Aug. 4, 1964 J. H. GREEN 3,143,111

BLOOD PRESSURE FOLLOWER

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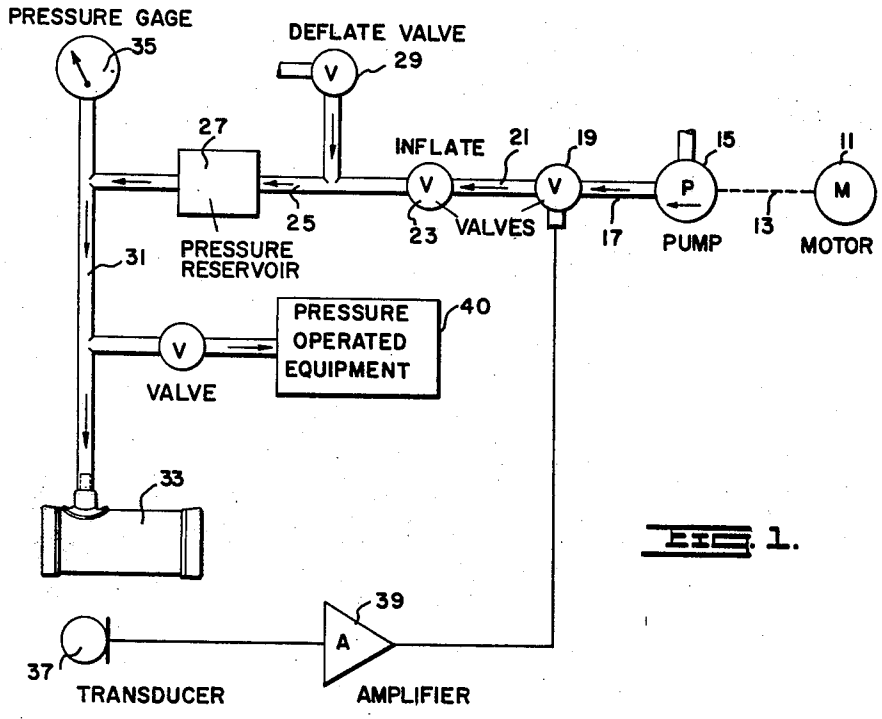


Fig. 1.

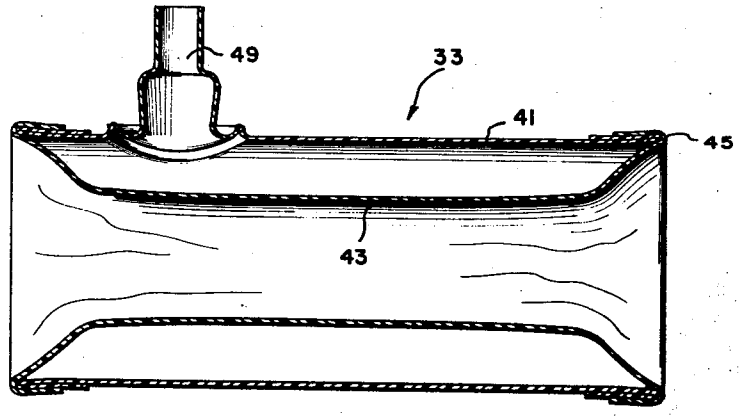


Fig. 2.

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Fig. 3.

