Journal of Hydroscience and Hydraulic Engineering
Vol. 5, No. 1, July, 1987, pp.49-55.

DEVELOPMENT OF LASER DOPPLER ANEMOMETRY(LDA) FOR RIVER FLOW MEASUREMENT

BY

S. Yoshida

Department of Engineering Science, Hokkaido University, Sapporo, 060, Japan

and

S. Yagi

Hokkaido Office, Japan Weather Association, Sapporo, 060, Japan

SYNOPSIS

The underwater LDA probe and the portable signal processor for river flow measurement were developed. The development has been accomplished by adopting a diode laser and an active band-path filter in which the central frequency of a specific band is automatically set through the control of the input voltage. The use of the new LDA system for river flow measurement provides new information on high frequency velocity fluctuations and accelerated flows induced by high frequency water waves with large amplitudes.

INTRODUCTION

The mechanical current meter having moving blades has been used as the principal instrument for measuring river flows. It is easy to operate and handy for measuring the mean velocity of weak turbulent flows. However, for the statistical analysis of acquired data, it is necessary to calibrate the data at the high frequency domain.

Attempts are being made to develop new equipment that doesn't involve complicated procedures. Two current meters were developed through these attempts; one being based on an electromagnetic principle and the other on an acoustic principle. It is certain that the measurements of high frequency velocity fluctuation can be made through the use of these new current meters. Nevertheless, these methods have the following problems, namely, it is difficult to remove the effect of wake flow on the level of output signals in the electromagnetic method and it is not easy to maintain an initially calibrated relationship between velocity and output signal in the acoustic method. In addition, their measuring volumes essentially are not reduced in comparison with that of the current meter with blades. Therefore, river flow measurement undertaken with the aim of obtaining high space resolution is still impossible by using either one of the above current meters.

There are many advantages of using a LDA (1) that resolve all the above problems. However, for the application of LDA to underwater measurement, how to constract the optical system not interfering with the flow and how to facilitate the operation of a signal processing procedure have become serious problems. We have overcome these problems by using a diode laser and an active band-path filter. The new LDA system appears to surpass the latest optical fiber method(2,3,4) as proven in operation during field work.

DESCRIPTION OF THE LDA SYSTEM

The Structure of LDA Probe and the Frequency-Velocity Relationship

The LDA system is composed of a miniature LDA probe and a signal processing system. Fig.1 shows the physical arrangement of the probe consisting of an optical transmitter and receiver sealed completely in a protective brass tube with an outside diameter of 13.0 mm. Resistance against physical shock was the main factor that decided the diameter of the tube. From the transmitter, two beams, made by splitting the initial beam, are emitted after passing through a lens sothat they are focused at the center of the space between the transmitter and the receiver. Because of the instrument configuration, the flow velocity in the measuring volume rises about 1 %. As the intersecting angle between the reference beam and scattering beam is 4.43° and the wave length of the diode laser is 780 nm, the flow velocity component perpendicular to the optical axis and in the surface including the two beams is given by the following relationship:

$$U=\lambda_0 f/(2n\ \sin\theta)=0.00101f/n\ (\text{ cm/sec })$$

Here, f is the beat frequency, n the index of refraction, θ one half of the intersecting angle, and λ_0 the wave length of the diode laser in a vacuum.

