United States Patent [19]

Wastl et al.

[11] **3,915,156**

[45] **Oct. 28, 1975**

[54] **POLYGRAPH INCLUDING A CARDIOGRAPH WITH DICROTIC NOTCH ENHANCEMENT**

[75] Inventors: **Max E. Wastl; Richard L. Poppy,** both of Lafayette, Ind.

[73] Assignee: **Lafayette Instrument Company, Inc.,** Lafayette, Ind.

[22] Filed: **Feb. 15, 1974**

[21] Appl. No.: **442,865**

[52] **U.S. Cl.** ... **128/2.05 P;** 128/2.05 E; 128/2.05 Q

[51] **Int. Cl.²** **A61B 5/04**

[58] **Field of Search** ..... 128/2.05 A, 2.05 E, 2.05 G, 128/2.05 M, 2.05 P, 2.05 Q, 2.05 R, 2.05 T, 2.06 A, 2.06 B, 2.06 G, 2.06 R, 2.1 B, 2.1 R; 73/388 R

[56] **References Cited**

UNITED STATES PATENTS

2,538,125	1/1951	Reid	128/2.05 R
3,040,736	6/1962	Jackson	128/2.05 P
3,139,086	6/1964	Botsch et al.	128/2.05 P
3,542,011	11/1970	Langenbeck	128/2.05 E
3,575,162	4/1971	Gaarder	128/2.06 A
3,581,735	6/1971	Gentner et al.	128/2.05 T
3,590,811	7/1971	Harris	128/2.06 R
3,699,948	10/1972	Ota et al.	128/2.06 G

