG. **5** and will be more fully described in connection with the detailed description of the timing unit **56** hereinafter.

To retrieve the data stored in the 36 storage registers **64**, the computer sends a retrieval command to an address decoder **70**. This retrieval command is an address code which is decoded in the address decoder **70** to provide 36 enable signals for the addressing of the 36 storage registers **64**. As each of the storage registers is sequentially addressed, the data stored in the registers is sequentially shifted onto data output lines **1–36** leading to the computer. More particularly, as the address decoder **70** receives the address code for a particular storage register, it provides an enable signal to that register to enable the information stored in the register to be shifted out of the register onto the register's data output line. The data is shifted out of the storage registers in response to the register output clock from timing unit **56**. This clock is connected to each of the storage registers **64** by way of common bus **71**. For example, when the computer sends a retrieval command to the address decoder **70** for the addressing of storage register No. **1**, address decoder **70** provides an enable **1** signal to the storage register No. **1**. This enable **1** signal when applied to storage register No. **1** permits the register output clock to strobe the digital data out of storage register No. **1** onto data output line **1**. Following the receipt of the data stored in storage register No. **1**, the computer then initiates the address code for storage register No. **2**. Upon decoding retrieval command for storage register No. **2**, an enable **2** signal is applied to storage register No. **2** to enable the register output clock to strobe the digital data out of storage register No. **2** onto data output line **2**. This sequence of addressing the storage registers and shifting the data storage in the registers onto the data output lines continues until all 36 storage registers have been addressed and the data applied to the computer by way of data outputs **1–36**.

In addition to the monitoring and storing of the load characteristics on the beam pumping well, the remote terminal unit also records the stroke time of the pumping well in milliseconds from 0° to 70°, 0° to 140°, 0° to 210°, 0° to 280°, and 0° to 360°. This data is stored in five additional storage registers Nos. **37–41** as illustrated in FIG. **4**. To determine the stroke time of the pumping well, a 1-KHz signal is generated by timing unit **56** (FIG. **3**) and applied as one input to a stroke time unit **80**. Also applied as inputs to stroke time unit **80** are the 70°, 140°, 210°, and 280° signals from the register sequence **57** of FIG. **3**. The 1-KHz clock pulse is applied to a counter in the stroke time unit **80** which accumulates a count representative of the number of clock pulses applied. Upon the application of the 70° pulse to the input of stroke time unit **80**, the count stored in the stroke time counter is shifted into storage register No. **37**. Likewise, upon the occurrence of the 140°, 210°, and 280° signals, the count accumulated in the stroke time counter is shifted respectively into storage registers Nos. **38, 39**, and **40**. At the end of the 360° cycle, a reset pulse from timing unit **56** shifts the final count into storage register No. **41**. Storage registers Nos. **37–41** thereby store a count representative of the stroke time in milliseconds for the intervals 0° to 70°, 0° to 140°, 0° to 210°, 0° to 280°, and 0° to 360°. The contents of storage registers Nos. **37–41** are strobed out as data outputs **37–41** to the computer. The data is strobed out by the output clock signal in similar fashion to the strobing of data out of storage registers Nos. **1–36** of FIG. **3**. In addition to the enable signals **1–36** from address decoder **70** of FIG. **3**, the additional enable signals **37–41** are generated when the address decoder **70** decodes the retrieval command for storage registers Nos. **37–41**. Upon the application of an enable signal **37**, for example, to storage register No. **37**, the output clock from the timing unit **56** strobes the data in storage register No. **37** onto data output **37**. Similarly, upon the application of enable signals **38–41** to storage registers Nos. **38–41**, respectively, the output clock strobes the data from these registers onto data outputs **38–41**.

Having described the over-all system operation in relation to the block diagrams of FIGS. **2–4**, a more complete understanding of the invention may be had by reference to the detailed dircuit schematics of FIGS. **6–15** and to the timing graphs of FIG. **5**.

FIG. **6**: Relay

The relays **50–54** (FIG. **3**) are used to connect each of the well sites to voltage controlled multivibrator **55**. Each of these relays is identical in configuration and therefore only one relay is shown in detail in FIG. **6**. The signals from each of the well sites, that is, strain gauge, timing degree, and zero degree, are applied as inputs to a relay **100**. Also applied as input to relay **100** is the well monitor signal from the computer. The well monitor signal activates relay **100** to close the normally open contacts **101–105** and **110**.

