

[54] **ANGIOGRAPHIC INJECTOR EQUIPMENT**

[72] Inventors: **Marlin S. Heilman**, Gibsonia; **Rudolph J. Kranys**, Pittsburgh; **Donald Jones**, Churchill, all of Pa.

[73] Assignee: **Medrad, Inc.**, Allison Park, Pa.

[22] Filed: **Sept. 29, 1970**

[21] Appl. No.: **76,491**

[52] U.S. Cl.**128/2 R, 128/218 A, 128/DIG. 1**

[51] Int. Cl. **A61b 06/00, A61m 05/00, A61m 05/20**

[58] Field of Search**128/2 R, 2 A, 2.05 F, 2.05 R, 128/215, 218 R, 218 A, DIG. 1**

[56] **References Cited**

UNITED STATES PATENTS

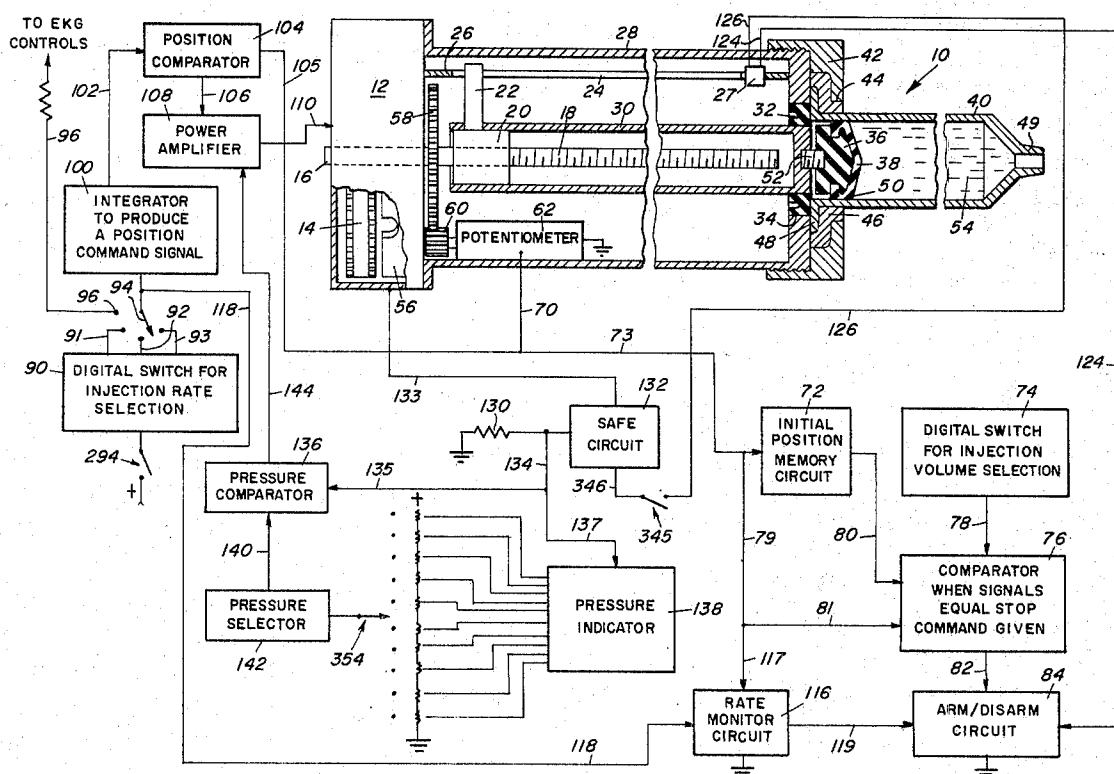
2,627,270	2/1953	Glass	128/218 A
3,155,090	11/1964	Holter	128/2 R
3,156,236	11/1964	Williamson	128/2.05 R
3,523,523	8/1970	Reich et al.	128/2.05 R
3,623,474	11/1971	Heilman et al.	128/2 R
3,631,847	1/1972	Hobbs	128/2 R

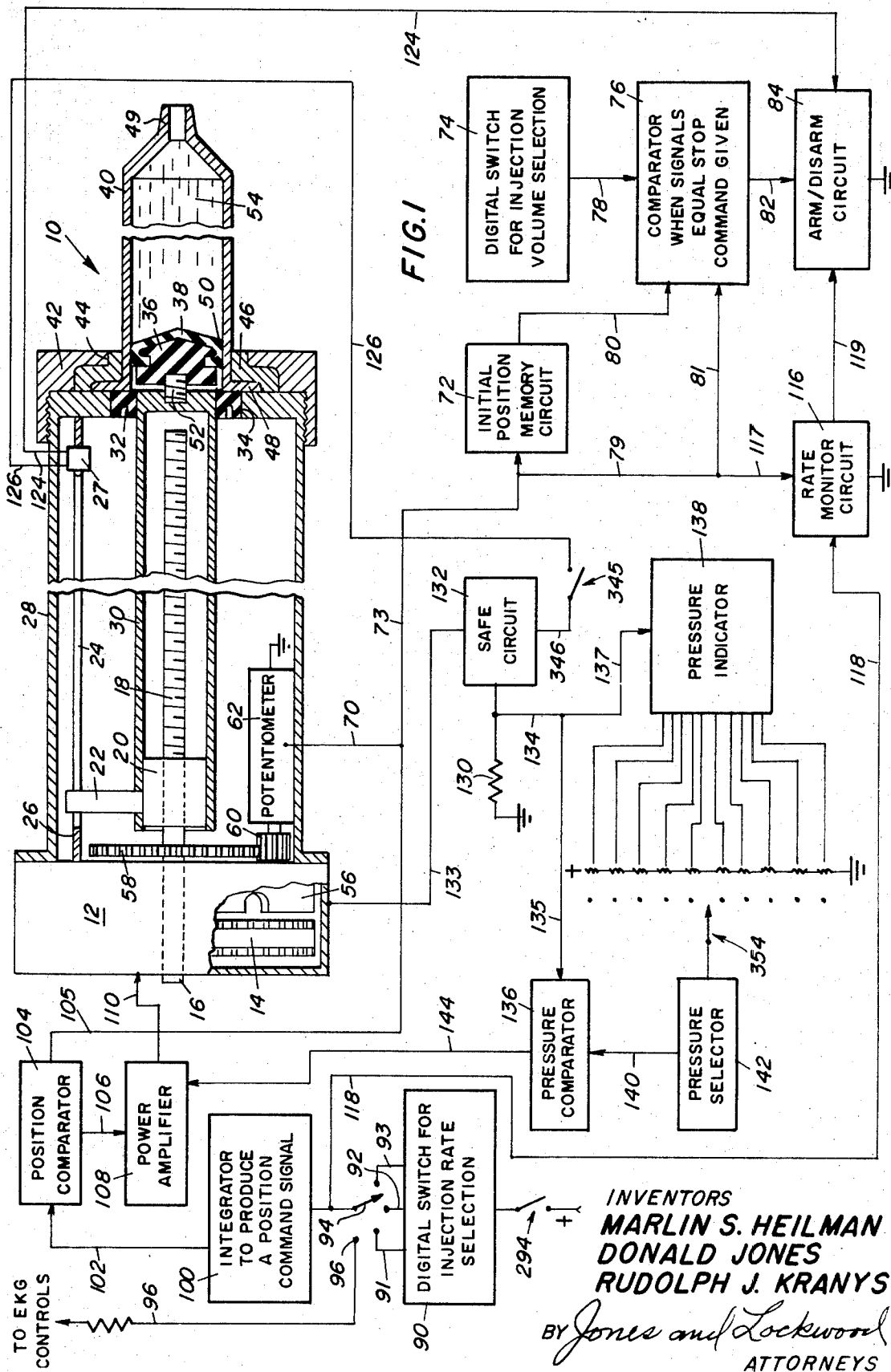
Primary Examiner—Dalton L. Truluck
Attorney—Jones and Lockwood