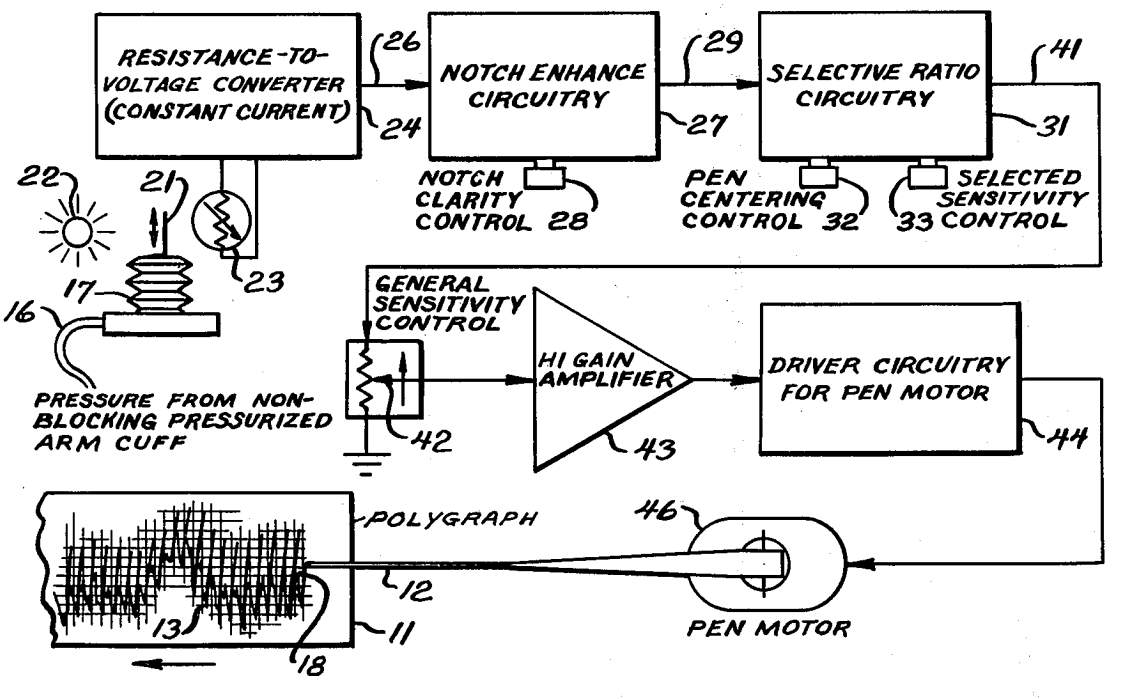
Primary Examiner—William E. Kamm

Attorney, Agent, or Firm—Darbo, Robertson & Vandenburgh

[57] **ABSTRACT**

Instead of mechanically deflecting the pen in response to pressure changes in the blood pressure cuff on the arm of the subject, this deflecting is accomplished electrically, the pen-deflecting motor being controlled by an electronic enhancing circuit. This permits use of much lower air pressure in the cuff so that the subject is comfortable and may be interrogated indefinitely instead of with a time limitation of about 3 minutes because of blood stoppage. New versatility of use is also achieved. The enhancements include controlled increase of sensitivity generally; and, if desired, selective control of sensitivity as to a subject's degree of reaction; also, the ability to sequelch unwanted variations of the input, and a clarified and controlled showing of the important irregularity in the pressure curve known as the dicrotic notch.

16 Claims, 2 Drawing Figures



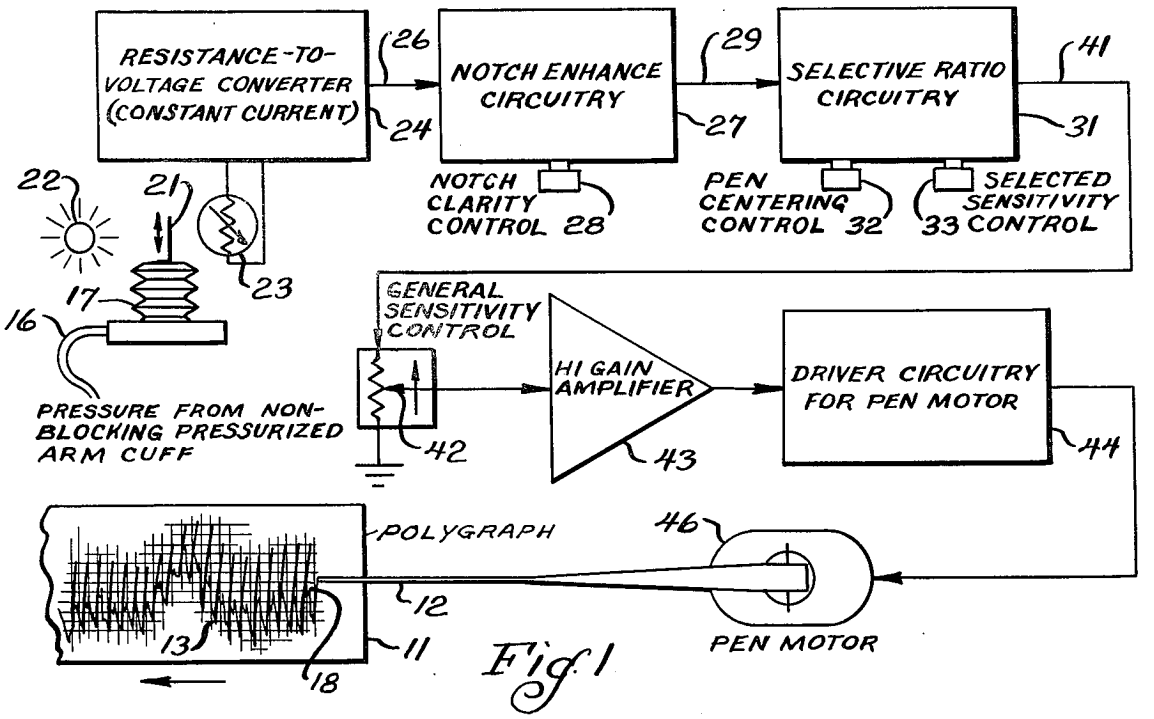

RESISTANCE-TO-VOLTAGE CONVERTER (CONSTANT CURRENT)
26
24
NOTCH ENHANCE CIRCUITRY
29
27
SELECTIVE RATIO CIRCUITRY
41
31
NOTCH CLARITY CONTROL 28
PEN CENTERING CONTROL 32
SELECTED SENSITIVITY 33 CONTROL
22
21
23
17
16
PRESSURE FROM NON-BLOCKING PRESSURIZED ARM CUFF
GENERAL SENSITIVITY CONTROL
42
HI GAIN AMPLIFIER
43
DRIVER CIRCUITRY FOR PEN MOTOR
44
POLYGRAPH
46
12
13
11
18
PEN MOTOR