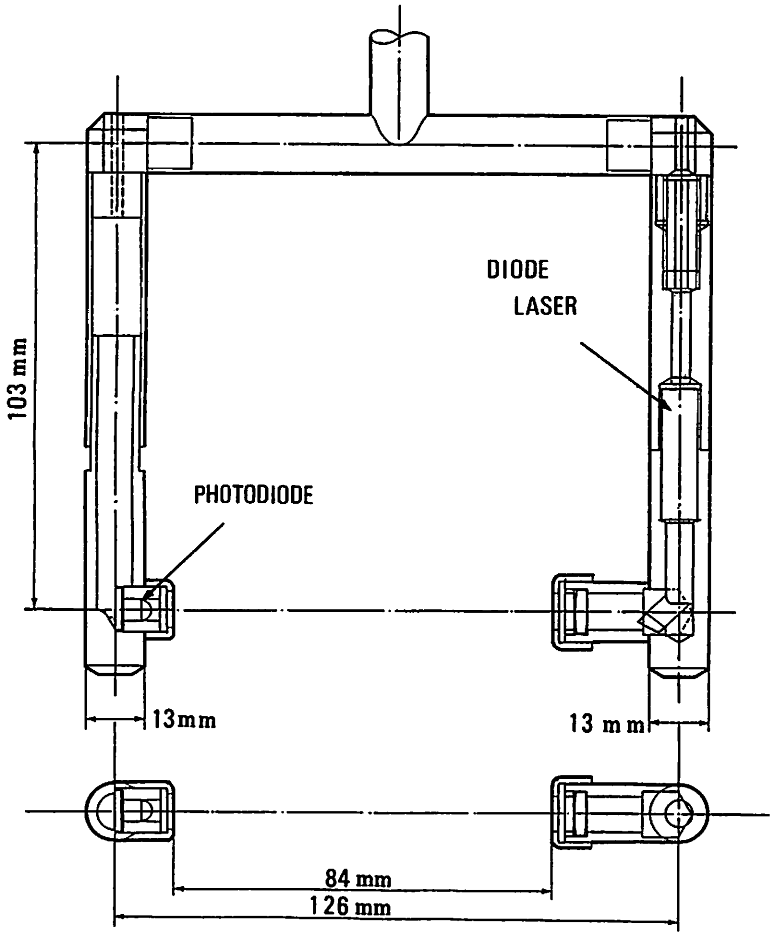

Fig.1 LDA probe consisting of an optical transmitter and receiver

The Signal Processing System and its Features

There are two real-time signal processing systems working in the time and the frequency domains. The band path filters of these systems are necessary for avoiding pedestal signals. However, skill in distinguishing the beat signals from the pedestal signals is required. This operational difficulty appears to be the reason that the LDA method is not widely used. In addition, the specific band of the filter is too narrow for measuring river flows with widely varying velocities. For example, the flow velocity induced by surface wave propagation could vary over one order of magnitude in CGS units and the minimum or maximum beat frequency would then deviate from the attenuated frequency band.

For the signal processing system described here, the above problem has been solved through the use of a 10 dB active band-path filter controlled by the input voltage. Fig. 2 shows the signal processing system using this filter. The system is essentially based on a frequency counting method and has a circuit which evaluates whether the signal envelope passes through two specific threshold levels or not. Since the noise level does not exceed the lower one and the pedestal signal level exceeds the higher one, only the Doppler beat signals pass through the circuit. The beat frequency processed by these circuits is converted into a voltage and is registered as a velocity in CGS units. It is easy to add this active filter circuit to the normally available counter type or the trucker type processors. Fig. 3 shows an example of this circuit with an analogue control active band-path filter.

