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[54] CARDIAC SYNCHRONIZATION SYSTEM AND METHOD

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[52] **U.S. Cl.** .... **128/64**, 128/2.05 R, 128/2.06 R
[51] **Int. Cl.** **A61h 9/00**
[58] **Field of Search** .... 128/1 D, 2.05 P, 2.05 R, 128/2.06 R, 30, 64

[56] **References Cited**

UNITED STATES PATENTS

3,626,932	12/1971	Becker	128/2.06 R
3,734,087	5/1973	Sauer et al.	128/64

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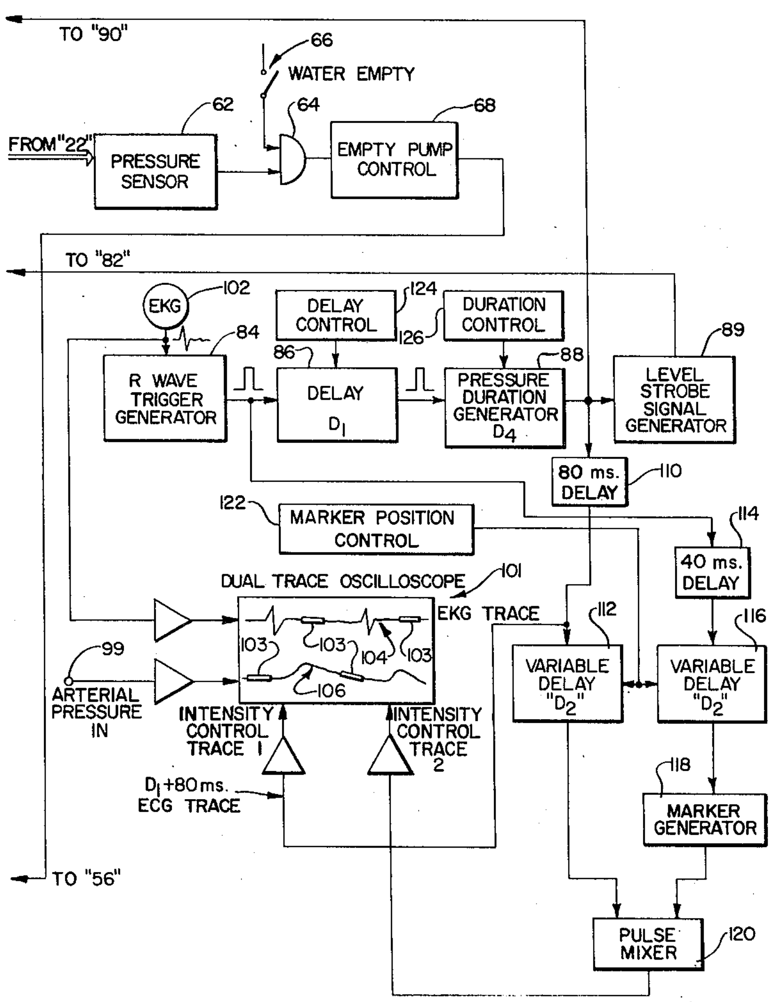
Attorney, Agent, or Firm—Robert A. Cesari; John F. McKenna; Andrew F. Kehoe

[57] **ABSTRACT**

Improved internal circulatory assist apparatus comprising control means whereby the optimum synchronization of the assist apparatus with the beat of the heart can be effectively achieved while using any of a plurality of parts of the body as monitor sites for obtaining an arterial signal representative of the patient's heartbeat. The control means consists of a marker means, such as a pip on an oscilloscope, which is adjustable by variable-delay circuitry throughout a range equal to the time difference between the sensing of a selected cardiac event at an earliest-reacting monitoring site and the sensing of a selected cardiac event at a later-reacting monitoring site.