Fig. 1

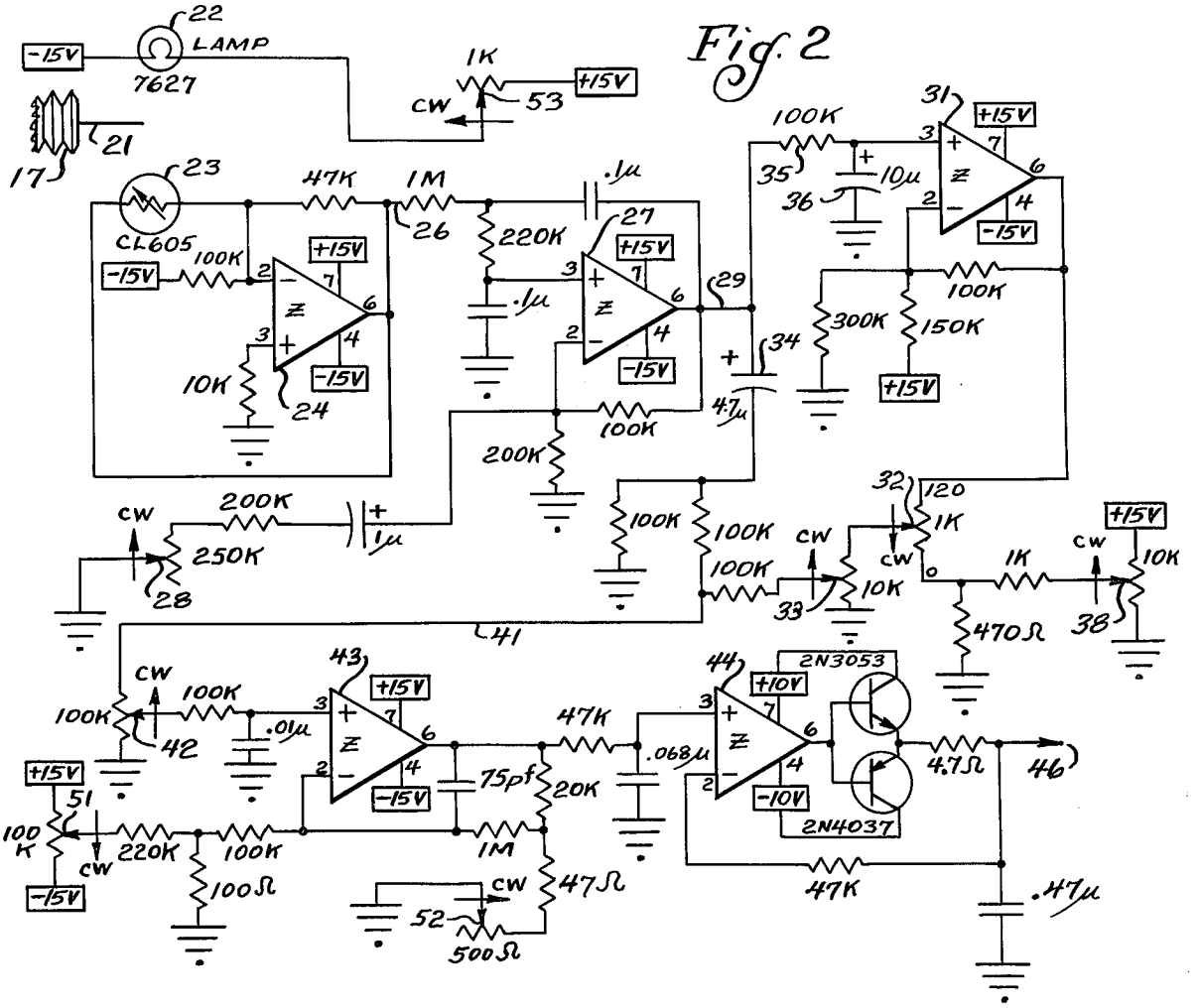

22
LAMP
-15V
7627
21
17
23
CL605
100K
47K
1M
.1μ
26
220K
27
+15V
10K
24
1K
CW
53
+15V
100K
35
10μ
36
31
300K
150K
34
4.7μ
29
200K
1μ
250K
28
120
32
33
10K
470Ω
38
41
43
.01μ
75pf
20K
42
51
100K
220K
100Ω
52
500Ω
47Ω
44
2N3053
+10V
-10V
2N4037
.068μ
4.7Ω
46
47K
.47μ

Fig. 2

POLYGRAPH INCLUDING A CARDIOGRAPH WITH DICROTIC NOTCH ENHANCEMENT

The invention of which the present disclosure is offered for public dissemination if adequate patent protection is available relates to detection polygraphs more commonly known as lie detectors.

