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INVESTIGATION OF TRIAXIAL SHOCK MEASUREMENT BY USING THREE LASER DOPPLER VIBROMETERS

Hideaki Nozato[1], *Wataru Kokuyama*[1] *and Takashi Mashiko*[2]

[1]National Metrology Institute of Japan, Tsukuba, Ibaraki, Japan, hideaki.nozato@aist.go.jp
[1]National Metrology Institute of Japan, Tsukuba, Ibaraki, Japan, wataru.kokuyama@aist.go.jp
[2]Shizuoka University, Hamamatsu, Shizuoka, Japan, mashiko.takashi@shizuoka.ac.jp

Abstract: This manuscript describes a novel concept of triaxial shock measurement system with three combined laser Doppler vibrometers and Hopkinson bar. This system measures three-dimensional acceleration at one point for evaluating frequency response (sensitivity and phase shift) of triaxial accelerometers. At the conference, the experimental results will be presented.

Keywords: Shock, Triaxial shock measurement, Hopkinson bar, heterodyne laser interferometer, accelerometer

1. INTRODUCTION

Triaxial shock measurement using accelerometers is widely used from the viewpoint of safety evaluation for human bodies or various products in industries. For such accelerometers, although primary shock calibration by means of hammer-anvil or Hopkinson bar [1] is carried out in compliance with ISO 16063-13[2], previous primary shock calibration is mainly limited for uniaxial accelerometers [3, 4]. Using sinusoidal motion and matrix sensitivity, the sensitivity, transverse sensitivity or phase delay are also calibrated [5]. However, since each laser interferometer monitored at different measurement points in the calibration method, it is difficult to precisely evaluate the sensitivity along to the sensitive axis.

So, triaxial shock measurement system with a laser head of three laser Doppler vibrometers (LDVs) has been developed at National Metrology Institute of Japan (NMIJ). The triaxial shock measurement system measures one point at the same time, and can evaluate matrix sensitivity. The final goal is to evaluate triaxial accelerometers by considering transverse sensitivity in a shock facility.

2. TRIAXIAL SHOCK MEASUREMENT SYSTEM

Figure 1 presents schematic concept of the triaxial shock measurement with a certain angle for measuring one point. The triaxial shock measurement system mainly consists of three laser Doppler vibrometers which equip a high-sensitivity laser head as heterodyne laser interferometer. The heterodyne laser interferometer has a carrier frequency of 80 MHz and a He-Ne laser source with a wavelength of 632.8 nm. In the specification sheet, the measurable upper limit is 20 m/s. The three heterodyne laser interferometers measure one point crossing three sight lines with a certain angle of 17 degree. Consequently, the focal length is constant on the surface of Hopkinson bar which is steel circular cylinder with a length of 3 m and a diameter of 0.03 m. From the opposite surface of measuring point, aluminium bullet is beaten by pressurized air.

The system equips two PXI-5152 digitizers with a sampling frequency of 500 MHz and a vertical resolution of 8bits. In current situation, the triaxial shock measurement system employs the output of a single-axial accelerometer (B&K 8309) as a trigger in which PXI 5922 with vertical resolution of 18 bits and sampling frequency of 10 MHz is used. These PXI digitizers receive reference signal of 10 MHz from rubidium time base. BK 8309 is a piezo-electric accelerometer for high-acceleration measurement up to 1,000,000 m/s^2.

The three heterodyne laser interferometers output a Doppler signal $V_{Doppler}(t)$ depending on displacement $s(t)$ as equation (1).

$$V_{Doppler}(t) = V\cos\left(\omega t + \frac{4\pi\, s(t)}{\lambda}\right), \qquad (1)$$

where ω and V are the carrier frequency (80 MHz) of the Doppler signal and its amplitude, Each Doppler signal is directly recorded by the PXI 5152. After that, the Doppler signal is mixing with the carrier frequency, and the displacement is derived through 4th–order digital Butterworth low-pass filter with a cut-off frequency of 100 kHz.

