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Electronic Scale for Measuring Mass Flow

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by

George N. Rupert

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ELECTRONIC SCALE FOR MEASURING MASS FLOW

by
George N. Rupert

Abstract

An electronic scale which measures small rates of mass flow ($\sim 1.5 \times 10^{-4}$ lb/sec) from a large gross weight (250 lb) is described. Four meters indicate the gross weight of the sample and container, sample weight loss, rate of weight loss, and deviation of rate of weight loss from a preset desired rate.

In operation, a semiconductor load cell senses the gross weight. The output of the load cell is amplified to produce an analog signal proportional to the gross weight. This signal is differentiated electronically to produce the rate of mass flow information in units of 0.1 lb/10 min. An additional output circuit shows the deviation of the rate of mass flow from a present desired rate.

INTRODUCTION

An electronic scale designed to measure very small rates of mass flow of a volatile material contained in a large stainless steel vessel or saturator is described. The vaporized material is transported from the saturator by means of a carrier gas. The saturator is suspended inside a furnace. Thus, the vapor pressure of the volatile material can be regulated by changes in the furnace temperature.

The first application of the electronic scale was to measure the rate of mass flow in units of 0.1 lb/10 min and to continuously monitor the rate of mass flow so that the rate could be held constant at predetermined levels by regulating the flow of carrier gas. Mechanical scales are unable to supply the information desired.

An all-electronic system was developed which has the sensitivity and resolution required. The method used is to convert the gross weight of the saturator and sample into an electrical analog signal by weighing the saturator with a semiconductor load cell. The electrical signal after amplification is then differentiated by an electronic differentiator circuit to produce the rate of weight change signal. Output circuits show the rate of

mass flow as well as the deviation of the rate of mass flow from a preset desired rate.

The weight loss may be advantageously plotted against the rate of weight loss on an x-y recorder to show the complete record of mass flow information. Time markers may be applied to the rate of weight loss axis if desired.

The present instrument could be made more versatile by employing a servo feedback system to control the flow of carrier gas in response to changes in the signal which shows the deviation of the rate of mass flow from the programmed rate of flow.

DESCRIPTION OF APPARATUS

1. Physical Arrangement

Figure 1 shows the physical arrangement of the various components of the weighing system. The saturator is supported from the load cell by a flexible steel cable. A resistance furnace surrounds the saturator. Carrier gas inlet and outlet connections are made to the saturator by flexible stainless steel bellows. Because of the great sensitivity of the weighing system no unbalanced forces should bear on the saturator; bellows connections and

thermocouple wires should have minimum effect; and room temperature changes, vibration, and wind forces should be minimized.

2. Electronic Circuit

Gross weight measuring section. The weight transducer used is a type-USG1 250-lb BIH Electronics¹ semiconductor load cell. It has a full load output of 1V at the recommended electrical excitation of 12V dc.

Excitation is supplied by a type PR-300R $\pm$ 15V power supply made by Philbrick Researches, Inc.² This power supply has good regulation, and has proved sufficiently stable for this application. A second power supply of this type powers the electronic circuits. The five operational amplifiers used in the analog computer circuits of the electronic scale are also manufactured by Philbrick.

Referring to the circuit diagram, Fig. 2, the output of the load cell is amplified X25 by the inverting amplifier circuit³ employing amplifier A1. Figure 3 shows the scaling factors used to process the analog signals in the various circuits of the electronic scale. The amplification factor is determined by the ratio of the 5-m Ω feedback resistor to the 0.2-m Ω input resistor. The load cell sensitivity of 4 mv/lb multiplied by the amplification factor of this stage results in an output voltage of 0.1 V/lb. An output meter indicates 100 lb at full-scale deflection. Rapid weight fluctuations due to vibration are smoothed out by the 25-sec time constant of this amplifier circuit.

Weight suppression circuits are connected to the input of this circuit to bring the meter pointer back on scale when the gross weight exceeds 100 lb. A constant suppression of 50 lb is provided by the 5-m Ω resistor connected to the 5 V developed across the 5-k Ω "Weight Suppression" potentiometer. This control provides an additional 50 lb of adjustable weight suppression, and is located on the back of the chassis. The gain of these suppression circuits is X1 because the feedback and input resistors are equal.

Weight loss circuit. The output of the gross weight amplifier circuit is fed into another inverting operational amplifier circuit using amplifier A2. This circuit is used to measure the weight loss of the sample during a run. The weight loss divided

by the time period gives the average rate of mass flow. It can be used as a check on the operation of the differentiator circuit to be described in the next section. The weight loss and weight suppression circuits both have a gain of X1. One volt output from this circuit indicates a weight loss of 10 lb and produces full-scale deflection on the output meter, M2.

At the beginning of a run the "Zero Weight Loss" control is used to zero the output of this circuit. If the weight loss exceeds 10 lb during a run, then additional weight suppression may be employed by using the "20-lb Suppression" control to bring the meter pointer back on scale.

Rate of weight loss circuit. An electronic differentiator circuit³ is employed to obtain the rate of mass flow analog signal. The output of this circuit employing amplifier A3 is equal to $-RCde/dt$. The amplification factor RC may be set at a value which will cause the output to read in the desired units. An output of 0.1 V was desired for a weight change of 1 lb/10 min. The required RC product is 600. A value of 2 mF was selected for C. The necessary R factor of 300 was supplied by a 50-m Ω feedback resistor used in combination with a gain-increasing fractional feedback circuit of X6. The capacitor should be a low leakage Mylar or polystyrene dielectric type. Leakage currents in this capacitor will appear at the output as a false rate of weight loss signal.

