Measurement of blood velocity using Laser Doppler method for the designing module

Guo-Liang Chen [a], Jen-Ai Lee [b], Tung-Wu Lu [c], Zhao-Cheng Chen [a], Chien-Ming Chen[* a]
[a] Department of Electro-Optical Engineering, National Taipei University of Technology, No.1, Sec. 3, Chung-Hsiao E. Rd. Taipei 106, Taiwan
[b] Department of Pharmaceutical Analysis, School of Pharmacy, Taipei Medical University,
[c] Institute of Biomedical Engineering, National Taiwan University

ABSTRACT

We built the Dual Beam Mode of the LDA (Laser Doppler Anemometry) frame, set the photodetector at the same side with light source which collect the scattering light of blood cell. It's proper to reduce LDA optical path and convenient for our designing module. The concentration of chicken blood in this study is about 1% and we measured the relations actually between flood velocity and the angle of beams cross on particles, temperature, and the diameter of aqueduct. We found better results while the cross angle was less than 38.8 degree, diameter of aqueduct was 6 mm, and temperature of blood was set to 36 $^{\circ}C$. These parameters can also provide important basis for the LDA module kit that we are designing.

Keywords: Laser Doppler Anemometry, blood cell velocity, module

1. INTRODUCTION

Laser Doppler technology was widely used to measure velocity of fluid flow.[1] It was first demonstrated in 1964.[2] The main characteristic of laser Doppler technology was utilizing scattering light of particles in the fluid, which is related to the velocity of particles. Because using laser Doppler method has some advantages such as noninvasive, accurate and instantaneous, it is suitable for measuring blood cell velocity. In these years, designer trend to make it into miniature and portable module.[2, 3] In their studies, they chose Two Scattered Beam Mode optical system. There were two mainly shortcomings, the signals of photodetector were weaker and the Doppler shift frequency was constrained to the detected direction. Here we used optical system of Dual Beam Mode.[4] The scattered light can be collected in most direction by a light detector, to improve the constrained condition. By the way, they didn't measure the velocity of blood, but to measure the velocity of silica particles in fluid. In this study, we chose chicken red cell as sample with 1% concentration.

In this paper, in order to miniaturize LDA module, we did experiments on optical table to decide the conditions of optical system.

2. EXPERIMENTAL SETUP

2.1 Optical System

The main structure of LDA was described in Fig.1. We use a 1mW 632.8nm Helium Neon laser as light source and split the laser beam into two beams with identical intensity and coherence. The two laser beams crossed and were focused on blood flow in the glass aqueduct. It produced interference pattern on intersection point, and the spacing between two fringes δ depends on the wavelength of the light λ and cross angle ϕ.

$$\delta = \frac{\lambda}{2 \sin \frac{\phi}{2}} \tag{1}$$

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While uniform red cell passes through the intersection point with velocity *v*, it will scatter light. The scattered light was collected through an aperture to a photodetector. The light was so-called Doppler shift frequency, and the formula can be shown as, [5]

