United States Patent [19]

Mahawili et al.

[11] **4,315,523**

[45] **Feb. 16, 1982**

[54] **ELECTRONICALLY CONTROLLED FLOW METER AND FLOW CONTROL SYSTEM**

[75] Inventors: **Imad Mahawili**, Sunnyvale; **Timothy J. Boyle**, Cupertino, both of Calif.

[73] Assignee: **American Flow Systems, Inc.**, Sunnyvale, Calif.

[21] Appl. No.: **127,918**

[22] Filed: **Mar. 6, 1980**

[51] **Int. Cl.**[3] **G01F 3/20**

[52] **U.S. Cl.** **137/486**; 137/487.5; 73/269

[58] **Field of Search** 137/486, 487.5; 73/269, 73/270, 271

[56] **References Cited**

U.S. PATENT DOCUMENTS

287,587	10/1883	Spooner	73/270
3,181,360	5/1965	Hederborst	73/270
3,906,793	9/1975	Wurzbacher	73/269
4,067,239	1/1978	Arvisenet	73/270
4,134,423	1/1979	Mayer	137/486

Primary Examiner—Alan Cohan

Attorney, Agent, or Firm—Alan H. MacPherson; Steven F. Caserza

[57] **ABSTRACT**

A novel, low-friction, low-inertia flexible diaphragm containing a magnet formed as an integral part of the diaphragm is mounted in a chamber (preferably cylindrical). The chamber comprises part of the flow meter in a flow control system. One or more sensing devices are mounted on the walls of the chamber to sense the instantaneous position of the diaphragm. A novel electronic control circuit processes the data from the one or more sensing devices to provide measures of the flow rate during the displacement of the diaphragm along the cylinder. Signals are generated by the electronic control circuitry for switching a pair of three-way valves (one valve comprising the input valve and the other valve comprising the output valve) such that during one-half of a cycle the intput valve transfers fluid into the cylinder on one side of the diaphragm and, during the other half of the cycle, transfers fluid into the cylinder on the other side of the diaphragm. The output valve is switched synchronously with the input valve to transmit fluid from the other side or one side of the diaphragm to the output valve.

The electronic control system includes means for amplifying the output signals from the one or more sensing devices ("sensors") to provide one or more signals representing the position of the diaphragm as a function of time, means for converting the output signals from these amplifiers to digital form, and computation means for operating on the digitized output signals from the sensing devices to provide control signals for controlling a second input valve thereby to control the flow rate of the fluid being metered to within a desired range.

11 Claims, 16 Drawing Figures

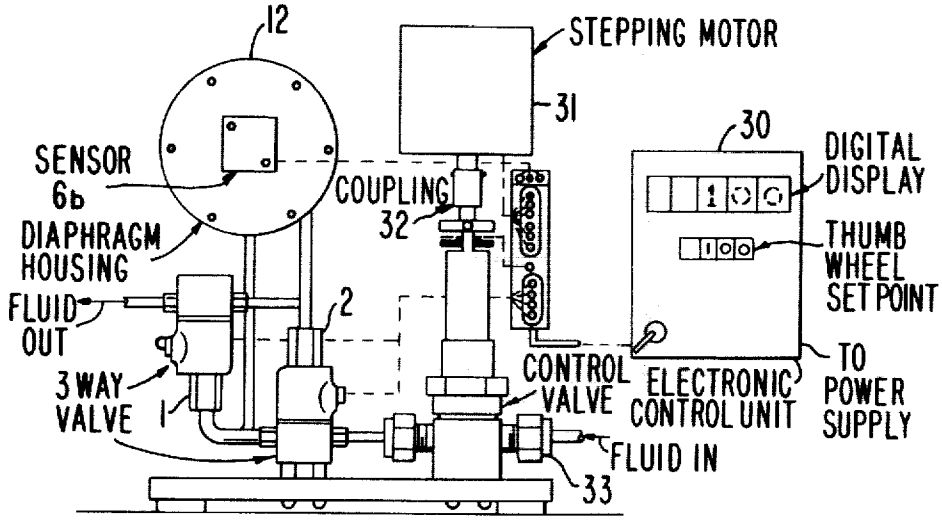
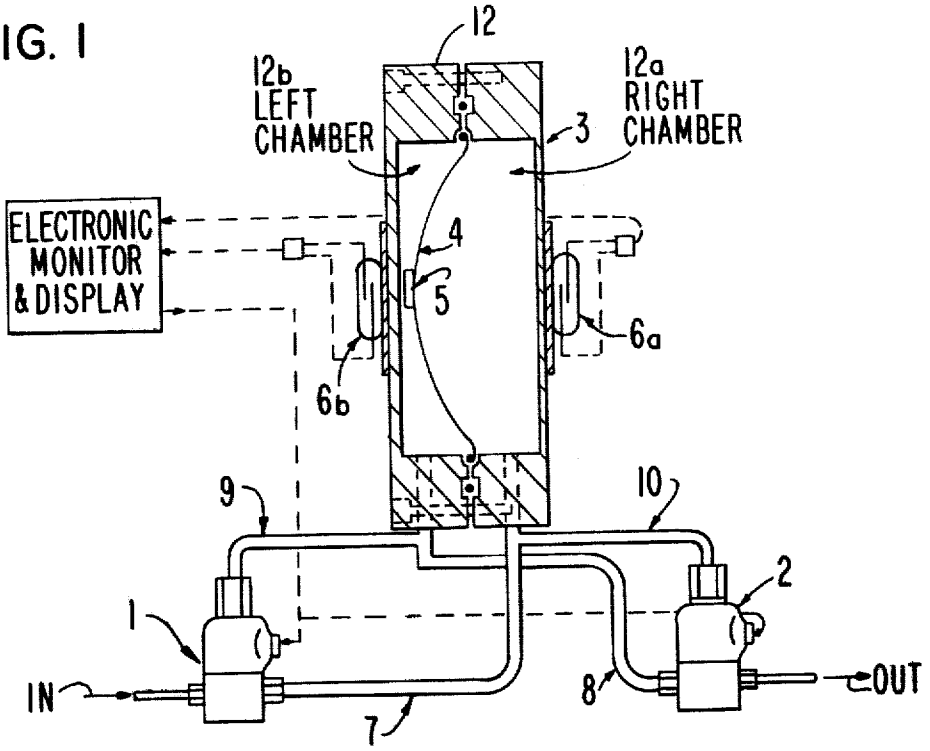


FIG. 1



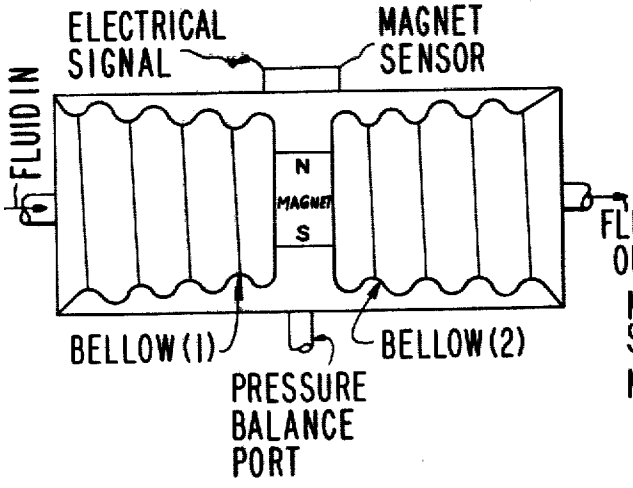
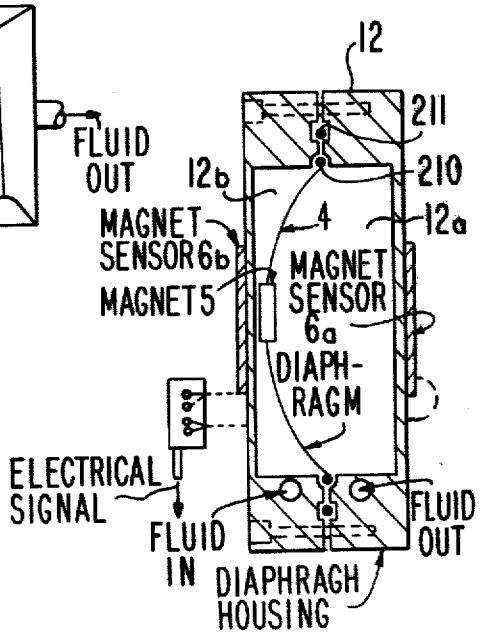


FIG. 2a

FIG. 2b



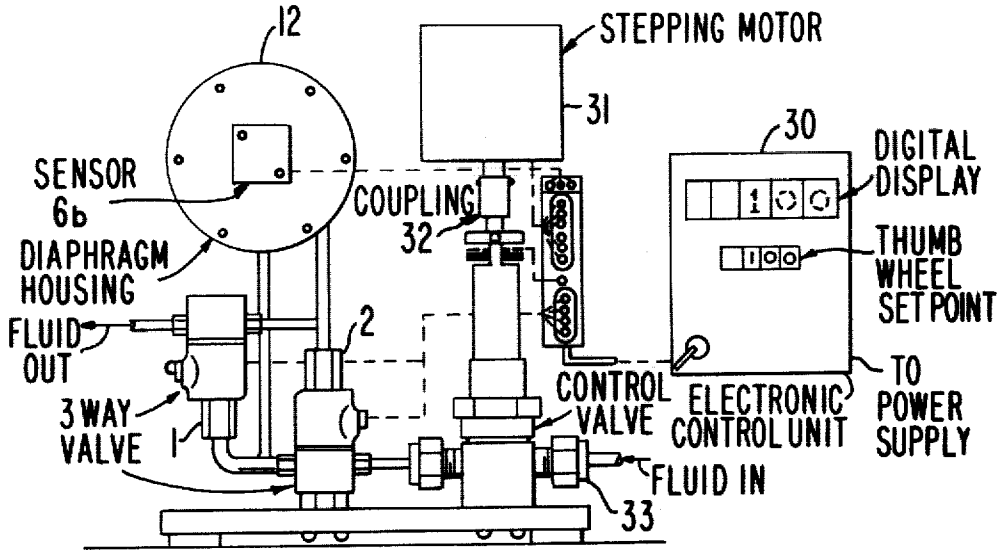
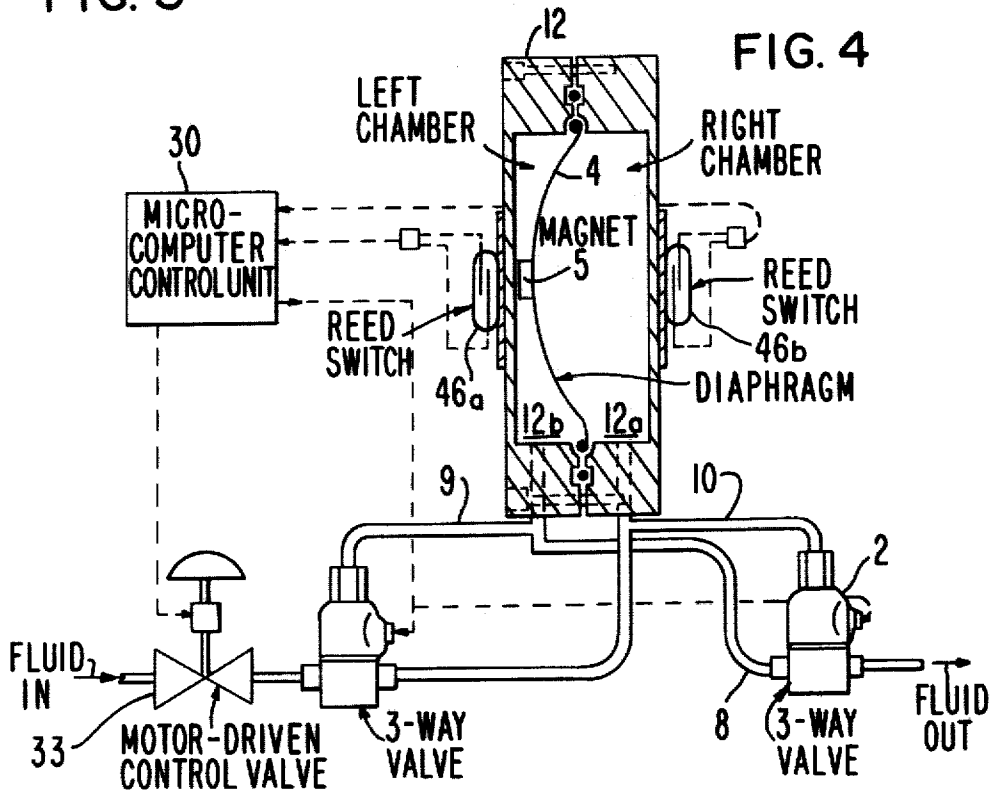

12
STEPPING MOTOR
31
30
DIGITAL DISPLAY
SENSOR 6b
COUPLING 32
DIAPHRAGM HOUSING
THUMB WHEEL SET POINT
FLUID OUT
2
3 WAY VALVE
1
CONTROL VALVE
ELECTRONIC CONTROL UNIT
TO POWER SUPPLY
FLUID IN
33

FIG. 3

FIG. 4


12
LEFT CHAMBER
RIGHT CHAMBER
30
4
MICRO-COMPUTER CONTROL UNIT
MAGNET 5
REED SWITCH 46b
REED SWITCH 46a
DIAPHRAGM
12b
12a
9
10
2
FLUID IN
33
MOTOR-DRIVEN CONTROL VALVE
3-WAY VALVE
8
3-WAY VALVE
FLUID OUT

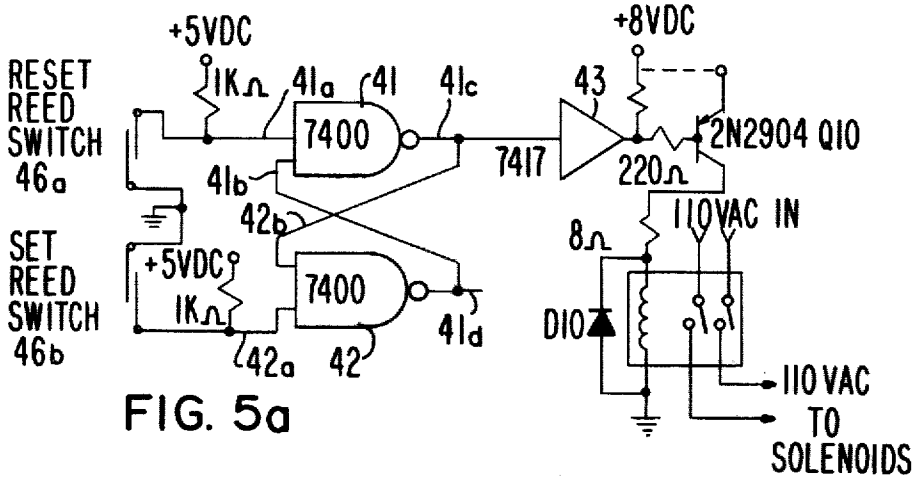

+5VDC
RESET REED SWITCH 46a
1K
41a
41
41c
7400
41b
42b
SET REED SWITCH 46b
+5VDC
1K
7400
42a
42
41d
+8VDC
43
7417
2N2904 Q10
220
110VAC IN
8
D10
110 VAC TO SOLENOIDS

FIG. 5a

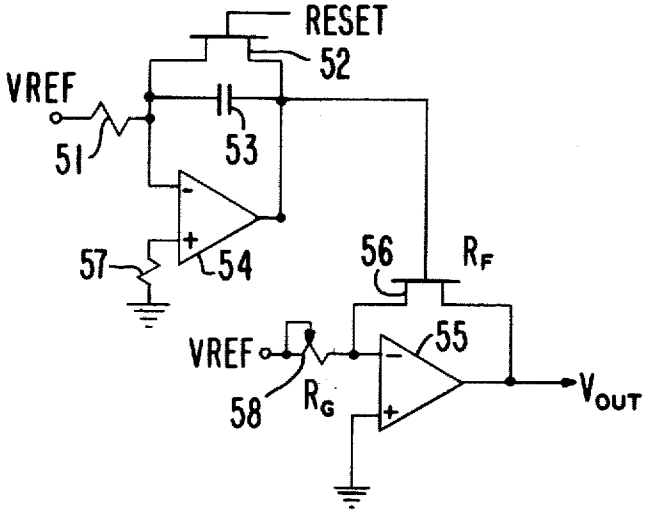

RESET
52
VREF
51
53
57
54
56
R_F
VREF
58
R_G
55
V_{OUT}

FIG. 5b

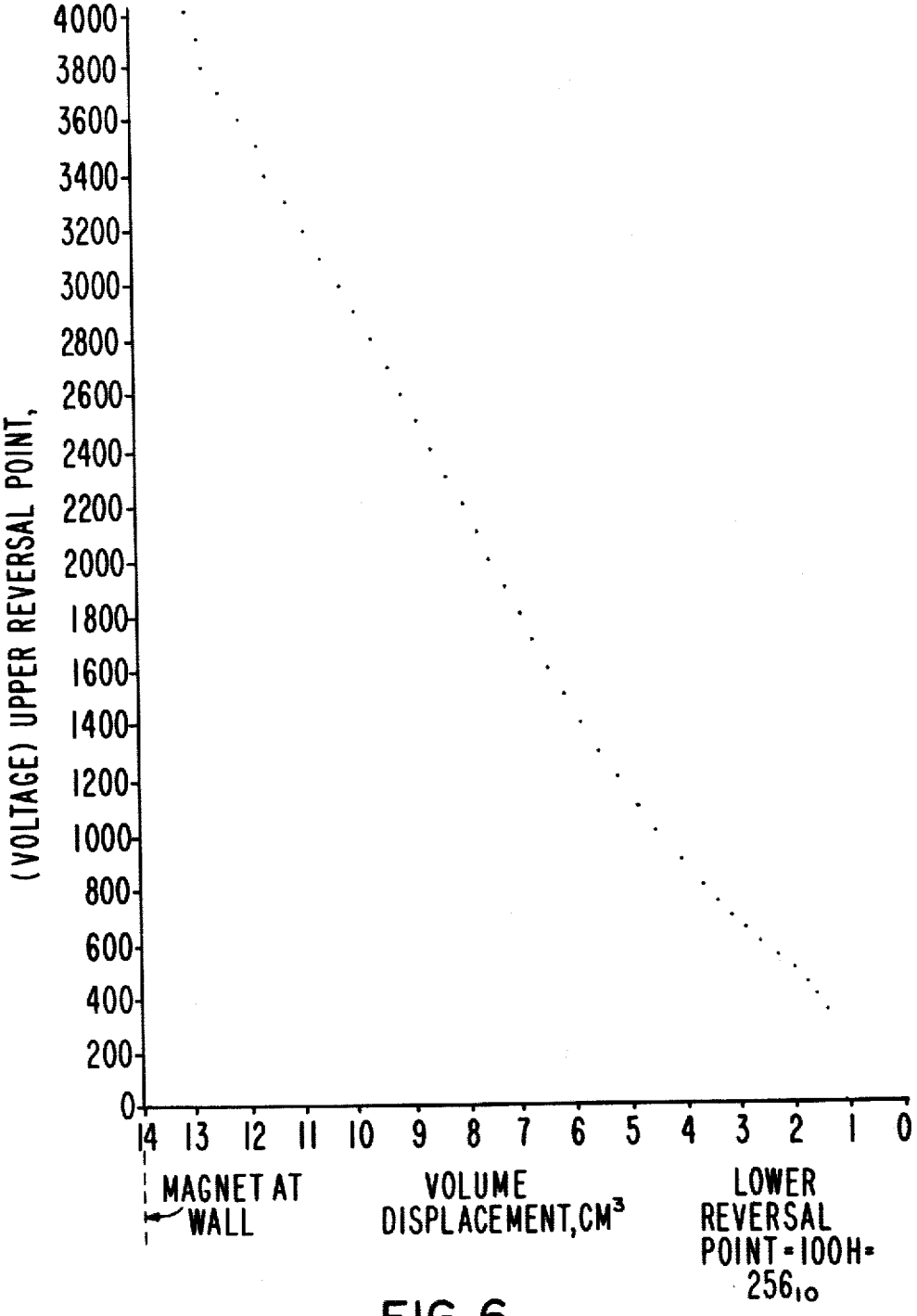

(VOLTAGE) UPPER REVERSAL POINT,
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
MAGNET AT WALL
VOLUME DISPLACEMENT, CM³
LOWER REVERSAL POINT = 100H = 256₁₀