8 Claims, 4 Drawing Figures



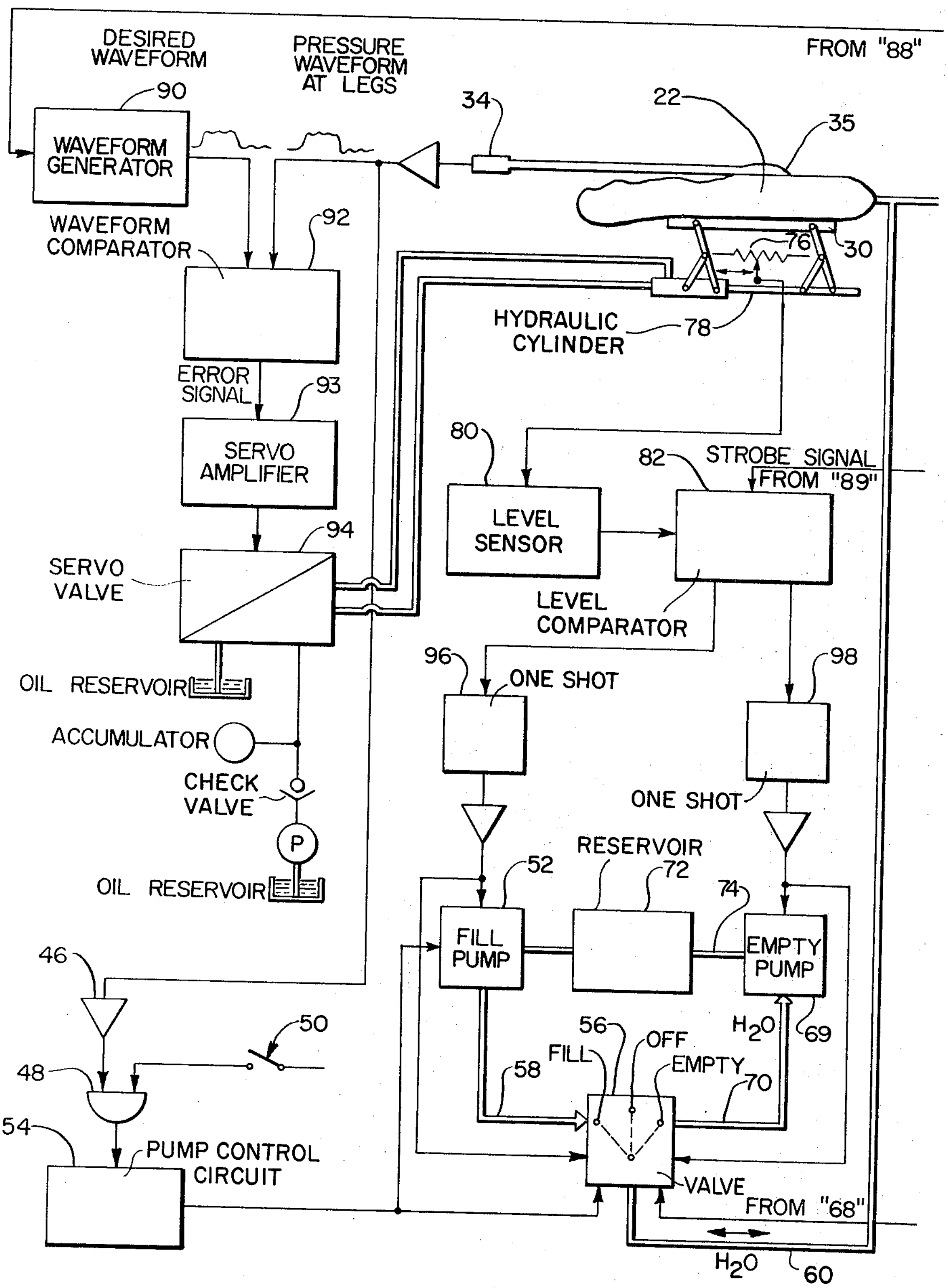

DESIRED WAVEFORM
PRESSURE WAVEFORM AT LEGS
FROM "88"
90
WAVEFORM GENERATOR
34
22
35
WAVEFORM COMPARATOR
92
76
30
HYDRAULIC CYLINDER
78
ERROR SIGNAL
93
SERVO AMPLIFIER
80
82
STROBE SIGNAL FROM "89"
LEVEL SENSOR
94
SERVO VALVE
LEVEL COMPARATOR
OIL RESERVOIR
96
ONE SHOT
98
ACCUMULATOR
CHECK VALVE
ONE SHOT
P
RESERVOIR
OIL RESERVOIR
52
72
74
FILL PUMP
EMPTY PUMP
46
50
56
H_2O
69
FILL
OFF
48
58
EMPTY
70
54
PUMP CONTROL CIRCUIT
VALVE
FROM "68"
H_2O
60

