United States Patent [19]

Bottcher et al.

[11] **3,810,457**

[45] **May 14, 1974**

[54] **DIAGNOSTIC APPARATUS FOR AUTOMATICALLY GENERATING AN INTENSITY-TIME DIAGRAM SHOWING POINTS OF MINIMUM INVOLUNTARY MUSCLE MOVEMENT**

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[73] Assignee: **Robert Bosch Elektronik GmbH,** Berlin, Germany

[22] Filed: **Oct. 27, 1972**

[21] Appl. No.: **301,675**

[30] **Foreign Application Priority Data**

Nov. 24, 1971 Germany..... 2158132

[52] **U.S. Cl.**..... **128/2.1 R,** 128/421

[51] **Int. Cl.**..... **A61b 5/05**

[58] **Field of Search**..... 128/2.1 R, 419 P, 419 R, 128/421, 422, 423

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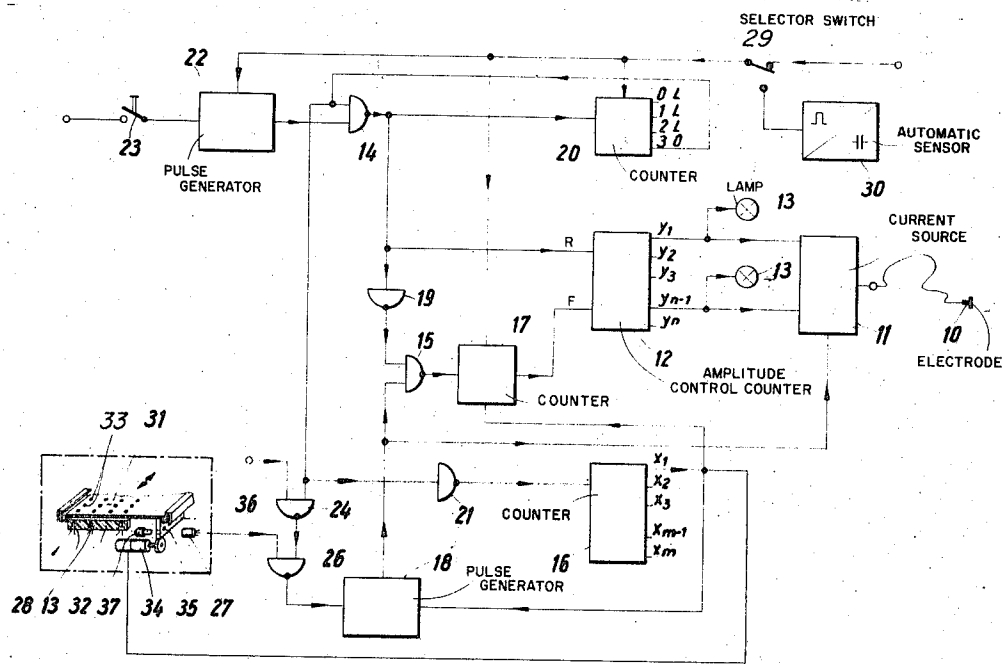
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Attorney, Agent, or Firm—Michael S. Striker

[57] **ABSTRACT**

Both amplitude and pulse width of pulses applied to the muscle are varied automatically, a given number of pulses being applied at a given amplitude and pulse width prior to increasing the amplitude. The given number varies with the pulse width. The amplitude is increased until involuntary muscle movement results. The same procedure is repeated at the subsequent pulse width.

27 Claims, 9 Drawing Figures



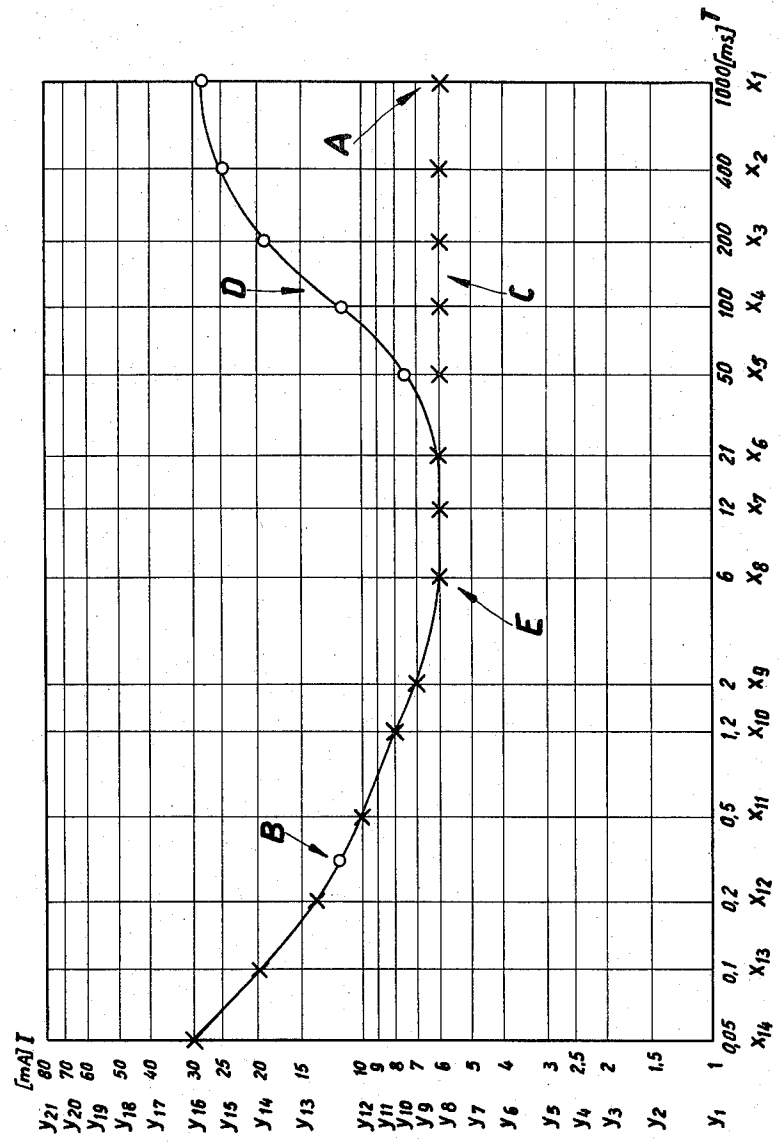

[mA] I
y21 80
y20 70
y19 60
y18 50
y17 40
y16 30
y15 25
y14 20
y13 15
y12 10
y11 9
y10 8
y9 7
y8 6
y7 5
y6 4
y5 3
y4 2.5
y3 2
y2 1.5
y1 1
T
1000[ms]
x1
x2 400
x3 200
x4 100
x5 50
x6 21
x7 12
x8 6
x9 2
x10 1.2
x11 0.5
x12 0.2
x13 0.1
x14 0.05
A
B
C
D
E

