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Patents Act 1990

28260/92

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Section 29

PATENT REQUEST: STANDARD PATENT / PATENT OF ADDITION

I / We, being the person(s) identified below as the Applicant, request the grant of a patent to the person identified below as the Nominated Person, for an invention described in the accompanying standard complete specification.

Full application details follow.

| [71] Applicant | SECTION 113 DIRECTION SEE FOLIO 13 |
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[54] Invention Title   ACOUSTIC DISPLACEMENT FLOW METER

[72] Name(s) of actual inventor(s)   W. STEPHEN WOODWARD

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ASSOCIATED PROVISIONAL APPLICATION(S) DETAILS

[60] Application Number(s) and Date(s)

BASIC CONVENTION APPLICATION(S) DETAILS

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DIVISIONAL APPLICATION DETAILS

[62] Original application number

PARENT INVENTION DETAILS (Patent of Addition requests only)

[61] Application number _____   Patent number _____

TICK IF APPLICABLE

☐ I am an eligible person described in Sections 33 - 36 of the Act.

☐ For the purposes of Section 40, the specification relies on Section 6 of the Act (Microorganisms).

Drawing number recommended to accompany the abstract __1__

DATED THIS 11th DAY OF November, 1992
8033391 11/11/92

CURTIN MATHESON SCIENTIFIC, INC.

By Our Patent Attorney

MICHAEL ANDERSON-TAYLOR

FEE: $ 365.00

Australia

Patents Act 1990

NOTICE OF ENTITLEMENT

I, We   CURTIN MATHESON SCIENTIFIC, INC.

of

          9999 Veterans Memorial Drive
          Houston, Texas 77038
          United States of America

being authorised by the Applicant(s)/Nominated Person(s) in respect of an application entitled:

ACOUSTIC DISPLACEMENT FLOW METER

state the following:-

1.   The Applicant(s)/Nominated Person(s) has/have, for the following reasons, gained entitlement from the actual inventor(s):-   W. Stephen Woodward By deed of Assignment dated 27 January, 1992

2a.* ~~The Applicant(s)/Nominated Person(s) is/are the applicant(s) of the of the basic application(s) listed* on the Patent Request/ *in the Declaration under Article 8 of the PCT.~~

2b.* The Applicant(s)/Nominated Person(s) is/are entitled to rely on the basic application(s) listed* on the Patent Request/ *~~in the Declaration under Article 8 of the PCT~~ as follows:-

        US Patent Appln. 07/827,176 dated 28 January, 1992
        & filed in the name of the inventor W. Stephen Woodward

3.* The basic application(s) listed *on the Patent Request/ *~~in the Declaration under Article 8 of the PCT~~ is/are the application(s) first made in a Convention Country in respect of the invention.

4a.* ~~The Applicant(s)/Nominated Person(s) is/are the depositor(s) of the deposit(s) listed in the Schedule hereto.~~

4b.* ~~The Applicant(s)/Nominated Person(s) has/have the consent of~~ _____ ,of

~~the depositor(s) of the deposit(s) listed in the Schedule hereto, to rely on that/those deposit(s).~~

DATED this 5TH   day of JANUARY   199~~2~~3 BC

                                    (Signature)

                                    BOB CLARKE
         (Name & Title)   VP/GM

* Delete if not applicable.

(12) PATENT ABRIDGMENT   (11) Document No. AU-B-28260/92
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ACOUSTIC DISPLACEMENT FLOW METER

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(56) Prior Art Documents
US 4550615
US 4315523

(57) Claim

1. A method of determining the flow rate of a fluid flowing along a path, said method comprising the steps of:

(a) establishing fluid flow along the path,

(b) directing the flow of the fluid to a transducer by restricting the flow path downstream from the transducer for a variable period of time, the transducer having a displacement element;

(c) generating a signal from the transducer representative of displacement of the displacement element due to fluid flow while the flow path is restricted;

(d) using the transducer signal to determine the fluid flow rate; and

(e) reestablishing fluid flow along the path by removing the restriction after the variable period of time.

10. An acoustic displacement flow meter for determining

the flow rate of a fluid in a path containing a

controllable valve, said flow meter comprising:

a displacement transducer having a fluid port

adapted to be coupled to said fluid path, a displacement

element, and a signal output for manifesting a signal

representative of movement of said displacement element

due to the ingress of fluid through said port; and

computing means having an input coupled to said

displacement transducer signal output for computing the

average value of the fluid flow path over a variable

measurement period, said computing means including means

for generating a control signal for enabling the controllable

valve to divert fluid into said fluid port, means responsive

to the generation of the control signal for masking an

initial portion of the signal at said transducer signal

output, means for integrating the signal at said transducer

signal output after the initial portion, means for sampling

the values of the integrating means, means for summing the

sample values, and means for terminating the control signal

when one of the following conditions occurs

(a) the magnitude of the integral of the sample

value reaches a predetermined maximun value;

(b) the measurement period reaches a predetermined

maximum value, the duration of said control signal

determining the length of said variable measurement period.

COMPLETE SPECIFICATION

FOR OFFICE USE

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Int. Cl:

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Complete Specification—Lodged:
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Related Art:

TO BE COMPLETED BY APPLICANT

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Complete Specification for the invention entitled: ACOUSTIC DISPLACEMENT FLOW METER

The following statement is a full description of this invention, including the best method of performing it known
to me:

BACKGROUND OF THE INVENTION

5   A portion of the disclosure of this patent document contains material which is subject to copyright protection. The copyright owner has no objection to the facisimile reproduction by anyone of the patent document or the patent disclosure, as it appears in the Patent and Trademark Office patent files or records, but otherwise reserves all copyright right whatsoever.

10   This invention relates to fluid flow measuring devices. More specifically, this invention relates to fluid flow measuring devices for providing electrical signals representative of fluid flow.

Many techniques exist in the prior art for the electronic measurement of fluid flow. Typically, such techniques require prior knowledge of the physical properties of the fluid to be measured so that the measuring

15   instrument can be calibrated. Typical examples of such physical parameters are the specific heat capacity, compressibility, density, viscosity, and thermal conductivity of the fluid. Many of these physical parameters are themselves dependent upon the composition of the fluid. For applications in which the

20   fluid composition is unknown or variable in an unpredictable way, such techniques are both inaccurate and unsuitable.

Additional disadvantages inherent in many prior art techniques include limitations in the range of flow rates over which accurate measurements can be reliably made, sometimes termed the "turn-down ratio",

25   and the generation of unacceptable back pressure in the fluid path when the flow meter is connected and operational.

In an attempt to overcome the above-noted shortcomings of the prior art, flow meters have been developed which are less sensitive to fluid physical parameters. This class of flowmeter is generally termed a positive

30   displacement type flowmeter. In a positive displacement flowmeter, the fluid whose flow is to be measured is periodically accumulated in a separate

confining chamber, such as a cylinder with a tight fitting piston, whose volume increases at a rate equal to the flow of the fluid (e.g., by displacement of the piston). By measuring the rate of increase of the confined volume (e.g., by generating a signal representative of the amount of displacement of the

5   piston), the fluid flow rate may be computed. While specific flowmeter details (such as the manner of defining the confined volume and the technique for transducing the rate of volume change) differ depending on the style and application of a given positive displacement flowmeter, all such flowmeters possess the desirable property of reasonable accuracy in the fluid flow

10   measurement independent of the physical parameters of the fluid being measured. However, a severe disadvantage in known positive displacement flowmeters is the disturbance in the fluid flow caused by the necessity of displacing the movable surface of the confining chamber in order to generate the measurement signal. This introduces back pressure characteristics which

15   render such flowmeters unsuitable for use in any application sensitive to the periodic introduction of fluid flow back pressure.

