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Stabilizing Circuit of Doppler Beat Signal Obtained by Coherence-Dependent Fiber-Optic Laser Doppler Velocimeter

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Abstract

Described is a stabilizing circuit of the Doppler beat signal obtained by the coherence-dependent fiber-optic laser Doppler velocimeter (LDV), which employs both a self-mixing laser diode (SM-LD) and a 10m-100m long optical fiber. The stabilizing circuit maintains the SM-LD drive current at an optimum value, which gives a maximum Doppler signal during long hours.

1. Introduction

Recently, we proposed a simple fiber-optic laser Doppler velocimeter (LDV), which employs both a self-mixing laser diode (SM-LD) and a 10m-100m long optical fiber.(1)

The LDV can measure a Doppler beat signal with a high signal to noise ratio (SNR). However, when the drive current of the SM-LD is increased, the Doppler beat signal amplitude as a whole increases rapidly to a top at near above the threshold current, and after that gradually decreases showing some peaks followed by each valley. The reason of the repetition of the peak and valley has been explained by the coherence enhancement of the SM-LD.(2)

Provided that the fiber length is comparable with or more than a half of minimum coherence length of the SM-LD, the Doppler beat signal which is initially adjusted at a maximum amplitude at a certain drive current gradually decreased to a minimum during a few minutes. The temporal change is presumably caused by the deviation of the reentering light phase from the coherence enhancement condition due to inevitable change of the temperature of the room and/or the SM-LD.

In this paper, proposed is a stabilizing circuit of the Doppler beat signal obtained by the coherence-dependent fiber-optic LDV. The stabilizing circuit maintains the LD drive current at an optimum value, which gives a maximum Doppler signal during long hours.

2. Fiber-Optic LDV(2)

2.1 Experimental Setup

A schematic configuration of experimental setup for a fiber-optic LDV using a 10m polarization maintaining fiber (PMF) is shown in Fig.1.

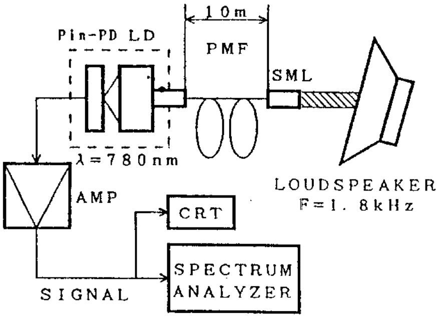
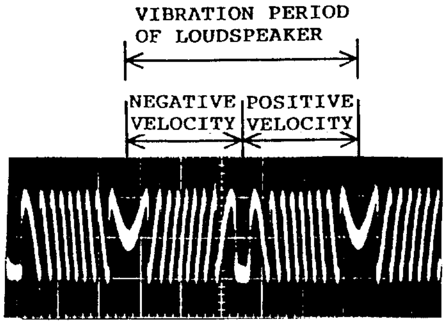


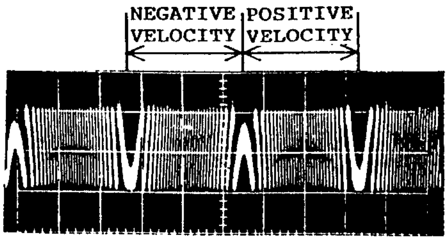
Fig.1 Schematic configuration of experimental setup for an LDV using a polarization maintaining fiber (PMF).

The emitted light from the LD passes through the PMF and illuminates a vibrating loudspeaker surface. The scattered light from the surface having a Doppler frequency shift is collected by a selfoc microlens (SML) and reenters the LD after traveling the same path. Then a Doppler beat signal is produced in the LD as a result of the self-mixing effect, and the beat signal is extracted from the photodiode (PD) accommodated in the LD package. The beat signal is displayed on a cathode-ray tube (CRT) and its frequency spectrum on a spectrum analyzer.

The laser used in the experiment is an AlGaAs type connected with a 10m PMF. The threshold current is Ith=45mA, the output power at the SML is 0.9mW at I=70mA (=1.56Ith) and the light wavelength is λ =780nm.