Fig. 1

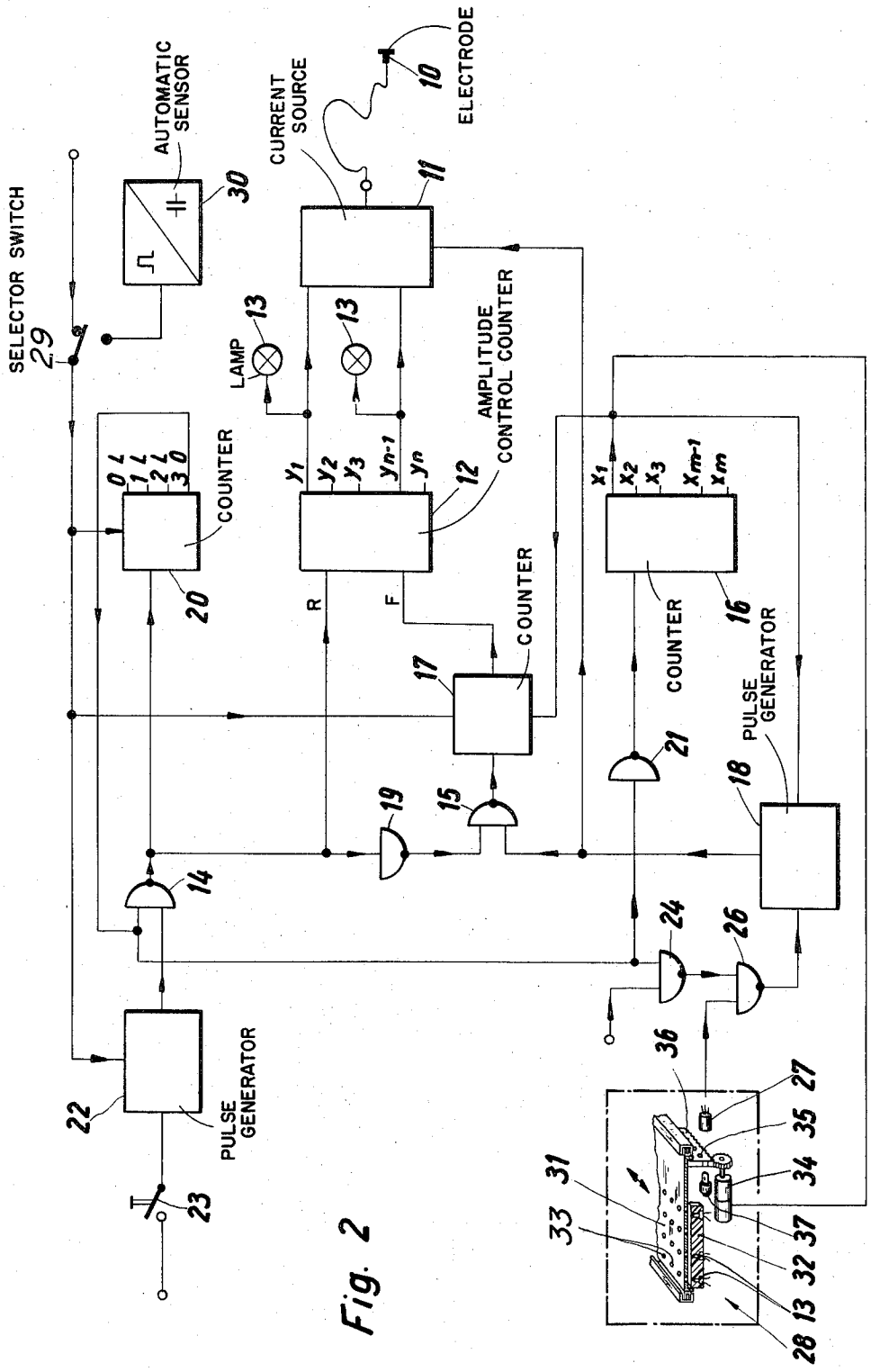

SELECTOR SWITCH
29
AUTOMATIC SENSOR
30
CURRENT SOURCE
11
ELECTRODE
10
LAMP
13
13
AMPLITUDE CONTROL COUNTER
12
COUNTER
20
COUNTER
17
COUNTER
16
PULSE GENERATOR
18
PULSE GENERATOR
22
14
19
15
21
24
26
23
36
27
35
34
31
33
37
32
13
28

Fig. 2

Fig. 3

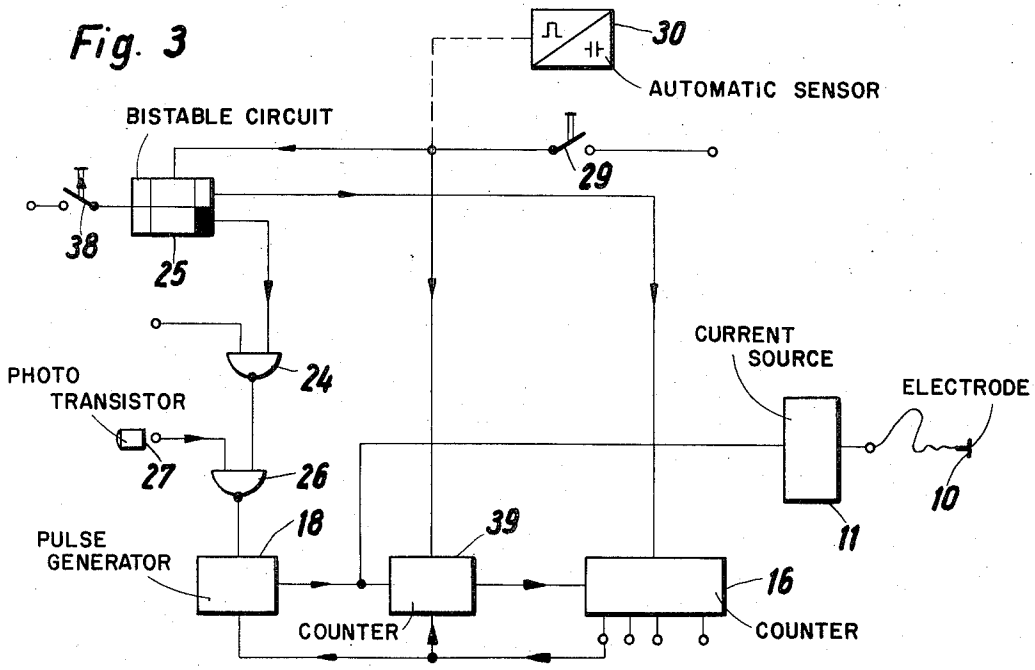

30
AUTOMATIC SENSOR
BISTABLE CIRCUIT
29
38
25
CURRENT SOURCE
ELECTRODE
PHOTO TRANSISTOR
24
27
26
10
11
18
39
PULSE GENERATOR
16
COUNTER
COUNTER

Fig. 4

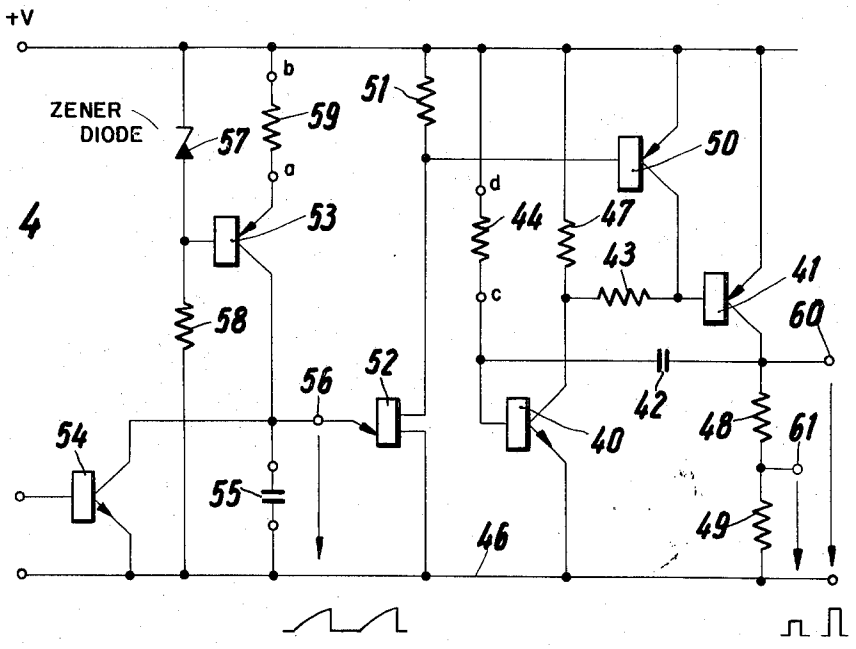

+V
b
ZENER DIODE
57
59
51
50
a
d
53
44
47
43
41
58
c
60
56
52
42
54
40
48
61
55
46
49