One positive displacement type gas flowmeter which has been developed to reduce the adverse back pressure effect is the soap-film type of positive displacement flowmeter. In this type of flowmeter, the confined

20   volume is defined by a smooth-walled cylindrical tube typically fabricated from transparent glass. The tube has an inlet end connected to the gas whose flow is to be measured and an outlet end open to ambient. Adjacent the inlet end is an arrangement for introducing a soap film to be swept along the inner volume of the tube by the advancing gas flow. Optical sensors arranged at

25   predetermined locations along the tube measure the transit time of the soap film translated along the interior of the tube, and this time value is converted to a fluid flow rate using a known algorithm. Due to the fact that only the relatively small forces of viscosity and surface tension effects oppose the motion of the soap film and thus the flow of the gas stream, the back

30   pressures generated by this type of flowmeter are generally sufficiently low to be acceptable. In addition, the soap film flowmeter has a dynamic

measurement range which is substantially broader than that of other positive displacement flowmeters (typically in the range from about 0.5 to about 500 Ml/min.). Also, this type of flowmeter is relatively inexpensive to manufacture and maintain. The major disadvantage of the soap film flowmeter is the requirement that soap film must be periodically generated, introduced into the fluid stream and somehow exhausted. Generation of the soap film is typically performed by means of a manually operated bubble generating device, which requires the presence of a human operator and prevents automatic or unattended operation. Also, due to the fact that the wet film is introduced into the gas stream, the stream is contaminated with water vapor, which is unsuitable for many in-line applications involving gasses. In addition, the soap film type flowmeter is entirely unsuited for any flowmeter applications involving liquids.

OBJECT AND SUMMARY OF THE INVENTION

It is an object of this invention to ameliorate the aforementioned disadvantages and accordingly there is disclosed a method of determining the flow rate of a fluid flowing along a path, said method comprising the steps of:

(a) establishing fluid flow along a path,

(b) directing the flow of the fluid to a transducer by restricting the flow path downstream from the transducer for a variable period of time, the transducer having a displacement element:

(c) generating a signal from the transducer representative of displacement of the displacement element due to fluid flow while the flow path is restricted:

(d) using the transducer signal to determine the fluid flow rate; and

(e) reestablishing fluid flow along the path by removing

the restriction after the variable period of time.

In another aspect this invention also discloses an acoustic displacement flow meter for determining the flow rate of a fluid in a path containing a controllable valve, said flow meter comprising:

a displacement transducer having a fluid port adapted to be coupled to said fluid path, a displacement element, and a signal output for manifesting a signal representative of movement of said displacement element due to the ingress of fluid through said port; and

computing means having an input coupled to said displacement transducer signal output for computing the average value of the fluid flow path over a variable measurement period, said computing means including means for generating a control signal for enabling the controllable valve to divert fluid into said fluid port, means responsive to the generation of the control signal for masking an initial portion of the signal at said transducer signal output, means for integrating the signal at said transducer signal output after the initial portion, means for sampling the values of the integrating means, means for summing the sample values, and means for terminating the control signal when one of the following conditions occurs

(a) the magnitude of the integral of the sample value reaches a predetermined maximum value;

(b) the measurement period reaches a predetermined

maximum value, the duration of said control signal determining the length of said variable measurement period.

The computing means preferably includes means for determining the value of the fluid flow rate from the equation:

$$F = 2S/[bn(n+1)]$$

where F is the determined flow rate, S is the totalized value of the summed samples, n is the number of samples obtained, and b is a predetermined calibration constant. The masking means preferably includes means for determining the length T of the initial portion to be masked using the algorithm:

if f is $\geq$ K, then T = 0

if f is < K, then T = A[(K-f)/K],

where f is the fluid flow rate determined from a previous measurement, K is a preselected constant flow rate value lying within the desired range of values to be measured, and A is a preselected constant time duration.

The computing means also optionally includes a manually operable switch for initiating a flowmeter operation, a timer for terminating operation of the flowmeter after the lapse of a predetermined time period, and means for extending operation of the flowmeter whenever a sampling means indicates that the manually operable switch means was activated before the lapse of the predetermined time period.

From a method standpoint, the method comprises the steps of establishing fluid flow along a fluid path, directing the flow of the fluid to a transducer having a displacement element by restricting the flow path, generating a signal from the transducer representative of displacement due to fluid flow while the path is restricted, using the transducer signal to determine the fluid flow rate, and reestablishing fluid flow along the path by removing the

restriction. The step of establishing fluid flow along the path preferably includes the step of providing a controllable valve in the path; and the step of directing the flow of the fluid to a transducer preferably includes the step of operating the valve to provide the temporary flow path restriction.

5   The step of generating a signal from the transducer preferably includes the step of allowing the diverted fluid to displace the transducing element for a period of time dependent upon the magnitude of the signal.

The step of reestablishing the fluid flow along the path preferably includes the steps of commencing a measurement period in response to the

10   step of directing the flow to the transducer, monitoring the magnitude of the fluid flow rate signal, and commencing removal of the restriction when one of the following conditions occurs: (a) the magnitude of the integral of the flow rate signal reaches a predetermined maximum value; or (b) the measurement period reaches a predetermined maximum value.

15   The step of generating a signal from the transducer preferably includes the step of ignoring an initial portion of the transducer signal representative of a transient condition, the initial portion being determined from a previous determined fluid flow rate. In a specific embodiment, the initial portion is determined in accordance with the algorithm:

20   if f is $\geq$ K, then T = 0

          if f is < K, then T = A[(K-f)/K],

where f is the fluid flow rate determined from a previous measurement, K is a preselected constant flow rate value lying within the desired range of values to be measured, T is the time value of the initial portion, and A is a preselected

25   time duration.

The step of using the transducer signal to determine the fluid flow rate preferably includes the steps of integrating the signal over a measurement period, sampling the value of the integrated signal, summing the sample values, and determining the flow rate from the equation:

30          $$F = 2S/[bn(n+1)]$$

where F is the determined flow rate, S is the total of the summed samples, n is the number of samples obtained, and b is a predetermined calibration constant.

In another method aspect, the invention comprises a method of using a displacement transducer signal representative of flow of a fluid to determine the fluid flow rate, the method including the steps of masking an initial portion of the transducer signal for a time period, integrating the transducer signal over a measurement period, sampling the value of the integrated signal, summing the sampled value, and determining the fluid flow rate from the equation:

$$F = 2S/[bn(n+1)]$$

where F is the determined flow rate, S is the value of the summed samples, n is the number of samples obtained, and b is a predetermined calibration constant. The initial portion time period is determined from a previous determined fluid flow rate, preferably in accordance with the algorithm:

$$\text{if f is} \geq \text{K, then T} = 0$$

$$\text{if f is} < \text{K, then T} = A[(K-f)/K],$$

where f is the fluid flow rate determined from a previous measurement, K is a preselected constant flow rate value lying within the desired range of values to be measured, T is the time value of the initial portion, and A is a preselected time duration.