FIG. 6

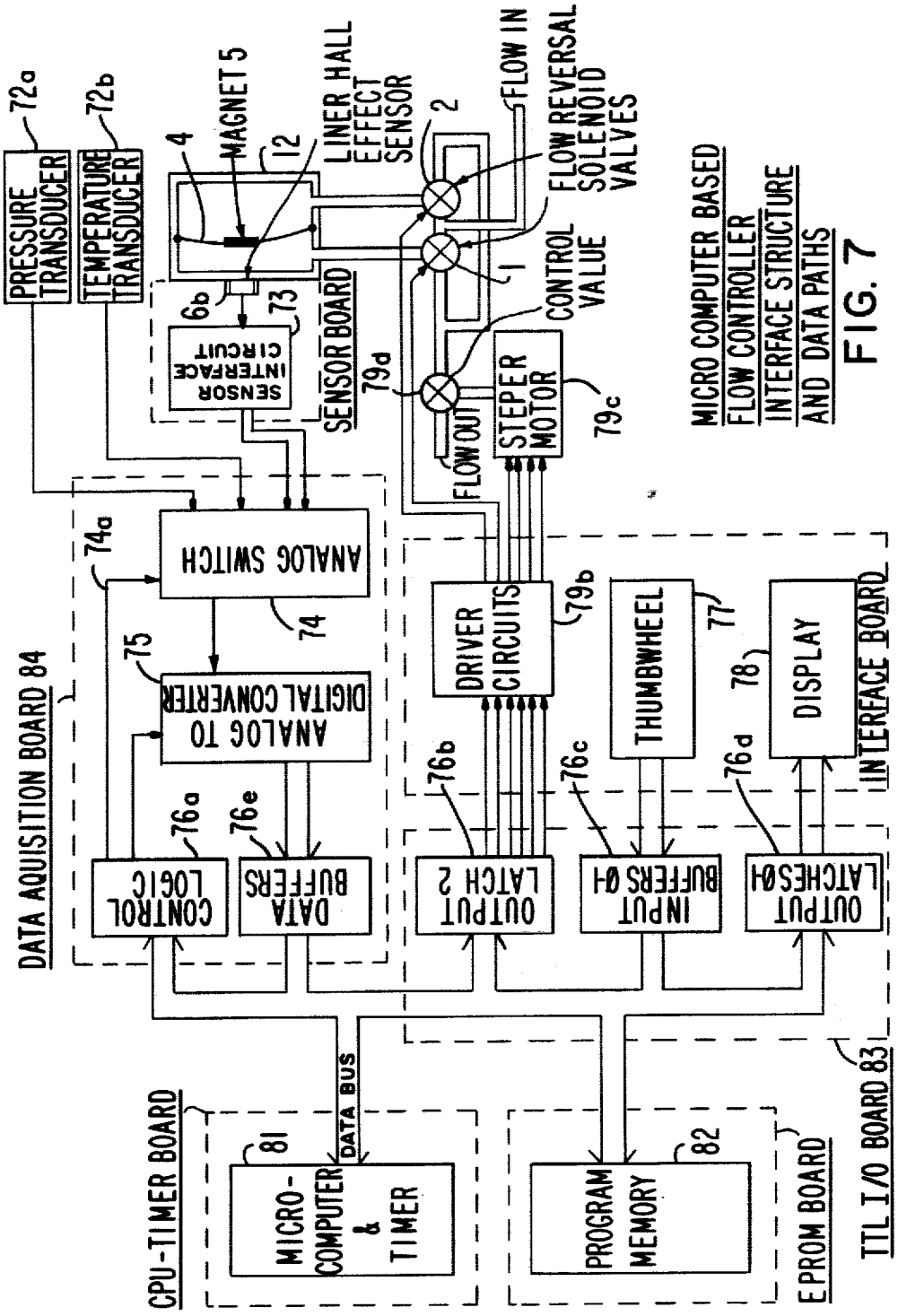

PRESSURE TRANSDUCER
TEMPERATURE TRANSDUCER
MAGNET 5
LINER HALL EFFECT SENSOR
FLOW IN
FLOW REVERSAL SOLENOID VALVES
CONTROL VALUE
SENSOR INTERFACE CIRCUIT
SENSOR BOARD
STEPER MOTOR
FLOW OUT
MICRO COMPUTER BASED FLOW CONTROLLER INTERFACE STRUCTURE AND DATA PATHS
ANALOG SWITCH
ANALOG TO DIGITAL CONVERTER
CONTROL LOGIC
DATA BUFFERS
DRIVER CIRCUITS
OUTPUT LATCH 2
INPUT BUFFERS Ø-1
OUTPUT LATCHES Ø-1
THUMBWHEEL
DISPLAY
DATA AQUISITION BOARD 84
INTERFACE BOARD
DATA BUS
CPU-TIMER BOARD
MICRO-COMPUTER & TIMER
PROGRAM MEMORY
EPROM BOARD
TTL I/O BOARD 83

FIG. 7

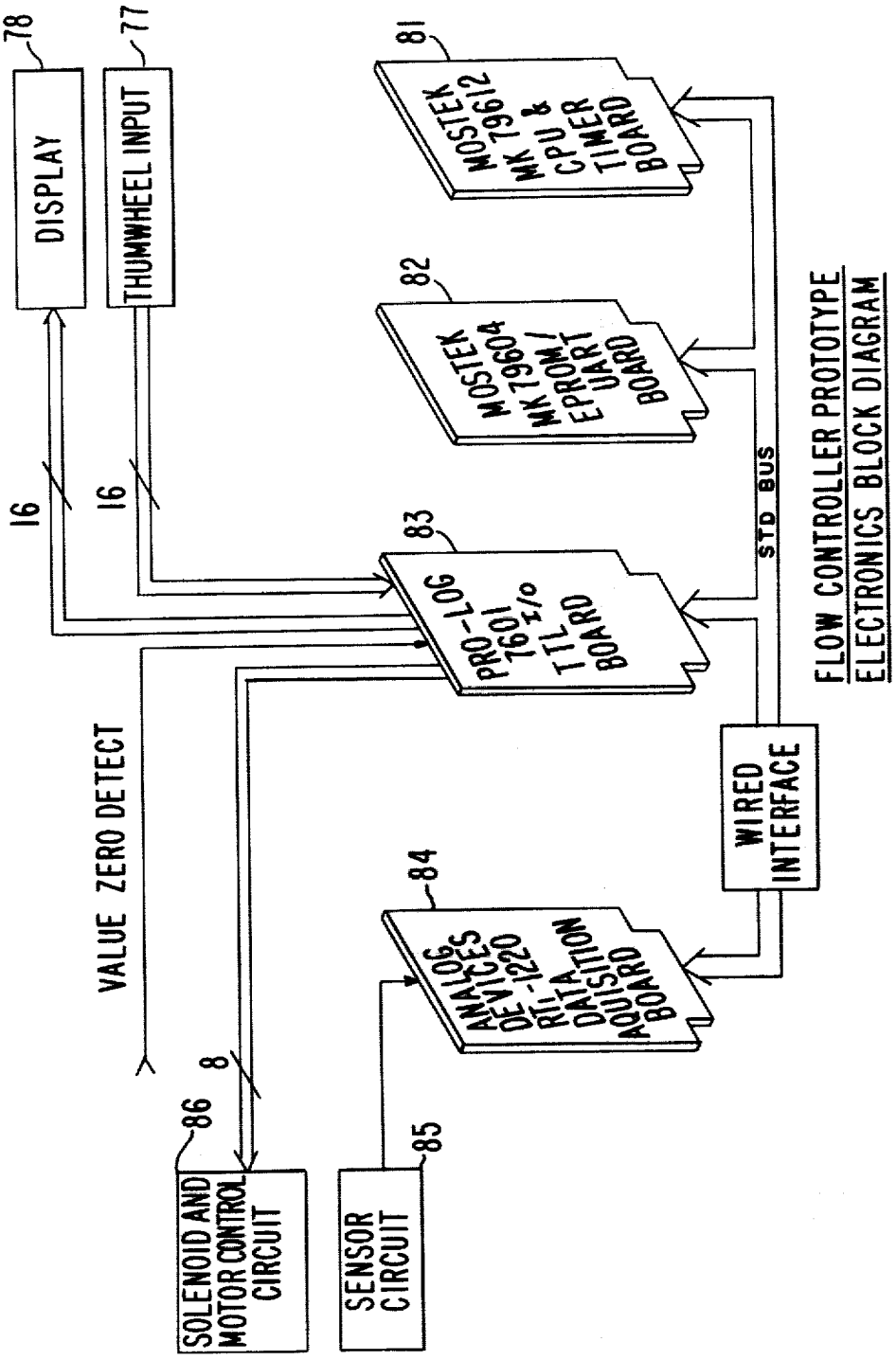
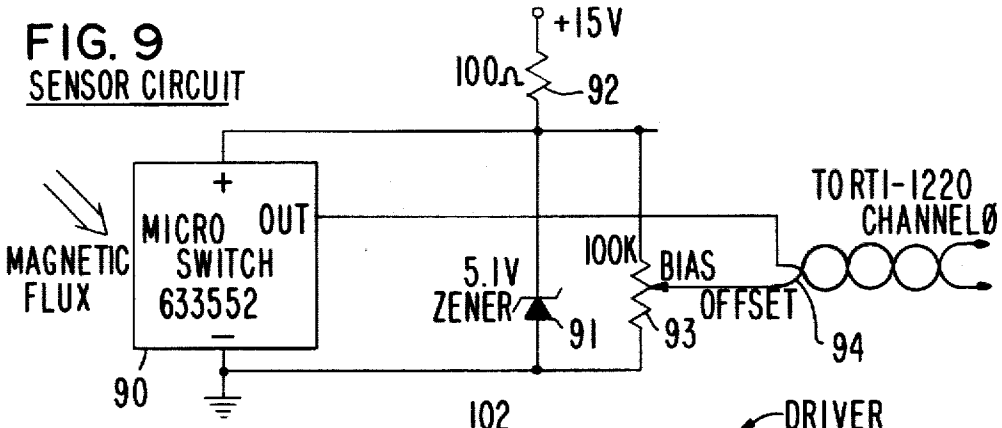


FIG. 8

FLOW CONTROLLER PROTOTYPE ELECTRONICS BLOCK DIAGRAM

FIG. 9
SENSOR CIRCUIT



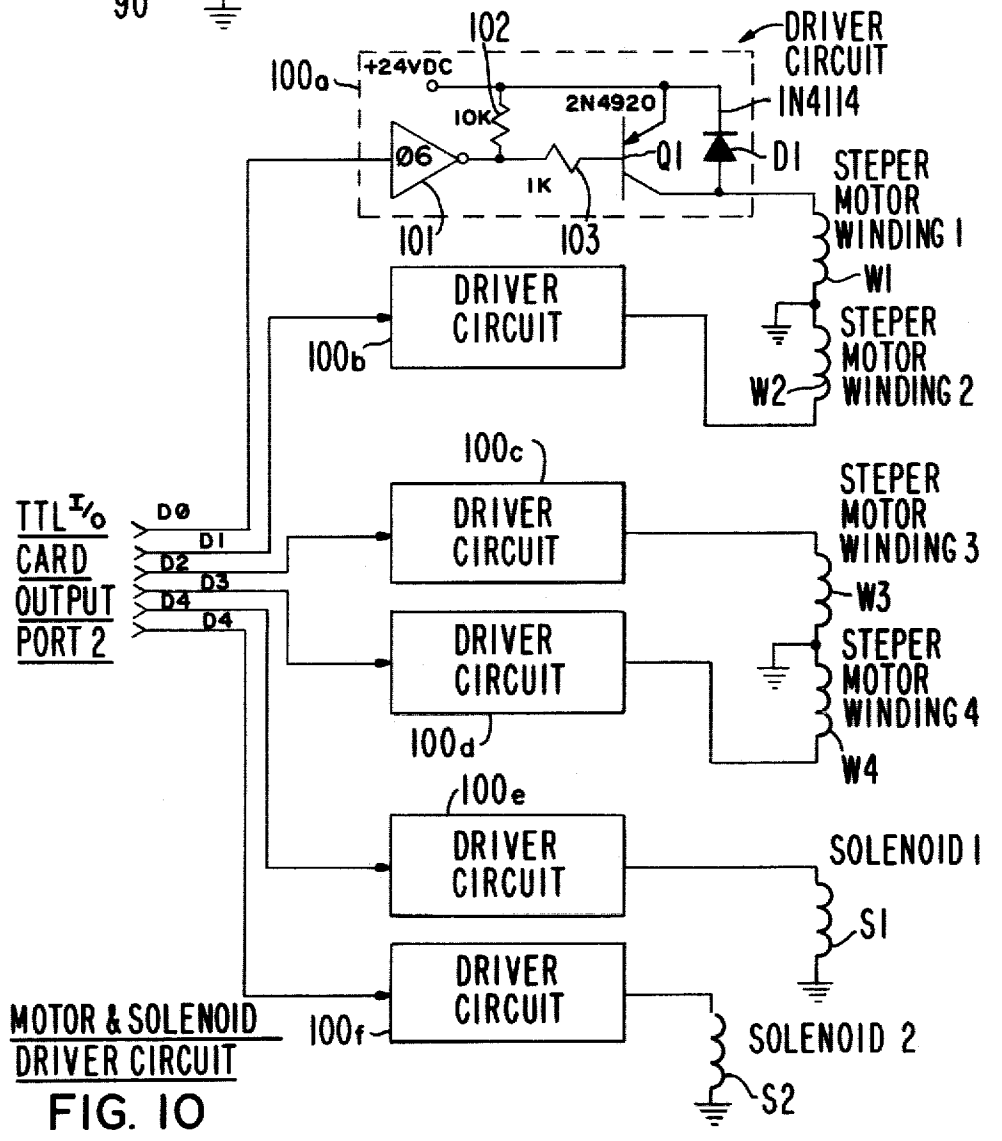
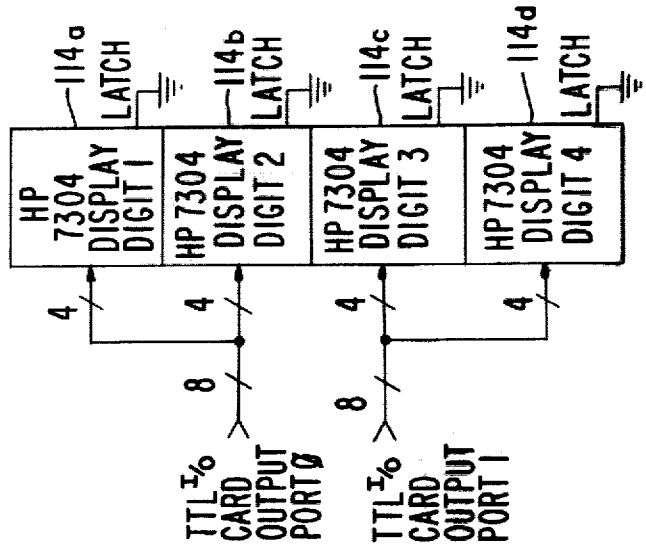
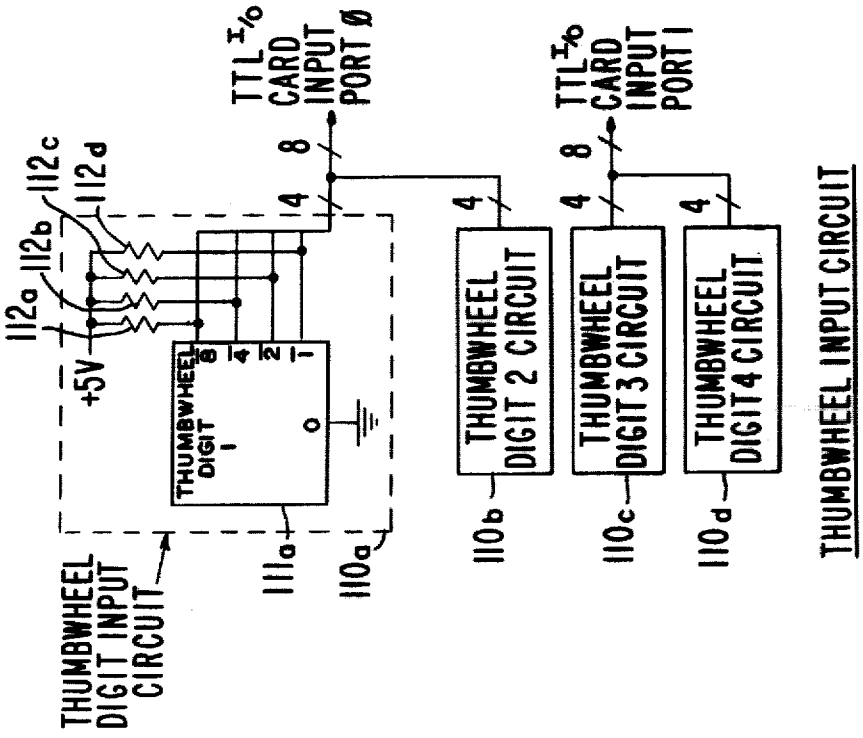


FIG. 10



DISPLAY CIRCUIT

FIG. 11b



THUMBWHEEL INPUT CIRCUIT

FIG. 11a

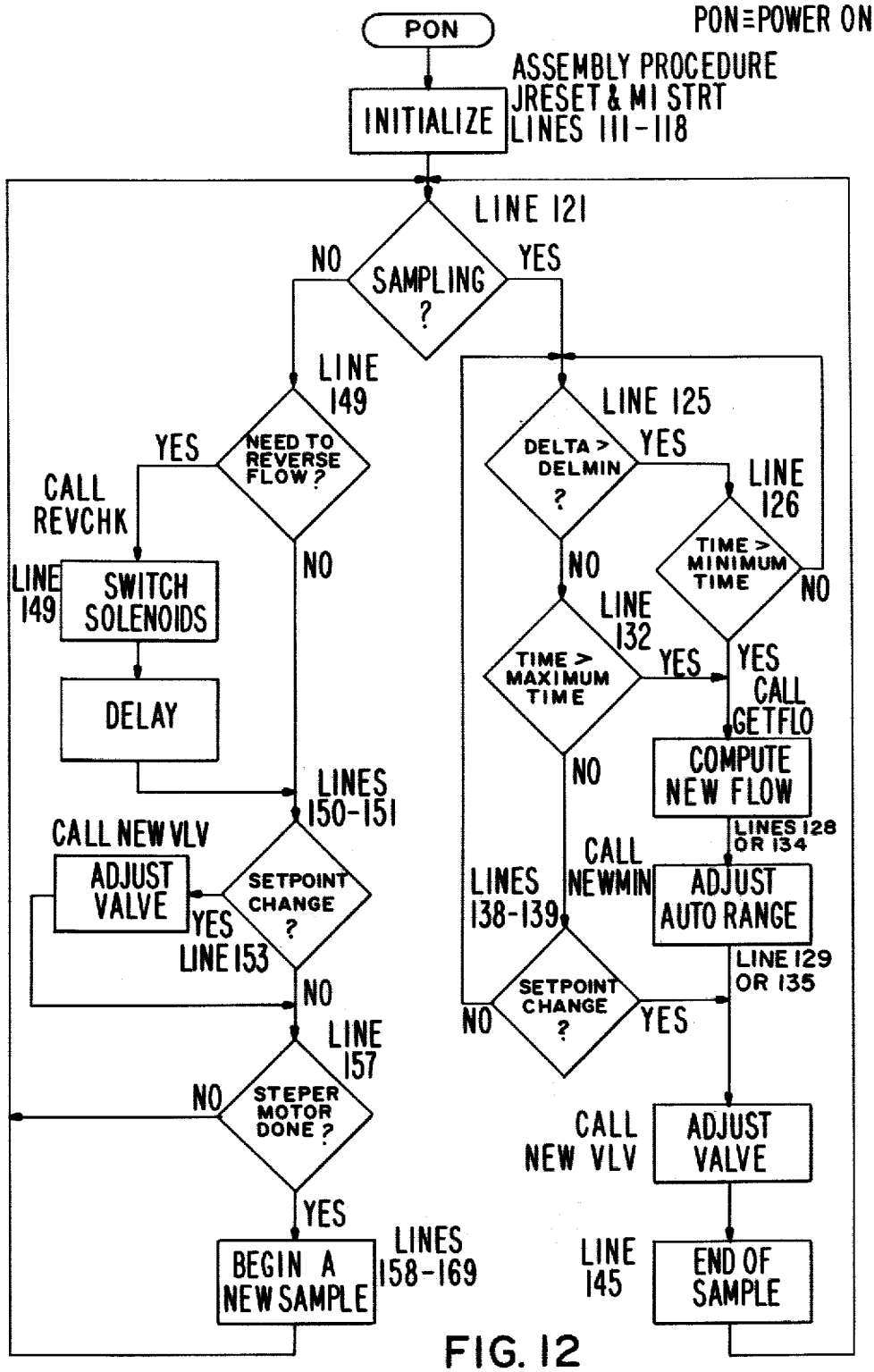

PON
PON=POWER ON
ASSEMBLY PROCEDURE
JRESET & MI STRT
LINES 111-118
INITIALIZE
LINE 121
SAMPLING ?
NO
YES
LINE 149
NEED TO REVERSE FLOW ?
YES
CALL REVCHK
LINE 149
SWITCH SOLENOIDS
DELAY
NO
LINES 150-151
CALL NEW VLV
ADJUST VALVE
SETPOINT CHANGE ?
YES LINE 153
NO
LINE 157
STEPER MOTOR DONE ?
NO
YES
BEGIN A NEW SAMPLE
LINES 158-169
LINE 125
DELTA > DELMIN ?
YES
LINE 126
TIME > MINIMUM TIME
NO
NO
LINE 132
TIME > MAXIMUM TIME
YES
YES CALL GETFLO
COMPUTE NEW FLOW
NO
LINES 128 OR 134
CALL NEWMIN
ADJUST AUTO RANGE
LINES 138-139
LINE 129 OR 135
SETPOINT CHANGE ?
NO
YES
CALL NEW VLV
ADJUST VALVE
LINE 145
END OF SAMPLE

FIG. 12

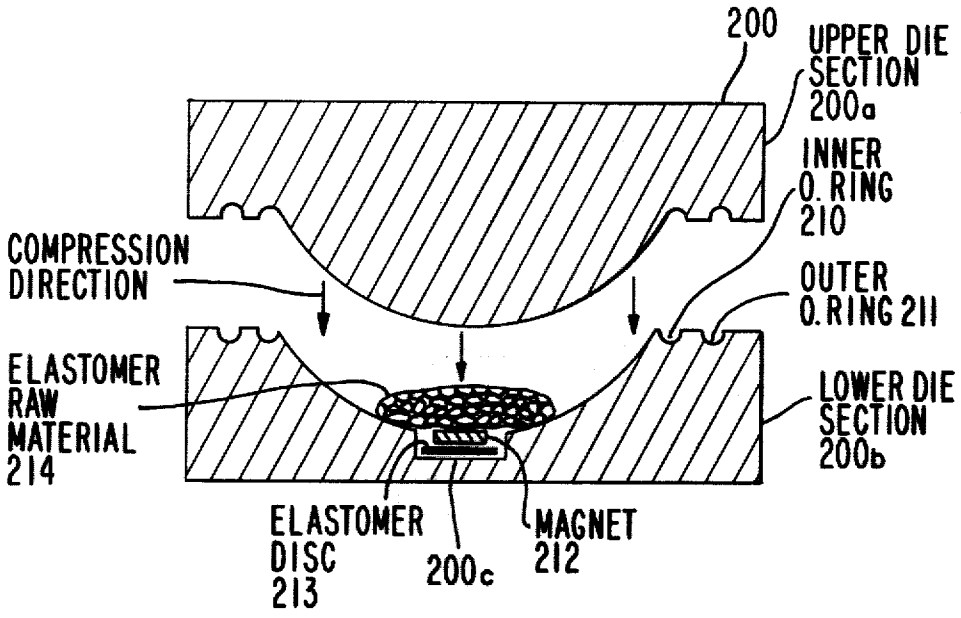

200
UPPER DIE SECTION 200a
INNER O. RING 210
COMPRESSION DIRECTION
OUTER O. RING 211
ELASTOMER RAW MATERIAL 214
LOWER DIE SECTION 200b
ELASTOMER DISC 213
200c
MAGNET 212

FIG. 13

ELECTRONICALLY CONTROLLED FLOW METER AND FLOW CONTROL SYSTEM

1. Field of the Invention

This invention relates to an electronic flow control system using an electronically-controlled positive displacement flow meter.

