LASER DOPPLER VELOCITY MEASUREMENT SYSTEM

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ABSTRACT: *Laser Doppler Velocimetry technique (LDV) isa measuring technique which has been developed since early 1980s. LDV has many advantages such as non-invasive measurement of one or all three components of velocity vector, measured dimensional vector of velocity, high accuracy, high resolution, wide measurement range ... Commercial Equipment based on LDV principle was applied to measure flow in industrial applications, in biomedical applications, etc. ... However, most of them are the specialized equipment which have high cost. In terms of technical training and education, LDV experiment is one of the basic experiments of application in high-tech optical measuring techniques, showing the skills of application of the principle of optical measurement applications in practical conditions. A model LDV system was designed and complete development within the lab for training purposes.*

Keywords: *Laser Doppler Velocimetry.*

1. INTRODUTION

In many aspects of engineering, physics, medicine and life, there are needs for components that can measure velocity without violating or changing the original flow of the objects. LDV technique is a useful technique that allows us to do it. LDV technique is a technique with high accuracy and resolution capabilities thanks to the increasing development of manufacturing techniques and equipment acquisition and signal processing techniques. However, most of them are the specialized equipments and high cost.

In this research we tried to use the available equipment such as He-Ne laser, optical components and systems in the **National Key Lab. of Digital Control & System Engineering** to set up a simple system can be applied to measurements above.

2. PRINCIPLE OF LDV

Laser Doppler velocimetry (LDV), also known as laser Doppler anemometry (LDA) is a technique for measuring the direction and speed of fluids (or any other material that is processed like metal, paper etc) like air and water. Measurements are made at a point (a small, non-intrusive optical probe volume) defined by the intersection of two laser beams. As a particle passes through the probe volume, it scatters light from the beams into a detector. The frequency of the resulting Doppler burst signal is directly proportional to the particle velocity.

The LDV optical system can be the system of two or five beam (one or three different wave length) depend on the application and the requirement in research or industrial purpose.[1][2][3]

The experiment uses the Doppler effect to calculate the velocity of particles in fluids. Light scattered on moving particles experiences a shift in frequencies according to[1][2][3]:

$$f_r = f_L \frac{\left(1 - \frac{\vec{u}.\overline{e_b}}{c}\right)}{\left(1 - \frac{\vec{u}.\overline{e_{pr}}}{c}\right)} = f_L\left(1 - \frac{\vec{u}.\overline{e_b}}{c} + \frac{\vec{u}.\overline{e_b}}{c}\right) \quad (1)$$

Where: f_b, f_r are frequencies of the beam and the light at detector. v_p is the velocity of the particle and e_b is the unit vector in beam direction.e_{pr} is the unit vector pointing from the particle to the receiver. λ_b is the wavelength of the beam [3].

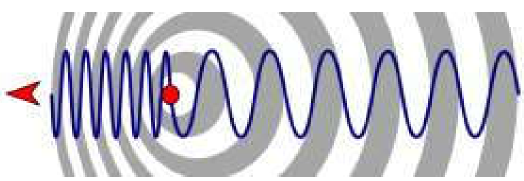

Figure 1. Doppler effect (Figure from: http://mail.colonial.net/~hkaiter/bigbang.htm)

It's easy to recognize that in this case (when v_p<<c) the Doppler shift is too small to directly measure, so we used the principle of optical beating. That mean we have to use two beams, coming in at an cross angle θ between the beams.

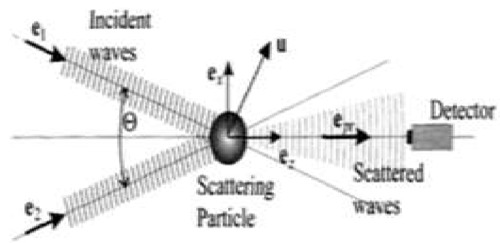

Figure 2. Schema of using two-beams.