For a fuller understanding of the nature and advantages of the invention, reference should be had to the ensuing detailed description, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic block diagram illustrating the preferred embodiment of the invention;

Fig. 2 is a timing diagram illustrating the operation of the embodiment of Fig. 1; and

Fig. 3 is a detailed schematic of the preferred embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

5   Turning now to the drawings, Fig. 1 is a schematic block diagram illustrating the major units comprising the preferred embodiment of the invention. As seen in this Figure, a portion of a fluid flow path includes an inlet 11 into which a fluid, either a gas or liquid, is introduced and a flow outlet 12 which is coupled to the downstream portion of the fluid flow path. An

10   electrically operable flow restricting valve 14 is positioned upstream of the outlet 12 and downstream of the inlet 11. The portion of the fluid flow path between inlet 11 and valve 14 is branched at 15, and the lower portion 16 is coupled to the inlet port of a displacement transducer 20.

       Flow restriction valve 14 is preferably a normally opened valve

15   such as a type C42533 valve available from Edmund Scientific Co., 101 Gloucester Pike, Barrington, NJ 08007. This valve is controlled by a valve control unit 18 which receives a control signal termed VALVE ON from a microcomputer unit 30. Valve 14 is operated to the closed state by valve control unit 18 whenever the VALVE ON signal, depicted in Fig. 2, is in the

20   active state illustrated.

       Displacement transducer 20, which preferably comprises a high-compliance acoustic-type displacement transducer, such as a type 255P223 transducer available from Mouser Electronics Co., 12 Emery Ave., Randolf, NJ 07869, generates an electrical signal termed signal S in Fig. 2 on

25   a signal output line 21. The displacement transducer output signal on output conductor 21 is ac coupled via a capacitor 23 to the signal input of a gated integrated unit 25. Gated integrated unit 25 is controlled by an integrator enable signal from microcomputer 30 which is generally a fixed time period after the commencement of the VALVE ON enable signal. The purpose for

30   this delay between the two signals is to provide a settling time for masking the initial transient signals present on displacement transducer output signal line

21. The output of the gated integrator 25 is coupled to the signal input of an analog to digital converter 27, which is also illustrated in detail in Figure 3.

Analog to digital converter 27 has a sample control signal input which controls the sample rate, the sampling signal being supplied by the

5 microcomputer 30. The digital samples periodically output from converter 27 are supplied to a dedicated input port of the microcomputer 30.

Power to the analog to digital converter 27 is controlled by a power control unit 29 which receives a power on control signal from the microcomputer 30, and which includes a manual operable switch 32 which

10 enables manual control of the start of the measurement operation.

Microcomputer 30 has an output port coupled to a display unit 35 via connections 36 to permit visible display of the computational results and the status of the system. In the preferred embodiment, microcomputer 30 uses a type Z84C004 microcomputer available from Zilog Inc., 1315 Dell Ave.,

15 Campbell, CA 95008, with the configuration illustrated in Fig. 3.

Power regulation is provided by a power regulator unit 38 shown in detail in Fig. 3.

In operation, the fluid flow to be measured is applied to inlet 11 and normally passes through normally open valve 14 to the outlet 12. Thus,

20 while the valve 14 remains deenergized, the path is unobstructed and the input flow is free to exhaust via outlet 12. When valve 14 is energized in response to the receipt by valve control unit 18 of a valve on active signal, valve 14 diverts fluid flow into the displacement transducer 20 via path 16. The displacement transducer in the preferred embodiment comprises[a]two

25 mylar-diaphragm acoustic transducers (such as audio earphone elements) mounted in facing relation so that the fluid can be introduced to a chamber bounded by the two diaphragms. The electromagnetic outlet coils of the transducers (shown in Fig. 3) are connected electrically in series so that electrical signals produced by flow-induced diaphragm motion are in phase

30 and constructively sum. However, diaphragm motions due to mechanical vibration and ambient noise produce signals of equal magnitude but opposing

polarity and thus, to the production tolerance of the elements, interfere and cancel. This results in a substantial improvement in measurement stability. As a result of fluid diverted into the transducer chamber, the diaphragms are displaced in opposing directions and therefore produce an electrical signal

5   proportional to the rate of accumulation of fluid and, thus, to flow. Since the period of valve closure with consequent fluid flow diversion and diaphragm displacement is so short as to be in the range of acoustic frequencies, and due to the positive displacement nature of the flowmeter, the term acoustic displacement has been created for this invention.

10   After the valve 14 has been enabled by valve control unit 18 in response to the valve on signal, the valve 14 undergoes a transition from the fully opened state to the fully closed state. The time period during which this takes place is designated T1 in Figure 2. As the valve 14 closes, the displacement transducer 20 begins to generate the output signal S. The initial

15 portion is a transient portion, and the invention is designed to ignore this transient portion of the signal. For this purpose, another time period T2 is provided during which the output signal S from transducer 20 is ignored. The manner in which the time period T2 is chosen is described below. After the initial portion has elapsed, the integrator unit 25 is enabled at the beginning of

20 period T3 so that the integrator output rises at a rate determined by the magnitude of the displacement transducer signal S. The integrator output signal I is periodically sampled in response to the receipt of the ADC sample signal by analog to digital converter 27. The resulting sample values are supplied to the microcomputer unit 30 for computation in the manner

25 described below. The number of samples n, which are generated at a rate of 1.09 milliseconds in the preferred embodiment, is not fixed but is determined in the manner described below. After the last sample has been obtained, the valve 14 is deenergized by the microcomputer 30 and the valve returns to the normally open position. During this inactive period T0, microcomputer 30

30 performs other control functions, such as sampling the state of the control switch 32 through the power control unit 29 in order to determine whether or

not the switch 32 has been reactivated. In addition, the microcomputer 30 may sample the state of the battery 40 used to power the system to determine whether a low battery condition exists. If so, the low battery condition can be displayed on display unit 35.

5   One flow sample in the preferred embodiment requires the four phase measurement cycle illustrated in Fig. 2. This cycle is timed by the microcomputer 30 as follows. The first phase, T0, has a fixed duration of approximately 450 milliseconds in the preferred embodiment. In this phase, valve 14 is deenergized, the analog to digital converter 27 is disabled, and the

10   integrator 25 is held reset. Because of this persistent reset of the integrator 25 and of the AC coupling provided by capacitor 23 for the transducer output signal, any DC offset error displayed by the integrator input is nulled to zero during this phase. Because of the open state of the valve 14, any fluid previously accumulated during earlier measurement cycles is allowed to

15   exhaust via outlet 12 and the diaphragms within displacement transducer 20 are permitted to relax to the undisplaced positions.