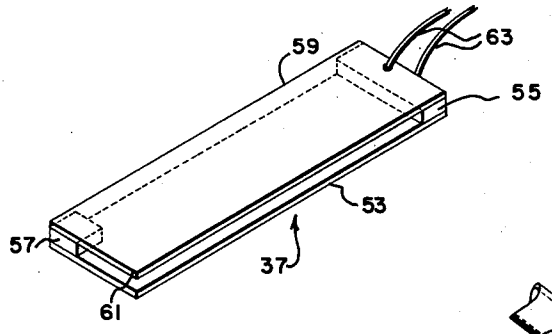
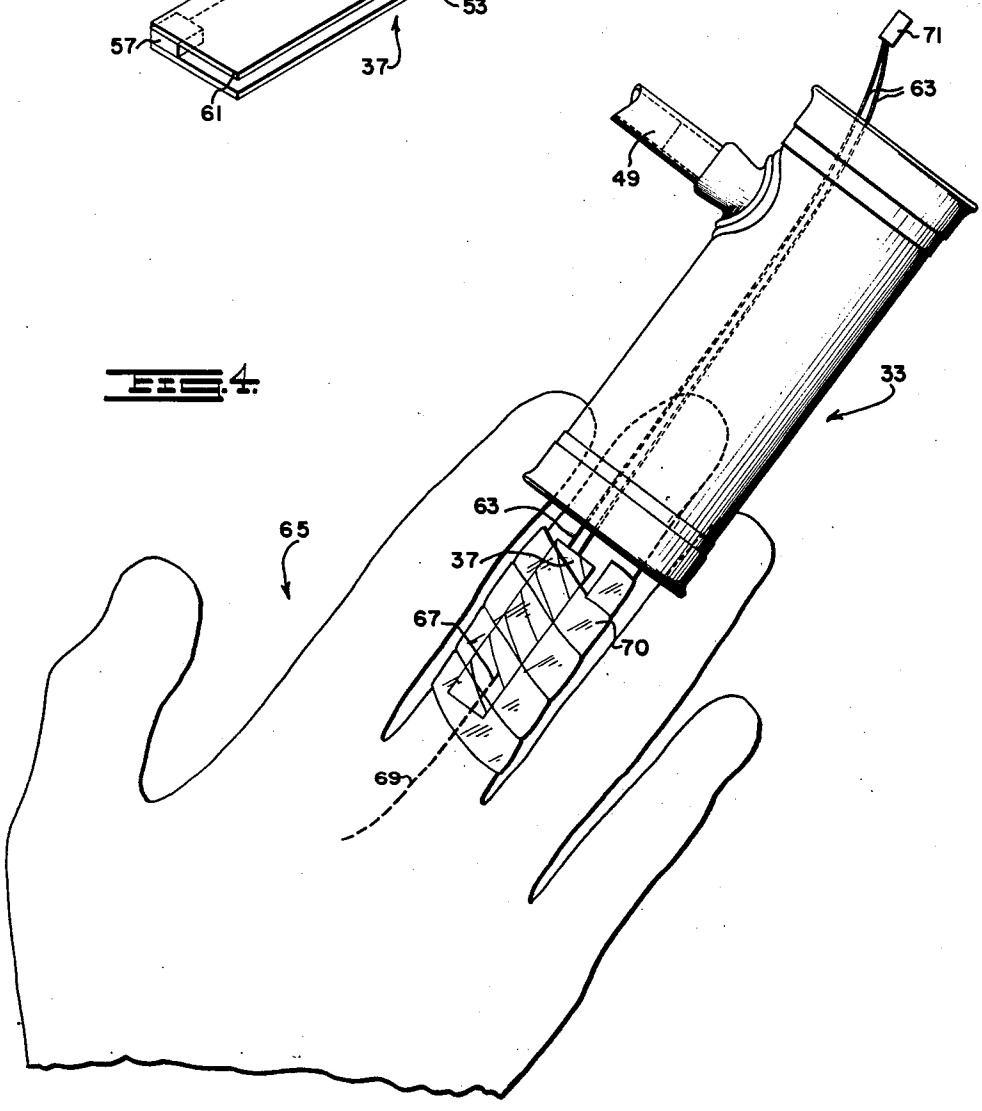


Fig. 4.



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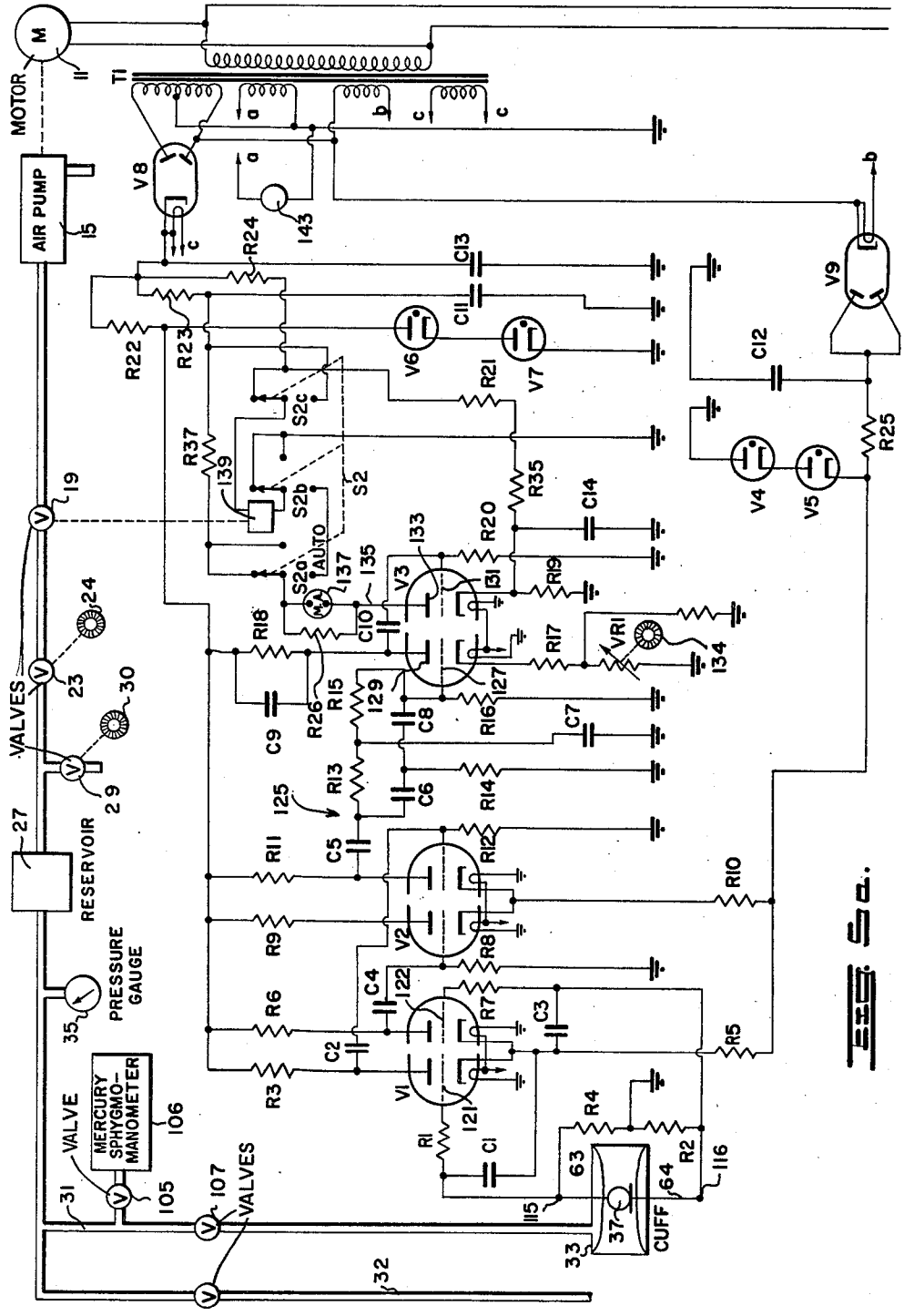