One of the polygraph pens is known as the cardio-pen and provides a chart or graph derived from the subject's pulse, conveniently called a cardiogram. The most satisfactory form of such charting heretofore has used an arm cuff such as doctors use for blood pressure measurements, with the air pressure therein connected to a highly sensitive bellows which was mechanically coupled to the shaft carrying the pen. Satisfactory graphing required that the pressure in the cuff be quite high, with some discomfort to the subject and with blood circulation below the band greatly reduced or shut off. Usually interrogation could only be continued about three minutes at a time because the lower arm was turning blue.

One of the major accomplishments of the present invention is to permit the use of a lower pneumatic pressure, corresponding to **60** mm of mercury or even less instead of **90,** which avoids discomfort to the subject and allows the blood to circulate through the lower arm so that interrogation need not be interrupted to release the arm cuff. In the preferred form of the invention this is accomplished by having the bellows (which need not be as sensitive as before) merely move a flag for variably interrupting a light beam. The resultant modulations of the output of a photocell responsive to the light beam are electronically amplified to drive the pen-deflecting motor.

Without more, the foregoing does not yield a graph as satisfactory in the view of experienced operators as are the better cardiograms of the conventional polygraphs. One serious discrepancy is in barely showing the dicrotic notch (a step-like interruption of the smoothness of the downsweep of the pen) which had been quite evident in the cardiograms of conventional polygraphs. It was found that the discrepancy could be overcome by providing notch-enhancing circuitry. In the preferred form of the invention the notch enhancement is adjustable. An operator accustomed to the conventional polygraph can turn the adjustment to substantially duplicate the notch characteristics of the cardiogram to which he is accustomed. However, greater or less emphasis of the notch can be provided, depending on the operator's preference and the degree of need for enhancement encountered with a particular subject.

The ability to record with a lower air pressure in the cuff is accompanied by an inherent difference, which at least initially had to be regarded as a disadvantage. This related to signal factors which are relatively stronger compared to a **60** mm pressure than they are compared to a **90** mm pressure. Some of these factors are useful, but their relative scale must be reduced to keep the pen from hitting stops or running off scale. Other signal factors are unwanted signal factors called "artifacts" by polygraph operators, and correspond roughly to signal factors called "noise" in some of the electronic industries. Here they may be called "chaff." In the preferred form of the present invention, selective ratio circuitry is provided which reduces chaff and the relatively-increased factors. The particular circuitry

chosen couples the chaff reduction to a "balance" or centering adjustment by which the operator in effect balances out the static air pressure in the cuff. As a result of the coupling, if the static air pressure is near the **90** mm of mercury which has been used with the conventional polygraphs, there may be relatively little suppression of chaff, or none, thus duplicating the conventional cardiograms to which polygraph operators are accustomed. At progressively lower air pressures in the cuff, the balancing adjustment made to bring the pen to its normal range of operation will give progressively increased suppression of chaff, which may be such that the relationship of the main pulse graphing to effects due to chaff or heightened factors will remain approximately that to which skilled operators are accustomed.

The electronic system lends itself to still other means of enhancement, some of which are described below or embodied in the drawings.

DESIGNATION OF FIGURES

FIG. **1** is a schematic drawing of a preferred form of the invention, with some circuitry represented by boxes.

FIG. **2** is a circuit diagram of the form of apparatus shown in FIG. **1.**

INTENT CLAUSE

Although the following disclosure offered for public dissemination is detailed to ensure adequacy and aid understanding, this is not intended to prejudice that purpose of a patent which is to cover each new inventive concept therein no matter how others may later disguise it by variations in form or additions or further improvements. The claims at the end hereof are intended as the chief aid toward this purpose, as it is these that meet the requirements of pointing out the parts, improvements or combinations in which the inventive concepts are found.