2. Prior Art

Positive displacement flow meters are well known. Thus British Pat. No. 1,051,710 published Dec. 21, 1966, discloses a positive displacement flow meter utilizing a cylinder wherein a reciprocating piston is controlled to move from one end to the other of the cylinder in response to the alternate passage of the fluid whose flow is being measured into the cylinder at one or the other end of the piston. As fluid under pressure enters one end of the cylinder via an inlet pipe, the piston is pushed along the cylinder and the fluid which entered the cylinder at the other end of the piston as a result of the previous stroke is forced into the outlet pipe. Valves in a well known arrangement allow fluid to alternately enter one end of the cylinder and be withdrawn from the other end of the cylinder and vice versa.

Other positive displacement flow meters are shown in U.S. Pat. No. 2,772,664 issued Dec. 4, 1956 to Jones, et. al., U.S. Pat. No. 3,181,360 issued May 4, 1965 to Hederhorst, and U.S. Pat. No. 3,657,925 issued Apr. 25, 1972 to Gross. The '710, '664, '925 and '360 patents all disclose reciprocating pistons as the positive displacement member. However, the '360 patent discloses in addition, the use of a flexible diaphragm **18** to seal a rigid piston **16** (FIG. **1** of the '360 patent), which travels between two chambers in a cylinder, to the cylinder wall. As one chamber is filled with gas or fluid, a like amount of gas or fluid is expelled from the other chamber. Reversal of the chambers in which gas is inserted and from which the gas is removed causes the diaphragm to reciprocate back and forth across the chamber. The number of strokes of the piston-diaphragm combination (with the diaphragm made of Teflon or rubber), is representative of the volume of gas passing through the meter.

U.S. Pat. No. 3,974,825 issued Aug. 17, 1976 discloses a pump using a flexible, pneumatically-driven diaphragm for pumping blood in an artificial heart.

Each of the above structures has certain disadvantages. A piston introduces inertia and friction into the flow system thereby affecting the flow to be measured. Moreover, the fluid whose flow is being measured often leaks past the piston. In addition, the frequency response of the system is limited by the inertia of the piston. For accurate flow control, a low inertia, low friction, accurate flow meter is required as an essential part of the control system.

SUMMARY OF THE INVENTION

This invention overcomes certain of the disadvantages of the prior art positive displacement flow meters. In accordance with this invention, a novel, low-friction, low-inertia flexible diaphragm containing a magnet formed as an integral part of the diaphragm is mounted in a chamber (preferrably cylindrical). The chamber comprises part of the flow meter in a flow control system. One or more sensing devices are mounted on the walls of the chamber to sense the instantaneous position of the diaphragm. A novel electronic control circuit processes the data from the one or more sensing devices to provide measures of the flow rate during the displacement of the diaphragm along the cylinder. Signals are generated by the electronic control circuitry for switching a pair of three-way valves (one valve comprising the input valve and the other valve comprising the output valve) such that during one-half of a cycle the input valve transfers fluid into the cylinder on one side of the diaphragm and, during the other half of the cycle, transfers fluid into the cylinder on the other side of the diaphragm. The output valve is switched synchronously with the input valve to transmit fluid from the other side or one side of the diaphragm to the output valve.

The electronic control system includes means for amplifying the output signals from the one or more sensing devices ("sensors") to provide one or more signals representing the position of the diaphragm as a function of time, means for converting the output signals from these amplifiers to digital form, and computation means for operating on the digitized output signals from the sensing devices to provide control signals for controlling a second input valve thereby to control the flow rate of the fluid being metered to within a desired range.

As a feature of the invention, an output flow rate is not determined unless and until the diaphragm has traveled a selected distance or until a maximum time has elapsed, thereby to ensure that a minimum volume of fluid has entered the positive displacement flow meter portion of the control system and displaced the diaphragm at least a selected amount. By dividing this displacement by the time over which it occurs, the volumetric flow rate is obtained.

DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates schematically the chamber in which is located the positive displacement diaphragm used for measuring flow rate.

FIGS. **2***a* and **2***b* show diaphragms connected to the chamber by bellows and an O-ring type seal, respectively.

FIG. **3** shows schematically the connection of the sensing element on the end of the chamber containing the diaphragm through an electronic controller to an electronically controlled valve for maintaining the proper fluid flow.

FIG. **4** shows schematically the relationship of the diaphragm, flow chamber, sensing elements, the microcomputer used to compute the control signals used to control the fluid flow rate, the fluid control valve and the structure for controlling the fluid flow into the flow chamber.

FIG. **5***a* shows the reed-switch flow reversal control circuit useful with this invention.

FIG. **5***b* shows a circuit useful with the circuit of FIG. **5***a* for producing an output voltage proportional to flow rate.

FIG. **6** shows a typical output voltage versus displacement curve used with this invention for calibrating the output voltage from a sensing element on the end of the cylinder to the position of the diaphragm within the cylinder.

FIG. **7** shows the microcomputer based flow controller structure connected to the sensing element on the end of the chamber containing the diaphragm.

FIG. **8** shows the relationship of the various circuit boards used to process the signals from the sensor and to control the settings of the three-way flow valves **1** and **2** (FIGS. **1** and **7**) which allow the fluid to pass into

one or the other of the chambers in the cylinder, and which control the setting of the fluid control valve.

FIG. **9** shows a sensor circuit useful with this invention.

FIG. **10** shows the motor and solenoid driver circuits used with this invention.

FIGS. **11***a* and **11***b* show schematically the thumbwheel digit input circuit and the display circuits used with this invention;

FIG. **12** shows the logic diagram for the computer program used in the microcomputer shown in FIG. **7** as part of the structure of this invention; and

FIG. **13** shows schematically the method and structure for fabricating the diaphragm with an enclosed magnet used with this invention.

DETAILED DESCRIPTION

While this invention will be described in conjunction with specific components in the electronic control circuitry, this description is exemplary only and is not intended to limit the scope of the invention.

Turning now to FIG. **1**, a flow chamber **12** containing a right chamber **12***a* and a left chamber **12***b* separated by diaphragm **4** is shown schematically. Diaphragm **4** has mounted on its center as an integral part thereof a magnet **5**. Magnet **5** is completely coated with the material of which diaphragm **4** is constructed to protect magnet **5** from the fluid (possibly corrosive) being metered. On the left face of chamber **12** is a sensor **6***b* and on the right end of chamber **12** is a second sensor **6***a*. If desired, only one sensor (either **6***a* or **6***b*) can be used. While shown as reed switches, preferably, these sensors comprise Hall effect devices of the type known as LOHET (for "linear output, Hall-effect transducer") sensors such as described in more detail in *Electronic Design* 19, dated Sept. 27, 1979, on page 23. This article is incorporated herein by reference. Other Hall effect sensors can, of course, also be used with this invention.

The input flow is transmitted through three-way valve **1** (shown schematically) arranged to allow the flow to pass into line **9** connected directly to left chamber **12***b*. The entry of fluid into left chamber **12***b* displaces diaphragm **4** to the right thereby expelling fluid in the right chamber **12***a* through line **10**. Three-way outlet valve **2** is, in this mode, adjusted to allow the fluid flowing from line **10** to pass directly into the output line.

During the entry of fluid into left chamber **12***b*, diaphragm **4** and magnet **5** move to the right toward Hall effect sensor **6***a*. The output signal from Hall effect sensor **6***a* is a function of the position of magnet **5**, which in turn, is proportional as a function of time, to the rate of fluid flow through line **9** into left chamber **12***b*. As magnet **5** moves closer to sensor **6***a* due to the displacement of diaphragm **4** to the right, the Hall effect sensor **6***a* produces an output signal uniquely related to the position of magnet **5**. This position as a function of time is a function of the flow rate. Sensor **6***a* produces an output signal which is monitored in a manner to be described later by the electronic control circuits. As magnet **5** reaches its rightmost position, a control signal is generated switching valves **1** and **2** such that the input gas now flows through line **7** into rightmost chamber **12***a* while the fluid in leftmost chamber **12***b* is expelled from this chamber through line **8** and outlet valve **2**. Consequently, diaphragm **4** is forced to the left and magnet **5** now travels away from Hall effect sensor **6***a* and toward Hall effect sensor **6***b*. The output voltage from Hall effect sensor **6***b* is also uniquely related to the position of magnet **5**. Since each sensor's output voltage is uniquely related to the position of the diaphragm, by measuring time independently, the sensor output voltage and thus the diaphragm position is determined as a function of time which allows the flow rate to be calculated given a calibration curve of volume versus diaphragm position (as shown in FIG. **6**).

The use of a flexible diaphragm as part of a fluid meter is based on our discovery that, contrary to expectation, the diaphragm position as a function of volume of fluid in each chamber is predictable and repeatable each cycle despite the fact that the diaphragm is flexible and "loose" (i.e., the diaphragm is designed to interfere minimally with the fluid flow). Thus, diaphragm **4** serves to separate the left chamber **12***b* from the right chamber **12***a* while supporting magnet **5**, the position of which is used to measure the fluid flow rate. The calibration of the position of magnet **5** to the output signals from sensors **6***a* and **6***b* is essential to the proper operation of this system. As is apparent from FIG. **1**, diaphragm **4** can easily be replaced should it wear out by separating the two halves of cylinder **12**, removing the old diaphragm and inserting a new diaphragm. Typically, to ensure a leakproof connection, diaphragm **4** has two "O-rings," an inner "O-ring" **210** and an outer "O-ring" **211** as shown in FIG. **13** (which shows the die used to fabricate the diaphragm).

It is apparent from the above description that the position of diaphragm **4** as a function of time is directly proportional to the volumetric flow rate of the fluid. By knowing the temperature and the pressure of the fluid the mass flow rate can be determined in a well known manner.

When sensors **6***a* and **6***b* comprise reed switches, the output signals from these switches occur with a frequency directly proportional to the flow rate and are used directly to actuate electronic circuitry for both valve actuation and feedback or other fluid control purposes. On the other hand, when the output sensors **6***a* and **6***b* are Hall effect devices, a continuous output signal is generated from each of these sensors. This output signal is related to the flow rate. By knowing the calibration curve of output signal level versus displacement of the diaphragm **4** and magnet **5**, the volumetric flow rate can be calculated continuously as a function of the output signals from sensors **6***a* and **6***b*.

Diaphragm **4** is preferably made of an elastomeric material (viton is preferred but neoprene, silicon rubber and butyl rubber can also be used, as appropriate) which is suitable for use for temperatures up to 150° C. (180° C. for viton). For higher temperatures metal bellows can be used in place of the elastomeric diaphragm. The choice of the diaphragm **4** material depends on the particular fluid that is to be used, and the preferred operating temperatures. The differential pressure across the diaphragm is small in comparison to the working fluid pressures. Preferably this pressure difference is negligible. Viton is appropriate for temperatures between −40° C. and 180° C. and pressures between vacuum and 300 atmospheres.

The diaphragm with encapsulated magnet is made by a compression or transfer molding process. In this process (illustrated in FIG. **13**), a metal die **200** containing upper section **200***a* and lower section **200***b*, is fabricated to the exact dimensions of the diaphragm. Die section **200***b* includes a central cavity **200***c* to house the magnet **212** (corresponding to magnet **4** in FIG. **1**). A thin disc of the elastomer material **213** having the same or

slightly larger diameter as the magnet disc **212** (approximately ½ inch and preferably formed of Alnico 8 or Cemarium cobalt) is first inserted into the magnet cavity **200***c* and the magnet **212** is placed on top of this thin disc. A pre-weighed amount of the elastomer raw material **214** is then put on top of the magnet **212**, the material is heated to about 400° F. when Viton is the material and pressure is applied to it by the upper half **200***a* of the die **200** to mold and cure the elastomer **214** to the desired diaphragm shape. The pressure is merely that sufficient to achieve the desired result. The compression is conducted at an elevated temperature whose magnitude depends on the particular elastomer and results in elastomer material **214** and **213** assuming a substantially uniform thickness (typically 0.015" to 0.020" when Viton is the material) and consistency throughout the die **200**. This operation ensures complete encapsulation of the magnet by the elastomer and excellent control of the diaphragm thickness. A Viton diaphragm typically has a durometer of fifty (50).

A particularly suitable valve for use as valves **1** and **2** (FIGS. **1** and 7) is the D30 three-way valve made by Precision Dynamics Company. This valve switches within about eight milliseconds and is fabricated out of 303 and 430 stainless steel with viton elastomer for the seals and O-rings. Other valves are also appropriate depending on design requirements.

The flow measurement by this device is reproducable well within one percent. Diaphragms or bellows can be easily replaced before fatigue sets in.

FIGS. **2***a* and **2***b* show two configurations for the diaphragm inside the cylinder. In FIG. **2***a*, a diaphragm has a magnet mounted internally to it which is protected by the material of the diaphragm. The diaphragm is then connected and sealed to the ends of two bellows. Each bellows is capable of contracting or expanding in response to lateral movement of the diaphragm in response to fluid entry into one or the other chambers of the cylinder. Thus when fluid enters the left chamber of the cylinder, the diaphragm and the magnet move to the right and the fluid in the right chamber is expelled. When fluid enters the right chamber, the magnet and the diaphragm move to the left expelling the fluid in the left chamber. A magnetic sensor mounted on the cylinder detects the motion of the magnet and thereby produces an output signal proportional to the position of the diaphragm. Typically the bellows comprises either a metal or polymer material and the diaphragm likewise comprises a polymer or metal material.

FIG. **2***b* shows a different construction wherein the diaphragm is attached between two portions of the cylinder. Again, a magnet **5** is mounted on the diaphragm **4** and coated with the diaphragm material thereby to protect it from the fluid whose flow is being measured. The entry of fluid to the left chamber **12***b* displaces diaphragm **4** and magnet **5** to the right as with the structure of FIG. **2***a* and similarly the entry of fluid to the right chamber displaces the diaphragm **4** and magnet **5** to the left, again as with the structure of FIG. **2***a*. The diaphragm is constructed such that its motion to the right or left occurs with very little friction or resistive force. Thus the flow of the fluid is not disturbed by the presence of the diaphragm. In addition, the weight of the diaphragm is kept very low thereby minimizing the inertia of the diaphragm. Magnetic sensors **6***b* and **6***a* are mounted on the left and right walls of the cylinder to detect the movement of the diaphragm-mounted magnet **5** to or from a given wall. In both FIGS. **2***a* and **2***b* a conventional set of two three-way flow valves (such as shown in FIG. **1**) is used to first route the fluid into one chamber and out of the other chamber and then to reverse this pattern.

Contrary to the prior art meters using a free flowing piston, wherein the fluid whose flow is being measured can often leak from the left chamber to the right chamber and vice versa, this invention uses a flexible, low inertia diaphragm to seal one chamber from the other and thereby to prevent leakage while at the same time providing a relatively instantaneous measure of fluid flow rate.

FIG. **3** shows the structure of FIG. **1** (or the chambers of FIGS. **2***a* and **2***b*), in combination with an electronic controller **30**, a DC stepping motor **31**, and a clutch or coupling **32** joining the stepping motor to a valve **33** (typically a needle flow valve) for controlling the flow of fluid. The DC stepping motor **31** adjusts the position of the valve **33** until the flow rate detected by the meter corresponds to a flow rate setpoint input to the electronic controller **30**. As will be shown later, the electronic controller **30** preferably comprises a microprocessor controlled digital circuit with an analog-to-digital converter, a sampling circuit, buffer stores, memory and selected input and display elements. The electronic controller **30** also controls the setting of the two three-way valves **1** and **2** to ensure that the fluid flow into the meter and from the meter is reversed at appropriate times to obtain maximum accuracy in the flow measurements. The system provides accurate and responsive feedback (or feed forward if desired) control. In the simplest form, the flow into one side of the cylinder **12** is reversed when the diaphragm reaches its extreme position one way or the other. The flow rate can, in this embodiment, be simply measured by the time it takes for the diaphragm to travel between the two extremes. That is, the flow rate is equal to the volume between the two extreme positions of the diaphragm **4** divided by the time taken by the diaphragm to travel between these two positions.

FIGS. **4** and **5***a* show an embodiment of this invention using a reed switch to detect the maximum displacement of the diaphragm adjacent each of the two walls of the cylinder **12**. The reed switch signal is transmitted to a microcomputer control **30** which then calculates from the time taken for the two reed switches **46***a* and **46***b* to be sequentially actuated, the measured flow rate. This measured flow rate is compared to a reference flow rate set into memory and the difference is used to set a control valve **33** to bring about the proper flow rate. Solenoids and solid state relays are also actuated by the microcomputer control **30** to reverse the fluid flow into cylinder **12** at the maximum displacement points of the diaphragm **4**.

FIG. **5***a* shows a circuit schematic of the structure used to respond to the change in state of the reed switches **46***a* and **46***b* due to the approach of magnet **5**. A flip flop comprising two 7400 NAND gates **41** and **42** has as one input signal to each of the NAND gates the output signal representing the state of a given reed switch. Thus normally, when reed switch **46***a* is open, the signal level on input lead **41***a* to NAND gate **41** is at a high level corresponding to the 5 volt DC supply voltage. The other input lead **41***b* is coupled to the output lead **41***d* from the other NAND gate **42**. The output signal on lead **41***d* is normally high level for at least one low level input signal. Thus, with the signal on output lead **41***c* low level, the signal on input lead **42***b* is

low level and the signal on output lead 41*d* from gate 42 is high level, thereby holding the output signal from gate 41 at low level. When reed switch 46*a* is closed, the input signal on lead 41*a* to NAND gate 41 goes low thereby driving the output signal from NAND gate 41 to a high level. This high level output signal is transmitted to input lead 42*b* of NAND gate 42 and drives the output signal from NAND gate 42 to a low level thereby latching up the output of NAND gate 41 to a high level. The high level output signal from NAND gate 41 is amplified by amplifier 43 and turns off transistor Q10 (2N2904) thereby changing the current through a coil to close two relay control switches thereby activating solenoids to change the settings of the two three-way valves 1 and 2 shown in FIG. 1 and thus to reverse the flow. When diaphragm 4 arrives at the other side of the cylinder 12, reed switch 46*b* closes thereby driving the output signal from NAND gate 42 from low level (corresponding to two high level input signals) to high level thereby driving the output signal from NAND gate 41 to low level. This low level output signal is also amplified and used to turn on transistor Q10 thereby again activating a relay to reverse the two three-way flow valves 1 and 2 (FIG. 1) and thereby again to reverse the fluid flow.

FIG. 6 shows a typical curve of output signal from a Hall effect device (such as sensor 6*b* or 6*a* in FIG. 2*b*) versus position of the flow diaphragm 4. This curve is substantially linear over short portions but gradually flattens out as the diaphragm 4 moves away from the Hall sensor. The slope of voltage versus position (i.e., displacement) is negative such that the output voltage as a function of the distance of the diaphragm from the sensor increases with decreasing distance of the diaphragm from the sensor. Operation of the sensor in a region of substantially steep slope gives greater sensitivity and accuracy to the measurement of the fluid flow than does operation in a region of flatter slope. As will be discussed shortly, this feature is used to enhance the accuracy of certain flow measurements.