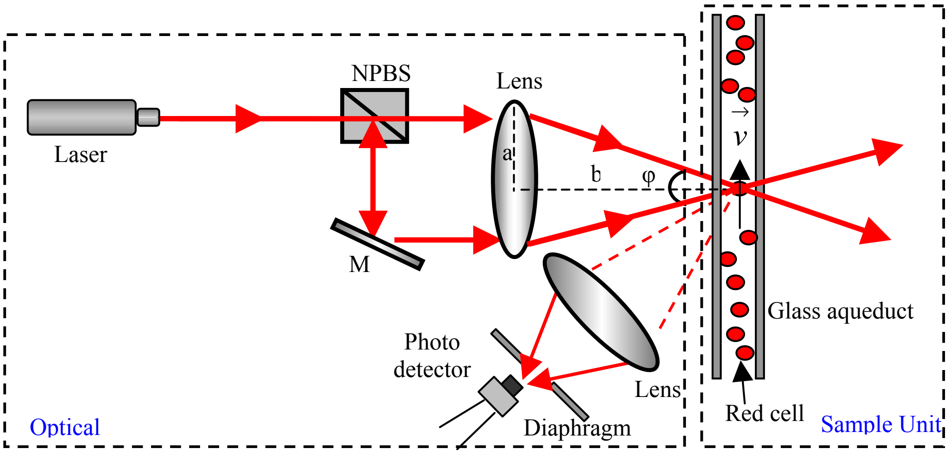


Fig. 1. Description of the LDA system

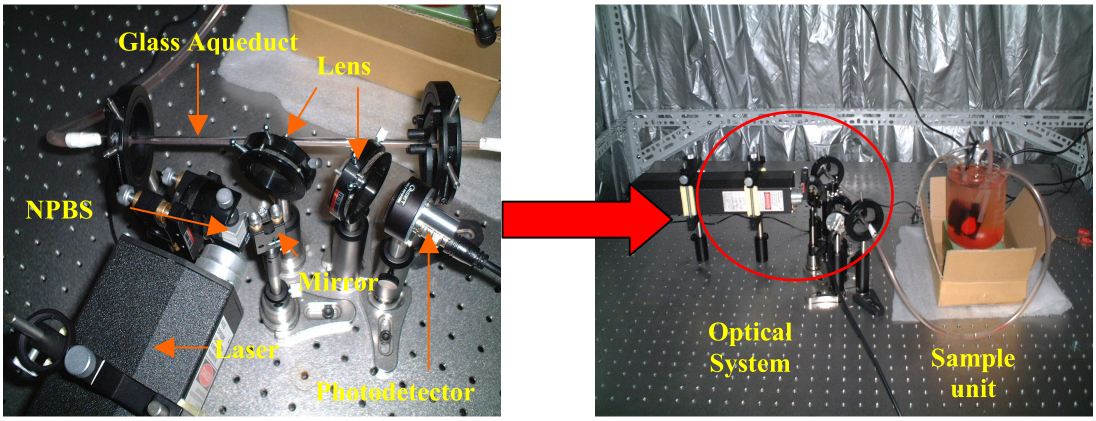


Fig. 2. Pictures of Experimental setup included optical system

$$f = \frac{v}{\delta} = \frac{2\,v\,\sin\left(\frac{\phi}{2}\right)}{\lambda} \qquad (2)$$

By equation (2), if we measured the frequency of scattered light *f* and cross angle ϕ, and substitute the wavelength of light λ, then the velocity *v* of red cell in the blood can be calculated.

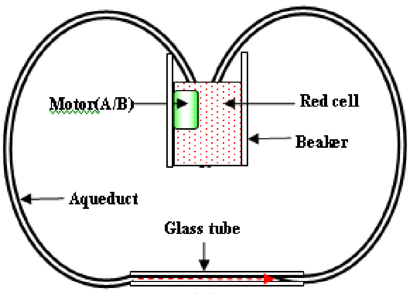
For example, we set the angle ϕ, which can be obtained by the dimension a and b in Fig. 1 is equal to =38.8 degree. After proper signal processing from photodetector, we can get the Doppler frequency 1.34 MHz. Due to the wavelength of He-Ne laser is 632.8nm, the velocity can be calculated as 1.274×10^3 mm/s. The pictures of our experimental setup with optical system were shown in Fig. 2.

2.2 Sample unit

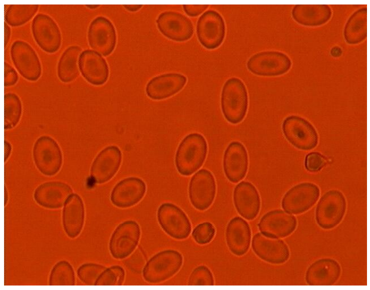
The sample unit was constructed as Fig. 3(a). We added anticoagulant and antiseptic into fresh chicken blood and diluted it to 1% by physiological saline. The microscopic picture of diluted blood was shown as Fig. 3(b). It showed the uniform size of red cell distributed separately in the diluted blood. We put the diluted blood into a beaker with a motor on the wall. The motor pump diluted blood into aqueduct, which is connected to glass aqueduct, and back to the beaker to form a circulation system.

2.3 Electronic unit

The electronic unit was shown as Fig.4. Output signal from the photodetector was amplified by a differential amplifier circuit and then filtered by a bandpass filter. The amplification factor was 10000 and bandwidth was limited from 60 Hz to 5MHz. An analog to digital converter (ADC) was set on an interface card in a personal computer. The ADC samples the signal with 12 bit resolution and the sample rate is 400 kHz.



(a)



(b)

Fig. 3. (a)Sample unit (b)Picture of Chicken blood with concentration was 1% at 36 $^\circ C$ by 40X microscopy

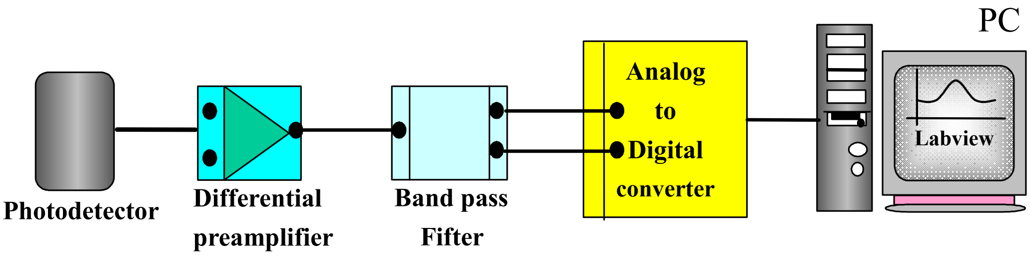


Fig. 4. Block diagram of the signal processing

We programmed Labview software to display the graph of frequency spectrum and waveform in time domain. Our program can find the Doppler shift frequency and calculate the velocity of diluted blood. We used excel to analyze these data in statistics.

