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A STUDY OF SHOCK MEASUREMENTS USING HOMODYNE AND HETERODYNE LASER INTERFEROMETERS

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Abstract: A comparison measurement using homodyne and commercial heterodyne laser interferometers was investigated in the primary shock facility of NMIJ. Each derived shock waveform was calculated by applying a two stage differentiation process with 4th order Butterworth low-pass filter. As results, the time difference and the deviation between peak accelerations for two amplitude levels were respectively less than 1 μs and quite less than 0.01 %.

Keywords: shock, accelerometer, shock calibration, acceleration measurement, homodyne laser interferometer, heterodyne laser interferometer, laser Doppler vibrometer.

1. INTRODUCTION

Some national metrology institutes (NMIs) have developed vibration and shock calibration facilities with an acceleration measurement system using homodyne and heterodyne laser interferometers for primary calibration [1,2]. Recently, heterodyne laser interferometers of laser Doppler vibrometer (LDV) have started to be used in some facilities for primary calibration. In particular, commercial LDVs have some advantages as for instance non-contact high frequency measurement, easy position adjustment and sufficient signal intensity. Thereby, laser vibration calibration was investigated at high frequencies up to 100 kHz [3]. However, no comparison result between homodyne and heterodyne laser interferometers have been reported with a fast velocity measurement up to several m/s in primary shock calibration. A measurement comparison was implemented by comparing a commercial LDV with a homodyne laser interferometer in NMIJ. At the IMEKO conference, the comparison results will be presented.

2. SET-UP OF TWO LASER INTERFEROMETERS

Figures 1 and 2 show a set-up photography and a schematic diagram of the homodyne and heterodyne laser interferometers used in the NMIJ shock calibration facility. The homodyne system with two ATS660 digitizers is the standard measurement instrument in the primary shock calibration facility of NMIJ. The homodyne interferometer has a stabilized He-Ne laser light with a wavelength of 632.8 nm, and the ATS digitizer records interferometric quadrature signal with 16-bit resolution (input voltage of ±16 V) and 50 MHz sampling frequency. A LDV, LV-1800 manufactured by Ono Sokki co., ltd., with a PXI 5152 digitizer is also installed for the comparison. The LDV has a non-stabilized He-Ne laser light and the reference signal with a frequency of 80 MHz. The PXI 5152 digitizer records interferometric signal with 8-bit resolution (input voltage of ±1 V) and 500 MHz sampling frequency. Both laser interferometers monitor a same position of a dummy mass (DM) which presents an optically polished surface and are independently operated by two different personal computers. So, in order to adjust the start time of shock measurement in the two digitizers, each initial phase was evaluated using a 1 kHz sinusoidal function (See figure 3). Because the two digitizers have slightly different voltage scales. Figure 4 presents a result of each initial phase. Here, the trigger level in the ATS 660 digitizer was fixed at around 0.3 V at 4 ms for measurement of sine waves. Only the PXI 5152 digitizer was operated setting several trigger levels from 0.28 V to 0.33 V. As result, both initial phases were matched around 0.3 V. Thus, for proper synchronization between the two outputs, the trigger level of the PXI 5152 digitizer was determined as 0.3 V.

The LDV furnishes two outputs, i.e. for the Doppler and reference signals. The Doppler signal is directly recorded by the PXI 5152 digitizer to obtain an acceleration waveform without a time delay typically given by an analogue demodulator. The digital demodulation calculation is implemented by a Labview program. Firstly, a low-pass filtering was carried out to obtain quadrature signals after a mixing between the Doppler signal and an artificial array of 80 MHz. The acceleration waveform is given by a difference method applied twice in seaquence, together with a 4th-order Butterworth low-pass filtering; according to the basic concept which is introduced in ISO 16063-13 [4] .

3. EXPERIMENTAL RESULT

Figure 5 shows typical interferometric signals of the homodyne laser interferometer (upper) and LDV (bottom). The two interferometric signals (p and s waves) of the homodyne laser interferometer have a phase difference of 90 degree between each other and maintained constant amplitude before and after the shock. On the other hand, the amplitude of the LDV has changed, but the LDV’s signal amplitude is not important to precisely measure the motion quantity velocity by frequency demodulation. Thus, the effect of the changing amplitude would be small compared with the case of a homodyne laser interferometer.

