Application Brief

Measuring Air Flow Using a Self-Balancing Bridge

The design of a hot wire anemometer presents an interesting application for operational amplifiers.

The purpose of the instrument is to measure air speed by its cooling effect upon an electrically heated platinum filament that exhibits a high positive temperature coefficient of resistivity.

The filament characteristic is shown in Figure 1, for two values of air speed. Two classical ways of operating it would be at constant voltage or constant current.

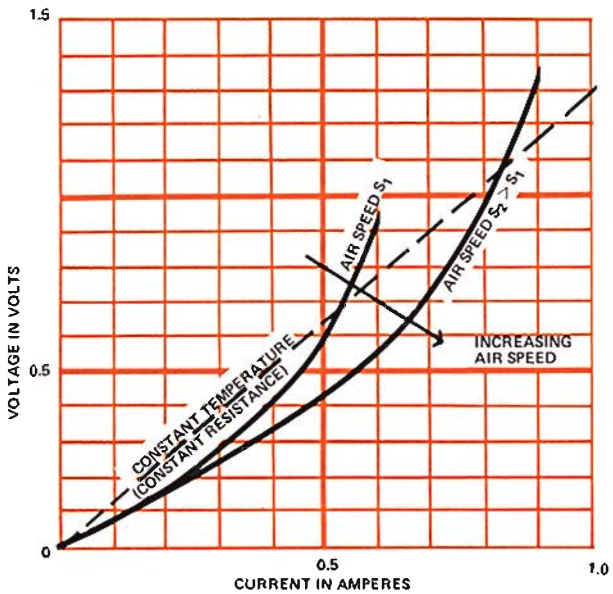

Figure 1. Volt-ampere characteristics of 7/16"L X 0.002"D straight filament of pure platinum in the presence of moving air, for two values of air speed.

With constant current applied (say, 0.6 amperes), the sensitivity is reasonably good—about 0.4V change for $\Delta s = s_2 - s_1$. However, there is every prospect that in still air the filament has the potential of burning itself up (resistance increases as temperature increases, due to lack of air flow, which causes the voltage to increase [constant current], increasing the dissipation, the temperature, and again the resistance, etc.).

With constant voltage applied, the increase of resistance with temperature causes operation to be quite safe, but also relatively insensitive, especially at low air speeds.

Another factor that makes both constant-current and constant-voltage operation unsatisfactory is the necessity for the temperature of the filament to change to detect a change in air speed; this necessarily causes delay. If the air speed indicator is part of a control loop, the measurement delay could cause slow response or instability of the control loop.

An approach that answers all of these objections satisfactorily is to operate the filament as though it had constant resistance (i.e., constant temperature).

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If, for example, the resistance were maintained at 1.3Ω, as indicated by the dashed line, one could obtain a current change of 0.3A and a voltage change of 0.4V, with no danger of overheating in normal operation. Response would be quite speedy, since temperature changes are momentary and small.

The basic circuit for achieving constant temperature operation is the feedback circuit of Figure 2, consisting of a bridge, an op amp, and a power amplifier. The operational amplifier continuously adjusts the flow of current (through the power transistor) to maintain its two inputs equal. This can be done only by keeping the voltage across the filament equal to that across R2, and the filament current equal to the current through R1. However, since the current through R1 is proportional to the current through R0, (which has the same voltage drop as R1) and the current through R0 is determined by the voltage drop across R2, it can be seen that the resistance of the filament, R_P, must be equal to that of R2, multiplied by the ratio of R_1 to R_0.

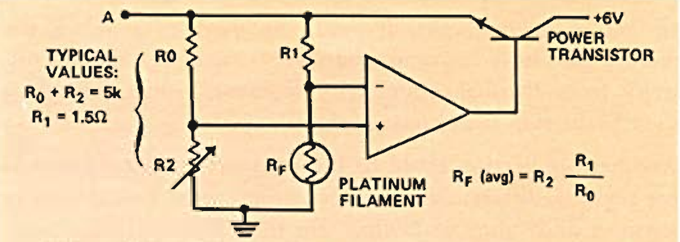

Figure 2. Basic circuit of the temperature-controlled bridge

Suppose now, that, starting from a given operating equilibrium point, the air flow increases. This will take heat away from R_F, causing its voltage to tend to drop. The amplifier's output voltage increases, which increases the current through the power transistor, and thus makes more power available for the filament to dissipate to maintain its temperature (and hence its resistance) constant.