FIG. 1

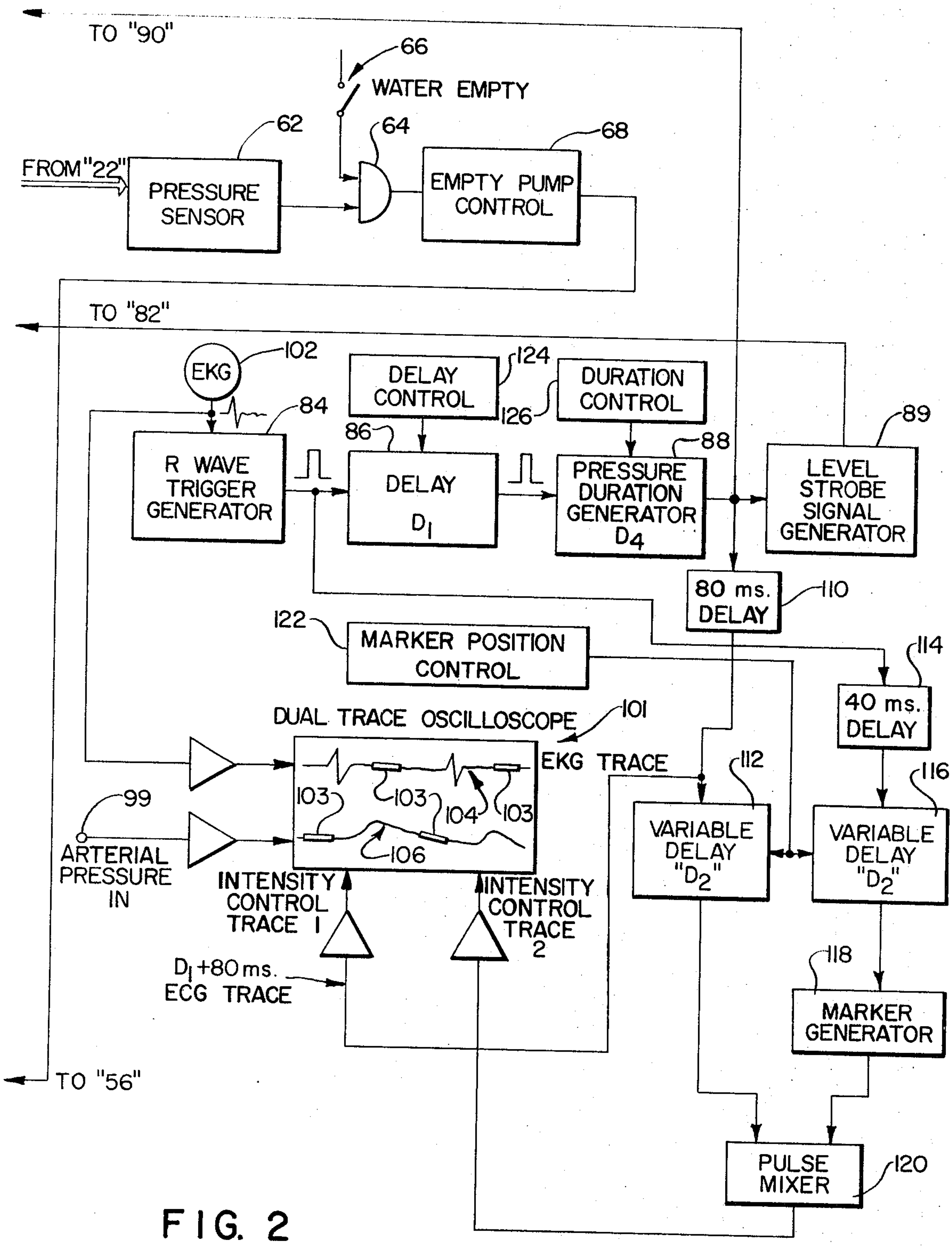

TO "90"
66
WATER EMPTY
62
64
68
FROM "22"
PRESSURE SENSOR
EMPTY PUMP CONTROL
TO "82"
EKG
102
DELAY CONTROL
124
DURATION CONTROL
84
126
86
88
89
R WAVE TRIGGER GENERATOR
DELAY D1
PRESSURE DURATION GENERATOR D4
LEVEL STROBE SIGNAL GENERATOR
80 ms. DELAY
110
122
MARKER POSITION CONTROL
114
DUAL TRACE OSCILLOSCOPE
101
40 ms. DELAY
EKG TRACE
112
116
99
103
103
104
103
106
ARTERIAL PRESSURE IN
VARIABLE DELAY "D2"
VARIABLE DELAY "D2"
INTENSITY CONTROL TRACE 1
INTENSITY CONTROL TRACE 2
118
D1+80ms. ECG TRACE
MARKER GENERATOR
TO "56"
PULSE MIXER
120

FIG. 2

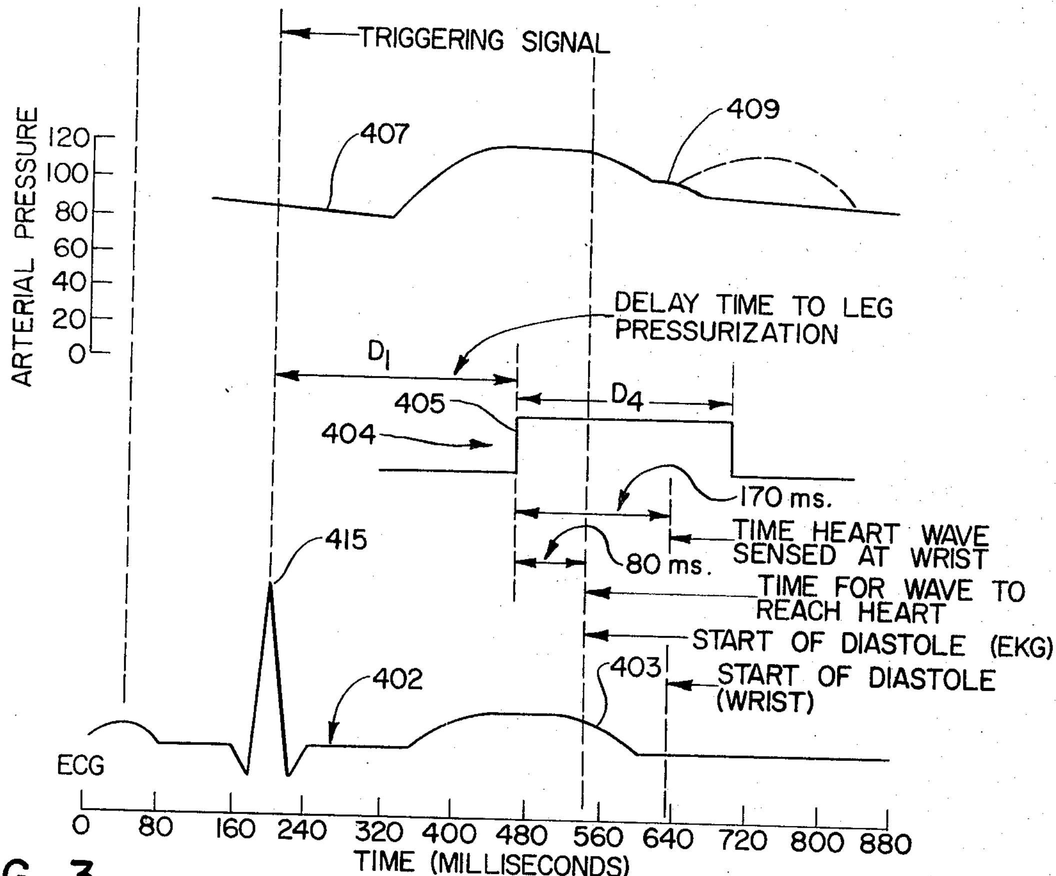

TRIGGERING SIGNAL
409
407
ARTERIAL PRESSURE
120
100
80
60
40
20
0
DELAY TIME TO LEG PRESSURIZATION
D1
405
D4
404
170 ms.
TIME HEART WAVE SENSED AT WRIST
415
80 ms.
TIME FOR WAVE TO REACH HEART
START OF DIASTOLE (EKG)
402
403
START OF DIASTOLE (WRIST)
ECG
0 80 160 240 320 400 480 560 640 720 800 880
TIME (MILLISECONDS)

