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A microprocessor-based anemometer for low air velocities

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A MICROPROCESSOR-BASED ANEMOMETER FOR LOW AIR VELOCITIES

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Introduction

In the field of indoor climate there is frequently a need to measure low air velocities in several positions simultaneously, for instance in draught studies in ventilated rooms. At The National Swedish Institute for Building Research, thermistor anemometers have been used for several years. A constant-current transducer was constructed in 1974 (Hårdeman 1974), and has been in use since then.

In order to increase measurement precision a new multichannel anemometer offering improved properties has been constructed. It´s main features are low directional sensitivity and fast response. Information on temperature and velocity are provided simultaneously. The instrument is intended for laboratory use in conjunction with a host computer for data acquisition.

Basic theory

When a small heater, such as a thermistor, is positioned in an air stream, the heat transfer from the heat source is a function of flow velocity. The heat balance can be expressed as:

$$P = K(T_s - T_a) \tag{1}$$

where P is the power dissipated in the thermistor, K is the thermistor dissipation factor, T_s is the thermistor temperature and T_a is the temperature of the air.

The dissipation factor of a given thermistor depends on the air velocity and the thermal properties of the air. If the ambient temperature fluctuations are limited to that for which the variation in fluid properties is negligible, the dissipation factor, K, is a function of the air velocity only.

Thermal anemometers can be divided into different basic types depending on operation:

In the constant-current anemometer (CCA), the thermistor is supplied with a constant current, and it attains an equilibrium temperature when the electric heat generated is balanced by the convective heat loss. The temperature of the thermistor is the output. As the thermistor temperature varies with air velocity, the thermal time constant of the thermistor makes the constant-current anemometer a rather slow device.

In the constant-temperature anemometer, (CTA), the thermistor is incorporated in a control loop which adjusts the current to keep the thermistor temperature constant. The electric power supplied to the thermistor is the output. The main advantage over the constant-current type is a faster dynamic response. One problem is however that variations in ambient temperature can cause the difference in temperature between the sensor and ambient to be too high or too low for proper operation.

This lead us to the constant temperature-difference anemometer (CTDA). The working principle is similar to that of the constant-temperature type, but here the difference in temperature between the sensor and ambient is kept at a constant value. The anemometer presented in this paper is of the constant temperature-difference type.

Principle of operation

The anemometer probe carries two sensors, one for temperature and one for velocity. The temperature of the velocity sensor is controlled by a microprocessor-based regulator. The regulator ensures that the velocity sensor is always operated at 20^{o}C above the ambient temperature.

Both sensors are glass-coated bead thermistors with a diameter of approximately 1 mm. They are almost spherical in shape and are well suited for velocity sensing. Unfortunately they have non-linear resistance/temperature characteristics and must be linearized to achieve the accuracy needed here. This is done by means of software. The thermistors are calibrated individually, temperature vs resistance, and the calibration data is programmed as "look-up tables" into an EPROM-memory.

A block diagram of the anemometer is shown in fig 1. The A/D-converter with multiplexer reads the voltage over the two sensors, and the D/A-converter controls the current through the velocity sensor.