BACKGROUND DESCRIPTION

Detection polygraphs, commonly called lie detectors, have heretofore used a moving chart, here represented by chart **11** in FIG. **1,** on which several physiological or vital-function curves were constantly plotted by pens such as pen **12,** each responsive to one of the conditions of the person being questioned (who is usually called the "subject"). Curve **13** is representative of the curve commonly called the cardio curve or graph. Although the term "cardio" refers to the heart, the curve is actually more directly representative of the pulse and of the blood pressure and volume variations evident in the pulse. In fact, the part of the equipment applied to the subject for this purpose has been, most commonly, the same type of arm cuff, inflated with a pressurizing hand-bulb, used by physicians for measuring a patient's blood pressure. A tube **16** leading from the pressure chamber of the cuff to a bellows, here represented as **17,** would cause expansion and contraction of the bellows for each pulse beat. Heretofore, the bellows, preferably a very sensitive bellows of relatively expensive nature, has been mechanically coupled to the pen arm **12** through the shaft by which the pen arm is supported and deflected.

The frequency of the pulse and hence of the heart beat can be determined by the spacing of the peaks of the curve **13.** The subject's increased blood pressure would be shown by a rising of the peaks or of the entire

curve. In addition, polygraph operators have paid considerable attention to the dicrotic notch **18.** This dicrotic notch has been easily seen in the mechanically coupled cardiopolygraphs and is a valuable part of the graph. It is one more physiological indicator that is beyond the control of the subject. Its relative position on the curve can shift.

Polygraph operators are accustomed to the characteristics of the curves or graphs of the mechanically coupled cardio pen of the polygraph. Hence an important consideration in any new apparatus for operating the pen, to overcome deficiencies of the mechanically coupled apparatus, is to be able to produce a curve closely resembling that of the mechanically coupled pen at its best. This has presented difficulties derived from two sources. One source is the fact that a major purpose of the present invention is to be able to have the cuff pressure lower than the circulation-blocking pressure which has commonly been used with detection polygraphs heretofore. The reason pressures high enough to block adequate circulation have been used heretofore is because the higher pressures produce a better curve. Nor can this better curve be obtained by mere amplification of the output of a cuff inflated at the desired lower pressure for reasons indicated in the introduction.

PREFERRED TRANSDUCER OF THE PRESENT INVENTION

For the preferred forms of the present invention, a pressure-to-voltage transducer is chosen which is free of friction and play and which produces a signal indicative of the amount of pressure, not merely of the change of pressure. There are many forms of pressure-sensitive devices which could be used. Other features of the invention permit the choice of a form of relatively low cost, now being used commercially, in which the bellows **17** moves a flag **21** progressively through a light beam from a lamp **22** falling on a photocell **23.** If the photocell **23** is of the photoresistor type, circuitry **24** is used which converts the varying resistance of the photocell **23** to a varying voltage at the output **26** of circuitry **24.**

NOTCH ENHANCEMENT

Inasmuch as it has been found that the signal at output **26** will not provide a good notch **18** on the graph, especially when the desired nonblocking cuff pressure is used, a notch-enhancement circuitry **27** is provided. The need for this may be surprising. It turns out that with mechanical coupling in prior polygraphs, factors which might be regarded as inherent faults (resonance of the pen system, and perhaps some backlash) have had the effect of making the dicrotic notch more apparent than it would otherwise have been. Also they may have given the curve some of its more general characteristics to which polygraph operators have become accustomed. The present invention overcomes the deficiencies of mere amplification in not having these "faults," as well as overcoming the difficulties which were expected to be encountered in using lower cuff pressure. Electronic-enhancement of the dicrotic notch is one important aspect of this invention.

Since the amount of notch-enhancement needed varies with the subject and with the cuff pressure chosen by the operator, the notch-enhancement circuit **27** includes adjustability controlled by a notch clarity control knob **28.**

Although details of the circuitry of the preferred and commercial form of the notch-enhancement circuitry is shown in FIG. **2,** it may be helpful on any new designing to state certain applicable principles. Any method of relatively increasing the visibility of the notch on the curve could be used, such as a lowpass underdamped amplifier. However, for closer simulation of the conventional curve obtained with mechanical pen coupling, the illustrated low-pass filter with resonance or a tendency toward oscillation, but adjustable to be damped just sufficiently to prevent detectable separate oscillations, is preferred. Good results have been obtained with both types of circuits having relatively high response in the frequency range from about four to five cycles per second.

