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(56) Documents cited
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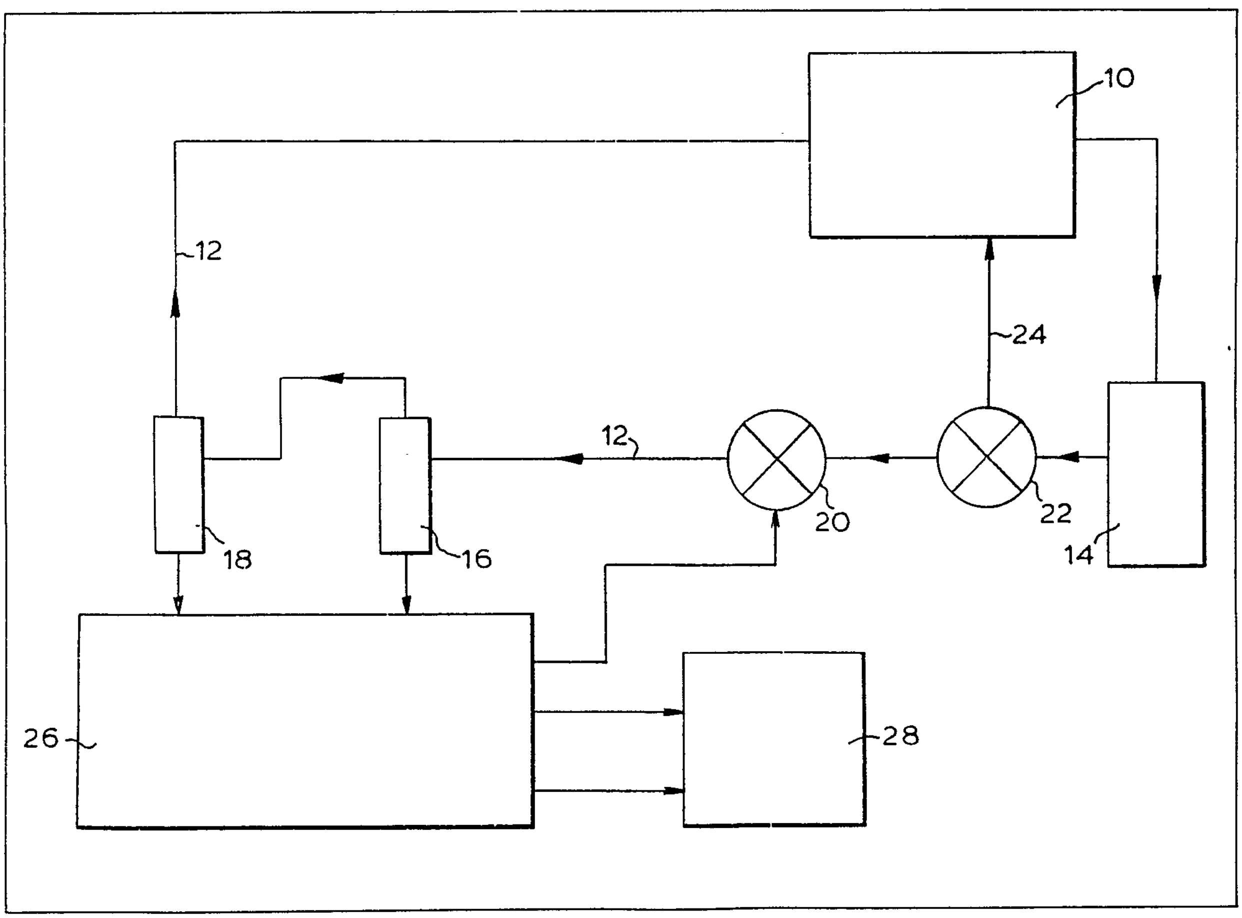
(54) Flow rate sensor

(57) Although flow rate sensors are manufactured to have output characteristics falling within a specified range of tolerances, such variation may not be acceptable for certain applications, such as monitoring fuel flow rate in i.c. engines.