FIG. 3

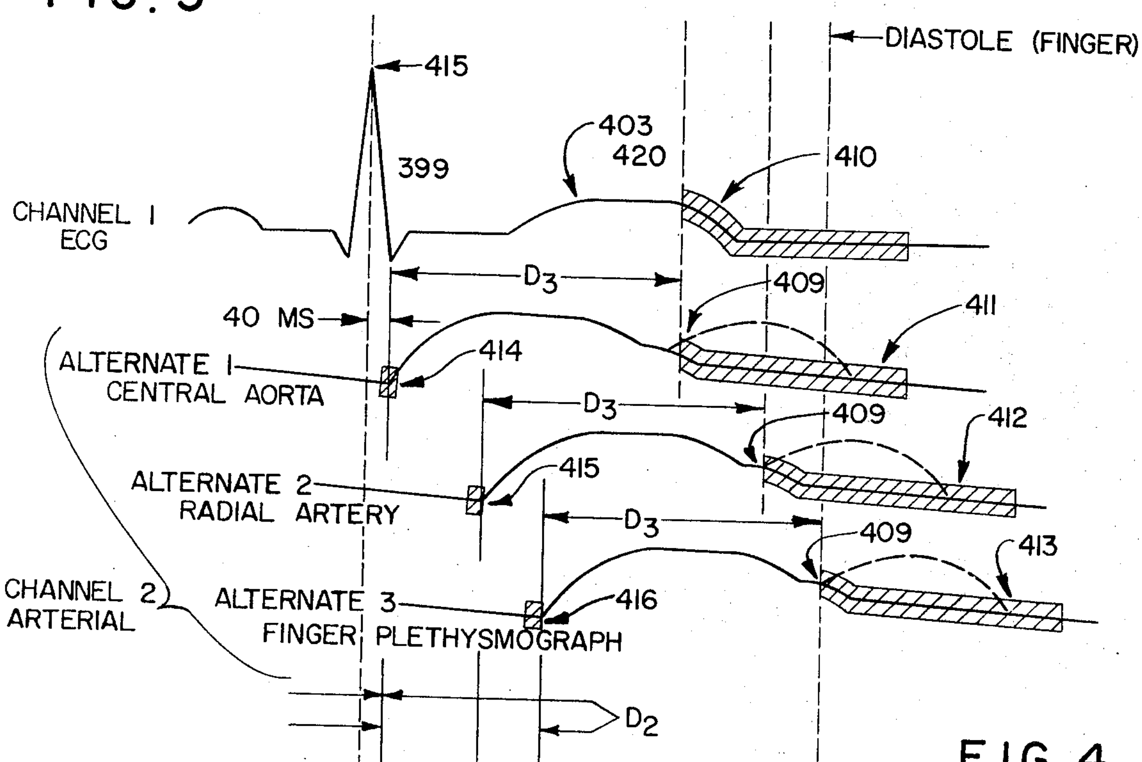

DIASTOLE (FINGER)
415
403
420
399
410
CHANNEL 1 ECG
D3
409
40 MS
411
414
ALTERNATE 1 CENTRAL AORTA
D3
409
412
415
ALTERNATE 2 RADIAL ARTERY
D3
409
413
CHANNEL 2 ARTERIAL
ALTERNATE 3 FINGER PLETHYSMOGRAPH
416
D2

FIG. 4

CARDIAC SYNCHRONIZATION SYSTEM AND METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a novel apparatus for assisting blood flow in the circulatory system by synchronizing the pulsing of an external-assist means with the heartbeat and particularly relates to a novel synchronization-control system for use with the aforesaid apparatus.

2. Background of the Invention

Methods for atraumatically assisting blood circulation of patients have been described in the art. In U.S. Pat. No. 3,303,841 to Dennis, a process is described whereby an external compressing of the lower part of the body expresses a volume of blood larger than the volume of blood pumped in a single stroke of the heart. The blood so expressed is forced back into the aorta and greater arterial vessels and thereby allows a reduction in ventricular workload while maintaining a satisfactory perfusion of blood during ventricular diastole. This general type of process has been elaborated upon in an article entitled "Synchronous Assisted Circulation" by Birtwell et al., appearing in *The Canadian Medical Association Journal* (Vol. 95, pages 652–664) on Sept. 24, 1966. In general, synchronous external pressure assist processes are distinguishable and advantageous over pre-existing counter-pulsation processes because the latter kind of procedure involves the cannulation of a major artery, use of an extra-corporeal blood handling device, the use of stringently sterile techniques and the necessity of administering anticoagulants to the patient. Moreover, the blood trauma or hemolysis produced by extra-corporeal pumping devices limits permissible duration of the assist procedure and compromises the condition of the patient. Finally, these trauma-requiring procedures are not only time consuming, they can present a very significant hazard to many patients, and they increase the risk factor in treating all patients.

In U.S. Pat. No. 3,654,919 to Birtwell, an improved external assist apparatus was described wherein the effective pressure on circulatory passages of the legs could be cycled to valves at or below ambient pressure. This apparatus is a major advance in the art and has been extensively used as a vehicle for evaluating the therapeutic potential of externally assisted circulation. Some results of this work are reported in a paper entitled "The Hemodynamic Evaluation of External Counterpulsation in Man" by T. J. Ryan et al., and presented at the American Heart Association Scientific Sessions held in Atlatntic City, N.J., during November 1970.

At the present time the external counterpulsation method is the only controlled method of assist which requires no surgical intervention or sterile procedures, no use of anticoagulants or anesthesia, and produces no significant trauma. These factors are most important because they usually allow a much earlier use of the apparatus on a patient in, say, a state of circulatory shock than could be justified if another type of assist apparatus had to be used.

The selective application of positive and negative pressures to the portion of the vascular bed in the legs serves to control directly the volume of blood within that portion of the vascular bed and, hence, the pressures within the arterial system, particularly the pressures of the aorta. It is these controlled changes in aortic pressure that lead directly to a reduction in cardiac work, to increased perfusion of the systemic circulation, and to preferential perfusion of the myocardium.