A "Zero" push-button switch is provided to zero the output of the differentiator. A "Time Constant" control is provided to reduce the response of the circuit to high frequency noise.

Rate display circuits. The rate of weight loss signal is fed into two similar circuits using amplifiers A4 and A5.

Rate of weight loss indicator. This circuit, which employs amplifier A4, has a gain of X10 for the rate signal and a gain of X1 for a bias voltage obtained from the bias circuit consisting of the "Desired Rate" control and the range changing resistors selected by switch sections SW2E and SW2F. The basic full-scale sensitivity (1 lb/10 min) of meter M3 is increased in positions 4 and 5 of switch SW2 in increments of 1 lb/10 min as shown in Table I.

Deviation from desired rate of weight loss indicator. This circuit, employing amplifier A5, is similar to the previous circuit. It is designed to show any deviation from a desired rate of weight loss, which is selected by the "Desired Rate" control. The basic full-scale 1 lb/10 min sensitivity of this control is increased in positions 4 and 5 of switch SW2 as before. The calibration of this control and output meter M4 is given in Table I.

Meter M4 may be observed by an operator to detect any deviation from the preset desired rate of mass flow. Corrections in the rate of mass flow may be made by manual adjustment of the carrier gas flow. An automatic servo system arranged to keep the deviation of rate signal zero by controlling the carrier gas flow could also be used to perform this operation.

OPERATION OF APPARATUS

1. Offset Voltage Adjustments

The offset voltage of the five operational amplifiers should be adjusted to zero. This can be accomplished for amplifier A1 with an external offset adjustment.⁴ The input resistors connected to the summing point of the amplifier should be grounded during this operation.

Amplifiers A2, A4, and A5 have built-in voltage offset adjustments. The input resistors should also be grounded during this operation.

The offset voltage of amplifier A3 can be adjusted to zero with the built-in adjustment after temporarily grounding the junction of the 2-mF input capacitor and the 20-k Ω resistor. This changes the differentiator into a high gain inverting amplifier which is easier to adjust.

2. Calibration

The gross weight and weight loss circuits may be checked by letting these circuits come to equilibrium with a removable weight of 5 lb resting on top of the saturator. The gross weight signal may be brought on scale with the "50-lb Suppression" control. The weight loss meter may be zeroed with the "Zero Weight Loss" control. When the 5-lb weight is removed, the "Gross Weight" meter reading should decrease 5 lb, and the "Weight Loss" meter should read 5 lb. This can be done with switch SW2 in position 1.

The differentiator circuit is more trouble to check; it can be done in two ways. The first method consists of measuring the quantity of a fluid like water that flows from a container supported by the load cell during a known time. The average value of mass flow can be calculated and compared to the average value of mass flow shown on meter M3. A measurement of this type produced a total system and measurement accuracy of 98%.

The second calibration method consists of generating a slowly decreasing voltage with an electronic integrator circuit³ and feeding this voltage into the differentiator and observing the indicated rate on meter M3. For an indicated rate of 1 lb/10 min, the input voltage to the differentiator decreases at the rate of 0.1 V/600 sec. This voltage can be supplied by an integrator circuit consisting of a low-offset-current operational amplifier such as the SP2AU with 0.1 V connected to an input resistance of 300 m Ω and a 2-mF feedback capacitor connected from output to summing point.

3. Use of Apparatus During a Run

Data observed on the meters during a run may be conveniently plotted on an x-y recorder. The plot of weight loss versus rate of weight loss is shown in Fig. 4 for a typical run. This type of display⁵ shows pertinent mass flow information in a straightforward manner.

Preliminary to observing mass flow information, several adjustments may be made. Switch SW2 is set at "Warm Up" position 1 to deactivate the mass flow measuring and indicating circuits. The gross weight and weight loss circuits can be brought onto scale and zeroed as described in "Calibration." After 30 min, the circuits should have reached equilibrium and the differentiator circuit may be turned on by switching SW2 to position 2. This low sensitivity position is used to see if the gross weight signal has stabilized. The "Zero" switch may be used to zero the differentiator to reduce the rate signal to zero. When the rate signal is approximately zero, switch SW2 may be turned to position 3, "Operate," to measure mass flow at maximum sensitivity. The "Time Constant" control may be advanced to reduce rate fluctuations. The rate indicated on meter M3 should be close to zero. If all is well, SW2 may be switched back to "Warm Up" and

the carrier gas flow may be initiated. Switch SW2 is then turned to the position which will cover the desired rate of mass flow. The carrier gas flow is adjusted to control the rate at the desired value. Any deviation from the desired rate can be easily seen on meter M4 after the "Desired Rate" control has been adjusted to this value.

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Table I. Sensitivities of the Rate Indicator Circuits

Switch SW2 Position	Function	Meter M3 (1 lb/10 min Basic full- scale sens.)	"Desired Rate" Control (1 lb/10 min Basic full- scale sens.)	Meter M4 (±0.5 lb/10 min Basic full- scale sens.)
1.	Warm up	Zero check	-	Zero check
2.	Operate	X10 Basic sens.	-	X10 Basic sens.
3.	Operate	Basic sens.	Basic sens.	Basic sens.
4.	Operate	1 lb/10 min + basic sens.	1 lb/10 min + basic sens.	Basic sens.
5.	Operate	2 lb/10 min + basic sens.	2 lb/10 min + basic sens.	Basic sens.

Fig. 1. Physical arrangement of apparatus.