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Research Paper

Physics

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Flow Rate and Level Measurements Using Modulated Laser Technique

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ABSTRACT

In this paper a method for measuring flow rate and level of a liquid simultaneously is discussed. The method is based on use of a single laser source (Ne-He Type) with low power and an AO (A cousto-optic) device, which works as a modulator-deflector (with optical frequency shifting).An ASK (Amplitude shift Keying) single is supplied to the modulator-deflector driver(signal processor)to produce amplitude and frequency shift simultaneously. This AM/deflected laser beam passes through a moving liquid and carries the required information on the level of the liquid (amplitude modulation part) and the flow rate measurement (Deflection or FM modulation part). Heterodyning detection using large area photodetector with nonlinear characteristic is proposed to measure the flow rate of the moving field while large area with linear characteristic photodetector is used to calculate the level of the liquid.

Introduction

The development of advanced laser-based instrumentation for producing accurate measurements of drop or liquid velocity distribution remains of importance over a diversity of application. These applications include research in fuel spray combustion, coal-oil and coal- water slurry combustion, nuclear safety, aircraft icing, agricultural sprays, metrology, and a variety of industrial process.

$$\frac{\Delta f}{f} = \frac{u}{c-u} \cong \frac{u}{c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(1)$$

Many methods has been presented for measuring the flow of a moving field [1, 2, and 3]. Laser dopple Anemometer (LDA) is well-established methods used for this purpose our contribution here is to use another technique, which is based on Acoustic-optic device to implement the measurement. The level of fluid is usually changed through the dynamic process with a feedback system, which can actually be sensed precisely by laser. Various characteristics (e.g., frequency, intensity, and direction) of laser beams can be controlled effectively using AO modulators, greatly expanding the application areas of the laser. The unique feature of AO devices is that despite the characteristics of laser beam to be controlled, the principle, structure, and manufacturing technology of the corresponding device remain the same. The various requirements of the measurement is impractical .the phenomena of the Doppler shift state that the light scattered from devise can be through the proper design consideration, and often a single device can be constructed to perform several functions at once.

The direct measurement of the frequency of light after passing through a moving field is named the Doppler shift a moving object undergoes a frequency shift Δf in proportion to the object velocity. The relative frequency shift is given by:

Where u is the velocity component of the moving object measured in the direction of the observed scattered light and c is the velocity of the light. In this technique there are two drawbacks. First, the sign of Δf (and thus u) cannot be determined, and measurement become inaccurate at velocities nearing zero, second, the absolute value of the frequency shift is often quite large, in the ring of Giga Hertz, which means difficultly in reception and measurement of such a high frequency [5]. Fortunately, using an AO frequency modulator can solve both problem (i.e. sign of the frequency shift and the large value of the frequency received).

PHYSICAL PRINCIPLES

In principle frequency modulation is a process where in incident photon either absorbs or release a photon [5]. As a consequence the frequency of the diffracted photon changes of the form:

$$f_d = f_i \pm f \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Thus, we can control the frequency f_d of the diffracted light by changing the acoustic wave frequency, f or actually, the frequency of the applied electric signal.

This is the principle which lies behind frequency modulator.

If a light beam incident on a particle of small size with a normal vector of the area is in parallel to the direction of the light beam, then this area will behave as a new source of light [6], provided that the area of the particle is smaller than the cross section of the light beam. If the particle is moving, then the frequency of the light incident will be affected by Doppler phenomena, this shifting in frequency will by relative to the velocity of the particle speed [5].A transparent or white particles mixed with the liquid can be used to produce the diffraction for measuring the Doppler frequency [7].

Two principle phenomena will be explained in this section firstly, the AO device operation and secondly, the heterodyning detection.

a. AO Device

Some materials have properties that its refractive index depends on the propagation direction and polarization state of the light wave [8]. When an acoustic wave propagates through this type of material, its index is periodically modulated by the strain and the medium becomes equivalent to a moving phase grating. Acousto-optic devices have the property that the frequency if the diffracted light, is either up-shift or down-shift by the frequency of the acoustic wave. The undiffracted light is not shifted. When the optical beam enters acousto-optic device in a direction opposite to the direction of sound travels, the light is up-shifted. Light is down shifted for other case where the two directions coincide; Fig (1) shows the two case. Another property of this device: a light beam entering the sound at nearly normal incidences is deflected at an angle proportional to the acoustic.