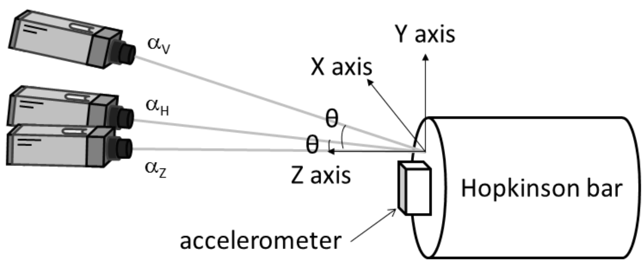

Fig. 1 Schematic configuration of triaxial shock measurement using three heterodyne laser interferometer and Hopkinson bar.

3. EXPERIMENTAL SET-UP

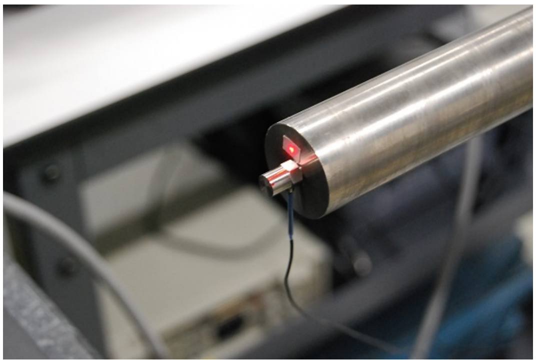

Fig. 2 Appearance of reflective tape and accelerometer on surface of Hopkinson bar.

Figure 2 shows the appearance of a reflective tape with the thickness of 0.1 mm to get sufficient scattered light from the surface of the Hopkinson bar. Then, the indicator about light intensity of a detector implies maximum. Since the thickness is much shorter than the wavelength of the elastic wave, the existence of the tape would be negligible on shock measurement. The details are described later.

Figure 3 presents an original result of measured acceleration and accelerometer signal by triaxial shock measurement system. The noise level is roughly ± 50 m/s^2 depending on the cut-off frequency of the low-pass filter. The three acceleration waves look almost the same

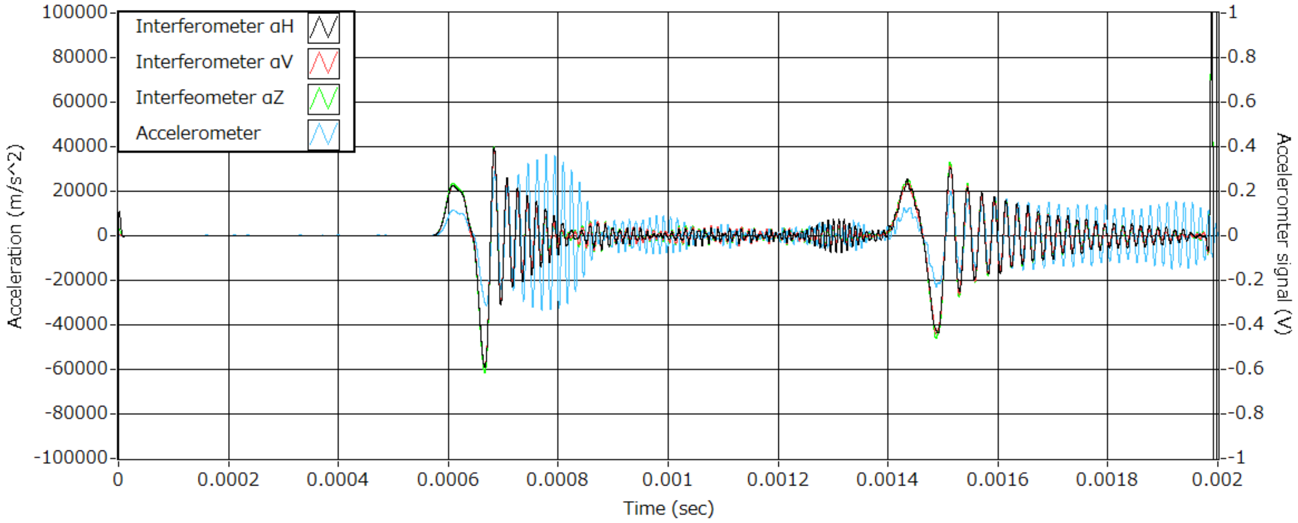

Fig. 3 Original signals from three laser interferometers and accelerometer signal with reflective tape.