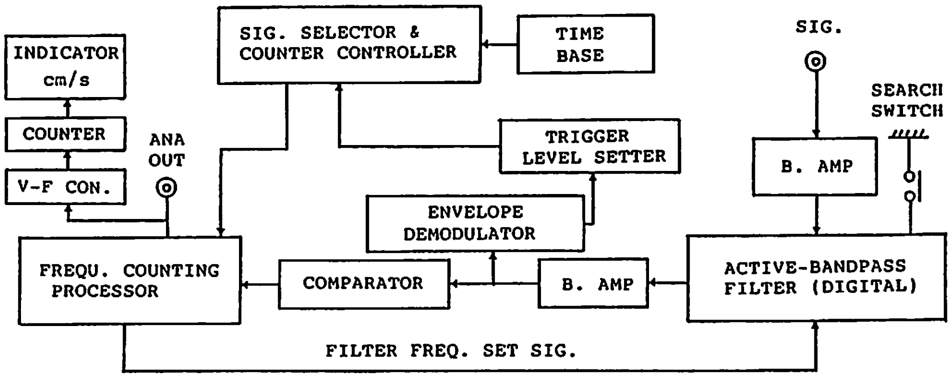

Fig.2 The signal processing system

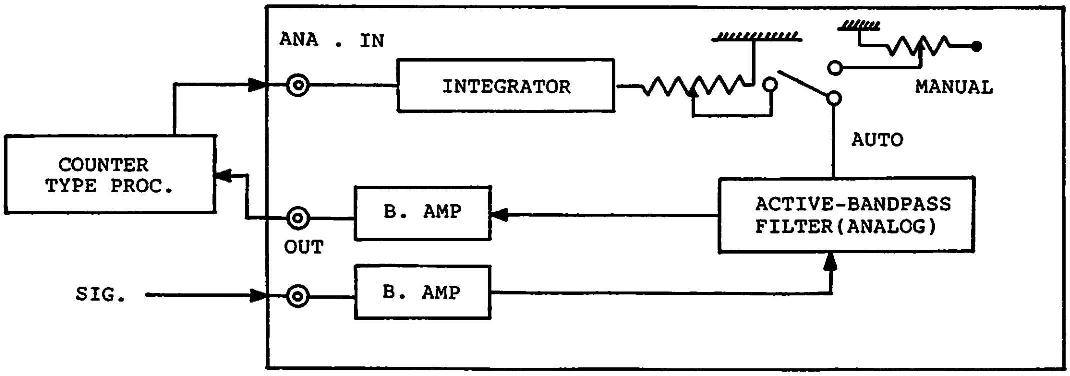

Fig.3 The analogue-control active band-path filter

CHARACTERISTICS OF THE OUTPUT SIGNALS

Firstly, the results of the performance tests on a counter type processor connected with the circuit shown in Fig. 3, system A, are described. Fig. 4 compares the output signals from system A and a hot-film anemometer for water flow containing oscillating flow induced by surface waves. Since the signals are obtained at two measuring points separated by a distance of 1.0 cm in the flow, it cannot be

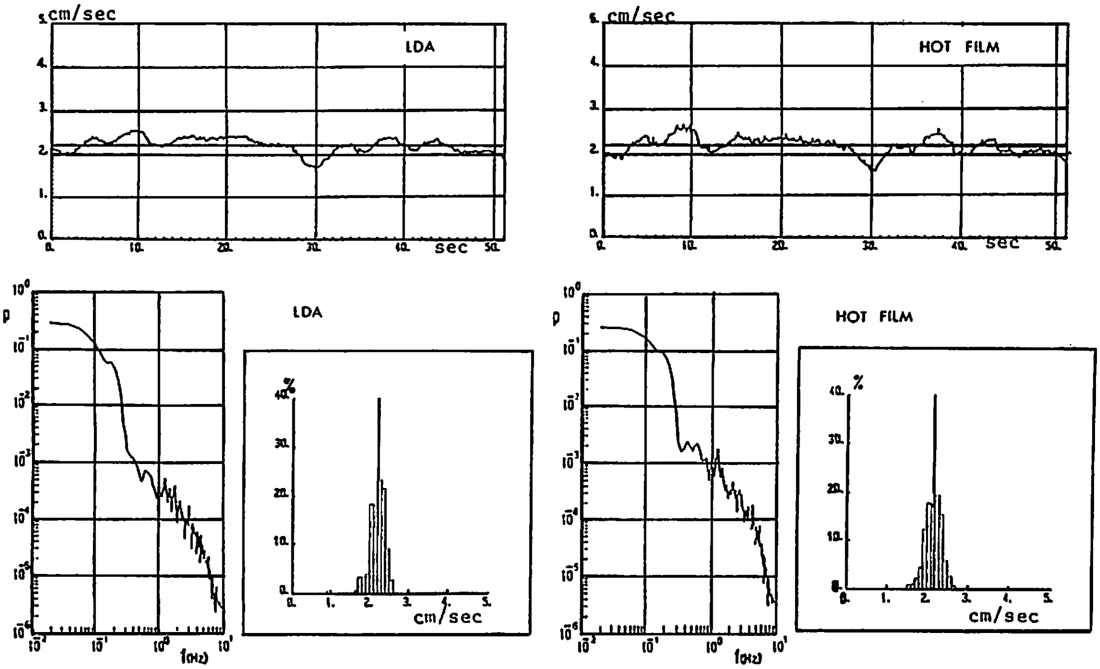

Fig.4(a) Time series of the channel flow velocity obtained through the system A and a hot-film anemometer; (b) Power spectrums; (c) Probability distributions

expected that the two signals will agree precisely. However, it is evident that each method produces similar output signals for normal water flow measurement. In the same test condition, exchanging system A for the system shown in Fig.2, system B, does not show any characteristic discrepancy between the two output signals.