Contact **101** connects the strain gauge information to the voltage controlled multivibrator **55** (FIG. **7**). Contacts **102** and **103** connect the timing degree and zero degree information to the timing unit **56** (FIG. **9**) and to the register sequence **57** (FIG. **10**).

Contacts **104** and **105** connect the 28-volt, d-c supply to relay **100** through the normally closed contact **107** of relay **106**. Relay **100**, after being energized, will remain energized until relay **106** is energized by the reset signal from the register sequence **57** (FIG. **10**), indicating the end of monitoring operation. This reset signal energizes relay **106** and opens normally closed contact **107** to break the 28-volt supply line to relay **100**, thereby deenergizing relay **100**. The digital reset signal is converted into a suitable current level signal for application to relay **106** by means of resistor **108**, transistor **109**, and a 5-volt, d-c supply.

Contact **110** connects the 5-volt, d-c supply to pulse generator **111** which provides the initial reset signal for resetting the shift registers in the register sequence (FIG. **10**) each time the relay **100** is energized by the well monitor signal.

FIG. **7** and **14**: Voltage Controlled Multivibrator

The frequency of the voltage controlled multivibrator **55** is controlled by the strain gauge current signal from the relay unit (FIG. **6**). This relationship is a linear function, with the frequency signal output of the voltage controlled multivibrator **55** increasing as the strain gauge current input increases. This conversion of the strain gauge current signal to a frequency-dependent signal occurs through the operation of operational amplifiers **115** and **116**, transistors **117** and

118, and the associated bias components, resistors R_1–R_{13} and capacitors C_1–C_5 of FIG. 7.

The voltage controlled multivibrator 55 also provides the basic clock timing for the system in the form of a 24-KHz clock and a 384-KHz clock. The basic timing is derived from the 3.072-megahertz crystal 120 and the multivibrator 121 of FIG. 14. The output of multivibrator 121 is divided to 384 KHz by the divider 122 which is a divide-by-8 circuit. The 384-KHz signal is then divided to a 24-KHz signal by the divide-by-16 circuit 123. Further control for the 3.072 -megahertz crystal and multivibrator 121 is provided by means of variable capacitor 124.

FIG. 8: F/D Converter

The variable-frequency output signal from the voltage controlled multivibrator 55 is applied to the F/D converter 63 which is more fully illustrated in FIG. 8. The variable-frequency signal is applied to one input of a gate 129. A 100-millisecond count enable signal from the timing unit 56 (FIG. 9) is applied to a second input of gate 129. This 100-millisecond signal enables gate 129 and allows the frequency signal to pass into binary counters 130, 131, and 132. At the end of the 100-millisecond count period, a preset pulse from the timing unit 56 (FIG. 9) is applied to each of shift registers 133, 134, and 135. The application of this preset pulse enables the loading of shift registers 133, 134, and 135 with the count stored in the counters 130, 131, and 132. The digital data is then strobed out of the shift registers at the 384-KHz clock rate as provided by the register load clock signal from timing unit 56. After the digital data is shifted out of the shift registers, both the shift registers 133–135 and the counters 130–132 are reset by means of a reset pulse from the timing unit 56. The F/D converter is now ready for the next count period which will be initiated upon the application of the next 100-millisecond count enable signal to gate 129.

FIGS. 9 and 15: Timing Unit

The timing unit 56 provides the clock pulses necessary for synchronizing the loading of the digital data from the F/D converter 63 into the storage registers 64.

Referring now to FIG. 9, in conjunction with the timing diagram of FIG. 5, the timing degree and zero degree signals from the relay unit (FIG. 6) are applied as inputs to gates 140 and 141, respectively. Upon the presence of either a timing degree signal or a zero degree signal, gate 142 enables pulse generator 143 to produce a 5-microsecond reset pulse which is used to reset the binary counters 130–132 and the shift registers 133–135 of the F/D converter 63. On the positive-to-negative transition of the reset pulse, the pulse generator 144 produces a 100-millisecond count enable pulse which is applied to the F/D converter 63. At the end of the 100-millisecond count enable pulse, the pulse generator 145 produces a 5-microsecond preset pulse which is applied to the F/D converter 63 to preset the shift registers 133–135. The preset pulse is also coupled as one input to a register load clock generator 150. This reset pulse is applied to a pulse generator 151. A second pulse generator 152 is coupled at its input by the 24-KHz clock from the voltage controlled multivibrator 55. The 384-KHz clock from the voltage controlled multivibrator 55 is coupled to the clock inputs of a pair of JK flip-flops 153 and 154 and is also coupled as one input to a gate 155. Upon the application of the 5-microsecond preset pulse to pulse generator 151, the generator 150 produces a 41.7 -microsecond clock enable pulse at one input to the gate 155. This 41.7-microsecond pulse enables gate 155 and gate 156 to provide a register load clock comprising 16 384-KHz clock pulses to storage register 64. These 16 384-KHz clock pulses strobe the digital data from the F/D converter 63 into the storage register 64.