This invention provides a flow rate sensor comprising a sensing element (18) and storage means, the storage means having a plurality of adjustment factors stored therein which relate to respective sections within the operating range of the sensor and which are for use in adjusting the output of the sensor from the respective section so as to reduce deviation from a desired output characteristic. The storage means is preferably in the form of a PROM, which may be programmed by PROM programmer (28) under the control of microcomputer (26), which also controls a range of flow rates through sensing element (18) and a standard sensing element (16), in order to derive the adjustment factors.



The drawing originally filed was informal and the print here reproduced is taken from a later filed formal copy.

GB 2 116 720 A

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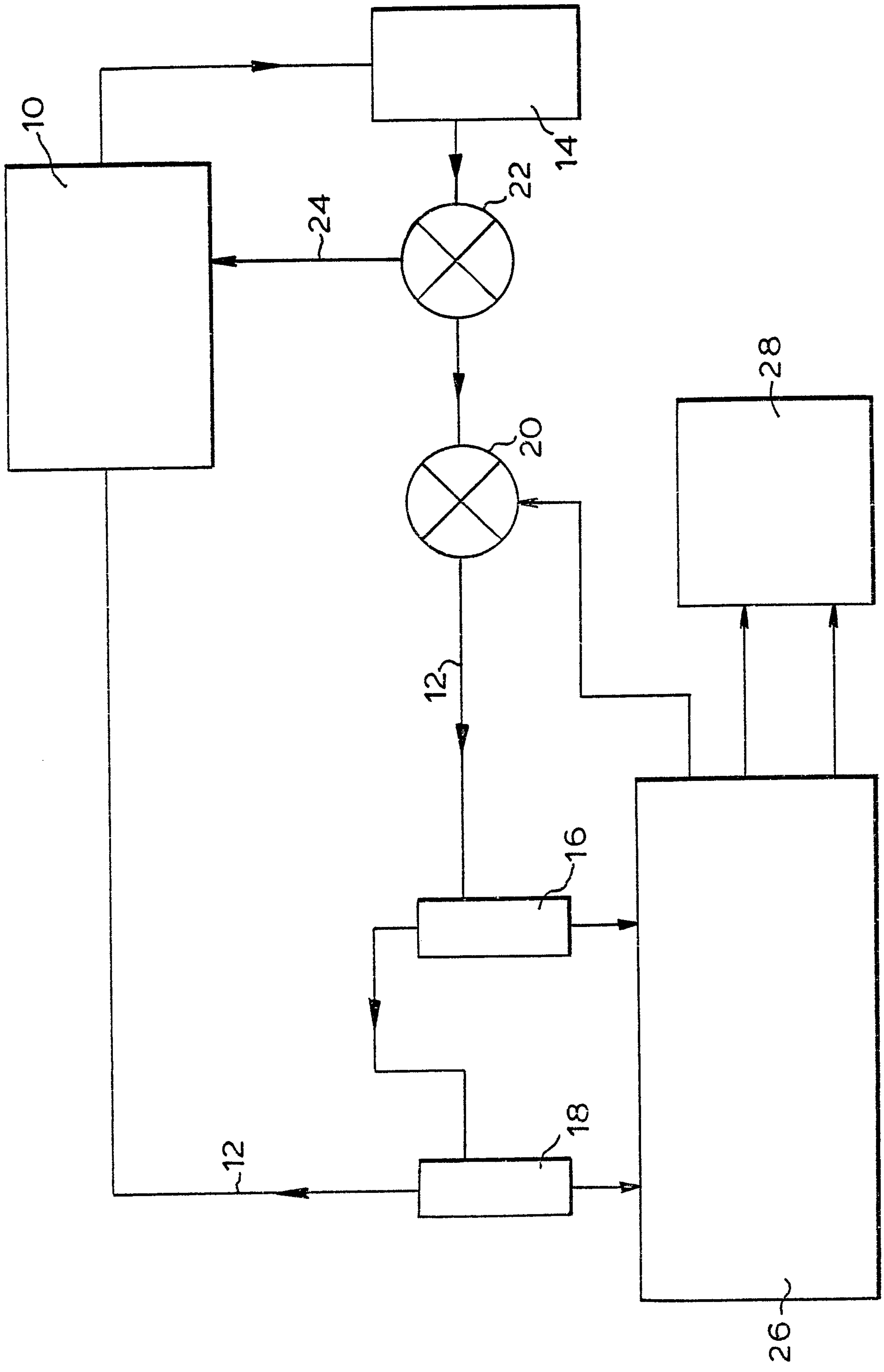

SPECIFICATION

Flow rate sensor

The present invention relates to flow sensors and is particularly concerned with reducing deviation from a desired output characteristic of flow rate sensors.