The two beams are then heterodyned on the detector to obtain an optical beating frequency in a range which can be measured. Using the formula above and some geometrical arguments we obtain[3][4]:

$$f_2 - f_1 = f_D = \frac{2u_x \sin\left(\frac{\theta}{2}\right)}{\lambda} \quad (2)$$

Actually, when we use this schema (two-beams) and only focus into measuring magnitude of velocity, we can explain by model interfering fringe:

The fringe spacing δ is:

$$\delta = \frac{\lambda}{2\sin\left(\frac{\theta}{2}\right)} \quad (3)$$

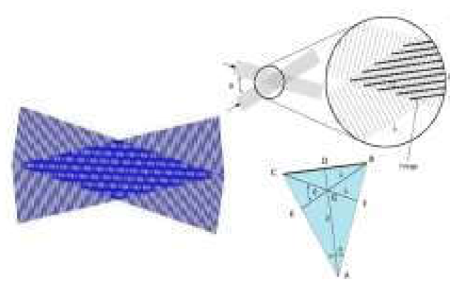

Figure 3. Model interfering fringe

The LDV system collects laser light scattered from particles as they cross the fringes, and signal processing is used to obtain the Doppler heterodyne frequency. Finally, the particle velocity is determined through the relationship $v=f_D*\delta$, where v is the particle velocity, f_D is the Doppler heterodyne frequency measured for each particle, and δ is the spacing between adjacent fringes[4][5].

$$f_D = \frac{2v\sin\left(\frac{\theta}{2}\right)}{\lambda} \quad (4)$$

Signal detected at receiver will be processed using a software written in Matlab with some of digital filters. Due to the ability to reliably predict laser interference patterns, the fringe spacing, δ, is known from system parameters and the particle velocity follows directly from the Doppler frequency.

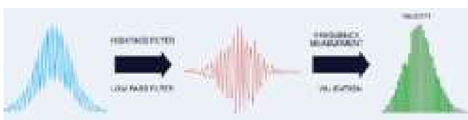

Figure 4. Signal processing.

3. DECRIPTION SYSTEM

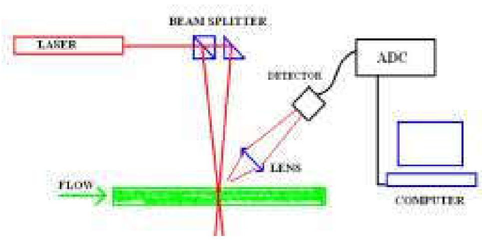

Figure 5. Schema LDV system

In our system we used Laser He-Ne of power of 5mW, wave length 632,8nm, Silicon detector, CASSY SENSOR, optical elements (beam splitter 50/50, prism, lens of focus 20, 40mm). The fluid is water with particles of red color. Laser beam is splitted in two beams by beam splitter and then those two beam are made to intersect at measurement volume (in flow). Angle θ between two beams in our system is $2{,}28^0$ (sin(θ/2)=0,01989), CASSY SENSOR have the maximum sample rate 100kS/s and minimum Voltage Range -0,1V;0,1V. The flow is driven by a height difference of the water level in the container with the test solution and the end of the flow tube. This method also enables us to easily change flow velocities.

Figure 6. Photo of real LDV system

4. RESULTS

Figure.7 is picture of interference fringe at the measuring volume, this photo taken from measuring microscope MYTUTOYO in our Laboratory.