      The second phase of the measurement cycle T1 has a fixed duration of 10 milliseconds in the preferred embodiment. During this phase, power is applied to the solenoid valve 14 via valve control unit 18. Subject to

20   the mechanical delay inherent in the specific valve employed, the application of power to the valve results in closing of the valve and diversion of flow into the inter-diaphragm chamber of the transducers. For the valve used in the preferred embodiment, approximately 7 milliseconds is required for this action to be completed. The additional 3 milliseconds allowed is designed to

25   accommodate uncertainties in valve actuation delay which are apt to result from fluctuations in the power supply and mechanical variations. Closure of valve 14 causes a sizable oscillatory disturbance in the displacement transducer output signal S. At lower flow rates (up to 128 ml per minute in the preferred embodiment), the initial amplitude of this disturbance can be very

30   large compared to the rate of transducer displacement due to measured flow. If this initial amplitude were included in the flow signal acquisition,

measurement accuracy could be severely affected. In order to suppress this potential error source, a third phase T2 of the measurement cycle is added by microcomputer 30. The duration of phase T2 is computed by the microcomputer 30 according to the following algorithm:

5   1.   Let f=measured flow in ml/min flow from the preceding measurement cycle (set f=0 if no such flow value is available, as is the case just after power on).

2.   If $f \geq 128$ ml/min, then T2=0.

3.   If $f < 128$ mil/min, then T2=[(128-f)/12.8] milliseconds.

10   Thus, the duration of T2 decreases from 10 milliseconds to zero as the flow increases from 0 to 128 ml/min. The extra time allowed at low flows for damping of the valve-actuation disturbance provides an important improvement in measurement stability. But at high flows (>128 ml/min), the flow-related signal is so large that possible disturbance-related errors are

15   relatively inconsequential, and a non-zero T2 is unnecessary.

Moreover, a non-zero T2 would actually be harmful to measurement accuracy at high flow rates. This phenomenon results from the finite range of travel available to the transducer diaphragms. The transducers used in the preferred embodiment have a displacement limit for linear

20   measurement of approximately 0.1 ml. If a greater volume than this is allowed to accumulate in the course of a measurement cycle, the mylar diaphragms will be displaced so far from their rest position that the constant relationship between diaphragm motion and transducer output signal amplitude will fail and the flow measurement will be corrupted. Because the range of accurate flow

25   measurement for the preferred embodiment flowmeter was desired to extend beyond 1000 ml/min = 16.7 ml/sec = 0.0167 ml/msec, and the capacity of the transducer is 0.1 ml, the maximum total flow displacement interval is 0.1/.0167 = 6 msec at 1000 ml/min. Because the total flow displacement interval is the sum of:

30   (T1-valve actuation delay) +T2+T3

no fixed value for T2 can be compatible with all flow measurement regimes. A fixed value of 10 msec for T2, for example, would "use up" available transducer displacement capacity at a flow of 462 mi/min, even assuming a T3 duration of zero.

5   The fourth and last phase T3 of the measurement cycle is the phase during which the flow-related signal acquisition actually occurs. The duration of T3 in the preferred embodiment can vary from a low of 2.8 milliseconds to a maximum of 43.6 milliseconds as a function of flow rate. This is due to the method used to convert the analog output of the

10   displacement transducer 20 to a digital reading compatible with microcomputer 30. At the onset of T3, the reset signal is removed from the integrator 25, allowing the output I of the integrator 25 to rise at a rate proportional to the output signal S from the displacement transducer 20. This can be expressed as follows:

15    $$I = aFt$$

where I is the integrator output signal, a is a transducer calibration constant, F is the flow rate, and t is the elapsed time since the enabling of integrator 25. In the preferred embodiment, the analog to digital converter 27 is controlled to periodically sample (at a sample rate of 1.09 millisecond between samples) the

20   output I of integrator 25 during phase T3. The nth sample result can be expressed as:

$$A = bFn$$

where A is the analog to digital sample value, b is the calibration constant for the analog to digital converter 27, F is the fluid flow rate, and n is the sample

25   number relative to the onset of phase T3.

In the preferred embodiment, acquisition of the flow rate signal samples proceeds from the onset of phase T3 according to the following algorithm:

1.   Set sum S = 0, sample count n = 0.

30   2.   Wait 1.09 msec from last sample.

3.   Sample integrator 25 output I to 8 bit (fullscale/256) resolution. Set A = ADC result.

4.   If A > 255 (integrator output signal I has exceeded ADC fullscale), discard sample and go to step 6.

5   5.   Set S = S + A, n = n+1. If n < 40 then go to step 2. Because A = bFn, it can be shown that S = bFn (n+1)/2.

6.   If n = 0, then flow rate exceeds maximum flowmeter is capable of measuring (1024 ml/min in preferred embodiment). Report overflow in readout display 35 and terminate measurement cycle. ·

10   7.   Set E = flow estimate for this measurement cycle = 2S/[bn(n+1)].

The signal acquisition thus implemented displays a number of desirable features. Firstly, a very wide range of flows can be digitized with adequate resolution. In the preferred embodiment, a flow measurement range

15   of 1 to 1024 ml/min with a minimum resolution of 1% of reading was desired. This is equivalent to a 100,000:1 dynamic range. Used alone, the 8 bit resolution ADC 27 has only a 256:1 dynamic range. Indeed, a traditional ADC of 100,000:1 dynamic range would likely be prohibitively expensive for incorporation into a low cost instrument such as the preferred embodiment.

20   The combination of gated integrator 25, low resolution ADC 27, and the algorithm above, however, easily meets the preferred requirement. Analysis of the relationship between flow rate and n, the number of ADC samples that the illustrated algorithm will sum during T3, indicates that measurement resolution varies from a maximum of 1/128 of reading for a flow of 512 ml/min (n=1) to a

25   minimum of 1/8166 of reading at 25.6 ml/min (n=40, n(n+1)/2=820). Resolution remains better than 1% of reading all the way down to 0.125 ml/min, corresponding to a dynamic range of 800,000:1.

Further, relatively high noise immunity to noise-induced errors is enjoyed due to the relatively long integration times (up to 43.6 msec) applied

30   to low flow rates. Also, since the T3 phase of the measurement cycle is terminated and the valve 14 deenergized immediately after completing the

signal acquisition algorithm, the flow accumulation interval is kept short (as short as 2.18 msec at F>512 ml/min) at high flows. This prevents exceeding transducer displacement limits at even the highest flows.

5   Completion of the T3 phase marks the end of a measurement cycle. Flowmeter operation continues with T0 of the next cycle. During T0, in addition to the functions of this phase outlined above, the E value from the most recently completed cycle is summed with the E values from the three preceding cycles to form a two second running average of flow. This sum is then displayed in display unit 35. In addition, during T0 the flowmeter-operator

10   accessible control switch 32 is sampled to permit the entry of a number of commands (e.g., power off), and a check of battery condition is performed so that a warning message can be displayed in the display unit 35 if a state of discharge is imminent.