Fig. 5a.

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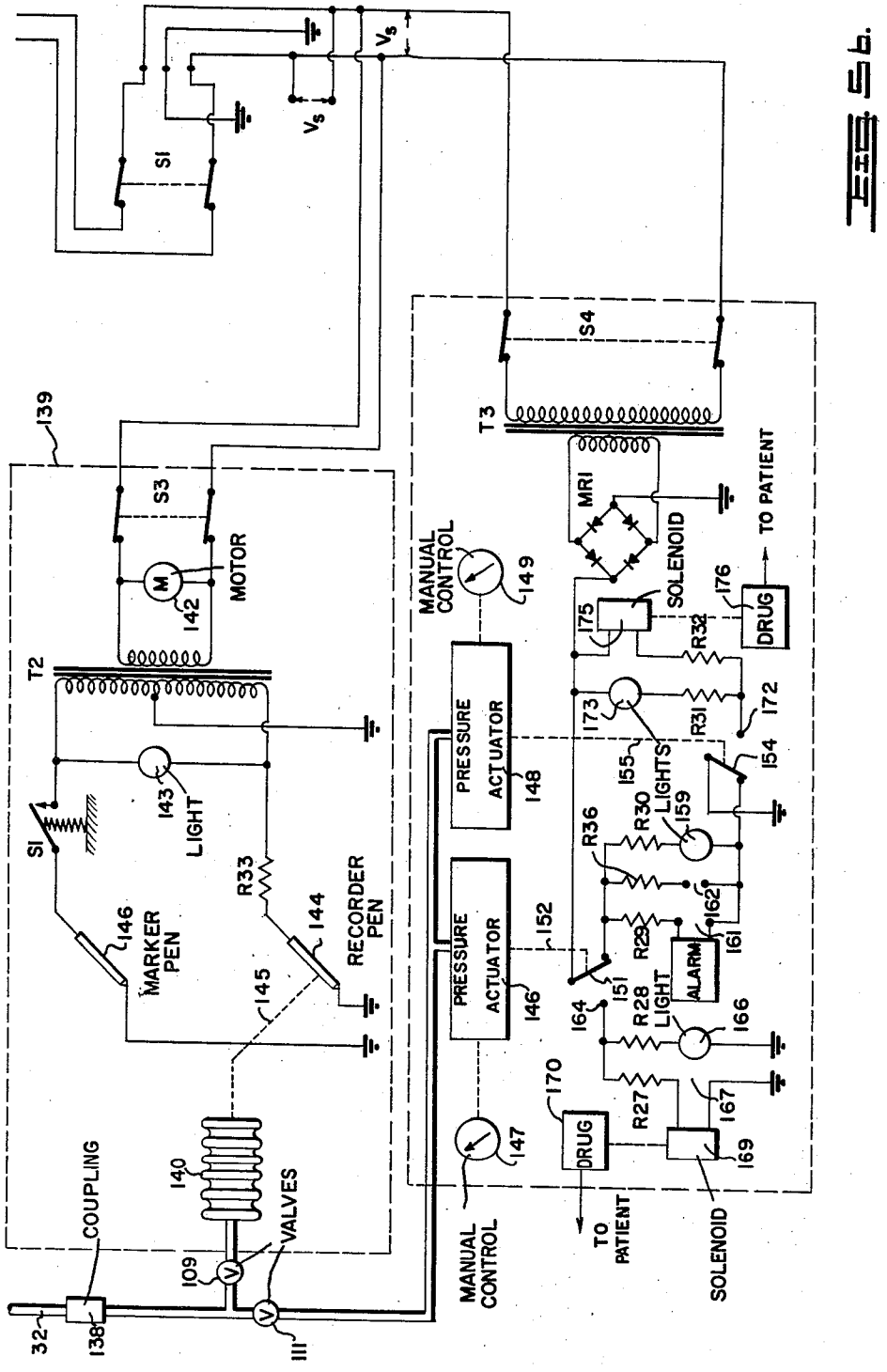


