Velocity measururment of liquid flow by using Laser Doppler Velocimetry(LDV)

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Abstract:

In this research, laser Doppler velocimetry (LDV)apparatus used to measure velocity of liquid flow .Doppler signal originated by scattered &reflected light (by moving small glass beads with flow liquid) which detected by photodetector as electrical signal in time domain (voltage-time on the oscilloscope) that is by unique wave shape of Doppler signal which appears as burst shape (packet wave) differs from other waves (resulting from noise produced by chopping of two intersected laser beams by small glass beads &air bubbles). Doppler signal can also be recognized by spectrum analyzer (voltage-frequency) as a high peak at a distinct frequency which differs from other peaks that are with low values peaks belongs to the noise.

Introduction:

Laser Doppler Anemometry (LDA) is a technology used to measure velocities of flows or more specifically small particles in flows. The technique is based on the measurement of laser light scattered by particle that pass through a series of interference fringes (a pattern of light and dark surface).The scattered laser light oscillates with a specific frequency that is related to the velocity of particles [1].The technology has numerous advantage over other techniques. There is for instance no need for physical contact with flow, so no disturbance occur and the technique can be applied to flows of highly reactive or extremely hot fluid and the like[1]. Particle image velocimetry (PIV) is successfully utilized for investigation of slurry flow in the impeller of a centrifugal slurry pump[2,4].further more a relatively high spatial resolution can be obtained by focusing the two laser beams .These characteristics make LDV avail measuring technique with many applications as air flow measurements within combustion engines and airplane engines to improve fuel efficiency reduce pollution and airplane noise [3][4].

Theory:

Two cases of Doppler effect are used to discuss the LDA principle as shown in fig (1) :

1-In the first case, stationary light source and moving source receiver are present. The light frequency f_R is given as following:

$$f_R = f_s\left[1-\frac{\vec{V}.\vec{l}}{C}\right]..(1)$$

where: $\vec{V}$ is the velocity of the receiver.

f_s is the frequency of light source.

C speed of light.

2-In the second case moving light source & receiving is stationary. Thus , the received light frequency is given as[5][6] :

$$f_R = f_s \Big/ \left[1-\frac{\vec{V}.\vec{k}}{C}\right]..(2)$$

In LDA a laser is used as stationary light source and small flowing particles scatter the light, which is then received by a photodiode.

The application of two equations (1,2) provide the frequency of the `light at the photodetector after the laser has been scattered by moving particles and received by the stationary receiver[5][6]:

$$f_R = f_s\left[1-\frac{\vec{V}.\vec{l}}{C}\right] \Big/ \left[1-\frac{\vec{V}.\vec{k}}{C}\right]....(3)$$

In the study ,only a small Doppler shift of light frequency due to the movement of particles results as follows from equation (3) compared with light's frequency, (thus, a direct measurements of the frequency is the rather difficult & can be performed with insufficient accuracy). Doppler shift frequency measured by homodyne (self beating)[7] .One of the methods of avoiding a direct optical frequency measurements is by using photo detector having quadratic characteristic line which is possible to mix two light frequencies.

Thus the beat frequency of the the two signals can detected. In the self-beating methods, the frequency–shifted signal is mixed with itself (as measuring frequency, one obtains twice the difference frequency).

In the arrangement presented here, the twin-beam configuration (two crossed beams from the same light source) is used. In this arrangement, a laser beam is split into two partial beams having equal intensities, which are then focused in the measuring control volume (mcv) and made to intersect within this volume. Particles in the flow which passes through this overlap volume scatter the light of both partial beams. The Doppler shift of the scattered light is different for the two partial beams (different $\vec{l}$ vector, but the same $\vec{k}$ vectors).This differences, generally known as the beat frequency, is measured in the scattered light. This frequency difference is designated as the the Doppler frequency and is substantially lower frequency and has amore narrow band width has source frequency of the light .thus an exact detection and measurement of this frequency with electronic means is possible[6]. Now we will shown that the Doppler frequency is proportional to the particle velocity The frequency of the scattered light of each of the two partial beams is given by eq(4)

