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HOT BODY ANEMOMETERS

by

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Abstract

Several types of hot body anemometers are described. Their main characteristics, calibration methods and important defects are given.

In ordinary meteorological observations of the true wind speed the cup anemometer is used almost exclusively. There often exist, however, some factors which are largely reducing the use of these anemometers. In micrometeorology we are obliged to work among growing plants where the space is very limited and the wind speed very low. Similar problems will meet us in indoor climatic investigations whereas rapid wind fluctuations are of great importance in turbulence observations [9]. As is well known, the cup anemometer is able to show only velocities above 0.5—1 ms^{-1} and even then as a mean of a rather long time interval.

If we are willing to study some problems subjected to low wind speeds, there is a group of instruments which have proved considerably correct. It is a common feature in them that a wire, a coil or generally a body is heated and the rate of heat loss caused by the wind is measured. For that reason we call them here as hot body anemometers. As far as we know, the terminology is here defective. Because the heating and recording process will mostly go electrically, the name electric anemometers is used now and then. On the other hand this name is often allowed to cup anemometers with an electric recording system.

1. *Several constructions.*

a) *Kata thermometer.* The Kata thermometer was developed as a meteorological instrument by L. HILL about 1915. It is a liquid-in-glass thermometer with a large bulb, about 4 cm long and 2 cm thick with only two marks, 35° and 38°C, on the stem. If the thermometer is heated to above 40°C and then allowed to cool, the same amount of heat will always go lost while the column falls from 38° to 35°. The rate of heat loss, however, will depend on atmospheric conditions. The mean rate of cooling is related to the wind speed v by the equation:

$$H = (a + b\sqrt{v})(36.5 - t) \tag{1}$$

where:

H = the total heat lost in cooling from 38° to 35° divided by the area of the cooling surface and by the cooling time,
t = temperature of the surrounding air,
$\left.\begin{matrix} a \\ b \end{matrix}\right\}$ = constants [8].

The Kata thermometer is mostly used in bioclimatic and indoor climatic measurements. It will give of course only mean speeds of the prevailing wind. The mean of the values on its stem, 36.5°C, indicates the normal temperature of the human body. Thus the Kata thermometer is principally a means for estimating the cooling power or the fundamentals of the climatic comfort.

b) *Hot wire anemometer.* For a heated circular cylinder with its axis at right angles to the flow, the following semi-empirical equation may be written:

$$H = \frac{a}{d} + b\sqrt{\frac{v}{d}}(t - t_a) \tag{2}$$

where:

H = rate of the heat loss per unit length of the wire,
d = wire diameter,
v = wind speed,
t = wire temperature,
t_a = air temperature,
$\left.\begin{matrix} a \\ b \end{matrix}\right\}$ = functions of the temperature and of the physical properties of the air.

If the cylinder is of the shape of a metal wire and is heated by a current i, then under steady conditions:

$$Ri^2 = \frac{a'}{d} + b'\sqrt{\frac{v}{d}}(t - t_a) \tag{3}$$

where R is the resistance per unit length of the wire when heated to the temperature t. The mechanical equivalent of heat is included in a' and b'.

(2) and (3) are two modifications of the King's equation, called after L. V. KING, the first careful investigator of the hot wire anemometers [1]. It is noteworthy that equations (1) and (2) are of the same form.

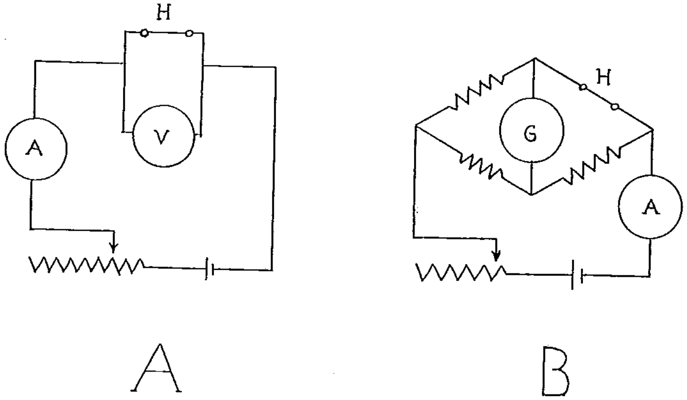

Fig. 1. Two simple circuits of hot wire anemometers. A = constant current method, B = constant resistance method. H = hot wire.

The electrical circuit of hot wire anemometers can be made either by giving i a constant value and measuring R (constant current method) or by keeping R or wire temperature constant and measuring i (constant resistance method). A simple sketch of these both methods is illustrated in Fig. 1. The sensitivity of both methods increases with decreasing air speed. Numerous more complicated modifications of these circuits have been made.

