Optik 131 (2017) 609–614

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

The characteristic of laser Doppler signal of solid-state surface

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ARTICLE INFO

Article history:
Received 3 March 2016
Accepted 28 November 2016

Keywords:
laser Doppler velocimeter
Solid-state surface
Speckle
Signal intensity

ABSTRACT

In the designed laser Doppler velocimeter (LDV) for the vehicle self-contained navigation system, the reference object is a kind of solid-state surface. This paper expounded the generation mechanism of laser Doppler signal of this solid-state surface according to the order of the speckle field intensity variation. The expression of laser Doppler signal intensity of solid-state surface is derived based on the theory of speckle and stochastic process. Results of theory and experiments show that the essence of laser Doppler signal of solid-state surface is the coherence stack of two speckles. The signal intensity is directly proportional to the diameter of the photosensitive surface of detector and is inversely proportional to the diameter of laser spot on ground.

1. Introduction

Since the laser Doppler velocimeter (LDV) was conceived in the mid-1960's [1], soon after the invention of laser, its development has been led to widespread ongoing applications in many scientific fields for the advantages of good linearity, fast dynamic response, noncontact measurement and high resolution [2–4].

A typical application of LDV is utilizing this kind of instrument to determine flow velocities. Aiming at the situation of a single particle or several particles in the measuring volume, Rudd proposed an interference fringe model to give a complete description of the performance of the system [5]. Recently, some attempts using an LDV to offer parameter of velocity for the vehicle self-contained navigation system have been reported [6–8]. In this configuration, the ground is the reference object, so there is a great many particles in the measuring volume and each particle will produce a Doppler burst. Accordingly, the interference fringe model is not suitable for explaining the performance of the system any longer. As a matter of fact, little detailed attention has been given to the generation mechanism of laser Doppler signal of solid-state surface.

In the paper, the essence of laser Doppler signal produced by the motion of solid surface is explained according to the order of the speckle field intensity variation. The expression of laser Doppler signal intensity of solid-state surface is derived based on the theory of speckle and stochastic process, while the relationship between the signal intensity and the light spot size on ground is analyzed. In addition, the Doppler broadening caused by speckle is studied in experiment.

2. Theory and analysis

2.1. Optical setup for the vehicle self-contained navigation system

A typical configuration of LDV for the vehicle self-contained navigation system is shown in Fig. 1. The light source is a 50 mW solid-state green laser operating in a single longitudinal mode and the TEM_{00} transverse mode. The output of the

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http://dx.doi.org/10.1016/j.ijleo.2016.11.193
0030-4026/

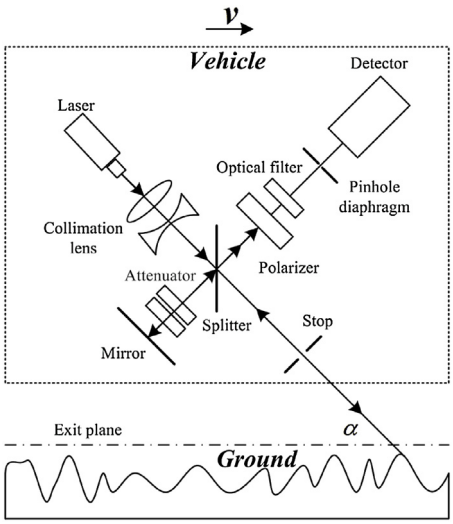

Fig. 1. Schematic of LDV for the vehicle self-contained navigation system.

laser passes through the collimation lens, which controls the divergence of the laser. The next element in the optical train is the splitter which divides the input beam into a transmitted and a reflected beam. The reflected beam passes through the attenuator on the mirror, then transmits along the negative direction and passes through the attenuator, splitter, polarizer, optical filter and pinhole diaphragm onto the detector. We call it "reference beam". The transmitted beam passes through the stop and the antenna on the ground so that scattered light is distributed in all direction. The light received by the antenna transmits along the negative direction and passes through the stop. Then it is partly reflected by the splitter. After that, it also passes through the polarizer, optical filter and pinhole diaphragm onto the detector. We call it "signal beam". As a result, the two beams combines and are photodetected with homodyne detection. When the vehicle is running on the ground, Doppler signal will be acquired by the data acquisition board, and is passed into the navigation computer which extracts the Doppler frequency and calculates the velocity of the vehicle [6].

$$v = \frac{\lambda f_D}{2\cos\alpha} \tag{1}$$

Where f_D is Doppler frequency, v is the velocity of the vehicle, α is the inclination angle of the probe and λ is the wavelength of laser.

2.2. Generation mechanism of laser Doppler signal of solid-state surface

It is well known that the reflection of coherent light from a rough surface produces speckle pattern. In the present LDV for the vehicle self-contained navigation system, when the vehicle runs on the ground, the speckle will also move in the same direction with a proportional velocity.

At the time of t_1, the resultant field of signal beam and reference beam falling on the detector is

$$U_1 = A_o \exp(i\varphi_o) + A_R \exp(i\varphi_R) \tag{2}$$

Where A_o and A_R are amplitudes of signal beam and reference beam respectively, φ_o and φ_R are phases on the detector of signal beam and reference beam respectively.

The intensity of the total field is

$$I_1 = A_o^2 + A_R^2 + 2A_oA_R\cos(\varphi_o - \varphi_R) \tag{3}$$

However, at the time oft_2, the intensity of resultant field falling on the detector is

$$I_2 = A_o^2 + A_R^2 + 2A_oA_R\cos(\varphi_o - \varphi_R + \delta_c) \tag{4}$$

Where

$$\delta_c = \Delta S \times \frac{2\pi}{\lambda} \tag{5}$$

is phase variation produced by the moving of the vehicle and ΔS is the optical path difference of the two fields. If the phase variation δ_c equals 2 pi, 4 pi, 6 pi et al. the intensity of speckle will be the same as primary, which is called correlation. But if the phase variation δ_c equals pi, 3 pi, 5 pi et al. the intensity of speckle will reverse so that bright speck turns into dark