Fig. 5

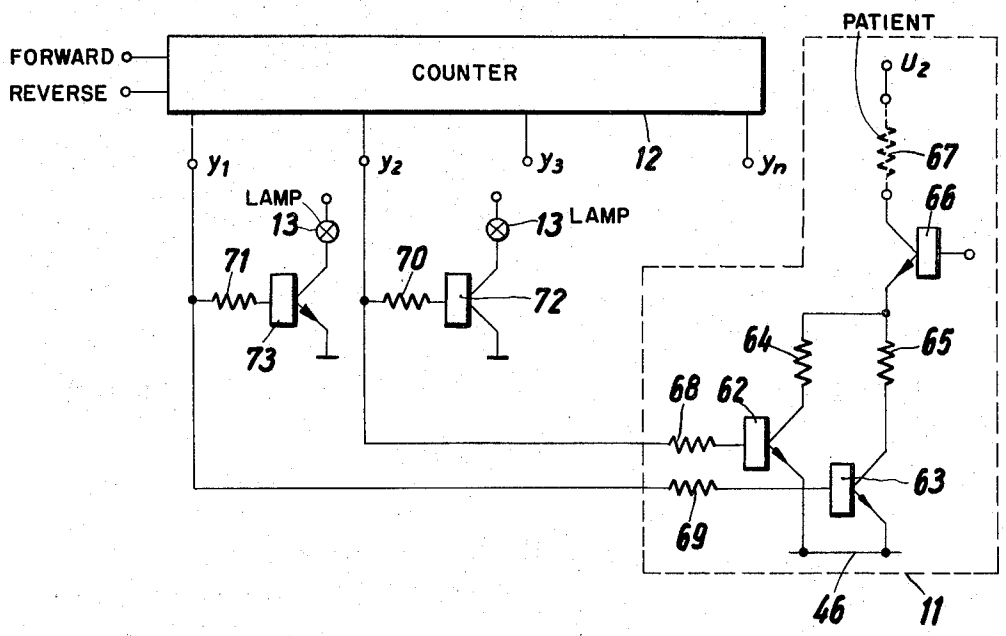

FORWARD
REVERSE
COUNTER
PATIENT
U_2
y_1
y_2
y_3
12
y_n
LAMP
13
LAMP
13
67
66
71
70
72
73
64
65
68
62
63
69
46
11

Fig. 6

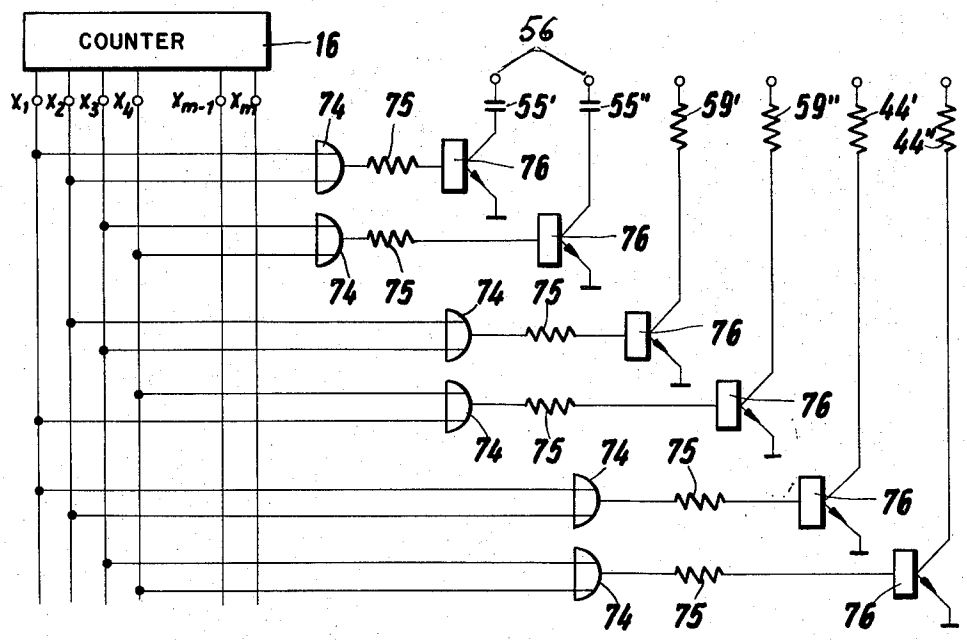

COUNTER
16
56
X_1 X_2 X_3 X_4 X_{m-1} X_m
74
75
55'
55"
59'
59"
44'
44"
76

Fig. 7

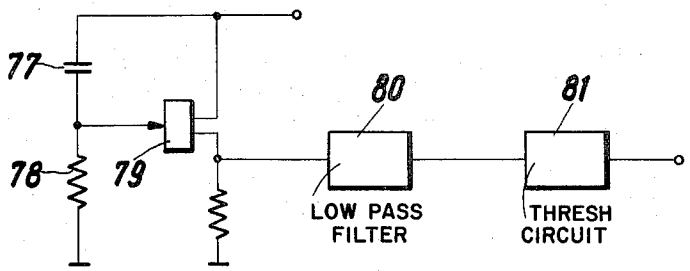

77
78
79
80
81
LOW PASS FILTER
THRESH CIRCUIT

Fig. 8

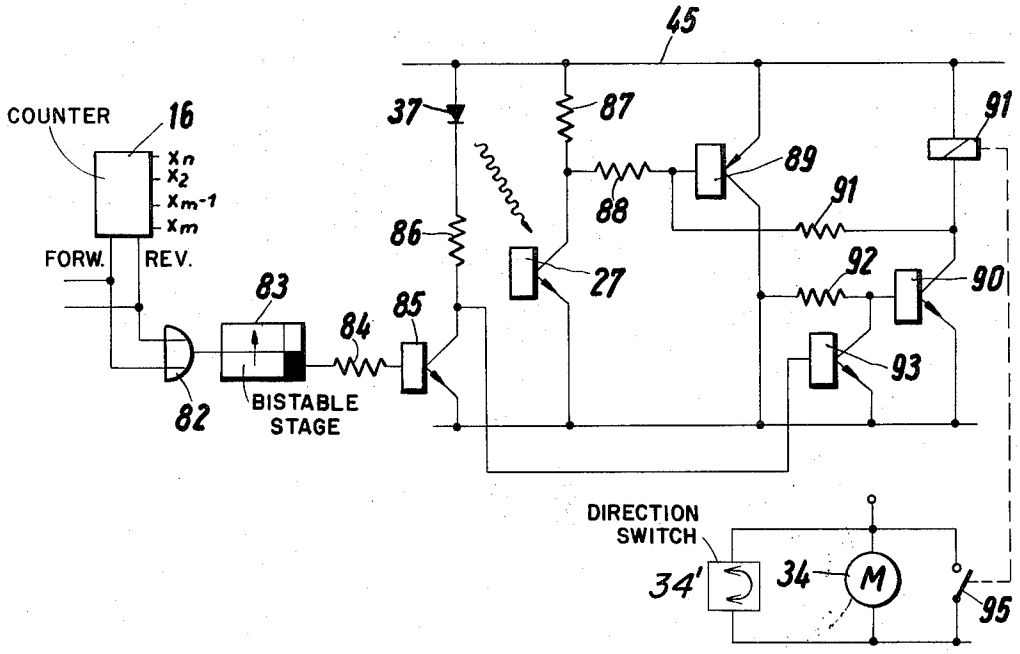
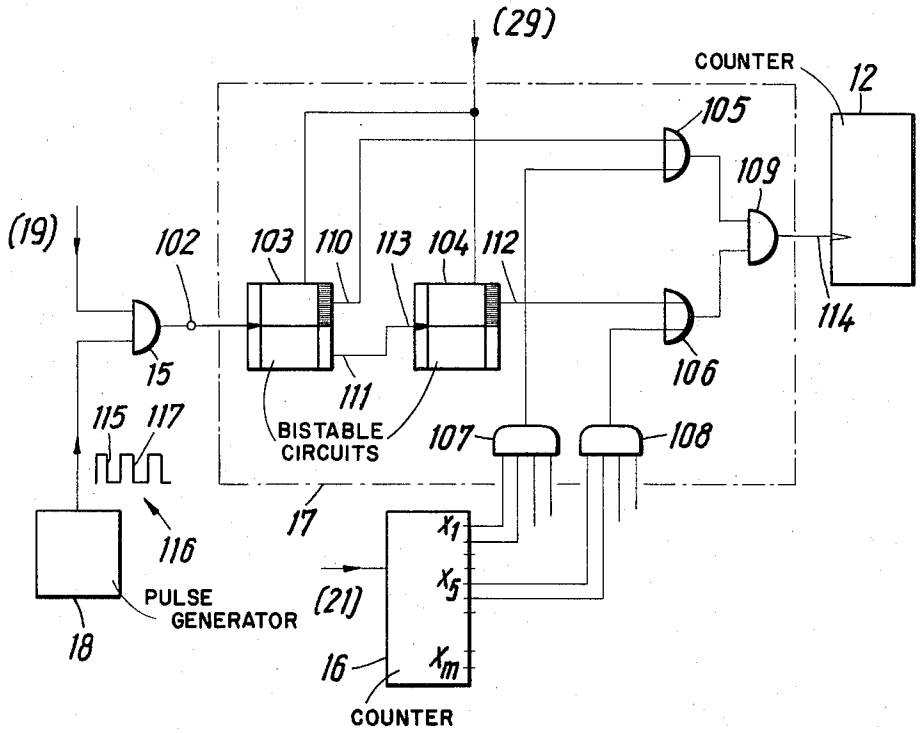

