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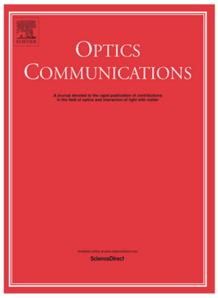

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Rotation Speed Measurement Based on Self-Mixing Speckle Interference

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A novel method to measure rotation speed on the basis of self-mixing speckle interference (SMSI) is proposed. The autocorrelation property of SMSI is used to determine the time delay combined with the circumference of one rotation period. In this way, the rotation speed can be measured. The proposed method is easy to implement, and it can reduce the limitation imposed by sampling rates on rotation speed range.

Keywords: self-mixing; speckle; interference

I. INTRODUCTION

Self-mixing interference (SMI) is a coherent light emitted by a laser and reflected back to the resonator changes the intensity and frequency of the light itself. SMI is used to measure the displacement, vibration, and velocity of objects [1-6]. Under SMI, when the beam illuminates a rough rotating object, the laser beam is scattered by random elements on the object, producing a moving random interference pattern known as dynamic speckle, which can be observed through a CCD [7]. When the object moves, the dynamic speckle moves with it. Thus, the properties of speckle patterns can be used to analyze not only the roughness of objects but also their movement. The properties of speckle patterns are combined with SMI; when a beam of light illuminates a rough object and is reflected back to the resonator, the self-mixing speckle interference (SMSI), which includes the motion information of the object, is generated [8]. SMSI can be used to measure the velocity, displacement of objects.

When using SMSI to measure the velocity of an object, the method usually employed is curve fitting [8-10]. A linear relationship can be obtained by fitting the statistical characteristics of a self-mixing speckle and several initial velocities. For this approach, essential parameters such as several initial velocities, the statistical characteristics of the self-mixing speckle, and the curve fitting function should be obtained so that velocity can be measured. In this method, the statistical characteristics of the self-mixing speckle can be the mean frequency [9], autocorrelation frequency, or energy density of the self-mixing speckle [8, 11]. Velocity measurement can also be achieved using the waveform characteristics of a self-mixing speckle signal; the waveform can be processed as a fractal pattern, and the velocity of the object can be determined by the relationship between the fractal boxes and the velocity [12]. The Doppler frequency shift method is usually used to measure the velocity of an object on the basis of $f_D = 2v\cos\theta/\lambda$ (where f_D is the Doppler frequency shift, θ is the angle between the laser and the object, and λ is the laser wavelength). In using the Doppler frequency shift method, obtaining f_D is crucial. In the experiment, a high sampling rate is required to measure the high speed, and data processing is needed to extract the Doppler frequency shift. The commonly used methods are fast Fourier transform (FFT) and power spectrum [4, 13, 14].

In the present study, a new method of rotation speed measurement based on SMSI is proposed. In this method, the autocorrelation of SMSI is used to obtain the time delay to measure the rotation speed. When a point on an object is illuminated by a laser and passes one rotation period of the object, the autocorrelation coefficient of the SMSI at the point reaches its maximum. According to the theoretical derivation of the Fabry–Perot (F-P) cavity, the corresponding time delay, combined with the circumference of the object, can be obtained to measure the velocity. This method does not require curve fitting to estimate velocity, and data processing is easy to implement. And it could reduce the high cost associated with the high sampling rate of the Doppler frequency shift. The method achieves simple, accurate, and noncontact measurement.

II. PRINCIPLE OF ROTATION SPEED MEASUREMENT BASED ON SMSI

The output power of the laser diode (LD) is modulated when SMSI occurs. When an object rotates, the self-mixing speckle signal reflects the movement information of the object, and the rotation velocity can be measured by analyzing the self-mixing speckle signal. In this study, the F-P cavity, combined with the Huygens–Fresnel principle, is used to describe SMSI.

In Fig. 1, r_1 and r_2 denote the reflectance coefficients of two laser internal cavities S_1 and S_2, respectively; L_D denotes the length of the internal cavity; L_E denotes the length of the external cavity; S denotes the rotating object; v denotes the angular velocity of the object; and C denotes the perimeter of the rotating object.