

Turbulence Measurement in a Cascade Wind Tunnel

By Marusuke GOMI, Toshiyoshi MIYAZAWA

Junjiro KUBOTA and Masaoki WADA

A hot wire turbulence-measuring equipment was constructed of 5-micron Wollaston wire. The equipment covers the frequency range from 50 to about 5000 cycles per second. Constant current operation was employed. Compensation for hot wire thermal lag was adjusted manually using square wave testing to indicate proper setting. Turbulence level and energy spectrum of a cascade wind tunnel flow of about 50 meter per second was measured. Even with this simple equipment, comparatively reasonable results were obtained.

INTRODUCTION

It is well known that turbulence measurement in a cascade wind tunnel is required to compare experimental results with some others which were obtained in different tunnels. Therefore we measured the mean square value of the velocity fluctuation along the mean flow and its energy spectrum in our cascade tunnel ¹⁾ using a hot wire probe which we constructed. It is regretful that there was no band-pass filter available for the measurement of energy spectrum. Consequently we did it by analysing the velocity fluctuation curves into Fourier series by numerical methods. Of course, the accuracy of the procedure is doubtful.

APPARATUS AND METHOD OF EXPERIMENT

The hot wire was made by soldering a Wollaston wire in a semicircular shape between two prongs

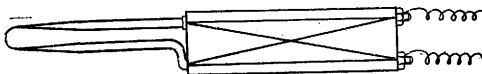


Fig. 1. Hot wire probe

and etching a portion of the silver sleeve in nitric acid with the aid of a small electric current (as is shown in Fig. 1). The density of the nitric acid and distilled water mixture is 1.19 (roughly one third nitric acid and two-thirds distilled water). An electric current (1.5 volt dry cell battery with 10,000 ohm resistor in series) starts the etching

process and the duration of about 5 minutes will be sufficient to complete the etching. The length of the etched portion is about 1 mm and its diameter is 5 microns (see Plate 1). The hot wire, operated in an electric circuit which provides it with a constant heating current, responds to the velocity fluctuations by temperature fluctuations. These temperature fluctuations are recorded as voltage fluctuations. The value of voltage fluctuations at constant current is ²⁾

$$\frac{\Delta e}{e} = - \frac{aw'}{2} \frac{1}{1 + \sqrt{U_0/\bar{U}}} \frac{\Delta U}{\bar{U}} \quad \dots\dots\dots (1)$$

where Δe stands for the voltage fluctuations (departure from the mean), $\bar{e} = IR_w$ is the mean direct current voltage drop across the wire, and ΔU is the velocity fluctuation. \bar{U} is the mean velocity of the turbulent flow, U_0 is the characteristic velocity of the wire and aw' is the dimensionless overheating ratio and is given by

$$aw' = \frac{R_w - R_e}{R_e}$$

where R_w and R_e is the resistance of the wire temperature T_w and T_e respectively (T_w is the wire temperature when heated and T_e is the equilibrium temperature attained if the wire is unheated.) I is the heating current. The overheating ratio increases with the heating current under constant air velocity and is shown in Fig. 2.

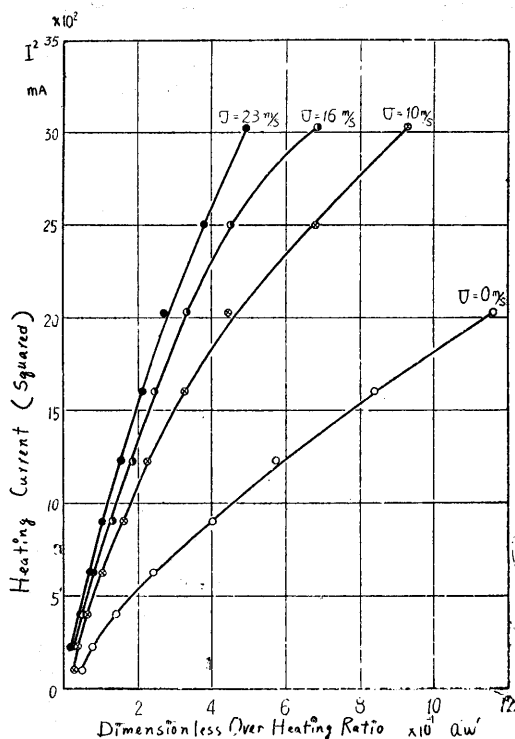


Fig. 2. Heating current dependence of hot wire resistance.