45
COUNTER
16
x_n
x_2
x_{m-1}
x_m
FORW.
REV.
82
83
BISTABLE STAGE
84
85
86
37
87
88
89
91
27
92
90
93
DIRECTION SWITCH
34'
34
M
95

Fig. 9


(29)
COUNTER
12
105
109
(19)
102
103
110
113
104
112
114
15
106
111
115
117
BISTABLE CIRCUITS
107
108
17
116
x_1
x_5
(21)
PULSE GENERATOR
18
16
x_m
COUNTER

DIAGNOSTIC APPARATUS FOR AUTOMATICALLY GENERATING AN INTENSITY-TIME DIAGRAM SHOWING POINTS OF MINIMUM INVOLUNTARY MUSCLE MOVEMENT

BACKGROUND OF THE INVENTION:

This invention relates to a diagnostic apparatus for generating an intensity-time diagram showing points of minimum involuntary muscle movement as a function of amplitude and duration of electrical pulses applied to said muscle.

It is known that when electrical pulses are applied to the muscles in a human body, and in particular when these pulses are current pulses, then a healthy muscle will respond to pulses having amplitudes larger than a given amplitude at a given pulse width by contracting. However, muscles injured by sickness contract at different values from those causing contraction in healthy muscles. Thus in order to diagnose illnesses certain intensity-time diagrams are recorded showing characteristic values at which the muscles contract. These diagrams give a good indication of the condition of the muscles. It should be noted that for this discussion the term intensity will be taken to mean the amplitude of the pulse applied to the muscle, while the term time will refer to the pulse width of the pulse applied to the muscle.

Diagnostic apparatus of the above-described type is known wherein the adjustment of the pulse width takes place automatically while the amplitude of the pulses is set by hand. The point at which the muscle contraction occurs is then recorded by means of a two coordinate type recorder which is activated by means of a switch.

SUMMARY OF THE INVENTION

It is the object of the present invention to furnish diagnostic apparatus for generating an intensity-time diagram showing points of minimum involuntary muscle movement as a function of amplitude and duration of electrical pulses applied to said muscle, wherein the required amplitude adjustment as well as the duration adjustments are carried out automatically.

It is a further object of the present invention that apparatus of this type be combined with recording apparatus which is both accurate and simple.

It is a further object of the present invention to greatly decrease the time required to generate the above-mentioned intensity-time diagram.

The present invention comprises adjustable pulse generator means furnishing a sequence of electrical pulses, each of said pulses having a determined amplitude and pulse width. It further comprises first counter means connected to said pulse generator means for counting said electrical pulses and automatically changing the amplitude of said pulses following receipt of a given number of said pulses. Varying means vary said given number in dependence upon said pulse width of said pulses. Finally, stop means stop said first counting means upon appearance of said involuntary muscle movement.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation,

together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING:

FIG. 1 shows an intensity-time diagram;

FIG. 2 is a block diagram of the apparatus of the present invention required for determining the rheobase;

FIG. 3 is a block diagram of the portion of the apparatus required for determining the chronaxie;

FIG. 4 is a circuit diagram showing the control pulse generator;

FIG. 5 is a circuit diagram showing the amplitude control control means;

FIG. 6 is a circuit diagram showing the circuit means for changing the pulse width and pulse interval of the pulses furnished by the generator of FIG. 4;

FIG. 7 is a schematic diagram of the sensor means for sensing the muscle contractions;

FIG. 8 is a circuit diagram showing the recording arrangement; and

FIG. 9 shows the interconnection between counters 12, 16 and 17 of FIG. 2.

DESCRIPTION OF THE PREFERRED EMBODIMENTS:

A preferred embodiment of the present invention will now be described with reference to the drawing.

FIG. 1 shows an intensity-time diagram as is to be generated by the present invention. The pulse width of the applied pulses is plotted along the abscissa, while the ordinate represents the amplitude of the pulses in milliamps. Associated with each of the pulse widths shown along the abscissa is a determined pulse interval. Thus for pulses having a pulse width of one second, the interval between pulses is two seconds and, therefore, the width/interval ratio 0.5. For a pulse width of one second and an interval of 2 seconds, the current intensity is measured which is just barely sufficient to effect a minimum involuntary muscle movement, that is a contraction or twitching. The so-found valve is designated as the basic threshold or rheobase. It is designated by the letter A in FIG. 1. A second important point in the diagram is designated with reference letter B, which represents the chronaxie. For determining the chronaxie, the time interval is measured for which a current having twice the amplitude of the rheobase value must flow in order that the minimum involuntary muscle movement takes place (the time interval herein referred to is the pulse width of the applied pulses). A further value, designated by E in FIG. 1 is designated as use time and represents the pulse width required to cause a minimum involuntary muscle movement when the pulse amplitude is the same as that of the rheobase.

The points mentioned above, as well as the curves connecting said points, can of course be derived from pulses having different pulse shapes. The curve designated by C was derived using rectangular pulses, while the curve having reference numeral D indicates a curve derived using pulses having a logarithmic shape. These curves and the rheobase and chronaxie values can be used to drawn conclusions about the condition of the muscles of the patient.

In FIG. 2, an electrode 10 is connected to the patient in order that the diagram described in FIG. 1 may be generated. The electrode 10 is connected to a current source 11 which has associated amplitude control circuit means. The current source 11 and the amplitude control circuit means associated therewith are connected to the outputs y_1–y_n of amplitude control counting means denoted by reference numeral 12. The amplitude of the current applied to the patient varies as a function of the count registered on the amplitude control counting means, that is on which the outputs y_1–y_n is energized. Lamps 13 are connected, one to each output y_1–y_n. These lamps thus indicate the count on counter 12 and thus the amplitude of the pulses applied to the patient. Each lamp lights when the output to which it is connected caries a "1" signal. The lamps 13 are also shown again as part of the means indicating the point in the intensity-time diagram, 28. They are mounted in a lamp bank 32.

The reverse counting input (R) of counter 12 is connected to the output of AND-gate means 14. The forward counting input (F) of counter 12 is connected to the output of control pulse counting means 17 whose input is connected to control pulse generator means 18 through additional AND-gate means 15. The second input of additional AND-gate means 15 is connected via an inverter 19 to the output of AND-gate 14, whereby control pulses generated by pulse generator 18 are transmitted to the counter 17 when the output signal of AND-gate 14 is a O signal. Under these conditions counter 17 counts the pulses generated by pulse generator 18. When the number of so-counted control pulses is equal to a given number, counter 17 furnishes a counter advance signal to amplitude control counting means 12, thereby advancing the count on counter 12 by one unit. This increases the amplitude of the pulses furnished by stage 11 to electrode 10. Further, it causes the next-following lamp 13 to light. The count of counter 17 at which the counter advance signal is furnished in turn depends upon the output of counter 16 herein referred to as timing counter means.

The control pulses furnished by the pulse generator 18 are also applied directly to stage 11. In this stage they operate switching means which cause the current pulses to be applied to electrode 10 with a frequency and a pulse width determined by the pulses furnished by pulse generator 18. The pulse width and the frequency of the pulses furnished by pulse generator 18 in turn depend upon the output of the timing counter means, namely counter 16.

The reset pulse counting means, namely a counter 20 have an input connected to the output of AND-gate 14. A predetermined reset counting output terminal is connected to one input of AND-gate 14, which causes AND-gate 14 to become conductive when counter 20 has reached a particular count. Further, the forward counting input of counter 16 is connected to the predetermined reset counting output terminal of counter 20 (designated 3 0 in FIG. 2) through an inverter 21. Thus as soon as a zero signal appears at the selected output of counter 20, counter 16 is advanced by one count. The second input of AND-gate 14 is connected to the output of second pulse generator means 22. Second pulse generator means 22 have an input connected to a switch 23, closing of which furnishes a reset signal starting said second pulse generator means. Power is supplied to the arrangement shown in FIG. 2 through a main switch which is not shown.

