PATENT SPECIFICATION (11) 1 570 217

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(21) Application No. 46837/76 (22) Filed 10 Nov. 1976 (19)
(31) Convention Application No. 69808 (32) Filed 14 Nov. 1975 in
(33) Italy (IT)
(44) Complete Specification published 25 June 1980
(51) INT. CL.^{3} G05D 21/02
(52) Index at acceptance
G3R A24 A523 A625 B23 BE39

(54) APPARATUS FOR AUTOMATICALLY PREPARING SOLUTION OF CONTROLLED CONCENTRATION

(71) We, SANDOZ LTD., of 35 Lichtstrasse, 4002-Basle, Switzerland, a Swiss Body Corporate, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to an apparatus for automatically preparing a solution of a conductive solute of controlled concentration.

The apparatus is particularly suitable for the preparation of dialysis liquid. For this specific purpose, in which a concentrate is mixed with water in a volumetric ratio 1:30 to 1:35, known types of apparatus for example comprise two volumetric pumps to supply water and concentrate to a mixer. Two such pumps are driven simultaneously by a main motor whose speed can be adjusted to vary the amount of liquid obtained. By means of a conductivity probe mounted at the outlet of the mixer, which compares its own output signal with a reference signal which is a function of the desired concentration, the stroke length of the piston in the pump for the concentrate can be varied to adjust the concentration of the liquid. For various reasons, equipment of this type does not function satisfactorily. For example, the volumetric ratio of the pumps varies widely to permit adjustment in the rate of flow of the liquid at the outlet from 200 cc/min. to 1000 cc/min., which places a heavy strain on the working capacity of the main motor. The flow at the outlet pulsates, so that a damper needs to be fitted which, at 200 cc/min., must be of considerable dimension. Further, the pressure of the inflowing water may reach dangerous levels, for which reason a safety valve is necessary, with a counterpressure valve in the water supply line to regulate flow and hence conductivity. Additionally, if complete mixing is desired the residence time in the mixer is too long, which causes the loop for regulating the concentration either to oscillate or to respond very slowly. Such an apparatus can therefore be operated only with manual control with the loop open, with fixed rates of flow at the outlet not lower than 500 cc/min. Such apparatus is moreover relatively expensive to construct.

The purpose of the present invention is therefore to provide an apparatus for automatically preparing a solution with continuous control and monitoring of the concentration and flow. The apparatus does not suffer from the disadvantages involved in adjusting the rate of flow and water can be supplied at a limited pressure without pulsating flow. This allows for thorough mixing of concentrate and water by means of a regulating loop (i.e. a level detector, a concentration probe, a regulator for regulating the supply of components and a regulator control device) for regulating and concentration, which functions with notable rapidity, and in which the regulator control device automatically controls both the liquid level and solution concentration.

According to the invention, there is provided an apparatus for automatically preparing a solution of a conductive solute of controlled concentration in a constant head solution supply system, which comprises a constant head mixer container in which preparation of the solution may take place, inlet conduits for the supply of components of the solution to the mixer container, an outlet conduit for passage of the solution out of the mixer container, a regulator for regulating the said supply, a level detector for detecting the level of solution in the mixer container in the vicinity of a prescribed primary level, a concentration probe for detecting concentration of solute in the solution, and a control device connected to receive electronic signals transmitted from said level detector and said concentration probe for producing a control output signal to control said regulator, whereby the level of solution in the container is maintained in the vicinity of said prescribed primary level and the concentration of solute in the solution is maintained in the region of a predetermined value.

Preferably, the control device includes a first element for emitting a level signal as a function of the signal from the level detector and at least second and third elements for combining the primary level signal with a reference level signal and for emitting a regulator control signal for controlling the regulator.

Further features of the invention will be understood from the following description of an exemplary embodiment of an apparatus in accordance with the invention. This description is made with reference to the accompanying drawings, in which:

Figure 1 is a diagrammatic illustration of the hydraulic and electronic principles involved in the apparatus of this invention;

Figure 2 is a diagrammatic illustration of the electronic circuitry of the command and monitoring block shown in the apparatus illustrated in Figure 1; and

Figures 3 and 4 are diagrammatic representatives of signals emitted by the command and monitoring block of Figure 2.