SELECTIVE RATIO CIRCUITRY

The output **29** from the notch-enhancement circuitry **27** passes to selective ratio circuitry **31.** The circuitry is preferably adjustable in at least two respects as represented by control knobs **32** and **33.** Control knob **32** is commercially called "balancing control" and operates to center the graph in the desired area of the moving tape or chart paper **11.** The other knob **33** preferably adjusts separately (after the balance adjustment) the relative strength of signal between the repetitive signals representing the pulse and the nonrepetitive signal variations including both chaff and those which would raise or lower the position of the repetitive pulse curves on the tape **11,** mentioned above as relatively heightened. In the commercial use of the present invention this adjustability has not yet been separately included, a predetermined change incidental to the balancing adjustment being provided, instead. If the knob **33** is provided, it may be commercially designated "subject activity control," the term "activity" being used by polygraph operators with respect to the degree of change in such variations as a shifting of the entire curve up or down on the tape. To provide the ratio of activity indication to repetitive pulse indication to which polygraph operators are accustomed (using high cuff pressure), it is necessary, with low cuff pressures, to provide a relative reduction of the activity factors. As may be seen from FIG. **2,** this can be accomplished by dividing the signal between two paths, one of which carries mainly the repetitive signal and the other of which carries mainly the nonrepetitive signal and partially squelching the latter (as is done) or selectively amplifying the former. The nonrepetitive signals are substantially blocked from the first path by a high-pass filter capacitor **34.** Likewise the repetitive signals are blocked from the second path by a low-pass filter which dissipates such signals beyond resistor **35** through shunt capacitor **36.** Resistor **35** also weakens the signal which the second path is intended to carry predominantly, and hence it is amplified to have a suitable strength ratio, as compared to the signal carried by the first path. This strength ratio may be reduced by the balance adjustment **32** and by the activity adjustment **33.**

Some operators who may on different occasions use different polygraphs may find it desirable to have positional similarity of the different polygraphs as to their balance adjustments. This may be provided in part by precalibrating adjustment **38** seen in FIG. **2.** This precalibrating adjustment should be made with the bal-

ance adjustment at its zero or lowest position, and with the corresponding cuff pressure. This adjustment, if provided, is preferably by an adjustment inside of the cabinet, and hence no corresponding control knob has been shown in FIG. 1.

The first and second paths of the selective ratio circuitry have a common output 41 which leads to the sensitivity control 42. The signal then passes to a high gain amplifier 43 and from that to the driver circuitry 44 for driving the pen motor or swing motor 46.

The high gain amplifier 43 and the driver circuitry 44 can be matters of routine design or selection and need no description. Two special features are shown in FIG. 2, however. A precentering adjustment 51, preferably inside of the cabinet, may be provided for centering the pen under predetermined conditions such as with no signal, so that the circuit null will correspond to the pen's natural center position, and the panel's balance adjustment may then have optimum characteristics. Also, an amplifier gain adjustment 52 may be provided (again preferably within the cabinet) to yield a desired range on the panel's sensitivity adjustment.

There may also be provided a precalibrating adjustment 53 which can be set with the balance adjustment 32 at its highest position, and with corresponding cuff pressure, e.g. 120 mm of mercury, to center the pen at that condition, thereby achieving uniformity between different polygraphs at the upper ends of the balancing adjustments, or a desired condition in one polygraph. This adjustment controls the brightness of the lamp 22. Preferably, its entire range is well below rated voltage of the lamp, to provide long lamp life.

FURTHER DATA

The bellows 17 need not be the highly sensitive type heretofore preferred. A good quality internally-pressured bellows works well. Good linearity of the system is desirable, and linear expansion of the bellows in the useful range is helpful to this end. Also, a strip-type photocell is helpful, e.g., type CL 605, as designated in FIG. 2. Other accurate pressure sensitive transducers would also be suitable, such as the quiet version of the LX 1601G (National Semiconductor Corp.), with appropriate circuitry. The illustrated transducer is preferred because at present it is of much lower cost.

A suitable pen motor is Model Z-335 of General Scanning Incorporated, or MFE type R4-077. The Z triangles in the drawings, operational amplifiers, may be type 741 except in the amplifier section 43, where type 3522K is suitable.