Also included within the timing unit 56 are a pair of counters 157 and 158 of FIG. 15. Counter 157 is a divide-by-2 counter and counter 158 is a divide-by-12 counter. The 24-KHz clock from the voltage controlled multivibrator 55 is applied as one input to counter 157 and is counted down to a 1-KHz signal at the output of counter 158 for use in the stroke time unit 80 (FIG. 13).

FIG. 10: Register Sequence

The register sequence 57 is utilized to enable the proper storage register to receive digital data from the F/D converter 63. After the addressing of one of the relays by a monitor signal from the computer, the initial zero degree signal received by the register sequence 57 from the addressed relay sets flip-flop 170. When flip-flop 170 is set, the Q output enables the J input of flip-flop 171 so that the next zero degree signal will set flip-flop 171. The setting of flip-flop 171 energizes pulse generator 172 which sets flip-flop 173 to provide a logic "1" bit on line 177. This enables the 0° output line to the storage register 64. The timing degree signal is applied as an input to pulse generator 174. The output of pulse generator 174 is applied as one input to a gate 175. The Q outputs of flip-flops 170 and 171 enable gate 175 to permit the output of pulse generator 174 to be applied by way of line 176 as a shift register clock to each of a plurality of shift registers 180–186. As the first 10° timing pulse is received, the logic "1" bit on line 177 at the input to shift register 180 is shifted to the right one position by the shift register clock, thereby enabling the 10° output line from shift register 180. Similarly, each successive 10° timing degree signal shifts the logic "1" bit one further position to the right in shift registers 180–186 to sequentially enable the 20°–350° output lines.

The shift register clock is also coupled by way of gate 190 to pulse generator 191. Pulse generator 191 provides a reset pulse by way of gates 192, 193, and 194 to the reset terminal of flip-flop 173. This reset pulse to gate 173 is delayed in time from the shift register clock pulse by the inherent delay through gate 190, pulse generator 191, and gates 192–194, thereby allowing the logic "1" bit at the input to shift register 180 to be shifted into the shift register 180 before the resetting of flip-flop 173. This sequence of shifting the logic "1" bit one position to the right in each of the shift registers 180-186 upon the application of a timing degree signal to the pulse generator 174 continues through all the 36 10° positions, thereby providing the 0°–350° output signals from the shift registers 180–186 for strobing the digital data into the storage register 64. When the next zero degree pulse is received, gates 195 and 196 are enabled to provide the end sequence reset signal. Upon enabling the gates 195 and 196, gates 197, 198, and 199 are also enabled to provide a shift register reset to each of the shift registers 180–186. This reset signal is

also applied to pulse generator **200** which, in turn, generates the reset signal for flip-flops **170** and **171**. A pulse generator **201** enables gates **196, 197, 198,** and **199** to reset shift registers **180–186** when power is first applied to the system or when a power failure occurs. An initial reset pulse from the relay (FIG. **6**) is applied through gate **202** each time a relay is energized by a monitor signal from the computer. This initial reset signal passes through gates **202, 198,** and **199** to likewise reset shift registers **180–186** and energize pulse generator **200** to reset flip-flops **170** and **171.**

FIG. **11**: Storage Register

The storage register receives digital data from the F/D converter by way of line **65** and retains it in the proper storage register until addressed by the computer during data retrieval. Each of the **36** storage registers is identical in configuration, and the digital data input line **65** (FIG. **3**) is common to each of these registers. FIG. **11** illustrates one such storage register, storage register No. **1.** The digital data is applied to one input of storage register **210.** The 0° output line from register sequence **57** (FIG. **10**) is connected to a second input of storage register **210** and also to one input of a gate **211.** A logic "**1**" bit on the 0° output line of the register sequence enables gate **211** to pass the register load clock through gate **212** to the storage register **210.** The logic "**1**" bit also enables the storage register **210** to permit the digital data to be strobed into the storage register **210** in response to the register load clock. The register load clock is also applied by gate **212** to a second storage register **213.** Upon the filling of storage register **210,** the digital data is shifted into storage register **213** at the register load clock rate.