FIG. 7 discloses the preferred embodiment of this invention using a microcomputer-controlled digital circuit to provide proper feedback signals to control the flow rate. The microcomputer 81 operates on an output signal produced from the Hall effect sensor 6*b* mounted on the wall of the chamber 12 containing the flexible diaphragm 4 with magnet 5 formed as an integral part thereof.

FIG. 7 shows in block diagram form the electronic control circuitry used to process the information produced by the sensor 6*b* attached to chamber 12 containing the flexible diaphragm 4 used to measure flow rates in accordance with the invention. The output signal from Hall effect sensor 6*b* is transmitted through sensor interface circuit 73 to analog switch 74. Analog switch 74 comprises in one embodiment a well-known device for selecting a particular signal path in response to digital input signals (input to switch 74 on lines 74*a* from control logic 76*a*) for the purpose of passing a selected signal from either a pressure transducer 72*a* and a temperature transducer 72*b* (for the purpose for allowing the mass flow rate to be calculated from the volumetric information produced from the signal generated by sensor 6*b* attached to flow meter chamber 12) or from sensor interface circuit 73.

The output signal from analog switch 74 is transmitted to an analog-to-digital converter 75 of well known construction. Preferably, this converter comprises a twelve bit converter such as is used with the Analog Devices RTI-1220 Data Acquisition Board 84 (FIGS. 7 and 8). The output signal from A-to-D converter 75 comprises a digital signal representing any one of 4,096 possible signal levels. Of course, by selecting an A-to-D converter containing a different number of bits, a different level of accuracy can be obtained.

The output signal from A-to-D converter 75 is then transmitted to input buffer 76*e*. Input buffer 76*e* buffers the output signal from A-to-D converter 75 and holds this information until a request for this information is received from microcomputer 81. Microcomputer 81 comprises a Mostek MK79612 CPU and Timer Board which contains a CPU corresponding to the well known Z80 microprocessor. The MK79612 is shown in more detail in the Mostek publication entitled "MD Series Microcomputer Modules, Operations Manual for MDX-CPU 1" and subtitled "Z80 Central Processor Module MDX-CPU 1", copyright 1978 by Mostek Corporation. This document is also incorporated herein by reference. FIG. 8 shows the relationship of the Mostek MK79612 to the remainder of the circuit, the components of which are also shown in more detail in FIG. 7.

The control logic 76*a*, input buffer 76*e*, A-to-D converter 75 and analog switch 74 comprise the Analog Devices RTI 1220 data acquisition board 84 (shown as such in FIG. 8).

The output latches 76*b*, 76*c* and 76*d* comprise the Pro-Log 7601 TTL I/O board 83 also shown in FIG. 8. The program memory of the microcomputer 81 comprises the Mostek MK79604 Eprom/UART board 82 shown as such in FIG. 8.

The data bus interconnecting the CPU timer and the Eprom/UART portions of the structure to the Pro-Log 7601 TTL I/O board and the Analog Devices RTI 1220 data acquisition board comprises the STD bus, a standard bus used by Mostek and Pro-Log for interconnecting the components of a typical eight bit microcomputer system using an eight bit microprocessor (such as the Z80). The operation of the STD bus is described, for example, in the Pro-Log publication copyrighted 1979 entitled "Series 7000 STD Bus, Technical Manual." The operation of this bus is thus well know in the art and will not be described in detail. The above cited Pro-Log technical manual is incorporated herein by reference.

Control logic 76*a* generates several sets of output signals. First this logic generates a set of signals for controlling the setting of analog switch 74. These signals are transmitted on lead 74*a*. Logic 76*a* is driven by signals taken off the STD bus and generated by microcomputer 81.

Output latch 76*b* (part of TTL I/O Board 83) generates a signal to actuate driver circuit 79*b* which in turn produces signals which operate three-way valves 1 and 2. Driver circuit 79*b* is shown in more detail in FIG. 10 and will be described below.

Additional signals from output latch 76*b* also actuate driver circuits 79*b* which in turn drive stepper motor 79*c*. Stepper motor 79*c* controls the setting of control valve 79*d* which controls the flow rate though valves 1 and 2. Thus the output of latch 76*b* (derived from microcomputer 81) controls the setting of valve 79*d* in response to the flow rate measured from the signals produced by sensor 6*b*.

The reference signal used to determine the magnitude and direction of change in the position of valve 79*d* is derived by comparing the signal representing the flow

rate computed from the signals from sensor **6***b* with another signal placed in input buffer **76***c* and derived from the setting of thumbwheel **77**. The setting of thumbwheel **77** can be varied as desired by the operator thereby changing as desired the setting of control valve **79***d*. Basically, thumbwheel **77** converts a setting visible to the user to four binary-coded decimal digits (corresponding to 16 bits). These signals are held in input buffer **76***c* and are used by microcomputer **81** to calculate the proper control signal to be transmitted through output latch **76***b* to control the setting of valve **79***d*.

Output latch **76***d* is configured to retain the output signals from microcomputer **81** corresponding to the latest reading of the flow rate. The signals retained in latch **76***d* activate display **78** to display the latest value of flow rate calculated by microcomputer **81**.

Structures corresponding to those shown in FIG. **7** are shown in FIG. **8**. Those elements shown in block diagram form in FIG. **8** function as described above in connection with FIG. **7** and thus will not be described in more detail here.

FIGS. **11***a* and **11***b* show in more detail the thumbwheel circuitry **110***a* through **110***b* and the display circuitry **114***a* through **114***b* used with this invention. The thumbwheel is capable of inputting four digits into the circuit. Each digit circuit **110***b*, **110***c* and **110***d* comprises a replica of the specific circuit **110***a* shown figuratively for digit one. This circuit is of a type well known in the arts and thus will not be described in detail except to say that if the thumbwheel is set, for example, on a 7, the switches within the thumbwheel corresponding to the 4, 2 and 1 level signals (connected to the 5 V supply voltage through resistors **112***b*, **112***c* and **112***d*, respectively), are closed thereby to provide an output signal for the TTL input at a level corresponding to the complement of 7 (negative logic). Any other decimal digit from 0 to 9 is selected by closing the corresponding switches to provide an output signal of the proper level.

The display likewise comprises a four digit display. Each display **114***a*, **114***b*, **114***c* and **114***d* comprises a well known decoder driver for taking a BCD input and converting it to a digital number ranging from 0 to 9. Typically, each display comprises an HP 7304 display of a type well known in the art.

FIG. **10** shows in more detail a typical drive circuit of the type used to drive the stepper motor **79***c* and the solenoid driven three-way valves **1** and **2** (the latter two valves being used as described above to reverse the flow in chamber **12**). The driver circuits are driven by signals on input leads **d0** through **d5** derived from the TTL I/O card (FIGS. **7** and **8**). The particular stepper motor windings to be energized depend upon the setting of the stepper motor (a record of which is recorded in the RAM memory of microcomputer **81**) and the direction in which it is desired to move the stepper motor. The stepper motor will move a standard distance (typically (1/200)th of a revolution) once each step. A timer in the microcomputer allows the generation of a new step after a fixed time has elapsed. In the embodiment of this invention, this time is 7.5 milliseconds. The timer on the microcomputer board **81** interfaces with the microcomputer central processing unit (CPU) via interrupts. The timer generates periodically signals which are transmitted to the CPU on a separate line thereby to activate an interrupt circuit within the CPU through an interrupt pin. This signal then activates the CPU to calculate the next setting for the stepper motor; that is the CPU determines whether the stepper motor should be driven such that the control valve **79***d* is either opened or closed based upon the last flow rate reading present in the microcomputer when compared to the thumbwheel setting. Typically, the stepper motor is driven by a sequence of signals on input leads **D0** through **D3** corresponding to hexadecimal **5**, **9**, **6**, A. Thus if the setting of the stepper motor corresponds to a **9**, then the hexadecimal encoded binary **6** transmitted on input leads **D0** through **D3** will activate the stepper motor to move one setting in the proper direction to open. Should the stepper motor be instructed to close rather than open, then a hexadecimal encoded **5** would be transmitted in binary form on leads **D0** through **D3**. In this latter case wherein the most significant digit corresponds to a zero, the second most significant digit corresponds to a one, the third most significant digit corresponds to a zero and the fourth most significant digit corresponds to a one (corresponding to the signals 0101 on leads **D3** through **D0**, respectively), then the "1" on lead **D0** will drive the output signal from inverter **101** to a low level thereby turning on transistor **Q1** and energizing winding **W1**. Diode **D1** prevents voltage pulses generated by changing the current through winding **W1** from burning out transistor **Q1** and resistors **102** and **103** comprise pull-up and base-drive resistors, respectively.

FIG. **9** shows the circuitry associated with the Hall-effect sensor **6***b*. The magnetic flux from the magnet **5** mounted within, and as an integral part of, diaphragm **4**, is converted to a voltage and amplified to produce an output signal. Hall-effect sensor **6***b* preferably comprises part number 633SS2 made by Microswitch, Inc., a division of Honeywell. The output signal from microswitch **90** is transmitted via twisted-pair cable **94** to Analog Devices data acquisition board **84** (FIGS. **7** and **8**). There this output signal activates the processor to operate in a way previously described. Pull-down resistor **92** (100 ohms) is connected between the fifteen volt power supply in series with a 5.1 volt zener diode **91** to ground. Variable resistor **93** (100K) is connected across the node between resistor **92** and diode **91** and ground. Resistor **93** is used to produce a bias offset for the other lead in the twisted pair **94** transmitting the output pulse from microswitch **90** to the data acquisition board **84**. This bias offset comprises a way of compensating for the fact that the curve of flux versus voltage for the Hall-effect sensor does not pass through the origin. By adjusting the setting of variable resistor **93**, the input signal to the control circuitry is offset (i.e., zero adjusted) to provide a signal within a desired range of magnitude.

Operation of the above described structure is implemented by a software program. The Microl high-level language version of this program is attached to this application as Appendix A. This program uses the Microl Language which is described in the User's Manual, Microl Language, dated Mar. 8, 1979. This Manual is incorporated herein by reference.

FIG. **12** illustrates the logic flow diagram of the computer program devised to operate microcomputer and timer **81** (FIGS. **7** and **8**) in accordance with this invention. The computer program is designed to operate on the output signals from sensors **6***b* as processed by the data acquisition board **84** to determine flow rates. To do this one of several algorithms is employed. In the preferred mode of operation the flow rate is measured on a relatively continuous basis as a function of the displacement of diaphragm **4** across chamber **12** with time. This

preferred mode does not depend upon the reversal of the direction of motion of diaphragm **4** to measure the flow rate but does set an optimum reversal point for changing the direction of motion of diaphragm **4** to ensure that at least a minimum voltage difference from sensor **6***b* as a function of the location of diaphragm **4** is obtained in a given time. In the limit, the minimum voltage difference per sample can be expanded to a value corresponding to the reversal point of the diaphragm. In this situation, the preferred mode reduces to the second, reversal dependent mode. In essence, the software emulates the operation of the reed switch mode, but in addition provides an autoranging capability (to be described later).

The second mode of operation contemplated for use with this invention is a reversal dependent mode. The program parameters are set to cover the highest and lowest expected flow rates (which correspond to the shortest and longest times for diaphragm **10** to complete one cycle). The setting of the reversal position for reversing the direction of motion of diaphragm **4** closer to its central neutral position results in a decrease in the cycle time. In this mode of operation, the reversal point is set to ensure at least one sample within some specified time for the lowest expected flow rate. In one embodiment, this specified time is on the order of two (2) seconds. This time must be much greater than eight milliseconds, the switching time of the valves.

In describing the operation of the program of this invention, certain conventions must be defined. Thus in the following description, a "conversion" comprises one look at the voltage produced by sensor **6***b* reflecting the position of diaphgram **4**.

The average of four conversions comprises one "reading." The signal representing the average of these four conversions is a digital signal as is the signal representing each conversion.

Continuous readings are then made of the output signal from sensor **6***b* on a periodic basis until a change in voltage from **6***b* in excess of a minimum voltage change (DELMIN) is obtained. At this time, the systems has completed one "sample."

The system actually takes four conversions at the start of operation and continues taking groups of four conversions and averaging each group of four. Since it takes about 25 microseconds for each A-D conversion and there are four conversions per reading, 100 microseconds are required at a minimum for one reading. After each sample, the program tests to determine whether the direction of movement of the diaphragm should be reversed. Every seven and one-half milliseconds or thereabouts there is an interrupt and for a few microseconds the program then decides whether stepper motor **79***c* should be instructed to step valve **79***d* in one or another direction.

Every flow rate calculated from each sample is sent to a memory location called "FLOW." By comparing the calculated flow rate to the set point (placed in thumbwheel **77**, FIG. 7) using the relationship "set point minus flow rate," a difference signal is obtained. Multiplying this difference signal by some non-negative control function gives a gain for use in determining the proper change in position of valve **79***d*. This gain is placed in "STPSIZ." The non-negative function is in turn a function of "set point minus flow rate" and can also be a function of one or more previous "set point minus flow rate" measurements. A separate interrupt program called "s-timer" looks every $7\frac{1}{2}$ milliseconds at STPSIZ to decide whether to step up or to step down the valve.

In the above calculation, the program uses the subroutine "GETFLO" to calculate the flow. Subroutine "NEWVLV" corresponds to the control function which generates the new valve position. "STPSIZ" corresponds on a one-to-one basis to the steps on a valve. It then takes 7.5 milliseconds for the valve **79***d* to make one step. The program does not sample while the valve is opening or closing.

Once sampling is started, a sample is always obtained before the direction of motion of diaphragm **4** is reversed and before it is necessary to reverse the motion of diaphragm **4**. An important part of the system is the calibration table calibrating the volumetric displacement of the diaphragm to the output signal from sensor **6***b*. To ensure an accurate conversion of the output signal from sensor **6***b* into a flow rate, the volumetric displacement of the diaphragm **4** represented by any given signal from sensor **6***b* must be determined accurately. Techniques for doing this are well known. One such technique comprises the discharge of a fluid from the output line into a vertical stand pipe in which the discharged fluid or gas displaces a colored liquid. By calibrating the stand pipe in terms of milliliters or cubic centimeters, for example, the volumetric displacement of diaphragm **4** can be measured with great accuracy. FIG. **6** shows a curve of voltage from sensor **6***b* versus volumetric displacement of diaphragm **4**.

While the structure in FIG. 7 has been described as using one Hall effect device sensor, using two Hall effect devices, one on each side of chamber **12**, yields twice the sensitivity to the measurement of flow rate. By using two Hall effect devices, the range of the devices is doubled. The diaphragm **4** can then travel a maximum excursion distance in chamber **12** and during its travel in the left portion of the chamber, sensor **6***b* is used while during its travel in the right portion of chamber **12** sensor **6***a* is used. In this manner, both sensors are operated in their range of maximum sensitivity and thus a sensor operating in its maximum range of sensitivity is used over the full travel of the diaphragm **4**.

The thumbwheel **77** (FIGS. 7 and 8) is used to place into the system a "set point" which determines the flow rate to be allowed by valve **79***d*. The set point is placed into the thumbwheel. The system then measures the difference between a new set point and the old set point. The program then loops back through the set point change logic and produces an output signal proportional to the difference between the new set point and the old set point. If there is no change in the set point during this loop back the system then looks at a measured variable called "sampling."

The concept of "sampling" means taking a reading, calculating a diaphragm displacement from the reading, starting a timer within the system, measuring the output voltage from sensor **6***b* and testing to determine whether the minimum change in voltage is greater than a selected value. In the preferred embodiment, the minimum voltage change required to be detected from sensor **6***b* before a flow rate is calculated is 200 millivolts. Thus in reading voltage when sampling, a sufficient voltage change is allowed to ensure that the minimum voltage change has occurred or a maximum time has elapsed without having this minimum voltage change occur. If in this maximum time the system does not record a minimum voltage change (DELMIN) the sys-

tem then assumes zero flow and opens the valve **79***d* (FIG. 7).

If the proper minimum voltage change (DELMIN) is obtained, the system then takes the measured voltage from sensor **6***b* and refers to the proper place on the voltage-displacement calibration curve (FIG. **6**) to calculate the displacement change over time. From the displacement change over time and the time, the average flow rate over this time is calculated. Referring now to the calibration curve (FIG. **6**) it is apparent that as the flow rate becomes lower, the displacement in a given time becomes less and the reversal point on the curve must move from right to left. That is, the diaphragm travels a smaller distance in a given time for a low flow rate than for a high flow rate and thus to maximize the sensitivity of voltage versus displacement, one must operate on the left-most portion of the curve rather than on the flatter right portion of the curve. The right most (farthest from sensor **6***b*) reversal point is selected to ensure that magnet **5** does not hit the wall and that there is time to generate a voltage change equal to DELMIN between the reversal point and the wall. The reversal point closest to sensor **6***b* is selected by a formula $C_1\text{-flow} \times C_2$ where C_1 and C_2 are selected constants equal to 3800 and 5, respectively, in the program of Appendices A and B.

The logic flow diagram shown in FIG. **12** describes the logic of the software program shown in Appendices A and B. The program is implemented in Microl, a block structured language for implementing programs on the Z80. This language is written in PASCAL and modeled after PASCAL. The Microl compiler produces the Z80 assembly language which is assembled and then linked with other modules to form the final object code. Microl is a publicly available high level language and is described in a document entitled "User's Manual Microl Language, Mar. 8, 1979." This document is herein incorporated by reference.

Referring to FIG. **12**, at the start of the program, power on reset results in the program going to "JRESET" which initializes the processor (CPU) and timer, stepper motor and valve. Essentially the program closes the valve and turns off the timer. The program then jumps to the main control algorithm represented in the Microl procedure by MISTRT.

The main control algorithm calls these other Microl procedures to implement the computation of flow or displacement or new valve setting. MISTRT and these other Microl procedures call numerous short assembly language procedures to implement low level functions directly on the hardware (such as moving the stepper up or down one step or outputting to the display LEDs from a specified register). The program includes routines for handling two vectored interrupts (i.e., means in the hardware and program for jumping to different locations in memory when the two interrupts occur) generated by the timer. One interrupt is activated by the timer to keep track of elapsed time during a sample by incrementing a register or memory location every one-half microseconds. Another interrupt is activated by the stepper timer which generates an interrupt every $7\frac{1}{2}$ milliseconds and vectors to the interrupt servicing procedure (STIMER) to determine from memory location (STPSIZ) whether to move the stepper motor up or down or not at all. Once the program has been initialized, the program checks to determine whether or not the system is sampling. If the answer is "no," the program then checks to determine whether the flow into chamber **12** should be reversed. This test, which comprises measuring the output of sensor **6***b* to determine whether diaphragm **4** has reached its minimum or maximum point of excursion, yields either a "yes" or "no." If the answer is yes, the flow should be reversed. The program then initiates the subroutine which switches the solenoids which drive valves **1** and **2** (FIGS. **1** and **7**) through driver circuit **79***b* and initiates a delay to ensure that the flow has actually reversed and the transients in the system have settled before starting to sample to measure flow rate during the reverse motion of the diaphragm. If the logic indicates there is no need to reverse flow, the system then determines whether or not there has been a set point change. If "yes," the valve **79***d* is adjusted by measuring the difference between the new set point and old set point. If the answer is "no," the system moves directly to the logical blocker stepper motor. If the valve was adjusted in response to a set point change, after the valve adjustment is completed the system also moves to the stepper motor logic. The stepper motor logic determines whether or not the stepper motor has moved to its desired position. If the answer is "no," then the system goes back to the initial sampling logic block. If the answer to "stepper motor done?" is "yes," the system begins a new sample and returns to sampling.

If the output of the system sampling block is "yes," the system determines whether the output of the sampling compared to a reference sample is greater than DELMIN. If the answer is "yes," the system determines whether or not the time is greater than the minimum time. If the answer is "yes," then the system computes a new flow rate and, depending upon the time, adjusts the auto range of the system. This last adjustment is an adjustment to the reversal point of diaphragm **4** by changing the level of the output signal from sensor **6***b* at which the direction of motion of diaphragm **4** is reversed. Once auto range has been completed, a new valve position is calculated from the flow rate measurement compared to the set point and valve **79***d* is appropriately adjusted. Finally an end of sample signal is produced which then causes the program to initiate sampling again.

If on the other hand the output signal from the DELMIN logic determines that the difference in the output signal from sensor **6***b* is less than the minimum required, a test is run to determine if the time between this sample and the previous sample is greater than the maximum time. If the answer is "yes," then a new flow rate is calculated and the auto range is adjusted as in the preceding sequence. If the answer is "no," then the system tests to determine if there has been a set point change. If the answer is "yes," the valve is adjusted as described above. If the answer is "no," the system loops back to run another test to determine if the new sampling voltage is greater than DELMIN.

The particular lines on the flow sample in the microcomplier version of the program shown in Appendix A which implement the particular logic block in FIG. **12** are shown on FIG. **12**.

Appendix B gives the assembly language procedures called for by the Microl procedures in Appendix A.

As a feature of this invention, for applications not requiring the precision and versatility of computer controlled logic circuitry, several lower cost embodiments are possible using either the reed switches or the Hall effect devices. A multiple segment down counter can approximate the flow rate by counting down from a

"maximum flow" between flow reversals. The rate of down counting is varied after a time interval lapses (the device will count slower after each elapsed interval). By this method, the function f=(c/t) is approximated by several straight line segments (where f equals the flow rate, c equals the count and t equals the time interval which has elapsed).

The method achieves moderate accuracy over a limited range with good repeatability and produces a direct digital output for very low cost when implemented using discrete logic.