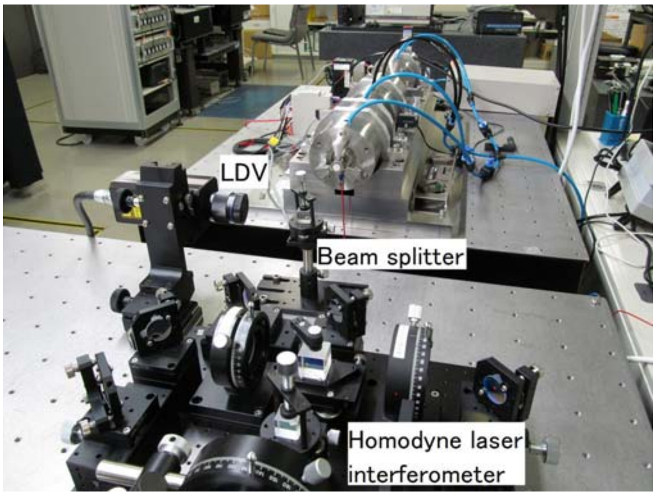
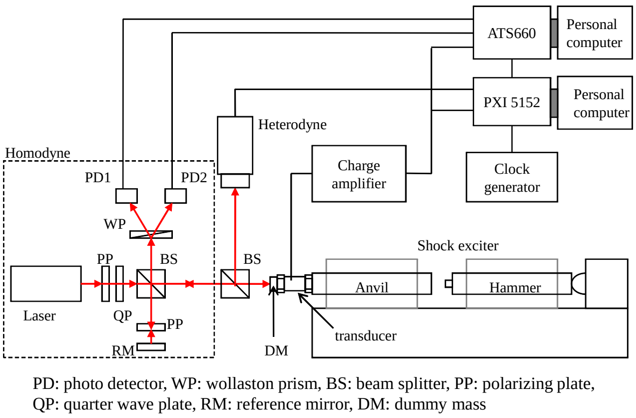


Figure 1 Photograph of homodyne laser interferometer and LDV for shock measurement.



PD: photo detector, WP: wollaston prism, BS: beam splitter, PP: polarizing plate, QP: quarter wave plate, RM: reference mirror, DM: dummy mass

Figure 2 Schematic diagram of homodyne laser interferometer and LDV for shock measurement.

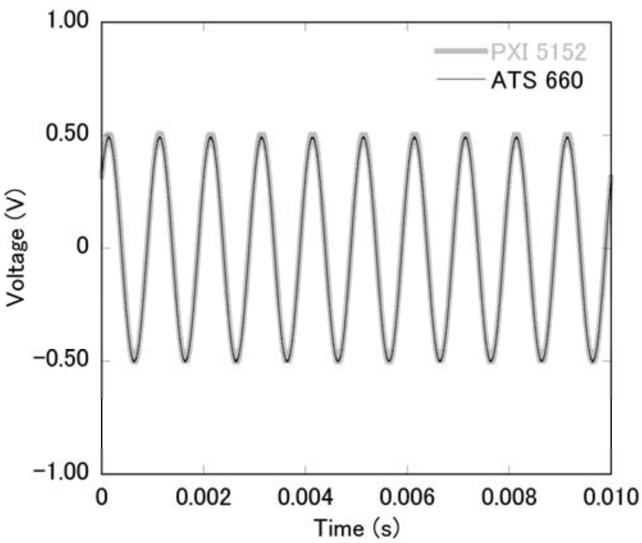


Figure 3 Sinusoidal waveform recorded by two digitizers; PXI 5152 and ATS 660.