Fig.5 shows simultaneous oscillograms from system B and a common blade type current meter. The output signals were obtained at two measuring points separated by a distance of 40 cm in a river flow. It is clear that there is a great difference between the two output signals and the Kolmogorov spectrum law does not emerge in the power spectrums obtained by the current meter. The result is due to the lack of response for high frequency components of flow. On the other hand, power spectrums from LDA show that the Kolmogorov law is quite apparent in the frequency band over about 0.2 Hz.

APPLICATION OF THE LDA SYSTEM TO RIVER FLOW MEASUREMENT

System B with the LDA probe described in Fig. 1 was used to measure a tidal river flow. The combined system is shown in Photo.1. Fig.6 shows oscillograms of the flow velocities obtained in the Teshio river. The measurement was carried out at a station constructed on the river bed 0.5 km upstream from the mouth. At the test point, the sea water, of 1.9 m in depth, intruded under the river water, of 2.2m in depth. Therefore, the bottom oscillograms in Fig. 6 shows the velocity just above the interface. The power spectra corresponding to the oscillograms are shown in Fig.7. There are three spectral peaks indicated by F1, F2 and F3 in addition to the spectral domain which follows the Kolmogorov spectrum law. F1 at 0.15 Hz and F2 at 0.33 Hz correspond to the interfacial waves and the surface waves, respectively. These were confirmed after comparing the peak frequencies with those of the hydrographs of the surface and the interface. The peak value F3 decreases a little with increasing of distance from the surface, but it does not suggest the existence of any regular velocity fluctuation. In fact, this spectrum appears to be due to Karman vortex shedding from the pole connected with the probe. This fact also suggests that firm support of the probe is required for deep flow measurement.