The hot wire should be made of some pure metal such as platinum, nickel or tungsten. The wire diameter ranges, as a rule, from 0.005 to 0.2 mm, the wire length from 0.5 mm to 20 cm. The dimensions should be selected according to the use. Thus investigations concerning e.g. the small scale turbulence will require small wire dimensions while measurements among plants will demand a rather robust instrument. The time lag can be reduced down to the order of a millisecond if very thin wires are used and electrical compensation methods for lag are employed.

c) *Thermocouple anemometer.* The idea of a thermocouple anemometer s to heat a junction of a thermocouple while the other junction is held in the air temperature. The heating is caused by a heating wire or coil on the hot junction. Here again two methods are alternative. Either the heating current is held constant and the thermoelectric power is measured or vice versa.

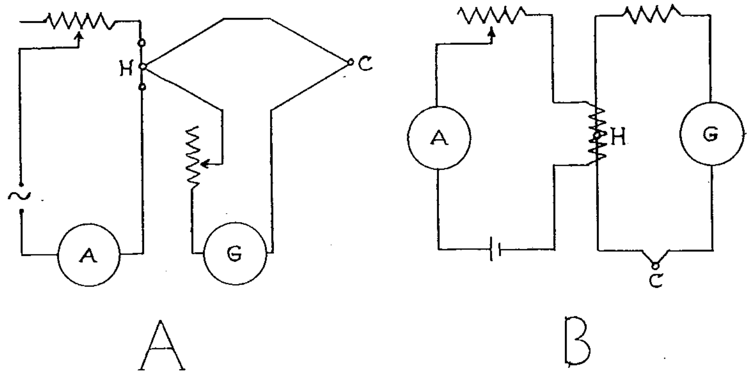

Fig. 2. Two circuits of thermocouple anemometers. A = after [12], B = after [4]. H = hot junction, C = cold junction. Both figures were simplified.

The thermocouple materials are commonly copper and constantan or iron and constantan while the heating wire is of constantan or manganin. In Fig. 2 we see two simple circuits of thermocouple anemometers. The hot junction of type A is heated directly by an alternative current while type B has an insulated heating coil on its hot junction [12], [4].

d) *Thermistor anemometer.* A thermistor is a small resistance body in the shape of a bead, a block or a short rod. The thermistor materials are characterized by a high negative temperature coefficient of resistance in such a manner that an increase in temperature of 10—50°C halves the value of the resistance. Thermistors can be made to cover a range of 100Ω—500 kΩ thus permitting a wide variation in the circuit design. The temperature-resistance relation is given to a first approximation by:

$$R = R_0 e^{\frac{b}{T}}$$

where:

R = resistance of the thermistor at absolute temperature T,
R_0 = resistance at some standard temperature,
b = a constant over a small temperature interval.

Thermistors are used as anemometers like hot wires referring to Fig. 1. As said before, wide variations in the circuit design are possible [5], [6], [11].

2. *Calibration methods.*

The calibration for wind velocities down to about 0.5 ms^{-1} can easily be made by comparing the hot body anemometer with a correct fan anemometer in a wind channel. Below the start velocity of the fan anemometer the rotation method on an enclosed whirling arm can be applied. An apparatus and method of correction for swirl within the enclosed space are presented in [10]. See also [2]. The instrumental constant of a Kata thermometer is given by the manufacturers.

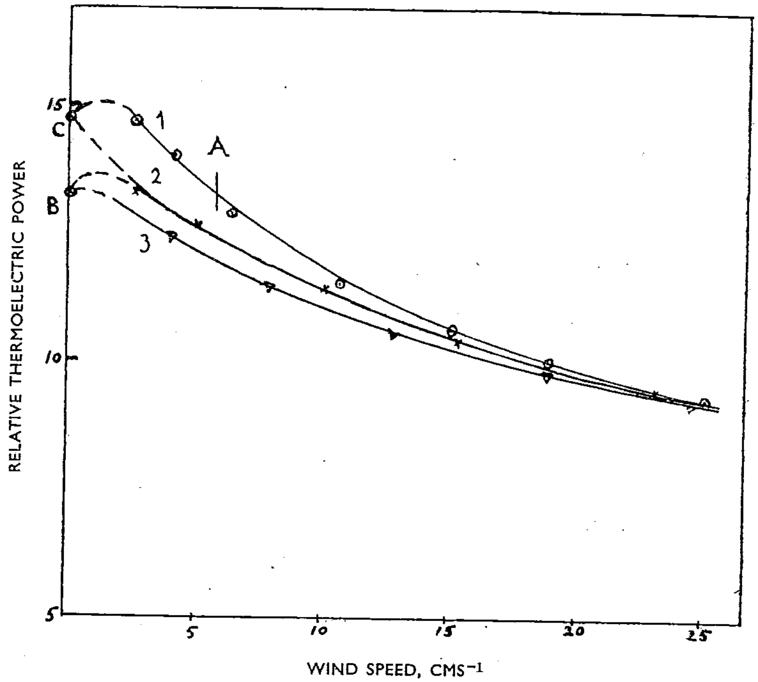

Fig. 3. Part of the calibration curves of a thermocouple anemometer of type B in Fig. 2. 1 = descending vertical currents, 2 = horizontal winds, 3 = ascending vertical currents. A = the highest speed below which the result will be ambiguous, B = zero-point in free air, C = zero-point, the hot junction being in a closed copper shield. Calibration made at the Institute of Meteorology, University of Helsinki by S. Huovila and E. Ruotsi.

