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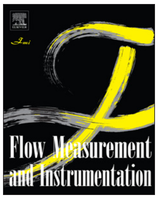

Improvement of the constant temperature anemometer and measurement of energy spectra in a turbulent jet

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ABSTRACT

This paper presents a rearranged electrical circuit for a constant temperature anemometer (CTA), along with details of calibration results and velocity measurement results for a plane jet and square jet that were obtained by using the rearranged CTA. In this rearranged CTA, the ratio of the electrical resistance of the Wheatstone bridge was set at one, and the feedback circuit used two operational amplifiers whose gain-bandwidth product and slew rate were 110 MHz and 20 V/μs, respectively. The results of a frequency response test showed that the roll-off frequency of the rearranged CTA was 20 kHz for a 5−μm hot-wire and 40 kHz for a 3−μm hot-wire, given a free stream flow velocity of 20 m/s; those of a basic CTA were 5 kHz and 6 kHz, respectively. It was also found that the energy spectra measured by the rearranged CTA yielded a power spectrum that agreed with the profile derived numerically from the Lagrangian direct-interaction approximation (LDIA) theory in the range of non-dimensional wave numbers smaller than 0.5. These results indicate that the rearranged CTA could be used for more accurate investigations of fine-scale structures in turbulent flows. Further, the profile obtained by the LDIA theory was valid and useful for discussing the turbulent flows.

1. Introduction

Hot-wire anemometers, which use a very thin heated wire as a sensor, are widely used to measure velocity fluctuations in turbulent flows [1]. The advantage of using a hot-wire anemometer is that it presents a large dynamic response to the turbulent velocity fluctuation. This large dynamic response is achieved by the very small thermal inertia of the hot-wire and from its compensation by the electrical circuit in the anemometer.

Several types of hot-wire anemometers with different operating methods are available. One of these is the constant temperature anemometer (CTA), which heats up a thin wire and keeps the wire's temperature constant using a feedback loop circuit in the CTA, automatically compensating for the thermal inertia of the wire. CTAs are widely used to measure velocity fluctuations in turbulent flows because of their ease in operation and their higher frequency response to velocity fluctuations compared with other types of anemometers.

In this paper, we present techniques to improve the frequency response of a CTA, which consist of bridge and feedback circuits [2–6]. We also present details of calibration results and some velocity measurement results for a plane jet and square jet obtained by using the rearranged CTA. We compare the measured energy spectra with those obtained numerically using the Lagrangian direct-interaction approximation theory [7] (hereinafter referred to as the LDIA theory), thereby verifying the accuracy of the latter.

2. Experimental setup

2.1. Electrical circuit for CTA

2.1.1. Basic electrical circuit

Fig. 1 shows an example of a typical, basic electrical circuit for the CTA. Hereafter, this circuit is referred to as Circuit 1. Circuit 1 consists of a Wheatstone bridge circuit and a feedback circuit to compensate for the thermal inertia of the hot-wire. R_w denotes the electrical resistance of the thin wire without heating, whereas VR denotes the variable electrical resistance. The bridge electrical resistance ratio R_1/R_2 is set at 10, and the overheat ratio of the thin wire is set by adjusting the electrical resistance R_3. The operational amplifier used in the feedback circuit is an OP37 (Analog Devices, Inc.). The gain-bandwidth product of the OP37 is 63 MHz, and the slew rate is 17 V/μs.

In Circuit 1, the roll-off frequency ω_0 of the electrical circuit is expressed by the following equation [5,6]:

$$\omega_0^2 \cong \frac{K_0}{M\mu} \tag{1}$$

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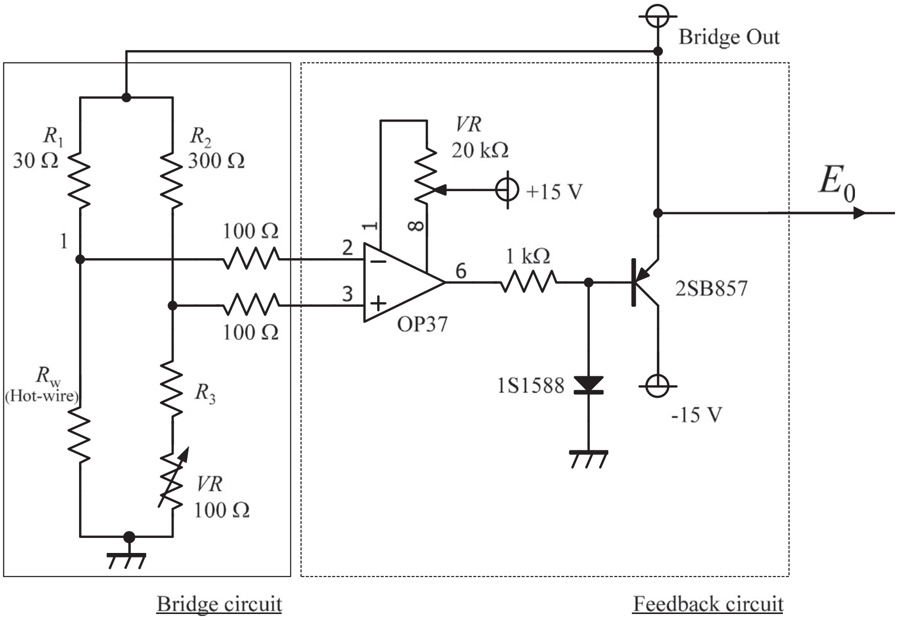

