Constant Temperature Anemometry

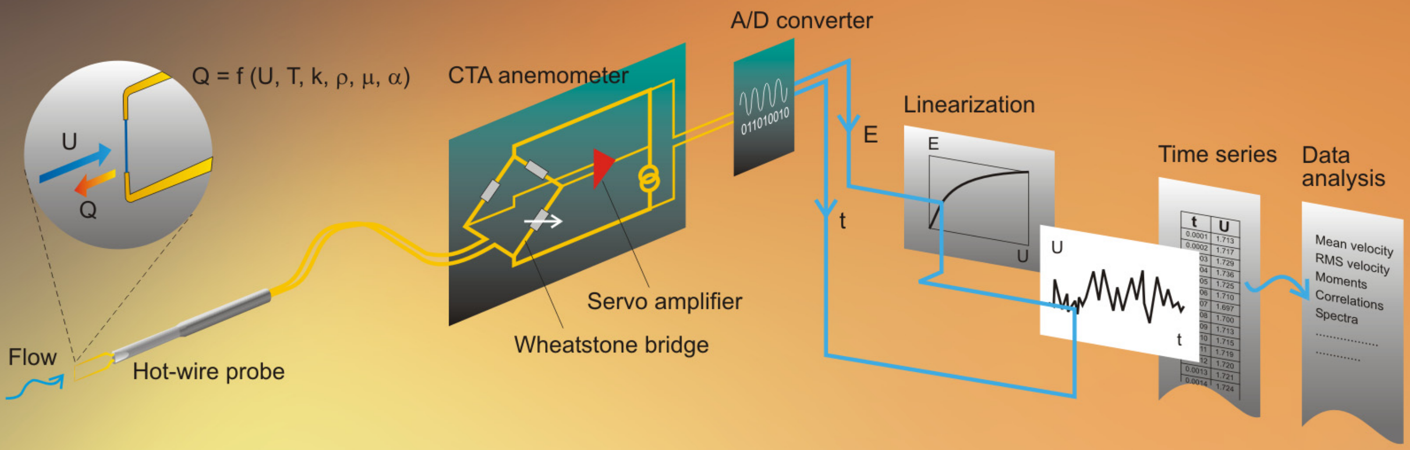
Introduction

Constant Temperature Anemometry (CTA) is used to measure fine structures in turbulent gas and liquid flows. The working principle is based on the cooling effect of a flow on a heated body.

The CTA measures velocity at a point and provides continuous velocity time series, which can be processed into amplitude and time-domain statistics. Examples are mean velocity, turbulence intensity, higher order moments, auto-correlations and power spectra.

Features

- Measures velocities from a few cm/s to supersonic
- High temporal resolution: fluctuations up to several hundred kHz
- High spatial resolution: eddies down to 1 mm or less
- Measures all three velocity components simultaneously
- Provides instantaneous velocity information



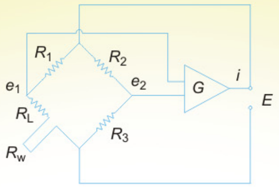
Heat transfer from cylinders

Convective heat transfer Q from a wire is a function of the velocity U, the wire over-temperature $T_w - T_0$ and the physical properties (k,ρ,μ) of the fluid. The basic relation between Q and U for a wire placed normal to the flow was suggested by L.V. King (1914). In its simplest form it reads:

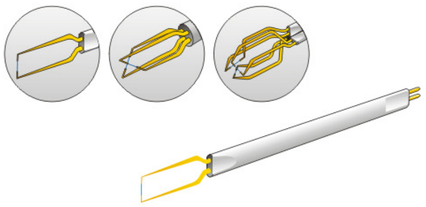
$$Q = (T_w - T_0)A_w h = A + BU^n;\ \ n \approx 0.5$$

where A_W is the wire surface area and h the heat transfer coefficient, which are merged into the calibration constants A and B.

Principles



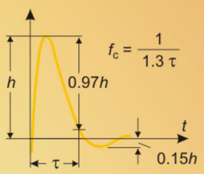
The wire, R_w, is connected to one arm of a Wheatstone bridge and heated by an electrical current.
A servo amplifier keeps the bridge in balance by controlling the current to the sensor so that the resistance - and hence temperature - is kept constant, independent of the cooling imposed by the fluid. The bridge voltage, E, represents the heat transfer and is thus a direct measure of the velocity. The combination of the sensor's low thermal inertia and the high gain of the servo loop amplifier gives a very fast response to fluctuations in the flow.



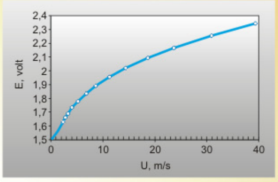
Probes

CTA probes normally have tungsten wire sensors, 1 mm long and 5 μm in diameter, mounted on two needle-shaped prongs. They are available with 1, 2 and 3 wires. Film probes with thin-film sensors are recommended for liquid flows.

Frequency response



The system bandwidth, f_c, is defined as the frequency at which the signal amplitude is damped by -3 dB. It increases with decreasing wire time constant, with increasing servo loop gain and with flow velocity. The bandwidth for a CTA with a 5 μm wire probe is around 100 kHz at 30 m/s. The system is optimised by applying a square-wave voltage to the bridge top and adjusting the servo-loop gain.



Velocity sensitivity

The relation between bridge voltage and velocity may be described as an exponential function or as a polynomial:

$$E^2 = (T_w - T_0)(A + BU^{0.5}) \quad \text{or}$$
$$U = C_0 + C_1E + C_2E^2 + C_3E^3 + C_4E^4 + C_5E^5$$

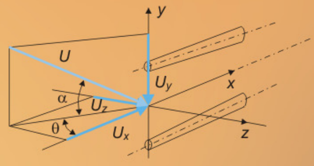
The relative velocity sensitivity, 1/U · dE/dU, is almost constant over a wide velocity range. Calibration in a known flow forms the basis for the curve fit used to convert probe voltages into velocities (linearization).

Directional sensitivity

As a wire is sensitive to both flow velocity and direction, orthogonally arranged wires give information about both. The effective cooling velocity for a wire in a three-dimensional flow can be expressed as:

$$U_{eff}^2 = U_x^2 + k^2U_y^2 + h^2U_z^2$$

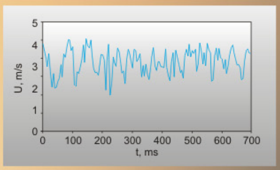
For 2- and 3-wire probes, the effective cooling velocity equations can be solved to provide the velocity components. The pitch and yaw factors k and h are determined by a directional calibration.



Temperature sensitivity

The bridge voltage depends on both velocity and temperature. A 1 K change gives an error of approx. 2% in velocity. The voltage may be corrected before linearization, using the ratio between the over-temperatures during calibration and measurement:

$$E_{corr} = E\left(\frac{T_w - T_0}{T_w - T_{meas}}\right)^{0,5}$$



Data conversion and reduction

Bridge voltages are acquired via fast A/D boards (up to 1 MHz or more) after proper low-pass filtering. They are converted into engineering units in three steps:

- Temperature correction
- Linearization
- Decomposition into velocity components

The converted data are then reduced into flow statistics.

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