$$f_{R1} = f_s \frac{(1-\vec{V}.\vec{l}_1/c)}{(1-\vec{V}.\vec{k}_1/c)} ....(4)$$

$$f_{R2} = f_s \frac{(1-\vec{V}.\vec{l}_2/c)}{(1-\vec{V}.\vec{k}_2/c)} ...(5)$$

The difference is given by :

$$f_D = f_{R1} - f_{R2} = f_s \frac{\vec{V}.(\vec{l}_2-\vec{l}_1)}{c} ...(6)$$

by using the relationship in figure (2) and the correlation :

c = f_s.λ **(** ***λ*** :wavelength of laser light **)**

The Doppler frequency can be expressed as follows:

$$f_D = \frac{\vec{V}.(\vec{l}_2-\vec{l}_1)}{\lambda} = \frac{\vec{V}.\vec{n}.2\sin\phi}{\lambda}$$

$$f_D = \frac{\vec{V}_\perp.2\sin\phi}{\lambda} ...(7)$$

Where $V_\perp$ is particle velocity component perpendicular to the angle bisection of the beam overlap region . equation (7) shows that the particle velocity can be measured by determining the Doppler frequency when a particle passes through the measuring control volume (mcv) [6] , So the particle velocity will be[2;4;5]:

$$\vec{V}_\perp = \frac{f_D.\lambda}{2\sin\phi} ...(8)$$

The beam overlap angle 2φ can be determined with a high accuracy as in fig.(3).

Experimental se t up:

Experimental procedure is 3sections:

1-setting up optical components as shown in figure(3) the laser light beam output from 5mW He-Ne laser reflected form M1toward beam splitter BS & M2 which were adjusted previously that the beam reflected by M1 travel towards which in turn divides in to two beams :one reflected from silvered face of BS and the other is transmitted into M2 which in turn reflects it, both reflected beams (from BS&M2)must be remain parallel along their path .The two parallel beams are made to cross by the lens L1 behind it , the cross point (intersection point) will be later the interference region ,this point will be the center of quartz cavetti which is apart of flow path. The emerged two beams after then must be screened by Irish diaphragm (ID) only passes the scattered light by its aperture out from the quartz cavetti focused onto avalanche photodiode(APD).

2- The liquid used as flow fluid prepared by mixing a small quantity (several drops of solution of silvered coated glass beads each one is with 8μm diameter) with quantity of distilled water (0.5Letter) then the solution fill in the upper bottle then from the lower neck of the of the bottle attached by silicon tubing hose (which is sealed by rubber stopper) to the lower drain bottle the quartz cavetti placed connecting both sides of silicon tubing hose.

3- set up the interface Cobra3 –frequency analyzer :

Interface used in this research is Cobra3 –frequency analyzer from Phywe Co.[6] it converts the signals received from the APD to digital form and fed these signals to the PC computer for signal processing by software based on Fast Fourier Transform (FFT) algorithm to find the spectrum of the signals to determining Doppler frequency shift .

Determining overlap angle Φ

From the fig (5) we can determine the overlap half angle Φ :

$$\tan\Phi = \frac{D/2}{l} \Rightarrow \Phi = \tan^{-1}\frac{D}{2l}$$

In our measurements the distance from the lens L_1 to the observation plane D=56 cm,

while focal length of lens L_1 was f=10 cm

$$l = l' - f = 200 - 10 = 190cm$$

$$\Phi = \tan^{-1}\frac{56}{2\times190} = 8.4^o$$

thus the results in the overlap half angle:

Evaluation (Frequency measurements):

The following frequencies (where measured directly from the program desktop which display the time signal F(t) [unit-volts (U/V) versus time (t)]and the spectrum [unit/volts(U/V) versus frequency Kilo Hertz (KHz)] of the Doppler signal detected by photodiode APD ,for each case of flow speed and the center of frequency of Doppler signal determined with high accuracy and labeled as f_D saved in the PC-computer) the measurements were for various flow velocities, see figures(6-10).