Referring to Figure 1 of the drawings, the apparatus comprises a mixing container 1 of about four litres capacity with inlet pipes 2 and 3 for respectively supplying concentrate of a conductive solute, for example salts, and water. In pipes 2 and 3 respectively are fitted two electric valves 4 and 5 which together comprise a regulator. A pipe 6 including a pump 7 leads from the vessel 1 and from it branch off successively a recirculation pipe 8 which returns to the container 1 and two pipes 9 and 10 for delivery and drainage respectively. In pipes 9 and 10 respectively are fitted two electric valves 12 and 13.

In the container 1 are mounted two level detectors 14 and 15 of known type at a primary and secondary level respectively and a probe 16 which measures the conductivity and hence the concentration of the solution in the vessel. The level detector 14 may, for example, be of the type consisting of a small magnet 17 connected to a float acting in conjunction with a fixed detector 18 and may be constructed to signal a positive or negative potential difference (see Figure 2). In such construction the magnet 17 moves to a point either above or below a level 19 which represents the maximum normal level of liquid in the container 1. In contrast, the level detector 15 is of the type which emits a signal when the liquid reaches a level higher than a minimum level 20, which is lower than the level 19.

The probe 16 may conveniently be of the type which emits a signal whose frequency is proportional to the conductivity value and hence to the concentration of the liquid, with compensation for the temperature being built in.

The output of the level detector 14 is connected to a control device including a command and monitoring block 22. The output of the probe 16 is connected to a converter block 23. The outputs of the block 23 lead to the block 22, to an indicating instrument 24, and to two threshold comparators 25 and 26. To the other input points of the comparators 25 and 26 are connected respectively adjustable resistors 27 and 28 for setting the threshold value. The outputs of the comparators 25 and 26 are connected to the inputs of two "OR" circuits 29 and 30, and these are connected respectively to earthed signalling lamps 32 and 33. The output of the "OR" circuit 30 is connected to an acoustic signaller 34. The output of the "OR" circuit 29 leads to an "AND" gate 35 and to an inverter 36, whose output is connected to an "AND" gate 37. A signal from a block 38 is transmitted to the second inputs of the "AND" gates 35 and 37. This block 38, which receives a signal from the level detector 15 emits from its output a signal 39 for the gates 35 and 37, and a command signal 40 for the pump 7. The outputs of the "AND" gates 35 and 37 are connected to command respectively the electric valves 13 and 12. The block 22 sends two output signals 42 and 43 which respectively command the electric valves 4 and 5.

Referring now to Figure 2, block 22 comprises a resistor 51, to which is transmitted the signal from the level detector 14 and which is connected to the inverting input of a first element of the control device comprising a difference amplifier 52 acting as integrator, the non-inverting input of which is earthed. Between the inverting input and the outputs is connected a capacitor 53. The output of the amplifier 52 leads to the inverting input of two difference amplifiers 54 and 55, the outputs of which are connected respectively to the negative inputs of second and third elements of the control device comprising two control device threshold comparators 56 and 57.

The output of the converter block 23 is connected to the non-inverting input of a fourth element of the control device comprising a difference amplifier 58, the inverting input of which is connected to receive an adjustable signal transmitted through a variable resistor 59. The output of the amplifier 58 is connected through a variable resistor 61 to the non-inverting input of the amplifier 54, and through a variable resistor 62 to the inverting input of the amplifier 55, which amplifiers 54 and 55 comprise respective fifth and sixth elements of the control device.

From the output of a generator 63, a delta signal is relayed to the non-inverting inputs of the comparators 56 and 57, while the outputs of these comparators respectively emit signals 42 and 43 commanding the electric valves 4 and 5.

The letters appearing in the diagram denote:

L: the hump repeater primary level signal from the output of the amplifier 52,

C: the signal proportional to the conductivity of the liquid,

R: the signal of the conductivity reference value (i.e. concentration reference signal),

E: the concentration error control signal reporting an error in conducitvity,

A_1: the output signal of the amplifier 54,

A_2: the output signal of the amplifier 55, and

T: the delta reference level signal.

From the circuit diagram shown in Figure 2, it will be noted that if the signals 42 and 43 at the outputs of the comparators 56 and 57 are actuated, the electric valves 4 and 5 open to admit concentrate and water, provided that the signal T is greater than the signal A_1 and A_2. The period of the signal T is about 1 second, and that of signal L, 30 or 40 seconds. The signal T is maintained between +12 V and −12 V, while the signals A_1 and A_2 are free to reach the saturation levels which, at ± 15 V current supply, are about +14 V and −13 V. At these two extreme levels, the connected electric valves 4 and 5 invariably remain closed or open. Between these two levels the electric valves 4 and 5 open for a period of time proportional to the values of A_1 and A_2. When A_1 and A_2 are zero, the open time of the valves 4 and 5 is obviously one half of the total time. The variable signals A_1 and A_2 and the delta signal T determine in the comparators 56 and 57, within fixed levels, the open and closed times of the electric valves 4 and 5. They are given by:

$$\begin{aligned} A_1 &= -L + K_1 E \\ A_2 &= -L - K_2 E \end{aligned} \qquad (1)$$

where K_1 and K_2 are proportionality constants determined by the resistors 61 and 62.