Flow rate sensors are known and although these are commonly precision made devices, at the end of the manufacturing process each sensor has a unique output characteristic. The output characteristics are, of course, restrained within what the manufacturer considers to be acceptable tolerances. However, for particular applications it is required that each individual flow rate sensor provides an output which is as close to an ideal output characteristic as possible. Factors affecting deviation from an ideal characteristic can be introduced at almost any stage during manufacture and it is expensive and sometimes impractical to improve upon the currently accepted manufacturing tolerances.

With a view to mitigating the above disadvantage, the present invention provides, in a first aspect, a flow rate sensor comprising a sensing element and storage means, the storage means having a plurality of adjustment factors stored therein which relate to respective sections within the operating range of the sensor and which are for use in adjusting the output of the sensor from the respective section so as to reduce deviation from a desired output characteristic.

According to a second aspect of the present invention there is provided a method of reducing deviation from a desired output characteristic of a flow rate sensor comprising the steps of; specifying a range of flow rates, specifying a plurality of sections within the range, determining an adjustment factor for each section and storing the adjustment factor such that, in use, output from the flow rate sensor is adjusted by the respective adjustment factor so as to reduce deviation from the desired output characteristic.

According to a third aspect of the present invention, there is provided a method of providing flow rate sensors having standardised output characteristics comprising the steps of; providing a standard sensor having a standard output characteristic, passing a variable common flow through the standard sensor and a sensor to be calibrated, for each of a plurality of sections within the operating range of the sensors; measuring the deviation of the output characteristic of the sensor being calibrated from the standard characteristic and calculating and storing an adjustment factor such that, when the sensor being calibrated is in use, output from that section can be adjusted so as to present the standard output characteristic.

Embodiments of the present invention will now be described by way of example only and with reference to the accompanying single *Figure* of drawing which is a block diagram of apparatus for providing flow rate sensors having standardised output characteristics.

In these embodiments the flow rate sensors are used for monitoring the rate of flow of fuel supplied to an internal combustion engine. The output from the flow rate sensor may be used as the input to a microcomputer which presents performance information to an operator or to the driver of a vehicle which is powered by the engine.

In such an embodiment the flow rate sensor provides an electrical output which is fed into a microcomputer. In particular, a circuit may be provided which in combination with the fuel sensor to act as an oscillator so as to produce input pulses for the microcomputer. The output pulses from the sensor circuitry vary with the rate of flow of fuel through the sensor. When the flow rate is high the frequency of output pulses is also high and when the flow rate is low the frequency of output pulses from the sensor is correspondingly low. However, the relationship between variations in flow rate through the sensor and frequency output from the sensor do not have a linear relationship.

Factors affecting the relationship between flow through the sensor and output frequency can be introduced by almost any of the stages of manufacture of the flow rate sensor. Consequently, although each flow rate sensor has an output characteristic, that is the relationship between flow through the sensor and frequency of the output pulses, which falls within a preset range, each sensor will in fact have a unique characteristic and although the variation in characteristics is considered to be within acceptable tolerances by the manufacturer, applications such as the present one require a more precise specification of the characteristic.

This problem can be overcome by calibrating the circuitry and microcomputer for the unique characteristic of the flow rate sensor being employed. However, such a solution is not practical for a mass produced system. The present invention overcomes this problem by standardising the output from individual flow rate sensors. This is achieved by comparing each flow rate sensor which provides a standard output characteristic. Adjustment factors are calculated from a comparison of the output characteristics and the adjustment factors are stored in an external storage medium such as a PROM. Output from the flow rate sensor being calibrated is adjusted by the relevant adjustment factor in order to present an output characteristic which emulates the standard output characteristic. The operating range of the sensors is divided into a number of sections for each of which an adjustment factor is calculated and stored.