Results &discussion:

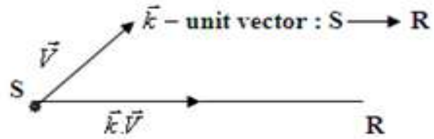
The table(1) shows the results of various velocities of particles (which represent flow velocities) $V_\perp$(m/s) obtained according to application of the equation (8) by substituting experimentally obtained frequencies in the figures (6 to 10) (mean frequency f_D of the peak Doppler signal frequency) and the overlap half angle (**$\Phi = 8.4^o$**) as determined above and laser wavelength **λ=632nm**. We note that in the spectrum of the figures (6b to 10b) appearing some of the fluctuations peaks with low frequencies these belongs to light intensity fluctuations due to chopping of laser beams by small glass beads particles, and some others caused by very small air bubbles blended in the water which also fluctuate the intensity; but in the figure (10b) there are other significant frequency peaks beside Doppler frequency peak, these peaks might at least one peak which is also another Doppler frequency shift referring that there are some particles takes different velocities indicating to turbulence flow (different in velocity from point to another) opposites off slow flow (Laminar flow). Doppler signal can be recognized from other signals by its time signal shape F (t) that is the Doppler signal is as Burst shape (packet wave) see Fig.(6) and other signals were randomly shapes like noise signals, furthermore Fast Fourier transform (FFT) algorithm increases signal to noise ratio and then enhances Doppler signal against other signals.

Table (1)

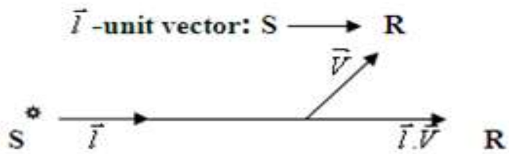
Fig. No.	Doppler frequency (f_D)KH_Z	Velocity of flow $V_{\perp}$(m/s) $=f_D.\lambda / 2sin\Phi$
6	2.2	4.75×10^{-3}
7	7	15.1×10^{-3}
8	2.24	4.84×10^{-3}
9	1.93	4.17×10^{-3}
10	0.87	1.88×10^{-3}

Conclusion:

An accuracy liquid flow velocity measurements depends on Doppler signal quality which in turn depends on some factors: some related on adjustment the point of two intersected beams ;the intensity of incident light on photodetector; some related on adjustment of signal amplifier .these factors affects on appearing Doppler signal which is resultant of homodyne interference of scattered light from two intersected beams through flow region .Doppler signal can be recognized in term of time domain that is from signal shape which appears as wave burst (packet waves). Some measurements contained two Doppler shifts which refers that there are more than one flow velocity.