(a) In case of small vibration amplitude



(b) In case of greater vibration amplitude

Fig.2 Typical waveforms of Doppler beat signal obtained when the loudspeaker is driven sinusoidally at a frequency 1.8kHz.

2.2 Doppler Signal Versus Drive Current

The typical waveforms of Doppler beat signal are shown in Fig. 2, which are obtained when the loudspeaker is driven sinusoidally at a frequency f=1.8kHz.

The beat signal has a feature of sawtooth-like waveform.(3) During positive velocity when the loudspeaker surface is approaching the LD the waveform rises rapidly and falls slowly, while in case of negative velocity the wave rises slowly and falls rapidly. The theoretical explanation of the sawtooth like waveform has been first given by the authors(4) and recently by M.Slot et.al.(5) When the amplitude of the loudspeaker driving voltage is increased keeping the other parameters constant the Doppler frequency becomes higher as shown in Fig.2(b). The amplitude of the Doppler beat wave is maintained almost constant, because the amplitude is determined mainly by the LD drive current and the reentered light power.

Figure 3 shows the Doppler beat signal power as a function of drive current. The optical spectral linewidth of the same LD is also shown in Fig.3.

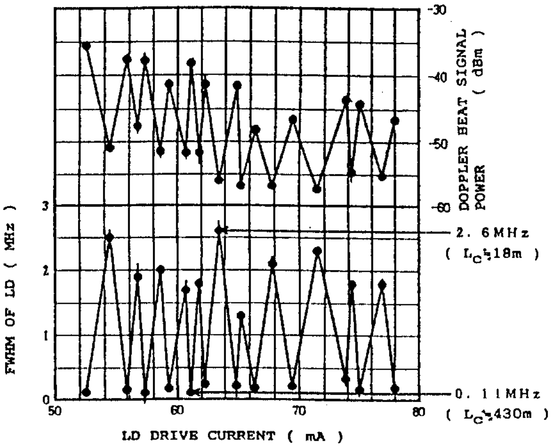


Fig.3 Doppler beat signal power and spectral linewidth expressed in FWMH of a self-mixing laser diode (SM-LD) as a function of LD drive current. The LD is connected with a 10m polarization maintaining fiber (PMF) through a lens.

At each of the linewidth peak expressed in full width at half maximum (FWHM), the Doppler beat signal becomes minimum, while at valley the signal becomes maximum. Since the LD coherence length L_c is inversely proportional to the linewidth Δf, the longer coherence length results in the stronger Doppler signal. The coherence length L_c is given by

$$L_c=c/2\pi\Delta f \qquad (1)$$

where c is the light velocity and Δf the spectral linewidth expressed in full width at half maximum (FWHM).

The amplitude i_b (L_c) of the Doppler beat signal is given by the following equation, provided that the conversion efficiency of the self-mixing effect which produces the Doppler signal is independent of the LD drive current.

$$i_b(L_c)=i_b(\infty)\exp(-2L/L_c) \qquad (2)$$

$$20\log i_b(L_c)=20\log i_b(\infty)-(40L\log e)/L_c \qquad (3)$$

where $i_b(\infty)$ is the Doppler beat amplitude when the coherence length L_c is much greater than the optical distance L between the LD and the loudspeaker surface. According to Fig.3 and eq.(1), the coherence length repeats many peaks followed by each valley as a function of LD drive current, showing a maximum 430m and a minimum 18m. In case of L=15.23m (=10x1.5+0.23), the experimental relation of the Doppler beat signal power in dBm versus the inverse coherence length becomes straight line, which is obtained from Fig.3 using the least square method. The experimental slope of the straight line coincides well with the theoretical slope obtained from eq.(3).

When the temperature of the room and/or the LD gradually changes with time as is usual case, the drive current must be readjusted after a few minutes so as to give a maximum Doppler signal. Therefore, it is necessary to maintain automatically the LD drive current at an optimum value to always obtain a maximum Doppler signal.

3. Stabilization of LDV Output

3.1 Principle

In order to obtain the error signal, i.e., the difference between the dc drive current and the optimum current giving a maximum Doppler signal, the LD drive current is lightly modulated at a very low frequency 8Hz.