By rearranging the parameters in Fig. 2, we can derive the relationship which states that the square of the heating current is a linear function of the square root of the velocity and is shown in Fig. 3. Points, which are obtained when $U = 10$ m/s do not lie well on the straight line, but perhaps it depends on the fact that air velocity U was measured by pitot tube and considerable error

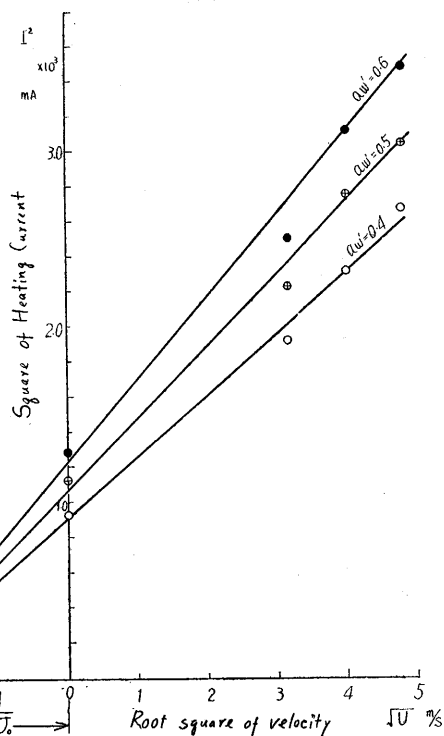


Fig. 3. Hot wire in thermal equilibrium.

might be involved in measuring low speeds. The value of U_0 is obtained from the distance between zero point and the intercept of $aw' = \text{const}$ which lies on the \sqrt{U} axis.

The heating current control and square wave feeding system is shown in Fig. 4.³⁾ The transformer is Sansui *Fi Hi* output transformer and seems to have enough characteristics for our purposes.

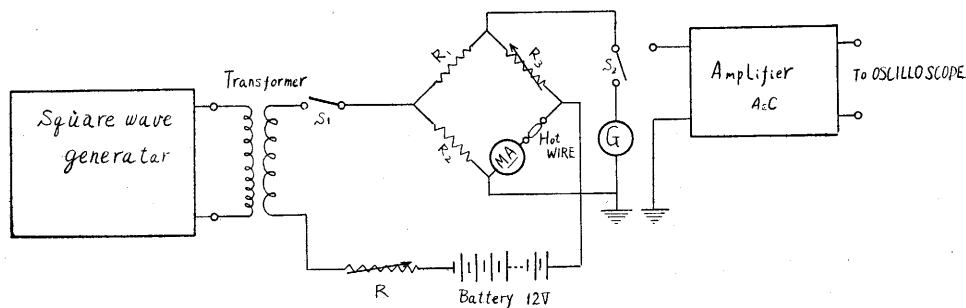


Fig. 4. Heating current control and square wave feeding system.

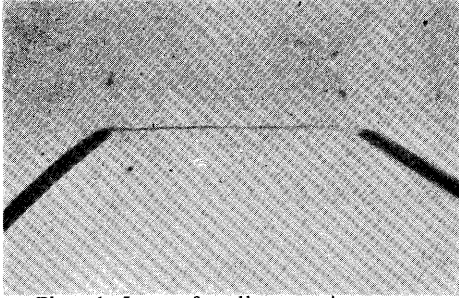


Plate 1. Loop of wollaston wire.

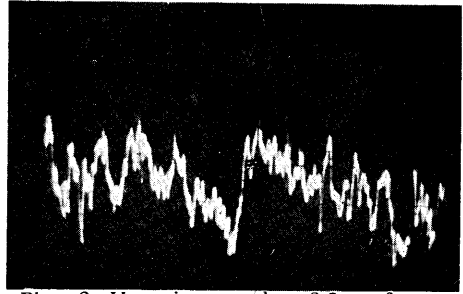


Plate 2. Hot wire record at 2.5mm from the wall.

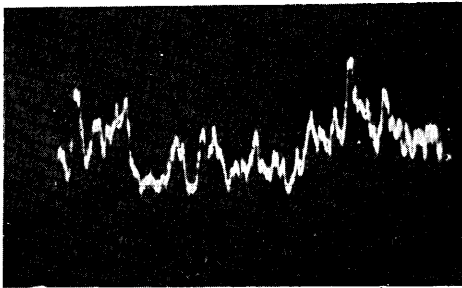


Plate 3. Hot wire record at 5.5mm from the wall.