An improved system for providing the desired synchronization of the heartbeat and the external assist apparatus has been developed more recently. That system utilized a feedback signal from the external pressurization of the legs, directly compared this signal to a control signal representative of the desired waveform for treatment of the patient and used an error signal derived from the difference between the aforesaid feedback signal and the control signal to achieve an adjustment of the pressurization to the desired waveform. This pressurization, if not properly timed with respect to the heartbeat, could cause a deleterious, physiological effect on the patient. Therefore, a simple, accurate, automatic phasing means was disclosed, whereby an arterial waveform from the patient is displayed on a multi-channel oscilloscope (or other suitable display device) in conjunction with an elecrocardiographic waveform. The arterial pressure waveform would be obtained at a pre-selected site, for example, at the wrist, and the electrocardiographic waveform is obtained by placement of sensors directly on the torso of the patient proximate the heart.

It takes about 80 milliseconds (ms) for a pressure wave, introduced in the femoral arteries with the apparatus of the invention, to reach the root of the aorta. The subsequent transmission from the root of the aorta to the wrist, where the arterial waveform was typically obtained, takes another 90 ms. It is important that the artificially-induced positive pressure waves be produced in the legs sufficiently before diastole (80 ms) and that the pressure wave reaches the root of the aorta at the beginning of diastole. Therefore the control system of the aforesaid improved apparatus comprises a built-in 80-second delay factor adapting it for use on the pre-selected wrist sensing site.

The start of the augmented diastolic waveform, as seen at the wrist, which results from use of the applicants' apparatus, therefore will take place about 170 ms after the pressure is applied to the legs of the patient. In such a situation, it is desirable to have the induced pressure wave initiated by a command signal timed to start 170 ms before the arterial wave, as seen at the wrist indicates the beginning of diastole and 80 ms before the ECG signal indicates the beginning of diastole. The beginning of diastole is indicated in the arterial wave by the so-called dicrotic notch in good approximation by the end of the so-called "T-wave" which is known to be positive indication of the relaxation of the left ventricle and the end of systole.

In the signal phasing system, the leg pressurization signal was used to intensify the ECG and arterial trace on the oscilloscope after this pressurization signal has been delayed for 80 and 170 ms respectively. The duration of intensification is the duration of each positive pressurization cycle of the leg. With the system, an operator could adjust the delay time until the intensified signal on the ECG or arterial wave form is located at the beginning of a diastole. At that point, leg pressurization can be triggered in correct synchronization with the cardiac cycle.

Although the above-described system is generally useful and has been used successfully in some situations, it had the drawback of depending on a predicted constant delay between the aortic event and the selected sensing site. It has now been discovered to be desirable to provide a more versatile means of synchronizing the heartbeat and the apparatus.

SUMMARY OF THE INVENTION

Therefore, it is an object of the invention to provide an improved external circulatory assist apparatus.

Another object of the invention is to provide an external circulatory assist device having a synchronizationcontrol means of greater versatility.

Another object of the invention is to provide an apparatus easily synchronized by personnel of moderate skill and training.

A further object of the invention is to provide an improved control means and method which allows the operator of the apparatus to accurately synchronize the apparatus without (1) the necessity of precise prediction of the time delay between the heart action and its effect on the arterial wave sensing site and (2) without predicting the sensing site to be selected.

Other objects of the invention will be obvious to those skilled in the art on their reading this application.

The above objects have been substantially achieved by controlling the synchronization of the external circulatory assist apparatus with a control means whereby the optimum time period between a certain cardiac event (typically the "R" wave of an ECG curve) and the triggering of the circulatory assist pressure is precisely achieved by a visual and movable indicator means which can be moved during the setting of a time variable, throughout a time range which allows compensation for the time differences between the cardiac event and its manifestation at any arterial-wave sensing site which may be selected at the time of treatment.

The visual marker is advantageously electronic and moved along a channel of an oscilloscope as a trace intensification of a finger plethysmograph, or some like manifestation of a cardiac event, until the marker is positioned at an easily-recognized point on the curve (e.g., at a point indicative of the start of systole).

ILLUSTRATIVE EXAMPLE OF THE INVENTION

In this application and accompanying drawings there is shown and described a preferred embodiment of the invention and suggested various alternatives and modifications thereof, but it is to be understood that these are not intended to be exhaustive and that other changes and modifications can be made within the scope of the invention. These suggestions are selected and included for purposes of illustration in order that others skilled in the art will more fully understand the invention and the principles thereof and will be able to modify it in a variety of forms, each as may be best suited in the condition of a particular case.

IN THE DRAWINGS

FIGS. **1** and **2**, taken together, are a schematic diagram of an external circulatory assist apparatus, including the control means which forms the particular improvement of this invention.

FIG. **3** is a graph illustrating, in real time, the relationship of an electrocardiographic curve and external circulatory assist pressurization.

FIG. **4** is a graph showing curves similar to those which would appear on a two-channel oscilloscope, displaying (1) an electrocardiographic curve and (2) any of several alternative curves manifesting the heartbeat as it is manifested by pressure at the central aorta, a radial artery or a finger.

Referring now to FIGS. **1** and **2**, it is seen that a transducer-type pressure sensor **34** including a sensing bladder **35** is utilized to sense hydraulic pressure in bladder **22**. If the pressure so sensed is less than **20** millimeters of mercury (mm of Hg), then a pressure-level amplifier **46** will provide an output to the "and-type" gate **48**. If during this low-pressure signal situation, the operator closes a water fill switch **50**, he will cause the "and gate" **48** to transmit a signal which will activate a fill pump **52** through pump control circuit **54** and simultaneously cause a multiposition, solenoid valve **56** to shift to its fill position, i.e., the position allowing water to flow from conduit **58** to conduit **60**. Thereupon water will flow into the bladder **22** until a pressure of 20 mm Hg is sensed by pressure sensor **34**. The signal from amplifier **46** will then drop consequently closing "and-gate" **48**. Thereupon, fill pump **52** is deactivated and solenoid valve **56** is shifted to its off position.