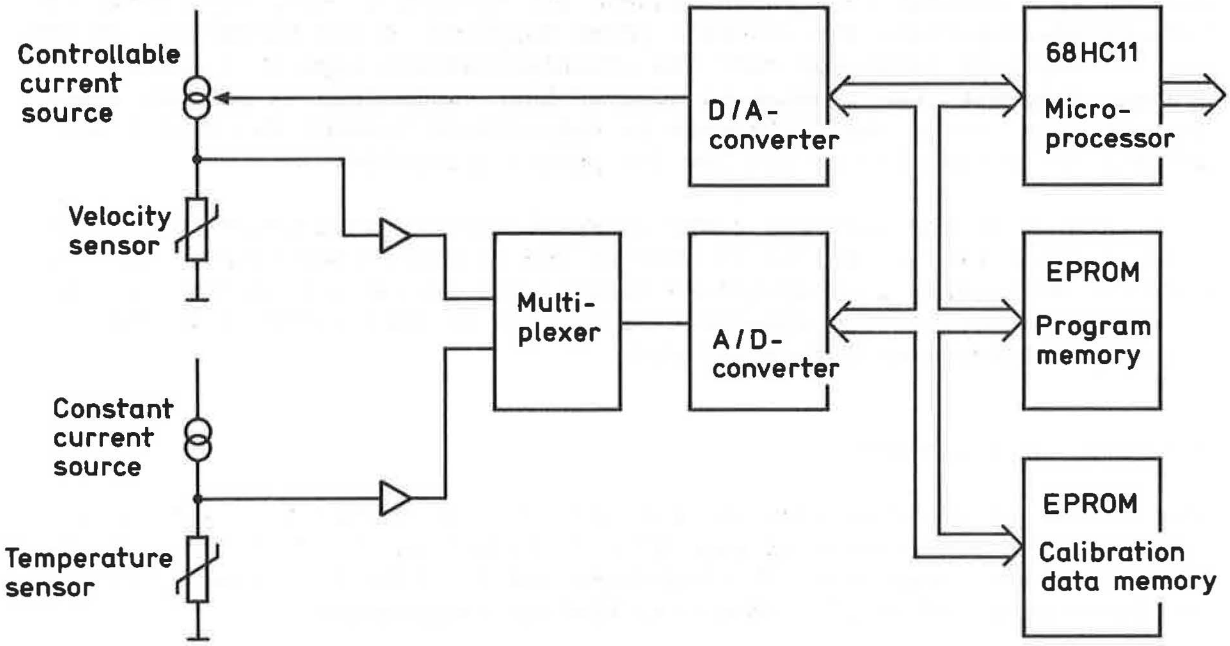

Fig. 1. Anemometer block diagram (one channel shown)

The operation of the anemometer is controlled by the microprocessor, which runs through the following sequence 60 times a second:

- Read resistance of temperature sensor.
- Find ambient temperature through calibration data in look-up table
- Add 20°C (=constant temperature-difference)
- Find resistance of velocity sensor through calibration data in look-up table
- Control current of velocity sensor to achieve desired resistance
- Calculate the power dissipated in the velocity sensor

The anemometer is interfaced to a host computer which calculates the velocity as a function of the velocity-sensor power dissipation. This is done by calibration and curve-fitting to an appropriate equation. The ambient temperature is available as output as well.

Practical design and assembling

As each microprocessor (Motorola 68HC11) is capable of handling two anemometer channels, the instrument is built up of plug-in units of two channels each. 30 channels can be housed in a 19-inch cabinet. The probes are connected by shielded 4-wire cables and, cable lengths of up to 10 meters can be used without affecting calibration. Connection to the host computer is made by RS-232 serial interface.

Probe construction, directional sensitivity

The temperature and velocity thermistors are soldered to 0.4 mm diam. stainless steel tubes which are mounted on a plastic support (fig 2). The shaft is made of 4 mm diameter stainless steel tube and a 5-pole miniature connector provides cable connection. A movable protection sleeve made of 8 mm diameter stainless steel tube protects the delicate sensors when not in use. The small dimensions ensure minimum disturbance of flow conditions. In order to prevent heating of the temperature sensor by the velocity sensor in the case of head-on flow, a small plastic shield is placed between the two sensors.