A further improvement is to continuously vary the rate of down counting by using, for example, a capacitive discharge to drive a VCO whose oscillations are then used to drive the down count. It may be necessary to use a capacitive charge if the VCO has a negative voltage to frequency characteristic. In this case a baseline (i.e., zero bias) count would also be taken and subtracted to produce the direct digital representation of the flow.

The capacitive discharge itself can produce an approximation of the flow as a voltage. Accuracy and range is limited but can also be improved by multiple interval method described above with respect to the countdown technique.

The above embodiments disclose the use of sensing devices on the external walls of the chamber. Under some circumstances, the Hall-effect sensor can be molded into the diaphragm (with lead wires also in the diaphragm) and the magnets can be placed on the external walls of the cylinder. Compensation for temperature can be done in either the transducer or externally by a computer using a temperature input. Likewise, compensation for pressure changes can also be done in a similar manner.

FIG. 5*b* illustrates a circuit which produces an output signal inversely proportional to time and therefore provides an output signal directly proportional to the flow rate. In this circuit, a reference voltage is applied to the negative input lead of operational amplifier **54** through input resistor **51**. The positive input lead of operational amplifier **54** is connected through resistor **57** to ground. The reference signal is integrated by capacitor **53** in a well known manner when the gate voltage on reset FET transistor **52** is such that this transistor is turned off (i.e., non-conducting). The negative going output signal from operational amplifier **54** across capacitor **53** is then applied to the gate of depletion mode N-channel FET transistor **56**. This transistor is a linear FET device with the source-drain resistance linearly proportional to the gate voltage. Thus as the gate voltage decreases linearly with time, the source-drain resistance of this transistor (a depletion mode device is normally conducting) increases with gate voltage. Thus, the output voltage from operational amplifier **55** (the negative input lead of which is connected to a reference voltage through input resistor R_G and the positive input lead of which is connected to a suitable reference) drops hyperbolically with time (since its output voltage is proportional to $1/R_F$ where R_F is the source to drain resistance of linear FET **56**). Accordingly, at the time FET transistor **52** is turned on to discharge capacitor **53**, the output voltage from operational amplifier **55** is proportional to the flow rate. Typically, FET transistor **52** is reset at each flow reversal of fluid into cylinder **12**. Thus the output voltage from operational amplifier **55** at this time represents the flow rate and can be sampled and suitably operated on by the other components of this invention, in the manner described above.

APPENDIX A

```
                                MICROL COMPILER VERSION 1.5
 1      0 0     (*$A-,M+,C+$*)
 2      0 0        MODULE TJBM1 ;
 3      0 0     (* Edit # : 44                                                    *
 4      0 0      *                                                               *
 5      0 0      *                                                               *
 6      0 0      *                                                               *
 7      0 0      * Created By: TIM                                               *
 8      0 0      * Date Last Edited: WED, FEB 20, 1980,  6:01 PM                 *
 9      0 0      * Last Edited By: TIM                                           *
10      0 0      * Date Last Compiled/Assembled: WED, FEB 20, 1980,  6:08 PM     *
11      0 0      * Last Compiled/Assembled By: TIM                               *
12      0 0      *                                                               *)
13      0 0
14      0 0     CONSTANT
15      0 0        TRUE=1;FALSE=0;
16      0 0        ADCMAX=3000;  (*HIGH REVERSAL POINT *)
17      0 0        MINMIN=1000;   (*MINIMUM LOW REVERSAL POINT*)
18      0 0        MINMAX=2300;   (*MAX. LOW REVERSAL POINT*)
19      0 0        MINCON=5;      (*AUTORANGING SCALE CONSTANT*)
20      0 0        MSTART=1.0;    (*STARTING VAL. OF d(VALVE)/d(FLOW) *)
21      0 0        MMAX=4.0;      (*MAX VALUE OF d(VALVE)/d(FLOW) *)
22      0 0        MMIN=0.1;      (* MIN. VALUE OF d(VALVE)/d(FLOW) *)
23      0 0        UP=1;DOWN=0;
24      0 0        SLOP=23;      (*FIXUP CONST. FOR PLAY IN VALVE COUPLING*)
25      0 0        SCALE=123.4;  (*CONVERSION CONST TO GET CC/MIN. FLOW *)
26      0 0        MAXTIM=6000; (*MAXIMUM SAMPLE TIME IN .5 mS *)
27      0 0        MINTIM=300;  (*MINIMUM SAMPLE DURATION IN .5 mS*)
28      0 0        DELMIN=300;  (*MIN. READING DIFFERENCE FOR ALLOWABLE SAMPLE*)
29      0 0        VLVMAX=800;  (*MAXIMUM VALVE POSITION IN STEPS FROM CLOSED *)
30      0 0        SPLDLY=20;   (*CONST. FOR DELAY BEFORE STARTING SAMPLE*)
31      0 0        AVECON=2;   (*CONST. FOR 1/2 NO. OF CONVERSIONS PER READING*)
32      0 0
```

```
33      0  0
34      0  0     EXTERNAL
35      0  0        RESET:ASSEMBLY PROCEDURE:BINT;
36      0  0        SETIN:ASSEMBLY PROCEDURE:BINT;
37      0  0        ADCIN:ASSEMBLY PROCEDURE:INTEGER;
38      0  0        ADCSTS:ASSEMBLY PROCEDURE:BOOLEAN;
39      0  0        ADCGO:ASSEMBLY PROCEDURE:BINT;
40      0  0        LEDOUT:ASSEMBLY PROCEDURE:BINT;
41      0  0        SINSTS:ASSEMBLY PROCEDURE:BOOLEAN;
42      0  0        SOUTST:ASSEMBLY PROCEDURE:BOOLEAN;
43      0  0        SIOIN:ASSEMBLY PROCEDURE:CHAR;
44      0  0        SIOOUT:ASSEMBLY PROCEDURE:CHAR;
45      0  0        VLVON:ASSEMBLY PROCEDURE:BINT;
46      0  0        VLVOFF:ASSEMBLY PROCEDURE:BINT;
47      0  0        SOLON:ASSEMBLY PROCEDURE:BINT;
48      0  0        SOLOFF:ASSEMBLY PROCEDURE:BINT;
49      0  0        STPOFF:ASSEMBLY PROCEDURE:BINT;
50      0  0        STPUP:ASSEMBLY PROCEDURE:BINT;
51      0  0        STPDN:ASSEMBLY PROCEDURE:BINT;
52      0  0        TM0ON:ASSEMBLY PROCEDURE:BINT;
53      0  0        TM0OFF:ASSEMBLY PROCEDURE:BINT;
54      0  0        TM1ON:ASSEMBLY PROCEDURE:BINT;
55      0  0        TM1OFF:ASSEMBLY PROCEDURE:BINT;
56      0  0        STMON:ASSEMBLY PROCEDURE:BINT;
57      0  0        STMOFF:ASSEMBLY PROCEDURE:BINT;
58      0  0        INTON:ASSEMBLY PROCEDURE:BINT;
59      0  0        INTOFF:ASSEMBLY PROCEDURE:BINT;
60      0  0        VLVSTS:ASSEMBLY PROCEDURE:BOOLEAN;
61      0  0        DCAL:ASSEMBLY PROCEDURE(INDEX:BINT):INTEGER;
62      1  0
63      1  0
64      1  0        B1,B2,B3,B4:BINT;     (*SCRATCH PAD 8-BIT INTEGERS*)
65      5  0        I1,I2,I3,I4:INTEGER;  (*SCRATCH PAD 16-BIT INTEGERS*)
66     13  0        R1,R2:REAL;           (*SCRATCH PAD FLOATING POINT NOS.*)
67     21  0        DUMMY:BINT;          (*BYTE BUCKET*)
68     22  0        STPPOS:BINT;          (*BITS 0-3=STEPER WINDING ENERGIZ-
69     23  0                              ATION PATERN (1=ON),BITS 4,5 ARE
70     23  0                              SOLONOID 1,2(RESP.) ON/OFF.(1=ON) *)
71     23  0
72     23  0        TIME0:INTEGER;      (*ELAPSED TIME KEPT BY TIMER 0 *)
73     25  0        TIME1:BINT;         (*ELASPED TIME KEPT BY TIMER 1*)
74     26  0        STPSIZ:INTEGER;   (*THIS LOCATION CAN BE LOADED WITH THE
75     28  0                 NO. OF STEPS (+/-) DESIRED TO MOVE THE STEPER;
76     28  0                 IT IS UPDATED AFTER EACH STEP BY THE STEPER
77     28  0                 TIMER INTERUPT ROUTINE.THUS AT ANY TIME IT
78     28  0                 SHOWS THE NO. OF STEPS REMAINING TO BE
79     28  0                 COMPLETED BEFORE THE STEPER IS AT THE DESIRED
80     28  0                 LOCATION.*)
81     28  0
82     28  0        VLVPOS:INTEGER;      (*CURRENT VALVE POSITION*)
83     30  0
84     30  0
85     30  0
86     30  0     GLOBAL
87      0  0        M1STRT:PROCEDURE:BINT;
88      0  0
89      0  0
90      0  0     INTERNAL
91      0  0        GETSET:PROCEDURE:INTEGER;
92      0  0        DELTA:PROCEDURE:INTEGER;
93      0  0        GETFLO:PROCEDURE:INTEGER;
94      0  0        NEWVLV:PROCEDURE:INTEGER;
95      0  0        FIXUP:PROCEDURE:BINT;
96      0  0        REVCHK:PROCEDURE:BINT;
97      0  0        FLOOUT:PROCEDURE:BINT;
98      0  0        DISP:PROCEDURE:REAL;
99      0  0        ADCAVE:PROCEDURE:INTEGER;
100     0  0        DELAY:PROCEDURE:BINT;
101     0  0        NEWMIN:PROCEDURE:INTEGER;
102     0  0
103     0  0        M:REAL;      (*CURRENT d(VALVE)/d(FLOW)*)
104     4  0        ADCOLD:INTEGER; (*READING AT START OF SAMPLE *)
105     6  0        SETPT:INTEGER;   (*CURRENT SETPOINT*)
106     8  0        SAMPLE:BOOLEAN ; (*FLAG SET WHILE TAKING SAMPLE *)
107     9  0        DIR:BINT;  (*DIRECTION VALVE LAST MOVED *)
108    10  0        DSPOLD:REAL; (*DISPLACEMENT AT BEGINNING OF SAMPLE*)
```

```
109    14 0       FLOPOS:INTEGER;  (*VLVPOS FIXED TO ACCOUNT FOR SLOP*)
110    16 0       TIME:INTEGER;    (*TIME FROM BEGINNING OF SAMPLE*)
111    18 0       FLOW:INTEGER;  (*LATEST CALCULATED FLOW*)
112    20 0       DSPNEW:REAL;  (*DISPLACMENT OF LATEST READING*)
113    24 0       ADCNEW:INTEGER;   (*LATEST ADC READING*)
114    26 0       ADCMIN:INTEGER;   (*LATEST LOW REVERSAL POINT*)
115    28 0
116    28 0
117    28 0    (*********BEGINING OF MICROL CODE*********)
118    28 0
119       0  0 PROCEDURE MISTRT (*BINT*);
120       0  0 (* MISTART IS THE MAIN CONTROL ALGORITHM. THE RESET
121       0  0    PROCEDURE JUMPS TO HERE AFTER POWER ON INITIALIZATION.*)
122       0  0 BEGIN
123       8  0 MI:=MSTART;
124      22  0 SAMPLE:=FALSE;
125      27  0 SETPT:=0;
126      34  0 ADCMIN:=MINMIN;
127      41  0 DIR:=DOWN;
128      46  0 FLOPOS:=VLVPOS;
129      54  0 DUMMY:=STMON;
130      60  0 DUMMY:=TMOON;
131      66  0 REPEAT
132      66  0 BEGIN
133      66  0 IF SAMPLE THEN
134      74  0    BEGIN
135      74  0    REPEAT
136      74  0       BEGIN
137      74  0       IF DELTA>DELMIN THEN
138      89  0          IF TIME>MINTIM THEN
139     100  0             BEGIN
140     100  0             FLOW:=GETFLO;
141     106  0             ADCMIN:=NEWMIN;
142     112  0             EXIT;
143     115  0             END;
144     115  0       IF TIME>MAXTIM THEN
145     129  0             BEGIN
146     128  0             FLOW:=GETFLO;
147     134  0             ADCMIN:=NEWMIN;
148     140  0             EXIT;
149     143  0             END;
150     143  0       I1:=SETPT;
151     151  0       IF I1<>GETSET THEN EXIT;
152     167  0       END;
153     169  0    STPSIZ:=NEWVLV;
154     175  0    DUMMY:=FIXUP;
155     181  0    DUMMY:=STMON;
156     187  0    DUMMY:=FLOOUT;
157     193  0    SAMPLE:=FALSE;
158     198  0    END
159     198  0 ELSE
160     201  0    BEGIN
161     201  0    DUMMY:=REVCHK;
162     207  0    I1:=SETPT;
163     215  0    IF I1<>GETSET THEN
164     228  0       BEGIN
165     228  0       STPSIZ:=NEWVLV;
166     234  0       DUMMY:=FIXUP;
167     240  0       DUMMY:=STMON;
168     246  0       END;
169     246  0    IF STPSIZ=0 THEN
170     255  0       BEGIN
171     255  0       DUMMY:=STMOFF;
172     261  0       I1:=SPLDLY;
173     268  0       DUMMY:=DELAY;
174     274  0       I1:=ADCAVE;
175     280  0       TIME0:=0;
176     287  0       I2:=ADCAVE;
177     293  0       ADCNEW:=(I1+I2) DIV 2;
178     309  0       ADCOLD:=ADCNEW;
179     314  0       DSPOLD:=DISP;
180     324  0       DUMMY:=STPOFF;
181     330  0       SAMPLE:=TRUE;
182     335  0       END;
183     335  0    END;
184     335  0 END;
```

```
185   338  0 END;
186   339  0
187   339  0
188   339  0 PROCEDURE GETSET;
189   339  0 (* GETSET INPUTS A SET POINT READING FROM THE THUMBWHEEL*)
190   339  0 BEGIN
191   340  0 REPEAT
192   340  0    BEGIN
193   340  0    DUMMY:=SETIN;
194   346  0    SETPT:=INTEGER(100*INTEGER(B3));
195   352  0    SETPT:=SETPT+10*INTEGER(B2);
196   383  0    SETPT:=SETPT+INTEGER(B1);
197   394  0    IF SETPT>=0 THEN
198   403  0    IF SETPT<1000 THEN EXIT;
199   418  0    B1:=0EH;
200   423  0    B2:=0EH;
201   428  0    DUMMY:=LEDOUT;
202   434  0    END;
203   436  0 RETURN(SETPT);
204   442  0 END;
205   443  0
206   443  0
207   443  0 PROCEDURE DELTA;
208   443  0 (* DELTA COMPUTES THE DIFFERENCE IN THE CURRENT ADC
209   443  0    READING FROM THE READING WHICH STARTED THE SAMLPLE*)
210   443  0 BEGIN
211   448  0 I1:=ADCAVE;
212   454  0 TIME:=TIME0;
213   462  0 I2:=ADCAVE;
214   468  0 ADCNEW:=(I1+I2) DIV 2;
215   484  0 I3:=ADCNEW-ADCOLD;
216   494  0 IF I3<0 THEN I3:=(-I3);
217   518  0 RETURN(I3);
218   524  0 END;
219   525  0
220   525  0 PROCEDURE GETFLO;
221   525  0 (*GETFLO COMPUTES THE FLOW FROM THE CHANGE IN DISPLACMENT
222   525  0   DURING A SAMPLE DIVIDED BY THE LENGTH OF THE SAMPLE*)
223   525  0 BEGIN
224   531  0 DSPNEW:=DISP;
225   541  0 R2:=DSPNEW-DSPOLD;
226   563  0 IF R2<0 THEN R2:=(-R2);
227   585  0 IF TIME=0 THEN TIME:=1;
228   602  0 R1:=(SCALE*R2)/REAL(TIME);
229   640  0 FLOW:=INTEGER(R1);
230   647  0 IF FLOW<0 THEN FLOW:=0;
231   661  0 IF FLOW>9999 THEN FLOW:=9999;
232   681  0 RETURN(FLOW);
233   687  0 END;
234   688  0
235   688  0 PROCEDURE DISP;
236   688  0 (* DISP USES THE CALIBRATION TABLE (ACCESSED THROUGH
237   688  0    DCAL) TO FIND THE VOLUME DISPLACEMENT CORRESPONDING
238   688  0    TO THE CURRENT ADC READING. IT USES LINEAR INTERPOLATION
239   688  0   BETWEEN CALIBRATION POINTS TO MAKE THE CALCULATION*)
240   688  0 BEGIN
241   693  0 B1:=BINT(ADCNEW DIV 100);
242   705  0 B2:=B1+1;
243   709  0 I3:=DCAL(B1);
244   721  0 I1:=DCAL(B2)-I3;
245   740  0 R1:=(REAL(ADCNEW MOD 100))/100.0;
246   773  0 RETURN(REAL(I3)+(R1*REAL(I1)));
247   809  0 END;
248   810  0
249   810  0
250   810  0 PROCEDURE NEWVLV;
251   810  0 (*NEWVLV CALCULATES THE REQUIRED CHANGE IN THE VALVE
252   810  0   POSITION BASED ON THE CURRENT VALVE POSITION,THE
253   810  0   SET POINT, AND THE FLOW. THE RESULT IS THE NUMBER
254   810  0   OF STEPS + OR - TO MOVE THE STEPER.*)
255   810  0 BEGIN
256   816  0 IF FLOPOS>0 THEN
257   829  0 IF FLOW>0 THEN
258   842  0    BEGIN
259   842  0    M:=REAL(FLOW)/REAL(FLOPOS);
260   867  0    IF M>MMAX THEN
```

```
261    879  0        M:=MMAX;
262    893  0     IF M<MMIN THEN
263    915  0        M:=MMIN;
264    929  0     END;
265    929  0  I2:=GETSET-FLOW;
266    942  0  R1:=REAL(I2);
267    953  0  I2:=INTEGER(R1*M);
268    975  0  IF I2<-200 THEN I2:=-200;
269    989  0  IF I2>200 THEN I2:=200;
270   1009  0  FLOPOS:=FLOPOS+I2;
271   1020  0  IF FLOPOS<0 THEN FLOPOS:=0;
272   1033  0  IF FLOPOS>VLVMAX THEN FLOPOS:=VLVMAX;
273   1053  0  RETURN(I2);
274   1059  0  END;
275   1060  0
276   1060  0  PROCEDURE FIXUP;
277   1060  0  (*FIXUP ALTERS THE NUMBER OF STEPS SENT TO THE STEPER
278   1060  0    TO ACCOUNT FOR THE SLOP IN THE COUPLING WHEN CHANGING
279   1060  0    DIRECTIONS.*)
280   1060  0  BEGIN
281   1065  0  IF STPSIZ>0 THEN
282   1078  0  IF DIR=DOWN THEN
283   1085  0     BEGIN
284   1085  0     STPSIZ:=STPSIZ+SLOP;
285   1093  0     DIR:=UP;
286   1098  0     END;
287   1098  0  IF STPSIZ<0 THEN
288   1110  0  IF DIR=UP THEN
289   1118  0     BEGIN
290   1118  0     STPSIZ:=STPSIZ-SLOP;
291   1130  0     DIR:=DOWN;
292   1135  0     END;
293   1135  0  END;
294   1136  0
295   1136  0
296   1136  0  PROCEDURE REVCHK;
297   1136  0  (* REVCHK CHECKS TO SEE IF THE FLOW SHOULD BE REVERSED
298   1136  0     BASED ON THE CURRENT VALUE OF ADCMIN AND ADCMAX.
299   1136  0     IF SO IT PERFORMS THE REVERSAL AND ALLOWS A SHORT
300   1136  0     DELAY FOR STABILITY*)
301   1136  0  BEGIN
302   1142  0  DUMMY:=INTOFF;
303   1148  0  I4:=(ADCAVE+ADCAVE) DIV 2;
304   1165  0  DUMMY:=INTON;
305   1171  0  IF I4>ADCMAX THEN
306   1184  0     DUMMY:=SOLON;
307   1190  0     REPEAT
308   1190  0        IF ADCAVE<(ADCMAX-50) THEN EXIT;
309   1207  0  IF I4<ADCMIN THEN
310   1220  0     DUMMY:=SOLOFF;
311   1226  0     REPEAT
312   1226  0        IF ADCAVE>(ADCMIN+50) THEN EXIT;
313   1249  0  END;
314   1250  0
315   1250  0
316   1250  0  PROCEDURE FLOOUT;
317   1250  0  (*FLOOUT TAKES THE CURRENT VALUE OF THE FLOW AND OUTPUTS
318   1250  0    IT TO THE LED DISPLAY*)
319   1250  0  BEGIN
320   1256  0  B1:=0EH;
321   1261  0  B2:=0EH;
322   1266  0  B3:=0EH;
323   1271  0  I1:=FLOW;
324   1279  0  IF I1>=0 THEN
325   1289  0  IF I1<10000 THEN
326   1301  0     BEGIN
327   1301  0     B1:=BINT(I1 MOD 10);
328   1314  0     I1:=I1 DIV 10;
329   1325  0     B2:=BINT(I1 MOD 10);
330   1335  0     I1:=I1 DIV 10;
331   1346  0     B3:=BINT(I1 MOD 10);
332   1356  0     I1:=I1 DIV 10;
333   1367  0     B4:=BINT(I1 MOD 10);
334   1377  0     END;
335   1377  0  DUMMY:=LEDOUT;
336   1383  0  END;
```

```
 337    1384  0
 338    1384  0
 339    1384  0 PROCEDURE ADCAVE;
 340    1384  0 (*ADCAVE TAKES "AVECON" ADC CONVERSIONS AND AVERAGES THEM TO
 341    1384  0   REDUCE ERROR AND NOISE*)
 342    1384  0 BEGIN
 343    1392  0    B1:=AVECON;
 344    1397  0    I4:=0;
 345    1404  0    REPEAT
 346    1404  0       BEGIN
 347    1404  0       DUMMY:=ADCGO;
 348    1410  0       REPEAT
 349    1410  0          IF ADCSTS THEN EXIT;
 350    1423  0       I4:=I4+ADCIN;
 351    1434  0       IF DECZ(B1) THEN EXIT;
 352    1444  0       END;
 353    1446  0    I4:=I4 DIV AVECON;
 354    1457  0    RETURN(I4);
 355    1460  0 END;
 356    1461  0
 357    1461  0
 358    1461  0 PROCEDURE DELAY;
 359    1461  0 (*DELAY IS A DELAY LOOP WHICH DELAYS I1/2 MILLISECONDS*)
 360    1461  0 BEGIN
 361    1463  0 TIME0:=0;
 362    1470  0 REPEAT
 363    1470  0    IF TIME0>I1 THEN EXIT;
 364    1488  0 END;
 365    1489  0
 366    1489  0
 367    1489  0 PROCEDURE NEWMIN;
 368    1489  0 (*NEWMIN CALCULATES A NEW REVERSAL POINT BASED ON THE
 369    1489  0   CURRENT FLOW*)
 370    1489  0 BEGIN
 371    1496  0 ADCMIN:=MINMAX-(MINCON*FLOW);
 372    1516  0 IF ADCMIN>MINMAX THEN ADCMIN:=MINMAX;
 373    1536  0 IF ADCMIN<MINMIN THEN ADCMIN:=MINMIN;
 374    1552  0 END;
 375    1553  0
 376    1553  0
 377    1553  0 END.
 378    1553  0
 379    1553  0
ERROR COUNT  0
```

