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Novel Velocity Detection of Moving Object with Rough Surface Vertically Illuminated by Self-Mixing Laser Diode

Takaaki Shibata, Shigenobu Shinohara, Hiroaki Ikeda,
Hirofumi Yoshida, and Masao Sumi*
Shizuoka University, Hamamatsu, 432 Japan
*Chiba Institute of Technology, Narashino, 275 Japan

Abstract

We propose a novel velocity detection method of moving object based on a speckle pattern on the target surface using a self-mixing laser diode (SM-LD). By this measurement, it was confirmed that the speckle signal has its waveform independent of the target velocity, and has its averaged frequency directly proportional to the target velocity. So it will be possible to detect the velocity of the target transversely translating against the laser light beam using a compact measuring system.

1. Introduction

Recently, we proposed and have developed various measuring instruments[(1)-(4)] for range and/or velocity using a self-mixing laser diode (SM-LD). An SM-LD uses a laser diode (LD) and detects a Doppler beat signal by heterodyning in the laser resonator, therefore by using this, we can make the measurement system very compact and simple.

In conventional velocity measurements using an SM-LD, a target is translated or rotated so as to have a velocity component in the same direction with the laser light beam. Then this directional component of the target velocity is detected by the measurement based on the Doppler effect.The detected Doppler beat signal is produced by mixing with an original light and a Doppler shifted reflected laser light beam.

Now, in this paper, we propose a novel method of detecting a target velocity using an SM-LD. In this case, a target is transversely translated against the laser light beam, then the measurement does not base on the Doppler effect but on a speckle pattern on the target surface. So, in this method a target velocity is obtained from an intensity change of the reflected laser light beam due to the speckle pattern on the target surface.

2. Measuring System

Fig.1 shows a schematic configuration of a velocity measuring system.

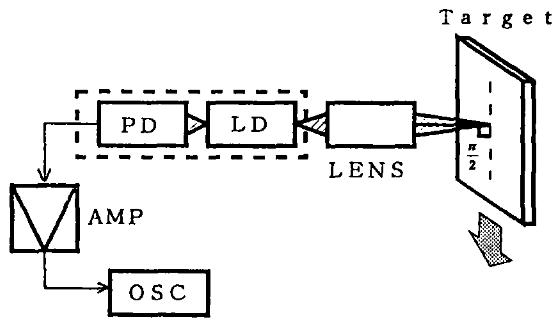


Fig.1 Schematic configuration of a velocity measuring system.

The light beam emitted from an LD illuminates the target, and is backscattered on the target surface. Some parts of the backscattered light reenters the laser resonator through the same path, and there, it is mixed with the original light to be detected as a speckle signal. The speckle signal depends on the apparent reflectance change due to a speckle pattern on the target surface. Then this signal is detected from a photodiode (PD) accomodated in the laser package.

The target placed on a rotating stage is assumed as transversely moving against the laser light beam during a short time. In this condition, the target is illuminated and continually scanned on its surface by a fixed laser light beam.

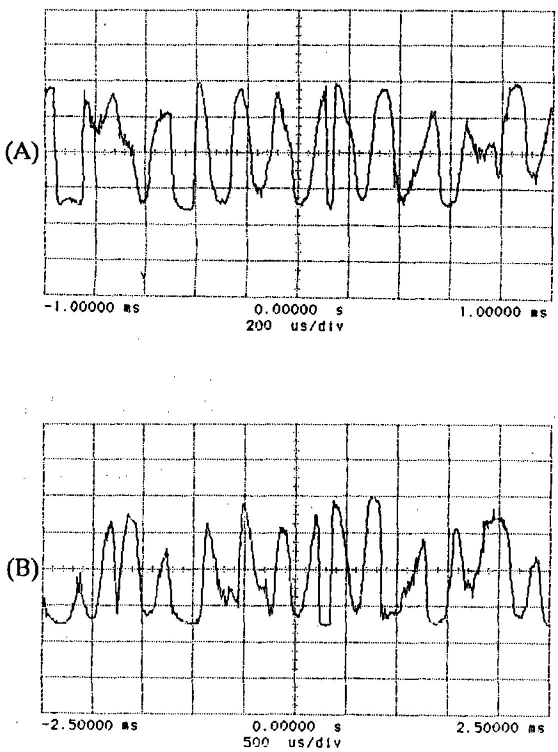
In the system, we can repeat the measurement along the same path on a target surface, the initial point of which is triggered by a trigger circuit detecting a hole in the rotating stage.