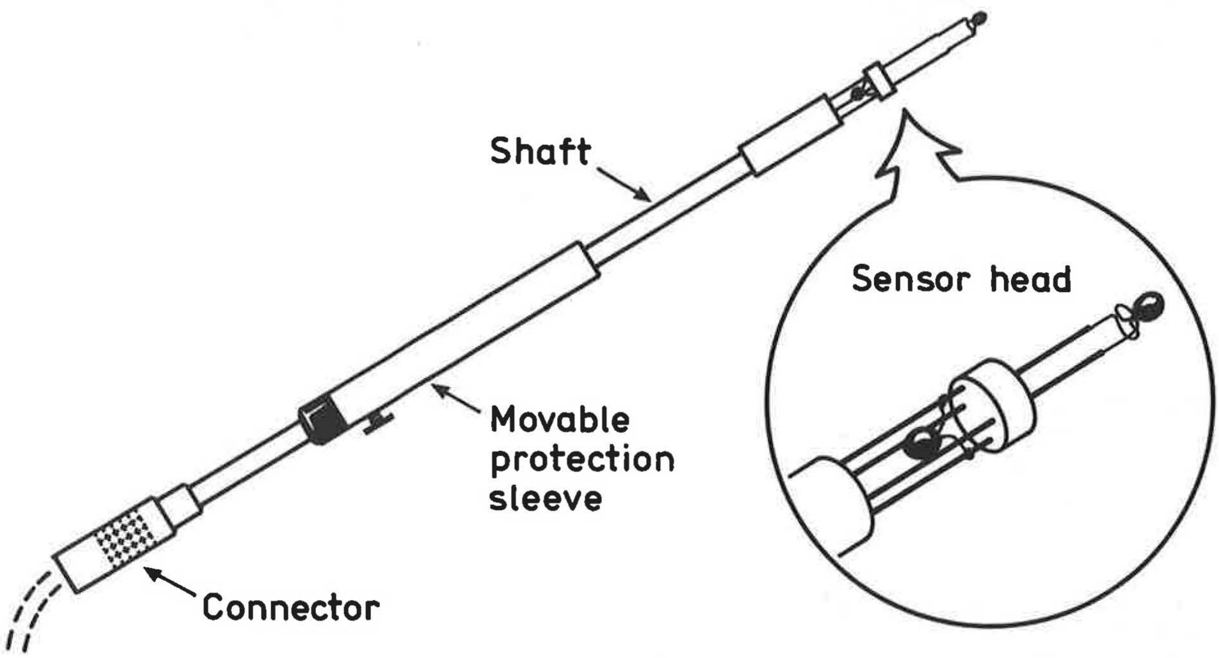

Fig. 2. Probe construction

A special problem to be overcome is the directional sensitivity of the thermistor. It is desirable that the anemometer should be insensitive to flow direction, i.e. the heat dissipation of the velocity sensor should be the same for all flow directions. A diagram over heat dissipation vs flow direction for a typical bead thermistor is shown in fig 3. The "bump" in the curve for flow from above stems from the fact that a portion of the heat is dissipated through the leads, and the heat removed from a heated wire has a minimum when the flow is parallel to it. Another reason for irregularities in the curve is due to the fact that bead thermistors are usually slightly elliptical in shape. To increase the heat transfer for flow from above in fig 3 the leads are bent 90 degrees so the flow will strike the leads at right angles. In order to maintain the insensitivity to direction in the horizontal plane the leads are bent in the shape of a ring (fig 4). However the ring obstructs the flow reaching the thermistor body, and thus the diameter of the ring and its position relative the thermistor body are critical for good performance.

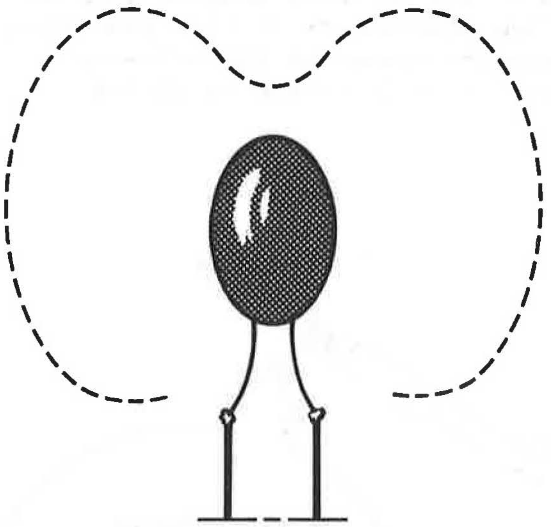

Fig. 3. Typical vertical directional sensitivity for a bead thermistor with adjacent leads