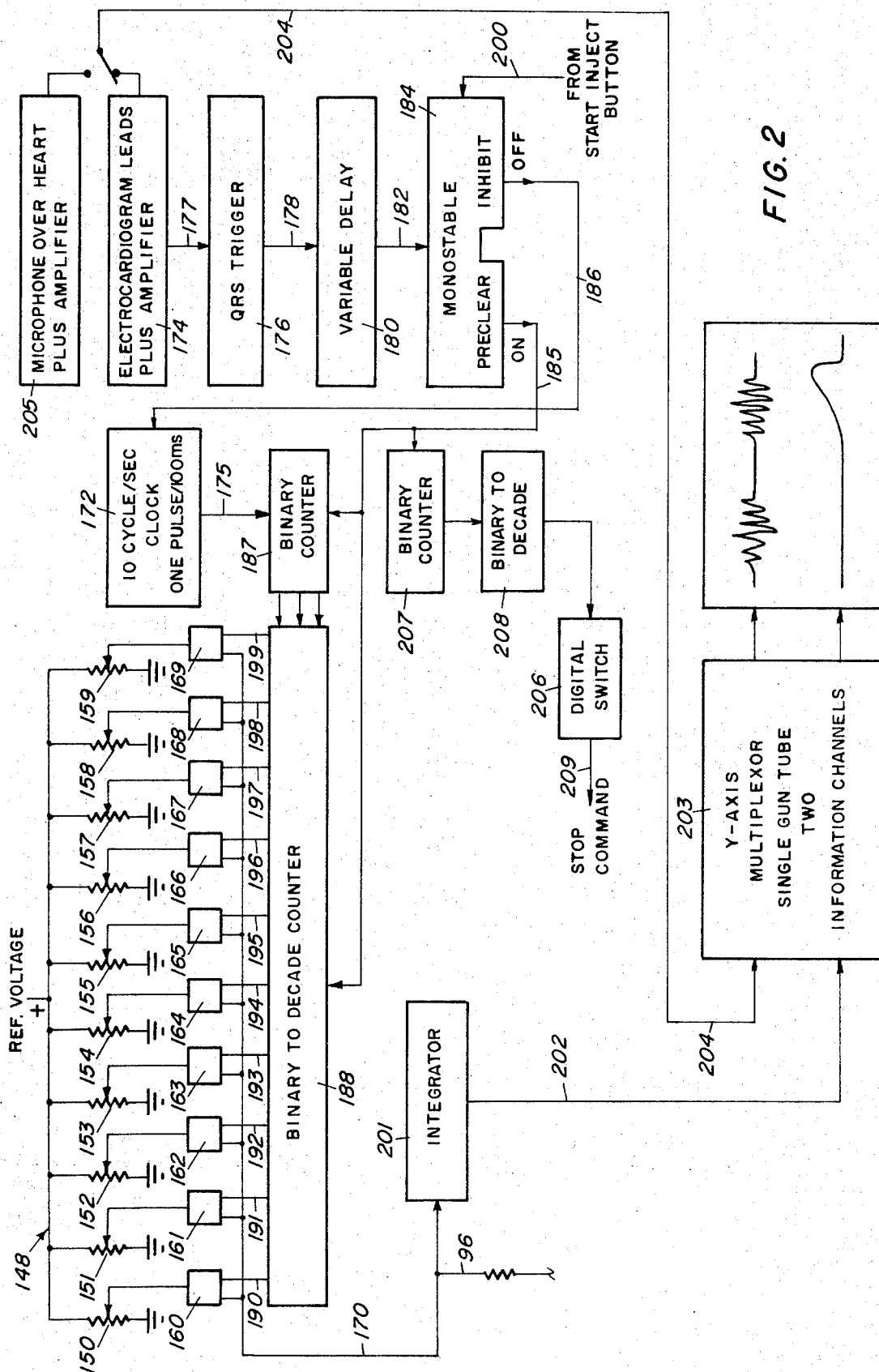
[57] **ABSTRACT**

An angiographic injector control system for delivering a controlled volume of injection fluid is described. The injector has a motor driven piston for ejecting fluid from a syringe cartridge contained within a pressure jacket. The drive motor is operated in accordance with a command voltage corresponding to an incremental position of the injector piston, the command position signal also corresponding to the volume of fluid to be ejected from the cartridge. This command position voltage signal is compared to an actual position voltage to produce an error signal for operating the drive motor, whereby the syringe piston follows the position command signal. Volume selector means produce a volume signal corresponding to a desired maximum volume of fluid to be ejected; this volume signal is compared to the sum of the position command increments, producing a stop signal when the position command signal equals or exceeds the volume limit signal. Thus, the injector control system regulates the injection of fluid by sensing and controlling the position of the injector piston.

33 Claims, 6 Drawing Figures







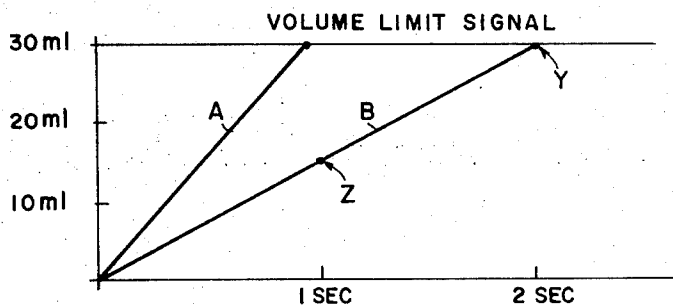
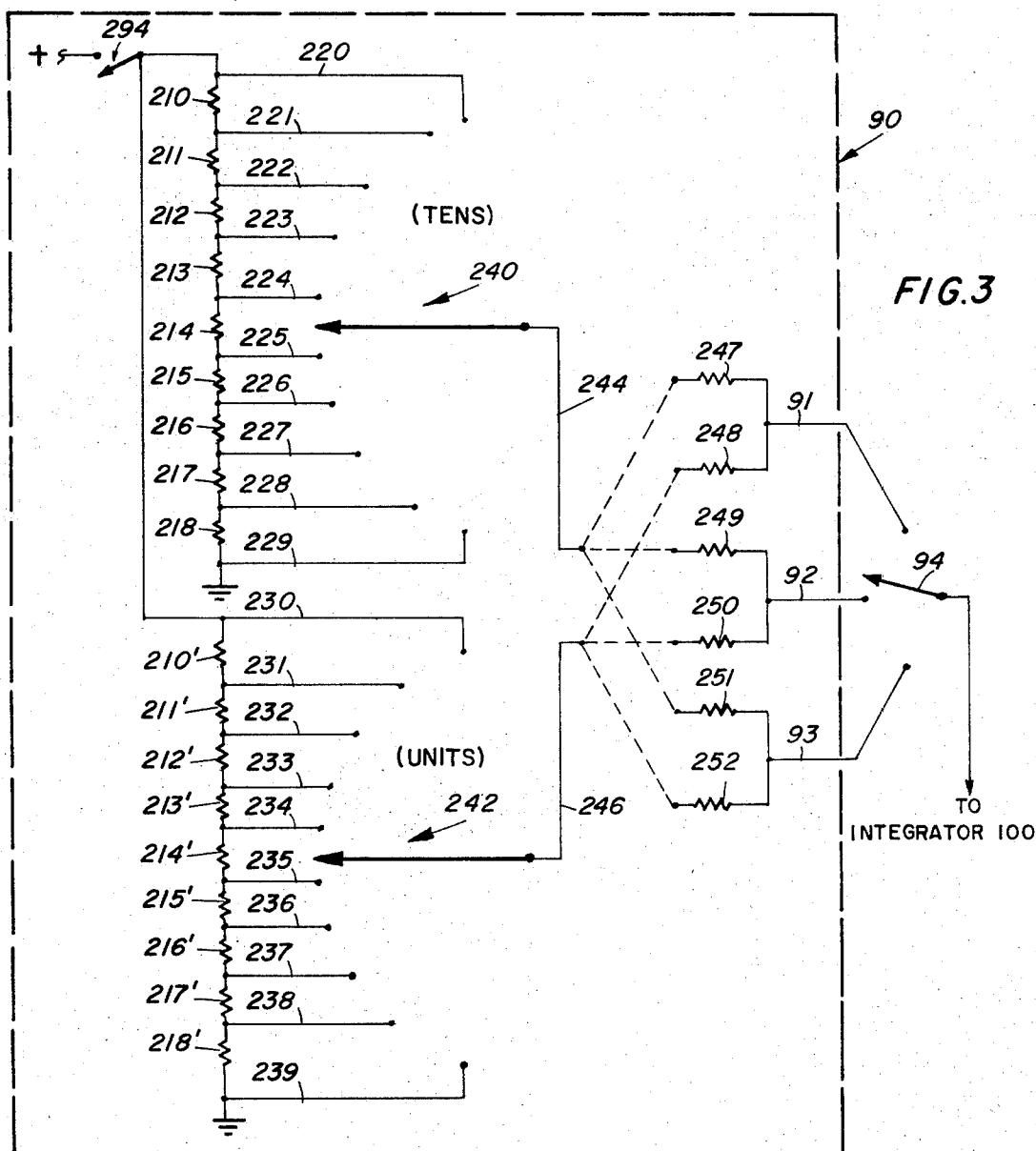
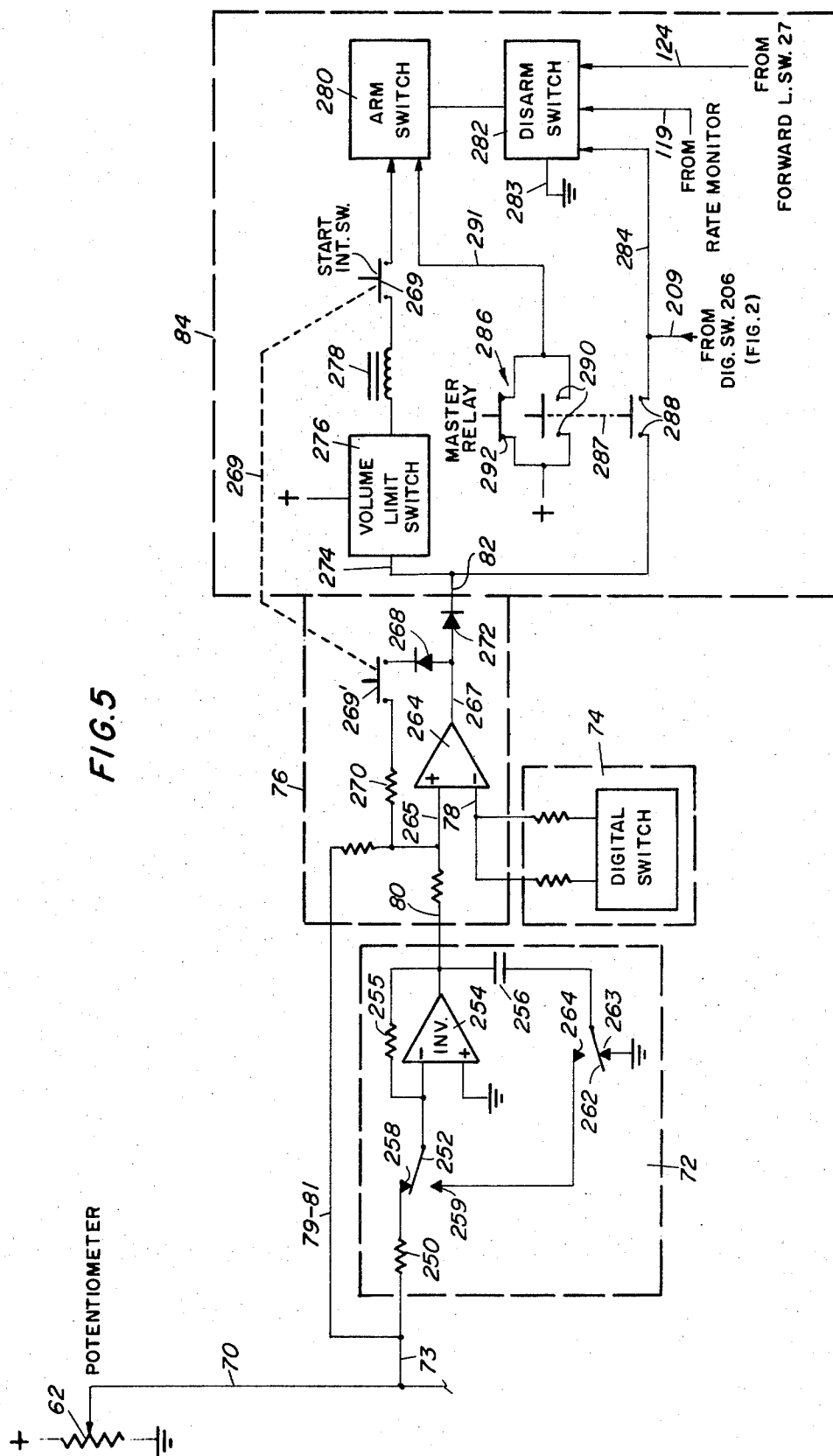
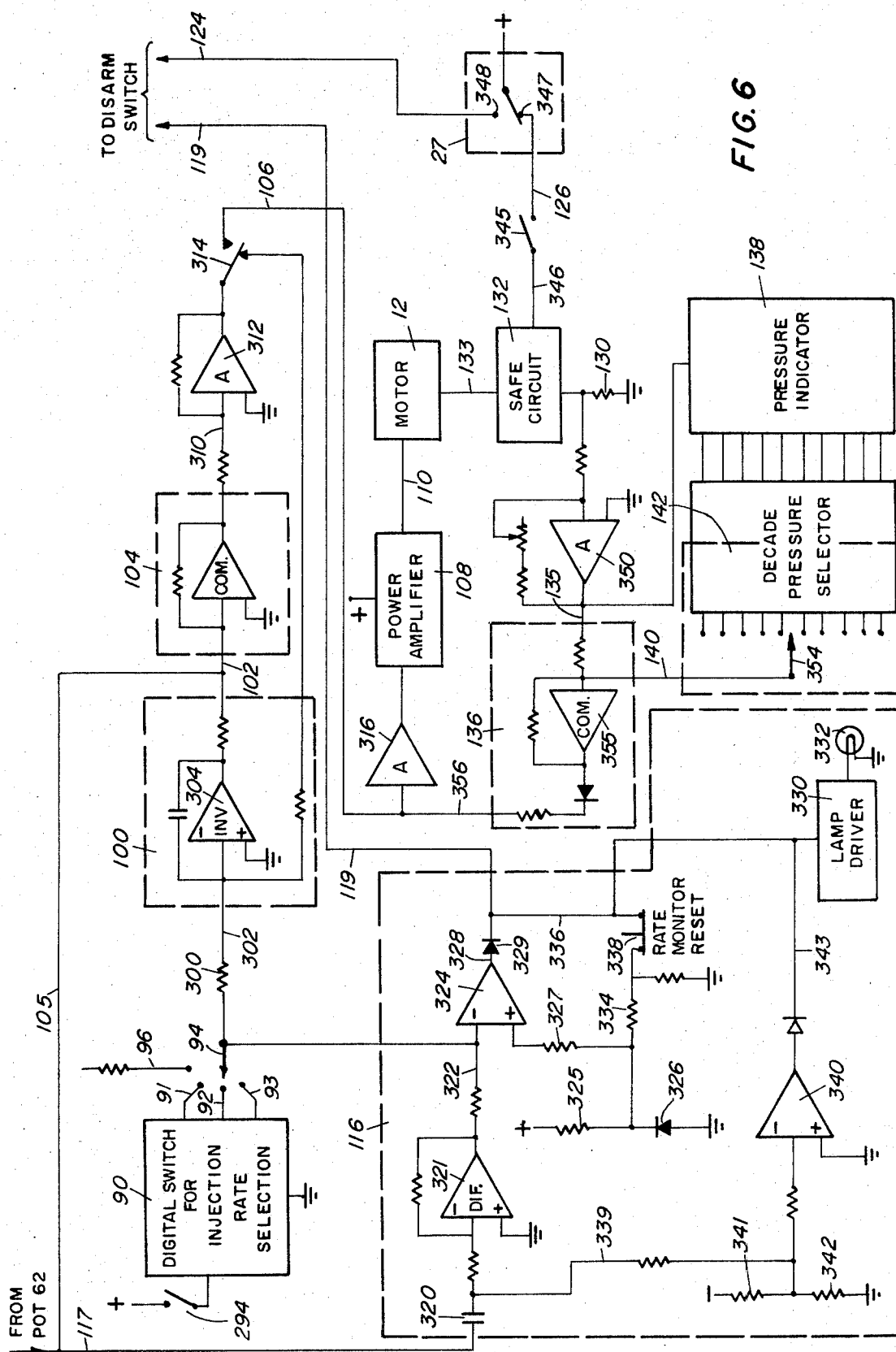