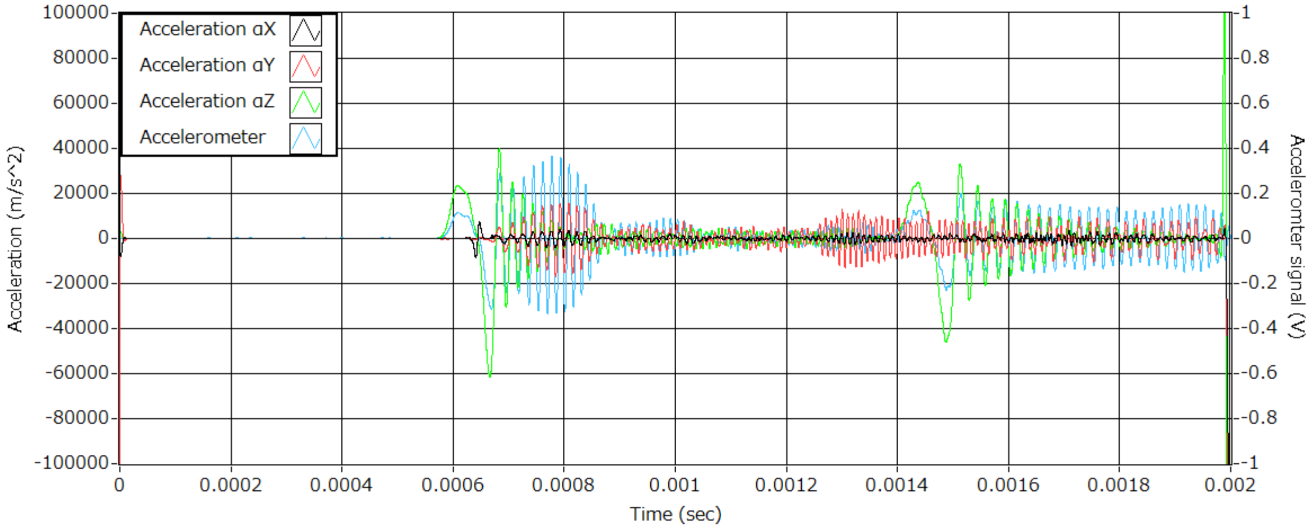

Fig. 4 Three accelerations in X, Y, Z directions and accelerometer signal based on figure 3.

In the triaxial shock measurement system, Z axis is the direction in which an elastic wave propagates in the Hopkinson bar. One laser interferometer measures the acceleration α_Z in parallel with Z axis. The two other laser interferometers monitors the focal point with a slight difference angle θ of 17 degree from Z axis. Denoting that the two other laser interferometers α_H and α_V, α_X and α_Y can be respectively written by calculating sin and cos components as follows.

$$\alpha_X = \frac{\alpha_H - \alpha_Z \cos\theta}{\sin\theta}, \qquad (2)$$

$$\alpha_Y = \frac{\alpha_V - \alpha_Z \cos\theta}{\sin\theta}. \qquad (3)$$

Figure 4 shows triaxial accelerations in X, Y and Z directions using equations (2) and (3). The dominant acceleration component in the first dipole waveform from 0.5 ms to 0.6 ms is mainly in Z axis. After that, twelve periodic waves are observed from 0.6 ms to 0.8 ms. Its frequency f corresponds to about 60 kHz which in Y direction is much smaller than that in X and Z directions. Also, the dominant shock component is only in Z direction during the first dipole waveform. After that, triaxial shock components in all the three directions are observed.