To retrieve the data, the proper address of the storage register No. **1** is decoded in the address decoder **70** (FIG. **12**) and an enable **1** signal applied to gate **214.** Gate **214** enables gate **215** to pass the register output clock to each of the storage registers **210** and **213** by way of gate **212.** Gate **214** also enables gate **216** to permit data stored in the registers **210** and **213** to be strobed out onto the data output **1** line in response to the register output clock.

FIG. **12**: Address Decoder

The proper storage register addressing commands are generated by address decoder **70.** The computer sends the address code in the form of signals $\overline{X}_1$, $\overline{X}_2$, and $\overline{X}_3$ and $\overline{Y}_1$, $\overline{Y}_2$, and $\overline{Y}_3$. The $\overline{X}_1$, $\overline{X}_2$, and $\overline{X}_3$ signals are applied to a binary to **1**-of-**8** line decoder **220,** while the $\overline{Y}_1$, $\overline{Y}_2$, and $\overline{Y}_3$ signals are applied to a second binary to **1**-of-**8** line decoder **221.** Outputs of each of the decoders **220** and **221** are combined to provide an enable **1** output signal from gate **222** when the proper address code for storage register No. **1** is sent by the computer to the decoder units **220** and **221.** Similarly, enable **2** – enable **41** signals are provided on the respective output lines from address decoder **70** upon the addressing of decoders **220** and **221** with the proper codes for storage registers No. **2** – No. **41.**

FIG. **13**: Stroke Time

The stroke time unit **80** provides the total time of the pumping stroke in milliseconds. As flip-flop **171** on the register sequence unit (FIG. **10**) is set, a second zero degree signal is applied from flip-flop **171** to pulse generator **230** in the stroke time unit. Pulse generator **230** thereby enables flip-flop **231** so that the next 384-KHz clock pulse will set the flip-flop **231.** As flip-flop **231** is set, the pulse generator **232** produces a clear pulse for shift registers **233–235** and for counters **236–239.** The setting of flip-flop **231** also enables gate **240** to allow the 1-KHz pulses from the timing unit to be gated into and counted by the binary counters **236–239.** As the 70°, 140°, 210°, and 280° pulses are sequentially received from the register sequence **57** (FIG. **10**), the pulse generator **241** produces a pulse on line **254** by way of gates **242** and **243** to parallel load the shift registers **233–235** with the binary count present in the counters **236–239** at the time of occurrence of the 70°, 140°, 210°, and 280° pulses. At the termination of the pulse from pulse generator **241,** pulse generator **244** produces a pulse, enabling a clock generator, comprised of gates **245–249** and flip-flops **252** and **253,** to produce a clock pulse on line **259** to shift the stroke count from shift registers **233–235** into the proper storage registers **37–41** by way of the count output line **260.** At the end of the 360° cycle of the pumping stroke, a reset pulse from the timing unit **56** is applied through gate **255** to reset flip-flop **231.** This resetting of flip-flop **231** inhibits gate **240** from passing the 1-KHz signal to the counters **236–239.** In response to this resetting of flip-flop **231,** pulse generator **256** generates a pulse on line **254** by way of gates **257** and **243** to parallel load the final 360° count in the counters **236–239** into the shift registers **233–235.** This final 360° count remains in the shift registers until the computer addresses the shift registers through gate **250.** At that time, the final 360° count is strobed out of the shift registers through gate **258** as the total time output signal.

Various types and values of circuit components may be utilized in the networks of FIGS. **5–15** to effect the previously described operation. The following TABLE I sets forth one specific example of components which are suitable for such use.