Figure 4 shows principle of a Doppler-signal stabilizing circuit when the amplitude of Doppler signal has a positive tangent against an increment of the LD drive current. When a modulating triangular wave with a small amplitude is added to the drive current, the envelope of the PD output signal i.e., the Doppler signal is in-phase with the modulating wave in case of a positive tangent, while the signal has a reversed phase in case of a negative tangent.

Therefore, we can determine whether the drive current is under or above the optimum current giving a peak of Doppler beat signal by comparing phase difference between the envelope of the modulated Doppler signal and the modulating triangular wave. Using the identified result of the slope sign, we can automatically increase or decrease the drive current during positive or negative slope, respectively, so as to keep the Doppler signal power a maximum value.

Figure 5 shows a block diagram of the Doppler-signal stabilizing circuit. To explain the principle of detecting the slope sign, the output waveforms of three comparators are shown in Fig.6 and Fig.7 in case for a positive slope and for a negative slope, respectively.

First, the envelope i.e., a triangular wave, of the PD output signal is obtained using an envelope detecting circuit. Then 2V square wave pulse is produced by a comparator 1 with a reference voltage $V_r1=0$V. Secondly, a 2V pulse is produced from the modulating triangular wave using a comparator 2 with a reference voltage $V_r2=1$V. The outputs of the comparator 1 and 2 are summed by an adder 1, and fed to a peak hold circuit.

In case of positive slope, since the outputs of the comparator 1 and 2 are in phase the adder 1 output becomes a 4V pulse with a pedestal during one cycle of the triangular wave as shown in Fig.6. Then the output of the peak hold circuit has a 4V plateau followed by a decaying tail, which is maintained greater than the reference voltage V_r3 (=2.2V) of a comparator 3. Therefore, the comparator 3 produces a high level signal 15V, indicating that the two triangular waves are in phase, i.e., the LD drive current is below an optimum value. In case of negative slope, the peak hold circuit produces a pulse signal which has five 2V plateaus followed by each decaying tail during 2 cycles as shown in Fig.7. Therefore, the comparator 3 produces a low level -15V, indicating that the LD drive current is above an optimum value.

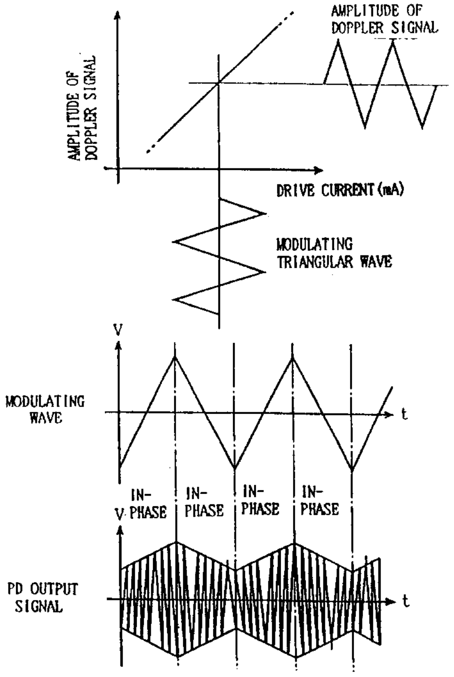


Fig.4 Principle of a Doppler-signal stabilizing circuit when the amplitude of Doppler signal has a positive tangent against an increment of the LD drive current.

The error signal is obtained from the output of an integrator which integrates the output of the comparator 3. The error signal and the modulating triangular wave are summed by the adder 2, and supplied to the current source which drives the LD. The error signal is automatically increased during the LD drive current is below an optimum value. When the drive current passes over the optimum current, the comparator 3 output becomes -15V, then the drive current is decreased until it returns to a certain value below the optimum. Thus the drive current is maintained in the vicinity of an optimum point.

Before applying the stabilizing circuit to the actual LDV system, the operation of the stabilizing circuit is confirmed by using a simulation circuit which simulates the operation of the LDV system.