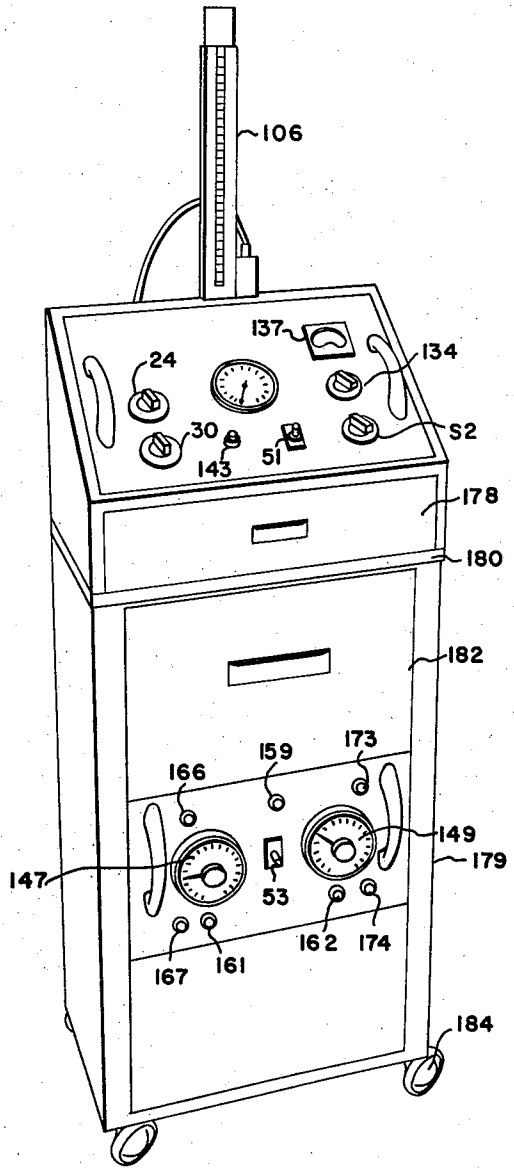
Fig. 5b.

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FIG. 6.



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3,143,111

BLOOD PRESSURE FOLLOWER

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3 Claims. (Cl. 128—213)

This invention relates to improvements in devices for measuring blood pressure and particularly to devices which give a continuous reading and recording of such blood pressure together with means for controlling the blood pressure of the patient within allowable limits.

The usual method of measuring blood pressure consists of using an inflatable cuff strapped to the limb of the patient and connected to a sphygmomanometer, such as a column of mercury. By means of a stethoscope, the operator estimates, from the sounds he hears, the instant the cuff pressure passes through the systolic and diastolic blood pressure values. These readings are determined by inflating the cuff to a pressure beyond the systolic pressure and allowing this pressure to decay. The pressure is visually read from the mercury column when the systolic and diastolic sounds are detected through the stethoscope. Such a method is cumbersome and requires great skill by the person reading the blood pressure. Automatic devices have been developed for providing direct readings of blood pressure on a meter, but these automatic systems have serious limitations. The cuffs which are conventionally used in the systems now in use cannot be left on the patient for a long period since they seriously hinder the flow of blood in the limb on which they are placed. Therefore, the readings obtained, even in the so-called automatic systems, merely provide a series of individual blood pressure readings.

Accordingly, it is an object of this invention to provide a device which will provide a continuous reading and recording of blood pressure.

Another object of this invention is to provide a continuous blood pressure follower which may be used on a patient for a very long period of time without causing discomfort or injury to the patient.

Yet another object of this invention is to provide continuous readings of blood pressure on a dial as well as on a sphygmomanometer and at the same time give a continuous recording of the blood pressure.

A further object of this invention is to provide a blood pressure follower which may be used with conscious or unconscious patients in all branches of medicine where blood pressure readings are required.

A still further object of this invention is to provide a blood pressure follower which controls the administration of hypo- or hypertensive drugs to a patient if the pressure falls below or exceeds predetermined limits.

Further objects and advantages of this invention will become apparent to those skilled in the art by referring to the following description when taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a simplified diagrammatic showing of a blood pressure follower system as contemplated by the present invention;

FIG. 2 is a sectional view of a digital cuff or sleeve means which may be used in conjunction with the present equipment;

FIG. 3 is a perspective view of an electrical transducer which may be used in the system for detecting the pulse pressures;

FIG. 4 is a showing of the method of applying the cuff of FIG. 2 and the transducer of FIG. 3 to a digit of the patient;

FIGS. 5*a* and 5*b* are schematic circuit diagrams of the

entire system including the blood pressure follower, recorder and drug control panel; and

FIG. 6 is a perspective view of a cabinet containing the equipment of FIGS. 5*a* and 5*b* and showing a preferred arrangement of the dial and indicator devices.

