RESEARCH REPORTS

AN IMPROVED HOT-WIRE ANEMOMETER

Yoshimasa FURUYA, Eiichi TANAKA, and Takehiro KUSHIDA

Department of Mechanical Engineering

(Received October 31, 1965)

1. Introduction

The hot-wire anemometer is an instrument whose application for measuring turbulent flow[1] have far outstripped those of other instrument up to now, but it has its own limitations. The hot-wire anemometer is worked on the cooling effect of air stream; that is, flow of air cools a thin wire heated by electric current and changes its resistance. The hot-wire technique is suitable for measurement of very low speed, but the cooling effect (output of the anemometer) is not proportional to the flow speed, then the calibrations for each test are required. The calibration of a thin hot-wire is reliable only for a limited interval of time. Although the small heat capacity of the wire can follow after the quick velocity variation, output of the wire decreases owing to the time lag caused by the heat capacity of the wire, as the frequency of the fluctuation increases.

Here, an instrument having linear characteristics was built for investigation of velocity fluctuation of flow. Velocity fluctuations in the wake behind a cylinder were measured by this instrument.

2. Compensation of thermal lag of the hot-wire

When the hot-wire technique are used for measuring velocity fluctuation, the wire has been heated usually by constant electric current. Hot-wire output signal due to velocity fluctuation varies as $1/(1+\omega^2M^2)^{1/2}$ with frequency of fluctuation ω, where M is a time constant caused by heat capacity of the wire which is a function of wire temperature, thus of mean flow velocity. Variation of the value of $1/(1+\omega^2M^2)^{1/_2}$ due to ω may be compensated by a compensating amplifier. However, the variation of the value due to M has not been taken into account, since the variation of the mean velocity has been considered to be small.

Here, we use the constant temperature method; when flow of air cools the hot-wire and decreases its resistance, the decreased voltage in the hot-wire is fed into a control amplifier which instanteneously works to increase the heating current in order to recover the temperature of the wire as before. Fig. 1. shows the block diagram of our electric instruments used here. In these instruments, the time constant of the hot-wire is $M/(1+S)$ where S is the gain of the loop.

The value of the time constant is nearly constant with large value of S which could be taken up to the value of $S \fallingdotseq 100$ without any unstable feed back oscillation. therefore, output signal does not vaties with frequency and complete compensation is obtained. Using a tungsten wire of 3.8 μ diameter, the output of the control amplifier has flat frequency characteristics up to 15 KC.

3. Linearizer

The hot-wire output is not proportional to the mean flow velocity V, and the output I (compensating heat current) is expressed as a function of V as