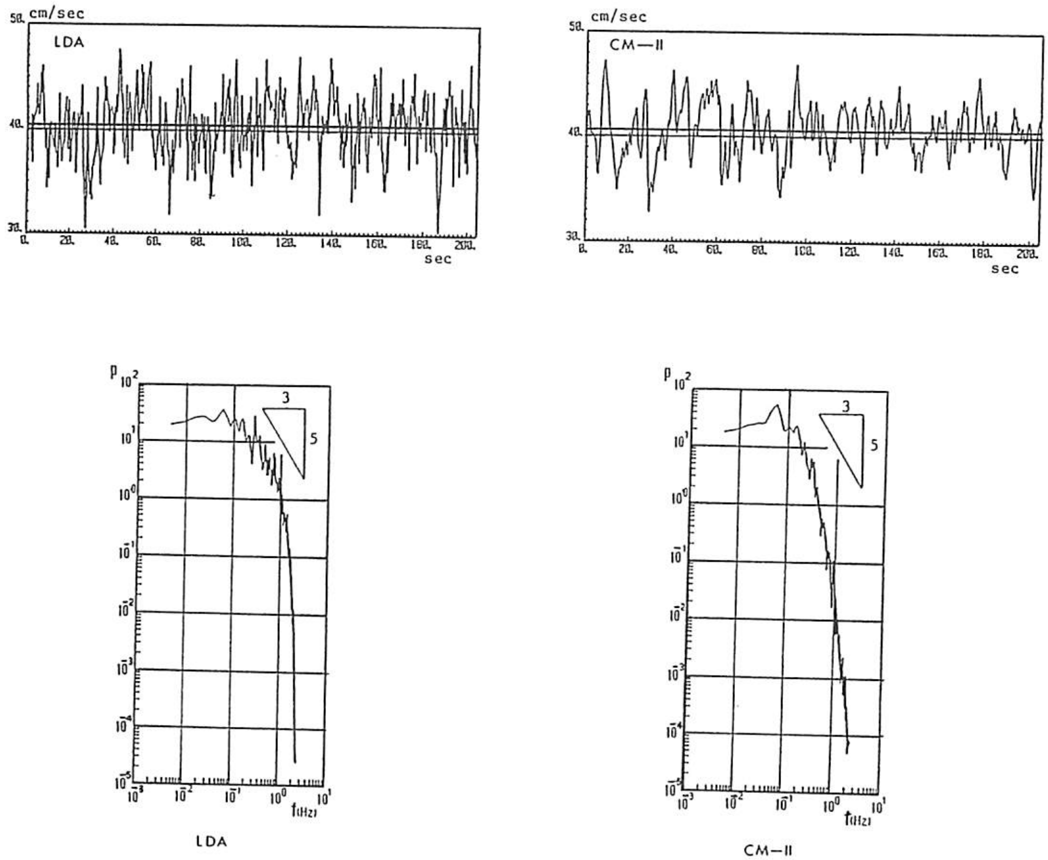

Fig.5(a) Time series of the river flow velocity obtained through the system B and a current meter having blades; (b) Power spectrums