In the present application the ideal characteristic is linear and the limits of the operating range of the sensors are set at zero litres per hour and 50 litres per hour. For a linear characteristic, any flow rate within the range specified by the limits can be calculated from the equation:

$$\text{Desired flow rate} = \frac{f(x)-f(0)}{f(50)-f(0)} \times 50$$

where f(50) is the frequency of output pulses at 50 litres per hour,
f(0) is the frequency of pulses at zero litres per hour,
f(x) is the frequency of pulses at the desired flow rate.

Since the characteristic of the flow rate sensor to be calibrated is non-linear, it is necessary to introduce an adjustment factor in order that the calculated flow rate equals that obtained by a linear characteristic. The equation thus becomes;

$$\text{Desired flow rate} = \frac{f(x)-f(0)}{f(50)-f(0)} \times 50 \times \text{adjustment factor} \qquad \ldots\ldots (1)$$

Rearranging the above equation produces;

$$\text{Adjustment factor} = \frac{\text{desired flow rate}}{f(x)-(f0)} \times \frac{f(50)-f(0)}{50} \qquad \ldots\ldots (2)$$

The above equation for the adjustment factor defines an infinite number of adjustment factors between the limits of zero litres per hour and 50 litres per hour. The number of adjustment factors which are to be calculated and stored must be limited to a finite number and this is achieved by dividing the operating range into a number of sections and then calculating and storing an adjustment factor for each of the sections. The adjustment factors then represent an average adjustment for points along the operating range which fall within that section. In order to improve the accuracy of the adjustment factors the sections are not of equal extent but are of a size determined by the magnitude of deviation from the ideal characteristic within that section. The extent of each section is approximately inversely proportional to the magnitude of deviation from the ideal characteristic within that section.

In practice the characteristic between zero litres per hour and 50 litres per hour has been divided into 14 sections, the extent of which decrease in regions where the characteristic of the sensor being standardised present maximum non-linearity. Taking these considerations into account it has been found possible to divide the operating range, in terms of litres per hour, into sections spanning the following boundaries;

0--1--3--7--12--16--20--25--30--35--40--44--46--48--50.

Several points are then selected within each section and for each of these points the deviation of the output characteristic from the standard characteristic is calculated and their mean value is then adopted as the adjustment factor for that section. For example, in the section spanning 12 to 16 litres per hour the deviation of the output characteristic from the standard would be calculated at the following values in terms of litres per hour; 12, 13, 14, 15, and 16. The mean of these calculated values is then adopted at the adjustment factor for this section.

The adjustment factors are stored in a PROM and when an output value is required from the flow rate sensor, the device requesting the information, such as a microcomputer CPU, accesses the PROM and the output from the sensing element is multiplied by the respective adjustment factor before the information is used by the requesting device.

In order to provide flow rate sensors having standardised output characteristics it is necessary to establish a process wherein the individual flow rate sensors are compared against a standard and to calculate the adjustment factors from that comparison. In addition, for practical mass production the process is required to be automated and to be controlled to a high degree of precision. A block diagram of apparatus suitable for carrying out this process is illustrated in the accompanying *Figure* of drawings.

The apparatus comprises a reservoir of test fluid 10 which is introduced into a pipe network 12 by the action of a pump 14. The pipe network 12 provides a common flow which first passes through a flow rate sensor 16 which has been designated as the standard and subsequently through the flow rate sensor 18 which is to be calibrated. Flow through the sensors 16 and 18 may be varied by means of a valve 20 which is situated in the pipe network 12 on the feed side of the standard sensor 16. In order to provide reliable comparisons a pressure equaliser 22 is inserted into the pipe network on the feed side of the valve 20. The pressure equaliser 22 is provided with a feedback 24 to a reservoir 10 so that fluid causing excess pressure can be fed back to the reservoir 10. Respective electrical outputs from the sensing elements 16 and 18 are fed into a calibration microcomputer 26. The calibration microcomputer 26 forms part of the calibration apparatus, as distinct from a microcomputer which may be used in combination with a standardised flow rate sensor in the final application of the product. The calibration microcomputer 26 is linked with a PROM programmer 28 and supplies both programme control and data inputs into the PROM programmer 28. The microcomputer 26 also controls operation of the valve 20.