Water is emptied from bladder **22** by using an analogous system whereby pressure is sensed by sensor **62**. In a typical mode of operation, if the pressure sensed is above a minus 15 mm Hg value, a signal is sent to "and-gate" **64**. If "empty switch" **66** is closed, the gate **64** will allow a signal command to actuate pump control **68** and "empty pump" **69** and cause solenoid valve **56** to shift to its empty position, i.e., the position allowing water to flow from conduit **60** to conduit **70** and thence back to water reservoir **72** through **74**. The pump **69** will empty until a pressure of less than the illustrative minus 15 mm Hg is sensed. At that time the "and-gate" **64** will no longer sense the required signal from sensor **62**, and the pump **69** will be turned off and valve **56** will return to its off position.

It is noted that the above-described filling and emptying operations are generally used at the beginning and ending of use and not as continuous control means. Nevertheless it is emphasized that the ability to fill the bladder to a particular pre-determined pressure by automatic means rather than judgement means is highly advantageous.

During operation of the apparatus, the pressure within bladder **34** is maintained at its desired level by adding or removing water from the bladder system as follows:

A displacement sensing type transducer **76** is mounted on hydraulically-actuated rod **78**. Transducer **76** is adapted to provide an electrical signal output proportional to the linear advance of rod **78** at any given moment.

A normalized value of the position of rod **78** is provided by feeding the signal from transducer **76** into a displacement level sensor **80**. Thence the normalized signal is provided to a level comparator **82**.

A second input to comparator **82** is derived as follows: An ECG signal from a patient being treated is fed into a trigger generator **84**. The trigger generator is so selected that it recognizes and responds to the so-called "R" wave of the ECG signal. (This wave is identified by numeral **415** in FIGS. **3** and **4**.) Thus when the R wave periodically occurs with each heartbeat, an output is triggered which is fed to a manually controlled delay **86.** The purpose of delay **86** is to convert the original signal from first trigger generator **84** to a second time-delayed signal corresponding in real time with the beginning of cardiac diastole. This second signal enters a duration signal generator **88.** Generator **88** is so selected that the signal therefrom continues for the length of time that leg pressurization (as caused by pressure in bladder **34**) is desired. This signal from generator **88** is fed to level comparator **82** through a level strobe signal generator **89.**

The signal from generator **88** is also fed to a waveform generator **90** which produces a wave whose amplitude and shape is analogous to that desired for the leg pressurization sequence. A typical such wave will be trapazoidal-like in shape with a rise of 60 ms, a plateau of 250 ms, and a fall of 60 ms. This wave from generator **90** is fed to a wave form comparator **92** wherein it is continually compared to a signal derived from the actual bladder pressure wave as experienced by sensor **34.** The output of comparator **92** is a so-called "error signal", i.e., a signal which is indicative of the quality and strength of the difference between the desired wave signal from generator **90** and the actual wave signal from sensor **34.**

It is to be noted in reference to waveform generator **90** that a typical generated wave will normally have a total positive pressure period of from about 250 to about 300 milliseconds. The rise and fall in pressure will take about 60 ms each and rise will start about 80 ms before diastole. In general, it is desirable to select a period-determining device which can maintain positive-pressure periods of up to about 500 ms.

The error signal is used to control servo valve **94** through a servo-amplifier **93** and thereby controls the supply of fluid to, and consequently the movement of, hydraulic cylinder **78.**

As has been described above, level comparator **82** receives two signals: one, a periodic signal from a duration signal generator **88,** via strobe signal generator **89** and the other from displacement level sensor **80.** lever comparator **82** compares these two signals, one indicative of the actual position of hydraulic cylinder **78** at a given time. It is the periodic, or "strobe" signal from duration signal generator **88,** as modified by a level strobe signal generator **89,** which determines when this comparison is to be made. The comparison is most usefully made at the time platen **30** is in the upper-most portion of its stroke and pressing firmly against bladder **22.**

If level comparator **82** senses that the uppermost position of platen **30** is too high, output signal is provided to a "one shot" (monostable multivibrator) **96.** This "one shot" **96** will then turn on fill pump **52** and also position solenoid valve **56** for a 0.5-second fill period. The 0.5-second fill periods will continue during each cardiac period, (i.e., each heartbeat) until the water volume in bladder **22** is sufficient so that the uppermost position of platen **30** is within an acceptable displacement range at the top of its stroke.

If, on the other hand, the level comparator **82** receives a signal that the uppermost position of platen **30** is too low in its stroke, the uppermost position of empty pump is turned on for one-half second on each cardiac cycle by activation of the "one shot" device **98** and the empty pump **69.** Water is then pumped out of the bladder until the platen achieves a desired rise during its stroke.

The general operation of the system described above is known in the art but is believed to be desirably set forth herein to fully describe the nature of the improved apparatus subject of the invention and the manner in which the operation is phased into correct synchronization with the heartbeat as described below:

A signal from any given arterial pressure-sensing device **99** is fed into a dual trace oscilloscope **101** along with a signal from ECG device **102.** These signals appear only as width intensifications **103** of ECG trace **104** and the arterial trace **106.**

Before discussing the processing of the ECG and arterial wave signals with respect to the oscilloscope, attention is called to FIG. **3** which shows the relative real timing of the cardiac cycle as represented by electrocardiogram **402,** radial arterial pressure waveform **407,** and the curve **404,** representing the leg pressure rise **405** exerted by the external circulatory assist device on legs of a patient.