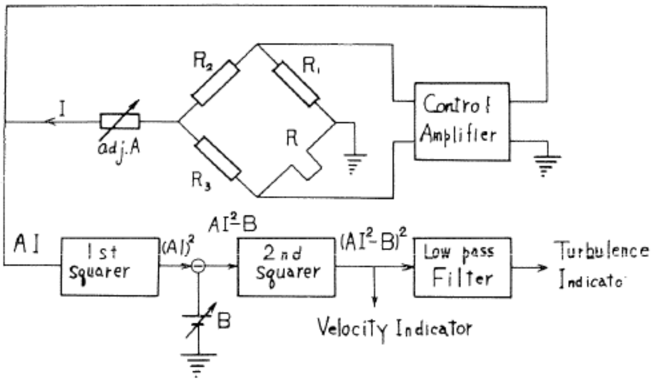


FIG. 1

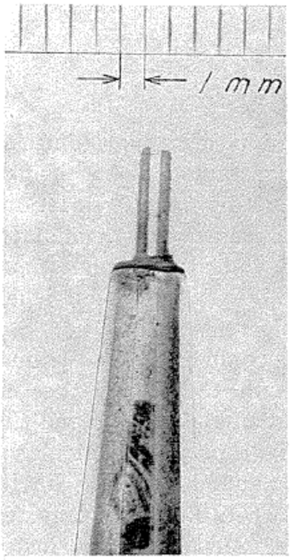


FIG. 2

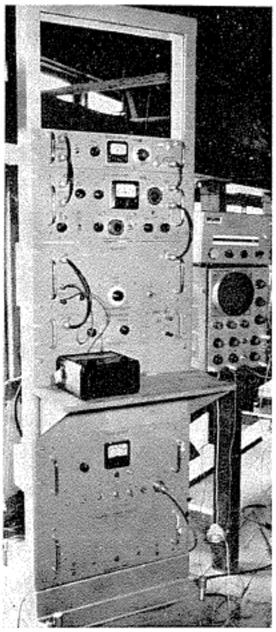


FIG. 3

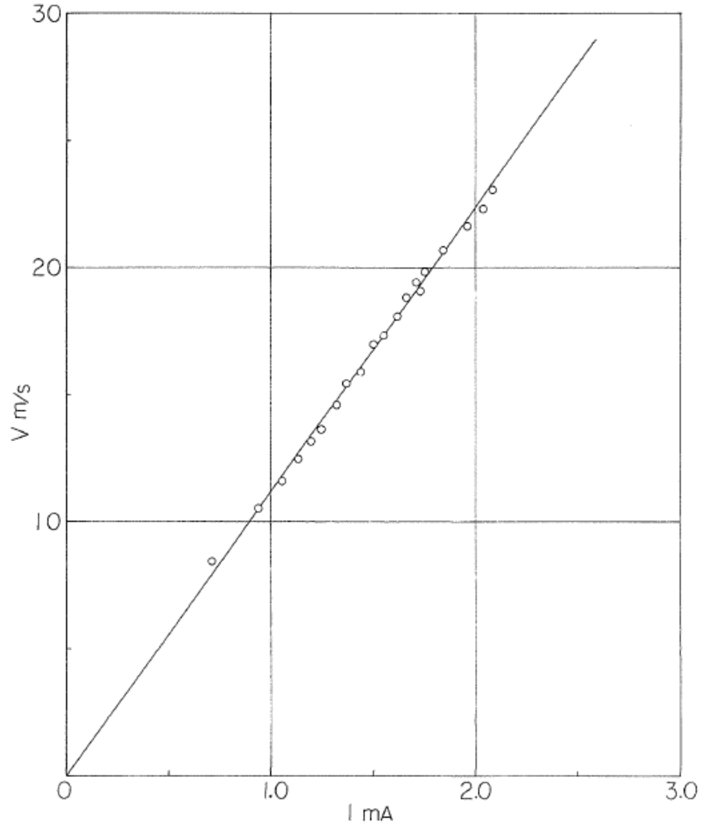


FIG. 4

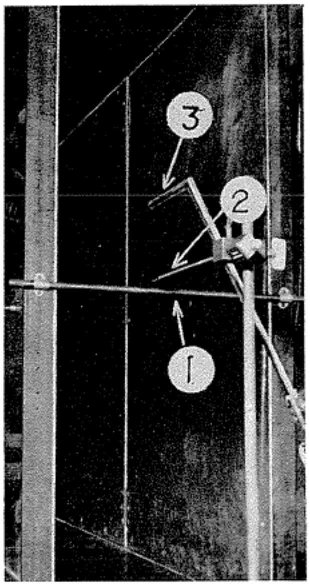


FIG. 5

$$I^2 = a + b\sqrt{V} \tag{1}$$

or

$$V = \{(AI)^2 - B\}^2 \tag{2}$$

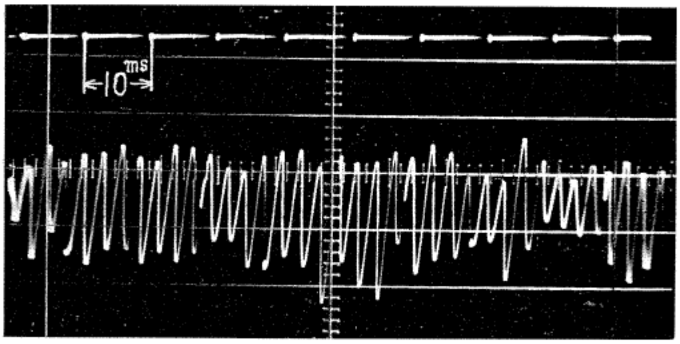
In order to find velocity V from the output I, it is necessary to use calibration curve or Eq. (1) or (2) with calibrated values of constants a and b. Differentiating Eq. (1), we have a relation between velocity fluctuation Δu and variation of output ΔI for each values of I and V. This relation has been used to calculate the root-mean-square velocity fluctuation, only when the velocity fluctuation Δu is very small compared to the mean velocity; that is $\Delta u/V \ll 1$. However, when $\Delta u/V$ is larger than 20%, accuracy of the measurement decreases.