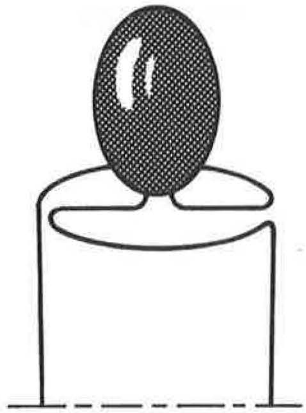

Fig. 4. Bending of thermistor leads to improve directional sensitivity

The directional sensitivity of the probe when rotated about the probe axis and flow perpendicular to the probe are shown in fig 5a. Rotation about an axis perpendicular to the probe axis are shown in fig 5b, for two planes of best and worst case. The decrease in heat transfer at great angles in curve B is due to the obstructing effect of the thermistor support rods. However the maximum error due to flow direction is ± 10% in angles between ± 130 degrees from anemometer axis measured at a velocity of 20 cm/s.

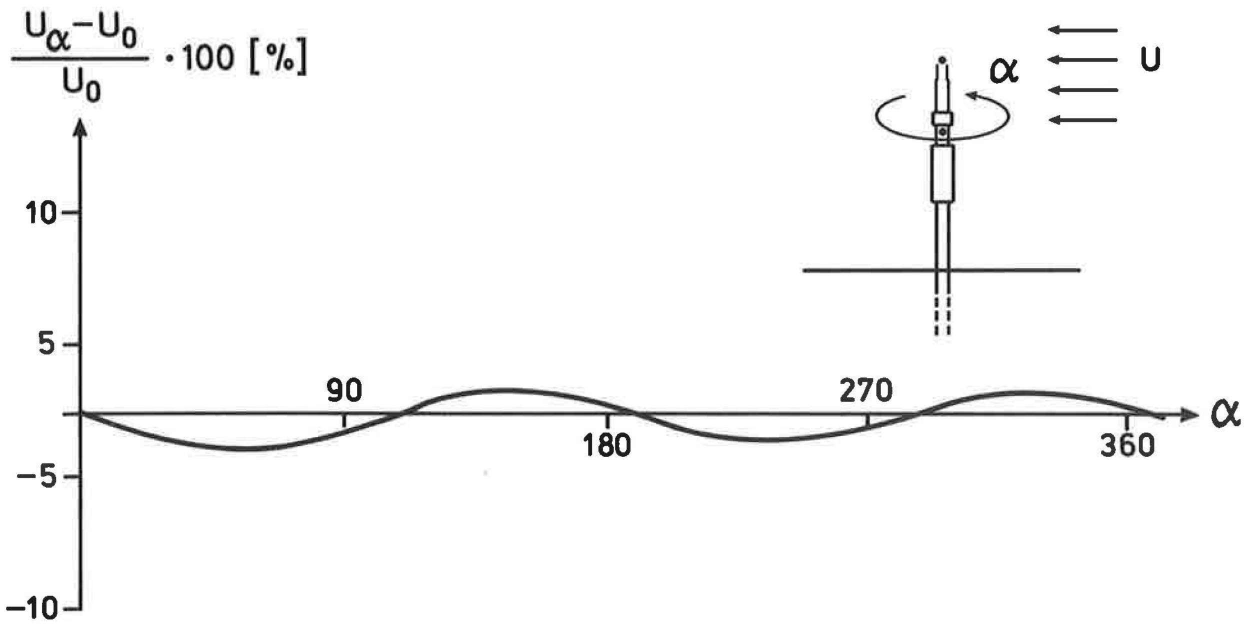

Fig. 5a. Typical directional sensitivity. Rotation about the probe axis