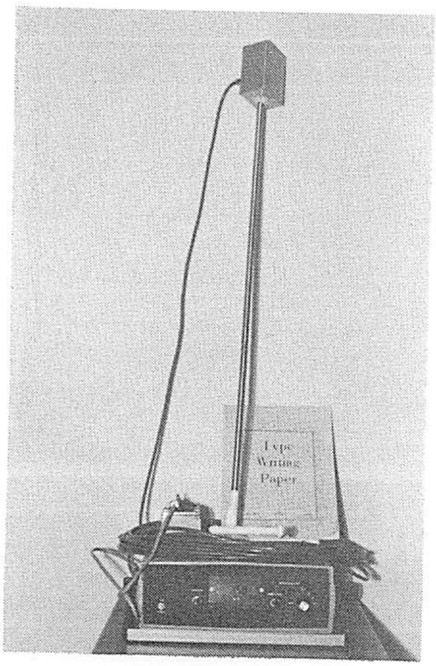

Photo.1 The LDA probe and the system B

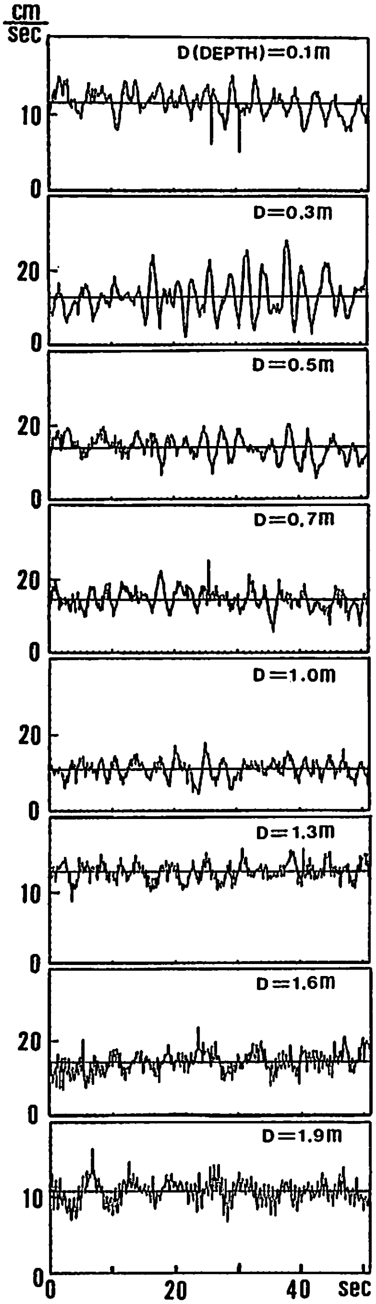

Fig.6 Oscillograms of the flow velocity obtained at the Teshio river

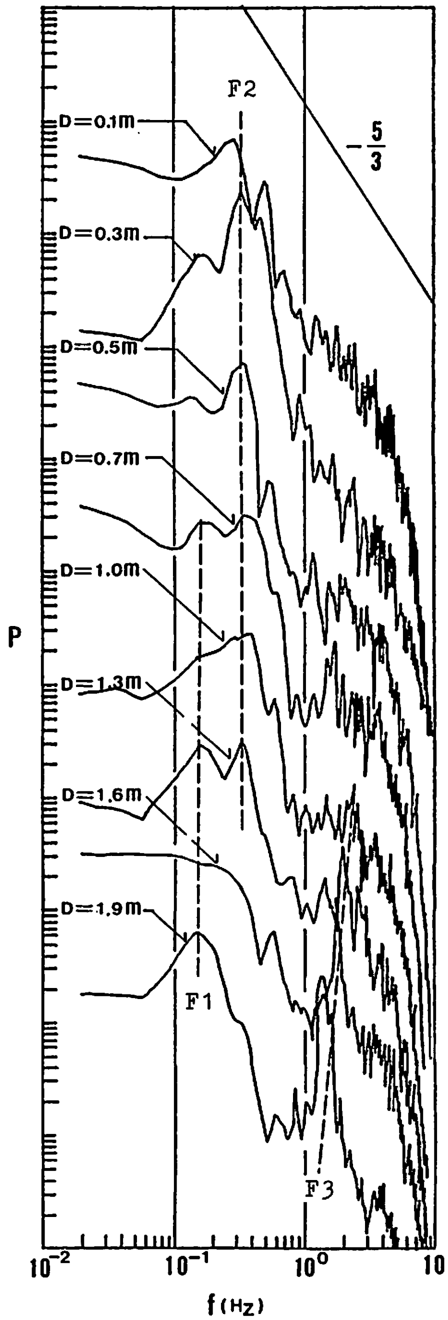

Fig.7 The power spectrums corresponding to the oscillograms shown in Fig. 8 and three spectral peaks

Fig.8 shows the oscillogram of the river flow velocities induced by ship waves which had about a 1.85 sec period and about a 30 cm wave height. The response to the induced flow velocity depends on the tracking speed of the active filter. Using this system, we can measure a velocity change from 0.50 cm/sec to 100.0 cm/sec occuring within 0.21 sec.

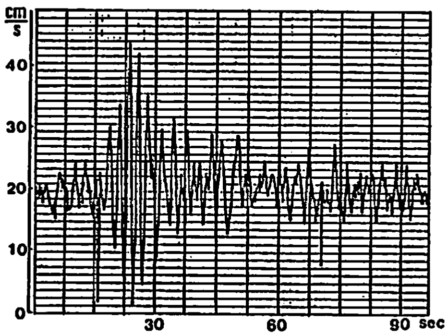

Fig.8 The oscillogram of the river flow velocities containing oscillating flow induced by ship waves

CONCLUSIONS

The LDA system developed through diode laser and an active band-path filter has the following characteristic features, even though it has no signal processing unit to confirm flow direction.

1) The system is very portable and can be operated easily for obtaining river flow measurements.
2) The flow velocity in the measuring volume rises about 1 %, due to the instrument.
3) The system can measure an extremely variable velocity as induced by high frequency waves with large amplitudes.

REFERENCES

1. Durst, F., A. Melling, and J.H. Whitelaw: Principles and Practice of Laser-Doppler Anemometry, Academic Press, London, 1976.
2. Yoshida, S. and M. Tsukada: Improvements in optical velocity measurements for water flow, Proceedings of the 26th Japanese Conference on Hydraulics, pp.489-494, 1982.
3. Hino, M., M. Sawamoto, T. Yamashita, and T. Muramoto: Improvementof a laser-Doppler anemometer by optical fiber, Proceedings of the 27th Japanese Conference on Hydraulics, pp. 561-566, 1983.
4. Knuhtsen, J., E. Olldag, and P. Buchhave: Fiber optic laser Doppler anemometer with Bragg frequency shift utilizing polarization-preserving single-mode fiber, J. Phys. E.: Sci. Instrum, 15, pp. 1188-1192, 1982.