Operation of an apparatus as described above will now be described with reference to Figures 3 and 4, which serve as illustration only and do not indicate the signals on the proper scale.

The initial steps for reaching a condition in which the apparatus is set for operation will now be described.

As the supply of liquid flows into and out of the container from the pipes 2, 3 and pipe 9 respectively, the magnet 17 of the level detector 14 continuously oscillates in the region of the level 19. These oscillating movements of the magnet 17, and of the liquid level in the vessel 1, are determined by the command and monitoring block 22, which actuates the electric valves 4 and 5 and regulates the time that they remain open or closed. By this means, the liquid level is maintained fairly constant at about the maximum level 19, and the rate of flow of the liquid varied as necessary.

Assuming that the effective concentration of the liquid is equal to the desired value, so that signal C equals signal R, then E = O, which in accordance with (1) gives

$$A_1 = A_2 = -L \qquad (2)$$

In Figure 3, A shows the magnet 17 signal as a function of time, which oscillates about the maximum normal level 19. When the magnet 17 is lower than the level 19, the negative terminal of the level detector 14 is connected to the inverting input of the amplifier 52 (B indicates the signal from the output of the level detector 14). Accordingly the signal L increases while, as given by (2), the signals A_1 and A_2 of (2) are equal and decrease. Due to the signals A_1 and A_2 and the delta signal T, the duration of the signal 42 and 43 grows progressively longer, thereby increasing the amounts of water and concentrate entering the vessel 1 so that the liquid level steadily rises.

Once level 19 is exceeded, the positive terminal of the level detector 14 is connected to the inverting input of the amplifier 52. The signal L then decreases while, in accordance with equation (2), the signals A_1 and A_2 are equal and increase. The signals 42 and 43 thereby grow progressively shorter in duration, causing the amounts of water and concentrate which flow into the container 1 to be reduced so that the liquid level rises more slowly, then stops, and afterwards falls.

When the liquid level, and with it the magnet 17, again falls below the level 19, the negative terminal of the level detector 14 is connected anew to the inverting input of the amplifier 52. The L signal is then amplified while signals A_1 and A_2 are equal and diminish. The duration of the signals 42 and 43 grows progressively longer, causing the liquid level to fall more slowly at first and then to stop, after which it again rises until it once more rises above the level 19, when the described phases of the first cycle are repeated.

Thus, in practice, the liquid level constantly fluctuates by about 10 mm about the maximum normal level 19. In the apparatus, this in effect amounts to a substantially constant level of liquid, also as regards variations in the amount of liquid delivered. If however the delivery of liquid along the delivery line 9 ceases, the level in the vessel gradually rises (Figure 3), and consequently the signal L gradually diminishes until it fades out. This amplifies the signals A_1 and A_2 to their maximum positive value, which is higher than the maximum value of the signal T, whereby the signals 42 and 43 remain at zero and the electric valves 4 and 5 remain closed. In these conditions, when no further liquid is being delivered, the vessel 1 remains full of liquid at the desired concentration, ready to meet a further demand for prepared liquid.

When delivery is resumed, the liquid level begins to fall until it falls below level 19, when the signal L is amplified, signals A_1 and A_2 diminish, and signals 42 and 43 grow gradually longer, thereby setting in motion a further flow of water and concentrate in accordance with the described phases of operation.

Supposing that an error occurs in the concentration of the liquid, then obviously the signal E will be other than zero. This changes the signals A_1 and A_2, and accordingly the times that the electric valves 4 and 5 remain open, by a factor proportional to E, obviously of opposite sign. The concentration of the solution is thus adjusted to the desired value.

Again, supposing too much concentrate has been supplied, Figure 2 shows that $C>R$ which makes $E>O$. The equations (1) indicates that A_1 is greater than A_2 less than the value which should prevail in exact concentration conditions as represented by the broken line (Figure 4). This signifies that the electric valve 4 for the concentrate has been open for shorter periods of time and the valve 5 for the water for longer periods, as is in fact necessary for further dilution of the concentrate.