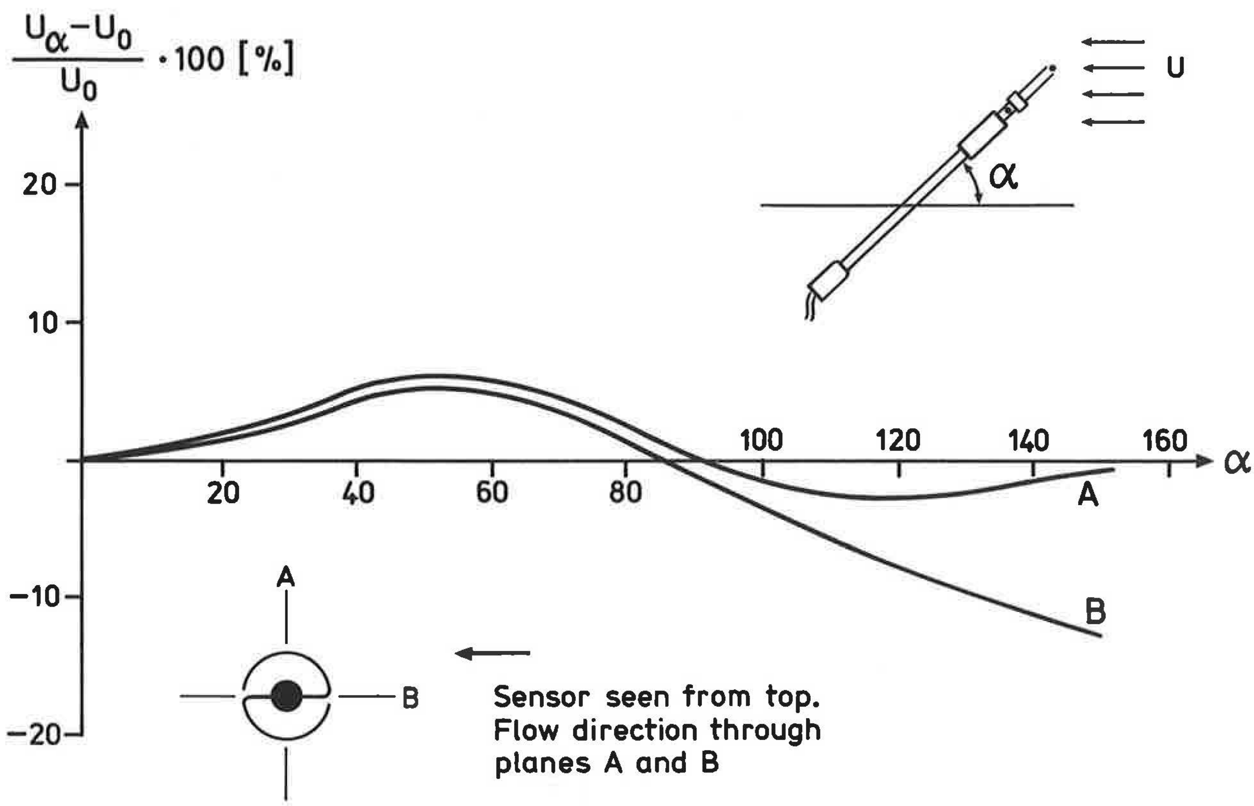

Fig. 5b. Typical directional sensitivity. Rotation about an axis perpendicular to probe axis

Natural convection

The heated velocity transducer creates an upward-directed natural convection flow which will introduce an error at low velocities. Heat transfer by natural convection can be characterized by Grashof number G_r which is defined by:

$$G_r = \frac{g\ h^3}{\nu^2} \frac{(T_s - T_a)}{T_a} \tag{2}$$

where g is the acceleration due to gravity, ν is the kinematic viscosity of the air, h is a characteristic length of the heated body, T_s is the body temperature and T_a is the air temperature. The Grashof number is proportional to the ratio of the buoyancy to the viscous forces within the airflow.