ACHIEVEMENT

In its preferred forms, such as illustrated in the drawings, a cardiogram or pulse curve can be generated having characteristics substantially identical with those to which experienced polygraph operators are accustomed, even though the cuff pressure is greatly reduced. With such reduced pressure such as 60 mm of mercury or less, there is no undesirable blockage of blood circulation in the subject's arm, the subject is comfortable, and interrogation need not be interrupted to release the cuff because the arm is turning blue. There is no longer danger that discomfort from the high cuff pressure will impair or retard the determinations for which the detection polygraph is being employed.

In addition, there are other aspects of new versatility. For example, if a subject abnormally produces only an almost imperceptible dicrotic notch, it can be given greater than normal enhancement for easier reading. If a pulse is unusually weak, the sensitivity can be increased. Satisfactory detection examinations can be achieved with some subjects for whom conventional polygraphs would be inadequate.

We claim:

1. Cardiographic apparatus including a substantially friction-free transducer system for providing an electrical signal responsive to a human subject and varying according to pressure variations of the subject's pulse; a circuit responsive to the transducer system, and a graphic output device responsive to the signal of said circuit for producing a curve representing the pulse conditions of the subject;

said apparatus including notch enhancement means for modifying the transducer signal to emphasize its dicrotic notch characteristic selectively in comparison to the main heartbeat characteristic.

2. Cardiographic apparatus including a substantially friction-free transducer system for providing an electrical signal responsive to a human subject and varying according to pressure variations of the subject's pulse responsive to the transducer; a circuit responsive to the transducer system, and a graphic output device responsive to the signal of said circuit for producing a curve representing the pulse conditions of the subject; said circuit including adjustable notch enhancement circuitry for modifying the transducer signal to emphasize its dicrotic notch characteristic selectively in comparison to the main heartbeat characteristic.

3. Cardiographic apparatus according to claim 2 in which the notch enhancement circuitry has relatively great responsiveness selectively at the level of approximately four to five cycles per second.

4. Cardiographic apparatus according to claim 2 in which the notch enhancement circuitry is in the nature of a conditionally-stable under-damped resonant circuit with a resonance frequency in the range of approximately four to five cycles per second.

5. Cardiographic apparatus including a substantially friction-free transducer for converting the pulse-varied pressure in a pressurized pulse detector on a human subject, effectively operable with pressurization low enough to allow adequate blood circulation, to an electrical signal varying according to both pressure variations and pressure level; a circuit responsive to the transducer; and a graphic output device responsive to the signal of said circuit for producing a curve representing the pulse conditions of the subject; said circuit being characterized by:

a. including notch-enhancement circuitry for adjustably modifying the signal derived from the transducer to emphasize its dicrotic notch characteristic;

b. including selective ratio circuitry for acting upon the signal for increasing the relative strength of the pulsing characteristics as compared to other characteristics in the signal;

c. including circuitry for centering the pen oscillations under given conditions at a given level; and

d. including amplification circuitry.

6. Cardiographic apparatus according to claim 5 in which the selective ratio circuitry transmits the signals through two paths, one of which is selectively transmissive to relatively abrupt changes and the other of which is selectively transmissive to slower changes, said paths

having a common output reflecting a greater proportion of the signal strength accepted by the first path than of the signal strength accepted by the second path.

7. Cardiographic apparatus according to claim **5** in which the selective ratio circuitry transmits the signals through two paths, one of which is selectively transmissive to relatively abrupt changes and the other of which is selectively transmissive to slower changes, said paths having a common output reflecting a greater proportion of the signal strength accepted by the first path than of the signal strength accepted by the second path, and having adjustable amplification means in one path to control said proportion.

8. Cardiographic apparatus according to claim **5** in which the selective ratio circuitry transmits the signals through two paths, one of which is selectively transmissive to relatively abrupt changes and the other of which is selectively transmissive to slower changes, said paths having a common output reflecting, at least when desired, a ratio drop of the signal output through the second path as compared to the signal output through the first path; with an adjustment element for said ratio drop which is correlated to an adjustment pertinent to the level of pressurization to provide increasing ratio drop as the pressurization is reduced.