In order to improve this defficiency, we developed an electric instrument having linear characteristics. Using a calculating curcuit to convert the output I to $\{(AI)^2 - B\}^2$, linear characteristics between output of the circuit and the velocity V could be obtained. Fig. 1 shows the block diagram of our calculating curcuit in which twelve parallel circuits approximate a quadric curve having twelve broken lines. Fig. 2 shows the probe in which 3.8 μ diameter tungsten wire of length of 1 mm is welded to the holder. The exterior of our instruments is shown in Fig. 3. Calibration curves of our instrument between the output I and the velocity V are shown in Fig. 4. As shown in the figure, the linearity between the values I and V is good. Fig. 5 shows a arrangement of pitot tube ③ and hot-wire probe ② in the windtunnel used for this calibration.

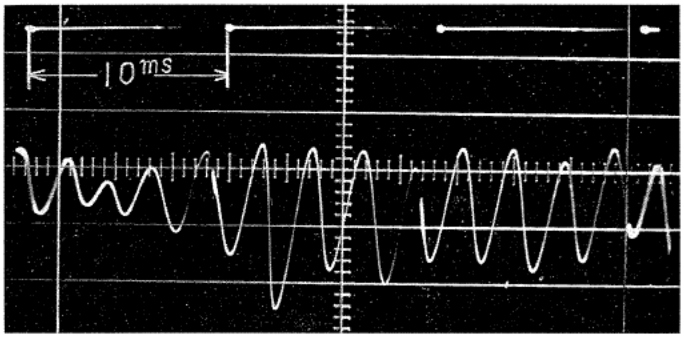
4. Measurements of velocity fluctuation behind a cylinder

The regular pattern of the vortex street behind a cylinder has attracted considerable attention in the past. The theoretical treatment of Kármán[2] does not take into account on the Reynolds number effect. The frequency of the vortex