An examination of (2) shows that a small sensor and a low temperature-difference is desirable to achieve low natural convection. Note that the sensor characteristic length, in this case the thermistor diameter, appears to the power of three. The 1 mm diam thermistor used here assures low natural convection and yet maintains a handy probe.

Influence from natural convection has been tested in a miniature wind tunnel, which can be rotated on a pivot. The measured power dissipation vs velocity for upward and downward-directed velocities are shown in fig 6. Note how the counteraction between natural and forced flow creates a "bump" in the curve for downward-directed flow at approx 2.5 cm/s. As can be seen from the figure the error due to natural convection is 1.5 cm/s at a velocity of 5 cm/s, and 0.5 cm/s at 10 cm/s. This was measured with a temperature difference of 20°C. With a temperature difference of 10°C the "bump" in the curve will appear at approx 1.6 cm/s and the natural convection errors will be lower. However low temperature difference also gives a slow time-response and 20°C was chosen as a compromise.

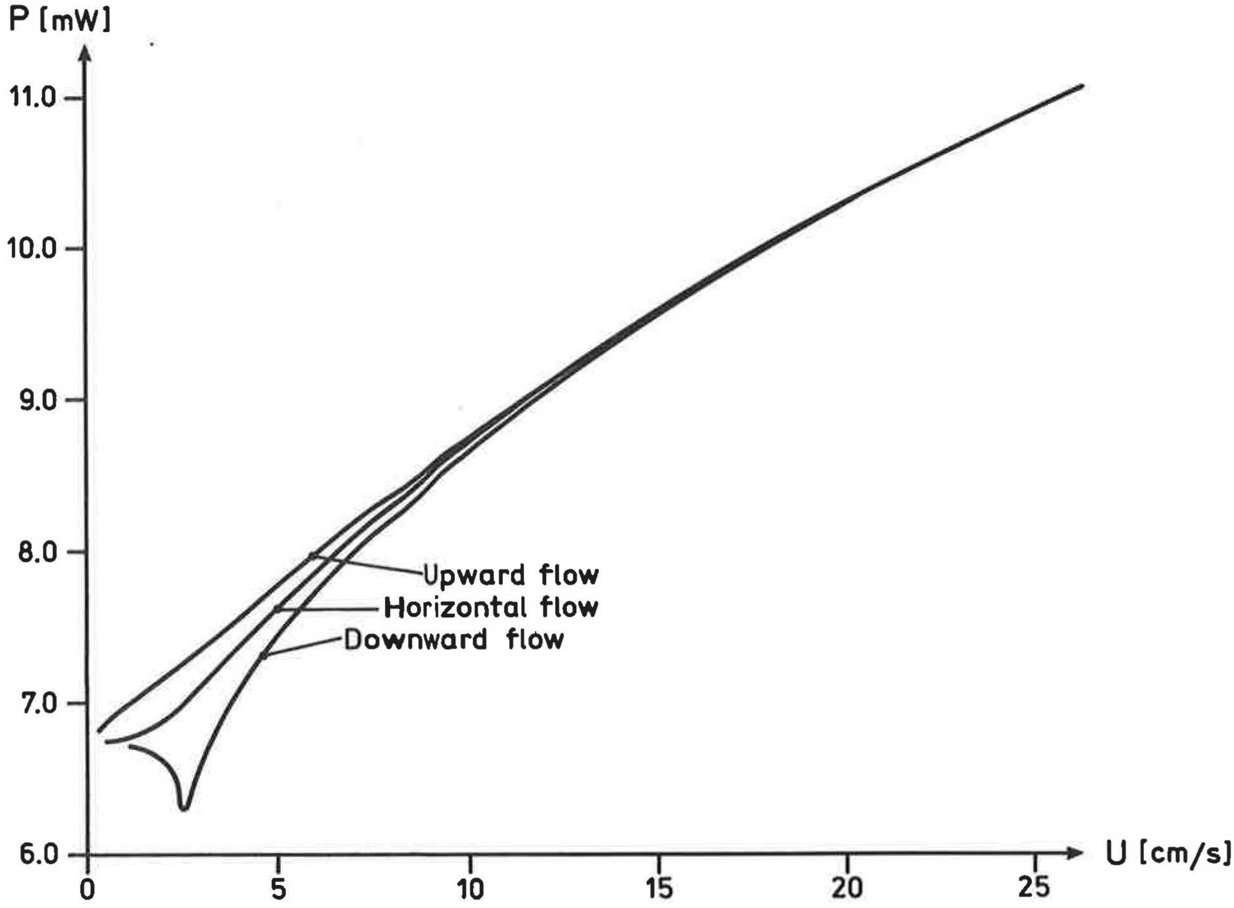

Fig. 6. Anemometer response to vertical flow at low velocities

Dynamic response

The dynamic behavior of the anemometer has been determined in two ways: by measuring the step response, and by measuring the cut-off frequency at sinusoidal input.

A step change in velocity is generated by positioning the anemometer in a small wind tunnel where the flow is changed by means of fast slide valves. From a step velocity change from 0.2 m/s to 0.6 m/s a time response of 0.2 s (to 90% of step) was measured.

The cut-off frequency was determined by recording the response to a sinusoidally varying velocity field of variable frequency. A 3-dB frequency of 2 Hz was measured. The sinusoidal velocity variation is created by modulating a constant flow field by means of a piston device. (Sandberg, Pettersson 1990)

The dynamic properties of a constant-temperature anemometer or a constant temperature-difference anemometer are not only dependent on the sensor characteristics but rather on the control system performance. The velocity thermistor itself has a step response of 7 s (90% value at air velocity = 0.4 m/s). Thus by using the sensor in a controlled loop an improvement in dynamic response of roughly 35 times is achieved.

Calibration and testing