The output voltage is measured at terminal "A", which provides an amplified version of the filament voltage, at an impedance level low enough to operate even the crudest of meter movements.

The zero-air-speed voltage is backed off by means of an auxiliary constant voltage, and the readings can be displayed with a moving coil meter. The scale is a nonlinear function of air speed, actually expanding toward the lowest values. Low air speeds can be read with high sensitivity; in fact, the device can virtually detect a whisper several feet away.

CIRCUIT NOTES

For practical realization, the following points must be considered:

1. A voltage offset must be deliberately introduced into the operational amplifier (or elsewhere) to insure that the output goes positive with zero differential input; otherwise, the circuit might remain dead when turned on.
2. The power transistor must have ample current-handling capacity; the filament requires several hundred mA.
3. Depending on the physical layout, especially when the filament is away at the end of a twisted pair, wild high frequency oscillations are possible. Though not visible with low

frequency readout devices (however, rectification can cause voltage offsets), they look nasty on an oscilloscope screen. A 0.1µF capacitor between the base and collector of the power transistor can often serve to stabilize these oscillations. A small resistor in series with the base may also be helpful.

4. The filament is a physical device with thermal lag. Although the circuit is fast enough to prevent loop oscillations when used in a larger control loop, it is itself a process control loop and may require the usual compensation techniques to maintain its own internal stability.

5. R0 and R2 form a trim potentiometer to set the operating temperature (e.g. resistance) of the filament. If R2 is a variable resistance, you start with R_2 = 0, and increase it until the filament just starts to glow, then back down a little. This will give optimal sensitivity.

APPLICATIONS

The device has been used in a commercially-produced apparatus to trip out equipment when the air speed in a forced draft duct falls below a preset value, but the approach is suggestive of a number of other applications in instrumentation.

In gas chromatographs, it could be used to monitor the minute gas flows required, and also to assure optimum sensitivity from thermal-conductivity filaments, while preventing their burnout in faulty operation.

Another application could be for constant-temperature ovens for crystals, differential pairs, etc., using copper or a thermally sensitive alloy such as "Balco" for the combined heater/temperature-sensor function. In such an arrangement, the controlled temperature could be slaved to another (arbitrarily) variable temperature (e.g., to insure a constant temperature difference) if R2 were a platinum temperature bulb with the circuit so dimensioned as to avoid causing it to introduce errors due to its own self-heating.

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Worth Reading

"Detection and Measurement of Three-Phase Power, Reactive Power, and Power Factor, with Minimum Time Delay," by I. R. Smith and L. A. Snider, University of Birmingham (England), *Proc. IEEE*, November, 1970, p. 1866

In this brief but significant communication, the authors show how to compute average power in a symmetrical 3-phase system with sinusoidal waveforms, without the time delay normally introduced by filtering. With three multipliers to compute the instantaneous power developed by the phase voltages and line currents in each phase, and summing the outputs with an op amp, the dc "average power" terms add, and the harmonic terms cancel algebraically, without the intervention of filters. By phase shifting either the voltages or the currents by 90°, reactive power can be computed in the same way. And the ratio of reactive to real power (using a divider) is tan ϕ, an often useful parameter in control systems. For small values of ϕ, it is, in fact, equal to phase angle.

"Selecting the Optimum Multi-Path Digital-to-Analog Configuration," by D. H. Sheingold, *Electronic Instrument Digest*, (A Kiver Publication), July, 1970

Virtually a complement to Mr. Anderson's paper (page 6 of this issue of *Dialogue*) for output systems, this article considers the question of whether to multiplex digitally and use many D/A converters, or to convert in one location, and route the analog output via sample-holds. The tradeoffs involved in selecting an output configuration that provides the desired performance at the lowest overall cost are identified and discussed. Copies of this six-page paper are available from Analog Devices. Use the reply card. *Circle* **A2**

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