On the other hand, strictly speaking, the scanned path on the target is not a straight line. Nevertheless, we use the rotating stage instead of a linear translator such as a linear rotary unit. The reason is that the influence of the vibration caused by the linear rotary unit could be suppressed by the use of the rotating stage.

3. Measurement and Results

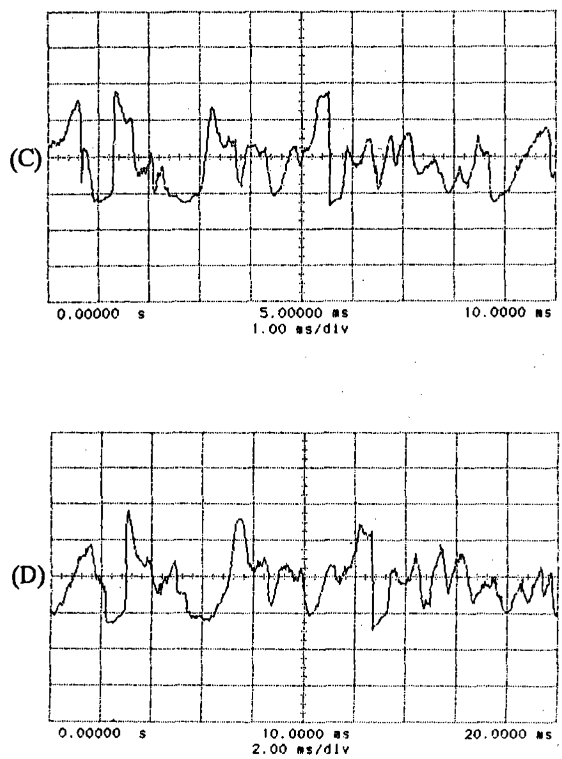
3.1 Speckle Signal Waveform

Typical examples of obtained speckle signals are shown in Fig.2.



Target: White painted rubber plate
Target velocity:(A) 426mm/s
(B) 182mm/s

Fig.2 Measured speckle signal waveforms.



Target: Copper plate
Target velocity:(C) 240mm/s
(D) 104mm/s

Fig.3 Another examples of measured speckle signal waveforms.

In Fig.2, the target is a white painted rubber plate, and it moves at a constant speed of (A): 426mm/s, and (B): 182mm/s, respectively. The observing times for (A) and (B) are so adjusted that they will make each scanned path on the target surface by a laser light beam nearly the same each other. The observing time or scanning time is chosen as inversely proportional to the target velocity.

The both waveforms (A) and (B) are obtained for the same scanned path on the target surface by using the trigger circuit.

From Fig.2, the following facts are comfirmed. Whenever the target is translated at a given constant speed along the same short path on its surface, the same waveform is observed. And in case of another speed, a signal waveform similar to the former one is observed on the cathode ray tube (CRT) of an oscilloscope with a horizontal time scale divided by the ratio of two speeds. In short, the measured speckle signal waveform depends only on the path on the target surface scanned by the laser light beam, and it is independent of the target velocity.

Now, another examples of obtained speckle signals are shown in Fig.3.

In this case, the target is a copper plate, and its surface is measured in like manner of Fig.2. From Fig.3, the signal waveform of (C) is similar to that of (D), so the same fact deduced from Fig.2 can be reconfirmed.

3.2 Mean Speckle Signal Frequency versus Velocity

As mentioned above, a speckle signal is peculiar to the scanned path, and the signal waveform obtained at another path is different from each other having a slightly different speckle signal frequency. We define the speckle signal frequency as an averaged frequency of the speckle signal observed during a measuring time. Provided that the target surface has uniform roughness, it is expected that the mean speckle signal frequency which is a mean of some speckle signal frequencies measured at different paths should be nearly constant irrespective of measured paths. Then Fig.4 shows the distribution of the speclke signal frequency measured at some paths on the target surface as a function of the target velocity. The target is a white painted rubber plate.