The first input of AND-gate 14 is also directly connected to the first input of a NAND-gate 24 to whose second input is applied one output of a bistable stage 25 which is shown in FIG. 3 and will be described in greater detail in connection with that Figure. The output of NAND-gate 24 is connected to the input of a second NAND-gate 26 to whose second input a phototransistor 27 is connected. This phototransistor is part of the fine positioning means for the table carrying the diagram and will be described in greater detail below. The output of second NAND-gate 26 is connected to the input of the control pulse generator 18. Pulse generator 18 is thus activated when the correct inputs are present for the NAND-gates 24 and 26.

Pulse generator 22, counter 17 and counter 20 are all connected to stop means, here a switch 29 which is closed by the operator of the apparatus when the minimum involuntary muscle movement is observed. Operation of switch 29 causes pulse generator 22 to be disconnected, and counters 17 and 20 to be deactivated and reset to zero. Alternatively (by switching a selector switch 29 from the position shown in FIG. 2 to a position connecting terminal *b* of said switch to the remainder of the circuit), the arrangement can be automated even further by substituting another embodiment of stop means, namely automatic sensor means 30 which, as will be described in more detail below, furnish a pulse upon occurrence of the muscle contraction. The pulse of course operates exactly as does the closing of switch 29, but the arrangement 30 does not require anyone to operate the equipment and observe the patient.

The above-described arrangement operates as follows:

To start the equipment, switch 23 is closed. This causes pulse generator 22 to start generating pulses. At this point counter 20 is in its null position which is so arranged that the predetermined reset counting output terminal carries a I signal. This I signal is applied to one input of AND-gate 14 and therefore allows this AND-gate to be conductive for pulses from the second pulse generator means. These pulses are therefore applied to the input of counter 20, where they continue to increase the count on said counter, one unit for each received pulse. The pulses appearing at the output of AND-gate 14 are also applied to the reverse counting input of counter 12, where they result in a reverse count of one unit for each received pulse. Thus counter 12 is reset, until, at the most, its zero position is reached.

For a predetermined count on counter 20, a O signal appears at the predetermined reset counting output terminal. This causes AND-gate 14 to be blocked so that no further inputs are received by counters 20 and 12. Further, the O signal at the predetermined reset counting output terminal of the reset pulse counting means 20 causes counter 16 to be moved to the x_1 position.

The x_1 output signal of counter 16 is used to move a table 31 which is part of the indicating means 28. The signal causes the table to be moved in a direction perpendicular to the axis of the lamp bank 32. This lamp bank, as previously explained, carries lamps 13. For greater clarity, lamps 13 are again shown in the lamp bank 32. Table 31 has a paper, recording means, which carry the diagram shown in FIG. 1. The paper is spread

upon the table in such a way that each intersection of the vertical and horizontal lines is over a hole **33** in the table. Movement of the table in the direction indicated by the arrow in proportion to the signal x_1 thus causes the x values to be generated, while the y value, that is the ordinate, is furnished by the lighting of one of the lamps **14.** Thus when counter **16** is switched to furnish the x_1 output signal, table **31** is driven by motor **34** into the position wherein the lamp bank is lined up with the x_1 coordinate shown in FIG. **1.** When the table has moved into the correct position the hole **35** shown in FIG. **2** is lined up with a light source **37** and a phototransistor **27** and phototransistor **27** thus furnishes a signal to the second input of NAND-gate **26** which causes this NAND-gate to become conductive for signals furnished by first NAND-gate **24.** The signal from phototransistor **27** is also used to stop the motor, **34,** which moves the table. This will be described in more detail below. When the zero signal next appears at the output of counter **20,** the control pulse generator means **18** are thus activated. At this point, pulse generator **18** commences to furnish pulses having a pulse width and pulse intervals determined by the output of counter **16.** To correspond with FIG. **1,** the first pulse width would be one second, and the first pulse interval two seconds. At this time counter **12** furnishes a y_1 output which controls the amplitude of the current to be a relatively small amplitude of, according to FIG. **1,** 1 milliamper.

Current pulses are thus applied to electrode **10** having a pulse width and pulse interval determined by pulse generator **18** and an amplitude determined by counter **12.** A number of identical pulses is applied to the patient in order that any muscle action may be observed before a higher amplitude current is used. The reaction time of the observer observing the patient, if such be present, must of course also be taken into consideration. Thus counter **17** counts the pulses furnished by pulse generator **18** and furnishes a counter advance signal to counter **12** only after a predetermined number of identical pulses has been applied to electrode **10** and thus to the muscle of the patient. Only when counter **17** has reached a predetermined counting output, which, in turn, is determined by the state of counter **16,** and no muscle twitching has been observed, is a counter advance signal applied to counter **12,** thereby increasing the amplitude of the current pulses applied to the patient. From FIG. **1** it is seen that when the counter **12** furnishes a count y_2, the amplitude of the current in the pulses applied to the patient is 1.5 miliamps. Simultaneously with the furnishing of the counter advance signal to counter **12,** counter **17** is reset. Further, the change in the count on counter **12** of course causes a different lamp **13** to light. Specifically of course the next lamp following the lamp activated by output y_1 will light. Again a predetermined number of identical pulses is furnished until counter **17,** in the absence of a muscle twitch, again advances counter **12.** The amplitude of the current pulses applied to the muscle of the patient is increased until the minimum muscle movement is observed and the operator of the machine operates stop switch **29** or, alternatively, the automatic stop means **30** are activated by the twitching of the muscle. This causes pulse generator **22** to be deactivated and counters **17** and **20** to be deactivated and reset to zero. The place on the paper may now be marked under which the lamp **13** is lit. This first measured value which was obtained from pulses having a pulse width of one second and an interval of two seconds is, as mentioned above, designated the rheobase.

For generating the next pulse on the diagram switch **23** must again be activated. The previously reset counter **20** is furnished pulses through AND-gate **14** for a forward counting operation, while counter **12** is simultaneously reset an equal number of steps. Counter **12** may not be reset all the way to the value of y_1 in order to speed the measuring process. The number of steps that counter **12** is reset is so chosen that one is absolutely certain that the minimum muscle twitching will be observed. Experience has shown that it is sufficient to reset counter **12** by approximately six steps, since this will result in a current pulse amplitude which does not as yet cause muscle twitching. Reference to FIG. **1** will show that for rectangular pulses the curve starting at the rheobase value at first is substantially horizontal.

When counter **20** has again reached the position wherein a zero signal appears at the predetermined reset counting output terminal, the resetting of counter **12** is stopped and counter **16** is advanced by one step. This again causes motor **34** to be activated and table **31** to be moved to the next position. Again, the signal from photo-transistor **27** serves as a fine positioning signal which stops the motor and causes pulse generator **18** to be activated as described above. The holes **35** in the table of course are bored in such a manner that each of the holes indicates the correct positioning in the x direction. Thus line x_2 will be directly aligned with the lamp bank when the next signal appears on phototransistor **27.** The pulse width furnished by pulse generator **18** now is the pulse width and pulse interval determined by count x_2 on counter **16.** This is a shorter pulse width and possibly also a shorter pulse interval. Again, pulses are applied to the patient with the pulse width and interval determined by pulse generator **18.** Again, the amplitude of the pulses depends upon the output of counter **12.** This amplitude is increased as stated previously after a predetermined number of identical pulses has been applied to the patient. Upon observance of the minimum muscle movement either the response of stage **30** or the closing of switch **29** causes the counters and pulse generators to be reset and deactivated as stated above. The lamp lit along the line x_2 then indicates the value of y which is to be entered on the diagram. This process is then repeated for other points in FIG. **1.**

In order to find the value required for the chronaxie, the procedure is the following: As mentioned above, pulses of twice the amplitude as the rheobase are applied to the muscle and the pulse width is increased until the minimum muscle twitching appears.

The portion of the apparatus for carrying out this procedure is shown in FIG. **3.** First, start switch **38** is activated, causing bistable circuit means **25** to switch to the second stable state. Switching the bistable circuit means **25** also causes counter **16** to be advanced to its end count, namely count x_{14}, at which the minimum pulse width is furnished by pulse generator **18.** The output at counter terminal x_{14} causes the motor to be energized, thereby moving table **31** into the position wherein point x_{14} is lined up with the lamp bank. The amplitude of the pulses applied to the patient is so adjusted that it is double the amplitude as was obtained by the rheobase measurement. Activation of the pulse

generator **18**, following correct position of the table, then causes short pulses to be delivered to the patient. Again, a predetermined number of equal pulses is applied to the patient until the count on counter **16** is changed. As previously stated enough time must be allowed, especially if the stop is manually operated, to allow the observer to see the muscle movement and to react thereto.