         Appendix I to this specification is an object code program in

15   decimal (base ten) formed of the program used in the preferred embodiment. Battery powered instruments such as the preferred embodiment are commonly provided with an automatic power-off function to prevent operator neglect from resulting in unacceptably short battery life. This function is performed in the preferred embodiment by the power control unit 29. The power on state is

20   initiated by operator actuation of the momentary switch 32. After ten minutes of flowmeter operation, if the switch 32 is not actuated to change the timeout, the microcomputer 30 sends a signal to the power control unit 29 to disconnect battery power and shut off the flowmeter.

         Proper operation of various flowmeter elements depends upon

25   regulation of the constant battery voltage to produce a constant voltage source. This function is performed in the preferred embodiment by power regulator 38.

         As noted above, displacement transducer 20 comprises a pair of high-compliance acoustic-type displacement type transducers. High

30   diaphragm compliance is exceedingly important to measurement accuracy when measuring compressible fluids, such as gasses, since only low pressure

is required to displace a high-compliance transducer. The exact relationship between diaphragm resiliency and measurement error is dependent upon the dead volume of the source of the flow stream. If a contribution of 1% from this error source to total measurement error is deemed acceptable, and if a

5   maximum flow-source dead volume of 10 ml is assumed, the total diaphragm compliance is 10 ml/.01 = 1 liter per atm.

While the above provides a full and complete description of the preferred embodiment of the invention, various modifications, alternate constructions and equivalents may be employed. For example, while specific

10   circuit elements have been described above, other specific elements may be employed, depending on the requirements of a particular application. Therefore, the above description and illustrations should not be construed as limiting the scope of the invention which is defined by the appended claims.

APPENDIX I

0	0	0	82	15	237	71	82	58	211	0
10	33	58	0	6	20	219	1	135	56	251
20	78	35	237	163	32	245	33	0	0	17
30	0	0	1	0	0	217	253	33	0	1
40	221	33	216	3	33	165	0	195	181	0
50	0	0	0	0	0	0	221	233	0	56
60	0	56	0	12	0	1	0	6	0	137
70	2	0	2	176	2	4	2	0	67	204
80	207	194	193	212	128	67	160	160	160	160
90	160	128	0	207	214	197	210	198	204	207
100	215	160	160	160	128	0	210	197	196	174
110	188	176	174	181	176	160	160	128	0	176
120	174	176	176	237	236	175	237	233	238	160
130	160	128	0	177	174	176	176	186	177	160
140	160	160	160	160	160	128	0	200	193	214
150	197	160	193	160	206	201	195	197	160	196
160	193	217	161	160	128	0	160	160	160	160
170	160	215	193	210	205	213	208	128	211	0
180	8	8	219	1	135	56	251	219	1	254
190	8	62	192	40	239	126	35	214	128	56
200	233	32	3	8	221	233	211	2	24	228
210	8	219	1	135	56	251	219	1	254	8
220	32	6	62	192	211	0	24	239	8	214
230	128	56	4	211	2	221	233	211	0	221
240	233	219	1	135	56	251	120	198	137	211
250	0	219	1	135	56	251	219	3	221	233
260	8	219	1	135	56	251	120	198	137	211
270	0	8	8	219	1	135	56	251	8	211
280	2	221	233	62	7	237	71	1	8	99
290	16	254	13	32	251	6	3	221	33	48
300	1	195	241	0	254	32	48	18	246	224
310	79	237	87	6	75	16	254	238	8	237
320	71	12	32	245	62	37	237	71	1	2
330	46	16	254	13	32	251	221	33	101	1
340	33	255	255	84	1	40	0	238	15	237
350	71	251	16	254	243	24	29	88	25	35
360	4	32	10	44	202	114	1	45	24	16
370	45	6	253	16	254	238	7	237	71	6
380	34	18	254	13	32	217	62	15	237	71
390	62	40	145	202	175	1	79	235	33	0
400	0	9	61	194	145	1	9	235	14	127
410	25	12	210	154	1	175	237	82	41	25
420	63	48	18	203	17	23	210	162	1	24
430	18	33	92	0	221	33	148	2	195	181
440	0	237	82	203	33	23	210	162	1	6
450	3	221	33	202	1	195	4	1	47	103
460	121	47	111	253	249	14	255	57	12	210
470	211	1	175	237	114	60	41	57	63	48
480	8	203	17	23	210	220	1	24	8	237
490	114	203	33	23	210	220	1	105	103	249
500	217	175	57	143	25	206	0	9	206	0
510	249	217	235	33	0	0	57	235	249	217
520	8	33	0	0	57	235	123	89	79	122
530	80	71	217	1	175	3	235	8	17	0
540	156	25	206	255	12	218	29	2	175	237
550	82	221	33	46	2	195	210	0	121	254
560	176	40	24	254	186	56	12	62	177	221
570	33	64	2	195	210	0	121	214	10	221
580	33	74	2	195	210	0	5	62	175	17
590	0	246	60	25	218	80	2	237	82	254
600	176	32	7	8	120	254	3	40	9	8
610	221	33	105	2	195	210	0	5	124	138

620	176	221	33	116	2	195	210	0	5	40
630	29	62	174	221	33	128	2	195	210	0
640	22	0	98	93	41	41	25	41	62	176
650	132	221	33	146	2	195	210	0	16	238
660	219	1	135	56	251	219	1	8	6	0
670	221	33	165	2	195	241	0	230	251	198
680	2	246	2	15	79	33	123	0	48	3
690	33	137	0	8	221	33	189	2	195	210
700	0	221	33	196	2	195	181	0	62	10
710	237	71	6	64	16	254	221	33	214	2
720	6	64	251	16	254	243	60	4	5	16
730	254	16	254	237	71	121	7	202	85	3
740	203	143	203	87	202	85	3	48	27	217
750	1	0	0	88	80	104	96	217	33	118
760	0	221	33	0	3	195	181	0	253	33
770	0	1	61	195	85	3	33	2	0	57
780	79	124	167	32	3	181	254	32	249	33
790	105	0	221	33	85	3	121	218	181	0
800	217	57	56	36	25	56	33	9	56	30
810	203	124	32	26	249	253	33	0	0	253
820	57	33	64	0	93	84	77	68	217	33
830	132	0	60	221	33	85	3	195	181	0
840	33	92	0	221	33	82	3	195	181	0
850	98	107	217	6	0	221	33	94	3	195
860	4	1	230	6	254	4	14	4	40	7
870	254	2	32	19	1	176	4	121	221	33
880	117	3	195	16	1	120	221	33	125	3
890	195	16	1	237	87	230	232	237	71	1
900	1	203	221	33	152	3	33	78	0	251
910	16	254	13	194	142	3	243	33	85	0
920	62	15	237	71	221	33	163	3	195	181
930	0	6	1	221	33	172	3	195	241	0
940	144	221	33	180	3	195	4	1	48	34
950	4	221	33	190	3	195	241	0	214	1
960	221	33	199	3	195	4	1	48	15	33
970	146	0	221	33	211	3	195	181	0	62
980	63	237	71	118	1	244	201	11	121	176
990	32	251	195	27	1	201	170	2	56	210

The claims defining the invention are as follows:

1. A method of determining the flow rate of a fluid flowing along a path, said method comprising the steps of:

    (a) establishing fluid flow along the path,

    (b) directing the flow of the fluid to a transducer by restricting the flow path downstream from the transducer for a variable period of time, the transducer having a displacement element;

    (c) generating a signal from the transducer representative of displacement of the displacement element due to fluid flow while the flow path is restricted;

    (d) using the transducer signal to determine the fluid flow rate; and

    (e) reestablishing fluid flow along the path by removing the restriction after the variable period of time.

