VLSI Based Fluid Flow Measurement Using Constant Temperature Hot Wire Anemometer

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Abstract— The performance of a hot-wire anemometer configuration is affected by variation in the fluid temperature. The classical temperature compensation techniques in such anemometers employ two sensors. The performance of a temperature-compensated hot-wire anemometer configuration using a single sensor alternating between two operating temperatures and proposed for constant fluid velocity is investigated under conditions of time-varying fluid velocity. The measurement error introduced is quantified and can be practically eliminated using a low-pass digital filter.

Keywords— Electrical equivalence, fluid temperature compensation, hot-wire anemometer and thermoresistive sensor, measurement error, op-amp, CMRR.

INTRODUCTION

Constant Temperature hot-wire anemometer (CTA) circuit based on a feedback self-balanced Wheatstone bridge containing a thermoresistive sensor is known to exhibit a relatively wide bandwidth [1]. The compensation of the effect of fluid temperature $T_f$ is usually done by employing an independent fluid temperature sensor [1]–[5] or two similar feedback bridge circuits with two identical sensors operating at two different constant temperatures [6]. The finite nonzero amplifier input offset voltage does not permit the sensor temperature to remain constant with varying fluid velocity [7]. This offset voltage also affects the dynamic response of the feedback circuit. The circuit temporal response is slower for a higher offset voltage. Further, it has been shown that when the amplifier input offset voltage is zero, or below a critical value, the circuit becomes oscillatory.

Thermal anemometry is the most common method used to measure instantaneous fluid velocity. The technique depends on the convective heat loss to the surrounding fluid from an electrically heated sensing element or probe. If only the fluid velocity varies, then the heat loss can be interpreted as a measure of that variable.

Thermal anemometry enjoys its popularity because the technique involves the use of very small probes that offer very high spatial resolution and excellent frequency response characteristics. The basic principles of the technique are relatively straightforward and the probes are difficult to damage if reasonable care is taken. Most sensors are operated in the constant temperature mode.

PRINCIPLE OF OPERATION

Based on convective heat transfer from a heated sensing element, possessing temperature coefficient of resistance.

Hot-wire anemometers have been used for many years in the study of laminar, transitional and turbulent boundary layer flows and much of our current understanding of the physics of boundary layer transition has come solely from hot-wire measurements. Thermal anemometers are also ideally suited to the measurement of unsteady flows such as those that arise behind rotating blade rows when the flow is viewed in the stationary frame of reference. By a transformation of co-ordinates, the time-history of the flow behind a rotor can be converted into a pitch-wise variation in the relative frame so that it is possible to determine the structure of the rotor relative exit flow. Until the advent of laser anemometry or rotating frame instrumentation, this was the only available technique for the acquisition of rotating frame data.
3. HOT WIRE EQUATION

To examine the behaviour of the hot wire, the general hot wire equation must first be derived. This equation will be used to examine both the steady state response of the hot wire, discussed here, and its frequency response, discussed later. By considering a small circular element of the hot wire, Figure 2, an energy balance can be performed, assuming a uniform temperature over its cross-section:

\[ I^2 \delta R_w = \rho_w C_w \frac{\partial T_w}{\partial t} A \delta x + K_w A \frac{\partial T_w}{\partial x} + h \pi d (T_w - \eta T_0) \delta x - K_w A \left( \frac{\partial T_w}{\partial x} + \frac{\partial^2 T_w}{\partial x^2} \delta x \right) + \sigma \varepsilon (T_w^4 - T_{sur}^4) \pi d \delta x \]  \tag{1}

This can be simplified, Højstrup et al., 1976, to give the general hot wire equation:

\[ K_1 \frac{\partial T_w}{\partial t} = \frac{\partial^2 T_w}{\partial x^2} - \beta_1 T_w + K_2 T_a - K_3 \]  \tag{2}

if radiation is neglected. The constants are given by:

\[ K_1 = \frac{\rho_w C_w}{K_w} \]  \tag{3}

\[ \beta_1 = \frac{h \pi d}{K_w A} - \frac{\alpha^2 \rho_{ref} \pi d}{K_w A^2} \]  \tag{4}

\[ K_2 = \frac{h \pi d}{K_w A} \]  \tag{5}

and

\[ K_3 = \frac{i^2 \rho_{ref}}{K_w A^2} (\alpha T_{ref} - 1) \]  \tag{6}

A heat balance can then be performed over the whole wire, assuming that the flow conditions are uniform over the wire:

\[ I^2 R_w = H_{cond} + H_{conv} \]  \tag{7}

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The two heat transfer components can be found from the flow conditions and the wire temperature distribution:

\[
\overline{H_{\text{conv}}} = 2l\pi dh(T_m - T_a), \quad (8)
\]

\[
\overline{H_{\text{cond}}} = 2K_w A \left[ \frac{\partial T_w}{\partial x} \right]_{x=1}, \quad (9)
\]

To give a steady state heat transfer equation:

\[
I^2 R_w = 2\pi h_c dl(T_m - T_a), \quad (10)
\]

HOT WIRE ANEMOMETER DESIGN

A fluid flow measurement using constant temperature hot wire anemometer is shown in fig. 5. The input stage consists of M1 and M2 and the biasing current is provided by M3 and M4 and the dc biasing current is given in A. The output port Vout is connected to M10 and M12 transistor.

![Schematic of CTA](image)

**Fig.3-Schematic of CTA**

The table 1 shows the dimension of each transistor in the circuit. The input transistor M1 and M2 are drawn with identical sizes and their width to length ratio as \((W/L)_1\), similarly transistors M8 and M9 are same size \((W/L)_2\). The PMOS current transistors M3, M4, M5 and M8 are same size \((W/L)_3\).

<table>
<thead>
<tr>
<th>Transistors</th>
<th>((W/L)) ((\mu m))</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1, M2</td>
<td>50/0.18</td>
</tr>
<tr>
<td>M3, M4, M5, M8, M9</td>
<td>4/0.18</td>
</tr>
<tr>
<td>M6, M7</td>
<td>1/0.18</td>
</tr>
<tr>
<td>M10</td>
<td>30/0.18</td>
</tr>
<tr>
<td>M11</td>
<td>50/0.18</td>
</tr>
<tr>
<td>M12</td>
<td>45/0.18</td>
</tr>
</tbody>
</table>
SIMULATION AND RESULT

Fig.4-Common mode supply

Fig.5- Fluid Flow Measurement Using Constant Temperature Hot Wire Anemometer

Fig.6-Output of common mode input supply
CONCLUSION

In this paper an Fluid Flow Measurement Using Constant Temperature Hot Wire Anemometer using on 0.18 \( \mu \)m technology proposed. The input can vary in the range of microvolts. Therefore the simulation result with 64.2dB value of gain, 70dB value of CMRR, and 400Hz bandwidth are obtained. These result demonstrate that the proposed circuit can be used to develop an integrated circuit. The output obtain is in milivolts and then amplify.
REFERENCES:


