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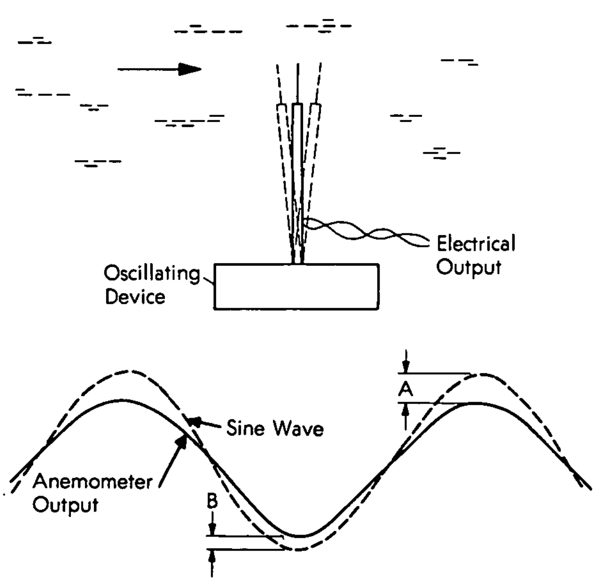
Oscillating Hot-Wire Anemometer

Anemometers which have a stationary hot wire operate on the principle that heat transfer from the wire to the fluid in which it is immersed is a function of the motion of the fluid past the wire. Unfortunately, anemometers of this type are severely restricted in their usefulness not only because they



must be calibrated empirically, but also because all nonspeed parameters must be continuously monitored to insure accurate indication of speed, in as much as the rate of heat loss from the wire is a function of the ambient gas viscosity, thermal conductivity, density, and temperature as well as the motion of the fluid. Anemometers which have a vibrating hot wire have been used to minimize the effect of local convection currents and the thermal boundary layer surrounding the wire at low fluid speeds, but the calibration problems are still present.

The results of a detailed analysis of the electrical output of an anemometer which has a hot wire oscillating in a gas stream suggest that this type of anemometer does not require calibration; moreover, the direction as well as the speed of the fluid can also be determined if the tip of the oscillating probe moves in a circle or if two probes are used, each oscillating perpendicular to the other. The diagram portrays the simplicity of construction of an oscillating hot-wire anemometer. On the other hand, the electrical output of the probe is quite complex; as indicated in the diagram, the fluctuating electrical component does not resemble the pure sine wave motion of the probe, for it is composed of at least a fundamental and higher harmonics. The deviation of the electrical output from a pure sine wave is greater at A than at B; the distortion has been exaggerated in the diagram for sake of clarity.

The relationship between fluid speed and the electrical output of a hot-wire anemometer (King's law) is normally written in the dimensionless form $N_u = A + B(R_e)^n$ where N_u is the Nusselt number, A and B are dimensionless functions of the fluid properties, R_e is the Reynolds number with respect to the wire diameter, and n is a constant which is very nearly 0.5. For operation at constant temperature, the expression is best written in the dimensional form, $P = A' + B'V^n$, where P is the wire heating power, V is the fluid speed normal to the wire, and A' and $(B'V^n)$ are the dimensional (watts) analogs of A and B. In practice, the voltage output of the wire is proportional to the fourth root of the fluid velocity.

(continued overleaf)

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When the wire is harmonically oscillated in the fluid stream at amplitude a and frequency ω, the apparent fluid speed relative to the wire is $V = u + \omega a \cos \omega t$ where u is the component of fluid velocity normal to the wire. Hence, the dimensional form of King's law becomes

$$P = A' + B'u^{1/2} [1+(\omega a/u) \cos \omega t]^{1/2}.$$

The trigonometric term is expanded by the binomial theorem to yield:

$$P = A' + B'u^{1/2} [1-(\omega a/4u)^2 + (\omega a/2u)\cos \omega t - (\omega a/4u)^2 \cos 2\omega t + \ldots]$$

Now, if the signal components at the fundamental frequency and the second harmonic are filtered, their ratio is

$$P_{2\omega}/P_{\omega} = \omega a/8u$$

and, for constant resistance, the wire voltage second harmonic distortion is

$$E_{2\omega}/E_{\omega} = (\omega a/8u)^{1/2}.$$

As can be seen from the above equation, the calibration constants A′ and B′ have been eliminated; the harmonic distortion is a function only of the oscillation frequency and amplitude as well as the speed of the fluid normal to the wire.

The probe frequency and amplitude can be measured or controlled precisely and made to remain constant indefinitely. Thus, the anemometer can record fluid speed without being degraded by variations in other parameters or by surface contaminants on the hot wire.

Note:

Requests for further information may be directed to:

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