FIG. 5





ANGIOGRAPHIC INJECTOR EQUIPMENT

BACKGROUND OF THE INVENTION

This application relates, in general, to the medical science of angiography, and more particularly to the injection equipment for use therein.

Angiography is the science of producing human body radiographs outlining vascular structures by means of contrast media fluid injections into the appropriate vascular areas. The contrast media is placed in an appropriate injection apparatus and forced through a long, thin tube (catheter) in such a way that the contrast media enters the blood stream at the appropriate time and place for the radiograph or angiogram. Early injection apparatus was designed to allow the operator to preset the driving force or pressure level necessary to propel the contrast media through the catheter. However, catheters vary greatly in their resistance to contrast media flow and it was found to be extremely difficult to control injection rates by presetting an injection pressure. Thus, the prior application of Heilman et al., Ser. No. 567,643, filed July 25, 1966, issued as U.S. Pat. No. 3,623,474, on Nov. 30, 1971, and entitled Angiographic Injection Equipment, proposed the use of a rate or speed indicating feedback signal from the injector motor for comparison with a selected command rate signal to produce a rate error signal. This rate error signal was then used to control the injector motor speed, and thus the injection pressure. The result of this prior control system was that the injector pressure automatically adjusted, within the pressure range available, to match actual injection rates with selected command injection rates regardless of varying catheter resistances; if increased flow resistance tended to slow the motor, the speed sensing mechanism would produce a larger error signal in an attempt to speed up the motor. This, in turn, increased the pressure to compensate for the flow resistance, thus tending to maintain the desired rate of injection.

Although the system described in the foregoing application presents a distinct improvement in the angiographic art, there are disadvantages of using a speed, velocity, or injection rate signal to control the injection rate. It has been found that one of the most significant factors in obtaining accurate angiograms is regulation of the volume of fluid injected, and a primary disadvantage of a rate control system is the difficulty of controlling the volume of contrast media injected. If a rate feedback control mechanism is used, the volume of contrast media injected is determined by setting an injection timer since, provided the injection rate is constant and controlled, the injection volume would equal the product of the injection time and rate. However, experience has shown that even with a rate feedback mechanism it is easy to get a low injection rate during some part of the injection cycle, particularly if one uses an excessively resistive catheter. Such a catheter may require the injector to deliver more pressure than it has at its command, and as a result there is a low injection rate. When this occurs, there would also be a low injection volume, since the injection timer would stop the injection before the system could compensate for the volume lost during the low rate period.

A second disadvantage to velocity feedback is the difficulty of measuring velocity over a wide range. Rate feedback measurements normally are obtained from a

tachometer connected to the injector drive motor, with the output voltage corresponding to the velocity of fluid flow. Angiography typically requires rates from 1 to 40 milliliters per second, whereas lymphography, which is the injection of contrast media into the body's lymphatic system, may require a rate of several milliliters per hour. If both injections are to be accomplished by the same machine, the variations in the amplitude of the tachometer output signal would be exceedingly large, and extremely difficult to measure accurately. At the lower end of the scale the voltage would approach zero and be indistinguishable from noise and interference, resulting in errors and inaccuracies.

In practice, the angiographer uses connector tubing between the injector and catheter which is partially within the patient's body, and this tubing produces another problem in successful angiography, for the tubing generally has a lower bursting pressure than does a catheter. Angiographers may inadvertently rupture this connector tubing or even, in extreme circumstances, the catheter itself if they place high resistive catheters on an injector and ask for a high injection rate. As alluded to above, if the catheter prevents the flow from reaching the selected value, the rate feedback system will produce a large error signal, and the injector will respond by developing the maximum pressure possible. This maximum pressure condition can present a serious hazard to the patient.

Finally, since angiograms generally show a static X-ray photograph of some vascular structure filled with contrast media, multiple films can show the progress of contrast media as it flows through the vessel. With prior methods, however, there was no simple way to estimate the actual rate of blood flow through a particular artery in question. It is well known, of course, that as blood is passing through the heart, it has a discontinuous, or non-linear flow pattern due to valve closure. If pathology exists, there may be reverse flow through the heart valves or flow from one chamber to another through a defective interchamber wall. The arterial system of the human body receives pulses of blood from the heart and immediately absorbs this output by expansion of the aorta, which is the first portion of the arterial system. The further out the arterial system blood travels, the less pulsatile both blood pressure and flow become. Blood flowing in and around the heart is synchronous with the electrocardiogram (the electrical signal that initiates the heart action) and the heart valve closure, the latter being detectable by sounds (phonocardiograms) emanating from the heart.

If, then, the injection of the contrast media can be synchronized with heart pulses, more accurate and meaningful measurements of blood flow can be obtained; for example, the distal resistance to the flow could be estimated and this information would be useful in the functional evaluation of arteriosclerosis.

SUMMARY OF THE INVENTION

It is, therefore, an object of the present invention to provide an improved method of controlling an angiographic injector, whereby reliance on rate measurements for injection control is eliminated.

A further object of the present invention is to provide an improved angiographic injector which is posi-

tion controlled to overcome the problems inherent in rate controlled devices.

Another object of the invention is the provision of a position control system for an injector, wherein a position command signal is compared to an actual position signal to provide an error signal which operates the injector, whereby a preselected volume of fluid is injected.

Still another object of the invention is to provide a position-controlled injector which will accurately inject a preselected volume of fluid in spite of variations in injection rate or pressure.

It is another object of the invention to provide a position controlled injector which is pressure and volume limited to prevent injury to the patient receiving the injection.

Another object of the invention is to provide a safe, efficient and accurate angiographic injector having a motor drive which is position controlled, the motor being energizable only when specified conditions exist.

A further object of the invention is the provision of a motor driven injector which is position controlled, the motor circuit including arm-disarm networks which provide safety interlocks responsive to volume injected, pressure of injection, overrate, and the like.

It is another object of this invention to provide an injector having pressure indicator means so that the angiographer will know how much pressure he is using with a particular catheter choice and injection setting. It is a further object of this invention to provide a control means for the angiographer to place a maximum pressure development capability on the injector.