From the following equation, the wavelength λ of the elastic wave can be estimated as 0.125 m.

$$\lambda = \frac{v}{f} \qquad (4)$$

Here, the velocity is calculated by taking time of 0.0008 s with reciprocating the Hopkinson bar due to figure 3. Since the thickness of the reflective tape is about 0.1 mm, the wavelength is much longer than the thickness. Thus, the effect using the reflective tape would be sufficiently small. Also, a time delay can be estimated as 13 ns due to the thickness of 0.1 mm.

Figure 5 shows the spectrum of the three accelerations in X, Y, Z directions and accelerometer signal on the basis of figure 4. The Z acceleration is most dominant, but some strong lines in the Y acceleration are observed. Around 60 kHz, a strong line commonly exists in Y acceleration and accelerometer signal. Over frequency range of 100 kHz, all the components gradually decrease because of the low-pass digital filter.

Figure 6 presents the effect of the reflective tape in high-shock measurement. For the purpose, two shock measurements are implemented with/without the reflective tape respectively. Black and red solid lines indicate high-shock waveform with the reflective tape, and green and blue lines are without one. Each characteristic is almost same. In order to experimentally investigate the effect of the reflective tape, the voltage shock sensitivities of an acceleration measuring instrument (an accelerometer BK 4809 and a charge amplifier BK 2635) are evaluated from the peak ratio between shock waveform and voltage waveform enclosed in a red circle. Around there, since the four waveform shape are resemble, the effect in relation to the frequency response of the acceleration measuring instrument is expected to be small. Table 1 shows the peak voltages, the peak accelerations and the voltage shock sensitivities among four high-shock waveforms.

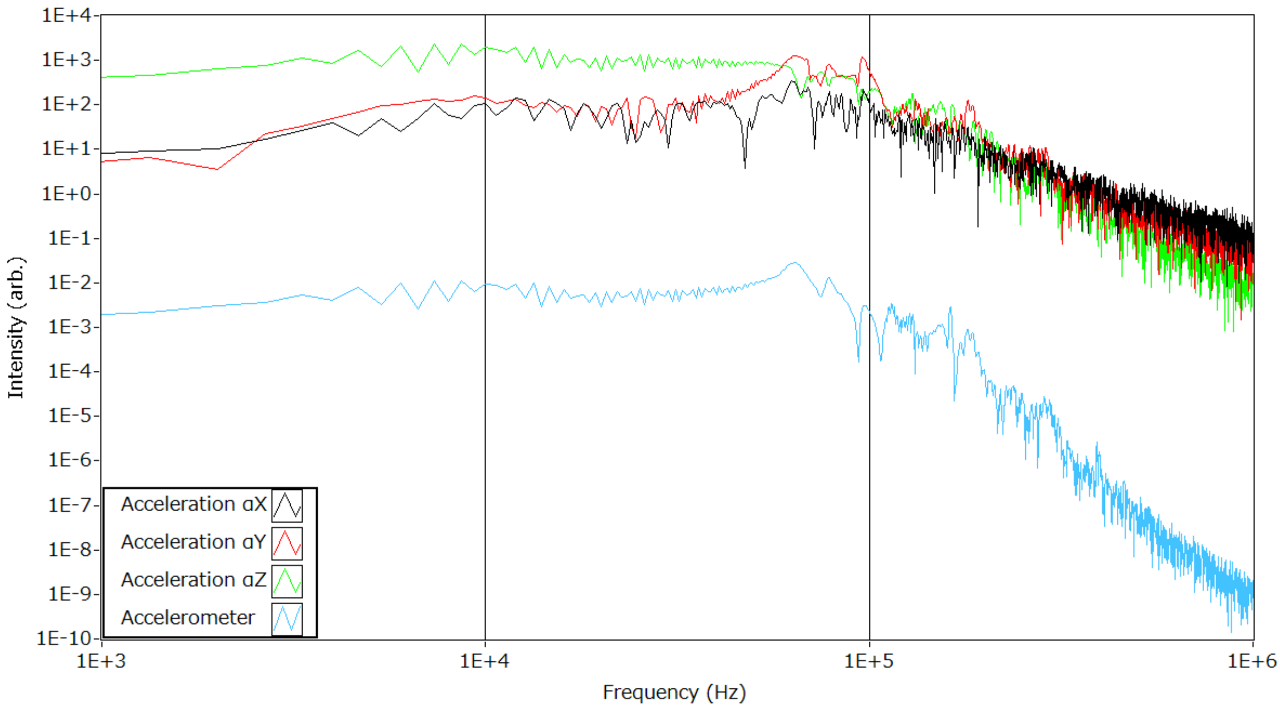

Fig. 5 Spectrum of three accelerations in X, Y, Z directions and accelerometer signal based on figure 4.

