A study on a hot anemometer to measure slow water velocity, BY ISAO MINAMI, September 1965

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A STUDY ON A HOT ANEMOMETER
TO MEASURE SLOW WATER VELOCITY

by Isao Minami

INTRODUCTION (Hot Anemometer)

A hot anemometer is a device for measuring slow water velocity, it is essentially a 'Wheatstone Bridge' composed of constant resistances a and b, a variable resistance c and a hot platinum wire x as shown in Fig. 1. A platinum wire is generally used as the hot wire x. A hot anemometer using a platinum foil instead of a platinum wire is being developed.

When a thin wire x, which is heated to a specified temperature, is immersed in running water, the electric resistance of the wire x changes in magnitude due to the difference in the rate of cooling which is in turn dependent on the water velocity u. The change in the resistance of the wire x breaks the electric balance of the 'Wheatstone Bridge' and a small current i flows through the galvanometer, Fig. 1. Thus, if a characteristic curve representing the relationship between the small current i and the water velocity u is established, the water velocity u can be obtained by measuring i.

Using a hot anemometer, two methods of measurement are available at present.

1. Method 1, constant current.
   Keep the electric current I constant, and establish the relationship between the reading of the galvanometer d and the water velocity u.

2. Method 2
   Keep the reading of the galvanometer d constant and establish the relationship between I and u.
In both methods, some difficulties are encountered, especially in measuring the water velocity. Due to the change of the water temperature and the contamination of the platinum wire, the characteristic curves vary as shown in Fig. 2 and 3.

Fig. 2: Characteristic curves obtained by method 1.
Fig. 3: Characteristic curves obtained by method 2.

Considering also the probability of the generation of bubbles at the hot wire x, the methods described above may include many unknown factors. Errors introduced in these measuring procedures would be comparable to the difference among \( u, u' \) and \( u'' \) in Fig. 2 and 3. It should be noted, however, that the variation of characteristic curves is approximately a parallel shift from each other. Therefore, a third method of measurement is developed on the basis of this observation.

Method 3:

As shown in Fig. 2, the obtained water velocities \( u, u' \) and \( u'' \) differ considerably. But the slopes of the characteristics curves at the corresponding points \( \alpha, \alpha' \), \( \alpha'' \) show considerable smaller difference. The following relationships exist:

\[
\frac{u' - u}{u} = \frac{\alpha' - \alpha}{\alpha}, \quad \frac{u'' - u}{u} = \frac{\alpha'' - \alpha}{\alpha}
\]

The relative change of the slopes of the characteristic curves is much smaller than that of the water velocities. Thus, the third method is devised as follows:
By increasing the electric current in the circuit from $I_1$ to $I_2$, obtain the change of reading of the galvanometer $d$, (Hereafter, $d$ stands for the change of reading, instead of the reading itself. J. K.) and establish the relationship between $d$ and the water velocity $u$. In comparison with other two methods, the third method is less affected by the change of water temperature and other factors.

Since the time required in increasing the current from $I_1$ to $I_2$ is very short, the probability of the generation of bubbles would be decreased considerably. An example of the characteristic curves obtained by Method 3 is shown in Fig. 4.

EFFECT OF THE CONTAMINATION OF THE PLATINUM WIRE:

The effect of the contamination of the platinum wire on the characteristic curves is shown in Fig. 5 and 6. When fibriform dusts and/or colloidal mud adhere to the platinum wire, they prevent the radiation from the wire and result in the considerable error as shown in Fig. 6.

The effect of the contamination of the platinum wire can be eliminated by using a new, clean wire in the measurement. The replacement of the wire can be easily done by attaching the wire in the circuit screws.

EFFECT OF THE CHANGE OF WATER TEMPERATURE:

In the hot anemometer used in this study, a platinum wire was used as the hot wire. The rest of electric circuit was composed of copper wires. At the junction of foreign metals, a thermal electric potential is generated with the change of water temperature. This potential is superimposed on the potential due to the cooling of hot wire and results in an error of measurement, even in the method 3.

* J. K. refers to the translator’s comments.
However, the error due to the change of water temperature can be calibrated experimentally, since it is one of systematic errors. In Fig. 7 to 12 are shown the results of experiments conducted changing water temperatures.

Fig. 7: water temperature $t = 5 - 7^\circ c$
" 8: " " $t = 7 - 10^\circ c$
" 9: " " $t = 10 - 13^\circ c$
" 10: " " $t = 13 - 16^\circ c$
" 11: " " $t = 16 - 19^\circ c$
" 12: " " $t = 19 - 22^\circ c$

In Fig. 13, average curves for each temperature are summarized. It is seen that a systematic error is introduced by the change of water temperature, and the greater the water velocity is, the greater the magnitude of the error becomes.