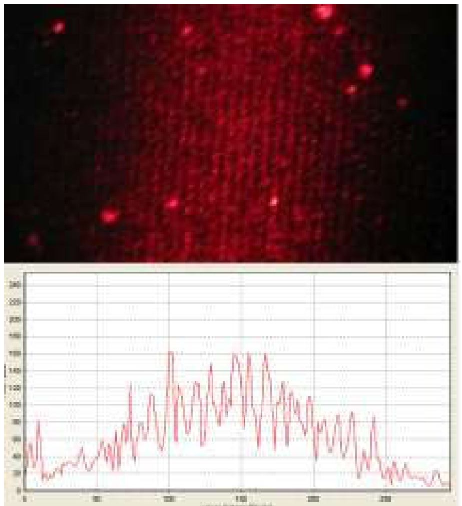

Figure 7. Interference patterns formed

Figure 8a, 8b are screen pictures after signal processing, some of peaks on spectrum is frequency of noise, that still were not deleted. Only one of those peaks is Doppler frequency, and that is the peak in the red circle on picture. Choosing Doppler frequency based on the notice that, Doppler frequency is the peak that not usually been on frequency-spectrum. First, we turn on the system without flow and we can easily define the frequency of noise, new peak when we put flow on the position is the Doppler frequency.

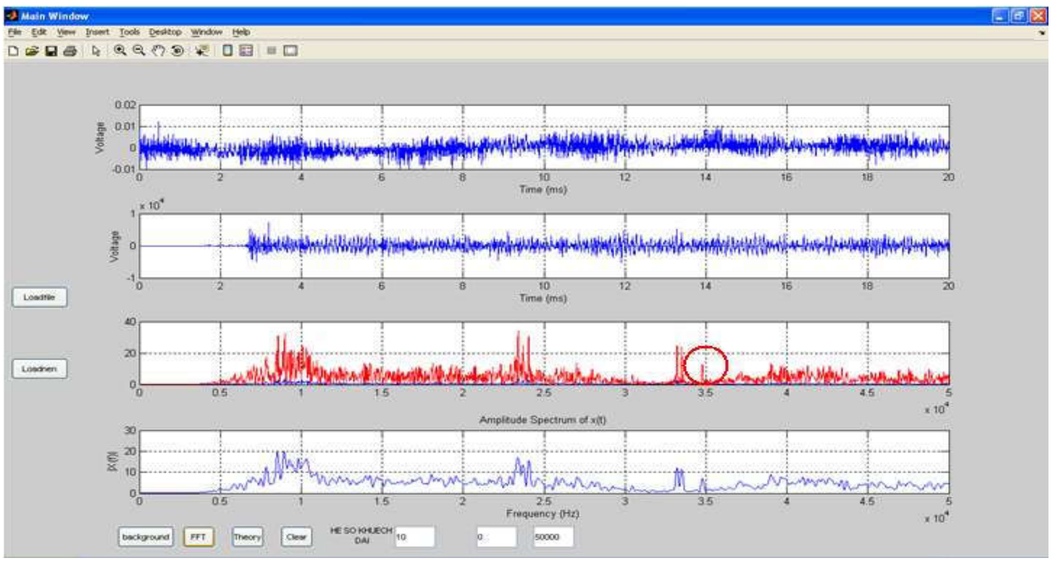

Figure 8a. Screen picture when v= 0,579 m/s.