Another object of the invention is to match contrast media flow from an injector with the blood flow of a patient receiving the injection by synchronizing the contrast media injection with the patient's heart cycles. The injection rate may be continuous, discontinuous, linear, or non-linear.

Another object of the invention is to automatically and positively disarm the mechanism once the injection has taken place to prevent inadvertent repetition of the injection cycle.

Briefly, the present invention overcomes the disadvantages of the prior art by the use of what may be termed a position control system for an angiographic injector having a motor-driven syringe plunger. The position control system utilizes a feedback voltage signal corresponding, not to the syringe plunger velocity, but to the injector syringe plunger position, this feedback signal being generated by a potentiometer mechanically driven by the syringe motor, and thus movable with the syringe plunger. Prior to injection, the actual position of the plunger is sensed and this position is used as a zero reference value for the injection, whereby an accurate measure is obtained for each in a series of injections. Independently, voltages proportional to the desired injection volume, pressure limits, and the desired rate are preset by the operator. Upon initiation of the injection, a command signal is generated which provides incremental position signals for comparison with the potentiometer position sensor. Any difference between selected and measured positions produces an error signal which is amplified and provides the motor armature current. This armature current is limited by the pressure limit voltage to

prevent the motor from building up excessive power. The potentiometer also feeds a comparator circuit for comparing actual volume injected, which is proportional to the position of the plunger, with a selected volume limit; when the limit is equalled or exceeded, the comparator produces an output which disarms the motor circuit. If the injector is operating in a single inject mode, disarming the circuit prevents further operation of the device until it is reset. A multiple inject mode is also provided which permits repetitive operation of the selected injection cycle without disarming the circuit.

In one embodiment of the invention, the position command signal may be generated by a selected direct current value; in another embodiment the command function may be variable in a selected manner to produce a variable injection. Further, the injection may be synchronized with the heart pulses of the patient receiving the injection.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects, features, and advantages of the invention will become apparent to those skilled in the art from the following description of a preferred embodiment thereof, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a block diagram of the control logic for the subject injector;

FIG. 2 is a block diagram of a variable function generator which may control the injection function of the subject injector;

FIG. 3 is a schematic diagram of a digital switch shown in FIG. 1;

FIG. 4 is a graphical representation of a volume limited injection compared to a time limited signal;

FIGS. 5 and 6 are schematic diagrams showing the injection control circuitry of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Turning now to a detailed consideration of the drawings, there is illustrated in FIG. 1 a control system for an angiographic injector wherein the operator of the injector system may select a precise volume of contrast media or equivalent material to be delivered to a patient. It will be understood that the contrast media is conventionally delivered to selected locations through a suitable catheter, where X-ray exposures are to be made at timed intervals.

Considering first the structure of an injector device, shown generally at 10, which is suitable for use with the control system to be described, it will be seen that the injector mechanism is constructed for lightness and compactness, without sacrificing the required power, and thus is driven by a direct current permanent magnet motor 12 preferably having a printed circuit armature 14. The shaft 16 of the motor is drivingly coupled to a threaded screw shaft 18 which thus rotates with the motor armature 14. Threaded engaging shaft 18 is a ball nut 20 which is prevented from rotating by pin 22, but which is free to move axially along shaft 18, the pin sliding in a guide slot 24 formed in a guide bar 26 and supported in the housing 28 of the injector 10. At the forward end of the guide slot 24 is a microswitch 27 which detects the forwardmost movement of the pin 22

and closes to provide an output signal. The microswitch function will be explained in detail in the description of the control circuitry.

The axial movement of ball nut 20 in response to rotation of the threaded shaft 18 converts the rotary motion of the motor 12 to a linear motion. Ball nut 20 is connected to a piston tube 30 which moves with the ball nut along shaft 18. The outer end of the tube is supported, during its linear motion, by an oil seal 32 secured in an opening 34 at one end of the housing 28. Piston tube 30 abuts directly against a piston head supporting member 36, which, in turn, provides mechanical support for a rubber piston cap 38. A syringe, or cartridge, 40 is mounted on the injector housing 28 by means of an internally threaded nut 42 adapted to engage external threads on the end of the housing 28. Nut 42 has a centrally located aperture 44 which receives the syringe in a seal member 46 to permit an airtight fitting on the end of the housing. A flange portion 48 is provided on the end of the syringe which faces the housing to facilitate a tight seal between the sealing members 34 and 46 when nut 42 is tightened. The other end of the syringe 40 forms a conduit 49 which is adapted for connection to a suitable catheter (not shown) through which fluid may flow for injection into a patient during operation of the injection.

The internal diameter of the syringe and the external diameter of piston 36 are selected to provide the clearance required to permit a flange edge 50 of the rubber piston cap 38 to seal the interior of the syringe. It will be apparent that different sizes of syringes will require pistons having varying diameters, but the construction of this mechanism is such that various sizes are easily connected to the injector drive mechanism. The aperture in nut 42 is sufficiently large to permit larger syringes than the one illustrated, while smaller diameter syringes with sufficiently large flanges can be used with this equipment as well. Piston member 36 in cap 38 may be driven in the forward direction (toward the right as viewed in FIG. 1) by piston tube 30 without any mechanical connections being made between the piston and the tube. This arrangement is often used where it is essential to prevent reversal of the motion of the piston. As an alternative, piston 36 may be connected to piston tube 30 by means of a screw 52 to permit both forward and reverse driving of the piston. It will be apparent that forward motion of the piston will expel fluid or any other matter within the syringe 40, such as contrast media 54. If the piston is attached to the piston tube 30, reverse driving can be used to fill the syringe with the desired amount of contrast material while the syringe is attached to the injector drive mechanism. To this end, a suitable motor reversing switch (not shown) may be provided in the control circuits to be shown.

The broken-away portion of motor 12 illustrates, in addition to the armature 14, the arrangement of the permanent magnet 56. In operation, direct current is commutated to the armature conductors, and the resultant alternating magnetic field interacts with the stationary magnetic field of the permanent magnet to produce the torque on shaft 16. The use of a printed circuit armature permanent magnetic torque motor allows for a maximum power for a minimum size and makes practical a hand-held injector much smaller than conventional electro-mechanical injectors.

A gear train consisting of a first gear 58 mounted on motor shaft 16 and a corresponding gear 60 drives a potentiometer 62 to provide a direct measurement of shaft rotation, and thus of the location of ball nut 20. Since the potentiometer is mechanically geared to the drive train of the injector via gears 58 and 60, and the syringe is mechanically connected to the ball nut which is driven by the drive shaft of the motor, the voltage appearing on the wiper arm of potentiometer 62 will correspond to the plunger position. When an injection is to take place, the voltage level representing the actual position of the piston plunger is sensed and registered in an initial position memory circuit 72 through lines 70 and 73. The memory circuit 72 acts as a zero reference for any subsequent injection so that a selected volume can be injected from any starting point of the syringe plunger, the starting point being represented by the existing potentiometer output. This memory circuit permits a selected volume to be injected upon demand, without requiring the circuit to start from the beginning each time an injection cycle is required.

The desired volume for the injection is set in an injection volume selection unit 74 and a corresponding signal is applied to a volume comparator 76 in the form of a volume reference signal on line 78. The voltage representing the position of the potentiometer 62 at the start of an injection is also applied to the comparator 76 in the form of an output on line 80 from the memory circuit 72. The memory voltage signal plus the selected volume signal, when summed in the comparator 76 provide a target position signal which corresponds to the location of the injector plunger after it has moved from its starting location and injected the selected volume of fluid. The incremental movements of the potentiometer which correspond to the injection of contrast media, and thus to rotation of the syringe drive motor, are also fed into the comparator 76 by way of lines 70, 73, 79 and 81. When the signal level received from the potentiometer, or the sum of the position increments of the syringe plunger movement, is equal to or greater than the desired volume signal selected on line 78 plus the memory signal, the comparator 76 produces an output on line 82. This output signal indicates that the plunger has moved from its initial position sufficiently far to inject the selected volume of fluid; therefore, the output is fed by way of line 82 to an automatic arm-disarm circuit 84 to terminate the injection. By making this control circuit sensitive to position rather than to a rate of fluid flow, it is assured that the desired volume of contrast media is ejected from the syringe even if the desired injection rate is not achieved, or is only partially achieved.

Logic circuitry for controlling and monitoring the rate of injection is also shown in FIG. 1, this circuitry serving to provide a command function for the injector motor so that the injection will at least tend to take place at a preselected rate, it being understood that the starting and stopping functions of the device are regulated by a volume, or position, control. The logic circuitry, which is shown in detail in FIG. 3, includes a digital switch 90 with outputs 91, 92 and 93 which may be selected by switch 94 to provide a desired rate signal. The digital switch illustrated herein produces a direct current voltage of desired level, which voltage corresponds to the desired rate of injection, for example, in cubic centimeters per unit time. It has also been

found desirable, on occasion, to modify the rate of injection during the course of an injection cycle, and to this end an additional line 96 is shown for selector switch 94. Line 96, as will be explained, may be supplied with a selectively variable voltage function which, when selected, will cause the drive motor to follow a corresponding rate function. If desired, this function may be synchronized with the heart beat of the patient receiving the injection, thereby providing further control over the injection, as is described in detail in FIG. 2. In any event, the injection control system is capable of operating with any constant rate or variable rate command function selected, with the successful completion of the injection being dependent on the movement of the plunger from one position to the next, rather than on the rate at which the piston moves and the fluid is injected.

The function selected by selector switch 94 is fed into an integrator 100 to produce a position command signal which is to be followed by the syringe motor. The integrator 100 integrates the function selected by switch 94 and produces the position command signal on line 102. In the case of a d.c. voltage function, the output of the integrator will be a negative-going ramp, while a variable function will produce a more complex signal. The output from the integrator is fed to a position comparator 104, this output providing a position command function for the injector plunger for each instant in time. A second signal is fed to the comparator from the potentiometer 62 through lines 70 and 105, the signal on line 105 corresponding to the actual instantaneous position of the injector plunger. When the two input signals to comparator 104 are equal, the syringe plunger is at the location dictated by the command signal; when the two signals are not equal, the position comparator 104 produces an error voltage on line 106 which is proportional to the difference between the two incoming signals. The error voltage on line 106 is fed into a power amplifier 108 which provides a corresponding armature current by way of line 110 to motor 12 to either speed up or slow down the motor.