The number of so-applied equal pulses depends upon the count on counter **16**. This is accomplished by providing a counter **39** which counts the number of pulses furnished by pulse generator **18**. The counter is preset to a number corresponding to the count on counter **16**. When counter **39** reaches zero, it furnishes a pulse to counter **16** which causes this counter to count backwards by one unit. Simultaneously, counter **39** is again set to its initial condition corresponding to the new count on counter **16**, causing pulse generator **18** to deliver a corresponding number of equal pulses having a slightly longer pulse width than the previously applied pulses. If no muscle movement is observed, the procedure is repeated until such muscle movement is observed, switch **29** is activated or unit **30** responds. The point on the diagram determined by the positioning of table **31** and the lighting of one of the lamps **13** can then be entered into the diagram.

The apparatus has a "repeat" key which causes the whole process to be repeated automatically for any desired point, so that the obtained values may be checked.

The individual units shown in FIGS. **2** and **3** and their interconnection will now be described in greater detail with reference to FIGS. **4–9**.

FIG. **4** is a circuit diagram of control pulse generator means **18**, pulse generator **18** comprises a monostable multivibrator having transistors **40** and **41**. The base of transistor **40** is connected to the collector of transistor **41** by means of a capacitor **42**, while the base of transistor **41** is connected to the collector of transistor **40** by means of a resistor **43**. Base of transistor **40** is connected through a resistor **44** to the common plus line **45**, while the emitter of transistor **40** is connected to the common minus line **46**. The collector of transistor **40** is connected through a resistor **47** to the plus line **45**. The emitter of transistor **41** is also connected to the plus line **45** and the collector of transistor **41** is connected to the minus line **46** by means of a voltage divider comprising resistors **48** and **49**. The collector-emitter circuit of a switching transistor **50** is connected in parallel to the base-emitter circuit of transistor **41**. The base of transistor **50** is connected to the positive line through a resistor **51** and is also connected to the base **2** of a unijunction transistor **52**, whose first base is connected to minus line **46**. The emitter of unijunction transistor **52** is connected to a terminal **56**. Terminal **56** is connected to the collector of a transistor **54** whose emitter is connected to minus line **46**. Terminal **56** is also connected to one terminal of a capacitor **55** whose other terminal is connected to minus line **46**. The collector of a transistor **53** is also connected to terminal **56**, while its emitter is connected to the plus line through a resistor **59**. The base of transistor **53** is connected to the tap of a voltage divider comprising a Zener diode **57** and a resistor **58**. The output of second NAND-gate **26** is applied to the base of transistor **54**.

The operation of the above-described pulse generator **18** is as follows:

When a O signal appears at the output of second NAND-gate **26**, which signal has approximately the potential of minus line **46**, then transistor **54** is blocked and capacitor **55** is charged through the collector-emitter circuit of transistor **53** and resistor **59**. The current charging capacitor **55** of course is determined not only by resistor **59** but by the voltage divider ratio of the voltage divider having Zener diode **57** and resistor **58**. Under these conditions transistors **40** and **41** of the monostable multivibrator are in the conductive state so that substantially the full positive potential appears at the collector of transistor **41** and thus at the right-hand electrode of capacitor **42**. Similarly, the left-hand electrode of capacitor **42** is the potential determined by the minus line **46**. When the voltage across capacitor **55** reaches a predetermined value, the internal base resistance of double base diode **52** is greatly reduced for a short time and capacitor **55** discharges through double base diode **52**. Thus a negative pulse is applied to the base of transistor **50**, causing this transistor to be switched to the conductive state. This in turn causes the base of transistor **41** to receive a positive signal, blocking transistor **41**. This causes the potential at the collector of transistor **41** and thus at the right-hand electrode of capacitor **42** to become substantially equal to the negative potential available on line **46**. The voltage on the left-hand electrode of capacitor **42** is still more negative than this value by approximately the operating voltage. Thus transistor **40** is also blocked and remains blocked until capacitor **42** has recharged through resistor **44** to such a point that the potential on the left electrode is sufficient to switch transistor **40** to the conductive state. This causes transistor **41** to become conductive again also and capacitor **42** recharges to its original potential.

The above-described process is repeated when the voltage across capacitor **55** again has reached the value for causing unijunction transistor **52** to become conductive. The voltage generated at terminal **56** to have a substantially exponential form. Corresponding to this exponential form, the output shown at terminal **60** and terminal **61** is a rectangular pulse sequence, the amplitude at terminal **60** being approximately twice the amplitude appearing at terminal **61**.

Changes in the pulse width and the pulse interval of the pulses are accomplished by changing the resistors and the capacitors in the above-described circuit. The pulse width depends at least in part on the values of resistors **59** and capacitors **55**, while the pulse interval depends at least in part on the value of resistor **44** and capacitor **42**. How these are changed will be shown in the description of FIG. **6**.

With reference to FIG. **5**, it will now be shown how the amplitude of the pulses applied to the patient is made to vary as a function of the output of counter **12**. FIG. **5** shows the circuitry required for this purpose. Specifically, FIG. **5** shows the amplitude control circuit means, namely transistors **62** and **63** and the associated resistors as well as output switch means **60** and the symbolically shown electrode **67**. Transistors **62** and **63** serve only as an illustration. A much larger plurality of such transistors would of course be used, namely one for each counting output of counter **12**. Specifically, the emitters of transistors **62** and **63** are connected in common to the minus line **46**, while the collector of

transistor 62 is connected to the emitter of a transistor 66 constituting output switch means through a resistor 64 while the collector of transistor 63 is connected to said emitter via a resistor 65. The collector of transistor 66 is connected to the electrodes shown in symbolic form as a resistor 67 to the voltage source denoted by U_2. The output of the pulse generator 18, namely terminal 60, is applied to the base of transistor 66.

The base of transistors 62 and 63 are connected to the respective counting outputs of counter 12 through resistors 68 and 69 respectively. Counter 12 may be any conventional counter and comprise bistable circuits in each counting stage. Further, each counting output y_1–y_n is connected to the base of a transistor 73, 72, etc. through resistors 71, 70 respectively. The emitters of transistors 73 and 72 are connected to ground potential, while the collectors are connected to the positive line through lamps 13. Transistors 73, 72, etc., operate as amplifiers. Thus when counter 12 furnishes a signal output y_1, transistor 73 becomes conductive causing lamp 13 to light. The lighting of the lamp thus indicates the state of counter 12. This in turn gives an indication of the amplitude of the pulses applied to the patient since transistor 63 is also put into the conductive state by a signal at terminal y_1 and causes current to flow upon application of a pulse to the base of transistor 66 which current depends upon resistor 65. Thus the current flowing through resistor 67 (which symbolizes the muscle of the patient) has an amplitude depending upon the state of counter 12 and a pulse width and interval depending upon the output of pulse generator 18. When the signal at counting output y_1 disappears and the signal at counting output y_2 appears, the amplitude of the current is determined by resistor 64, since transistor 62 will then be conductive.

FIG. 6 shows the circuitry which is required to change the pulse width and interval in dependence on the count of counter 16. It should be noted that terminals *a*, *b*, *c* and *d* in FIG. 4 are the same as those shown in FIG. 6. The top line of FIG. 4 is the plus line, while the bottom line is ground potential. Referring now to FIG. 6, it is seen that the outputs $x_1, x_2 \ldots x_m$ of counter 16 are connected in pairs to the inputs of OR-gates 74 whose outputs are connected through base resistors 75 to the bases of transistors 76. Although only two transistors 76 are shown for each element which may be varied (capacitor 55, resistor 59 and resistor 44) more of such transistors and associated elements may of course be furnished. In any case each count on counter 16 results in the energization of at least one OR-gate 74 for each of the above-mentioned elements. When a positive signal is passed through the OR-gate 74, the associated transistor 76 becomes conductive connecting the associated element (for example 55′) into the circuit. Since elements 59 and 44 do not have any connection to ground potential, an additional transistor 76′ must be provided for each of these components. Specifically, the transistor 76 which is associated, for example, with resistor 59′, has a voltage divider circuit in its collector circuit. Connected to the tap of the voltage divider is the base of a transistor 76′ whose emitter-collector circuit is connected from the positive line (terminal b) to one terminal of resistor 59′ whose other terminal is connected to point a of FIG. 4. When transistor 76 becomes conductive, the voltage at the base of transistor 76′ drops causing this transistor also to become conductive. This of course connects element 59′ into the circuit of FIG. 4. Resistors 44′ are connected into the circuit of FIG. 4 in the same fashion, except that the switching transistor which switches these between points *d* and *c* in FIG. 4 is labelled 76″ in FIG. 6. It best becomes evident that with a circuit such as shown in FIG. 6, the width and the interval between the pulses furnished by pulse generator 18 as shown in FIG. 4 may be varied over extremely wide ranges.

