DESIGN OF AN AIR-SPEED SENSOR SYSTEM

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To monitor ventilation rates and air-flow patterns in commercial livestock facilities, many air speeds have to be monitored simultaneously. The cost of purchasing commercial equipment for this purpose would be prohibitive. An air-speed measuring system was designed that was compatible with the data acquisition system currently used. The unit consists of the necessary electronic circuitry and 32 air-speed sensors. Each sensor has been calibrated and found to have a level of accuracy adequate for measuring air speeds in livestock facilities. The system also is very portable in that an air-speed sensor can be located anywhere within the livestock facility with little difficulty.

INTRODUCTION

To undertake a heat balance on confined livestock facilities, the heat gains and losses of the unit must be measured. The heat loss due to the ventilating air is one of the most difficult parameters to measure because of the fact that the air flow for each fan in the ventilation must be measured simultaneously. In many situations the heat loss due to the ventilating air accounts for the major proportion of the heat loss from a livestock facility. Therefore, an accurate measurement of the ventilation rate is of prime importance. The equipment used to measure air speeds or velocity pressures existing in livestock units, as described by Feddes and McQuitty (1977), was found to be inadequate. Velocity pressures were measured by pitot-static tubes in the calibration ducts which were positioned downstream from each exhaust fan. At lower ventilation rates and duct air speeds of less than 7.5 m/sec (1500 ft/min, the velocity pressures were too low to determine an accurate air-flow rate in the duct.

A logical solution to this problem was to substitute pitot-static tubes with air-flow meters that utilize horizontally positioned, omni-directional probes. However, to place these commercial air-flow meters in each duct and also within the zone of animal occupancy was simply too expensive since simultaneous measurements were of interest. The only apparent alternative to this high cost was to design a less expensive set of air-speed sensors compatible with the existing data acquisition system described previously (Feddes and McQuitty 1977). This paper describes the components of the air-speed sensor unit developed and the procedures used to establish a calibration curve for each sensor.

AIR-SPEED MONITORING SYSTEM

The unit consists of 32 air-speed sensors and the necessary electronic circuitry to ensure a voltage output compatible with the data acquisition system. Basically, a voltage is applied to thermistors (Fenwal Electronics, Framingham, Mass.) which are semiconductors exhibiting a change in electrical resistance with a change in temperature. The heated thermistor is placed in the air stream where the thermistor heat loss by forced convection is proportional to the air speed and the temperature difference between the thermistor and the air stream (American Societyy of Heating, Refrigerating and Air Conditioning Engineers 1972) as shown by the equation:

$$H \alpha U \text{ and } \Delta T \quad (1)$$

where

H = heat transfer by forced convection, watts/m²/°C

U = air speed, m/sec (ft/min)

ΔT = temperature differential between thermistor and ambient air, °C.

Therefore, U can be expressed as $H/\Delta T$. H also may be expressed as power, or the product of voltage (E) and amperage (I) applied to the thermistor. Thus, the new equation becomes:

$$U \alpha \frac{E \times I}{\Delta T} \quad (2)$$

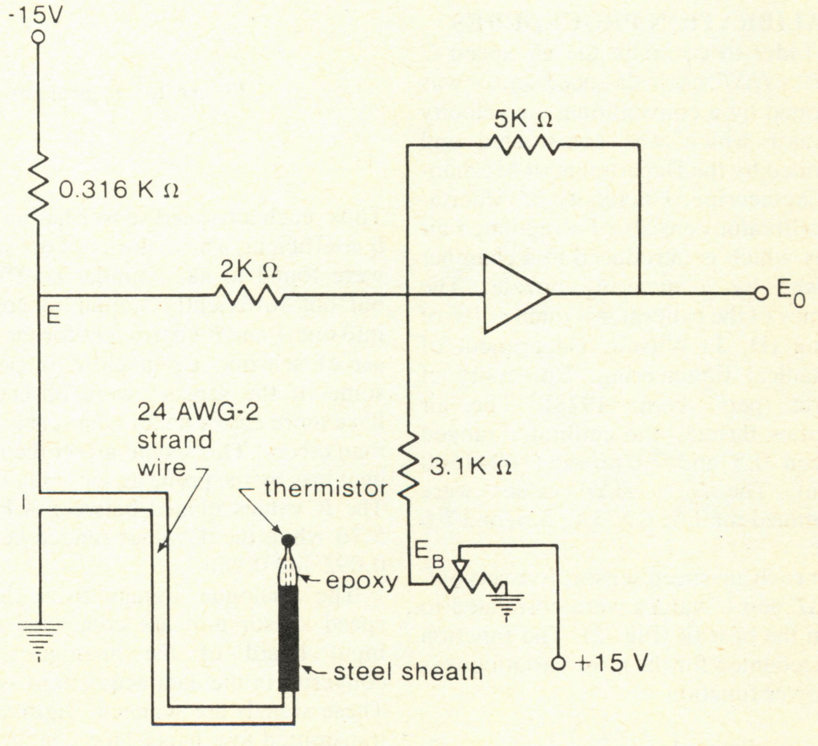

Figure 1. Electronic circuit for an air-speed sensor.

A voltage divider circuit was constructed for each air-speed sensor (Fig. 1). A bias voltage was provided for each circuit to ensure that the output voltage was between 0 and 10 volts. The voltage across the thermisor then may be expressed by the following equation:

$$E = (E_B \times 5/3.1 + E_o)/2.5 \quad (3)$$

where
E = voltage across the thermistor, volts,
E_B = bias voltage, volts, and
E_O = output voltage, volts.
The amperage (I) across the thermistor may be expressed as follows:

$$I = (15 - E)/316 - E/2000 \quad (4)$$

The temperature of the heated thermistor or air-speed sensor was determined from a regression equation provided by the manufacturer of the thermistor (Fenwal Electronics, Framingham, Mass.) which correlated temperature and resistance of a thermistor, the equation being:

$$\frac{1}{T} = A(X^3) + B(X) + C \quad (5)$$

where
T = °K
A,B,C = regression constants,
X = $\ln_e (R)$, and
R = resistance (ohms).
The resistance (R) of the thermistor was determined from Eq. 6 which is as follows:

$$R = E/I \quad (6)$$

CALIBRATION PROCEDURES

In order to correlate the air speed U with $E \times I/\Delta T$, each air-speed sensor was calibrated by a conventional air velocity calibrator which was constructed and calibrated by the Department of Mechanical Engineering, University of Alberta. The calibrator consists of a regulated air supply which is introduced to a chamber followed by a metering nozzle. The accuracy of the calibrator is rated at 1% of reading (D. J. Wilson, Department of Mechanical Engineering, University of Alberta; pers. com. 1978). The air velocities through the calibrator ranged between 0.5 and 7.6 m/sec (100–1500 ft/min). The $E \times I/\Delta T$ values were determined for 0.5, 1.5, 3.6, 5.6, and 7.6 m/sec.

For each air-speed sensor, five sets of $E \times I/\Delta T$ and U values were correlated to obtain the best fit (Fig. 2). The function that accounted for the most variation was the power function