It will be seen that if the motion of the syringe plunger is impeded during an injection cycle, the drive motor can be slowed, causing the actual position of the motor (plunger) to fall behind that which is dictated by the command signal. A large error signal can then be generated, increasing the motor torque and the pressure of the injection. If the flow impedance is momentary, its release will cause the motor to speed up in an attempt to "catch up" to the command signal; if the impedance is not released, the error signal will continue to increase. Either condition, if allowed to exist for an appreciable length of time, can result in serious injury to the patient, and thus the present system provides several safety systems. An overrate sensitive network responds to sudden increases in motor speed to shut off the injector if the speed increases outside predetermined limits, the network providing an offset to accommodate normal transient variations. Similarly, a settable pressure limit network responds to the injector pressure to modulate, and thus limit, the motor armature current, thereby effectively preventing excessive pressure conditions.

The overrate sensitive network includes a rate monitor circuit 116 which receives the output from the

potentiometer 62 by way of lines 70, 79 and 117 and modifies it for comparison with an input on line 118 which corresponds to the selected rate of the injection. When the input on line 117 is appreciably larger than the selected command rate value on line 118, the rate monitor circuit 116 will trigger the arm-disarm circuit 84 through line 119 and terminate the injection. A suitable difference between the actual rate on line 117 and the desired rate on line 118 is required before the injector will be disarmed so that normal transient conditions will be ignored and the circuit will operate upon failure of the equipment, or in emergency situations.

As mentioned above, microswitch 27 detects the forwardmost position of the syringe plunger. When all of the contrast media 54 has been injected and the plunger reaches this position, a signal from the microswitch 27 is generated on line 124 which triggers the arm-disarm circuit 84 to positively terminate the injection and prevent further operation of the system.

To monitor pressure conditions in the injector, a sampling resistance 130 is connected in series with a safe circuit 132 in the armature circuit of motor 12 by way of line 133. The current through this resistor establishes a voltage proportional to the motor current which, in turn, is proportional to injection pressure when a torque motor is used. Under normal operating conditions, safe circuit 132 which may, for example, be a power transistor in series with the armature circuit, is a short circuit (i.e., is closed) and allows the motor armature current to pass through resistor 130 to ground to establish the sampling voltage. Since the voltage across resistor 130 is proportional to the actual injection pressure, this voltage is referenced by way of lines 134 and 135 to a pressure comparator 136 and by way of lines 134 and 137 to a pressure indicator 138. The pressure indicator 138 preferably comprises a plurality of lamps corresponding to various pressure levels, with the pressure voltage being operative to illuminate a lamp corresponding to the pressure at which the motor is running. The pressure comparator 136 compares the actual pressure of the injector with a selected pressure limit voltage on line 140 which is derived from a pressure selector 142. Selector 142 permits the operator to preset a maximum injector pressure, and if the pressure signal on line 135 exceeds the limit voltage on line 140, the pressure comparator 136 provides an error voltage on line 144 corresponding to the magnitude of this difference. The pressure limit error voltage on line 144 is fed to the input of the motor power amplifier in opposition to any position comparator signal that would tend to increase the motor current. Thus, the pressure comparator limits the injector pressure to the preselected value by preventing the motor armature current from increasing.

If it is desired to provide a capability in the present injector for operating at a controlled, variable rate during the course of a single injection, a suitable function generator may be provided, as indicated above. One such function generator is illustrated in FIG. 2 as providing an output of selectable waveform on line 96.

Turning now to FIG. 2, a function generator 148 consists of ten manually settable sliding potentiometers 150 - 159, each connected between a positive reference voltage and ground. The wiper arm of each potentiometer is connected through a corresponding

one of electronic switches 160 - 169 to a common output line 170, the switches being normally open. A clock circuit 172 closes successive ones of switches 160 - 169 in a sequential fashion, each switch feeding its particular selected potentiometer voltage to the common line for a predetermined period of time, in this example, 100 milliseconds. Capacitance is generally added to common line 170 to get a smoothing effect during sequencing. As the clock sweeps the switches 160 - 169, closing each in turn, a stepped output voltage appears on line 170, each step corresponding in amplitude to the selected value of the connected potentiometer. It will be seen that if each potentiometer is set at the same level, a selected d.c. voltage will appear on the line; by setting the potentiometers at different values, any desired waveform may be generated.

In some circumstances it may be desired to correlate the generation of the command function with the heart pulses of the patient, and for this purpose each cycle of the waveform may be triggered by a signal derived from an electrocardiogram 174 in the following manner. The waveform corresponding to the heartbeat is fed from the electrocardiogram 174 to a QRS trigger 176 by way of line 177. The QRS trigger will trigger the injection at a selected slope along the electrocardiogram waveform by producing a triggering pulse which is conducted through line 178 to a variable delay 180 which will delay the triggering pulse with the contraction of the patient's heart. This delay differs with the individual involved so that different intervals will be selected for different patients. Once the triggering pulse passes through the variable delay, it is conducted through line 182 to a monostable circuit 184 having two outputs only one of which is on at a particular instant. In the normal mode of operation for the monostable circuit 184 output line 185 is in the on state and output line 186 is off. When output line 185 is on, a binary counter 187 is energized to receive and count pulses received from clock 172; the off condition of line 186 permits the clock to run freely. The counter 187 drives a binary to decade counter 188 which produces output signals sequentially on lines 190 - 199 to energize each of switches 160 - 169 in turn. When the output line 185 is in the off state, the binary counter 187 and the decade counter 188 are de-energized and automatically reset. At the start of an injection, the inject button is pushed and a start signal is fed into the monostable circuit through line 200 to switch circuit 184 to its unstable state. This turns output line 185 off, resetting the counters, and turns output line 186 on, which inhibits the clock from running. In other words, the pulse on line 200 is a resetting pulse which sets all the counter values to zero. A second pulse is then needed to trigger the monostable circuit back into its normal operating mode and this pulse is provided by the QRS trigger 176. In this manner, it can be seen that the electrocardiogram triggers the generation of the injection command function waveform. The injection function can be varied simply by varying the values of the potentiometer 150 - 159 and can be triggered in synchronism with the electrocardiogram. This output function is conducted through lines 170 and 96 to one of the terminals of selection switch 94.

The synchronizing of the injection with the electrocardiogram can be viewed graphically by feeding the

function output on line 170 through an integrator 201 where the function is integrated and conducted by way of line 202 into one of two information channels on a multiplexer single gun display tube 203. The waveform of the electrocardiogram may be fed to the second information channel of tube 203 by way of line 204, this input being derived either directly from the electrocardiogram output or from a microphone 205 which can be placed over the patient's heart.

Although it is usual to provide only a single injection of a preselected quantity of contrast media, it may be desirable to provide, instead, a series of injections, for example, of lesser quantities of fluid, in synchronism with successive heartbeats. The present invention provides such operation by a digital switch 206, which is settable to a selected number of successive injections. The switch is connected through a binary counter 207 and a binary to decade counter 208 which may be identical to units 187 and 188. If, for example, three injections are desired, the digital switch 206 is set to the number 3 and the injection cycle will repeat itself with each successive heartbeat until the number of injections totals three. The digital switch 206 will then produce a stop command signal on line 209 which is fed to the disarm circuit 84, simulating a volume limit signal and turning the injector off.

The function generator described and illustrated is, then, a means to selectively produce a linear, a non-linear, or a discontinuous flow rate command signal which may be synchronized with the patient's electrocardiogram. The injection would be discontinuous if one of the potentiometers 150 - 159 were set at zero and adjacent potentiometers had a flow setting.

Turning now to a more detailed consideration of the control circuitry of the present invention, FIG. 3 is illustrative of a preferred form of the digital switch 90 which produces the constant function for the injection rate selection. A stable reference voltage is divided into nine equal parts by a first series of precision resistors 210 - 218 connected between the reference and ground. The first divider provides a voltage corresponding to a tens value; a second divider comprising resistors 210' - 218' is used for units, and is similarly constructed. A precise digitized voltage for a desired number of tens or units may be chosen by the operator by selecting the desired detented position 220 - 229 and 230 - 239 on numbered digital switches. The selection is made by positioning arms 240 and 242, respectively, in the appropriate position. The tens and units outputs from arms 240 and 242 are conducted through lines 244 and 246, respectively, through pairs of scaling resistors 247 - 248, 249 - 250, and 251 - 252 which appropriately scale the value of the voltage to a flow rate per second, per minute, or per hour. The selection of appropriate scales can then be made by arm 94 by connecting it to one of the output lines 91, 92 or 93 to obtain a d.c. voltage level corresponding to a desired flow of injection fluid, for example, in milliliters per unit time.

Although the digital switch 90 provides a rate function as a command for the operation of the syringe, this rate function in the present system serves primarily as a position target for the drive motor operation, since no time limit is set for regulating the duration of the injection. Thus, the rate signal provided by switch 90 is es-

essentially an incremental position signal, commanding the motor to shift the position of the syringe piston a specified distance (volume) per unit of time. The distinction between this position control and the rate control of the prior art is illustrated in the graph of FIG. 4, wherein the volume of fluid injected is plotted along the ordinate axis and the injection time is plotted along the abscissa. Line A represents a selected injection rate of 30 milliliters per second. If the injection were time limited to, e.g., 1 second, the desired volume would be injected if no unexpected flow resistance were encountered, and the prior art devices could function properly. If, however, the operator had selected a more restrictive catheter, if unexpected resistance to flow were encountered, or if a catheter were used that could withstand only limited pressure, the actual flow rate might be considerably below the selected value, as indicated by line B. Safety factors such as pressure limiting circuits of the type disclosed herein might also reduce the flow by limiting the allowable pressure that could be developed by the motor. If under these circumstances the prior art rate control systems were used, a time limit of one second would result in a considerable reduction in the amount of fluid actually injected; as indicated by line B of FIG. 4, the actual injection might be only 15 milliliters. On the other hand, the present invention provides injections which are volume limited rather than time limited so that the probability of a satisfactory angiogram is much improved due to the fact that the desired volume of contrast media is injected even though the rate might be less than desired. In the graph of FIG. 4, Y represents the end of an injection which is volume limited, while point Z represents a time limited injection having an underrate injection due to a restrictive catheter or a catheter that could withstand only limited pressure.