2. The method as claimed in claim 1 wherein said step (a) of establishing includes the step of providing a controllable valve in the path; and wherein said step (b) of directing includes the step of operating the valve to provide the temporary flow path restriction.

3. The method as claimed in claim 1 wherein said step (c) of generating includes the step of allowing the diverted fluid to displace the displacement element for a period of time dependent upon the magnitude of the signal.

4. The method as claimed in claim 1 wherein said step (e) of reestablishing includes the steps of (i) commencing a

-18-

measurement period in response to the step (b) of directing

the flow; (ii) monitoring the magnitude of the integral of

the fluid flow rate signal; and (iii) commencing removal

of the restriction when one of the following conditions

occurs;

     (a) the magnitude of the integral reaches a

predetermined maximum value;

     (b) the measurement period reaches a predetermined

maximum value.

5. The method as claimed in claim 1 wherein said step (c)

of generating includes the step of ignoring an initial

portion of the transducer signal representative of a

transient condition.

6. The method as claimed in claim 5 wherein the initial

portion is determined from a previous determined fluid

flow rate.

7. The method as claimed in claim 5 wherein the initial

portion is determined in accordance with the following

algorithm:

$$\text{if } f \text{ is} \geq K, \text{ then } T = 0$$

$$\text{if } f \text{ is} < K, \text{ then } T = A\left[(K-f)/K\right],$$

where f is the fluid flow rate determined according to

step (d) from a previous measurement, K is a preselected

constant flow rate value lying within the desired range

of values to be measured, T is the time value of the

initial portion and A is a preselected time duration.

8. The method as claimed in claim 7 wherein K is 128 ml per minute and A is 10 milliseconds.

9. The method as claimed in claim 1 wherein said step (d) of using includes the steps of integrating the signal over a measurement period, sampling the value of the integrated signal, summing the sample values, and determining the flow rate from the equation:

$$F = 2S/[bn(n+1)]$$

where F is the determined flow rate, S is the value of the summed samples, n is the number of samples obtained, and b is a predetermined calibration constant.

10. An acoustic displacement flow meter for determining the flow rate of a fluid in a path containing a controllable valve, said flow meter comprising:

a displacement transducer having a fluid port adapted to be coupled to said fluid path, a displacement element, and a signal output for manifesting a signal representative of movement of said displacement element due to the ingress of fluid through said port; and

computing means having an input coupled to said displacement transducer signal output for computing the average value of the fluid flow path over a variable measurement period, said computing means including means for generating a control signal for enabling the controllable valve to divert fluid into said fluid port, means responsive to the generation of the control signal for masking an initial portion of the signal at said transducer signal output, means for integrating the signal at said transducer

-20-

signal output after the initial portion, means for sampling
the values of the integrating means, means for summing the
sample values, and means for terminating the control signal
when one of the following conditions occurs

       (a) the magnitude of the integral of the sample
value reaches a predetermined maximun value;

       (b) the measurement period reaches a predetermined
maximum value, the duration of said control signal
determining the length of said variable measurement period.

11. The acoustic displacement flow meter as claimed in
clair 10 wherein said computing means includes means for
determining the value of the fluid flow rate from the
equation:

$$F = 2S / [bn(n+1)]$$

where F is the determined flow rate, S is the totalised
value of the summed samples, n is the number of samples
obtained, and b is a predetermined calibration constant.

12. The acoustic displacement flow meter as claimed in
claim 10 wherein said masking means includes means for
determining the length T of the initial portion to be
masked, using the algorithm

          if f is $\geq$ K, then T = 0
          if f is $<$ K, then T = A $[(K-f)/K]$,

where f is the fluid flow rate determined from a previous
measurement, K is a preselected constant flow rate value
lying within the desired range of values to be measured,
and A is a preselected time duration.

-21-

13. The acoustic displacement flow meter as claimed in claim 12 wherein K is 128 mm per minute and A is 10 milliseconds.

14. The acoustic displacement flow meter as claimed in claim 10 wherein said computing means further includes manually operable switch means for initiating flowmeter operation.

15. The acoustic displacement flow meter as claimed in claim 14 wherein said computing means further includes timer means for terminating operation of the flow meter after the lapse of a predetermined time period.

16. The acoustic displacement flow meter as claimed in claim 15 wherein said timer means includes means for periodically sampling the state of said switch means, and means for extending operation of the flow meter when said sampling means determines that said switch means is activated.

17. A method of determining the flow rate of a fluid along a path, said method being substantially as described herein with reference to the drawings.
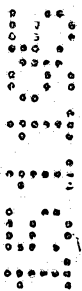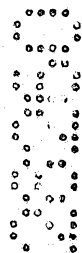
18. An acoustic displacement flow meter for determining the flow rate of a fluid in a path, said flow meter being substantially as described herein with reference to the drawings.