(a) moving light source and stationary receiver



(b) stationary lightsource and moving receiver

Fig(1)two cases for the discussion of Doppler effect

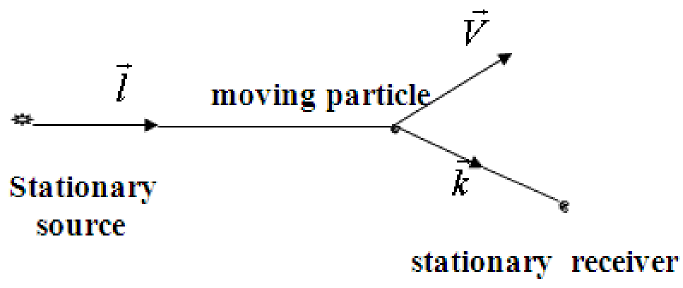


Fig.(2) : scattering light by moving particle

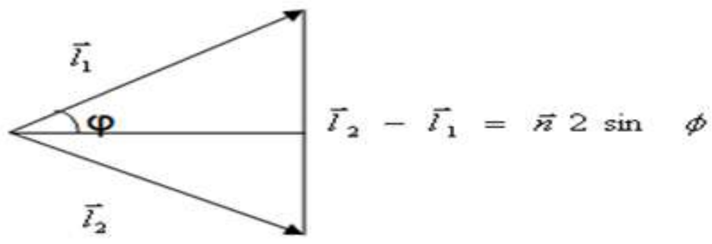
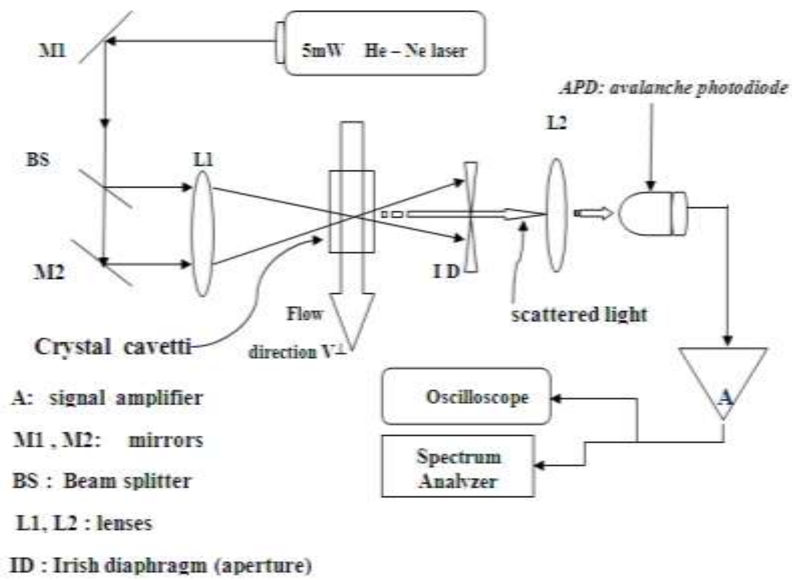
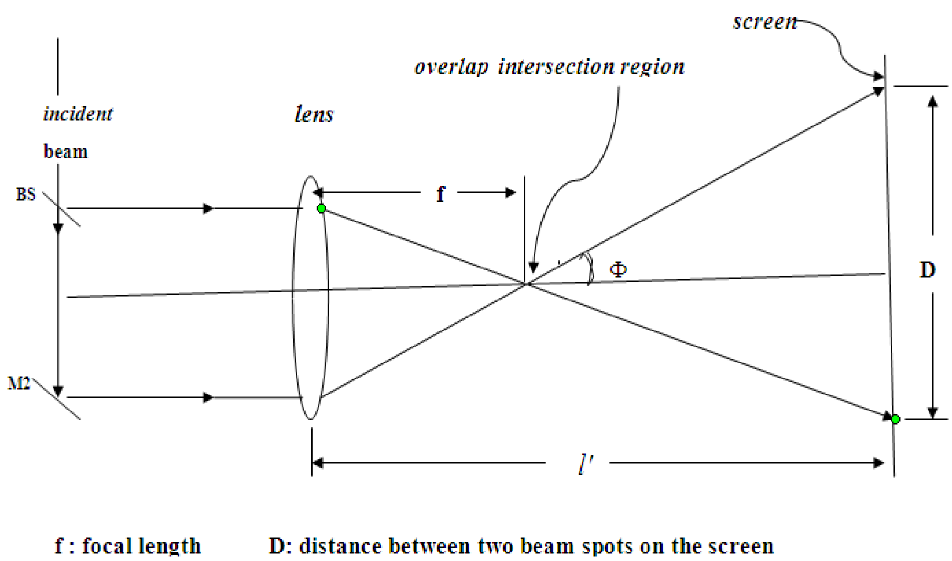