$$U = A \times \left(\frac{E \times I}{\Delta T} \right) B \quad (7)$$

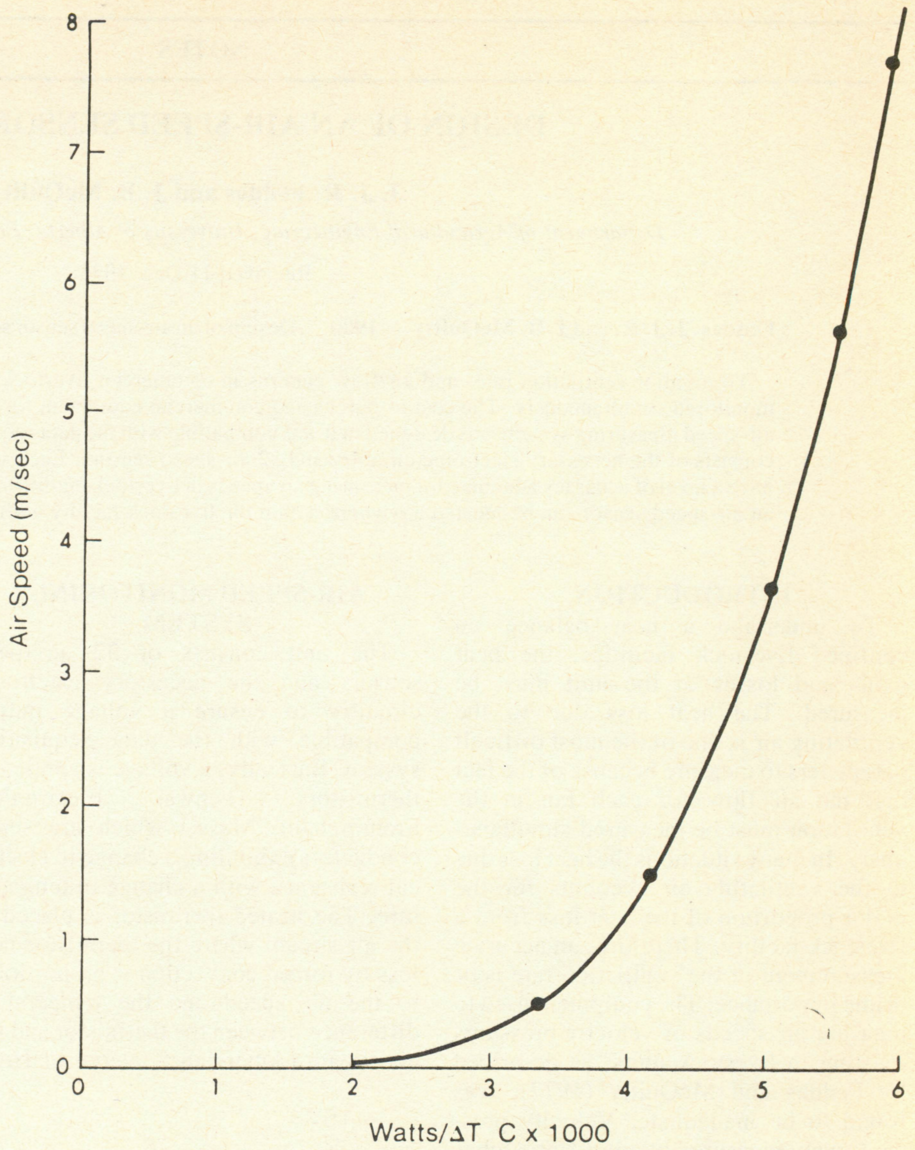

Figure 2. Typical power function curve for an air-speed sensor.

Thus, each air-speed sensor has an A and B coefficient. The majority of the sensors were found to have similar coefficients but not sufficiently similar to combine into one A and B coefficient for the entire set of sensors. Upon close inspection, some of the sensors were observed to have more epoxy next to the sensing bulb than others. This would affect the rate of heat loss by the probe as shown in Fig. 1. The B values ranged between 4.81 and 5.76 while the A values ranged between 0.092 and 0.286.

The analogue signals from the air-speed sensor unit are connected to the input board of the analogue signal converter in the data acquisition system. These signals are scanned, digitized and transmitted to a paper-tape punch. From the paper tape, the data are processed by a Fortran IV computer program. Other data that are entered into the program to calculate air speeds are bias voltages, lengths of extension wire between sensors and the remaining electronic circuitry (Fig. 1) to determine total resistance, and the A and B values.

DISCUSSION

The components described to measure air speeds within livestock facilities provide a greater capability to accurately monitor ventilation rates, and air flows in the zone of animal occupancy and in the air inlets. Since the data Acquisition system used (Feddes and McQuitty 1977) has a capability of handling up to 32 air-speed sensors, many locations within a livestock facility can be monitored simultaneously. The system also is very portable in that any length of extension wire can be used in connecting a sensor with the module containing the electronic circuitry (Fig. 2). In terms of cost, each air-speed sensor is equivalent to the cost of a thermistor plus the cost of calibration, a task that requires only a few minutes. If a sensor is broken, a new one can be fabricated very easily and quickly.

One disadvantage of the system is that, when used in the field, a programmable calculator is required to relate the output voltage to air speed although simple calibration charts can be constructed for use in the field.

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