FIG. 5 and FIG. 6 show schematically the circuit components of the control system shown in FIG. 1. In FIG. 5, the signal on line 73 is a voltage which is derived from potentiometer 62, and thus corresponds to the position of the injector plunger. Under non-inject conditions, the voltage from the potentiometer 62 is fed through line 73 to the position memory circuit 72, which includes resistor 250 and a switch 252 which is one of the five switches controlled by the master relay to be described. All of the switches denoted as being operable by the master relay will be shown in their non-inject mode, and when injection is to take place, the master relay will switch all five of these controlled switches to the opposite position, or their inject mode. Therefore, during non-inject conditions the voltage from the potentiometer travels through line 73, resistor 250, switch 252 and an inverting amplifier 254 having a bypass resistor 255 to charge a memory capacitor 256. This capacitor thus takes on a charge proportional to the voltage produced by the potentiometer so that each injection cycle will be measured from the actual position of the injector. Note that when the injection is to take place the master relay will move switch 252 from contact point 258 to contact point 259. The capacitor 256 is connected to ground through a relay contact switch 262, 263 during non-injection modes, allowing the capacitor to accumulate a charge. However, switch 262 will move from contact point 263 to contact point 264 when the inject mode begins,

thereby completing a bypass around amplifier 254 by way of the capacitor. Therefore, during injection, a completely closed loop exists involving the amplifying inverter 254, the memory capacitor 256, switch 262, and switch 252. During the inject mode, the reference voltage from the potentiometer is no longer applied to the memory capacitor 256 and normally the capacitor 256 would begin to discharge. However, should the capacitor begin to discharge, say by 3 volts, this change would be automatically fed back through switches 262 and 252 to the input of the inverter 254 where the -3 volt input would be inverted into a +3 volt output and fed back into the capacitor 256. The initial position memory circuit 72 will, therefore, memorize (retain) the voltage from the potentiometer corresponding to the position of the injector plunger immediately prior to the start of an injection. This initial position voltage is added to any incremental position changes required by the selected volume of fluid to be injected so that the final position of the injector will be that which is required to inject the selected volume. This initial position voltage memorized by the circuit 72 is fed into the comparator 76 by way of line 80 and the actual position voltage corresponding to incremental movements of the piston, and thus, of the potentiometer 62 during the injection is fed to the comparator 76 through lines 79 and 81. The actual position voltage is applied to one input of a summing amplifier 264 through line 265, the signal appearing at the summing amplifier as a positive voltage. The output of the digital switch 74, by which the operator may select the desired volume to be injected, is connected to the second input of the summing amplifier by line 78, this voltage appearing at the summing amplifier as a negative voltage. When the algebraic total of the signal voltages applied to the summing amplifier 264 goes positive, indicating that the position of the plunger has reached the position within the syringe which requires injection of the selected volume of fluid, an output is produced on line 267 which pulses the disarm circuit 84 and terminates the injection. The digital switch 74 may be of the type shown in FIG. 3 for the injection rate selection.

Termination of the injection is accomplished by the volume limit circuit as follows. The pulse output from the comparator circuit 76 is fed through line 267, diode 272 and line 82 into the automatic arm-disarm circuit 84. Note that when the injection has been instigated by depressing the start switch pushbutton 269, a clamp is placed across the summing amplifier 264 by way of diode 268, switch contact 269' and resistor 270. The clamp formed by these components prevents recycling of the injector after the volume limit has been reached. Since only a positive voltage on line 267 will cause diode 272 to conduct and operate circuit 84, any slight fluctuation in the positive voltage on line 265 could cause line 267 to once again go negative, remove the terminate signal and recycle the injector. Therefore, when a positive voltage appears on line 267, the comparator is clamped by feeding the signal back through diode 268, pushbutton switch contact 269', and resistor 270 to the input of the summing amplifier 264. This causes the input on line 265 to become more positive, thereby insuring that the summing amplifier output on line 267 will remain positive and keep the arm-disarm circuit 84 energized until such a time as the start injection button 269 has been released.

FIG. 5 also shows the schematic representation of the automatic arm-disarm circuit 84. As shown, the output signal on line 82 from the volume limit comparator 76 is fed through line 274 to volume limit switch 276 which opens upon reception of the signal to shut off the motor. Switch 276 is connected in series with the master relay 278 which controls five relay contacts in the control circuitry, and in series with normally open contact 269" of the start injection button. An arm switch 280, which typically is an SCR, is also connected in series with the master relay, and requires a pulse input to fire it into conduction. Once the arm switch 280 has been pulsed, it will continue to conduct until the circuit is disarmed; i.e., until the ground connection for the arm circuit is opened. The resetting of arm switch 280 to its off, or non-conductive, condition is accomplished by disarm switch 282, also in series with the master relay and the arm switch. The disarm switch 282 typically is a two transistor switch which is normally closed (conductive) but which opens when a signal input is present on any one of its input lines 284, 119, or 124. The disarm switch 282 resets the arm switch 280 to its non-conductive state by opening the series circuit and removing the ground connection 283 from the SCR.

The present control system provides a capability for either single cycle operation, where the start switch is closed, a selected volume of fluid is injected, and the system shuts down, or for a multiple cycle mode, where the system automatically recycles to inject repeatedly the selected volume. The single or multiple modes may be selected by operating one or the other of the mode pushbuttons 286 or 287. When a single injection is desired, the single mode button 287 is depressed, closing its corresponding contacts 288 and 290, while leaving contacts 292 of the multiple mode switch 286 open. Closure of contact 290 applies a positive bias voltage to arm switch 280 by way of line 291 so that this latter switch is enabled. Thereafter, closure of the start button 269 will apply a further positive bias to the second input of the arm switch 280 form the volume limit switch 276, and through master relay 278, causing the arm switch to close. This completes the circuit through the master relay to energize that relay and start the injector operation. One arm switch 280 is closed, the volume limit switch and the start switch may both be opened to stop the injection (by de-energizing relay 278) without disarming the circuit.

Closure of contact 288 of the single mode pushbutton 287 completes a circuit from the volume comparator circuit 76 by way of lines 82 and 284 to the disarm switch 282, whereby upon receipt of an output from the volume comparator circuit both the volume limit switch 276 and the disarm switch 282 are opened. This shuts down the injector and prevents it from recycling even if switch 276 should reclose.

If a series of injections is required, the multiple mode switch 286 is depressed, closing its contacts 292, while leaving switch 287 open. Again, this provides a positive bias to arm switch 280 through line 291, whereby switch 280 may be closed to permit energization of master relay 278 and consequent operation of the injector. As before, when the selected volume has been injected, comparator 76 will produce an output on line 82 which will open the volume limit switch 276; however, this signal will not disarm the circuit because con-

tacts 288 are open. When switch 276 opens, master relay 278 opens to stop the injection, memory circuit 72 acquires a voltage equal to the voltage on potentiometer 62, and comparator 76 again sees a voltage difference between the potentiometer and the volume selector 74. This removes the output from comparator 76, switch 276 closes, relay 278 is energized, and a second injection cycle occurs. This cycle recurs under these conditions until the start switch 269 is released, or until some other signal disarms the circuit. Such a signal might be provided by the forward limit switch 27, which produces a signal on line 124 when the syringe plunger reaches its forward limit, by the rate monitor circuit 116, or by a suitable counter circuit which may be provided to limit the number of cycles. Such a counter is illustrated in FIG. 2 in conjunction with the electrocardiogram synchronizing circuit, where counter 207 counts the number of cycles initiated by the synchronizing circuit. The counter operates in conjunction with a digital switch 206 to produce an output signal on line 209 when a selected number of cycles have occurred. As shown in FIG. 5, the signal on line 206 is applied directly to the disarm circuit 282 so that when the last cycle is complete, a simulated volume limit signal will be applied to the disarm circuit, disabling circuit 84.

The schematic of FIG. 6 shows the circuitry for the pressure and the position control portions of the present system. The digital switch 90 for injection rate selection with its outputs 91, 92 and 93 is once again shown, along with its positive bias supply which is connected to the resistor arrays of the switch by way of contact 294 of the master relay 278. This contact supplies the bias voltage which provides the selected injection rate signal on one of the outputs 91, 92 or 93 when injection is initiated by closing start switch 269 to energize relay 278. Also shown is lead 96 which may carry a variable waveform such as the electrocardiogram function described above. Switch 94 may be operated to select either a constant or a variable rate function from one of the four output lines 91, 92, 93 or 96. The injection rate function selected by switch 94 is conducted through a resistor 300 into the integrator circuit 100 by way of line 302. The integrator circuit 100 consists of an integrating amplifier and shunt capacitor 304 which produces a position command signal by integrating the function received on line 302. This position command signal, which appears on output line 102, is a negative going signal; in the case of a d.c. input voltage, the output signal will be a linear ramp waveform, while a variable input will produce a more complex output. The negative going voltage on line 102 is then summed with a positive going voltage from potentiometer 62 by way of line 105.

When the summation of the voltages on lines 102 and 105 is negative, it indicates that the actual position of the syringe piston is lagging behind the command position, and the comparator 104 produces an output in the form of an error voltage on line 310. This error voltage is conducted through an amplifying unit 312, a switch contact 314 of the master relay 278 (FIG. 5), and line 106 to a high gain amplifier 316 and the power amplifier 108. Although switch 314 is shown in its lower, or non-inject condition, it will be understood that the switch will move to the upper contact to

complete the circuit through line 106 when injection occurs. The amplified error voltage is then used to control the power amplifier and thereby regulate the amplitude of the armature current fed to the motor 12 by way of line 110. If, however, the sum of the voltages on lines 102 and 105 is positive, a positive input will exist at the input terminal of comparator 104 and no error voltage will be produced; therefore, no armature current will be conducted to motor 12 through the amplifying unit. By the use of high gain amplifiers, the motor will respond to very small error signals, and the syringe plunger will closely follow the position signal generated by the integrator 100. This method of controlling the motor insures that the actual position of the injector plunger is slightly behind the desired position selected by the command signal on line 102.