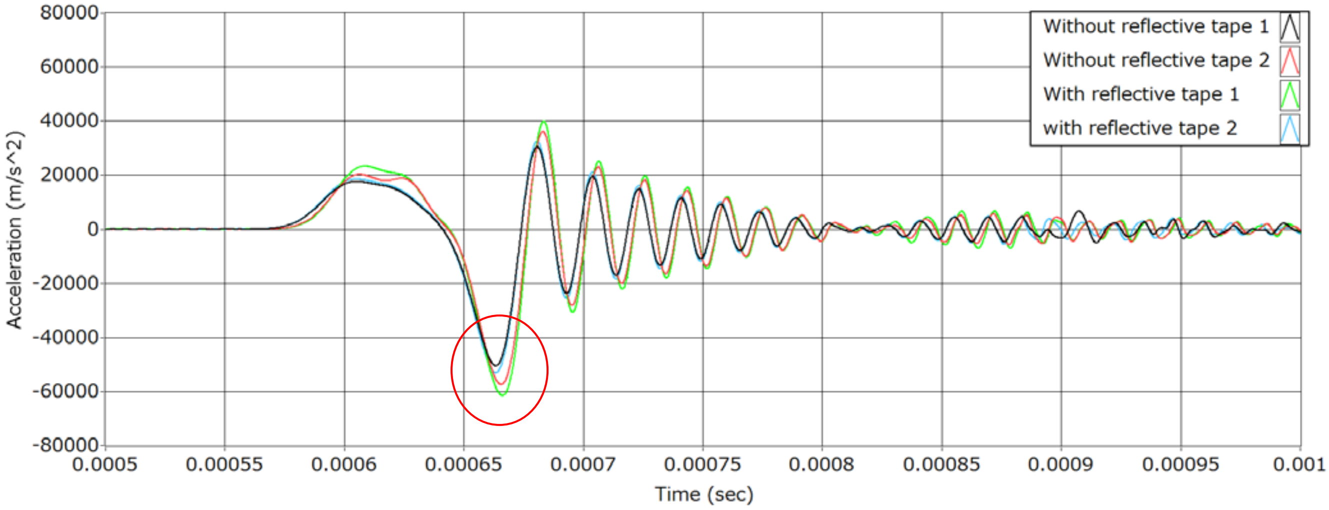

Fig. 6 Four high-shock waveforms with and without reflective tape.

Table 1 Four shock sensitivities with/without reflective tape.

Case	Peak voltage	Peak acceleration	Shock sensitivity
	V	m/s^2	$\mu V/(m/s^2)$
Without reflective tape 1	−0.258905	−50480.8	5.1288
Without reflective tape 2	−0.298277	−57370.7	5.1991
With reflective tape 1	−0.313240	−61454.5	5.0971
With reflective tape 2	−0.275078	−53010.1	5.1892

The average voltage shock sensitivities and its relative standard deviation are 5.1535 $\mu V/(m/s^2)$ and 0.82 %. Thus, it is expected that the reflective tape does not affect with several percents level in high-shock measurement.

4. SUMMARY AND FUTURE WORK

Initial experimental signals are obtained to measure triaxial high-shock using three heterodyne laser interferoemters monitoring the circular surface at the end on the steel Hopkinson bar. The signal level is sufficient to calculate triaxial acceleration components. Our final goal of this research is to evaluate a frequency response of triaxial accelerometers by considering input three-dimensional measured acceleration and accelerometer signal output. Further experiments will be required to confirm the validity of triaxial acceleration measurement toward high-shock calibration.

5. REFERENCES

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