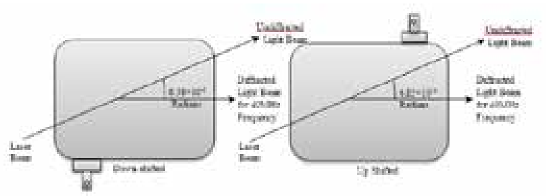

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Fig. 1. Top view of AO device placed in the direction of laser beam.

The laser beam will split after passing the AO deflector to two beam. The first one is direct and has the nominal optical frequency of the laser source, while the second beam makes an angle with first one and has optical frequency differ from the laser source frequency of the applied acoustic frequency (applied frequency).

In this work we will force the AO modulator to work in two modes depending on the voltage phases supplied to the modulator driver.

1. Deflection mode.

As an optical frequency modulator. The angle, α, between the deflected and undeflected beam depends upon the light wavelength acoustic frequency, α= 0.26.λ.f, where α is in mill radians, λ in microns and f is in MHZ. The total deflection angle of 6.58×10^{-3} radians is proportional to modulation frequency of 40MHZ, see Fig. 1.

2. Intensity Modulation Mode.

When the AO device is used as intensity modulator, the RF input frequency to device is held constant while the signal amplitude is varied to produce intensity modulation of the laser beam. The relation between light intensity and applied voltage to the device, as in any acousto-optic device, is not linear but is: I, where K is a constant and V is applied voltage. It is therefore necessary to incorporate a gamma correction circuit in the RF driver to linearize the input-output characteristics applied voltage.

Modulation bandwidth is inversely proportional to optical beam diameter. Depth of modulation as a function of frequency and beam diameter is given by exp $[-(f/f_e)^2]$, where f_e=3045/D MHz, D is laser beam diameter in mm and f is modulation frequency in MHz. the light wavelength dose not effect modulation frequency response, although the acoustic power needed to diffract a given light percentage is proportional to the square of the light wavelength.

The diffraction efficiency of the device used is the percentage of incident light diffracted into the first order is also dependent upon beam diameter. Efficiency is about 90% for the laser source used.

The technique often referred to as 'optical beating' is the heterodyning or time-dependent interference of two optical beams. Heterodyning is a well-known technique in radio in which two signals are added and passed through a non-linear circuit element or "detector". The mixed output then contains the sum and difference frequencies and harmonics. If the original frequency are close, the difference frequencies will be low and may readily by separated by allow pass means.

We may observe beating by illuminating an optical detector as a non-linear device in the electrical sense) since its output is proportional to the intensity of the incident light, i.e. the square of the optical electrical field. Thus, the addition of the two optical fields at the detector results in output containing the difference frequency.

Expressing the two field at time T by:

$$E = E_1 \cos(2\pi v_1 t + \emptyset_1) \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$E = E_2 \cos(2\pi v_2 t + \emptyset_2) \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where v1 and v2 are the frequencies and are arbitrary phases, we note that the output i(t) of the detector is proportional to the square of the total electric field. Thus:

$$i(t) = B(E_1 \cos(2\pi f_1 t + \emptyset_1) + E_2 \cos(2\pi f_2 t + \emptyset_2))^2 \ldots\ldots\ldots\ldots\ldots (5)$$

Where B is constant. Transforming this trigonometrically and neglecting terms of optical frequency which clearly cannot be observed at the output of the detector obtains:

$$i(t) = B\left[\frac{1}{2}(E_1^2 + E_2^2) + E_1 E_2 \cos(2\pi(v_1 - v_2)t + (\emptyset_1 + \emptyset_2))\right] \ldots\ldots\ldots (6)$$

The beat frequency ν_1-ν_2 or term is proportional to the product of the amplitudes E_1E_2 or where I_1 and I_2 are the intensities of the two beams.

HETERODYNE DETECTION IMPLEMENTATION

The crucial point in the system is to choose and design proper detector that produce the nonlinear detection (Heterodyne detection), taking in the consideration the change of the beam angle which is effected by the diffraction due to liquid motion.

An optical detector is connected as shown in Figure 2.a to measure the light under heterodyne means. The figure shows the method of measuring light by measuring the short circuit current I_{Sh}. An amplifier of gain (A) amplifies the voltage ($I_{Sh} R_L$) and use of the bias voltage V_R makes this circuit suitable for receiving high-speed pulse light (i.e. high speed response). The circuit can be optimized to work under nonlinearly by using proper value of RL. Figure 2.b shows that the nonlinear area is constraint between to load lines. The slope of the load lines depending on the value of the R_L used.