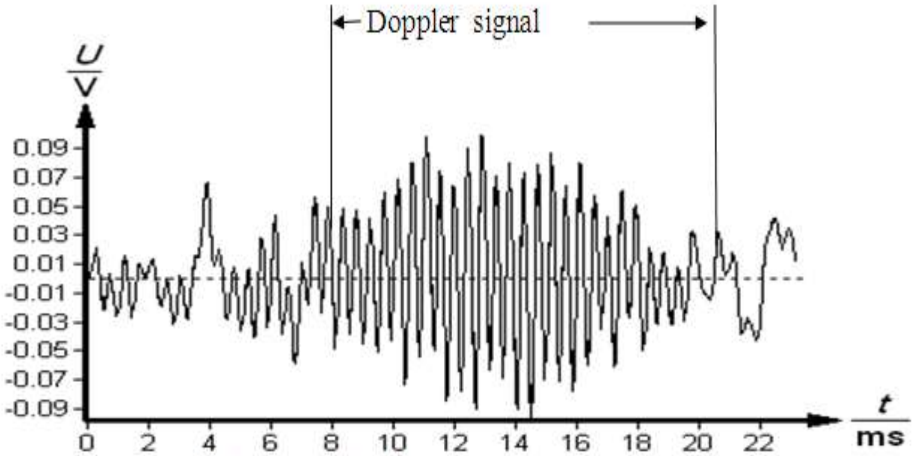
Figure (3) differences in unit vectors



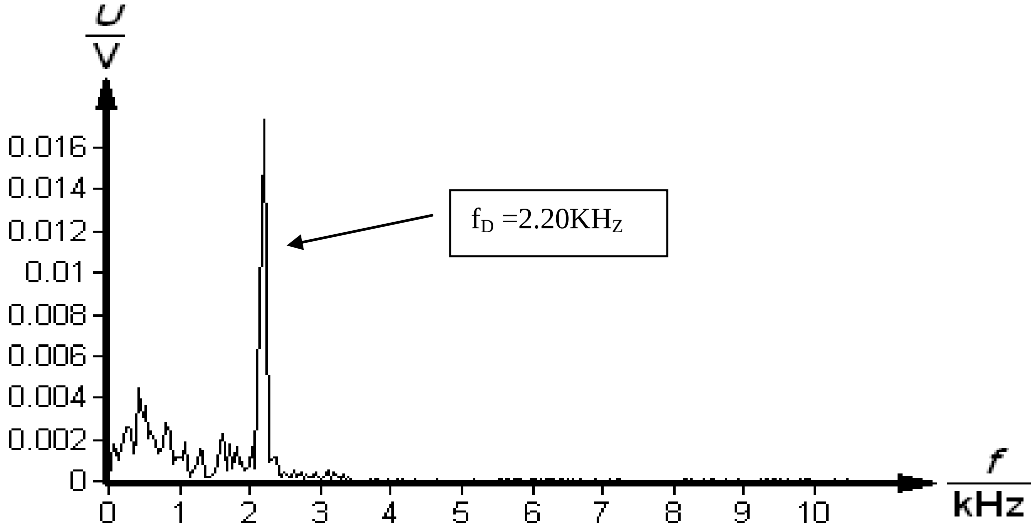
Figure(4) Experimental setup of Laser Doppler Anemometry (LDA)



Figure(5) determining overlap half angle (Φ)

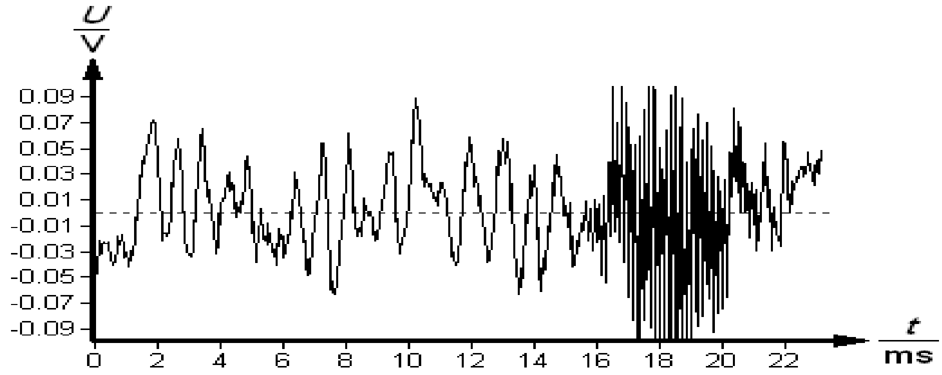


a-Doppler signal F(t)