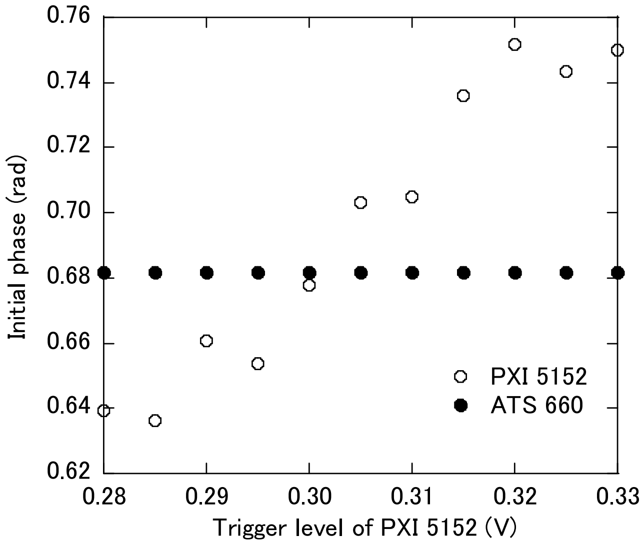


Figure 4 Evaluation of each initial phase in two digitizers; PXI 5152 and ATS 660.

Figure 6 shows a measurement result of two shock waveforms using the homodyne laser interferometer (thick grey line) and the LDV (thin red line). The velocity after the shock was about 1.5 m/s. (The velocity reached up to 3.0 m/s in the case of a peak acceleration with 10 000 m/s^2.) The two shock waveforms were decimated to a discrete-time frequency of 1 MHz. Each peak acceleration measured with the homodyne and the LDV was respectively 4 603.45 m/s^2 and 4 603.29 m/s^2, just at the same time of $t = 4.188$ ms. At that time, the deviation between the two peak accelerations was 0.003 5 %, which would be negligible in case of calculating the shock sensitivity. This happens because the typical uncertainty in the primary shock calibration of NMIJ is about 0.65 % [5]. Moreover, the difference (blue line) between the two shock waveforms was very small, being within ± 1 m/s^2.

Table 1 shows summarized values on the shock measurements by the homodyne laser interferometer and LDV. According to ISO 16063-22 [6], the duration was given by the time difference between two points at 10 % of the peak acceleration. Also, velocity after the shock was evaluated at t=6 ms and both velocities of homodyne laser interferometer and LDV were comparable. Although it was reported that LDV generally has a measurement dependence on velocity [7], such the dependence in this experimental comparison was not observed up to 3.0 m/s. Figure 7 presents a deviation of peak acceleration and difference of duration between homodyne laser interferometer and LDV from 2 000 m/s^2 to 10 000 m/s^2. The deviation between not only two peak accelerations but also two velocities was almost within ± 0.01 %, and the difference of two durations was also within ± 1×10^{-4} ms. Thus, these results demonstrate the similarity between the two shock waveforms and consistency of the two shock measurements, respectively.

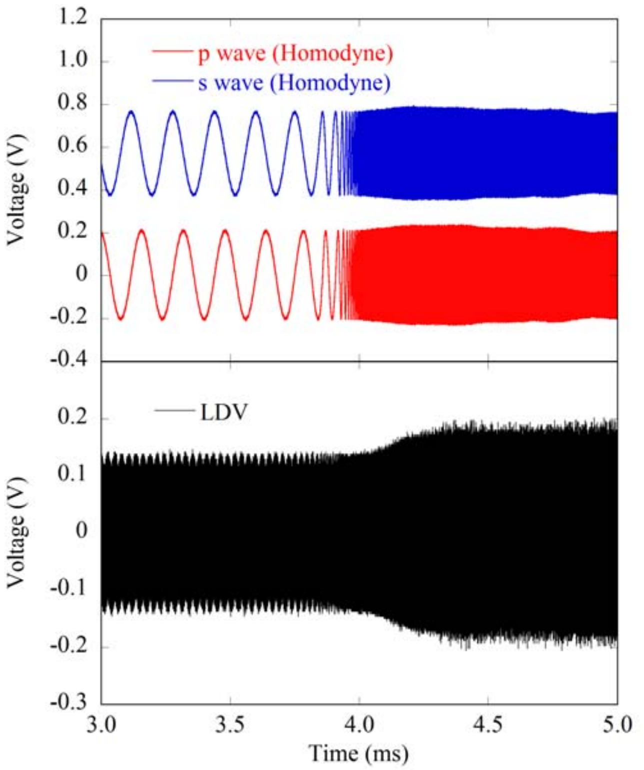


Figure 5 Interferometric signals of homodyne laser interferometer (upper) and LDV (bottom).