FIG. 7 shows one embodiment of the automatic stop means labelled stage 30 in FIGS. 2 and 3. The circuit shown in FIG. 7 shows a capacitive pickup 77 which is connected to the patient. The pickup, denoted by capacitor 77, forms part of a voltage divider whose other portion is embodied in a resistor 78. The voltage divider tap of this voltage divider is connected to the emitter of a field effect transistor 79 whose output is smoothed by a low pass filter 80. The output of low pass filter 80 is in turn connected to the input of a threshold stage 81. When the threshold of threshold means 81 is passed, threshold circuit 81 furnishes the proper signal for deactivating pulse generator 22 and counters 17, 20 and 39. This signal of course results when the signal at the input of field effect transistor 79 changes due to muscle contraction in the patient.

FIG. 8 shows the control circuit for controlling motor 34 which drives table 31. The direction of rotation of motor 34 is determined by the setting of a switch 34′. The remainder of the circuit is used to start and stop the motor. Specifically, both the forward and the reverse counting input of counter 16 are connected to the input of an OR-gate 82 whose output is connected to the switching input of a monostable multivibrator 83. An output of monostable multivibrator 83 is connected through a resistor 84 to the base of a transistor 85 whose emitter-collector circuit is connected in series with a resistor 86 and a light source 37, here a gallium-arsenide light emitting diode, the so-formed series circuit being connected from ground to the positive line. The emitter-collector circuit of a phototransistor 27 is connected to plus line 45 by means of a resistor 87 and is further connected to the base of a transistor 89 through a resistor 88. The emitter-collector circuit of transistor 89 is connected from positive line 45 to ground. Transistor 89 forms part of a bistable stage which also includes transistor 90 and resistors 91 and 92. Specifically, resistor 91 is connected from the base of a transistor 89 to the collector of the transistor 90, while resistor 92 is connected from the collector of transistor 89 to the base of transistor 90. Further, the emitter-collector circuit of a transistor 93 is connected between the base and emitter of transistor 90, the base of transistor 93 being connected to the collector of transistor 85. The emitter of transistor 90 is connected to ground potential, while its collector is connected to the coil of a relay 91 whose other terminal is connected to plus line 45. Relay 91 controls contacts 95 which, when closed, short circuits motor 34. The above-mentioned switch 34′ which determines the direction of rotation of motor 34 is connected in parallel with said motor and contacts 95.

The above-described circuit operates as follows:

When a pulse is received at either the forward or reverse counting input of counter 16, that is when the count on counter 16 is changed in either direction, this pulse is transmitted through OR-gate 82 to the monostable multivibrator 83, thereby switching this mono-

stable multivibrator to the unstabled state. At this time, transistor **85** is blocked, blocking the current flow through diode **37** and therefore causing diode **37** to stop the emission of light. Therefore, no more light is received by phototransistor **27** and this transistor blocks. However, the blocking of transistor **85** has caused a positive potential to be applied to the base of transistor **93,** causing this transistor to become conductive. This causes a negative potential to be applied to the base of transistor **90** causing this to block. Therefore, relay **91** is deenergized and contacts **95** open. Motor **34** will commence to run in the direction indicated by switch **34.** This causes table **31** to move until a hole **35** in the rod **36** affixed to table **31** causes light to be transmitted from diode **37** to phototransistor **27.** It should be noted that the time constant of monostable stage **83** is so arranged that diode **37** is again energized prior to the time that the next hole is positioned in front of diode **37.** Thus phototransistor **27** becomes conductive and a negative signal is applied to the base of transistor **89** causing transistor **89** and, therefore, transistor **90** to become conductive. Thus current again flows through the coil of relay **91** causing contacts **95** to close thereby stopping motor **34.**

The interconnection between counters **16, 17** and **12** is shown in FIG. **9.** Two flip-flop stages **103** and **104** of counter **16** are shown. Flip-flop stage **103** has an output **110** and a second output **111** while flip-flop stage **104** has an output **112.** Counter **17** further comprises two AND-gates, **107** and **108,** two OR-gates **105** and **106,** and a further AND-gate **109.** The output of gate **109** furnishes the counter advance signal to counter **12.** Specifically, this signal is furnished on a line **114** and it must be noted that counter **12** advances each time the signal on line **114** changes from a zero to a one state. AND-gates **107** and **108** each have a plurality of inputs connected with specific counting stages of counter **16** as will be discussed below. The output of AND-gate **107** is connected to one input of OR-gate **105** whose other input is connected to output **110** of flip-flop **103.** Similarly, the output of AND-gate **108** constitutes one input of OR-gate **106** whose other input is connected to output **112** of flip-flop **104.** The outputs of OR-gates **105** and **106** constitute the inputs to AND-gate **109** whose output, as discussed above, constitutes the counter advanced signal when changing from a zero to a one state.

The above-described arrangement operates as follows:

Initially it is assumed that counter **16** has a specified output at output x_1, that is for example a zero potential output. This indicates that two identical pulses are to be applied to the patient before any changes in amplitude occur. Pulse generator **18** (after depression of key **38**) delivers a pulse sequence **116** to the input **102** of counter **17.**

Initially output **110** of flip-flop **103** carries a I signal, output **111** a zero signal and output **112** of flip-flop **104** also carries a I signal. Only output x_1 of counter **16** carries a zero signal, that is outputs $x_2 \ldots x_m$ all have a "1" potential. Thus the output of AND-gate **104** is a "1" potential which does not serve to advance counter **12,** as stated previously, this counter responds only to changes from "0" to "1" on line **114.**

As shown in FIG. **9,** the first pulse in the first sequence **116** has a trailing edge **115.** This trailing edge **115** causes flip-flop **103** to flip, that is output **110** now carries a "0" output, while output **111** is fliped from the "0" to the "1" state. The state of flip-flop **104** is unchanged since this flip-flop reacts only to a change from "1" to "0." Both inputs of OR-gate **105** thus have a "0" signal which causes a "0" signal to appear at its output in turn causing a "0" signal to appear on line **114.** Counter **12** is not sensitive to change of state from "1" to "0." The trailing edge **117** of the second pulse in pulse sequence **116** again causes flip-flop **103** to flip. Output **110** therefore changes from a "0" to a "1" state while output **111** changes from a "1" to a "0" state. OR-gate **105** receives a "1" signal from output **110** and therefore furnishes a "1" signal to AND-gate **109.** Flip-flop **104** is sensitive to the change from "1" to "0" experienced at output **111** and therefore also changes state, that is output **112** changes from "1" to "0." Since its second input still carries a "1" signal, OR-gate **106** continues to furnish a "1" signal to AND-gate **109** causing the signal on line **114** to change from a "0" to a "1" state, thereby advancing counter **12** by one step.

Thus counter **12** is advanced for every other pulse in pulse sequence **116.** Once counter **16** has passed counting stage x_4, all outputs x_1, x_2, x_3 and x_4 carry a positive potential which cause AND-gate **107** and therefore OR-gate **105** to furnish a 1 signal without interruption. During the four subsequent pulses in pulse sequence **116** one of the outputs $x_5 \ldots x_8$ has a 0 potential. Thus the signal on line **114** will remain at 0. Following the fourth pulse flip-flop **104** changes state, causing a 1 signal to appear at output **112,** which in turn causes a 1 signal to appear at the output of OR-gate **106** and on line **114.** This change from 0 to one on line **114** causes counter **12** to advance by one step. FIG. **9** thus illustrates how the given number of pulses applied to the muscle at any amplitude as determined by the state of counter **12** depends upon the counting state of counter **16.** FIG. **9** only shows two stages of counter **17.** Of course further stages will be required in a practical case.