We shall meet an anomalous feature concerning electric hot body anemometers near the zero-velocity. At very low values of the wind speed the body is actually hotter than at rest. This phenomen is caused by the convection current arising from the heated body. When the body is at rest a stable system of convection currents is set up. At very low translational speeds the resultant air speed, which determines the cooling, is less than the speed caused by the convection only. Thus an yaw will be seen in the calibration curve as shown in Fig. 3. At speeds less than A we cannot get an unambiguous result. The distance from zero to A is usually of the order of 1—10 cms^{-1} and can be diminished by reducing the heating current [8].

To use the anemometer accurately for very low speeds it is necessary to mount it in the attitude in which it was calibrated. A vertical air current does not have the same cooling effect as a horizontal current of equal velocity. Nor do upward and downward vertical currents have equal cooling effects. The zero-point will be taken in a closed, definite shield where the free convection will be checked. Thus the zero will be independent of the occasional surroundings of the anemometer and more on its »right» place as we can see in Fig. 3.

3. *Some remarkable effects of the electric types.*

The effect of the wind direction is very notable upon the hot wires. If an anemometer is calibrated the wire being perpendicular to wind, even less than 50% of the true wind speed will be obtained if the wire is placed parallel to wind [2], [7]. The corresponding error of thermocouple and thermistor anemometers is in general of a much less magnitude depending on the shape of the hot body [11]. The ideal form here is spherical. This condition is nearly fulfilled in many thermistors.

Errors due to great variations in the relative humidity may arise to some 10% of the wind speed in hot wire anemometers [3]. Dust particles gathered by the wire are a usual reason of calibration changes of the hot wire anemometers. Thus a continual charge and regular recalibrations of them are needed whereas, by experience, the permanence of the calibration of thermocouple and thermistor anemometers is fairly good [4], [5], [7].

In view of these factors it is not surprising that many suspicions have arisen against hot body anemometers. An investigator to some extent familiar with them can, however, easily reach a relative accuracy of

5—10% on the interval of, say, 5—500 cms^{-1}. It is very noteworthy that the absolute sensitivity, in contrast to other anemometers, here increases with decreasing air speed. Thus the zero-indication of an electric hot body anemometer is the point most liable to translations.

REFERENCES

1. KING, L. V., 1915: Precision measurements of air velocity by means of the linear hot wire anemometer. *Phil. Mag.*, 29, 556—577.
2. ALBRECHT, F., 1930: Ein Messgerät zur Messung und Registrierung kleiner Windgeschwindigkeiten usw. *Met. Zschr.*, 47, 465—474.
3. PAESCHKE, W., 1937: Experimentelle Untersuchungen zum Rauhigkeits- und Stabilitätsproblem in der bodennahen Luftschicht. *Beitr. Phys. fr. Atm.*, 24, 163—189.
4. HUKILL, W. V., 1941: Characteristics of thermocouple anemometers. In: *Temperature, its measurement and control in science and industry*, New York, 666—672.
5. HALES, W. B., 1948: Thermistors as instruments of thermometry and anemometry. *Bull. Am. Met. Soc.*, 29, 494—499.
6. PENMAN, H. L. and LONG, I., 1949: A portable thermistor bridge for micro-meteorology among growing grops. *Journ. Scient. Instr.*, 26, 77—80.
7. SIMMONS, L. F. G., 1949: A shielded hot-wire anemometer for low speeds. *Ibid.*, 26, 407—411.
8. OWER, E., 1949: *The measurement of air flow.* London.
9. SHIOTANI, M., 1950: Turbulence in the lowest layers of the atmosphere. *Sc. Rep. Tohoku Univ. ser. Geoph.*, 2, 167—201.
10. COWDREY, C. F., 1950: A note on the calibration and use of a shielded hot-wire anemometer for very low speeds. *Journ. Scient. Instr.*, 27, 327—329.
11. SANFORD, E. R., 1951: A wind-tunnel investigation of the limitations of thermistor anemometry. *Journ. of Met.*, 8, 182—190.
12. HÖHNE, W., 1953: Ein thermoelektrischer Feinwindmesser. *Zschr. für Met.*, 7, 215—218.