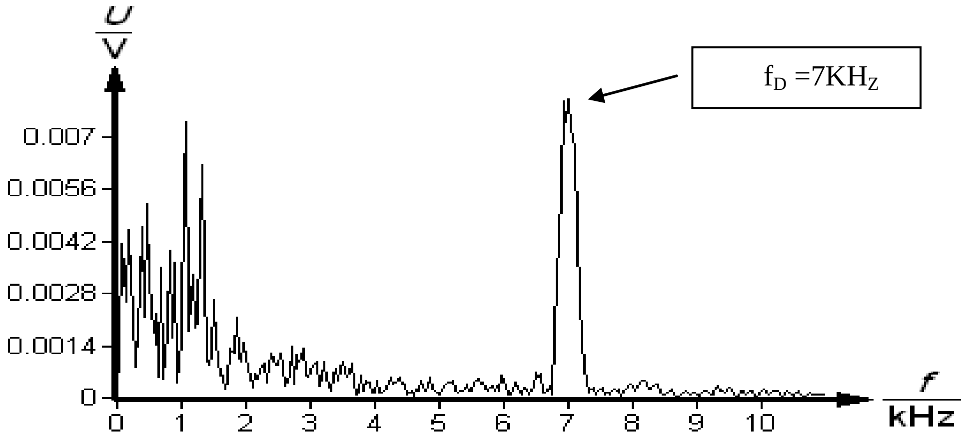
b- Doppler spectrum

Figure(6) a-Doppler signal b-Doppler frequency spectrum



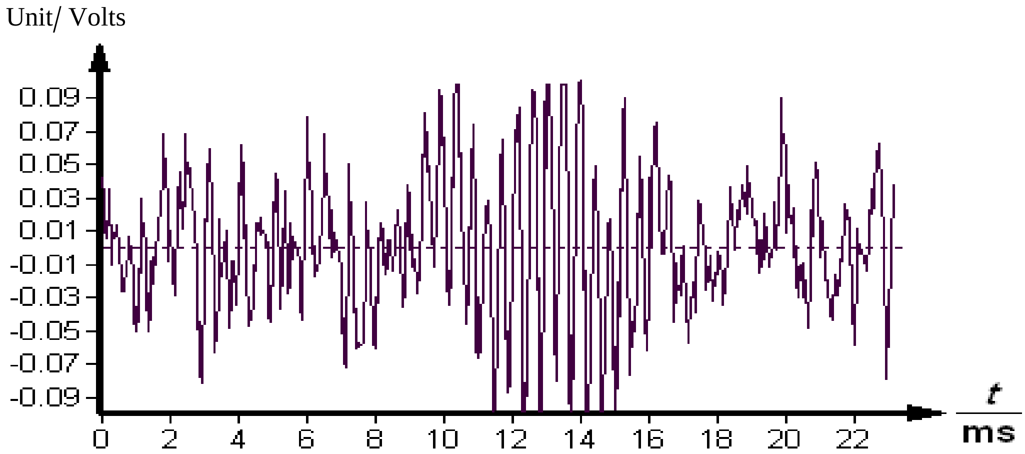
a-Doppler signal

a-Doppler signal

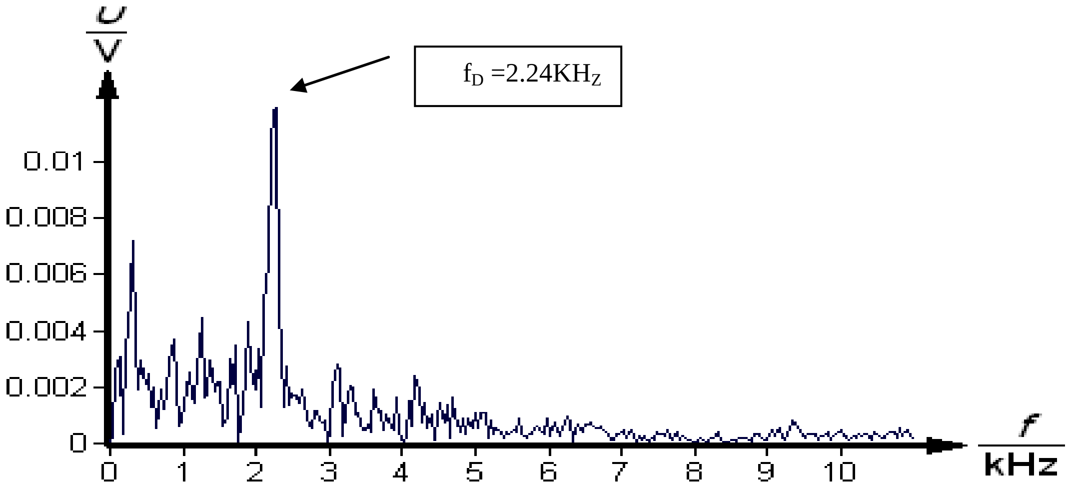


b-Doppler spectrum

Figure(7) a-Doppler signal b-Doppler frequency spectrum

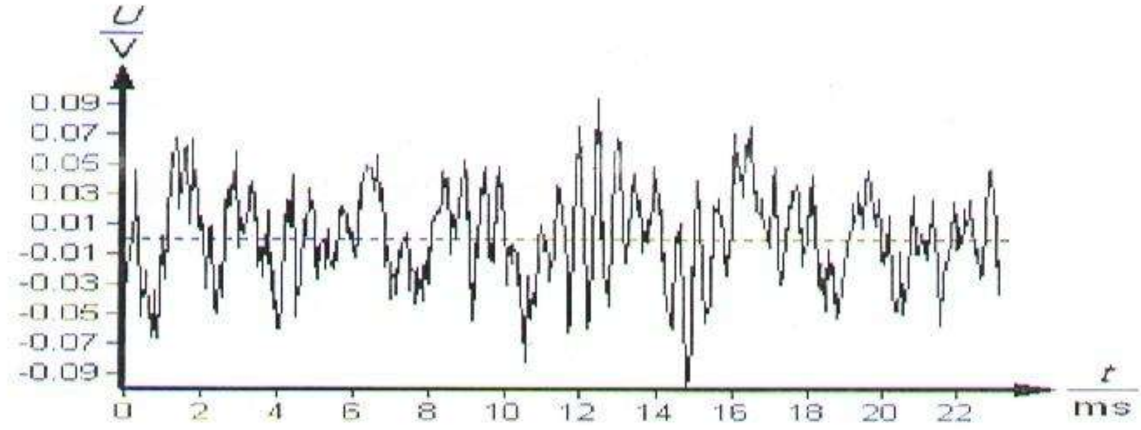


a-signal

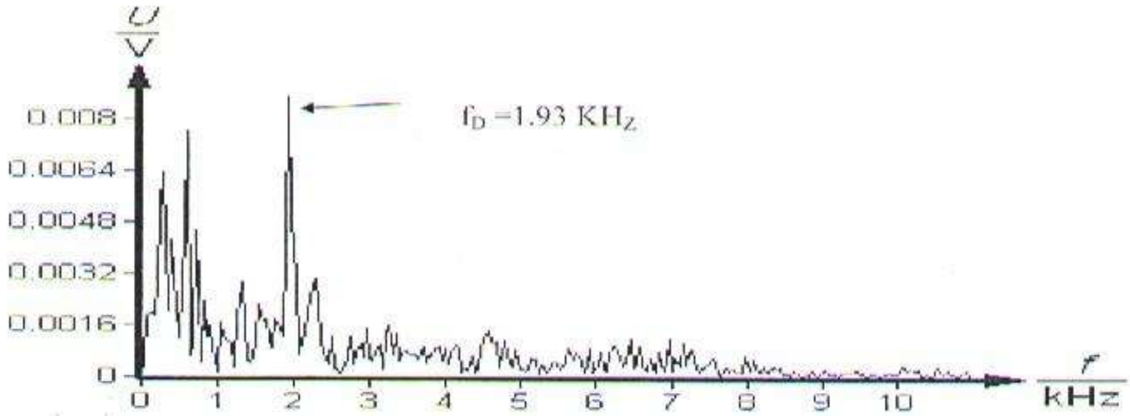


b-Doppler spectrum

Figure(8) a-Doppler signal b-Doppler frequency spectrum

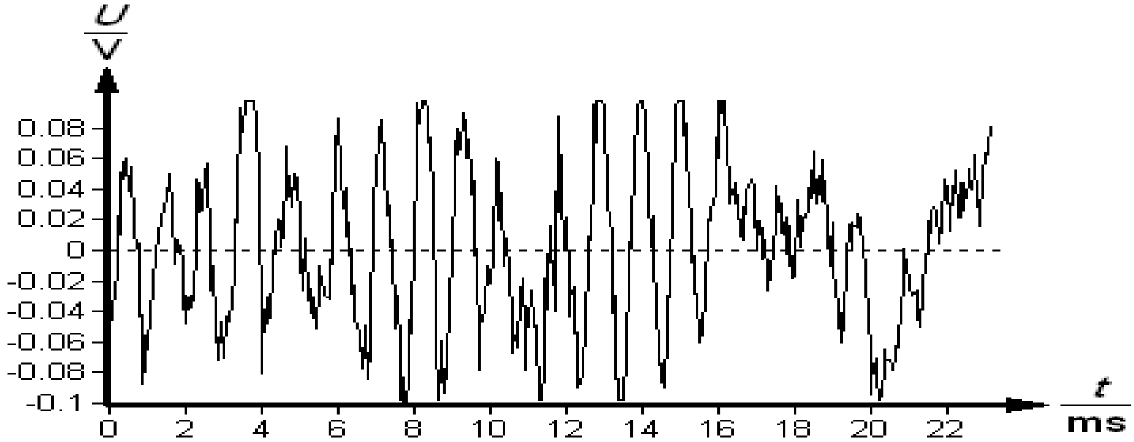


a-Doppler signal