As has been explained, it occasionally happens that a large error signal is generated in the system, because back pressure in the injector has severely slowed the motor or even stalled it, because of some fault in the control system, or for some other reason. If the error is large enough, it will cause a very high armature current to flow in the motor, thereby greatly increasing the pressure developed by the injector. If this condition is relieved suddenly, the motor will tend, in the present system, to speed up well above the selected rate value in order to "catch up" to the command position being generated, instead of merely resuming the command rate, as would occur in rate controlled systems. If care is not taken, this excess speed can cause an excessive flow of contrast media, and endanger the patient; thus, the present system provides the overrate monitoring circuit 116 shown in FIG. 6. As illustrated, this circuit receives the potentiometer voltage carried on line 117 where the voltage is fed to a differentiator 320 in which the incremental position signal is converted into a rate signal. The differentiated signal is inverted and amplified in amplifier 321, so that a negative going signal is produced at output line 322. This rate signal is a d.c. level which represents the actual rate at which the motor is moving the piston, and it may be compared to the desired rate signal level selected by digital switches 90 and 94 and conducted through line 118 to one input of a comparator 324. An offset is provided so that the actual and selected rates may differ by a predetermined amount. This limited overrate is provided by means of a predetermined voltage which is applied to the second input of comparator 324. This offset voltage is produced by a voltage divider consisting of a resistor 325 and a diode 326, the junction of which is connected to the second input of the comparator through a resistor 327. When the difference between the actual and selected injection rates equals or exceeds the offset voltage, the comparator produces an output signal on line 328 which is fed through a diode 329 and through line 119 to the disarm switch 282 (FIG. 5) to disable the injector. This offset insures that normal fluctuations in motor (and injector) speed will not cause the comparator to disarm the injector circuits.

The output of the comparator 324 is also applied to a lamp driver 330 which serves to turn indicator lamp 332 on in the event of an overrate condition. When the lamp driver is on, the output of comparator 324 is fed back to its input through diode 329, line 336, a normally closed rate monitor reset button 338, line 334,

and resistor 327 to hold the comparator output positive. This will keep the driver, and thus the lamp, turned on until the feedback path is opened by depressing button 338.

A second safety factor is included in the rate monitoring circuit 116 and is designed to detect failure of the potentiometer 62. In connecting the position sensing potentiometer to the injector, a minimum voltage output for the potentiometer is established when the syringe plunger is fully withdrawn from the syringe barrel. As an example, a minimum setting of 250 millivolts may be selected. If, then, the output of the potentiometer ever drops substantially below this value, it is an indication that the potentiometer has failed. Such an occurrence during an injection would endanger a patient, for it would result in a very high error signal at comparator 104. Because of the offset discussed above, the overrate circuit would not respond immediately to such a fault in the system, although as the motor speed increased under this condition it would eventually terminate the injection. To provide a quicker response to this condition, the potentiometer voltage is applied by way of lines 117 and 339 to a comparator 340. A reference voltage derived from a voltage divider 341, 342 is also applied to the comparator, this reference source providing a negative voltage of approximately 200 millivolts. The summation of the inputs from the potentiometer and the reference voltage divider would always be positive during non-failure conditions, since the potentiometer would provide a positive voltage in excess of 250 millivolts. Therefore, only upon failure of the potentiometer could the summation of the voltages at the comparator become negative, and when this occurs, comparator 340 immediately produces an output on line 343 which is conducted by way of lines 336 and 119 to the disarm switch 282.

Also illustrated in FIG. 6 are the pressure responsive circuits 136, 138 and 142. As mentioned previously, the armature current of motor 12 flows from power amplifier 108, through line 110, motor 12, line 133, safe circuit 130 and sampling resistor 132 to ground. This current is proportional to the torque of motor 12 and thus is proportional to the pressure being exerted by the motor on the injection fluid. This current can be conducted through the safe circuit 132, which may typically be a power transistor, only when the start inject button 269 has been closed to energize the master relay 278 which in turn closes its corresponding contact 345. When switch 345 is closed, line 346 is connected to a source of supply by way of line 126 and the normally closed contact 347 of the forward motion limit switch 27 (FIG. 1). This latter contact remains closed until the syringe plunger reaches the end of its path, at which time contact 347 is opened and contact 348 is closed. When the latter contact closes, a positive voltage is applied by way of line 124 to operate the disarm switch 282 and terminate the injection. Closure of master relay contact 345 causes the safe circuit to conduct, whereby the motor armature circuit is closed, and the motor can be operated; de-energization of the master relay, then, will serve to disable the motor by opening safe circuit 132.

The motor current passing through resistor 130 develops a voltage across the resistor which is propor-

tional to the pressure developed by the injector; this measured pressure signal is fed through amplifier 350 where the signal is increased before it is fed into the pressure comparator 136 by way of line 135. The second input to the comparator 136 is provided by way of line 140 from pressure limit selector 142. The pressure selector 142 may be similar to the selectors described previously, having a movable arm 354 which is connected to any one of 10 outputs from a resistive voltage divider. In this case, each output voltage corresponds to a specific pressure, and the selected voltage is also applied to the input of comparator 136. The actual pressure signal on line 135 is negative since amplifier 350 also has inverted the signal, while the pressure limit signal on line 140 is positive; these two signals are summed at comparator 136. When the sum of the two signals is negative, which indicates that the motor is operating at a pressure higher than that permitted by selector 142, an amplifier 355 in the comparator will produce an amplified error signal output indicating the motor is operating over maximum pressure. Since the comparator 355 also inverts the signal, a positive output will be produced on line 356 which is proportional to the amplitude of the overpressure condition.

The pressure limit signal on line 356 is then used to limit the pressure buildup in the injector by limiting the amplitude of the position error signal on line 106, which signal, as has been described, regulates the motor power amplifier. This limiting effect is obtained by feeding the positive pressure limit signal to the input of amplifier 316 in common with the negative error signal on line 106. The limit signal counteracts the position error signal and limits it to a value which will produce no more than the selected pressure in the injector, for the larger the pressure error, the larger will be the pressure limit signal.

In summary, the operation of the control circuit of the present invention under both modes of operation can be described. Prior to injection, the master relay 278 has not been energized and therefore switches 252, 262, 294, 314 and 345 are all in the position shown in the drawings. The desired injection volume is preselected in digital switch 74 while the desired maximum pressure is set in pressure selector 142. The rate function for producing a position command signal is selected by setting the digital switch 90 to the desired tens and units values, and by setting switch arm 94 to obtain the desired unit time. The single or multiple injection mode is then selected by switches 286 and 287. At this time, safe circuit 132 is an open circuit, preventing operation of the injector. If the multiple inject mode switch 286 is selected, the number of injections can be regulated by a suitable counter, such as digital switch 206 by selecting the appropriate number; if such a counter is not included in the circuit, the number of cycles is manually controlled by start button 269. Capacitor 256 in initial position memory circuit 72 is charged to the preinjection potentiometer voltage. The SCR in arm switch 280 is receiving an input through one of the two switch contacts 290 or 292 but still requires the closing of switch 269 to pulse it into conduction. Therefore, switch 280 is not armed prior to starting the injection.

When start button 269 is depressed to start the injection, the SCR in arm switch 280 is pulsed into conduction and will continue to conduct until such a time as disarm switch 282 opens and removes the ground terminal for arm switch 280. Master relay 278 is energized and shifts switches 294, 252, 262, 314 and 345 to the position opposite that which is shown in the drawings. The closing of switch 294 connects a source of supply for the injection rate selection circuit 90 while the closure of switches 252 and 262 connects capacitor 256 in a loop through inverting amplifier 254. The closing of switches 252 and 262 therefore memorizes the voltage corresponding to the initial position of the potentiometer. When switch 314 closes, it connects the output from the position comparator 104 to the power amplifier 108 controlling the motor 12, while the closing of switch 345 provides a base current for the power transistor in safe circuit 132 causing the safe circuit to close the motor armature circuit through sampling resistor 130.

When switch 294 connects the bias voltage to rate switch 90, the selected injection rate function is fed directly into integrator 304 to start the generation of the integrated position command signal. The integrator 304 produces a position command signal which is immediately and continuously compared to the potentiometer signal on line 105 by comparator 104 and when the signal on line 105 is less than the signal on line 102 the comparator 104 produces an output in the form of an error signal to the power amplifier 108. The power amplifier 108 in turn responds to this signal to modulate the armature current to the motor 12, increasing its torque to speed up the motor until the signal on line 105 balances the signal on line 102. However, to make sure that excessive pressure is not developed by motor 12 in an attempt to equalize the signals on line 105 and 102, a maximum pressure for motor operation is selected by pressure selector 142. The maximum pressure selected is then compared with a signal proportional to the pressure at which the motor is operating, the latter signal being obtained across resistor 130 by way of amplifier 350. When the pressure at which the injector is operating is slightly greater than the maximum pressure set by switch 142, an output from comparator 136 is produced which subtracts from the position comparator output on line 106 to prevent further increase of the motor pressure. The circuits will continue to function in this manner until a stop command is given.

Several conditions can exist in the injector system, any one of which can stop the injection. The first condition involves the termination of a single, successful injection involving no system malfunctions or safety failures in the equipment. In this case, the volume which is to be injected into the patient is selected by digital switch 74 and fed into comparator 78 as a reference voltage. The actual volume being injected is detected by potentiometer 62 since the position of the injector plunger is proportional to the amount of fluid displaced, and thus injected. This value is fed into comparator 76, indicating the amount of contrast media which has already been injected. When the amount of contrast media that has been injected is equal to or greater than the amount desired to be injected, the selected volume signal will become equal to or slightly

less than the measured value, and the comparator 76 produces an output on line 82 which passes through the closed switch contacts 288 and directly to the disarm switch 282, opening switch 282, removing the ground contact from the arm-disarm circuit 84, and terminating the injection.