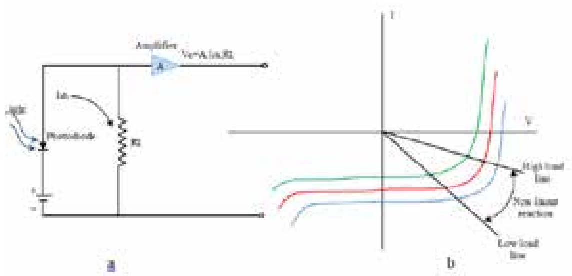

Fig. 2. Nonlinear photodetector a. Schematic diagram, b. I-V characteristics

SYSTEM DESCRIPTION

The system proposed is deliberated to reduce adjustment consideration and to be more practical in the real world situation also the system is built by using a commercial components without using optical multiplier as in most flow rate measurement system. The system consists Of Laser source of 6328 A wavelength of red Ne-He ,with beam diameter D of 1mm, maximum output power of 10m W and operating current of 1 Om A.

An AO device is placed in the direction of the direction of laser beam, such that the laser beam pass through the device. The device is also connected to a signal processor of 40MHz frequency, 2.5W power to provide required power for the diffraction of the light. As mentioned above tow beams will result after passing the AO device the first one is undiffracted with more power than the other and without frequency deviation. The other one will be diffracted with lower power and with frequency deviation from the optical frequency of 40MHz. since the undiffracted light is not shifted in frequency it can be used as a local oscillator for optical heterodyne detection.

To produce simultaneous AM-FM modulation, using single AO modulator, a signal source is connected. The connected source supplies an amplitude shift keying signal (ASK) to the signal processor (modulator driver). Figure 3 shows the signal supplied to the signal processor. In the case sinusoidal period the system will work to measure the attenuation (Level) of the liquid.

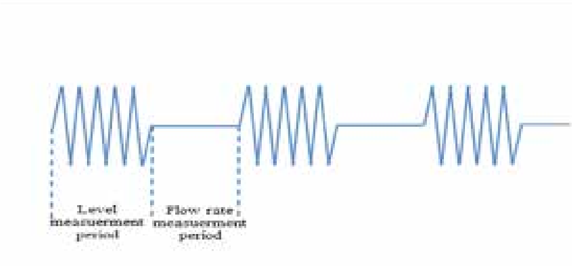

Fig.3. ASK Signal supplied to the signal processor.

The diffracted beam passes the pipe of the oil through a concave lens. The function of the concave lens is to increase the diameter of the laser beam. The diameter of the laser beam will be increased in a way such that it will be inversely proportional to the number of particles used per unit volume of the oil. The beam (P_1) that passes through the pipe is then faced by the mirror-2 and directed to a natural density filter, which has two purposes, first, the beam intensity must be adjusted to a proper level to be consistent with the deflected beam from the AO modulator secondly, the normal density filter will work as a splitter if its position adjusted to make an angle with direction of the beam.

From the other direction P_2 is passed through a concave lens to distribute the beam power on all the active medium of the detector. P2 together with P1 are directed towards the nonlinear photodetector circuit, for Doppler shift detection, P1 "that carries the information about the level of the liquid in the pipe will be directed towards the linear photodetector circuit. Optional device can be used after the detectors, here we propose a frequency counter and Oscilloscope respectively.

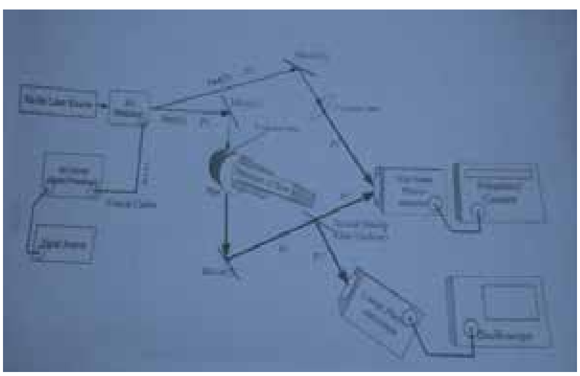

Fig.4 Shows the system suggested to measure the flow rate and the level of the liquid.