In the blood pressure follower of the present invention, the arterial pulsation from the digital artery of a finger or toe is picked up by a piezoelectric crystal placed over this artery. Each of these pulsations is employed to open a normally closed air valve which inflates a cuff or sleeve means from a small pump in the apparatus. The cuff occludes the artery proximally to the point of application of the crystal, and when this occlusion is complete the air valve is no longer actuated and a leak in the pressure system allows the cuff to deflate until pulsations reappear. Each of the pulsations causes the valve to open temporarily and allow further air to enter the cuff. The apparatus thus maintains the pressure within the cuff at substantially the same level as that of the digital artery.

The cuff or sleeve means of the present invention has been designed substantially to enclose the finger and to raise the pressure of the finger tissues to a level which varies above and below the arterial pressure. In this way, the cuff acts as a G-suit on the finger and allows the normal exchange of tissue fluid, nutrition and metabolites to continue with the blood flow which occurs when the cuff pressure is below that of the digital artery pressure. This, coupled with the low metabolism of the finger, permits the cuff to be kept in position for periods of four hours or more without cyanosis or oedema developing. The cuff is quite comfortable to the patient and there is no ischaemic pain during use.

Referring now to FIG. 1, an electric motor **11** drives an air pump **15** through any suitable mechanical linkage represented at **13**. Pump **15** provides air under pressure to a solenoid control valve **19** through conduit **17**. When the valve **19** is open, air passes through conduit **21**, through a manually adjustable inflation valve **23** and through conduit **25** into a pressure reservoir **27**. A manually controllable deflation valve **29** is placed between the inflation valve **23** and the reservoir **27**. The inflation valve **23** and the deflation valve **29** are adjusted relative to each other according to the desired operation of the system. It has been found that an adjustment allowing the inflation valve **19** to pass one and one-half times the amount of air that is allowed to pass through the deflation valve **29** results in satisfactory operation of the system. Since the solenoid control valve **19** is continually opening and closing due to the arterial pulsations within the digit, the pressure reservoir **27** is provided to absorb minor pressure variations and deliver a smooth flow of air at a slowly varying pressure to conduit **31**.

The pressure in conduit **31** inflates the cuff or sleeve means **33** to a value where it is slowly varying above and below the systolic pressure as detected by the transducer **37** which is strapped to the finger within the cuff **33**. A pressure gauge **35** gives a direct reading of the pressure within conduit **31** and, therefore, a direct reading of the systolic pressure of the patient. Arterial pulsations cause a signal to be developed by transducer **37** and these signals, which are amplified by amplifier **39**, open the solenoid valve **19** which remains closed unless energized.

The associated pressure operated equipment **40** may also be connected to conduit **31** in order that the pressure within the cuff may be used to control this equipment.

The system will operate properly with any device which is designed so as to provide a pressure on the digit which slowly varies about the systolic pressure within the artery. A highly successful, inexpensive device for applying such a pressure is shown in FIG. 2 which is a sectional view taken through the length of the cylindrical cuff **33**. Cuff **33** comprises an outer cylindrical sleeve

41 of a material which is flexible but non-stretchable. An inner liner sleeve 43 of generally cylindrical shape is secured within the outer sleeve 41 at the ends 45. The liner 43 may be made of the same material as the sleeve 41 and is expandable within the sleeve 41 and thus, constricts the diameter of the opening through the cuff 33 when inflated. The sleeve 43 may be secured to cylinder 41 by heat sealing or with a suitable adhesive depending upon the material used. An opening is provided in the body of the sleeve 41 in which is secured a hose 49 for supplying the air for pressurizing the cuff. The cuff may be formed of any suitable plastic material such as polyvinyl chloride.

Although the system will operate with any of the well-known electrical transducers, the particular transducer of FIG. 3 has proven to be advantageous in that it avoids the possibility of signals being produced due to the air pressure in the cuff rather than the pulsating pressure of the artery. The transducer 37 of FIG. 3 comprises a base plate 53 which may be of any rigid material, and, in order to provide a support for the crystal 59, a cross-piece 55 of dielectric material is secured between one end of the plate 53 and one end of the crystal 59. A small block of dielectric material 57 is secured at one corner on the opposite end of plate 53 between the plate and the crystal. The pressure exerted at or near the unsupported corner 61 of the crystal 59 will cause the crystal plate to twist and thus induce a signal in the leads 63. If the block 57 is not used, the signal will be induced in the crystal by a pressure exerted on the free end thereof. It has been found that such an operation often results in an unwanted signal being induced by the air pressure of the cuff, and, if the pressure of the cuff should become great enough, then the crystal would come into contact with plate 53 and destroy the operation of the device 37 entirely. The transducer shown in FIG. 3 substantially eliminates such a possibility.