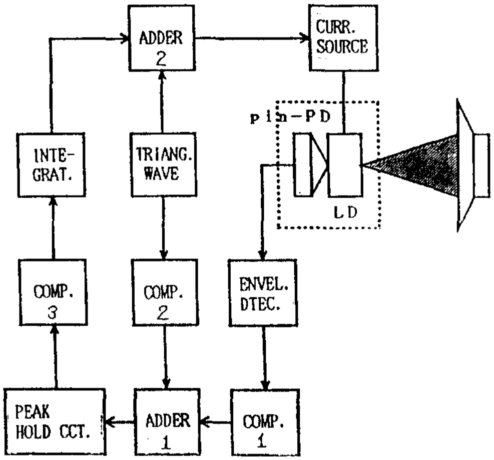


Fig.5 Block diagram of the Doppler-signal stabilizing circuit.

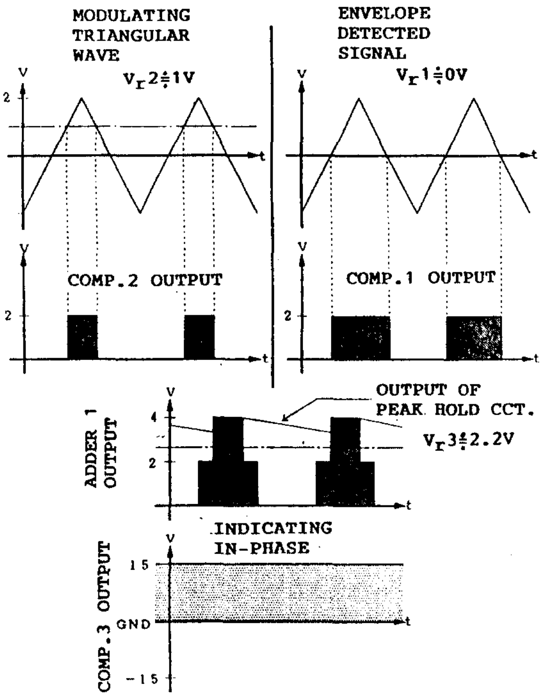


Fig.6 Principle of detecting the positive slope.

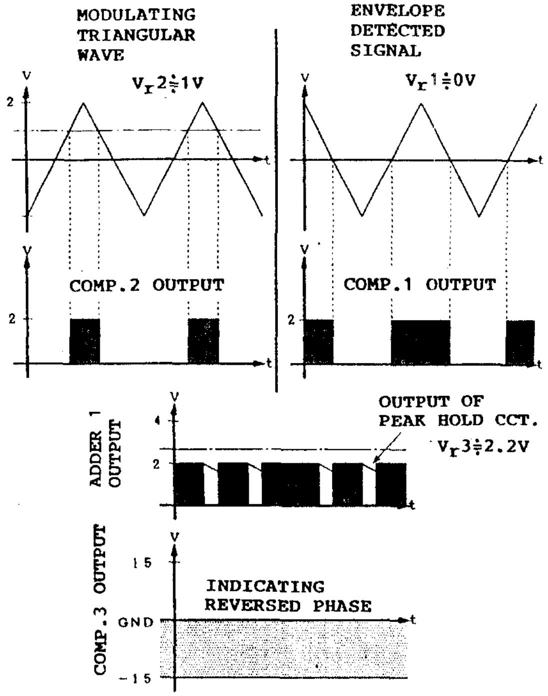


Fig.7 Principle of detecting the negative slope.

3.2 Simulation

Figure 8 shows the block diagram of the simulation circuit of the LDV system.

The voltage controlled oscillator (VCO) generates a square wave of which frequency is changed by the input voltage of 0-5V. When the dc current is increased the VCO output frequency decreases, so the amplitude of the output signal of the band pass filter (BPF) increases to a maximum and then decreases, thus showing some resonance curves consecutively. Consequently, the amplitude of the BPF output simulates the current dependence of the Doppler signal shown in Fig.3 except frequency change.

Figure 9 shows a simulated result of controlling the BPF output at approximately constant amplitude. In case of the positive tangent, initially the VCO output frequency is set below the center frequency of the BPF. Both the output of the peak hold circuit and the simulated Doppler signal are shown in Fig.9(a) for transient control and in Fig.9(b) for a stationary control. According to Fig.9(b), the BPF output, i.e., the simulated Doppler signal is stabilized between a maximum amplitude 11V and a half of it.