3. Experimental method

We used two motors with different pumping capacity in all experiments. In order to realize the flow in sample unit corresponding to the motors, we measured total volume of diluted blood in the circulation in one minute. After calculation, we got the flow volumes by motor A and B are 36.003 ml/s and 54.994 ml/s separately when 6 mm diameter aqueduct was used. These two values are equivalent to flow velocity 1.274×10^3 mm/s and 1.946×10^3 mm/s. If 7 mm diameter aqueduct is used, the flow volumes by motor A and B are 38.998 ml/s and 57.989 ml/s and are equivalent to 1.415×10^3 mm/s and 2.052×10^3 mm/s.

In our experiments, we evaluate the relationship between blood cell velocity and beams cross angle φ, diameter of aqueduct D, temperature variation T. First, we varied cross angle φ at 38.80°, 44.76°, 50.40°, 55.79°, and 60.93° at 36 $^\circ C$ to get velocity of blood flow by optical method, compared with flow velocity mentioned above. Next, we change the temperature of diluted blood from 29 $^\circ C$ to 36 $^\circ C$ when φ is 38.80°.

4. Results and Discussion

Fig. 5(a) was the graph of waveform in time domain from programmed software. It was measured at 6mm diameter aqueduct, 30 °C , and φ is equal to 38.8° for motor A. After Fast Fourier Transform (FFT), the signal was converted to frequency data (Fig .5(b)). The Doppler shift frequency at 1.19 MHz can be clearly seen and have narrow band in the highest peak. The value was used to calculate the blood cell velocity by formula (2).

The experimental results obtained by the motor A was shown as Fig. 6(a) (b). Relative error calculated from absolute error means the accuracy of flow velocity by laser Doppler method. In Fig. 6(a), as cross angle was 38.8°, we got lower relative error. In spite of aqueduct a or b, the relative error will also increase as cross angle increasing. In all conditions, relative error of a is lower than b. In Fig. 6(b), while the temperature is higher than 31 °C , the relative error didn't show obvious difference. Even we increase the temperature, the accuracy of blood cell velocity varied little. The difference between aqueduct a and b was not very obvious.

Results obtained by motor B were shown as Fig.7 (a) (b). We also got lower relative error at cross angle 38.8°. Relative error increases as cross angle increases. The relative error curve in Fig. 7(b) is similar to Fig. 6(b) when temperature was over 31 °C , the relative error will not be influenced seriously.

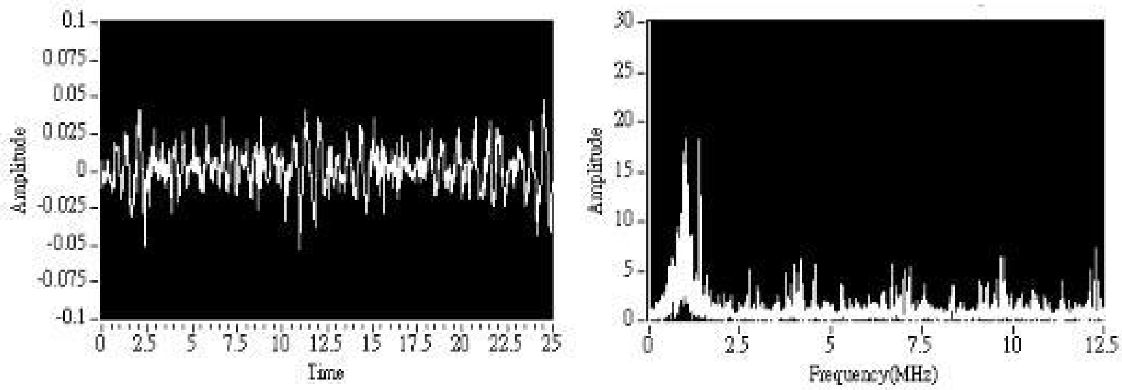


Fig. 5. (a)Doppler shift signal (b)power spectrum

(a) (b)