-22-

Dated this 13th day of November, 1995

Curtin Matheson Scientific, Inc.
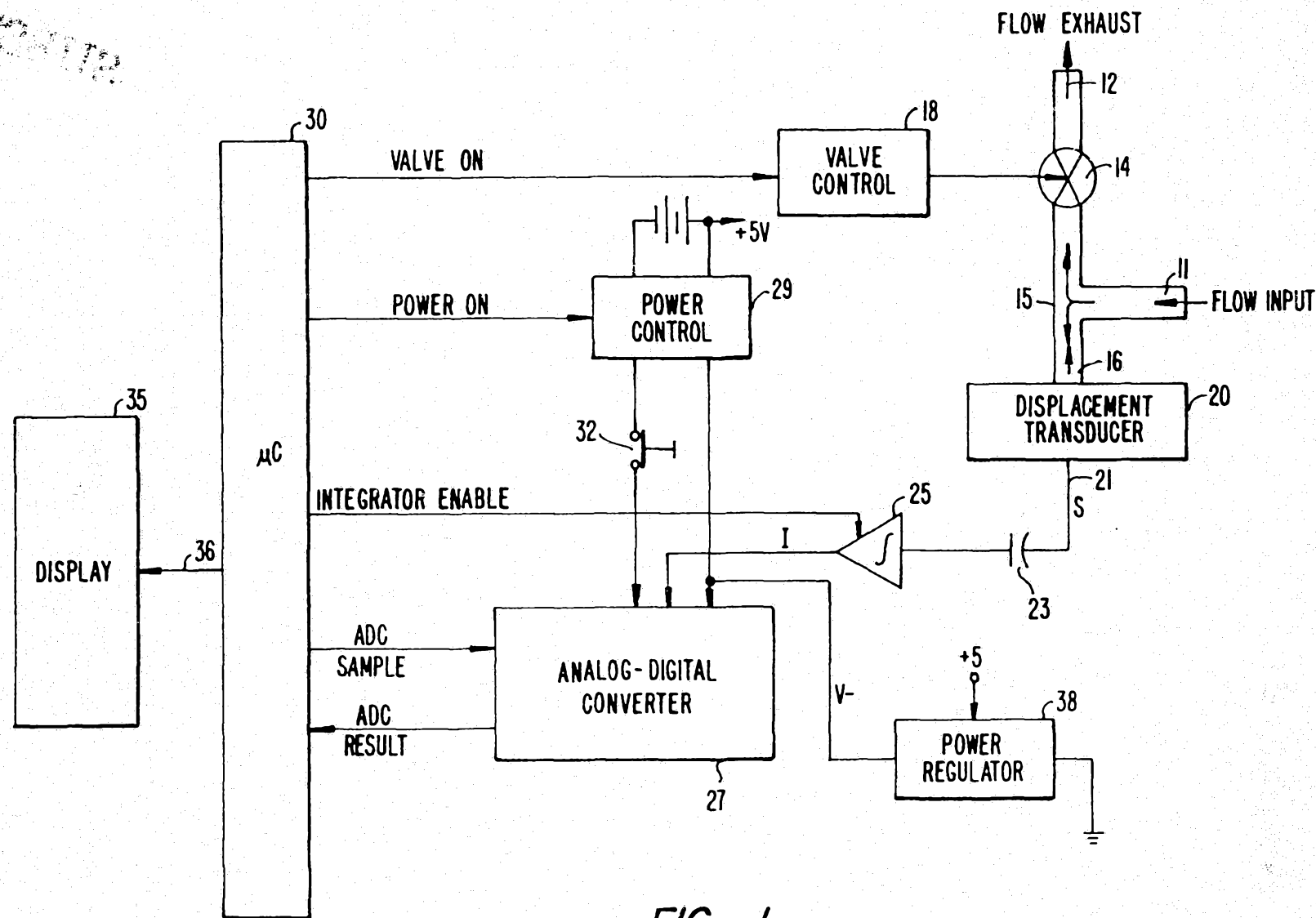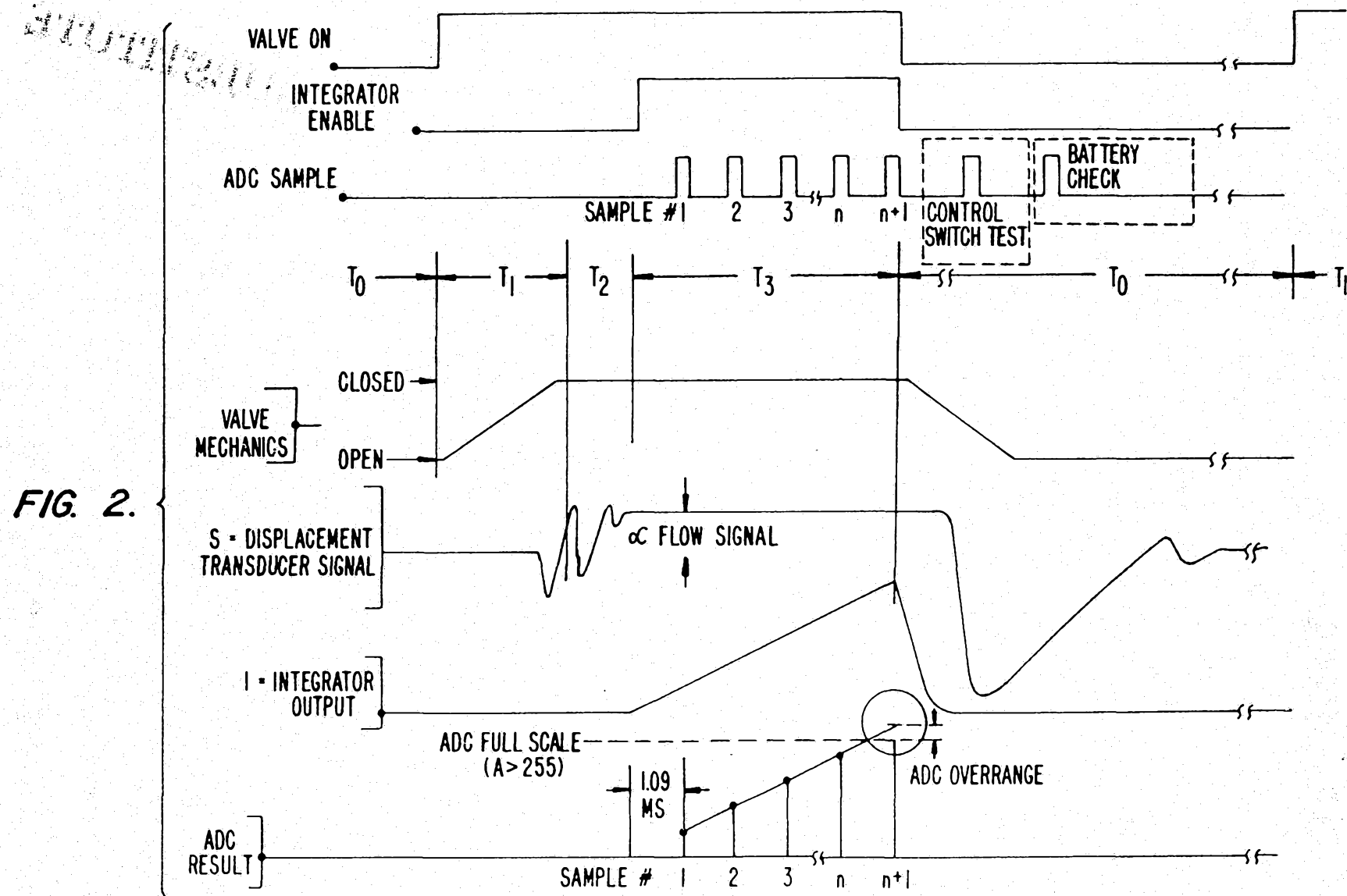By Our Patent attorney
MICHAEL ANDERSON-TAYLOR