The electrocardiograph is characterized by R wave **415,** sometimes called a "QRS" complex, and a T wave **420** see FIG. **4.** The beginning of systole is manifested at 399 or about 40 ms after the R wave peak **415.** A radial arterial sensing of this heart action will provide a waveform representative of the heart cycle; however, the precise time at which the arterial waveform is sensed, as shown in FIG. **4,** will be out of phase with the ECG signal itself by a time dependent on the particular site at which the arterial waveform is sensed. Moreover, a modified waveform, and not the arterial waveform itself, will be sensed at the radial arterial sites. These modified arterial waveforms are characterized by a so-called dicrotic notch **409** which is a manifestation of the beginning of diastole in the cardiac cycle.

In the apparatus described above and known in the prior art, the external assist pressurization, for example at the legs, was to occur at a time (D_1) after the triggering signal; 80 milliseconds later the pressure wave reached the heart and after 90 more milliseconds it was sensed at the wrist, the pre-selected sensing site. Thus, the external pressure wave became effective at the heart at the start of diastole as desired. This time corresponds, with reference to an arterial waveform, to the appearance of dicrotic notch **409** on the arterial waveform at the wrist and the apparatus was designed to initiate the pressure pulse at the legs at a time equal to **170** seconds before the manifestation of diastole at the wrist.

A signal from an arterial pressure-sensing device **99** was fed into a dual trace oscilloscope **101** along with a signal from ECG device **102.** The duration of an intensification of these signals was the duration of a pressure command signal as received from druation signal generator **88** and appeared as intensifications of ECG trace **104** and arterial trace **106.** Delay devices of 90 milliseconds and 80 milliseconds respectively, caused the pressure command signal to appear on both waveforms in approximately correct time relationship referenced to the actual ECG and arterial pressure. D_1 i.e., variable delay **86** was used to bring the intensification signal into register with the diastolic period as viewed on either the ECG or arterial traces, thereby simultaneously phasing the pressurization wave to the cardiac cycle.

The operator of the apparatus also has variable control means for changing the characteristics of the duration signal generator **88** to provide the intensified signal duration which is required for a particular patient. On the oscilloscope **100**, this duration showed up as intensifications **103** of the oscilloscope traces.

This prior control system depended for optimum operation on the pre-selection of a particular arterial-sensing site, such as the wrist, which would typically be about 90 milliseconds out of phase with the ECG cycle.

In order to make it possible to avoid pre-selection of a given delay such as the aforesaid 90 milliseconds between the ECG event and the sensing thereof at the wrist, the following system is utilized:

A signal from an ECG device **102** is fed through a trigger generator **84**, delay **86**, and duration signal generator **88**, into an 80 ms delay device **110** as before. The output from device **110**, a pulse equal in duration to D_4, is delayed from the R wave by a time D_1 (imparted by delay **86**) plus **80** milliseconds. This pulse is used to provide the ECG (Channel **1**) intensification.

The pulse is also fed into variable delay device **112**, from which a signal is obtained which is delayed from the R wave by a time equalling D_1 plus 80 milliseconds plus D_2, wherein D_2 is the variable delay imparted by adjustable delay device **112**.

The trigger signal from trigger generator **84**, meanwhile, is being fed to a 40-millisecond delay device **114**, and thence to a variable delay device **116**. The output from device **116** is fed to a marker generator **118**, which generates a marker pulse delayed from the R wave by D_2 plus 40 milliseconds wherein D_2 is the variable delay imparted by adjustable delay device **116**. The signals from marker generator **118** and delay device **112** are fed into pulse mixer **120** and the resulting signal is fed to the channel **2** trace of the oscilloscope, i.e., that channel showing the arterial waveform.

In operation, a marker pip from generator **118**, and illustrated alternatively as **414**, **415** or **416** on FIG. **4**, depending on the placement of the arterial sensor **99**, is moved along arterial trace **106** to a position which is at the start of systole, e.g., as shown at **414**. This position is characterized by the start of a fast rise **403** in the arterial trace.

The marker pip can be moved by use of marker position control **122** throughout a range equivalent to the D_2 variable time delay simultaneously achievable with delay devices **112** and **116**. As the marker pip is so moved, the intensified trace provided by duration generator **86** and representative of the external assist pressure stroke follows the marker pip but is delayed by an amount D_1 less 40 milliseconds from the marker pip.

In use, the operator of the apparatus will first look at the arterial trace and adjust marker position control **122** and move the marker pip to its desired position, indicative of the start of systole. This time is equal to **40** milliseconds plus the delay imparted by variable delay device **116.** Next variable delay device **86**, i.e., D_1 will be set by adjusting delay control **124** to bring the intensification signal into register with the dicrotic notch, thereby adjusting the time between notch and the intensification signal to a time represented in FIG. **4** by D_3. Finally duration generator **88** is set by adjusting duration control **126** to give the proper pulse length, i.e., as shown by numerals **410, 411, 412** and **413** for ECG, Central Aorta, radial artery and finger plethysmograph, respectively, thereby phasing the pressurization wave to the cardiac cycle.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described and all statements of the scope of the invention which might be said to fall therebetween.