If on the other hand there is not enough concentrate present, then $C<R$ and accordingly $E<O$. From (I) is follows that A_1 is too low and A_2 too high (Figure 4) with respect to the conditions for exact concentration, showing that the electric valve 4 for the concentrate has been open for longer times and valve 5 for the water for shorter times than necessary.

In order that correction of the concentration may be entrusted principally to the electric valve 4 for the concentrate, the proportionality constants K_1 and K_2 in (1) are different from each other. Convenient values are set such that $K_1 = 5K_2$ and this makes K_1E equal to the maximum value of L when $E = 1.5\%$. This means that adjustments in the open times of the electric valve 5 for the water serve in practice solely to correct a positive error in the concentration in the direction of the maximum level, and that, given a 1.5% concentration error, with open and closed times theoretically equal to those for the exact concentration, the valve 4 for the concentrate will remain completely closed.

The curves in Figure 4 are based on the assumption that the concentration error remains constant; in practice it tends to approximate to zero, for which reason the continuously drawn curves representing the signals A_1 and A_2 coincide more and more closely with the broken line referring to the conditions of exact concentration.

Preparation phases for preparing the apparatus to obtain such in its operating condition will now be described.

The container 1 being empty, the level detector 15 determines through the block 38 the level of the signal 39, which closes the outputs of the gates 35 and 37, and in consequence the electric valves 12 and 13 located in the supply and drainage pipes 9. and 10 remain closed. At the same time, the magnet 17 of the level detector 14 being below the level 19, the signal L is amplified to the maximum positive value and the signals A_1 and A_2 adjust to the maximum negative value, which is lower than the minimum value of the delta signal T. The signals 42 and 43 are then continuous, and the electric valves 4 and 5 are fully open to allow water and concentrate to enter the vessel 1 at the maximum rate of flow. When the liquid in the vessel 1 rises above the level 20, the level detector 15 emits a signal to the output of the block 38 which emits the signal 40 to activate the pump 7. This initiates recirculation of the liquid through the pipe 8 into the container 1 and sets off the signal 39 at a different level which activates a signal at the output of one of the gates 37 or 35, according to the value of the concentration. The potential signal at the output of the block 23 is transmitted to the instrument 24 which records the concentration value visually and is connected to the two concentration tolerance limit comparators 25 and 26. The upper and lower tolerance limits of the concentration value are controlled by the two resistors 27 and 28. A signal is generated from the output of one of the threshold comparators 25 and 26 when the concentration value falls below the lower limit or rises above the upper limit respectively. In such conditions of erroneous concentration, the lamp 32 or 33 lights up, the signaller 34 sounds an acoustic alarm, and a signal is sent to the gate 29, upon simultaneous emmission of the signal 39 emits a signal to the gate 35 which opens the electric valve 13 of the drainage pipe 10.

If however the concentration is correct, the signal at the output of the gate 29 is inoperative, so that the electric valve 13 stays closed. The inverter 36 then emits a signal to the gate 37, which, through the simultaneous emission of the signal 39, triggers off a signal which opens the electric valve 12 of the supply pipe 9.

Therefore, when the liquid level in the container 1 exceeds the level 20, the electric valve 12 or 13 of the supply or drainage pipe opens or not, dependent on whether the concentration is within the prescribed limits or beyond these limits.

Generally, the concentration in the container 1 is insufficient when the level 20 is reached in the first filling cycle. Consequently, the electric valve 13 in the drainage pipe 10 opens, and if the level 19 has been exceeded, the electric valves 4 and 5 close temporarily until, primarily through the action of the electric valve 4 in the concentrate pipe 2, the required concentration is attained.

The apparatus of the present invention, therefore possesses numerous advantages. Above all it provides for a supply of liquid at a rate of flow which is variable within wide limits, the concentration value of which remains substantially within the prescribed tolerance limits. The provision of the container 1, in which the concentration of all of the liquid it holds is controlled by the probe 16, eliminates problems with pulsating flow at the outlet, and there are no interfering effects on the rate of flow at the outlet or one the conductivity as a result of pressure differences of inflowing water.

The loop for the continuous control and monitoring of the concentration and rate of flow functions remarkably rapidly, and as a result the liquid level in the vessel remains in the vicinity of the level 19, with fluctuations over a range of only 10 mm. This is accomplished by the action which adjusts the open and closed times of the electric valves 4 and 5, which is controlled by the level detector 14 which controls the level of the signals A_1 and A_2 and thus ensures that the concentration value never deviates by more than 1% from the desired value, and also by the action of the probe 16 which, on encountering a prescribed concentration value, corrects the level of the signals A_1 and A_2. The adjustable resistors 61 and 62 permit the values of the correction constants K_1 and K_2 in (1) to be calibrated as desired, in order to obtain optimum values from the point of view of stability and response time.

