Measurement 77 (2016) 67–72

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Improvement and validity of shock measurements using heterodyne laser interferometer

H. Nozato *, W. Kokuyama, A. Ota

National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology, Tsukuba, Ibaraki 305-8563, Japan

ARTICLE INFO

Article history:
Received 23 January 2015
Received in revised form 11 August 2015
Accepted 19 August 2015
Available online 10 September 2015

Keywords:
Shock
Acceleration measurement
Homodyne laser interferometer
Laser Doppler vibrometer
Heterodyne laser interferometer

ABSTRACT

The improvement and validity of shock measurements using only the laser head (heterodyne laser interferometer) of a commercial laser Doppler vibrometer was investigated by comparing acceleration waveforms measured by a homodyne laser interferometer with those measured by a heterodyne laser interferometer. The acceleration waveforms were generated from the displacement waveforms obtained with a reference quadrature homodyne laser interferometer by applying a numeric differentiation process twice. The differences between the two acceleration waveforms were found to be small with the measurement uncertainty in case of high acceleration level. In a further investigation, the accuracy of the shock measurements taken by the homodyne and heterodyne laser interferometers were compared in computational simulation. The results indicated that the accuracy of the heterodyne laser interferometer was superior to that of the homodyne laser interferometer.

1. Introduction

This paper reports an investigation of shock measurements performed using only the laser head of a Laser Doppler Vibrometer (LDV). Recently, commercial LDVs with high sensitivity have appeared on the market and are being used to perform a variety of dynamic measurements. This is because, as a non-contact instrument, a LDV does not affect the object being measured. In general, LDVs have a compact laser head, a high frequency response, and a wide dynamic range for velocity measurement. These characteristics are also useful for measuring physical quantities such as displacement or acceleration.

LDVs are heterodyne-type measurement instruments that comprise a compact laser head and a signal demodulator. The laser head has a heterodyne laser interferometer with a built-in acousto-optic modulator (AOM) to obtain a frequency offset in the optical domain. At the output of the photo detector, the same frequency as the carrier frequency of the heterodyne Doppler signal occurs. The signal demodulator outputs a voltage signal proportional to the velocity signal with a little time delay by calculating the Doppler signal. According to a previous research, three different commercial analogue signal demodulators showed a deviation of several percentages from nominal sensitivity each other, and the nominal sensitivity also included nonlinearity higher than 5% in velocity range from 3 mm/s to 100 mm/s at 160 Hz [1]. However, in some cases the laser head of a commercial LDV has various advantages as heterodyne laser interferometer over our homodyne laser interferometer. First, the heterodyne laser interferometer does not utilize reflective mirrors on the back-to-back transducer's surface to obtain a sufficient intensity of interferometric signals; this is because the heterodyne laser interferometer equips optical lenses to efficiently collect scattered light in a larger area. However, our homodyne laser interferometer does not equip such optical lenses.

* Corresponding author.
E-mail address: hideaki.nozato@aist.go.jp (H. Nozato).

http://dx.doi.org/10.1016/j.measurement.2015.08.037
0263-2241/

Thus, the resonance frequency of the transducer does not shift in shock calibration. A second advantage, which relates specifically to compact laser heads, is the efficient and easy multi-point measurement. This allows various types of transducers to be calibrated. Based on these advantages, many users consider replacing homodyne laser interferometers with heterodyne laser interferometers of LDVs. Therefore, homodyne and heterodyne laser interferometers were compared with no time delay by recording both interferometric signals with digitizers and off-line processing. To confirm the reliability of shock measurements taken by the heterodyne laser interferometer, we evaluated the shock measurements with those taken by a homodyne laser interferometer. Both the homodyne and heterodyne laser interferometers' measurements were taken in the shock calibration system [2] at National Metrology Institute of Japan (NMIJ), which was developed with a He–Ne homodyne quadrature laser interferometer in compliance with ISO 16063-13 [3].

The shock waveforms typically have half-sine shapes with peak accelerations of 50–10,000 m/s^2 and durations of 0.5 –5.0 ms. Previous studies have evaluated the use of heterodyne laser interferometers to demodulate a Doppler signal from their laser head. NMIJ [1] and PTB [4,5] compared an in-house developed homodyne with heterodyne laser interferometers, respectively. However, since the acceleration measurements were performed using a vibration exciter, the sinusoidal velocity was limited to below a few hundredths of a meter per second. The Doppler signal frequency shifts in response to the velocity of the object being measured. For velocities lower than a few hundredths of a meter per second, the frequency shift is about 1 MHz. The velocity generated in shock calibration with a peak acceleration of 10,000 m/s^2 approaches 3 m/s, in which case the frequency shift of the Doppler signal could be up to 30 MHz. However, no report exist evaluating performance of heterodyne laser interferometer with large frequency shifts. Thus, it is significant to investigate the reliability of shock measurements taken using heterodyne laser interferometers in the velocity range up to 3 m/s. This study reports an investigation of such performances.

2. Methods and experimental configuration of homodyne and heterodyne laser interferometers

Fig. 1 shows a set-up photograph of the homodyne and heterodyne laser interferometers installed in the shock calibration system. Fig. 2 stands for a schematic block diagram of the set-up photograph. The homodyne and heterodyne laser interferometers measure the motion of the generated shock at the same position by means of a beam splitter. The homodyne laser interferometer is a modified Michelson type. It detects a pair of quadrature signals that have a phase difference of 90°. The quadrature signals respond to the change in displacement [6] and are twice transformed into acceleration through double numerical differentiation. The heterodyne laser interferometer is the laser head of a commercial LV-1800 manufactured by Ono Sokki Co., Ltd. It has high sensitivity with a carrier frequency of 80 MHz by an AOM. The Doppler signal includes the information in displacement change, which is finally converted to acceleration.

The output signals of the two measuring devices were connected to a PXI system to record the quadrature and Doppler signals respectively, as shown in Table 1. The PXI system consisted of two PXI 5152 digitizers with 8 bit resolution and maximum sampling frequency of 1 GHz. The system digitized both the quadrature and Doppler signals synchronously, even if their sampling frequencies would differ. A rubidium frequency standard provided the reference frequency of 10 MHz to the PXI system to improve the sampling accuracy from 10^{-5} to 10^{-12}. The phase-jitter of the PXI system is up to 1 ps RMS because of the specification sheet, and locked to the clock generator with rubidium frequency standard.

Fig. 3(a) presents typical quadrature (upper) and Doppler (bottom) signals of a shock with different sampling

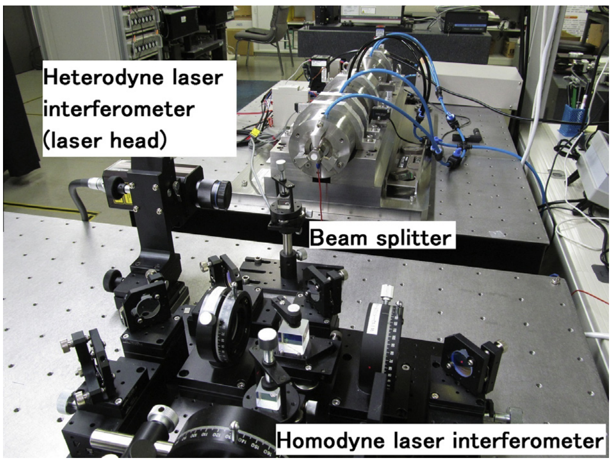

Fig. 1. Homodyne laser interferometer and laser head (heterodyne laser interferometer) of LDV in shock calibration system.