What is claimed is:

1. In an external circulatory assist apparatus comprising means to pressurize a portion of a patients body, means to synchronize actuation of said pressurization means on a portion of the body with the heart cycle of a patient being treated, means for creating an arterial waveforms signal representative of said heart cycle, and display means for monitoring a said waveform signal exhibiting a dicrotic notch portion representative of said heart cycle in the form of visible traces on said display means the improvement wherein said synchronizing means includes:

A. means to provide first and second intensified marker pips on said display means displaying a marker trace representative of said arterial waveform derived from a patient,

B. a first means to adjust the position of said first marker pip relative to and along said waveform to a characteristic and identifiable position of arterial waveforms, said adjusting means also forming,

C. means to, concurrently with the adjustment of said first marker pip, move a second intensified pip along said waveform at a constant distance from said first marker, and

D. A second independent adjusting means to bring said intensified trace into register with the dicrotic notch of said waveform, said first and second adjusting means for moving said trace pips further forming variable-time adjusting means and synchronization means between a patients heart cycle and the start of said pressurization of his body.

2. Apparatus as defined in claim **1** wherein said means to provide said second said intensified marker pip comprises means to form an ECG-derived signal, a signal generator, means for triggering said signal generator by said ECG-derived signal, a variable delay means, a marker pip generator, and a pulse mixer for integrating said second marker pip signal with a signal representative of a pressure wave exerted by said external assist apparatus on said patient.

3. Apparatus as described in claim **2** wherein said variable delay means provides a delay variable over a time difference at least equal to the time elapsing from diastole in a patient's heart cycle to the time such diastole is registered in said patient's digital extremities.

4. Apparatus as defined in claim **1** wherein said position adjusting means provide means to adjust said marker pip over a portion of the waveform equivalent in length to time elapsing from diastole in a patient's heart cycle to the time such diastole is registered in said patient's digital extremities.

5. In apparatus for applying external pressure assist action to the limbs of a patient in cyclic synchronization with the heartbeat of said patient, wherein said assist is achieved with means for transmitting pressure to said limbs through a fluid-filled bladder pressurizing means surrounding said limbs, means for creating an arterial waveform signal representative of said heartbeat and display means for monitoring a said waveform signal representative of said hearbeat in the form of visible traces on said display means, wherein the apparatus also includes a visual cycle-phasing monitor comprising:

A. a multi-channel display means for displaying
   1. an ECG trace, and
   2. a trace derived from an arterial pressure sensor,

B. means for visually displaying for the relative time duration of a pressure command signal on said traces, and

C. manual means to adjust the relative timing and duration of said pressure command signal, while simultaneously achieving a visual adjustment of said signal to bring it into the desired relationship to said ECG trace or arterial trace; and means to initiate said pressure command signal; and wherein said apparatus comprises:
   A. means to provide a first marker pip on display apparatus displaying a marker trace representative of a radial arterial waveform derived from a patient,
   B. means to adjust the position of said marker pip relative to said waveform to a characteristic and identifiable configuration of arterial waveforms, said adjusting means also forming,
   C. means to, form an intensified trace on said waveform,
   D. means to move, concurrently with said adjusting, an intensified trace along said waveform at a constant distance from said first marker, and
   E. means to bring said intensified trace into register with the dicrotic notch of said waveform, thereby adjusting the synchronization for activating said pressure command signal.

6. In apparatus for applying external pressure assist action to the limbs of a patient in cyclic synchronization with the heartbeat of said patient, wherein said apparatus comprises means for producing a pressure command signal, means for transmitting pressure through a hydraulic cylinder to said limbs through a fluid-filled bladder pressurizing means surrounding said limbs in response to means for activating said pressure command signal, and means for creating an arterial waveform signal representative of said heartbeat and display means for monitoring a said waveform signal representative of said heartbeat in the form of visible traces on said display means, and wherein the apparatus includes

A. an ideal pressure waveform generator means,
B. actual limb pressure waveform sensing means,
C. said display means forming means for continually comparing said ideal and actual waveforms, and
D. variable valve means, responsible to a signal from said comparing means, to modify fluid flow to said hydraulic cylinder and thereby to transmit pressure to said limbs through said fluid-filled bladder more nearly achieve said ideal-pressure waveform at said limbs the improvement wherein said apparatus comprises:
   A. means to provide a first marker pip on display apparatus displaying a marker trace representative of said arterial waveform derived from a patient,
   B. means to adjust the position of said marker pip relative to said waveform to a characteristic and identifiable configuration of arterial waveforms, said adjusting means also forming,
   C. means to, form an intensified trace on said waveform,
   D. means to move, concurrently with said adjusting, an intensified trace along said waveform at a constant distance from said first marker, and
   E. means to bring said intensified trace into register with the dicrotic notch of said waveform, thereby adjusting the synchronization for activating said pressure command signal.

7. Apparatus as defined in claim **6** comprising:

A. a multi-channel oscillosopce adapted to display
   1. an ECG trace, and
   2. a trace derived from an arterial pressure sensor,

B. means for visually displaying of the relative time duration of a pressure command signal on said traces, and

C. manual means to adjust the relative timing and duration of said pressure command signal, while simultaneously achieving a visual adjustment of said signal to bring it into the desired relationship to said ECG trace.

8. In a process for synchronizing a pulsed pressurizing action of an external pressure circulatory assist apparatus with the heartbeat cycle of a patient being treated with said apparatus, said process including the steps of using a display means exhibiting a trace derived from an arterial pressure sensor as a means to judge when said pressurizing action is to be initiated, the improvement comprising the steps of

1. adjusting a reference pip on said arterial trace display means to that portion of said arterial trace which is indicative of the start of the systole rise,
2. simultaneously positioning a second marker pip representative of the time and duration of said pressurization action on said arterial trace proximate and dicrotic notch portion of said trace so that said second pip coincides with the dicrotic notch of said arterial trace, and simultaneously adjusting, through setting a variable time delay means, the synchronization of a patient's heartbeat with said pulsed pressurizing action, and
3. adjusting the pulse time of said pressurization action by operating a duration control means which simultaneously expands the second marker pip to form a visual representation of the pulse time on said arterial trace.

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