Figure 10 shows the principle how the operating point is stabilized in the vicinity of the optimum point. When the drive current is set at near the optimum

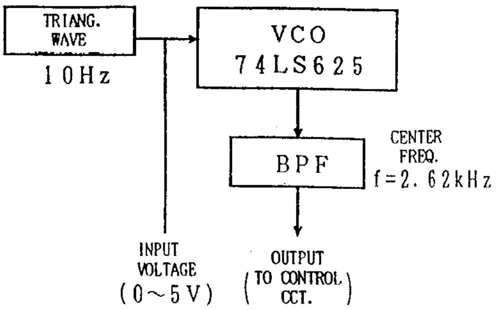
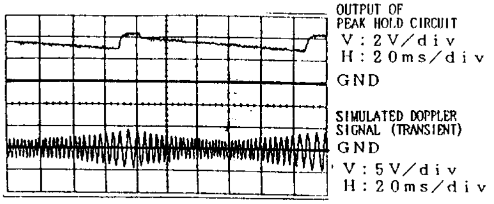
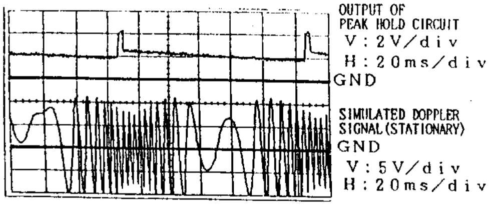


Fig.8 Block diagram of the simulation circuit of the LDV system.



(a) Transient control



(b) Stationary control

Fig.9 Simulated result of controlling the output, i.e., the Doppler signal output of the band pass filter (BPF) at approximately constant amplitude.

value, the BPF output, i.e., the simulated envelope of the Doppler signal becomes twin topped as shown by a dashed line. Then the switching rate between the in-phase and the reversed phase becomes more than two times the modulation period. Because the peak hold circuit cannot respond to the rapid switching its output becomes a narrow 4V pulse followed by a gradually decaying tail. When the tail crosses down the reference voltage $V_r3(=2.2V)$ the comparator 3 output is switched to -15V until the next 4V pulse arrives. The comparator 3 output oscillating at about 8Hz is integrated by the integrator with a time constant 22 seconds, so the integrator output is moderately averaged to give a proper stationary drive current.

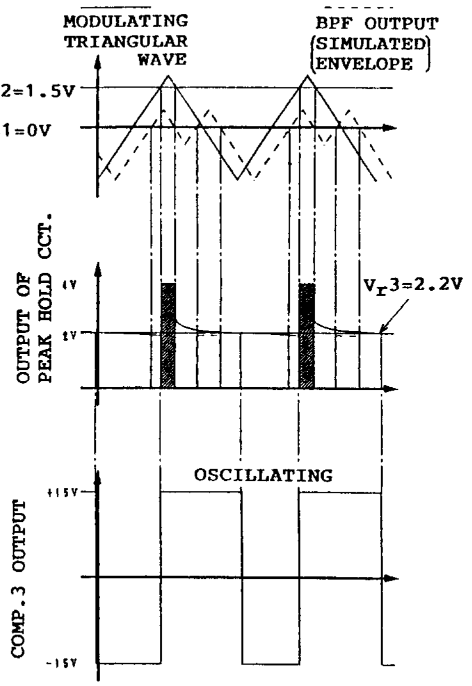


Fig.10 Principle how the operating point is stabilized in the vicinity of the optimum point.

4. Conclusion

A new stabilizing circuit of the Doppler beat signal obtained by the coherence-dependent fiber-optic laser Doppler velocimeter (LDV) is proposed and the feasibility has been verified using a simulation circuit of the fiber-optic LDV system.

The stabilizing circuit will expand the applicability of the fiber-optic LDV using a self-mixing laser diode (SM-LD) designed for remote sensing of a vibrating target placed in severe environment.

Acknowledgments

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