TABLE I

All gates, flip-flops, counters, pulse generators, and shift registers	7400 series logic (Texas Instruments)
Operation amplifiers **115** and **116**	709 (Texas Instruments)
Transistor **109**	T1S98 (Texas Instruments)
Transistor **117**	2N4857 (Texas Instruments)
Transistor **118**	2N7925 (Texas Instruments)
Multivibrator **121**	MC 4024 (Motorola)
Decoders **220** and **221**	MC 4006 (Motorola)
Resistor **108**	1 kohm
Resistor R_1	250 ohms
Resistor R_2	20 kohms
Resistor R_3	1.2 Kohms
Resistor R_4	200 ohms
Resistor R_5	4.3 kohms
Resistor R_6	1.5 kohms
Resistor R_7	1 kohm
Resistors R_8, R_9, R_{10}, R_{11}, and R_{12}	10 kohms
Resistor R_{13}	500 ohms
Capacitor C_1	0.1 μf
Capacitors C_2 and C_5	330 pf
Capacitor C_3	100 pf
Capacitor C_4	40 pf
Capacitor 124	25 pf

Various modifications to the disclosed embodiment, as well as alternate embodiments, may become apparent to one skilled in the art without departing from the scope and spirit of the invention as hereinafter defined by the appended claims.

We claim:

1. An automatic data retrieval system for monitoring the operating conditions of a pumping well of the type having a crank shaft and a downhole pump, comprising:

a. a sucker rod string reciprocated in response to rotational movement of the crank shaft to operate the downhole pump,

b. means for generating a load signal representative of the changing load conditions on the sucker rod string during pumping operation,

c. means for generating timing pulses at periodic intervals during each pumping stroke of the sucker rod string,

d. a computer for generating a monitor command, and

e. a storage unit coupled to said computer and responsive to said monitor command for storing said load signal and said timing pulses at the data rates at which they are generated.

2. The system as set forth in claim 1 wherein said storage unit comprises:

a plurality of storage registers, a register for each of said periodic intervals,

said storage registers being responsive to said timing pulses for storing said load signal for the periodic interval of the pumping stroke during which said load signal was generated.

3. The system as set forth in claim 2 wherein:

said means for generating a load signal is a strain gauge which generates a variable-current signal, and said storage unit further includes:

means for converting said variable-current signal to a digital signal for storage in said storage registers.

4. The system as set forth in claim 3 wherein said means for converting said variable-current signal to a digital signal comprises:

a. a multivibrator which is connected to said variable-current signal, said multivibrator generates a variable-frequency signal which varies linearly with said current signal, and

b. a frequency-to-digital converter, said converter including a binary counter connected to said variable-frequency signal, and a shift register into which the count in said binary counter is shifted, the contents of the shift register are strobed into said storage register in serial form in response to said timing pulses.

5. The system as set forth in claim 2 wherein means for generating a sequence of timing pulses comprises:

a. a ring adapted to be mounted around the crank shaft, said ring having a plurality of magnets located around its periphery, and

b. a pickup assembly adapted to be mounted adjacent the crank shaft and past which said magnets are passed upon rotation of the crank shaft, said assembly producing a timing pulse when each of said magnets passes by said assembly.

6. The system as set forth in claim 5 wherein each revolution of the crank shaft corresponds to one pumping stroke of the sucker rod string, and wherein said plurality of magnets are spaced every 10° around the periphery of said ring, whereby said pickup assembly produces a timing pulse for every 10° of crank shaft rotation.

7. The system as set forth in claim 1 further including:

a. a clock, said clock producing a plurality of clock pulses,

b. a counter coupled to said clock for accumulating a count of the number of clock pulses applied to said counter, and

c. means responsive to said timing pulses for storing the count accumulated in said counter, the stored count representing the stroke time of the pumping well at the time of the generation of each of said timing pulses.

8. The system as set forth in claim 7 wherein said means for storing said count comprises a plurality of storage registers, a register for each of said timing pulses, the count accumulated in said counter being strobed into said storage registers in response to said timing pulses.

9. The system as set forth in claim 8 wherein each revolution of the crank shaft corresponds to one pumping stroke of the sucker rod string, and wherein said timing pulses are produced for every 10° of rotation of the crank shaft.

10. The system as set forth in claim 9 wherein said means for storing the count accumulated in said counter is responsive to timing pulses produced by the magnets located at rotational positions of 70°, 140°, 210°, 280°, and 360°.

11. The system as set forth in claim 8 wherein said clock produces a 1-kilohertz clock pulse, the count accumulated in said counter thereby representing the stroke time of said pumping well in milliseconds.

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