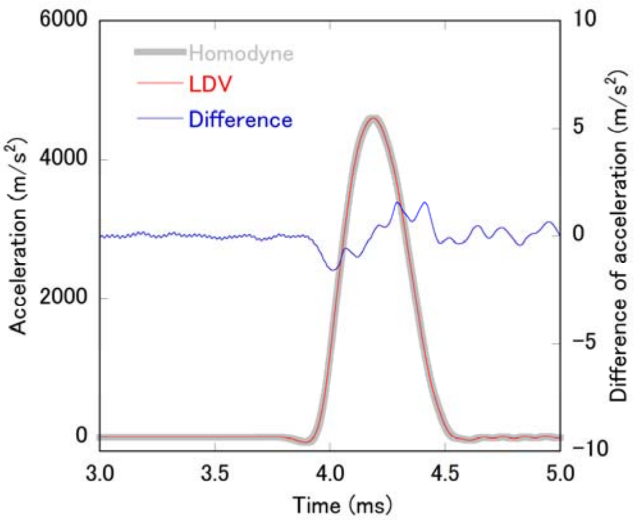


Figure 6 Shock waveforms measured by homodyne laser interferometer and LDV. Difference between the two shock waveforms.

Table 1 Summarized values on shock measurement by homodyne laser interferometer and LDV.

Homodyne			LDV		
Peak acceleration	Duration	Velocity (t=6 ms)	Peak acceleration	Duration	Velocity (t=6 ms)
m/s^2	ms	m/s	m/s^2	ms	m/s
2255	0.54	0.7676	2256	0.54	0.7677
5215	0.50	1.651	5215	0.50	1.651
4217	0.50	1.357	4217	0.50	1.357
4603	0.50	1.470	4603	0.50	1.470
4912	0.50	1.563	4913	0.50	1.563
7094	0.49	2.222	7094	0.49	2.223
7142	0.49	2.236	7142	0.49	2.236
8350	0.49	2.619	8350	0.49	2.619
8452	0.49	2.650	8453	0.49	2.650
8071	0.49	2.528	8071	0.49	2.528
9533	0.48	2.989	9534	0.48	2.990
9632	0.48	3.019	9633	0.48	3.020

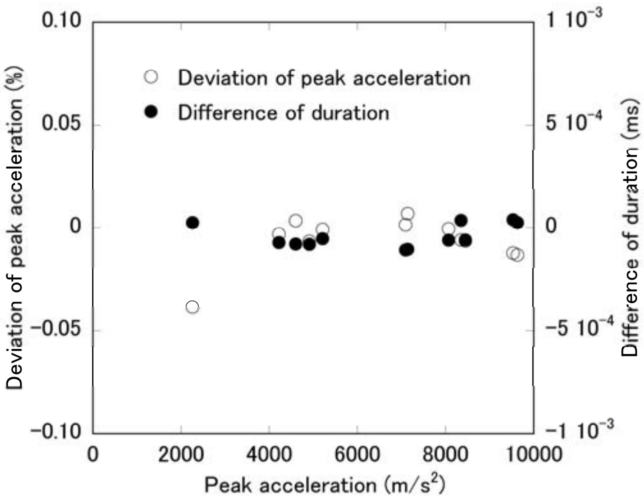


Figure 7 Deviation of peak acceleration and difference of duration on peak accelerations.

4. CONCLUSIONS

Two kinds of shock measurement using homodyne and heterodyne laser interferometers were investigated using the shock calibration facility of NMIJ. The homodyne laser interferometer is already established as the standard measurement device in shock calibration facility of NMIJ. The heterodyne is a commercial LDV, LV-1800 manufactured by Ono Sokki co., ltd.. The two laser interferometers were used to monitor monitored a same position at the same time during mechanical shocks with anvil velocities from 0.76 m/s to 3.0 m/s. According to the results, since the deviation of peak acceleration between the two shocks was almost within ± 0.01 %, the LDV can probably measure as same velocity up to 3.0 m/s as homodyne laser interferometer.

5. REFERENCES

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