In order to maintain the conductivity of the liquid in the container 1 within prescribed limits with minimal deviation, it can be useful to fit a pressure regulator on the water supply pipe 3 and an adjustable choke on the concentrate supply line 2. In this case, prior calibration of the choke is necessary. Together with the action of the block 22, this suppresses flow until the desired concentration value is reached. This rough means of regulation is thereby refined and the action of the block 22 fully retained.

WHAT WE CLAIM IS:—

1. An apparatus for automatically preparing a solution of a conductive solute of controlled concentration in a constant head solution supply system, which comprises a constant head mixer container in which preparation of the solution may take place, inlet conduits for the supply of components of the solution to the mixer container, an outlet conduit for passage of the solution out of the mixer container, a regulator for regulating the said supply, a level detector for detecting the level of solution in the mixer container in the vicinity of a prescribed primary level, a concentration probe for detecting concentration of solute in the solution, and a control device connected to receive electronic signals transmitted from said level detector and said concentration probe for producing a control output signal to control said regulator, whereby the level of solution in the container is maintained in the vicinity of said prescribed primary level and the concentration of solute in the solution is maintained in the region of a predetermined value.

2. An apparatus according to claim 1, in which the control device includes a first element for emitting a primary level signal as a function of the signals from the level detector, and at least second and third elements for combining the primary level signal with a reference level signal and for emitting a regulator control signal for controlling the regulator.

3. An apparatus according to claim 2, in which the control device additionally includes a fourth element for comparing the signal from the concentration probe with a concentration reference signal which is a function of the predetermined concentration value, and which emits a concentration error control signal, and fifth and sixth elements for emitting respective output signals as functions of said primary level signal and said concentration error control signal, said second and third elements furthermore being capable of combining said respective output signals with the said reference level signal to provide two said regulator control signals.

4. An apparatus according to claim 3, in which the regulator comprises a pair of electric valves for admitting or impeding supply of components of the solution to the container, the two said regulator control signals being for controlling the time at which and the period for which the respective electric valves open and close as a function of the primary level signal so as to maintain the level of the liquid in the container in the vicinity of the said primary level, and furthermore as a function of said concentration error signal so as to maintain the concentration value of the solution in the region of the predetermined value.

5. An apparatus according to claim 4, in which said respective output signals are functions of said primary level signal and said concentration error signal with different respective proportionality constants relative to said concentration error signal, whereby the variation in the open and closed periods of the electric valves produced by variation

of the concentration error signal is substantially greater for one of the valves than for the other.

6. An apparatus according to any one of claims 3, 4 or 5 in which each of the said fourth, fifth and sixth elements comprise difference amplifiers.

7. An apparatus according to any one of claims 2 to 6, in which the level detector is adapted to emit a positive or negative signal dependent on the level of solution with respect to said primary level, and in which said first element comprises an integrator.

8. An apparatus according to any one of claims 2 to 7, in which the second and third elements are both control device threshold comparators, and in which the reference level signal is in the form of a periodic delta signal.

9. An apparatus according to any one of the preceding claims, in which the concentration probe is coupled to the control device through a ocnverter block for converting potential to frequency whereby a signal having a frequency proportional to the conductivity of the solution may be transmitted.

10. An apparatus according to any one of the preceding claims, in which the signal emitted by the concentration probe is transmitted to two concentration tolerance limit threshold comparators for controlling lower and upper limits of concentration of the solution, the outputs and said concentration tolerance limit threshold comparators being connected to alarm elements, and also to gate devices for commanding opening of one or the other of at least two electric valves provided for controlling delivery and drainage of solution from the container.

11. An apparatus according to claim 10, in which a secondary level signal is transmitted to the gate devices in response to the level of liquid in the container falling to the level of a further level detector mounted in the said container at a secondary level which is lower than said primary level.

12. An apparatus for automatically preparing a solution of controlled salt concentration, substantially as herein described, with reference to Figure 1 and 2 of the drawings.

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Printed for Her Majesty's Stationery Office by Burgess & Son (Abingdon), Ltd.—1980.
Published at The Patent Office, 25 Southampton Buildings, London, WC2A 1AY,
from which copies may be obtained.