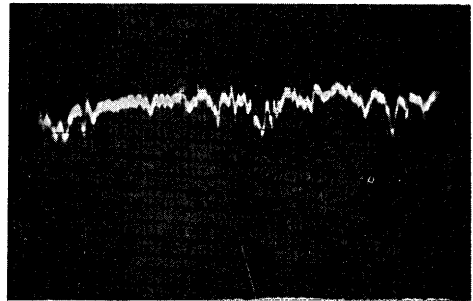


Plate 4. Hot wire record at 10mm from the wall.

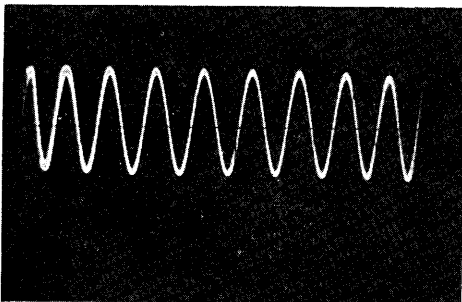


Plate 5. Sine wave for calibration of Plates 6, 7, 8, 9.
100 cps RMS 0.25 volt.

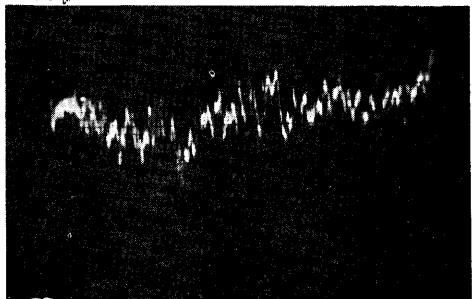


Plate 6. Hot wire record at 20mm from the wall.

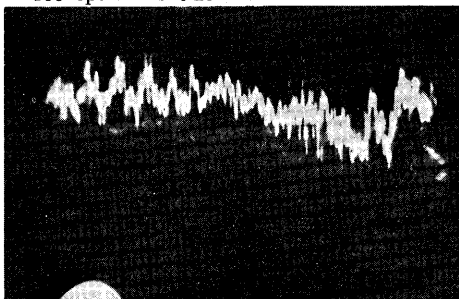


Plate 7. Hot wire record at 30mm from the wall.

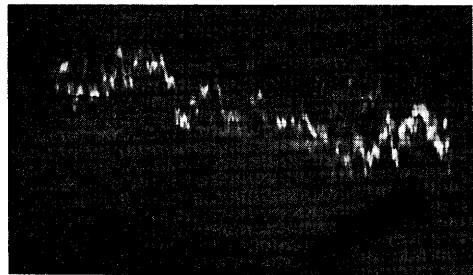


Plate 8. Hot wire record at 60mm from the wall.

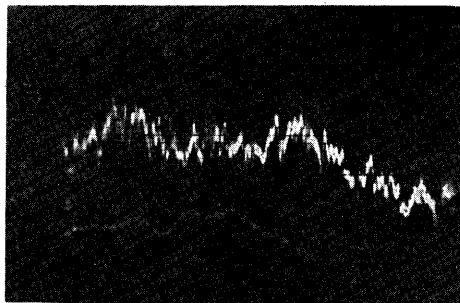


Plate 9. Hot wire record at 100mm from the wall.

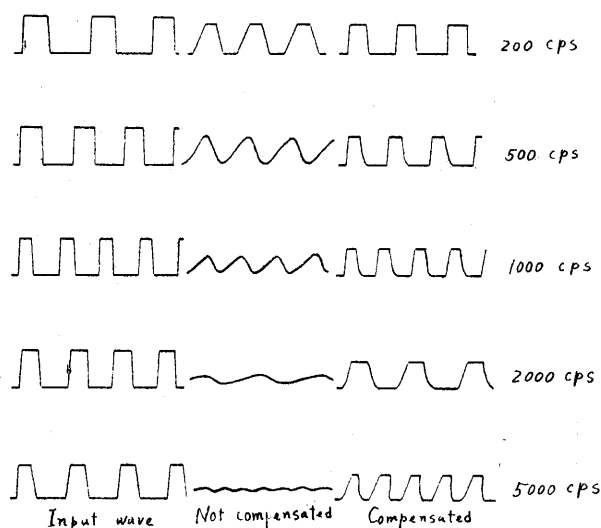


Fig 6 (b) Effects of compensation.

circuit of 6SJ7 — 6SJ7 — 6SH7 is about 67 db and decreases to 55 db in the fourth stage 6F6 which functions as the cathode follower.