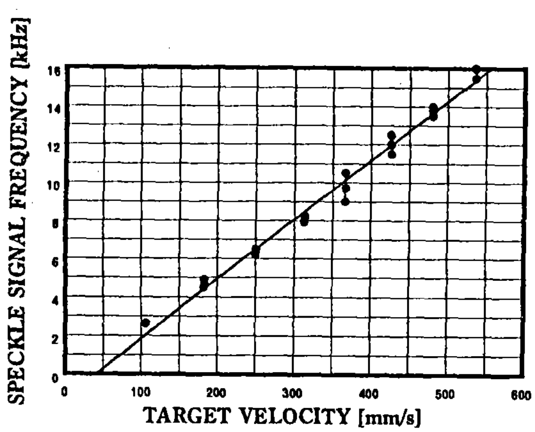


Fig.4 Distribution of the speckle signal frequency versus target velocity, which is measured at some paths on the target surface.

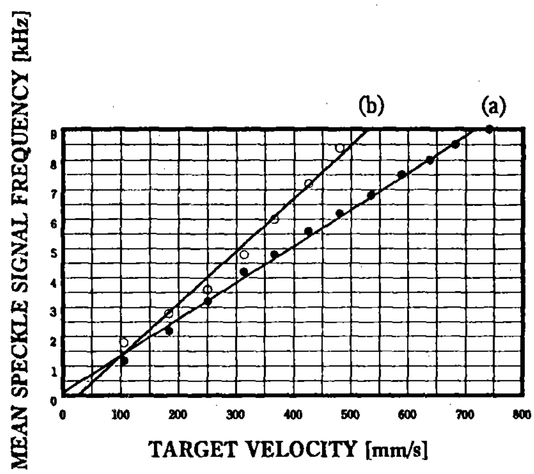


Fig.5 Relationship between the target velocity and the mean speckle signal frequency, which is obtained at one path on each target surface.
(a): a paper with a smooth surface
(b): a white painted rubber plate with a rugged surface

As seen from Fig.4, speckle signal frequencies have different values against the same velocity of the target, but the mean of the plotted points fit well with a straight line drawn by the least square method. Therefore, when the target surface has uniform roughness, the mean speckle signal frequency becomes indepent of the scanned places, and it will be directly proportional to the target velocity. The proportional coefficient will be different for different targets.

Fig.5 shows the relationship between the mean speckle signal frequency and the target velocity obtained for two objects. In Fig.5, the targets are (a): a paper with a smooth surface and (b): a white painted rubber plate with a rugged surface. From Fig.5, it is found that the mean speckle signal frequency is derectly proportional to the target velocity, and that each proportional coefficient for the two targets is different.

According to the results described above, provided that we find a proportional coefficient corresponding to the surface condition of the target in advance, it will be possible to measure the target velocity by detecting the mean speckle signal frequency with this measuring system.

In this paper, we measured the speckle signal frequency by visually counting the number of waves contained in the signal. It is necessary to automatically measure the mean speckle signal frequency, and to find the optimun measuring time.

4. Conclusion

It was confirmed that the speckle signal obtained by a self-mixing laser diode (SM-LD) has its averaged frequency directly proportional to the target velocity, and that the proportional coefficient depends on the roughness of the target surface. So, provided that we find a proportional coefficient corresponding to the condition of target surface, which affects the apparent reflectance of the target surface, it will be possible to measure the target velocity by detecting the mean speckle signal frequency with this measuring system.

In addition to the velocity measurement, it is also confirmed that the speckle signal waveform depends only on the place on the target surface scanned by the laser light beam, and does not on the target velocity. In this point of view, analyzing the speckle signal waveform will enable us to detect the target surface condition.

However, further reseach is needed to detect the velocity from an actual signal waveform.

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