9. A cardiographic apparatus according to claim **5** in which the transducer includes a bellows, a flag carried by the movable end of the bellows, and photoelectric means in which the actuating light strength upon a photosensitive element is progressively varied as the flag is moved by the bellows.

10. A detection polygraph including as one of its charting devices the cardiographic apparatus of claim **5**.

11. Cardiographic apparatus including a substantially friction-free transducer for converting the pulse-varied pressure in a pressurized pulse detector on a human subject, effectively operable with pressurization low enough to allow adequate blood circulation, to an electrical signal varying according to both pressure variations and pressure level; a circuit responsive to the transducer; and a graphic output device responsive to the signal of said circuit for producing a curve representing the pulse conditions of the subject; said circuit being characterized by:

a. including selective ratio circuitry for acting upon the signal derived from the transducer for increasing the relative strength of the pulsing characteristics as compared to other characteristics in the signal; and

b. including amplification circuitry.

12. Cardiographic apparatus according to claim **11** in which the selective ratio circuitry transmits the signals through two paths, one of which is selectively transmissive to relatively abrupt changes and the other of which is selectively transmissive to slower changes, said paths having a common output reflecting, at least when desired, a ratio drop of the signal output through the second path as compared to the signal output through the first path, below the input ratio of the corresponding parts of the signal input to the selective ratio circuitry.

13. Cardiographic apparatus according to claim **11** in which the selective ratio circuitry transmits the signals through two paths, one of which is selectively transmissive to relatively abrupt changes and the other of which is selectively transmissive to slower changes, said paths having a common output reflecting, at least when desired, a ratio drop of the signal output through the second path as compared to the signal output through the first path, below the input ratio of the corresponding parts of the signal input to the selective ratio circuitry, and having adjustable amplification means in one path to control said ratio drop.

14. Cardiographic apparatus according to claim **11** in which the selective ratio circuitry transmits the signals through two paths, one of which is selectively transmissive to relatively abrupt changes and the other of which is selectively transmissive to slower changes, said paths having a common output reflecting, at least when desired, a ratio drop of the signal output through the second path as compared to the signal output through the first path, below the input ratio of the corresponding parts of the signal input to the selective ratio circuitry, and having adjustable amplification means in one path to control said ratio drop; with an adjustment element for said ratio drop which is correlated to an adjustment pertinent to the level of pressurization to provide increasing ratio drop as the pressurization is reduced.

15. Cardiographic apparatus including a blood pressure type of inflatable arm cuff, a substantially friction-free transducer for converting the pulse-varied pressure in said arm cuff on a human subject to an electrical signal varying according to both pressure variations and pressure level; said transducer being effectively operable with pressurization in said arm cuff low enough to allow adequate blood circulation in the subject's arm; a circuit responsive to the transducer; and a graphic output device responsive to the signal of said circuit for producing a curve representing the pulse conditions of the subject; said circuit being characterized by:

a. including notch-enhancement circuitry for adjustably modifying the signal derived from the transducer to emphasize its dicrotic notch characteristic;

b. including selective ratio circuitry for acting upon the signal for increasing the relative strength of the pulsing characteristics as compared to other characteristics in the signal;

c. including circuitry for centering the pen oscillations under given conditions at a given level; and

d. including amplification circuitry.

16. A detection polygraph including as one of its charting devices a cardiographic apparatus capable of substantially duplicating the characteristics of conventional cardiographic tracings even when used at a lower pressure than would be satisfactory thereon, said cardiographic apparatus including a transducer for converting the pulse-varied pressure in a pressurized pulse detector on a human subject, effectively operable with pressurization low enough to allow adequate blood circulation, to an electrical signal varying according to both pressure variations and pressure level; a circuit responsive to the transducer; and a graphic output device responsive to the signal of said circuit for producing a curve representing the pulse conditions of the subject; said circuit being characterized by:

a. including circuitry with adjustably damped resonance for enhancement of the dicrotic notch for adjustably modifying the signal derived from the transducer to emphasize its dicrotic notch characteristic;

b. including selective ratio circuitry for acting upon the signal for increasing the relative strength of the

pulsing characteristics as compared to other characteristics in the signal, said selective ratio circuitry being correlated to circuitry for centering the pen oscillations under given conditions at a given level to adjust response level automatically with pen centering for low pressure; and

c. including amplification circuitry.

* * * * *