APPENDIX B

```
'40 RELOCATABLE ASSEMBLER -- VERSION 2.3  THU, FEB  7, 1980,  5:42 PM

 LINE  ERR ADDR R OBJECT
----   --- ---- - ------

   1                      (*$A+,M+,C+$*)
   2                         MODULE TJBA1 ;
   3                      (* Edit # : 9
   4                       *
   5                       *
   6                       *
   7                       * Created By: TIM
   8                       * Date Last Edited: THU, FEB  7, 1980,  5:39 PM
   9                       * Last Edited By: TIM
  10                       * Date Last Compiled/Assembled: THU, FEB  7, 1980,  5:41
  11                       * Last Compiled/Assembled By: TIM
  12                       *
  13                      *LIST
  14      ;(*$A+,M+,C+$*)
  15      0000            M?TJBA1             EQU $
  16      ;   MODULE TJBA1 ;
  17      ;(* Edit # : 9                                                    *
  18      ; *                                                              *
  19      ; *                                                              *
  20      ; *                                                              *
  21      ; * Created By: TIM                                              *
  22      ; * Date Last Edited: THU, FEB  7, 1980,  5:39 PM                 *
  23      ; * Last Edited By: TIM                                          *
```

```
24      ; * Date Last Compiled/Assembled: THU, FEB  7, 1980,  5:41 PM  *
25      ; * Last Compiled/Assembled By: TIM                            *
26      ; *                                                            *)
27      ;
28      ;EXTERNAL
30                      M?MISTRT            EXT L?MISTRT
31      ;   MISTRT:PROCEDURE:BINT;
32      ;
33      ;
34      ;
35      0000                            DATA
36      ;GLOBAL
38                      M?RESET             GBL L?RESET
39      ;   RESET:ASSEMBLY PROCEDURE:BINT;
41                      M?SETIN             GBL L?SETIN
42      ;   SETIN: ASSEMBLY PROCEDURE: BINT;
44                      M?ADCIN             GBL L?ADCIN
45      ;   ADCIN:ASSEMBLY PROCEDURE:INTEGER;
47                      M?ADCSTS            GBL L?ADCSTS
48      ;   ADCSTS:ASSEMBLY PROCEDURE:BOOLEAN;
50                      M?ADCGO             GBL L?ADCGO
51      ;   ADCGO:ASSEMBLY PROCEDURE:BINT;
53                      M?LEDOUT            GBL L?LEDOUT
54      ;   LEDOUT:ASSEMBLY PROCEDURE:BINT;
56                      M?SINSTS            GBL L?SINSTS
57      ;   SINSTS:ASSEMBLY PROCEDURE:BOOLEAN;
59                      M?SOUTST            GBL L?SOUTST
60      ;   SOUTST:ASSEMBLY PROCEDURE:BOOLEAN;
62                      M?SIOIN             GBL L?SIOIN
63      ;   SIOIN:ASSEMBLY PROCEDURE:CHAR;
65                      M?SIOOUT            GBL L?SIOOUT
66      ;   SIOOUT:ASSEMBLY PROCEDURE:CHAR;
68                      M?VLVON             GBL L?VLVON
69      ;   VLVON:ASSEMBLY PROCEDURE:BINT;
71                      M?VLVOFF            GBL L?VLVOFF
72      ;   VLVOFF:ASSEMBLY PROCEDURE:BINT;
74                      M?SOLON             GBL L?SOLON
75      ;   SOLON:ASSEMBLY PROCEDURE:BINT;
77                      M?SOLOFF            GBL L?SOLOFF
78      ;   SOLOFF:ASSEMBLY PROCEDURE:BINT;
80                      M?STPOFF            GBL L?STPOFF
81      ;   STPOFF:ASSEMBLY PROCEDURE:BINT;
83                      M?STPUP             GBL L?STPUP
84      ;   STPUP:ASSEMBLY PROCEDURE:BINT;
86                      M?STPDN             GBL L?STPDN
87      ;   STPDN:ASSEMBLY PROCEDURE:BINT;
89                      M?TM0ON             GBL L?TM0ON
90      ;   TM0ON:ASSEMBLY PROCEDURE:BINT;
92                      M?TM0OFF            GBL L?TM0OFF
93      ;   TM0OFF:ASSEMBLY PROCEDURE:BINT;
95                      M?TM1ON             GBL L?TM1ON
96      ;   TM1ON:ASSEMBLY PROCEDURE:BINT;
98                      M?TM1OFF            GBL L?TM1OFF
99      ;   TM1OFF:ASSEMBLY PROCEDURE:BINT;
101                     M?STMON             GBL L?STMON
102     ;   STMON:ASSEMBLY PROCEDURE:BINT;
104                     M?STMOFF            GBL L?STMOFF
105     ;   STMOFF:ASSEMBLY PROCEDURE:BINT;
107                     M?INTOFF            GBL L?INTOFF
108     ;   INTOFF:ASSEMBLY PROCEDURE:BINT;
110                     M?INTON             GBL L?INTON
111     ;   INTON:ASSEMBLY PROCEDURE:BINT;
113                     M?VLVSTS            GBL L?VLVSTS
114     ;   VLVSTS:ASSEMBLY PROCEDURE:BOOLEAN;
115     ;
116     ;
117                     M?B1                GBL BINT
118     0000            M?B1                DEFS    1
119                     M?B2                GBL BINT
120     0001            M?B2                DEFS    1
121                     M?B3                GBL BINT
122     0002            M?B3                DEFS    1
123                     M?B4                GBL BINT
124     0003            M?B4                DEFS    1
125     ;   B1,B2,B3,B4:BINT;
```

```
126                             M2I1            GBL INTEGER
127     0004                    M2I1            DEFS    2
128                             M2I2            GBL INTEGER
129     0006                    M2I2            DEFS    2
130                             M2I3            GBL INTEGER
131     0008                    M2I3            DEFS    2
132                             M2I4            GBL INTEGER
133     000A                    M2I4            DEFS    2
134     ;   I1,I2,I3,I4:INTEGER;
135                             M2R1            GBL REAL
136     000C                    M2R1            DEFS    4
137                             M2R2            GBL REAL
138     0010                    M2R2            DEFS    4
139     ;   R1,R2:REAL;
140                             M2C1            GBL CHAR
141     0014                    M2C1            DEFS    1
142     ;   C1:CHAR;
143                             M2DUMMY         GBL BINT
144     0015                    M2DUMMY         DEFS    1
145     ;   DUMMY:BINT;
146                             M2STPPOS        GBL BINT
147     0016                    M2STPPOS        DEFS    1
148     ;   STPPOS:BINT;
149                             M2TIME0         GBL INTEGER
150     0017                    M2TIME0         DEFS    2
151     ;   TIME0:INTEGER;
152                             M2TIME1         GBL BINT
153     0019                    M2TIME1         DEFS    1
154     ;   TIME1:BINT;
155                             M2STPSIZ        GBL INTEGER
156     001A                    M2STPSIZ        DEFS    2
157     ;   STPSIZ:INTEGER;
158                             M2VLVPOS        GBL INTEGER
159     001C                    M2VLVPOS        DEFS    2
160     ;   VLVPOS:INTEGER;
161     ;
162     ;
163     001E                            DATA
164     ;INTERNAL
165     ;   LOROM:ASSEMBLY PROCEDURE:BINT;
166     ;   PRCSET:ASSEMBLY PROCEDURE:BINT;
167     ;   MEMSET:ASSEMBLY PROCEDURE:BINT;
168     ;   PORTSET:ASSEMBLY PROCEDURE:BINT;
169     ;   ADCSET:ASSEMBLY PROCEDURE:BINT;
170     ;   SIOSET:ASSEMBLY PROCEDURE:BINT;
171     ;   CTCSET:ASSEMBLY PROCEDURE:BINT;
172     ;   STPSET:ASSEMBLY PROCEDURE:BINT;
173     ;   TIMER0:ASSEMBLY PROCEDURE:BINT;
174     ;   TIMER1:ASSEMBLY PROCEDURE:BINT;
175     ;   STIMER:ASSEMBLY PROCEDURE:BINT;
176     ;   JRESET:ASSEMBLY PROCEDURE:BINT;
177     ;   JSLTIN: ASSEMBLY PROCEDURE: BINT;
178     ;   JADCIN:ASSEMBLY PROCEDURE:INTEGER;
179     ;   JADCSTS:ASSEMBLY PROCEDURE:BOOLEAN;
180     ;   JADCSO:ASSEMBLY PROCEDURE:BINT;
181     ;   JLEDOUT:ASSEMBLY PROCEDURE:BINT;
182     ;   JSINSTS:ASSEMBLY PROCEDURE:BOOLEAN;
183     ;   JSOUTST:ASSEMBLY PROCEDURE:BOOLEAN;
184     ;   JSTOIN:ASSEMBLY PROCEDURE:CHAR;
185     ;   JSIDOUT:ASSEMBLY PROCEDURE:CHAR;
186     ;   JVLVON:ASSEMBLY PROCEDURE:BINT;
187     ;   JVLVOFF:ASSEMBLY PROCEDURE:BINT;
188     ;   JSOLON:ASSEMBLY PROCEDURE:BINT;
189     ;   JSOLOFF:ASSEMBLY PROCEDURE:BINT;
190     ;   JSTPOFF:ASSEMBLY PROCEDURE:BINT;
191     ;   JSTPUP:ASSEMBLY PROCEDURE:BINT;
192     ;   JSTPON:ASSEMBLY PROCEDURE:BINT;
193     ;   JTM0ON:ASSEMBLY PROCEDURE:BINT;
194     ;   JTM0OFF:ASSEMBLY PROCEDURE:BINT;
195     ;   JTM1ON:ASSEMBLY PROCEDURE:BINT;
196     ;   JTM1OFF:ASSEMBLY PROCEDURE:BINT;
197     ;   JSTMON:ASSEMBLY PROCEDURE:BINT;
198     ;   JSTMOFF:ASSEMBLY PROCEDURE:BINT;
199     ;   JINTOFF:ASSEMBLY PROCEDURE:BINT;
200     ;   JINTON:ASSEMBLY PROCEDURE:BINT;
```

```
201       ;   JVLVSTS:ASSEMBLY PROCEDURE:BOOLEAN;
202       ;
203       ;
204                           *NOLIST
207                           *LIST
208       0000                SETLO:    EQU       0
209       0001                SETHI:    EQU       1
210       0000                LEDLO:    EQU       0
211       0001                LEDHI:    EQU       1
212       0002                STPOUT:   EQU       2
213       0002                STATIN:   EQU       2
214       F0FC                ADCLO:    EQU       0F0FCH
215       F0FD                ADCHI:    EQU       0F0FDH
216       F0FH                ADCEOC:   EQU       0F0FHH
217       F0FF                ADCSEL:   EQU       0F0FFH
218       F0F9                ADCMUX:   EQU       0F0F9H
219       F0FA                ADCCON:   EQU       0F0FAH
220       00D0                SIOCON:   EQU       0D0H
221       00DE                SIOSC:    EQU       0DEH
222       00D0                SIOSTS:   EQU       0D0H
223       00DC                SIODAT:   EQU       0DCH
224       0040                DAVMSK:   EQU       40H
225       0080                RDYMSK:   EQU       80H
226       007C                CTC0:     EQU       7CH
227       007D                CTC1:     EQU       7DH
228       007E                CTC2:     EQU       7EH
229       007F                CTC3:     EQU       7FH
230       0008                CTCVEC:   EQU       08H
231       0085                CTCEN:    EQU       85H
232       00A5                CTCSEN:   EQU       0A5H
233       0003                CTCRES:   EQU       03H
234       0001                CTCDIS:   EQU       01H
235       004C                CTCTC:    EQU       76
236       004B                CTCSTC:   EQU       75
237       0320                VLVMAX:   EQU       800
238       0000                                    CODE
239       0000                M?MEMSET                EQU $
240       FF00                DSTART:   EQU       0FF00H
241       FFFF                DTOP:     EQU       0FFFFH
242       0000                R1:       EQU       M?R1
243       0001                R2:       EQU       M?R2
244       0002                R3:       EQU       M?R3
245       0003                R4:       EQU       M?R4
246       0004                I1:       EQU       M?I1
247       0006                I2:       EQU       M?I2
248       0008                I3:       EQU       M?I3
249       000A                I4:       EQU       M?I4
250       000C                P1:       EQU       M?P1
251       0010                P2:       EQU       M?P2
252       0014                C1:       EQU       M?C1
253       0018                DUMMY:    EQU       M?DUMMY
254       0016                STPPOS:   EQU       M?STPPOS
255       0017                TIME0:    EQU       M?TIME0
256       0019                TIME1:    EQU       M?TIME1
257       001A                STPSIZ:   EQU       M?STPSIZ
258       001C                VLVPOS:   EQU       M?VLVPOS
259       0000                                    CODE
260       0000                M?PRCSET                EQU $
261       007D                RESET     EQU       M?RESET
262       0108                TIMER0:   EQU       M?TIMER0
263       0123                TIMER1:   EQU       M?TIMER1
264       0134                STIMER:   EQU       M?STIMER
265       0194                TM0ON:    EQU       M?JTM0ON
266       019E                TM0OFF:   EQU       M?JTM0OFF
267       01A9                TM1ON:    EQU       M?JTM1ON
268       01B3                TM1OFF:   EQU       M?JTM1OFF
269       01BA                STMON:    EQU       M?JSTMON
270       01C4                STMOFF:   EQU       M?JSTMOFF
271       00E7                CTCSET:   EQU       M?CTCSET
272       023A                SIOSET:   EQU       M?SIOSET
273       0208                ADCSET:   EQU       M?ADCSET
274       02E8                STPSET    EQU       M?STPSET
275       00E5                INTOFF:   EQU       M?JINTOFF
276       00F3                INTON:    EQU       M?JINTON
277       0292                STPUP:    EQU       M?JSTPUP
```

```
278   02B0                STPDN:   EQU     M?JSTPDN
279   02BA                STPOFF:  EQU     M?JSTPOFF
280   0215                LEDOUT:  EQU     M?JLEDOUT
281   0306                VLVSTS:  EQU     M?JVLVSTS
282   0000                                 CODE
283   0000                M?LOROM          EQU $
284                       *NOLIST
286                       *LIST
287   0005 C 0901         VEC0:    DEFW    TIMER0
288   0007 C 2301         VEC1:    DEFW    TIMER1
289   0009 C 3401         VEC2:    DEFW    STIMER
290   000B C 7000         VEC3:    DEFW    RESET
291                       *NOLIST
295                       *LIST
296   0035 C C37D00       I8080:   JP      RESET
297                       *NOLIST
302                       *LIST
303   0066 C C37D00       NMI:     JP      RESET
304                       *NOLIST
307                       *LIST
308   007D                                 CODE
309   007D                M?RESET          EQU $
310   0070 C C3CB00               JP       M?JRESET
311   ;
312   0080                                 CODE
313   0080                M?SETIN          EQU $
314   0080 C C3CF01               JP       M?JSETIN
315   0083                                 CODE
316   0083                M?ADCIN          EQU $
317   0083 C C3FD01               JP       M?JADCIN
318   0086                                 CODE
319   0086                M?ADCSTS         EQU $
320   0086 C C3F401               JP       M?JADCSTS
321   0089                                 CODE
322   0089                M?ADCGO          EQU $
323   0089 C C31102               JP       M?JADCGO
324   008C                                 CODE
325   008C                M?LEDOUT         EQU $
326   008C C C31502               JP       M?JLEDOUT
327   008F                                 CODE
328   008F                M?SINSTS         EQU $
329   008F C C34302               JP       M?JSINSTS
330   0092                                 CODE
331   0092                M?SOUTST         EQU $
332   0092 C C34C02               JP       M?JSOUTST
333   0095                                 CODE
334   0095                M?SIOIN          EQU $
335   0095 C C35502               JP       M?JSIOIN
336   0098                                 CODE
337   0098                M?SIOOUT         EQU $
338   0098 C C35802               JP       M?JSIOOUT
339   009B                                 CODE
340   0098                M?VLVON          EQU $
341   009B C C35E02               JP       M?JVLVON
342   009E                                 CODE
343   009E                M?VLVOFF         EQU $
344   009E C C36902               JP       M?JVLVOFF
345   00A1                                 CODE
346   00A1                M?SOLON          EQU $
347   00A1 C C37F02               JP       M?JSOLON
348   00A4                                 CODE
349   00AA                M?SOLOFF         EQU $
350   00A4 C C37402               JP       M?JSOLOFF
351   00A7                                 CODE
352   00A7                M?STPOFF         EQU $
353   00A7 C C38A02               JP       M?JSTPOFF
354   00AA                                 CODE
355   00AA                M?STPUP          EQU $
356   00AA C C39202               JP       M?JSTPUP
357   00AD                                 CODE
358   00AD                M?STPDN          EQU $
359   00AD C C3B702               JP       M?JSTPDN
360   00B0                                 CODE
361   00B0                M?IMOON          EQU $
362   00B0 C C39401               JP       M?JIMOON
363   00B3                                 CODE
```

```
364     00F3                    M2IM0OFF        EQU $
365     00F3 C C3B301                   JP      M2JIM1OFF
366     00F6                            CODE
367     00F6                    M2IM1ON         EQU $
368     00F6 C C3A901                   JP      M2JIM1ON
369     00F9                            CODE
370     00F9                    M2IM1OFF        EQU $
371     00F9 C C3B900                   JP      M2IM1OFF
372     00FC                            CODE
373     00FC                    M2STMON         EQU $
374     00FC C C3BA01                   JP      M2JSTMON
375     00FF                            CODE
376     00FF                    M2STMOFF        EQU $
377     00FF C C3C401                   JP      M2JSTMOFF
378     0002                            CODE
379     0002                    M2INTON         EQU $
380     0002 C C3F300                   JP      M2JINTON
381     0005                            CODE
382     0005                    M2INTOFF        EQU $
383     0005 C C3F500                   JP      M2JINTOFF
384     0008                            CODE
385     0008                    M2VLVSTS        EQU $
386     0009 C C30603                   JP      M2JVLVSTS
387     000B                            CODE
388     000B                    M2JRESET        EQU $
389     000B   F3                       DI
390     000C   31FFFF                   LD      SP,0TOP
391     000F C CDF700                   CALL    CTCSET
392     0012 C CD0802                   CALL    ADCSET
393     0015 C CD3A02                   CALL    STOSET
394     0018   3E00                     LD      A,0
395     001A   ED47                     LD      I,A
396     001C   ED5E                     IM      2
397     001E 0 320000                   LD      (B1),A
398     0021 0 320100                   LD      (B2),A
399     0024 0 320200                   LD      (B3),A
400     0027 0 320300                   LD      (B4),A
401     002A C CD1502                   CALL    LEDOUT
402     002D C CDF802                   CALL    STPSET
403     0030 X C30000                   JP      M2M1STRT
404     ;
405     00F3                            CODE
406     00F3                    M2JINTON        EQU $
407     00F3   FB                       EI
408     00F4   C9                       RET
409     ;
410     00F5                            CODE
411     00F5                    M2JINTOFF       EQU $
412     00F5   F3                       DI
413     00F6   C9                       RET
414     ;
415     00F7                            CODE
416     00F7                    M2CTCSET        EQU $
417     00F7   3E08                     LD      A,CTCVEC
418     00F9   D37C                     OUT     (CTC0),A
419     00FB   D37C                     OUT     (CTC0),A
420     00FD   3E01                     LD      A,CTCDIS
421     00FF   D37C                     OUT     (CTC0),A
422     0101   D37D                     OUT     (CTC1),A
423     0103   D37E                     OUT     (CTC2),A
424     0105   D37F                     OUT     (CTC3),A
425     0107   C9                       RET
426     ;
427     0108                            CODE
428     0108                    M2TIMER0        EQU $
429     0108   F3                       DI
430     0109   F5                       PUSH    AF
431     010A   D5                       PUSH    DE
432     010B   E5                       PUSH    HL
433     010C 0 2A1700                   LD      HL,(TIME0)
434     010F   E5                       PUSH    HL
435     0110   11FF7F                   LD      DE,7FFFH
436     0113   A7                       AND     A,A
437     0114   ED52                     SBC     HL,DE
438     0116   E1                       POP     HL
439     0117   3004                     JR      NC,TM0RET
```

```
440     0119   23                  INC     HL
441     011A D 221700              LD      (TIME0),HL
442     011D   E1          TMORET: POP     HL
443     011E   D1                  POP     DE
444     011F   F1                  POP     AF
445     0120   FB                  EI
446     0121   ED4D                RETI
447                        ;
448     0123                       CODE
449     0123               M?TIMR1  EQU $
450     0123   F3                  DI
451     0124   F5                  PUSH    AF
452     0125 D 3A1900              LD      A,(TIME1)
453     0128   FE7F                CP      7FH
454     012A   3004                JR      NC,TM1RET
455     012C   3C                  INC     A
456     012D D 321900              LD      (TIME1),A
457     0130   F1          TM1RET: POP     AF
458     0131   FB                  EI
459     0132   ED4D                RETI
460     ;
461     0134                       CODE
462     0134               M?STIME? EQU $
463     0134   FB                  EI
464     0135   F5                  PUSH    AF
465     0136   D5                  PUSH    DE
466     0137   E5                  PUSH    HL
467     0138 D 2A1A00              LD      HL,(STPSIZ)
468     013B   7C                  LD      A,H
469     013C   B5                  OR      L
470     013D   2005                JP      NZ,STMCMP
471     013F C CD8A02      STM?:   CALL    M?JSTPOFF
472     0142   1843                JR      STMRET
473     0144   CB7C        STMCMP: BIT     7,H
474     0146   2024                JR      NZ,STMDWN
475     0148   2B                  DEC     HL
476     0149 D 221A00              LD      (STPSIZ),HL
477     014C D 2A1C00              LD      HL,(VLVPOS)
478     014F   23                  INC     HL
479     0150 D 221C00              LD      (VLVPOS),HL
480     0153   112003              LD      DE,VLVMAX
481     0156   A7                  AND     A,A
482     0157   ED52                SBC     HL,DE
483     0159   380C                JR      C,STMUP?
484     015B D ED531C00            LD      (VLVPOS),DE
485     015F   210000              LD      HL,0
486     0162 D 221A00              LD      (STPSIZ),HL
487     0165   1808                JR      STM?
488     0167 C CD9202      STMUP?: CALL    M?JSTPUP
489     016A   1823                JR      STMRET
490     016C   23          STMDWN: INC     HL
491     016D D 221A00              LD      (STPSIZ),HL
492     0170   DB02                IN      A,(STATIN)
493     0172   E601                AND     01H
494     0174   2008                JR      NZ,STMDN?
495     0176   210000      STMDN1: LD      HL,0
496     0179 D 221A00              LD      (STPSIZ),HL
497     017C D 221C00              LD      (VLVPOS),HL
498     017F   1808                JR      STM?
499     0181 D 2A1C00      STMDN?: LD      HL,(VLVPOS)
500     0184   7C                  LD      A,H
501     0185   B5                  OR      L
502     0186   28EE                JR      Z,STMDN1
503     0188   2B                  DEC     HL
504     0189 D 221C00              LD      (VLVPOS),HL
505     018C C CD8D02              CALL    M?JSTPON
506     018F   E1          STMRET: POP     HL
507     0190   D1                  POP     DE
508     0191   F1                  POP     AF
509     0192   ED4D                RETI
510     ;
511     0194                       CODE
512     0194               M?JTMOON EQU $
513     0194   3E85                LD      A,CTCEN
514     0196   D37C                OUT     (CTC0),A
```

```
515     0198   3E4C            LD      A,CTCTC
516     019A   D37C            OUT     (CTC0),A
517     019C   FB              EI
518     019D   C9              RET
519     ;
520     019E                           CODE
521     019E                M2JTM0OFF    EQU $
522     019E   F3              DI
523     019F   3E03            LD      A,CTCRES
524     01A1   D37C            OUT     (CTC0),A
525     01A3   3E01            LD      A,CTCDIS
526     01A5   D37C            OUT     (CTC0),A
527     01A7   FB              EI
528     01A8   C9              RET
529     ;
530     01A9                           CODE
531     01A9                M2JTM1ON     EQU $
532     01A9   3E85            LD      A,CTCEN
533     01AB   D37D            OUT     (CTC1),A
534     01AD   3E4C            LD      A,CTCTC
535     01AF   D37D            OUT     (CTC1),A
536     01B1   FB              EI
537     01B2   C9              RET
538     ;
539     01B3                           CODE
540     01B3                M2JTM1OFF    EQU $
541     01B3   F3              DI
542     01B4   3E03            LD      A,CTCRES
543     01B6   D37D            OUT     (CTC1),A
544     01B8   FB              EI
545     01B9   C9              RET
546     ;
547     01BA                           CODE
548     01BA                M2JSTMON     EQU $
549     01BA   3EA5            LD      A,CTCSEN
550     01BC   D37E            OUT     (CTC2),A
551     01BE   3E4B            LD      A,CTCSTC
552     01C0   D37E            OUT     (CTC2),A
553     01C2   FB              EI
554     01C3   C9              RET
555     ;
556     01C4                           CODE
557     01C4                M2JSTMOFF    EQU $
558     01C4   F3              DI
559     01C5   3E03            LD      A,CTCRES
560     01C7   D37E            OUT     (CTC2),A
561     01C9   3E01            LD      A,CTCDIS
562     01CB   D37E            OUT     (CTC2),A
563     01CD   FB              EI
564     01CE   C9              RET
565     ;
566     01CF                           CODE
567     01CF                M2JSETIN     EQU $
568     01CF   DB00            IN      A,(SETLO)
569     01D1   F5              PUSH    AF
570     01D2   E60F            AND     0FH
571     01D4 D 320000          LD      (BL),A
572     01D7   F1              POP     AF
573     01D8   E6F0            AND     0F0H
574     01DA   0F              RRCA
575     01DB   0F              RRCA
576     01DC   0F              RRCA
577     01DD   0F              RRCA
578     01DE D 320100          LD      (B2),A
579     01E1   DB01            IN      A,(SETHI)
580     01E3   F5              PUSH    AF
581     01E4   E60F            AND     0FH
582     01E6 D 320200          LD      (B3),A
583     01E9   F1              POP     AF
584     01EA   E6F0            AND     0F0H
585     01EC   0F              RRCA
586     01ED   0F              RRCA
587     01EE   0F              RRCA
588     01EF   0F              RRCA
589     01F0 D 320300          LD      (B4),A
```

```
590     01F3   C9                RET
591     ;
592     01F4                                CODE
593     01F4           M?JADCSTS              EQU $
594     01F4   3AF8F0             LD        A,(ADCEOC)
595     01F7   2F                 CPL
596     01F8   A7                 AND       A,A
597     01F9   C8                 RET       Z
598     01FA   3E01               LD        A,1
599     01FC   C9                 RET
600     01FD                                CODE
601     01FD           M?JADCIN               EQU $
602     01FD   3AFCF0             LD        A,(ADCLO)
603     0200   2F                 CPL
604     0201   6F                 LD        L,A
605     0202   3AFDF0             LD        A,(ADCHI)
606     0205   2F                 CPL
607     0206   67                 LD        H,A
608     0207   C9                 RET
609     ;
610     ;
611     0208                                CODE
612     0208           M?ADCSET               EQU $
613     0208   AF                 XOR       A
614     0209   2F                 CPL
615     020A   32FFF0             LD        (ADCSEL),A
616     020D   32F9F0             LD        (ADCMUX),A
617     0210   C9                 RET
618     ;
619     0211                                CODE
620     0211           M?JADCGO               EQU $
621     0211   32FAF0             LD        (ADCCON),A
622     0214   C9                 RET
623     0215                                CODE
624     0215           M?JLEDOUT              EQU $
625     0215 D 3A0100             LD        A,(B2)
626     0218   E60F               AND       0FH
627     021A   07                 RLCA
628     021B   07                 RLCA
629     021C   07                 RLCA
630     021D   07                 RLCA
631     021E   47                 LD        B,A
632     021F D 3A0000             LD        A,(B1)
633     0222   E60F               AND       0FH
634     0224   B0                 OR        B
635     0225   D300               OUT       (LEDLO),A
636     0227 D 3A0300             LD        A,(B4)
637     022A   E60F               AND       0FH
638     022C   07                 RLCA
639     022D   07                 RLCA
640     022E   07                 RLCA
641     022F   07                 RLCA
642     0230   47                 LD        B,A
643     0231 D 3A0200             LD        A,(B3)
644     0234   E60F               AND       0FH
645     0236   B0                 OR        B
646     0237   D301               OUT       (LEDHI),A
647     0239   C9                 RET
648     ;
649     023A                                CODE
650     023A           M?SIOSET               EQU $
651     023A   3E02               LD        A,2
652     023C   D300               OUT       (SIOCON),A
653     023E   3E00               LD        A,0
654     0240   D3DE               OUT       (SIOSC),A
655     0242   C9                 RET
656     ;
657     0243                                CODE
658     0243           M?JSINSTS              EQU $
659     0243   3AD900             LD        A,(SIOSTS)
660     0246   E640               AND       DAVMSK
661     0248   C8                 RET       Z
662     0249   3E01               LD        A,1
663     024B   C9                 RET
664     ;
```

```
                                                CODE
                        M?JSOUTST:              EQU $
0024C 3AD000                    LD      A,(SIOSTS)
0024F E680                      AND     RDYMSK
00251 C8                        RET     Z
00252 3E01                      LD      A,1
00254 C9                        RET
                        ;
00255                                   CODE
                        M?JSIOIN:               EQU $
00255 DBDC                      IN      A,(SIODAT)
00257 C9                        RET
                        ;
00258                                   CODE
                        M?JSIOOUT:              EQU $
00258 D 3A1400                  LD      A,(C1)
0025B D3DC                      OUT     (SIODAT),A
0025D C9                        RET
                        ;
0025E                                   CODE
                        M?JVLVON:               EQU $
0025E D 3A1600                  LD      A,(STPPOS)
00261 F640                      OR      40H
00263 D302                      OUT     (STPOUT),A
00265 D 321600                  LD      (STPPOS),A
00268 C9                        RET
                        ;
00269                                   CODE
                        M?JVLVOFF:              EQU $
00269 D 3A1600                  LD      A,(STPPOS)
0026C E6BF                      AND     0BFH
0026E D 321600                  LD      (STPPOS),A
00271 D302                      OUT     (STPOUT),A
00273 C9                        RET
                        ;
00274                                   CODE
                        M?JSOLOFF:              EQU $
00274 D 3A1600                  LD      A,(STPPOS)
00277 E64F                      AND     4FH
00279 D 321600                  LD      (STPPOS),A
0027C D302                      OUT     (STPOUT),A
0027E C9                        RET
                        ;
0027F                                   CODE
                        M?JSOLON:               EQU $
0027F D 3A1600                  LD      A,(STPPOS)
00282 F630                      OR      30H
00284 D302                      OUT     (STPOUT),A
00286 D 321600                  LD      (STPPOS),A
00289 C9                        RET
                        ;
0028A                                   CODE
                        M?JSTPOFF:              EQU $
0028A D 3A1600                  LD      A,(STPPOS)
0028D E670                      AND     70H
0028F D302                      OUT     (STPOUT),A
00291 C9                        RET
                        ;
00292                                   CODE
                        M?JSTPUP:               EQU $
00292 D 3A1600                  LD      A,(STPPOS)
00295 F5                        PUSH    AF
00296 E60F                      AND     0FH
00298 FE06                      CP      6
0029A 2004                      JR      NZ,SU5
0029C 3E05                      LD      A,5
0029E 1812                      JR      SUEND
002A0 FE05              SU5:    CP      5
002A2 2004                      JR      NZ,SU9
002A4 3E09                      LD      A,9
002A6 180A                      JR      SUEND
002A8 FE09              SU9:    CP      9
002AA 2004                      JR      NZ,SUA
002AC 3E0A                      LD      A,0AH
002AE 1802                      JR      SUEND
002B0 3E06              SUA:    LD      A,6
002B2 47                SUEND:  LD      B,A
```

```
742     0283    F1              POP     AF
743     0284    E6F0            AND     0F0H
744     0286    B0              OR      B
745     0287    D302            OUT     (STPOUT),A
746     0289 D  321600          LD      (STPPOS),A
747     028C    C9              RET
748     ;
749     028D                            CODE
750     028D            M2JSTPDV        EQU $
751     028D D  3A1600  SD2:    LD      A,(STPPOS)
752     02C0    F5              PUSH    AF
753     02C1    E60F            AND     0FH
754     02C3    FE0A            CP      0AH
755     02C5    2004            JR      NZ,STEP9
756     02C7    3E09            LD      A,9
757     02C9    1812            JR      STPEND
758     02CB    FE09    STEP9:  CP      9
759     02CD    2004            JR      NZ,STEP5
760     02CF    3E05            LD      A,5
761     02D1    180A            JR      STPEND
762     02D3    FE05    STEP5:  CP      5
763     02D5    2004            JR      NZ,STEP6
764     02D7    3E06            LD      A,6
765     02D9    1802            JR      STPEND
766     02DB    3E0A    STEP6:  LD      A,0AH
767     02DD    47      STPEND: LD      B,A
768     02DE    F1              POP     AF
769     02DF    E6F0            AND     0F0H
770     02E1    B0              OR      B
771     02E2    D302            OUT     (STPOUT),A
772     02E4 D  321600          LD      (STPPOS),A
773     02E7    C9              RET
774     ;
775     02E8                            CODE
776     02E8            M2STPSET        EQU $
777     02E8    3E00            LD      A,0
778     02EA    D302            OUT     (STPOUT),A
779     02EC D  321600          LD      (STPPOS),A
780     02EF    2188FA          LD      HL,-1400
781     02F2 D  221A00          LD      (STPSIZ),HL
782     02F5    21DC05          LD      HL,1500
783     02F8 D  221C00          LD      (VLVPOS),HL
784     02FB C  CDBA01          CALL    STMON
785     02FE D  2A1C00  STPST2: LD      HL,(VLVPOS)
786     0301    7C              LD      A,H
787     0302    B5              OR      L
788     0303    20F9            JR      NZ,STPST2
789     0305    C9              RET
790
791     0306                            CODE
792     0306            M2JVLVSTS       EQU $
793     0306    DB02            IN      A,(STATIN)
794     0308    E601            AND     01
795     030A    C9              RET
904                             END
```

```
ERROR COUNT 0
```

```
PU (SEC)=58
```

```
 1                      (*$A+,M-,C+$*)
 2                        MODULE TJBTL ;
 3                      (* Edit # : 4
 4                       *
 5                       *
 6                       *
 7                       * Created By: TIM
 8                       * Date Last Edited: THU, FEB  7, 1980,  5:44 PM
 9                       * Last Edited By: TIM
10                       * Date Last Compiled/Assembled: THU, FEB  7, 1980,  5:47
11                       * Last Compiled/Assembled By: TIM
12                       *
13                      *LIST
```

```
14      ;(*$A+,M-,C+$*)
15      0000                M?TJBT1             EQU $
16      ;   MODULE TJBT1 ;
17      ;(* Edit # : 4                                                          *
18      ; *                                                                    *
19      ; *                                                                    *
20      ; *                                                                    *
21      ; * Created By: TIM                                                    *
22      ; * Date Last Edited: THU, FEB  7, 1980,  5:44 PM                      *
23      ; * Last Edited By: TIM                                                *
24      ; * Date Last Compiled/Assembled: THU, FEB  7, 1980,  5:47 PM          *
25      ; * Last Compiled/Assembled By: TIM                                    *
26      ; *                                                                    *)
27      0000                                CODE
28      ;CONSTANT
29      0029                M?MAXTAB            EQU         41
30      ;   MAXTAB=41;
31      ;
32      ;
33      0000                                DATA
34      ;GLOBAL
35                          M?1DCAL               GBL BINT
36      0000                M?1DCAL               DEFS    1
38                          M?DCAL              GBL L?DCAL
39      ;   DCAL:ASSEMBLY PROCEDURE(INDEX:BINT):INTEGER;
40      ;
41      ;
42      ;
43      ;(*********************************)
44      ;
45                          *NOLIST
48                          *LIST
49      0000                DINDEX:  EQU        M?1DCAL
50      0029                MAXTAB:  EQU        M?MAXTAB
51      0000 D 3A0000               LD          A,(DINDEX)
52      0003   FE2A                 CP          MAXTAB+1
53      0005   3802                 JR          C,DGLT2
54      0007   3E29                 LD          A,MAXTAB
55      0009   87          DGLT2:   ADD         A,A
56      000A   5F                   LD          E,A
57      000B   1600                 LD          D,0
58      000D C 211600               LD          HL,DTABLE
59      0010   19                   ADD         HL,DE
60      0011   7E                   LD          A,(HL)
61      0012   23                   INC         HL
62      0013   66                   LD          H,(HL)
63      0014   6F                   LD          L,A
64      0015   C9                   RET
65      ;
66      0016                DTABLE   EQU        $
67      0016   0000         D0:      DEFW       0000
68      0018   0000         D1:      DEFW       0000
69      001A   43FD         D2:      DEFW       -701
70      001C   8303         D3:      DEFW       0899
71      001E   9406         D4:      DEFW       1620
72      0020   E907         D5:      DEFW       2023
73      0022   250A         D6:      DEFW       2597
74      0024   590C         D7:      DEFW       3161
75      0026   4A0E         D8:      DEFW       3658
76      0028   1110         D9:      DEFW       4113
77      002A   8011         D10:     DEFW       4529
78      002C   EA12         D11:     DEFW       4842
79      002E   6014         D12:     DEFW       5216
80      0030   C015         D13:     DEFW       5568
81      0032   0117         D14:     DEFW       5889
82      0034   2F18         D15:     DEFW       6191
83      0036   4319         D16:     DEFW       6467
84      0038   531A         D17:     DEFW       6739
85      003A   581B         D18:     DEFW       7000
86      003C   541C         D19:     DEFW       7252
87      003E   5C1D         D20:     DEFW       7516
88      0040   761E         D21:     DEFW       7798
89      0042   8B1F         D22:     DEFW       8075
90      0044   8D20         D23:     DEFW       8333
91      0046   9721         D24:     DEFW       8599
```

```
 92       004B   8D22      D25:     DEFW     8845
 93       004A   A123      D26:     DEFW     9121
 94       004C   9D24      D27:     DEFW     9371
 95       004E   B525      D28:     DEFW     9653
 96       0050   E226      D29:     DEFW     9954
 97       0052   FF27      D30:     DEFW     10239
 98       0054   4929      D31:     DEFW     10569
 99       0056   8B2A      D32:     DEFW     10888
100       0058   BF2B      D33:     DEFW     11199
101       005A   3C2C      D34:     DEFW     11580
102       005C   F12D      D35:     DEFW     11761
103       005E   242F      D36:     DEFW     12068
104       0060   7030      D37:     DEFW     12400
105       0062   9031      D38:     DEFW     12701
106       0064   1232      D39:     DEFW     12818
107       0066   CF32      D40:     DEFW     13005
108       0068   F333      D41:     DEFW     13297
109       ;
110                                  END

(*$R-,S-,P- *)
   LOADMODULE TJHMOD
(* Edit # : 41                                                          *
 *                                                                      *
 *                                                                      *
 * Date Created: THU, FEB  7, 1980,  5:52 PM                           *
 * Created By: TIM                                                     *
 * Associated Loadlist: TJHLL                                          *
 * Loadlist Edit # : 7                                                 *
 *                                                                      *)
/0003210633343536370901260137018000313132333435363738394142434445463231323300
/0024210934353637383941424344454633313233343536373C380004243444546343132333 4F9
/0045210C3536373839414243444546353132333435363738394142434445463631323334350 3
/0066210FC380003941424344454637313233343536373839414243444546C3CE00C3D201C326
/0087211D003C3F701C31403C31803C31603C34F02C35802C35B02C36102C35C02C38202C338
/00A8211577703C38D03C395D3C3C003C33701C38601C3AC01C3BC00C3BD01C3C701C3F600C370
/00C9211BF800C30903F331FFFFCDFA00CDD802CD3D023E00CD47CD5E3200FF3201FF3202FFDB
/00EA211330303FFCD1802CDEB02C30010FBC9F3C93E08D37CD37C3E01D37CD37DD37ED37FC9FC
/0109210FF3F5D5F52A17FFE511FF7FA7ED52E1300423221 7FFF1D1F1FBED40F3F53A19FFFE29
/012C21127F30043C3219FFF1FBCD40FBF5D5E52A1AFF7CB52005CD8002184BCB7C200242822CC
/014D2115 1AFF2A1CFF23221CFF1120003A7ED52390CED531CFF210000221AFF18D8CD95021883
/016F211823232 1AFFDB02E601200821000221AFF221CFF18BE2A1CFF7CB528EE2822 1CFFB0
/018F211BCDC002E1D1F1ED403E85D37C3E4CD37CFBC9F33E03D37C3E01D37CFBC93E85D37D23
/01B0210F3E4CD37DFBC9F33E03D37DFBC93E A5D37E3E4BD37EFBC9F33E03D37E3E01D37EFB42
/01D2112C9DB00F5E60F3200FFF1E6F00F0F0F0F3201FFDB01F5F60F3202FFF1E6F00F0F0FEF
/01F221150F3203FFC93AFBF02FA7CB3FD1C93AFCF02F6F3AFDF02F67C9AF2F32FFF032F9F02D
/0213210 9C932FAF0C93A01FFE60F07070707473A00FFE60FB0D3003A03FFE60F07070707 47AE
/0234210C3A02FFF60FB0D301C93E02D3703E00D3 3EC93A0D00E640C83E01C93A0D00E680C8EC
/0255210F3E01C9 0DDCC93A1AFFD3DCC93A15FFE640D3023216FFC93A16FFE63F3216FFD3020B
/0276211C93A16FFE64F3216FFD302C93A16FFE638D3023216FFC93A16FFE670D302C93A0B
/0297211416F5F5F60FFF0620043E09181 2FE052004 3E091B0AFF092004 3E0A18023E0647F180
/02B7211 7E6F0B0D3023216FFC93A16FFF5E60FFF0A20043E09181 2FF092004 3E05180AFE05B2
/02D8211A20043E0618023F0A47F1E6F0B0D3D23216FFC93E0003023216FF2198FA221AFF2185
/02F9152 0DC05221CFFCDB0012A1CFF7C3520F9C9D802E601C94C
/0400210 73A1FFFFE2A3802E22875F1600211604197E23666FC900000000043FD83035406E975
/0421210A07250A590C4A0E1110B011EA126014C01501172F18431953 1A5818541C5C1D761E47
/0442210D8B1F8D209721 8D22A1230B240525E226FF274929882ABF283C2DF12D242F70309DB5
/0463071431123 2CF32F33343
/0480210BA7FD52CB1CCB1DFD6AC9A7ED5218011DF51FAAF3CB95FA1B08C9D5E3F1C9D5E8CD41
/0921210E0F08D1C90E0057CDD6097817300 37C9D677AA7FA38094 1ED42C97A0FBA280FEB7AD1
/0842211 10FBA2809447A2FA8C3060A575F177B444DCDD6083003 3FED4240 6F78177C613001BA
/0863211493CB11CE0020DD474FA7ED4AC97BACF67C078D200B0C2008C5424BFDE5D1180C78E8
/0884211 078920468B2043FDE5C1E51F3001D578CDD6085F7ACDD908 57D5FDE1D130073FEDE8
/08A5211A52D1D5F5377BCDD908 5F7ACDD908CB1 3003 3FED42CB1A573005F1C1ED427A0701CA
/08C6211D0000ED4AFDE5E1EBC1C8782F67C3F50A2100001FCDDDD830010 9CB1CCB1D1F3001B2
/08F7210009CB1CCB1D1F300109CB1CCB1D1F300109CB1CCB1D1FC9B72002AFC95FA817781FD4
/0908211457708F5A1009 D445F78B7F21B09ED443F0E07AFCB15178 3DA2409930DF21C09CBE1
/0929211715CB722802FD44477DFF802808CB7A2402ED443FC9CB7A20FAAF7DC9B72004AF67F4
/094A211A6FC947AC177C1F577B7FA5709ED444 7CB7C2806AF956F9F9467AF0E0FED6A17801A
/0968211DDA6F099000F26709ED6ACB722802ED44477DB7200584FE80280CCB7A2806AF956FE2
/098C21209F9467BFC9CB7A20FAAFC9EBAF958DD42002AFC90600AA17CB107A17CB10CB7C20FF
/09AD2022206AF956F9F9467C37A2806AF935F9F925778444D26006CB7CB13CB12ED6A090AE8
/09CD2125D109ED42CB13CB12ED6AC610D2CB09B7CB1CCB1D471F300FAF956F9F94677BB720F6
/09EF212805B2FEB0280DCB4B2806AF935F9F925 BBFC9CB4A20F9EBAFC9FD19ED4AFDE5D141
/0A0F211C 0C3F30AAFFDF5L3CD5 D2001306 1ED42 A 30AC03CC9AF47935F789A577806
```