The calibration microcomputer 26 varies the flow through the sensing elements 16 and 18 by controlling the valve 20 and compares the output characteristics of the sensing elements 16 and 18 as the flow rate is varied over the entire operating range of the sensing elements 16 and 18. Data thus collected by the microcomputer 26 undergoes arithmetic operations in accordance with the above described algorithm so as to calculate the adjustment factors for each of the sections of the operating range. The data is then passed to the PROM programmer 28 which, under programme control from the microcomputer 26, encodes the adjustment factors in a PROM. The calibrated flow rate sensing element 18 and the encoded PROM can subsequently be connected together so as to present a flow rate sensor which has a standard output characteristic.

The microcomputer 26 opens the valve 20 in a controlled manner and at the same time monitors the flow rate by taking inputs from the standard flow rate sensor 16 and the flow rate sensing element 18. When a calibration point is reached, signals from both the sensor 16 and the sensing element 18 are taken and stored in the microcomputer 26. This process continues until measurements have been taken from all of the calibration points. Then using the above equation (1) the flow rate at a particular calibration point can be calculated from data provided by the standard flow rate sensor 16. For the flow rate sensing element 18, the coefficient $(f(50)-f(0))/50$ can be easily determined. Consequently, for each calibration point the adjustment factor is determined in accordance with equation (2). The mean of the adjustment factors for calibrations points within each section is calculated and consequently, the set of averaged adjustment factors for the 14 sections, together with the coefficient $(f(50)-f(0))/50$, are permanently stored in the PROM and the calibration process is thus completed.

CLAIMS

1. A flow rate sensor comprising a sensing element and storage means, the storage means having a plurality of adjustment factors stored therein which relate to respective sections within the operating range of the sensor and which are for use in adjusting the output of the sensor from the respective section so as to reduce deviation from a desired output characteristic.
2. A flow rate sensor as claimed in claim 1, wherein the storage means is in the form of a PROM.
3. A flow rate sensor as claimed in claim 1 or 2, wherein the extent of each section is inversely proportional to the magnitude of deviation from the desired output characteristic within that section.
4. A flow rate sensor as claimed in any preceding claim, wherein the desired output characteristic is linear.
5. A flow rate sensor as claimed in any preceding claim, wherein the sensor has an output in the form of electrical impulses, the frequency of which vary with flow rate through the sensor.
6. A method of reducing deviation from a desired output characteristic of a flow rate sensor comprising the steps of; specifying a range of flow rates, specifying a plurality of sections within the range, determining an adjustment factor for each section and storing the adjustment factor such that, in use, output from the flow rate sensor is adjusted by the respective adjustment factor so as to reduce deviation from the desired output characteristic.
7. A method of providing flow rate sensors having standardised output characteristics comprising the steps of; providing a standard sensor having a standard output characteristic, passing a variable common flow through the standard sensor and a sensor to be calibrated, for each of a plurality of sections within the operating range of the sensors; measuring the deviation of the output characteristic of the sensor being calibrated from the standard characteristic and calculating and storing an adjustment factor such that, when the sensor being calibrated is in use, output from that section can be adjusted so as to present the standard output characteristic.
8. A method as claimed in claim 6 or 7, wherein the extent of each section is inversely proportional to the magnitude of deviation from the desired or standard output characteristic within that section.
9. A method as claimed in any of claims 6 to 8, wherein the desired or standard output characteristic is linear.
10. A flow rate sensor substantially as hereinbefore described with reference to the accompanying Figure of drawings.
11. A method of reducing deviation from a desired output characteristic of a flow rate sensor, substantially as hereinbefore described with reference to the accompanying Figure of drawings.
12. A method of providing flow rate sensors having standardised output characteristics, substantially as hereinbefore described with reference to the accompanying Figure of drawings.

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