-23-

FLOW EXHAUST

12

VALVE CONTROL 18

14

VALVE ON

+5V

POWER CONTROL 29

POWER ON

11

FLOW INPUT

15

16

DISPLACEMENT TRANSDUCER 20

30

μC

32

INTEGRATOR ENABLE

25

21

S

I

∫

23

35

DISPLAY

36

ADC SAMPLE

ADC RESULT
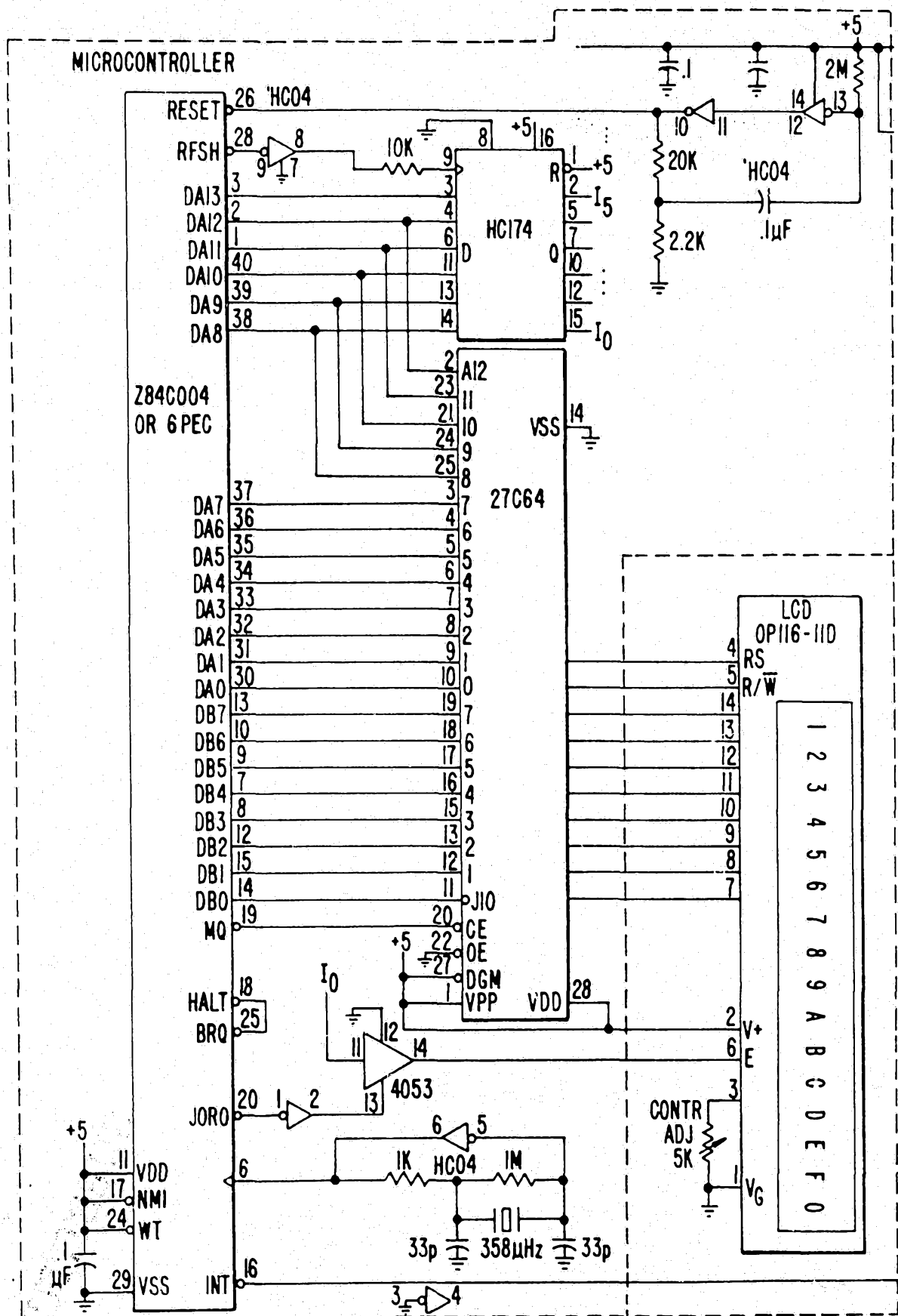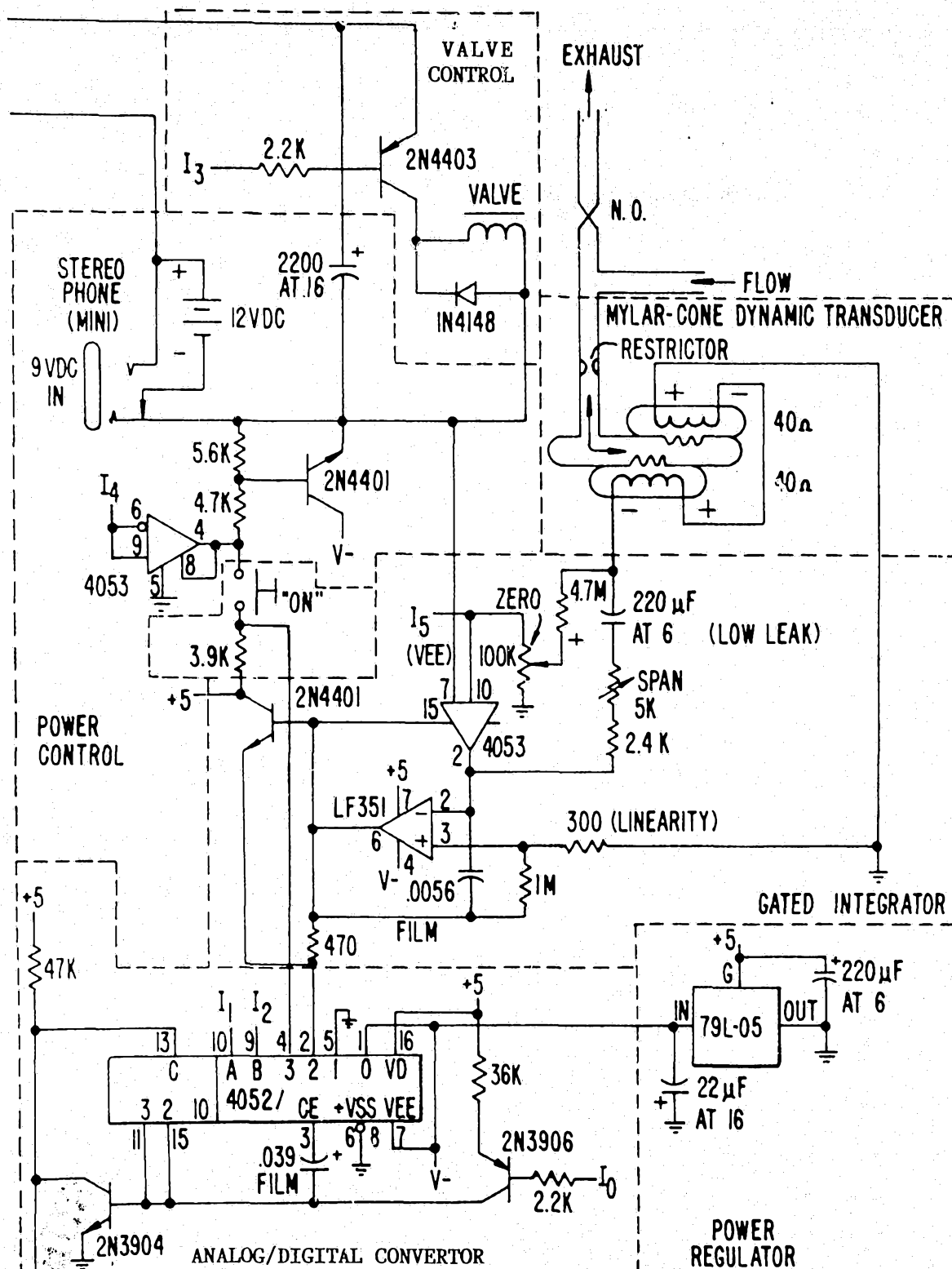
ANALOG-DIGITAL CONVERTER

V−

+5

POWER REGULATOR 38

27

FIG. 1.

FIG. 2.

FIG. 3A.

FIG. 3B.

FIG. 3A. | FIG. 3B.

FIG. 3.