/0A302110D6F789C67E0C3E30A7C4502345E01FB5[illegible]7333E3E0024573E0090SFF0E2580A2EF7
/0A512012F24EAECDA2CC987[illegible]FCDAFCDA[illegible]FC3FDF30C0028632C2D285F788437E2FD
/0A712115740A3F4[illegible]5C53[illegible]F5045C54CC54[illegible]52100000FCB1930021989[illegible]FCB1CCB1DCBA8
/0A912118390C2B8DAC110FDC10C00E2A3CAA7ED5[illegible]8D1040SF24D0AA7FD5299160215298FE2BE
/0AB5211BAF0A1FCB1CCB1D5B6E7CC1B067E2C404[illegible]CCB1930D7AF85FDE9C1AF67CDEC0AFDC93C
/0AD4211C2425E20F0A21FFA0[illegible]5C12100[illegible]7F24C91415CDD60AFB636BC92425E2FE0A7D2F3C3DCE
/0AF521210DD50A55D6C267[illegible]C92100F0555D2C29C91F8FC9F2100B3E805DC93E7E3CC97A93F1
/0B1521157ACAFE0AB1001005CB258FE2100[illegible]FCB135356F5960C9EB7AB3B485CAFE0A06207A07
/0B3721180529CB138FF2370B1FCF1BCB1C6F535C[illegible]0C92425FA550B3E0F94F2590BC9975575FDE
/0B5501AC947974FBB28013C0405280[illegible]CB20CB1A8910F9656A23047C17FD4ABC92425FAC0
/0B7821100405E1F94F28A0[illegible]A0C3[illegible]5DA776F675[illegible]57C947635A553E004F6FC9CB2ACB1BCB1C01
/0B9901F2CCB1D8910F52B047A1FED4AF8ED4AC9FA
/0BA8212005D50BF1C1C1B7FC5F0CBFCA0CDD508F1D1E1477DB2B5200CB4FF802007CB40200AED
/0BC9213AF1908CB402803C05F0CBFCA7DB285F20C081[illegible]42004AFFDE1C9FAEC0BCD5F0CAF2C
/0BEA2126180[illegible]3CB1E5E5D5660[illegible]E5D1C1EDE17B42B5CB8FB4F20ADCC05F0CF13CCBFFF5F127
/0C0B211AF305F5E5FDF5FD210900FD5[illegible]210000110000[illegible]3E04B7EDCB0016CB15CB14CB13CB129D
/0C2C211D09E5EBFD5AFBE3DA3E0CFD42E3EBED52FBE3FDCB0016FD6ACB13CB12C620D22C0C29
/0C4021209B7CB1ACB1BCB1CCB1DFD2B3DC2200CEBC1C9AF335F3C009A573E009D6F3E009C6708
/0C6F0121C915
/0C6F2124AFBD200DAFC9B920055[illegible]F5F5CC97D6C5047E5FDE5F1A9F5F5FD210500FD397D6C03
/0C9021189614A57CB7C281CAF925[illegible]3E009D6F3E03[illegible]C67E2930CFD3400E2B10CF1F1F1C3EC0AD9
/0CB121102640[illegible]D2BFD2BFD2BCB7B200DAF935F3[illegible]3E0098477A1601CD310DCD310DCDDC
/0CD2211E31008BCDAA0E00CB11E1D10600CB7B280D04CB45280320E01CB38CB1CCB1D7D816FAE
/0CF521213E009C573E009B5FCB7B2805CB3B0478C1800600E2080D491E2100D04CB1B300A78
/0D1421198B7F2FE0A3EFFAAC3[illegible]C04CB7A57280BAF956F3C009C573F009B5FBFEHC983ED4ADA44
/0D3518213A0D93ED42CB123[illegible]9617ED6AC3310DFD7200FD281601CB27ED6AC97B
/0D5021150C1E17DA7F25F0DE944C3D10DC1E17DD1F1C5977C[illegible]BCB3830729CB138FEACA0DC910
/0D7121183830[illegible]E29CB138FEACA0[illegible]29C[illegible]38FEACA0DCB38301C29CB138FEACA0D29CB138FEA0B
/0D9221180A0[illegible]29CB138FEACA0D2[illegible]CB138FEACA0DCB38300DCB03CB08CE00201C7B5C652E00E8
/0DB5211FCB38201330C0CB04B8200CC3DC8[illegible]8200750[illegible]58C957CB80C9FBC3F30AC1E17DD1E1C5BA
/0DD4212147E4E020660B04C80C9F4F781F300AC32CCB19CB1ACB1BCB181F3012CB2CCB1DCBF6
/0DF5212141ACB1BCB2CCB1DCB1ACB1BCB181F3022CB2CCB1DCB1ACB1BCB2CCB1DCB1ACB1BCB29
/0E1621192CCB1DCB1ACB1BCB2CCB1DCB1ACB1BCB181F3005435A556C611F300444EB6169CBDD
/0E370E2610007CA5A2A33CC0210000545CC926
/0E4501258467E0C3ECDAED448467E0C3FE0A0A
/0E5521190D410A7B9428[illegible]BFAB10FE2A00EFEE9FAB70ECDA70EFD4460477BC92DCB1A1F10F911
/0E7421109FFD197089FDE5010600CA900E6F02B3[illegible]AFE0A7DFB042[illegible]8FE2890EEB1FCB1ACB1B2F
/0E9501E056F7C9067EAECDAAF85C9FE18F2840E18C3D5FDE35050444DE1EBC9F2870ECD1B
/0EB50523A70FAF85C95A
/0ED[illegible]A0326AF85C93[illegible]
/10002104110000FD531FFF114001FD5321FF2127FFCB8611000ED5325FF2128FF3600FD5B96
/10212107[illegible]FD542DFFCDBF003215FFCD03003215FF2127[illegible]FCD462851CD5111A7116400EDDB
/10421[illegible]A52FA551028[illegible]A7EBFD582FFFED52F2551018[illegible]1A721204EFD582FFFED52F264101BD8
/10632100021[illegible]D4CD9C112231FFCDAA122[illegible]1AFFCD9D133215FFCDBF003215FFCD3814321[illegible]FFD9
/10842005212[illegible]FCD3851[illegible]5CC9[illegible]2133215FFED561AFF7AB32050C9C2003215FF111400ED5385
/10A4201104FFCDF7143215FFCDB8142204FF110000ED517FFCDB8142206FF2A04FFED5BD3
/10C4211406FF193E02CD45092237FFE[illegible]D5323FFCD3712[illegible]D532FF222BFFCDAA003215FF21F1
/10E5211727FFCBC6C3331[illegible]0C9C[illegible]83003215FF3A02FF5F17[illegible]F57216400CD3B082225FF3A01FFC6
/1106210B5F179F57210A00CD3B09ED5B25FF192225FF3A00FF5F179F57192225FFA711000080
/1127210EFD52FA3A11A72A25FF11FB03ED52F23A1118122100FF360F2101FF360ECD8F003298
/1148211115FF18A12A25FFC9C9C[illegible]8142204FFED5B17FFED532FFFCDB8142206FF2A04FFED2F
/1169201358B06FF193E02CD45092237FFA7ED5B23FFED532208FFA7110000ED52F297113A8B
/118[illegible]1508FF2F5F3A02FF2F5713CD5308FF2A03FFC9C9CD3712FD5333FF2235FF444DD5FD23
/11A[illegible]1[illegible]ED5B2[illegible]FF2A2BFFCD530ED5310FF2212FFCDBA0EF2D311ED5B10FF2A12FFCD1F
/11CA211B410AFD5310FF2212FFED5B2FFF7AB32007110100FD532FFFED5B10FF2A12FFFD21E3
/11E8211F666601780[illegible]CD630AF5D5[illegible]D5B2FFFCD1[illegible]08FD[illegible]1C1CD6F0CED530CFF220EFFCD490B26
/1208211[illegible]FD5331FFA7CB110000FD52F21E12[illegible]D5331FFA7210F27[illegible]D5431FFED52F23212110FC0
/1228211527ED5331FF2A31FFC9C92A37FF3E64CD[illegible]5097D3200FF3C3201FF3A00FF321EFFCD00
/1247211800042204FF3A01FF521[illegible]FFCD0004A7F5[illegible]B0FFED522204FF2A37FF116400CD9709C5
/126F211BCD140B444D05F0F111000021[illegible]407C[illegible]C[illegible]D530CFF220FFFED5804FFCD140BE5D5E8
/1290200FFD5804FFCD140BFD2A0CFFED4B0FFFCD[illegible]30AFDE1C1CD560EC9C9A7210000ED5B1D
/12B0211120FFED52F21C13A7210000FD5831FFE[illegible]2F21C13CD140BE5D5FD5B2DFFCD140BE001
/12D1211[illegible]1C1CD6F0CED531FFF2221FF[illegible]210000[illegible]14002[illegible]D530FF2F8121110000ED531FFF11A1
/12F2211740[illegible]02ED5321FFED5B1FFF2A21FFFD21[illegible]60156FDCD530FFA1C13280E116666ED530E
/1313210B1FFF1166F3ED5321FFC[illegible]7D10A7ED5B31[illegible]FED[illegible]22206FFE8CD140BED530CFF220CFF38
/1334210E444D05FDE1FD5B1FFF2A21FFCD630ACD190BED5306FFA7EB113BFFED52F25B13ED34
/1355201053067FFA721C800FD5B06FFED[illegible]2F26C1511C800FD5305FF2A2DFFED5B06FF1222DF
/1376211320FFA7110009ED52F2B413CD5320FFA721200[illegible]D5B29FFED52F29B131120003ED5386
/1396201520FF2A06FFC9C9A721000[illegible]ED5B1AFFED52F2BD133A2BFFA7200DCB11170019220C4
/13B6211B1AFF2128FF3601A72A1AFF110000FD52F2F113[illegible]28FFFE012011A72A1AFF11170C93
/13D7201AFD5[illegible]21AFF2128FF3600C9C[illegible]C800321[illegible]FCD0814[illegible]5CCD814D1193F02CD450922BD
/13F7201C0AFECDC5003215FF115802ED5304FFA721AC0DED5B0AFFED52F21914CDA40032C9
/1417211015FFCDF7143215FFA72A0AFF11F401FD52F25114CDA70D3215FFCDF7143215FFC9DD
/1438211321[illegible]FF3[illegible]E2101FF360F2102FF360E[illegible]B31FFED5304FFA7EB110000ED52FAB114B5
/1459211[illegible]A72A04FF111027ED52F2B1142A04FF110A00CD97097B3200FF2A04FF3E0ACD4509A4