If multiple injections are desired, switch contacts 288 will be open, inhibiting passage to the disarm switch of the comparator output on line 82 and thus requiring a different type of volume limit control. Since a pulse on line 82 cannot operate the disarm switch to disable the control circuitry during multiple injections, the pulse on line 82 will travel through line 274 to the volume limit switch 276. This also occurs during single injection although its effect is overridden by the disarming of the circuitry. When the volume limit switch 276 is pulsed, it opens and de-energizes the master relay 278 which in turn opens switches 294, 252, 262, 314 and 345. However, note that switch 280 is still armed since its ground has not been removed. Therefore, to produce multiple injections it is necessary only to hold down the start injection switch 269, and recycling will automatically take place. The first part of the recycling has already been completed since the volume limit switch has opened and caused the master relay 278 to de-energize. The master relay 278 has opened its switch contacts and switch contact 294 has removed the reference voltage from the injection rate selection switch. Switches 252 and 262 have opened and memory capacitor 256 is charging to a voltage representing the present position of the potentiometer, and switch 314 has shifted, producing a feedback pulse to reset the integrator 304. Switch 345 is open, causing safe circuit 132 to open, which action, combined with the movement of switch 314, removes all error voltages from the operating circuit of the motor 12. With switches 252 and 262 in the position shown in the drawing, the input to the comparator 264 on line 265 has been eliminated by the cancelling effect of the inverter 254, which produces a voltage equal and opposite to the potentiometer voltage. Since the value of the voltage on line 265 must be greater in magnitude than the value of the voltage on line 78 for the comparator 264 to produce an output on line 267, the disappearance of a voltage on line 265 will eliminate the output on line 267 which provides through lines 82 and 274 the pulse necessary to keep the volume limit switch 276 open. Therefore, shortly after the master relay 278 has been de-energized, the volume limit switch 276 will close once again, to energize the master relay which, in turn, will once again close the five switches 294, 252, 262, 314, and 345. Therefore, complete recycling of the control system will occur and multiple injections will continue, under normal conditions, until either switch 269 is released, the syringe limit switch is reached, or a counter such as digital switch 206 in FIG. 2 reaches the number selected therein. The digital switch 206 is shown as one means of stopping the injection after a predetermined number of injections have occurred. However, it will be obvious that a counter of any type may be placed in the circuitry which is capable of pulsing the disarm circuit after a predetermined number of injections have taken place.

It will be noted that repetitive injection cycles may also be accomplished when the injector is in the single

inject mode, merely by releasing the manual start button prior to injecting the selected volume of fluid. In this case, the master relay is de-energized by opening switch contacts 269'', again without operating the disarm switch. Therefore, when the start switch is reclosed, the cycle will be repeated in the manner described above.

The various safety factors provided in the circuits of the present invention which are also capable of terminating the injection have been described above, but may be briefly summarized as follows. The overrate circuit 116 compares the desired injection rate, which is referenced to the circuit by line 118, to the actual injection rate, which is the differentiated output from the potentiometer. An offset is constructed in the rate monitor circuit 116 so that the actual rate at which the motor is running must be a predetermined percentage higher than the rate selected for the motor to run before a fault condition exists and the circuit is triggered to pulse the disarm switch 282. The comparator 324 compares the actual rates with the desired rates and triggers the disarm circuit when the actual rate is significantly higher.

A circuit is also included to detect failure of the potentiometer 62. This involves setting up a minimum voltage at which the potentiometer can operate. If the voltage produced by the potentiometer is significantly lower than its predetermined minimum output value, the comparator 340 will sense this faulty condition and disarm the control circuitry through line 119, without waiting for an overrate condition to appear.

When the injector plunger has reached the maximum limit of its forward travel, indicating that all of the contrast media within the injector syringe has been ejected, the microswitch 27 provides a signal by way of line 124 to the disarm circuit.

An improved angiographic injector control system has thus been described and illustrated. The system controls the volume of contrast media which is injected into a patient by regulating the position of the injector plunger in accordance with a position command signal and a volume limit signal. The system is capable of synchronizing the injections to correspond to the heartbeat of a patient or to any other linear or irregular function program. Suitable circuitry for detecting and responding to malfunctions of equipment has also been described and illustrated although it will be understood that modifications and additions to this circuitry can be made without departing from the true spirit and scope thereof. Many counters or regulating circuits for limiting the number of injections to take place can be developed as well as different means for producing an irregular function to operate the injector. Therefore, it is desired that such modifications and additions be recognized and that the injector and control system of the present invention be limited only by the following claims.

What is claimed is:

1. An injection system for producing a controlled volume of injection fluid for use in angiography comprising:

a. an injector including syringe means for said fluid, piston means connected to said syringe and movable along a linear path for ejecting said fluid from said syringe means, conduit means for connecting

said syringe means to a patient, and a drive motor for moving said piston; and

b. control means for said injector, said control means including command means for producing a command signal which is a function of the desired injector piston position, sensing means for producing a position signal which is a function of the actual injector piston position along its path, and means for comparing said command and actual position signals to produce a resultant signal for operating said drive motor, whereby said piston is advanced along said path to its command position to eject said controlled volume of fluid.

2. The injector system of claim 1 wherein said sensing means is a potentiometer driven by said injector to produce said position signal.

3. The injector system of claim 2 wherein said control means further includes means for selecting the volume of fluid to be injected by said injector, and means for regulating the operation of said drive motor to terminate an injection after said selected volume has been injected.

4. The injector system of claim 3 wherein said means for regulating the operation of said drive motor includes a comparison means responsive to a first signal corresponding to the selected volume and to said position signal, said position signal corresponding to incremental movement of said drive motor, said comparison means producing an output when the position signal is equal to or greater than said first signal.

5. The injector system of claim 4 wherein said control means further includes a disarm circuit for said injector, the output from said comparison means being effective to trigger said disarm circuit and stop said drive motor.

6. The injector system of claim 1 wherein said command means includes means for selecting a predetermined command function, and integrator means for integrating said command function to produce said command signal.

7. The injector system of claim 1 wherein said control means further includes means for selecting a maximum injector pressure in said syringe and means for regulating the operation of said drive motor to limit said injector pressure to the selected value.

8. The injector system of claim 7 wherein said means for limiting said injector pressure includes means for producing a signal proportional to the actual torque of said drive motor, comparing said torque signal to a signal proportional to said selected injector pressure and producing a resultant pressure limit signal for regulating said drive motor.

9. The injection system of claim 8 wherein said means for producing a signal proportional to the actual torque of said drive motor comprises a resistor in series with said motor.

10. The injector system of claim 8 wherein said means for selecting a maximum injector pressure further includes actual means responsive to said signal proportional to the actual torque of said drive motor for displaying the torque in terms of injector pressure.

11. The injector system of claim 5, further including fault detector means responsive to malfunctions in said injector for triggering said disarm circuit to stop said drive motor.

12. The injector system of claim 1, wherein said resultant signal for operating said drive motor is an error signal proportional to the difference between the instantaneous value of said command signal and the incremental position of the injector piston, the instantaneous value of said position signal being proportional to said incremental position.

13. The injector system of claim 1, further including means for producing a volume selector signal which may be varied to select a desired displacement of said piston, means responsive to said actual position signal for establishing a signal proportional to the initial location of said piston, and means for comparing said initial location signal, actual position signal and volume selector signal and for producing a volume limiting signal when the difference between said initial location signal and said actual position signal equals said volume selector signal, said volume limiting signal terminating an injection after said selected volume has been injected.

14. The injector system of claim 13 wherein said means for establishing said signal proportional to the initial location of said piston comprises a memory circuit for storing the position signal at the start of an injection.

15. The injector system of claim 14, wherein said means for producing a volume selector signal comprises a digital switch array.

16. The injector system of claim 1 wherein said control means further includes an arm/disarm circuit for said injector drive motor, said arm/disarm circuit being operable to establish and to interrupt the armature current of said motor.

17. The injector system of claim 16 wherein said control circuit further includes means for generating a volume limit signal, and means within said arm/disarm circuit responsive to said volume limit signal for terminating the operation of said injector after a predetermined amount of fluid has been ejected from said syringe means.

18. The injector system of claim 1, wherein said control circuit further includes pressure limit means for limiting the armature current of said motor.

19. The injector system of claim 18, said pressure limit means comprising means for producing an actual pressure signal proportional to the actual armature current in said motor, pressure selector means for producing a selected pressure signal proportional to the desired maximum armature current, and comparator means for producing a pressure limit signal proportional to the difference between said actual pressure signal and said selected pressure signal, said pressure limit signal modifying said resultant signal for regulating the operation of said drive motor.

20. The injector system of claim 17 wherein said means within said arm/disarm circuit responsive to said volume limit signals comprises a volume limit switch, said volume limit switch serving to terminate the operation of said injector and permitting subsequent injection cycles in a multiple inject mode.

21. The injector system of claim 17 wherein said means within said arm/disarm circuit responsive to said volume limit signals comprises a disarm switch to terminate the operation of said injector and preventing subsequent injection cycles to thereby establish a single inject mode.

23

22. The injector system of claim 21 wherein said arm/disarm circuit further includes an arm switch, a master relay, and a volume limit switch in series with said disarm switch and with a start switch, closure of all said arm/disarm circuit switches and consequent energization of said master relay being required for operation of said injector.

23. The injector system of claim 22 wherein said arm/disarm switch further includes a safe circuit in series with the armature of said drive motor, said safe circuit being controlled by said master relay, whereby said arm/disarm circuit regulates the operation of said drive motor.

24. The injector system of claim 22, further including fault detector means responsive to malfunctions in said injector for opening said disarm switch, thereby to disable said drive motor.

25. The injector system of claim 24, wherein said fault detector means includes overrate sensing means responsive to the speed of said drive motor, said overrate sensing means producing a fault output for disabling said motor when said motor exceeds a predetermined speed.

26. The injector system of claim 1 wherein said means for producing a command signal comprises a digital switch array having adjustable switch contacts for selecting a desired command signal level.

27. The injector system of claim 1, wherein said means for producing a command signal comprises a source of variable voltage, whereby said command signal varies in accordance with a preselected program to produce a desired command signal function.

24

28. The injector system of claim 27, wherein said source of variable voltage comprises an array of potentiometers connectable to a common line, and means for sequentially connecting said potentiometers to said line, whereby said variable voltage is a step function corresponding to the settings of said potentiometers.

29. The injector system of claim 28 wherein said means for sequentially connecting said potentiometers to said common line comprises clock-driven counter means having a plurality of outputs, each output being energized in sequence to connect a corresponding potentiometer to said common line.

30. The injector system of claim 29, further including means for synchronizing said counter means with an electrocardiogram, whereby said command signal function is initiated at a selected time.

31. The injector system of claim 30, further including counter means for counting the number of times said command signal function is generated, said counter means producing an output signal after a predetermined count is reached to terminate operation of said drive motor.

32. The injector system of claim 1, further including fault detector means responsive to malfunction in said injector for stopping said drive motor.

33. The injector system of claim 32, wherein said fault detector means includes overrate sensing means responsive to the speed of said drive motor, said overrate sensing means producing a fault output for disabling said drive motor when said drive motor exceeds a predetermined speed.

* * * * *

35

40

45

50

55

60

65