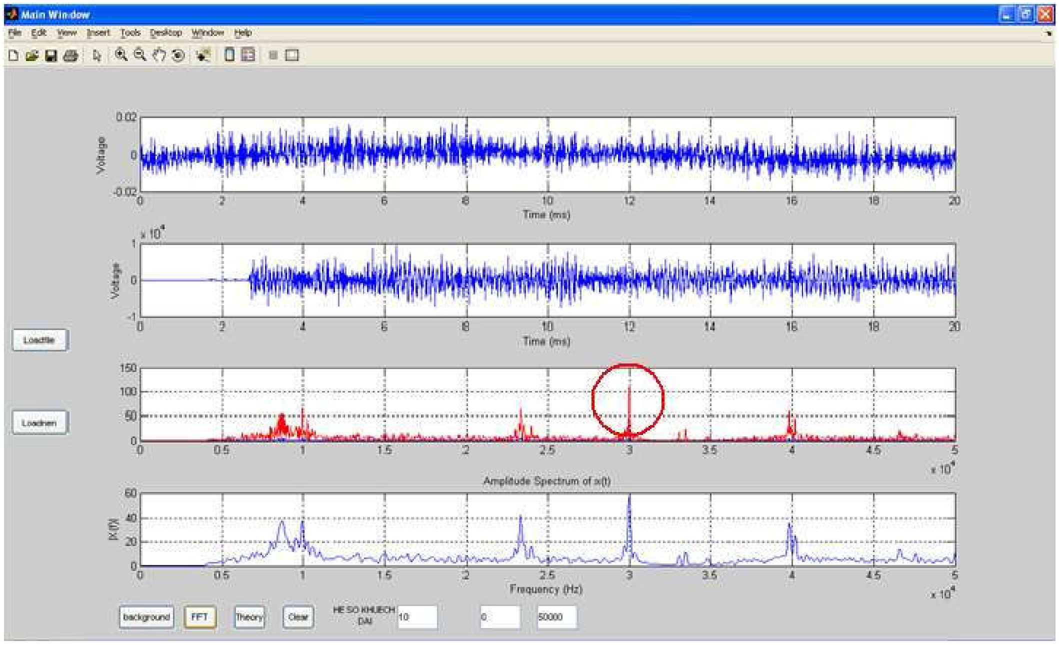

Figure 8b. Screen picture when v= 0,499 m/s.

Table 1. Results measuring.

V (directly mesure) (m/s)	fD (kHz)	V (by LDV) (m/s)
0,589 ±0,021	34,773	0,579±0,015
0,500±0,018	29,995	0,499±0,013
0,415±0,015	24,575	0,409±0,010
0,172±0,006	10,010	0,167±0,004

5. DISCUSSION

The results of the experiment accorded with our expectations. Measuring velocity were approximate to directly measuring velocity with small absolute error. Those results obtained with this basic setup motivate further improvement. Adding a collimator, for example, would enhance the spacial resolution by creating a smaller measurement volume. Using Bragg-Cell can help us define not only magnitude but also direction of velocity, using a more powerful laser would eventually make the signal strong enough to increase the resolution of the receiving optics. The receiving optics could also be enhanced by choosing a more adequate objective (with shorter focus length-for example). However, the reported results were selected results from hundreds of measuring results, in many of which we didn't obtain the signal as expected. From these signals the spectral analysis does not give reasonable results, and many times the main peak of the spectrum falled on 50Hz. The reason could be followings:

- Low intensity laser beam, scattering signal falls on the detector is relatively weak.

- Laboratory did not have a common grounding wire for electrical equipments and recievers.
- The flow in the tube is not laminar flow, due to low flow rate and small diameter of tube.
- The nuclear scattering is not the standard form used in nuclear industry. (The order is difficult because demand is very low, foreign companies do not want to receive these orders.)
- In the course of flowing water can be deposited.

HỆ THỐNG ĐO LƯỜNG VẬN TỐC SỬ DỤNG LASER DOPPLER

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TÓM TẮT: *Kĩ thuật Laser Doppler Velocimetry (LDV) là một kĩ thuật đo lường đã được xây dựng và phát triển từ đầu thập niên 80 với rất nhiều những ưu điểm như: đo không xâm lấn một hoặc cả ba thành phần vector vận tốc, đo được chiều của vector vận tốc, độ chính xác cao, độ phân giải cao, dải đo rộng… Thiết bị thương mại theo nguyên lý LDV được ứng dụng để đo dòng lưu ứng dụng trong công nghiệp, dòng chảy trong ứng dụng y sinh vv… nhưng phần lớn là các thiết bị chuyên biệt và có giá thành cao. Về phương diện đào tạo kỹ thuật, thí nghiệm LDV là một trong những bài thí nghiệm cơ sở về ứng dụng quang học công nghệ cao trong kỹ thuật đo lường, thể hiện kỹ năng vận dụng các nguyên lý đo lường quang học ứng dụng trong điều kiện thực tiễn. Một mô hình hệ thống LDV hoàn chỉnh được thiết kế và phát triển trong phạm vi phòng thí nghiệm phục vụ cho mục đích đào tạo.*

Từ khóa: *Kĩ thuật Laser Doppler Velocimetry, kĩ thuật đo lường.*

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