FIG. 1

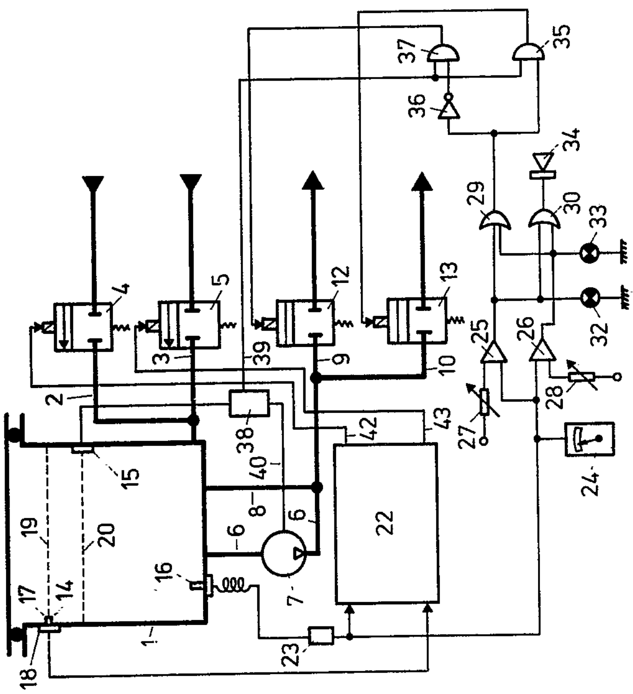


FIG. 2

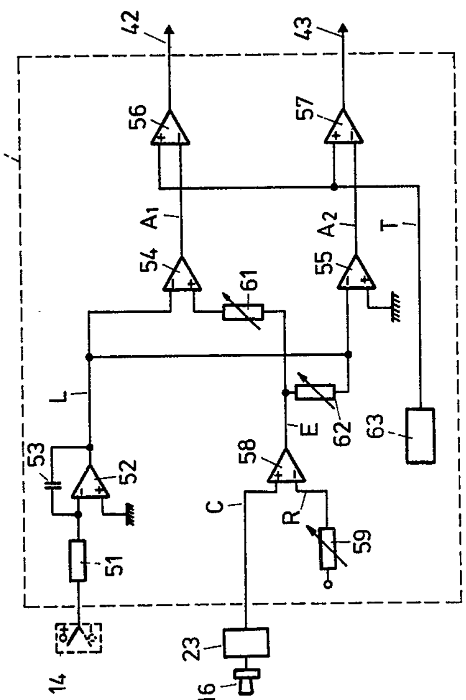
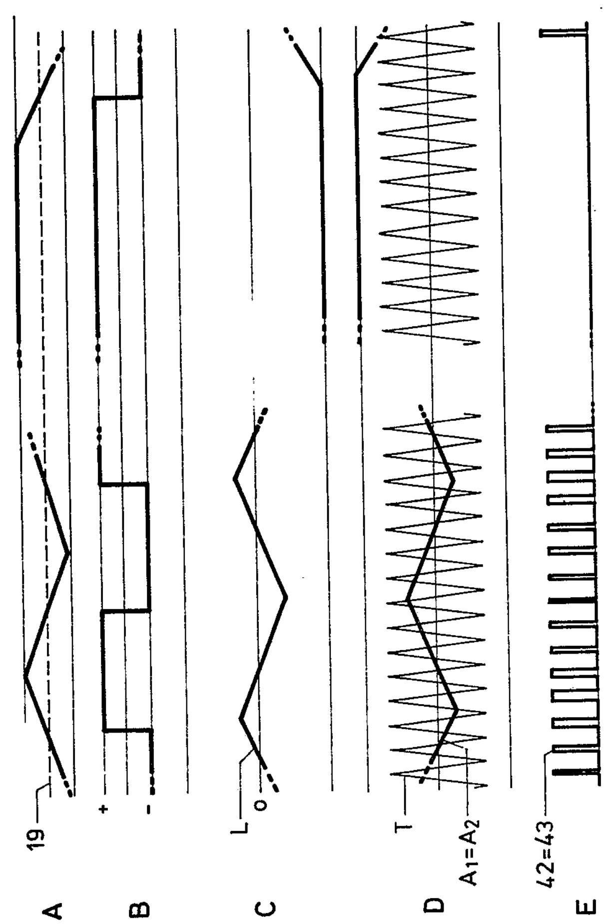


FIG. 3



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4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 4

FIG. 4