EXPERIMENTAL RESULTS

The implemented nonlinear detector is used to confirm the capability for Doppler frequency detection Eq. (6) Two AO modulated paths were used to simulate the flow rate measurement. The first path, path (1), of the beam was set as shown in fig.4 without the pipe, while the second path, path (2), predetermined with an AO modulator. The second modulated path was directed towards mirror (3) and derived as a frequency that differs from the first path. Fig.5 shows the ability of the detector for linearly measuring the frequency difference Δf between the frequencies of the two beams.

It can be seen that the range from 1-15 MHz is linear. So, for any flow rate we can adjust the frequency shift (by deflection means) and work in the linear region of Fig 5. It is worthy to note here that even if the direction of the flow of the liquid is changed, a simple adjustment of the frequency supplied to the AO modulator/deflector will produce the required measurement.

A high performance photodetector with large area of 100mm^2, (the active detection area of the detector), with R_L=27.3 and V_R=0 volts is used. The effect of the VR is only to increase the response of the system, which is not important requirement in our objective. The use of a large area photodiode is important as the incident light will occupy all the area required at which the laser beam will be diffracted.

Fig. 6 shows the relation between the levels of the liquid in the pipe with voltage received in the period of level measurement. It is obvious that the value of the peak voltage decreases as the level increases due to the scatter of the light in the liquid and attenuation after passing through the medium [8]. The relation is linear and can be used as an indication to the level correctly.

Summery and Conclusion

A new method for simultaneous measurements of flow rate and level of the liquid has been described. The method, which yield the flow rate of the liquid from the shift in optical frequency due to Doppler Effect has no conflict with measuring the level of liquid using the laser beam during intensity modulation. The output from frequency stabilized, signal longitudinal mode laser is passed through an AO device and the zero-order beam was used to interrogate the moving object and its level. The diffracted light, which has been frequency shifted by the AO cell by set amount f, interferes with the scattered radiation from the moving field, and the heterodyne frequency is determined by a photo receiver. One advantage realized by this design is that the previously set frequency shift f acts as a bias, so the sign of the Doppler shift can be determined. Another advantage is that the frequency difference between the scattered light and diffracted light can be significantly decreased by simple adjusting f. this virtue can successfully by used in the case where fluid flow in two opposite directions.

The linear relationship between the variables to be measured and the known values simplifies the implementation of the method and creates a uniform sensitively over the measurement range. Only the dynamic range of the detectors used essentially limits the dynamic range of the technique and its performance in real would. These difficulties include environmental conditions and simple alignment errors. In terms of operating requirement and error produced, it is expected the operations analogous to the conventional laser Doppler Anemometer (LDA). The detector used in level measurement has linear characteristics, which is a specification exists in approximately all productions of the photo detectors and it is easy to implement. The nonlinear detection is the critical part of the experiment and required realignment; however we cannot make conclusion about the relative measurement accuracy. The availability of standard measuring devices for flow rate and level measurement would facilitate the evaluation of this new measuring technique.

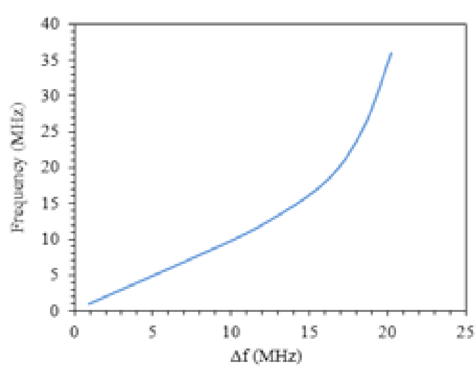

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Fig.5 the response of the nonlinear detector for the two beam with difference in their frequency of

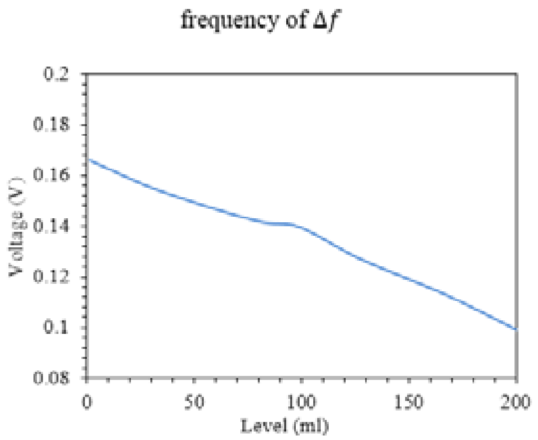

Fig. 6. The peak output voltage from the linear detector versus the level of the liquid in ml.

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