**ELIMINATION OF THE EFFECT OF THE WATER TEMPERATURE: (CALIBRATION)**

From Fig. 13, water velocities at various temperature are tabulated in Table 1. The relative velocities computed with respect to $u_{14.5}$, water velocity at $t = 14.5^\circ c$, are also shown in the parentheses. From these values, the calibration equation is derived as follows: (Try to express the modification function as a series function of temperature $t$. (The reading of the galvanometer is not included, J.K.)

$$\frac{u_t}{u_{14.5}} = 1 + K_1(t_{14.5} - t) + K_2(t_{14.5} - t)^2 \quad \ldots \ldots 1$$

If we assume $K_2 = 0$ as a first approximation, the relationship between the water velocities for $t = 14.5^\circ c$ and a given temperature is given as,

$$\frac{u_t}{u_{14.5}} = 1 + K_1(t_{14.5} - T) \quad \ldots \ldots 2$$

Where $K_1$ is constant, and is determined according to the experimental data.
Thus, if a characteristic curve of a hot anemometer is established for the water temperature $t = 14.5$ the water velocity for any water temperature can be obtained using the established characteristic curve and Eq. 2.

The plot of relative water velocities is shown in Fig.14.

CONSTANT $K_1$ IN EQ. 2 IS DETERMINED FROM EXPERIMENTAL DATA AS FOLLOWS:

Substituting the average values of relative water velocities for various temperatures, Eq. 4 is derived. Solving Eq. 4 for $K_1$, five different $K_1$'s are obtained, each corresponding to different temperatures.

The average magnitude of $K_1$ is

$$K_1 = -0.0332$$

Using the $K_1$ obtained above, the water velocity at given temperatures is established by Equation 5 or Eq. 6.

ACCURACY OF METHOD 3:

In measuring the water velocity by Method 3, it is recommended to observe the following characteristics.

1. This method would give good results for water velocity from 0 to 30 cm/sec. Especially in the vicinity of $u = 0$, good accuracy can be expected.

2. The shorter the time required in measurement, the better the accuracy. Since the measurement of a point would be complete within a few seconds with Method 3, the change of the characteristic of the anemometer in this short duration can be neglected.

3. A hot anemometer demands a very careful measurement. If the current $I$ is kept constant the balance of the Wheatstone Bridge is taken painstakingly, the accuracy could be expected to be less than 5% error.
For the measurement of the slow water velocity, the propeller type anemometers are in practical use. However, these rapidly lose their accuracy with the decrease in water velocity. Thus, the characteristic of the hot anemometer, that is, the accuracy improves in the vicinity of zero water velocity, is quite important. Therefore, although it included some unknown and instable factors, the hot anemometer would be a quite useful tool with a careful measuring technique (Method 3).
Figure 1  Schematic of Hot Anemometer

Figure 2  Characteristic Curves Obtained by Method 1

Figure 3  Characteristic Curves Obtained by Method 2

Figure 4  Characteristic Curve Obtained by Method 3

Figure 6  Effect of Contamination of Platinum Filament on Characteristic Curves of Hot Anemometer
Figure 7-12 Study on Hot Anemometer

**Figure 7**

- $I = 0.3 - 0.72$ amp., $5.5' - 6.2'$ (水温)
- $I = 0.3 - 0.74$ amp., $4.5' - 7.1'$
- $I = 0.3 - 0.71$ amp., $3.6' - 6'$

**Figure 8**

- $I = 0.3 - 0.72$ amp., $7' - 11.1'$ (水温)
- $I = 0.3 - 0.74$ amp., $6.6' - 9.0'$
- $I = 0.3 - 0.73$ amp., $7.8' - 9'$

**Figure 9**

- $I = 0.3 - 0.72$ amp., $12.5' - 13.1'$ (水温)
- $I = 0.3 - 0.71$ amp., $11.0' - 12.2'$
- $I = 0.3 - 0.73$ amp., $12.0' - 12.5'$

**Figure 10**

- $I = 0.3 - 0.72$ amp., $13.7' - 15.5'$ (水温)
- $I = 0.3 - 0.74$ amp., $14' - 15.3'$

**Figure 11**

- $I = 0.3 - 0.72$ amp., $16.0' - 17.1'$ (水温)
- $I = 0.3 - 0.70$ amp., $165' - 182'$

**Figure 12**

- $I = 0.3 - 0.77$ amp., $20' - 20.3'$ (水温)
- $I = 0.3 - 0.73$ amp., $19.6' - 20.1'$
- $I = 0.3 - 0.78$ amp., $19.0' - 20.1'$
- $I = 0.3 - 0.78$ amp., $19.4' - 20.2'$
- $I = 0.3 - 0.78$ amp., $20.2' - 20.7'$
- $I = 0.3 - 0.78$ amp., $20' - 20.6'$

Characteristic Curves
**Figure 13**
Relationship Between $d$ & Water Velocity at Different Temperatures

**Figure 14**
Plot of Data From Table 1

<table>
<thead>
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<td>Test Results of Slow Water Velocity</td>
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<th>10~13°C</th>
<th>13~16°C</th>
<th>16~19°C</th>
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<td>0.2(0.66)</td>
<td>0.25(0.83)</td>
<td>0.3(1.0)</td>
<td>0.35(1.16)</td>
<td>0.4(1.33)</td>
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<td>0.55(0.91)</td>
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<td>40.0(1.18)</td>
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|  | 平均 | 平均 | 平均 | 平均 | 平均 | 平均 |
|  | (0.576) | (0.817) | (0.909) | (1.0) | (1.086) | (1.175) |