Fig. 1. Electrical circuit (Circuit 1).

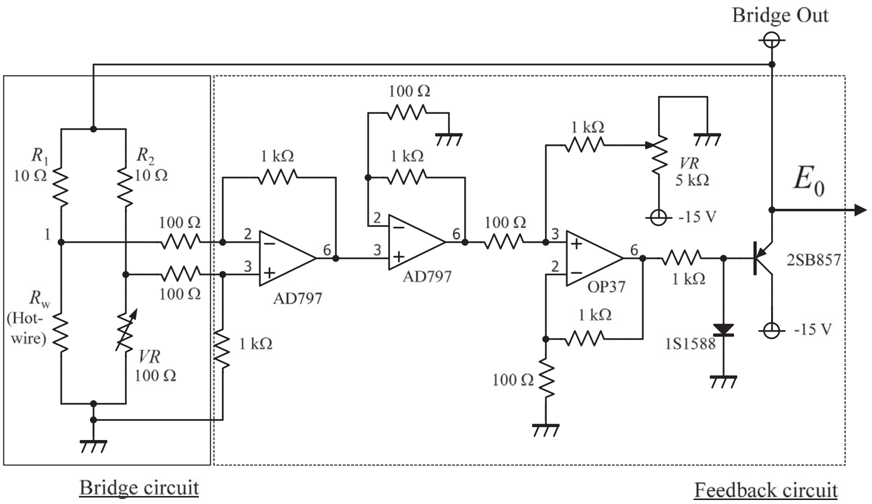

Fig. 2. Electrical circuit (Circuit 2).

Here, M is the time constant of the hot-wire, and μ is the time constant of the feedback circuit. K_0 is expressed by the following equation:

$$K_0 = \frac{2a_w A_0 \tilde{R}_w}{\tilde{R}_w + R_1} \tag{2}$$

Here, a_w is the overheat ratio, A_0 is the amplification factor, $\tilde{R}_w$ is the operating electrical resistance of the hot-wire, and R_1 is the electrical resistance of the bridge circuit.

2.1.2. Rearranged electrical circuit

From Eqs. (1) and (2) in the previous section, we chose two methods to increase ω_0. One method was to decrease μ by changing the operational amplifier and the other method was to increase K_0 by decreasing the resistance R_1.

Fig. 2 shows rearranged electrical circuit for the CTA, hereinafter referred to as Circuit 2, which uses three operational amplifiers in its feedback circuit. Two of these amplifiers are the AD797s (Analog Devices, Inc.), which provide a gain-bandwidth product of 110 MHz and a slew rate of 20 V/μs. Circuit 2 uses the OP37 as the final-stage amplifier in the feedback circuit to adjust the bridge balance. Further, R_1 is varied from 30 Ω to 10 Ω, and the bridge ratio is set at one. It should be noted here that the sensitivity of new circuit to the roll-off frequency is very high because its bridge circuit is "symmetrical" (i.e., the bridge ratio is 1.0) and the resistance R_1, R_2, and VR are almost the same order with that of hot-wire (4.0–8.0 Ω). Therefore, it involves difficulty to adjust the bridge as symmetrical and a slight difference (about 5%) of the resistance R_1, R_2, and VR makes the circuit oscillate and it does not work properly.

2.1.3. Electrical circuit for linearizing

Fig. 3 shows the electrical circuit used to linearize the output voltage E_0 of Circuits 1 and 2. We can obtain the linearized output voltage using this circuit as E_L. In addition, in this paper, the CTA, with Circuit 1 is called CTA 1, and that with Circuit 2 is called CTA 2.

2.2. Plane jet

Fig. 4 shows the schematic view of the experimental apparatus and the coordinate system of the plane jet. This plane jet has