Time constant was measured by feeding the square wave and adjusting the capacitance to indicate proper square on cathode ray oscilloscope. The effects of compensation at various frequencies are shown in Fig. 6(b). Response of compensation to very high frequency over 5,000 cycles per second was not sufficient.

EXPERIMENTAL RESULTS

The fluctuation velocity along the mean flow at several stations in the cascade tunnel, which has the height of 50cm and the width of 28cm were recorded by cathode ray oscilloscope. Plate 2, Plate 3, Plate 4, show the fluctuations inside the wall boundary layer which has the thickness of about 20mm, and we can recognize that fluctuations are becoming greater at stations nearer to the wall. Plate 5 shows the calibration curve of 1000 c.p.s. sine wave and of 0.25 volt R.M. S. for Plate 6. Plate 7. Plate 8. Plate 9 which show the fluctuations outside the boundary layer. Notice that the amplification of the oscilloscope for fluctuations outside the boundary layer is 5.7 times as large as that inside the boundary layer, but the amplification for time marks is equal for both. The mean flow velocity was 51 m/s and the hot wire heating current was 60 milliamperes. The time

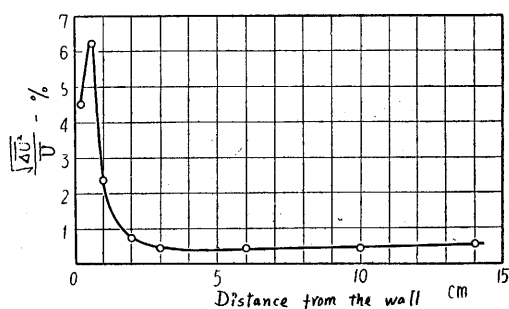


Fig. 7. Turbulence level in the wind tunnel.

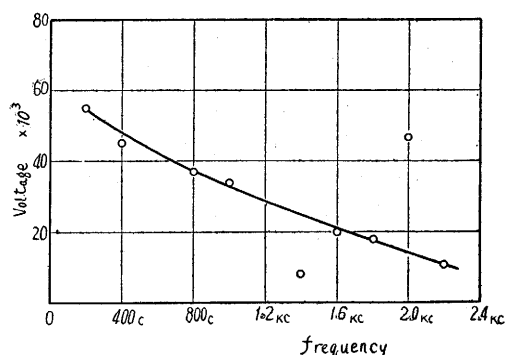


Fig. 8. Fluctuation voltage spectrum.

constant at the working condition was 0.36 milliseconds and the computed wire temperature based on specific resistivity was 115°C. Large amplitude waves of very low frequency can be seen in g.m.e records, but some of them may come from the occasional vibration of the hot wire supporting tube.

Root mean squares of fluctuation velocities are obtained from these records and are plotted against the distances from the side wall and are shown in Fig. 7.

A vacuum thermocouple is best fitted for measuring the root mean square of velocity fluctuation, but we did not employ it because of the difficulty of using it.

The energy spectrum of the velocity fluctuations was obtained by analysing the fluctuation records into Fourier series by numerical method without using a tape recorder and a band-pass filter. The result is shown in Fig. 8. Perhaps the accuracy of the obtained result is not secured, but the shape of the curve seems to be reasonable.

CONCLUSION

The frequency characteristics of our compensated amplifier was not so superior and the hot wire support was not sufficiently rigid, therefore the accuracy of the obtained results may not be well secured. But, as previously mentioned, we could confirm the fact that the level of the velocity fluctuation in our wind tunnel was preferably small outside the wall boundary layer and considerably large inside. Furthermore, from the energy spectrum curve, we can notice the fact that the fluctuation energy gradually increases with the decrease of fluctuation frequency. For further accuracy, we think it necessary to use a vacuum thermocouple, a tape recorder and a band-pass filter. It is also necessary to make the hot wire supporting tube sufficiently rigid.

ACKNOWLEDGEMENTS

We express our sincere thanks to Assist. Prof. I. Kimura of Tokyo University, Prof. Tomizuka, Mr. Ishida, Mr. Nakazawa of Yamanashi University and Prof. Y. Yamada of Defence Academy for their kind advises and for lending us many precious equipments.

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- 3) I. Kimura; On the turbulent diffusion flame;