The interconnection between **18** and **16** and **39** of course can be carried out in an analogous fashion. Under those circumstances the counter indicated as counter **17** in FIG. **9** would correspond to counter **39** of FIG. **3.** The output of AND-gate **109** would be connected to the counting input of counter **16,** whose outputs $x_1 \ldots x_m$ would be connected to AND-gates **107** and **108** as in FIG. **9.**

It will be noted that the indicating arrangement shown in the drawing and comprising table **31** which is moved perpendicular to the axis of a lamp bank **32** constitutes only one possible embodiment. It is of course equally possible to record the results of the measurements by means of known *x–y* recorders, the count on counter **12** constituting one coordinate while the count on counter **16** constitutes the other coordinate of a measuring point. Further, the points can be indicated by a field of light sources in which every possible point, namely all the intersections of lines x_1 to x_n with lines y_1 to y_n are represented by a lamp. Logic circuit means can then be used to cause that particular lamp to light up which has the coordinate x_1 corresponding to the count of counter **16** and the coordinate y corresponding to the count on counter **12.**

While the invention has been illustrated and described as embodied in a specific indicator and counting circuit, it is not intended to be limited to the details

shown, since various structural and curcuit changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can by applying current knowledge readily adapt it for various applications without omitting features that, from the standpoint of prior art fairly constitute essential characteristics of the generic or specific aspects of this invention and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the following claims.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims:

1. Diagnostic apparatus for generating points of minimum involuntary muscle movement as a function of amplitude and duration of electrical pulses applied to said muscle for entry of an intensity-time diagram, comprising, in combination, adjustable pulse generator means for furnishing a sequence of pulses, each of said pulses having an amplitude and a pulse width; electrode means connected to said adjustable pulse generator means and adapted to be placed in operative proximity of said muscle for applying said pulses thereto; control means connected to said adjustable pulse generator means for controlling said pulse width to one of a number of selectable pulse widths; first counting means connected to said pulse generator means, for counting said pulses and automatically changing said amplitude of said pulses following receipt of a given number of said pulses; varying means connected to said first counting means, for varying said given number in dependence upon said pulse width of said pulses; and stop means for stopping said first counting means upon appearance of said involuntary muscle movement, said amplitude and said pulse width of said pulses of said adjustable pulse generator means at appearance of said involuntary muscle movement constituting the coordinates of one of said points of minimum involuntary muscle movement.

2. Apparatus as set forth in claim **1,** wherein said stop means comprise manually activated switch means for activation by the operator of said apparatus upon observance of said involuntary muscle movement.

3. An arrangement as set forth in claim **1,** wherein said stop means comprise sensor means for sensing said involuntary muscle movement and furnishing a corresponding stop signal.

4. Apparatus as set forth in claim **1,** wherein said adjustable pulse generator means comprise a source of current, output switch means for connecting said source of current to said electrode means when activated, and control pulse generator means for furnishing control pulses for activating said output switch means.

5. Apparatus as set forth in claim **4,** wherein said output switch means comprise semi-conductor switch means.

6. Apparatus as set forth in claim **4,** wherein said control pulse generator means comprise first timing means for determining the pulse width of said control pulses; and wherein said control means comprise additional timing means, and timing switch means for connecting said additional timing means to said control pulse generator means for varying the pulse width thereof.

7. Apparatus as set forth in claim **6,** wherein said timing switch means comprise timing counter means.

8. Apparatus as set forth in claim **7,** wherein said first counting means comprise amplitude control counting means furnishing counting output signals each signifying a predetermined multiple of said given number of electrical pulses, and amplitude control circuit means connected between said amplitude control counting means and said source of current, for varying the amplitude of said electrical pulses in dependence upon said counting output signals.

9. Apparatus as set forth in claim **8,** wherein said first counting means further comprise control pulse counting means connected to said control pulse generator means, for counting said control pulses and furnishing a counter advance signal advancing the count on said amplitude control counting means when the number of so-counted control pulses is equal to said given number.

10. Apparatus as set forth in claim **9,** further comprising first connecting means connected between said timing counter means and said amplitude control counting means for varying said given number in dependence upon the output of said timing counter means.

11. Apparatus as set forth in claim **10,** further comprising means resetting said control pulse counting means in response to said counter advance signal.

12. Apparatus as set forth in claim **11,** further comprising reset means connected to said amplitude control counting means for resetting said amplitude control counting means a predetermined number of counts in response to each activation of said reset means.

13. Apparatus as set forth in claim **12,** wherein said amplitude control counting means has a reverse counting input; and wherein said reset means comprise second pulse generator means for furnishing a sequence of reset pulses upon activation, reset pulse counting means for counting said reset pulses and for furnishing corresponding reset counting output signals, and means for applying said reset pulses to said reverse counting input of said amplitude control counting means and for blocking the application of said reset pulses to said reverse counting input in response to a predetermined one of said reset counting output signals.

14. Apparatus as set forth in claim **13,** wherein said means for applying and blocking said reset pulses from said reverse input comprise AND-gate means.

15. Apparatus as set forth in claim **14,** wherein said reset pulse counting means furnish said predetermined one of said reset counting output signals at a predetermined reset counting output terminal; wherein said timing counter means has a forward counting input; further comprising inverter means connecting said predetermined reset counting output terminal and said forward counting terminal of said timing counter means.

16. Apparatus as set forth in claim **15,** further comprising additional inverter means connected to the output of said AND-gate means; and additional AND-gate means having a first input connected to the output of said additional inverter means, a second input connected to the output of said control pulse generator means, and an output connected to the input of said control pulse counting means, whereby said predetermined reset couting output signal causes said additional AND-gate means to become conductive and permit the application of said control pulses to the input of said control pulse counting means.

17. Apparatus as set forth in claim 16, wherein said stop means furnish a stop signal for terminating the operation of said second pulse generator means and for resetting said reset pulse counting means and said control pulse counting means.

18. An arrangement as set forth in claim 17, wherein said stop means comprise manually activatable switch means.

19. An arrangement as set forth in claim 17, wherein said stop means comprise electromechanical transducer means.

20. Apparatus as set forth in claim 19, wherein said electromechanical transducer means comprise capacitor winding means applied in operative vicinity of said muscle, circuit means connected to said capacitance pickup means to furnish an electrical signal in response to capacitance changes resulting from said involuntary movement of said muscle, filter means for filtering said electrical signal, and threshold means connected to the output of said filter means.

21. Apparatus as set forth in claim 20, further comprising start signal furnishing means; bistable circuit means connected to said start signal furnishing means and having a "0" output connected to said timing counter means for setting said timing counter means to a determined count and a "1" output; NAND-gate means having a first input connected to said "1" output of said bistable circuit means, a second input connected to said predetermined reset counting output terminal and an output connected to said control pulse counting means; and additional control pulse counting means for counting said control pulses and for advancing said timing counter means in response to a predetermined number of so-counted control pulses, said predetermined number varying as a function of the count on said timing counter means, said additional control pulse counter means having reset means for resetting said additional control pulse counting means upon receipt of said predetermined number of control pulses.

22. Apparatus as set forth in claim 23, wherein said stop means furnish a stop signal resetting said bistable means to furnish said "0" output.

23. Apparatus as set forth in claim 22, further comprising means interconnecting said stop means and said additional control pulse counting means for causing said stop signal reset said additional control pulse counting means.

24. Apparatus as set forth in claim 1, further comprising means for indicating said points on said intensity-time diagram, said means comprising a plurality of lamp means each connected to a corresponding output of said amplitude control counting means, lamp back means for supporting said lamps, each in a predetermined position relative to the other of said lamps, recording means for having said intensity-time diagram inscribed thereon positioned to receive light from said lamp means, table means for supporting said recording means, and moving means for moving said table means in a direction perpendicular to said lamp bank means, to a position corresponding to the output of said timing counter means.

25. Apparatus as set forth in claim 24, further comprising fine positioning means for furnishing an exact adjustment of the position of said recording means relative to said lamp bank means.

26. Apparatus as set forth in claim 25, wherein said moving means comprise motor means; wherein said table means has a plurality of markings in the direction perpendicular to the axis of said lamp bank means; and wherein said fine positioning means comprise sensor means for sensing said markings and furnishing a marking signal in response thereto, and connecting means connecting said sensor means to said motor means for stopping said motor means in response to said marking signal.

27. Apparatus as set forth in claim 26, wherein said sensor means comprise photoelectric sensor means.

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