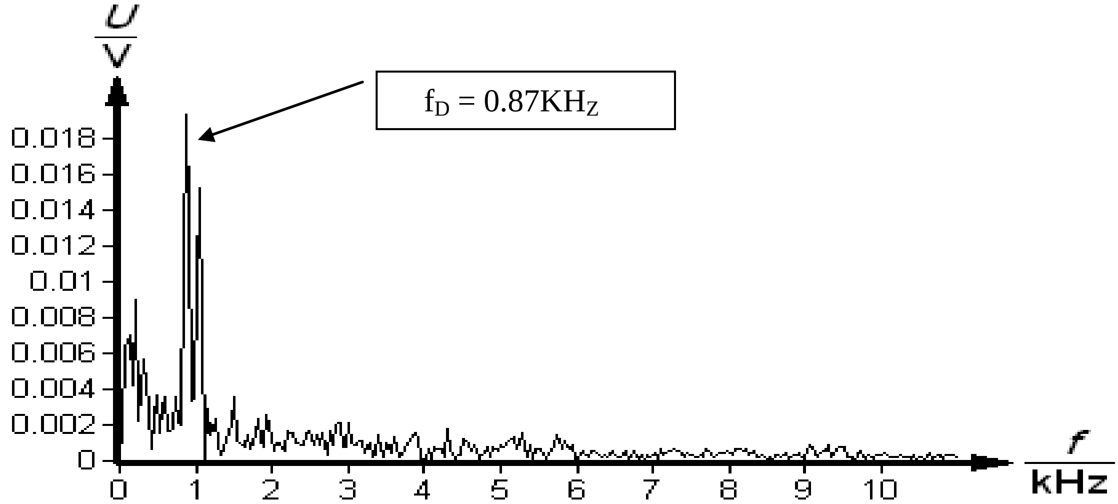


b-Doppler spectrum

Figure(9) a-Doppler signal b-Doppler frequency spectrum



a-Doppler signal



b-Doppler spectrum

Figure(10) a-Doppler signal b-Doppler frequency spectrum

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قياس سرعة جريان سائل بتقنية قياس إزاحة دوبلر لتردد الليزر

قحطان نوفان عبد الله ، يونس ذنون يونس

قسم الفيزياء ، كلية التربية ، جامعة تكريت ، تكريت ، العراق

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الملخص

تم في هذا البحث اعداد منظومة قياس سرعة جريان سائل على مبدا ليزردوبلر.يمكن تمييز أشارة دوبلر المتولد في الضوء المتشتت والمنعكس (من الجسيمات المنسابة مع السائل المتدفق)والتي يتم كشفه بواسطة الكاشف الضوئي على شكل أشارة كهربائية في حقل الزمن(الفولتية –الزمن على شاشة الاوسلسكوب)وذلك على شكل دفقة (رزمة موجية) والتي تختلف عن بقية التموجات (الناتجة عن الضوضاء الناشئ عن تقطيع الضوء من جسيمات الخرز الزجاجية المنسابة مع جريان السائل وفقاعات الهواء)،وتكون هذه الاشارة(أزاحة دوبلر) واضحة بشكل جلي من خلال طيف الاشارة (الفولتية –التردد)على محلل الطيف وذلك على شكل قمة عالية عند تردد معين يمكن تمييزه من بين بقية القمم ذات القيم الواطئة والتي تعود للضوضاء .