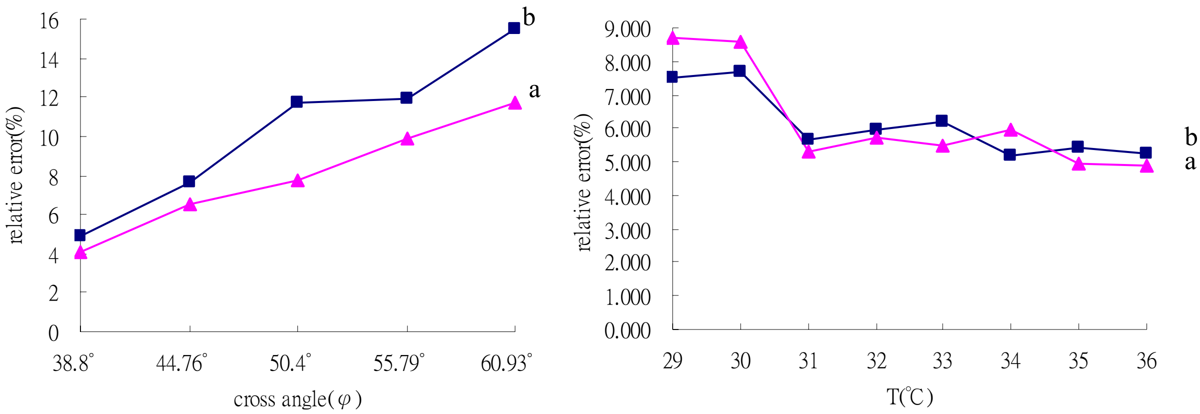


Fig. 6. Relative error of motor A versus: (a) cross angle and (b) temperature. a: D=6mm; b: D=7mm.

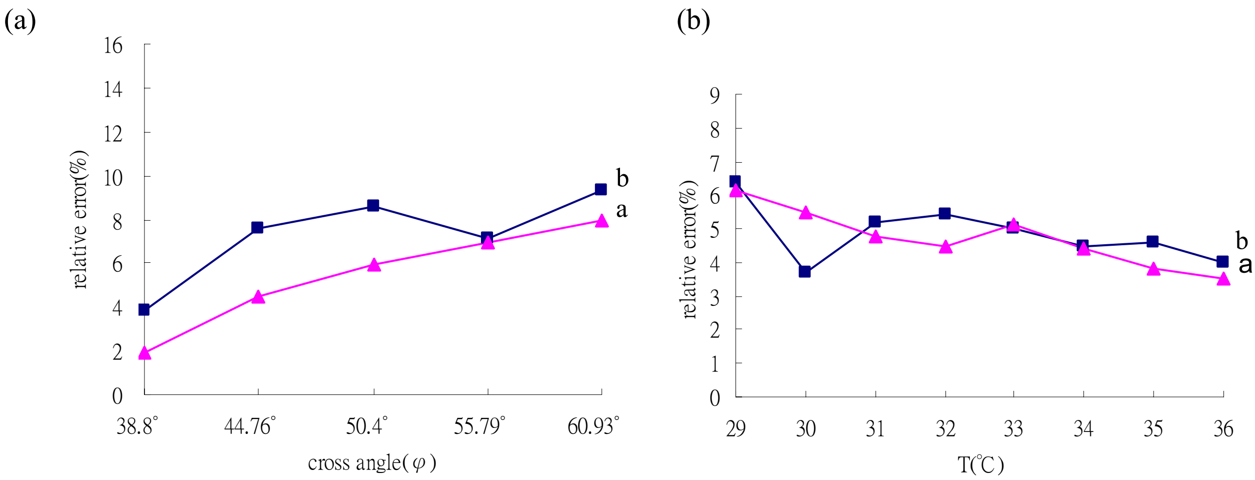


Fig. 7. Relative error of motor B versus: (a) cross angle and (b) temperature. a: D=6mm; b: D=7mm.

From the results of motor A and B, we design the cross angle of our module to be 38.8°. Thus our module is suitable for measuring in the condition that the diameter of aqueduct D is smaller than 6 mm at body temperature.

5. CONCLUSION

In this paper, we successfully built a Dual Beam Mode LDA system to do experiments on measuring blood velocity. The sample in our experiments is chicken blood whose red cell is uniform and distributed separately after diluting it to concentration about 1%. It is applicable in laser Doppler method. Under our constraint of working space, reducing cross angle to 38.8° is helpful to lessen the relative error. And from 31 $°C$ to body temperature, the difference is not evident. Although in our system we have no idea how small D can be, we get lower error when D is 6 mm or a little less than 6 mm. According to these results, we determined the cross angle to be 38.8° in our module. Because 780nm is better than 632nm to pass through skin and have lower absorption to human blood red cell. Therefore we shall replace the He-Ne laser by a laser diode with 780nm wavelength in our designing module. We propose relative error of blood cell velocity will be less than 5% in our designing module. We also expect to solve the average velocity of blood flow by the method of statistics when concentration of blood red cell reaches 100% that is the red cell moving in group.

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