Transducer 37 is wrapped in a protective coating and is secured to the digit of the patient 65 as indicated in FIG. 4. A mark 67 is preferably placed on the wrapping adjacent the base plate 53 to indicate the free corner 61 of the crystal 59. This mark is placed over the digital artery 69 and the unit is secured to the finger by means such as tape 70, here shown as transparent tape for purposes of clarity. Leads 63 extend outwardly from the finger to a connector 71 which provides a means for connecting the signal output of the crystal to the control circuits of the system. The cuff 33 is slipped over the digit so as to enclose the transducer 37 with the leads 63 extending beyond the cuff. The cuff is then inflated and the automatic process is put into operation.

FIG. 5*a* is a schematic showing of the controls for the pressure follower. The electric motor 11 is supplied from a standard single phase three-wire source V_s when the main switch S_1 (FIG. 5*b*) is closed. The path of the air under pressure from the pump 15 through the conduits, valves and reservoir to the cuff is as explained in the discussion in connection with FIG. 1.

The power source for the amplifying and control circuit is derived from the power supply V_s through transformer T_1. Two full-wave rectifying tubes V_8 and V_9 are connected across a secondary of transformer T_1 and provide equal voltage outputs having opposite polarities. The output rectifier V_8 provides the plate supply voltage for the various components and the power for operating the solenoid valve. The output of rectifier V_9 provides the negative voltage bias for the various cathode elements used in the tubes.

The leads 63 and 64 from the transducer 37 are connected to the input terminals 115 and 116 of the amplifying and control circuit. Since leads 63 and 64 are necessarily relatively long, the circuit connections to tube V_1 are employed in order to eliminate any induced signals which might appear in the leads. The signal from terminal 115 passes through resistor R_1 to the control grid 121 of the dual triode tube V_1. The signal from terminal 116 passes through resistor R_7 to the other control grid 122 of tube V_1. Equal resistors R_2 and R_4 connect terminals 116 and 115 to ground.

In accordance with standard operation, the signals appearing in leads 63 and 64 are of opposite phase as is usual with the output of a crystal transducer and the signals from the transducer 37 appear at the control grids 121 and 122 of the tube V_1 out of phase. Because of the differential amplifier arrangement of tube V_1, this signal is amplified. However, any signals which are induced in leads 63 and 64 by means other than the transducer 37, such as hum and lead movements, appear at the control grids 121 and 122 in phase and are cancelled by the differential amplifier. Thus, any spurious signals induced in the leads are cancelled. Capacitors C_1 and C_3 remove any high frequency signals which may be present due to the operation of high frequency equipment in the vicinity. The anodes of V_1 are connected through capacitors C_2 and C_4 to opposite grids of dual triode tube V_2. The output of tube V_2 is passed through a double-T network 125 to the grid 127 of tube V_3. Anode 129 of tube V_3 is connected through capacitor C_{10} to the control grid 131 of tube V_3. A manual gain control 134 is provided for adjusting a variable resistor VR_1 through a mechanical linkage for controlling the gain of the amplified signal which appears on grid 131. The protective resistor connected in parallel with resistor VR_1 is of a comparatively large magnitude and is included to partially reduce the sensitivity of adjustments of VR_1.

A switch S_2 is provided in the circuit to control the switch arms S_{2a}, S_{2b} and S_{2c} which are ganged, three position switches. Switch S_2 controls the position of valve 19 and, thus, the inflation and deflation of the cuff 33. The three positions of the switch are inflation (+), deflation (−) and automatic (auto). When the switch is in the inflation position as shown in FIG. 5*a*, the plate supply for anode 133 is through lead 135, pulse indicator milliammeter 137, through switch S_{2a}, resistor R_{37}, and resistor R_{23} to rectifier V_8. Since the valve 19 remains closed unless the solenoid 139 is energized, current must be supplied to the solenoid when the switch is in the inflate (+) position. This current is supplied from rectifier V_8 through resistor R_{24}, switch S_{2c} to solenoid 139 and switch S_{2b} to ground. Thus, when switch S_2 is in the inflate position, the signal output or lack of signal output from the double triode V_3 has no effect on the operation of the valve since the solenoid is continually energized.

When switch S_2 is moved to the deflate position (−) the plate supply to the anode 133 remains the same. However, switch S_{2c} opens the circuit to the solenoid and the deenergized valve 19 closes allowing the cuff to deflate through deflation valve 29.

When the switch S_2 is moved into the automatic position (auto) the plate supply through resistor R_{37} is removed. However, the value of resistor 37 is matched to the value of the internal resistance of the solenoid 139. Therefore, when the switch is in the auto position the plate supply is through lead 135, milliammeter 137, switch S_{2a}, switch S_{2b} through solenoid 139, switch S_{2c}, and resistor R_{23} to rectifier V_8. Accordingly, every pulse that passes through the pulse indicator 137 will energize the solenoid and open the valve 19 allowing air under pressure to pass therethrough. It is also to be noted that the operation previously described acts as an integrating circuit in that the valve 19 will remain open for the approximate period of time equal to the width of the pulse passing through the pulse indicator. As the pressure increases and the pulsations become weaker, a shorter pulse will be generated and the valve 19 will open for a shorter period of time. This prevents excessive hunting about the systolic pressure when the system is in operation.