/147A2018220 4FF110A00CD97097832 01FF2A04FF 3E0ACD4509220 4FF110A00CD97097832 89
/149A211B02FF2A04FF3E0ACD4509220 4FF110A00CD97097832 03FFCD8F003215FFC92100FFBF
/14BB211E3604110000ED530AFFCD8C003215FFCD39003A472802180218F5CD8600ED5B0AFFAA
/14DC20201922 0AFF2100FF3520021802180A2A0AFF3E04CD4509220AFFC9C9110000ED537D
/14FC142517FFA72A04FFED5B17FFED52F20D151802 18EFC942
/00000303C3800017
/00000000

We claim:

1. Structure comprising:

a chamber containing a first and a second opening through which fluid can pass;

a flexible diaphragm located in said chamber so as to divide said chamber into two portions, a first chamber accessed through said first opening and a second portion being accessed through said second opening;

a magnet attached to said flexible diaphragm;

means for directing fluid whose flow is being measured through said first opening into said first chamber while withdrawing the fluid whose flow is being measured through said second opening from said second chamber and, into response to a control signal, reversing the chambers in which the fluid is inserted and from which the fluid is withdrawn, the movement of fluid into one chamber and out of the other chamber causing said flexible diaphragm to move into the chamber from which the fluid is being withdrawn;

means for continuously producing an output signal representative of the position of said magnet;

means for converting said output signal to a sequence of digital signals;

means for processing said sequence of digital signals to produce a second signal representative of the flow rate of said fluid into and out of said chamber;

means for comparing said flow rate to a reference flow rate to produce a control signal representative of the difference between said measured flow rate and said reference flow rate; and

means, responsive to said control signal, for changing the flow rate of said fluid.

2. Structure comprising:

a chamber containing a first and a second opening through which fluid can pass;

a flexible diaphragm located in said chamber so as to divide said chamber into two subchambers, a first subchamber which is accessed through said first opening and a second subchamber which is accessed through said second opening;

a magnet attached to said flexible diaphragm, said magnet being formed as an integral part of, and being completely enclosed by, the material of said flexible diaphragm;

means for directing fluid whose flow is being measured through said first opening into said first subchamber while withdrawing the fluid whose flow is being measured through said second opening from said second subchamber and, in response to a control signal, reversing the subchambers into which the fluid is inserted and from which the fluid is withdrawn, the movement of fluid into one subchamber and out of the other subchamber causing said flexible diaphragm to move into the subchamber from which the fluid is being withdrawn;

means for producing an output signal representative of the position of said magnet;

means for converting said output signal to a sequence of digital signals;

means for processing said sequence of digital signals to produce a second signal representative of the flow rate of said fluid into and out of said chamber;

means for comparing said flow rate to a reference flow rate to produce a control signal representative of the difference between said measured flow rate and said reference flow rate; and

means, responsive to said control signal, for changing the flow rate of said fluid.

3. Structure as in claim 2 including:

means for sensing the approach of said magnet to one or the other ends of said chamber and for switching the flow of fluid into said chamber from said first subchamber to said second subchamber and for switching the flow of fluid from said chamber from said second subchamber to said first portion.

4. Structure as in claim 3 including reference means representing the relationship between the position of said magnet and the volumetric displacement of said diaphragm, thereby to enable the determination of the volumetric displacement of said diaphragm from the output signal from said means for producing.

5. Structure as in claim 4 including:

means for varying the position at which the motion of said flexible diaphragm is reversed by determining the flow rate of said fluid and selecting a reversal point to maximize the sensitivity of the output signal from said means for producing as a function of the displacement of said flexible diaphragm.

6. Structure as in claim 4 including:

means for reversing the direction of motion of said flexible diaphragm in response to the expiration of a predetermined time.

7. Structure as in claim 2 wherein said chamber is cylindrical.

8. Structure which comprises

a chamber containing two openings therein;

a flexible diaphragm containing as a part thereof a magnet, said diaphragm separating said chamber into a first and a second portion and sealing said first portion from said second portion so as to prevent leakage of fluid from said first portion to said second portion or vice versa;

means for continuously producing an output signal representative of the position of said diaphragm;

means for selectively controlling the flow into said first portion and out of said second portion and for reversing the flow as desired so that the fluid flows into the second portion and from the first portion;

means for processing the output signal from said means for producing including

switching path means for selectively accessing the output signal from said means for producing

conversion means for converting said output signal from said means for producing to a first digital signal;

buffer means for storing said first digital signal from said conversion means;

means for inputting to said system a second digital signal representing a desired fluid flow rate;

means for storing said second digital signal represent-

ing said desired fluid flow rate;

processing means for operating on said first and second digital signals to produce an estimate of the flow rate of fluid into and out of said chamber;

means for storing a signal representative of the flow rate calculated by said processing means; and

driver circuit means periodically actuated by said output signal from said processing means to move a control valve either open or closed in response to the output signal stored in said means for storing.

9. Structure as in claim **8** including

means for storing the output signal from said processing means representing the calculated flow rate; and

means for displaying the calculated fluid flow rate.

10. The method of measuring a fluid flow rate using a chamber containing a first opening and a second opening through which fluid can pass with a flexible diaphragm located in said chamber so as to divide said chamber into two subchambers, a first subchamber which is accessed through said first opening and a second subchamber which is accessed through said second opening, and a magnet attached to said flexible diaphragm, comprising:

directing the fluid whose flow is being measured through said first opening into said first subchamber while withdrawing the fluid whose flow is being measured through said second opening from said second subchamber and, in response to a control signal, reversing the subchambers in which the fluid is inserted and from which the fluid is withdrawn, the movement of fluid into one subchamber and out of the other subchamber causing said flexible diaphragm to move into the subchamber from which the fluid is being withdrawn;

producing a continuous output signal representative of the position of said magnet;

converting said output signal to a sequence of digital signals;

processing said sequence of digital signals to produce a second signal representative of the flow rate of said fluid into and out of said chamber;

comparing said flow rate to a reference flow rate to produce a control signal representative of the difference between said measured flow rate and said reference flow rate; and

changing the flow rate of said fluid in response to said control signal.

11. Structure as in claim **2** wherein said means for producing comprises means for continuously producing an output signal representative of the instantaneous position of said magnet, thereby to enable a measure of the instantaneous flow rate of the fluid entering said chamber to be obtained during the trave of said diaphragm from any one position to any other position in said chamber.

* * * * *