Temperature calibration of the two thermistors in each probe is made in a special calibration box where the temperature can be varied by means of a Peltier element. This is done during manufacturing of the probe, and the calibration data is programmed as "look-up tables" into an EPROM-memory which are installed in the plug-in units, one for each probe. Glass-coated bead thermistors are stable devices so recalibration is probably not necessary during the lifetime of the probe.

Velocity calibration is carried out in a small open-circuit wind tunnel offering a stable and low-turbulent flow. The directional sensitivity is tested by tilting and rotating the probe in the flow by means of a specially made fixture.

Conclusion and results

A newly developed multichannel anemometer utilizing modern microprocessor technique has been presented. It is shown that thermistors make good velocity sensors if their drawbacks can be overcome. A prototype of the instrument has been used at the National Swedish Institute for Building Research and has yielded good results.

Technical specifications for the instrument are:

Velocity measurement:
Measurement range: 0.05 - 3 m/s
Accuracy: ±5% ±0.05 m/s excluding directional error
Directional sensitivity: ±10% at angles within ± 130° relative to the probe axis.
Response time: 0.2 s to 90% of a step change.

Temperature measurement:
Measurement range: 10-40°C
Accuracy: ±0.2°C
Resolution: 0.1°C
Response time: 12 s to 90% of value in still air

Communication:
RS-232 serial interface

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References

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SUMMARY

An anemometer for measuring low air velocities has been developed. The air velocity is determined as a function of the forced convective heat loss from a heated thermistor. The temperature of the thermistor is controlled by a microprocessor-based regulator, which keeps the difference in temperature between the thermistor and ambient at a constant value.

The paper shows that thermistors make excellent velocity sensors once their drawbacks are overcome. Here their non-linear resistance/temperature characteristics are linearized utilizing modern microprocessor technology, and their large directional sensitivity is eliminated by bending the thermistor leads in a special configuration.

The anemometer has been built in a 30-channel system which easily interfaces to a host computer such as IBM-PC or PDP-11.

The directional sensitivity and dynamic properties of the anemometer are presented.