The normal procedure followed when the digit and transducer are in place within the cuff is to switch S_2 to the inflate position which causes valve 19 to remain open.

After the pressure within the cuff, as indicated by pressure gauge **35**, reaches a nominal amount such as 40 mm. of Hg, switch S_2 is placed in the automatic position. Transducer **37** detects the arterial pulsations of the digit causing valve **19** to open with each pulsation, allowing air to pass therethrough. The pulses from the transducer **37** will continue on a gradually diminishing scale until the systolic pressure is reached in the cuff, at which time no signal will appear to energize solenoid **139** and valve **19** remains closed. The pressure system will then gradually begin to deflate through valve **29**. When the pressure in the cuff is reduced to slightly below the systolic pressure arterial pulsations will reappear and inflation will again occur. Accordingly, the pressure gauge **35** will vary slightly in a rhythmic manner about the systolic pressure.

Glow tubes V_4, V_5, V_6 and V_7 are provided in order to insure a stable voltage supply from the rectifiers and capacitors C_{11}, C_{12}, C_{13} and C_{14} are provided for smoothing purposes.

Additional secondary windings are provided in transformer T_1 to supply the necessary current for the various cathode heaters as indicated at *a*, *b* and *c*. An indicator lamp, such as a red light **143**, is connected across one of the secondaries to give a positive indication that power is being supplied to the transformer T_1.

FIG. *5b* shows the recorder and drug control panel which may be connected to the pressure system by means of a standard connector **138**. Recorder **139** is provided with a small torque motor **142** which receives its power supply from the main power source V_s. Motor **142** drives a reel to move a heat sensitive paper at a constant speed past the recorder and marker pens. This paper drive mechanism is of a standard type and is not shown in FIG. *5b* for purposes of clarity. Air pressure equal to that of the cuff passes through valve **109** and actuates a bellows **140** which moves a recorder pen **144** through a mechanical linkage **145**. The recorder pen **144** is of the "hot wire" type and receives current from the secondary transformer T_2 through resistance R_{33}. Thus, a continuous recording on the heat sensitive paper of the systolic blood pressure of the patient is available. There is also provided a marker pen **146** which is also of the "hot wire" type. Current is supplied to pen **146** only when switch S_1 is held in a depressed condition. This allows the intermittent marking of the heat sensitive paper for purposes of indicating the commencement and ending of certain test periods, the injection of drugs, etc. Indicating light **143** is provided to give a visual showing that switch S_3 is closed and the recorder is in operation.

Two adjustable pressure switch actuators **146** and **148** are also connected to conduit **32** through connector **138** and valve **111**. These adjustable pressure switch actuators control administration of hypo and hypertensive drugs to the patient. Actuators **146** and **148** are of the well-known type which are manually adjustable through linkages connected to control knobs **147** and **149** which adjust the tension on the diaphragm within the switch. Pressure switch actuator **146** is adjusted to the allowable lower limit to which the blood pressure may fall while actuator **148** is adjusted to the allowable maximum limit to which the blood pressure may rise. Power is supplied to the drug control circuit from the voltage source V_s through the transformer T_3 when switch S_4 is closed. Rectifying bridge MR_1 is connected across the secondary of transformer T_3 with the output of the rectifier passing to the switch arm **151** of pressure switch **146**. The switch arms **151** and **154** are shown in their normal position which exists when the pressure in the conduit is between the set upper and lower limits of actuators **146** and **148**. Under this condition, current passes from the rectifier through switch arm **151**, through an indicating lamp **159**, such as a green light, and through switch **154** to ground. Outlets **161** and **162** are provided in parallel with light **159** and may be used for any other indicating purpose, such as an audible alarm which would sound should the current through the switches be cut off. Remote visual indicating lamps could also be connected to one of these outlets.

Should the pressure in the conduit fall below the set allowable lower limit, pressure switch actuator **146** will move switch arm **151** to terminal **164**, thus opening the circuit through indicator light **159** and closing the circuit through indicator light **166**, such as red light, and outlet **167**. This energizes the solenoid **169** which is connected to outlet **167** and opens a valve in a drug container **170** to allow the proper drug to be delivered to the patient. Normally, the drug container **170** would be such that it provides drip gravity delivery to the patient through a tube and a needle in the patient's arm. Should the pressure exceed the allowable limits, pressure actuator switch **148** will move arm **154** into contact with termainl **172**. This will also open the circuit through light **159** and cause a similar operation of solenoid **175** which will deliver the opposite type of drug to the patient. Thus it can be seen that fully automatic control of the blood pressure of the patient is achieved by the system of this invention.