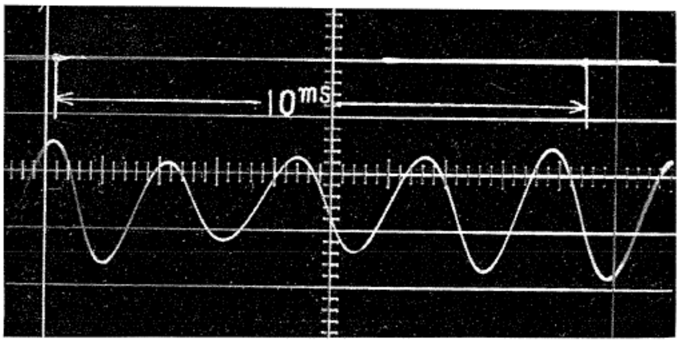
$D=9.99$ mm



$V=18.6$ m/s



$V=20.5$ m/s



$V=23.1$ m/s

FIG. 6

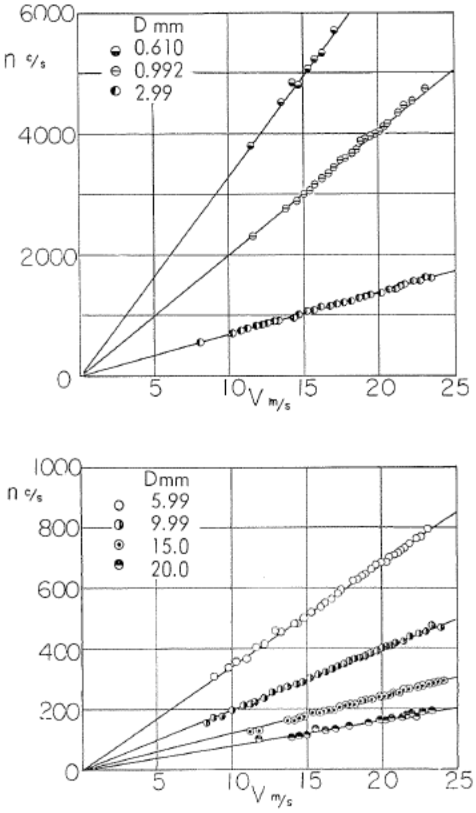


FIG. 7

pattern varies with Reynolds number. This variation has been measured by several authors[3]. The frequency of the periodic wake is regular at relatively low Reynolds numbers, but at higher Reynolds numbers the frequency is not yet clear.

Here, experiments were carried out to obtain velocity fluctuation and its frequency behind a cylinder at Reynolds number from 10^2 to 3×10^4, using our improved hot-wire anemometer. The cylinders used were steel rod of 0.2, 0.6, 1, 3, 6, 10, 15 and 20 mm diameters. Windtunnel used is shown in Fig. 5 where the working section is 1000 mm × 300 mm and speed of air flow are from 8 to 25 m/sec. Typical oscillograph records are shown in Fig. 6. This records were taken at downstream of several diameters and at sideway of a diameter from the center line. As shown in the figures, patterns are pure periodic with a little irregularity. The results are expressed in terms of Strouhal number $S=nD/V$ where n is the observed frequency, D the diameter of cylinder, V the undisturbed mean speed. Fig. 7 shows the relations

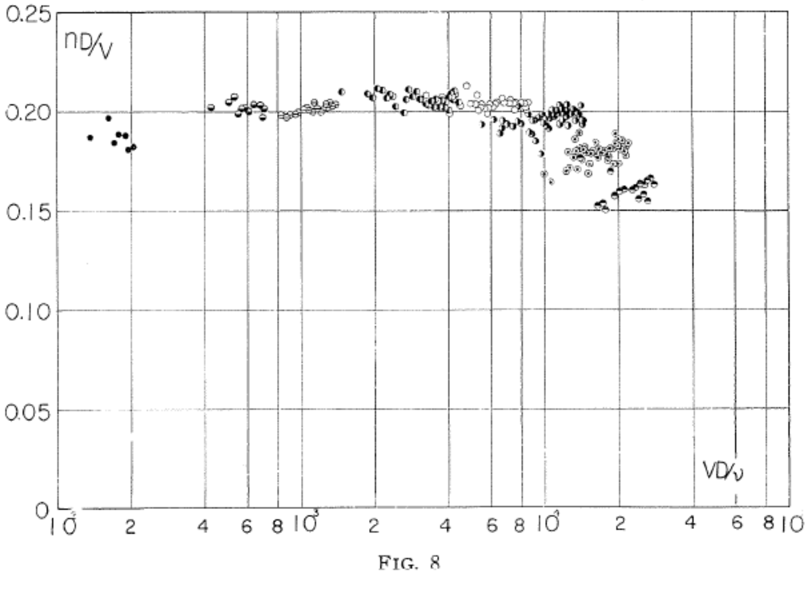


FIG. 8

between n and V for several values of D. Fig. 8 shows the Strouhal number S as a function of Reynolds number $R=VD/\nu$, where ν is kinematic viscosity of air. As shown in Fig. 8, Strouhal number decreases, as Reynolds number increases over 10^4.

The authors wishes to express his thanks to Mr. T. Kagawa of Sanko Electronic Co. for his help to develop these apparatus.

References

1) Kovasznay, L. S. G: N. A. C. A. Tech. Mem. No. 1130 (1947). Townsend, A. A: Proc. Camb. Phil. Soc. **43**, 560 (1947). Jansen, J. M. L. *et al.*: Proc. of the I. R. E. April 1956, 555.

2) Karman, Th: V. "Aerodynamics" Cornel University Press. (1954).

3) Roshko, A: N. A. C. A. Tech. Rep. No. 1191 (1954). Kovasznay, L: Proc. Roy. Soc. A. 198, 174 (1949).