FIG. 6 shows the cabinet in which the equipment is housed and the preferred arrangement of the associated dials, indicators and control knobs. The cabinet is formed in two main compartments, the upper compartment **178** housing the pressure control equipment illustrated in FIG. *5a* and the lower compartment **179** housing the recorder and drug control equipment shown in FIG. *5b*. The upper compartment **178** slips over the lower compartment at the flange **180** and is removable therefrom by merely disconnecting the mechanical release, the electrical leads from the main power source and the pressure conduit from the main pressure line at connector **138** of FIG. *5b*. Thus, the air pressure control and indicator equipment is removable from the main cabinet so as to be usable in a portable manner.

Dials **24** and **30** provide the manual control of inflation valve **23** and deflation valve **29**, respectively. As explained hereinabove, this setting is made prior to placing the equipment in operation. The manual switch S_2 provides the control for automatic operation and manual inflation or deflation. Knob **134** controls the gain of the output to pulse indicator **137** which indicates the presence of a pulse. Pressure may be read visually on either the pressure gauge **35** or the mercury sphygmomanometer **106** which is detachable from the equipment if desired.

The lower compartment **179** of the cabinet has a sliding drawer **182** which houses the recording equipment shown in FIG. *5b*. The manual controls for the drug control equipment are provided on the face of the lower compartment. Dials **147** and **149** provide the adjustment of pressure switches **146** and **148**, respectively. The red indicator lights **166** and **173** indicate, when illuminated, that the blood pressure is either below or above the set limits, while the jacks **161**, **162** are the outlets for the alarm circuits. The connections to the solenoids **169** and **175** are provided through the jacks **167** and **174**. Wheels **184** are provided in order to facilitate movement of the cabinet to the desired position.

The blood pressure follower of the present invention has many uses throughout the whole field of medical practice. The use of this instrument in an operating room gives continuous blood pressure readings on the dial, the mercury column and the chart recorder as well as providing complete control of blood pressure through the automatic application of drugs. During the recovery phase of an operation the continuous information as to blood pressure changes is available even though the patient may be under the influence of anesthetic and drugs or may even be receiving a blood transfusion.

It is also noted that, by having a continuous recording of a patient's blood pressure, certain errors which result in the normal procedure of obtaining blood pressure may be avoided, such as temporary emotional reactions which give a false indication of the normal blood pressure.

The specification and drawings are illustrative only of one preferred embodiment of the present invention and are not to be considered as limiting the invention in any manner. Many changes could be made in individual elements or in the circuitry used for controlling these elements, and such changes would be obvious to any person skilled in the art in the light of this disclosure. Such modifications are considered to be within the scope of the present invention as defined in the appended claims.

The present application is a continuation-in-part of my co-pending application Serial No. 763,957, filed September 29, 1958, and now abandoned.

I claim:

1. A system for the continuous control of blood pressure in a digit comprising a cuff for application to a portion of said digit and including flexible inflatable means, pneumatic pressure means connected to said inflatable means, a pressure transducer within said cuff adjacent to said digit for producing a signal in response to each arterial pulsation in said digit, a normally closed air valve between said pneumatic pressure means and said inflatable means, means controlled by said transducer for temporarily opening said valve in response to each of said signals produced by said transducer, means connected to said inflatable means for indicating the pressure therein, at least one drug container, means for controlling the flow of drugs from said container, an adjustable pressure actuator connected to said means for controlling the flow of said drugs, and means connecting said pressure actuator to said inflatable means whereby said actuator is operated when the pressure in said inflatable means reaches a predetermined limit.

2. The apparatus of claim 1 further comprising indicating alarm means connected to and operated by said pressure actuator.

3. A system for continuously measuring the blood pressure in a digit comprising an electric motor driven fluid pressure pump, an inflatable cuff for substantially surrounding said digit and connected to said pump by a conduit, a solenoid, a valve in said conduit between said pump and said cuff, means connecting said solenoid to said valve, said valve being open when said solenoid is energized, manually adjustable inflation and deflation valves in said conduit between said cuff and said solenoid operated valve, a pressure gauge connected to said cuff for indicating the pressure therein, a transducer adjacent to said digit within said cuff for producing a signal in response to each arterial pulsation within said digit, means connected to said transducer for amplifying said signals, a manually operable three position switch for controlling said soleniod, said solenoid being continually energized when said switch is in its first position and de-energized when said switch is in its second position, the output of said amplifier being connected to said solenoid when said switch is in its third position so that each arterial pulsation in said digit energizes said solenoid, a recording means having a movable pen, a bellows for actuating said pen, conduit means connecting said bellows to said cuff whereby the movement of said bellows is controlled by the pressure within said cuff, first and second drug containers each having solenoid actuated fluid valves therein, first and second normally open switches for energizing said solenoid actuated fluid valves respectively, a first and second adjustable pressure operated means for closing said first and second switches respectively, and conduit means connecting said first and second pressure operating means to said cuff whereby said pressure operating means are controlled by the pressure within said cuff.

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