Time delay evaluation for laser interferometer using electro-
optical modulator

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Abstract. Evaluating the response time of the laser interferometer for primary calibration of
the phase shift of accelerometers is an essential prerequisite. Therefore, the authors propose a
method to evaluate the response time of the laser interferometer with an easy and inexpensive
experimental set-up using an electro-optical modulator. This research uses the EOM to
modulate the optical length and gives the phase change to the quadrature signal, thereby this
method determines the intrinsic time delay of the photo-detector with a preamplifier in the
laser interferometer used in NMIJ.

1. Introduction
CCAUV (consultative committee for acoustics, ultrasound and vibration) implements to assess the
degree of equivalence with calibration and measurement capabilities of accelerometers through
international key comparison every few years. In vibration for frequency range from 10 Hz to 20 kHz,
CCAUV.V-K5 [1] assesses the degree of equivalence among 14 participants which were assigned as a
home country’s national metrology institute in CCAUV. The primary calibration of accelerometers [2]
becomes difficult to evaluate its phase response particularly in high-frequency region due to the time
delay of photo-detector in laser interferometer.

One of the most precise evaluation methods for the time delay is an optoelectronic measurement [3]
using a femto-second pulse laser and an ultrafast photodiode (probably in GHz bandwidth) as a
measurement trigger. But, since the resonance frequency of accelerometers to be calibrated is tens of
kHz, we propose more simple evaluation method using an EOM (electro-optical modulator).

In sine approximation (method 3 of [2]), a laser interferometer outputs two quadrature signal used to
calculate a reference acceleration from the sinusoidal motion. The quadrature signal includes the time
delay of the two photo-detector with preamplifier. As with [3], the phase shift of accelerometers is
given as follows.

$$\phi = 2\pi f (t_u - t_a)$$ (1)

Then, the time difference

$$t_u - t_a = (t_u - t_i) + (t_i - t_a)$$ (2)
can be expressed. Here, \(f\) is the mechanical vibration frequency in calibration. Each subscript \(u\), \(a\) and \(i\)
of time series \(t\) means the electric output, the measured and the true accelerations. The first term of
equation (2) is obtained through sine approximation, but the second term has to be determined by separately evaluating the time delay of the photo-detector.

2. Experimental set-up

Figure 1 presents the experimental set-up to simply evaluate a time delay of two photo-detectors with a preamplifier in a modified Michelson homodyne-type laser interferometer using an EOM with a bandwidth up to 250 MHz. The laser interferometer equips He-Ne laser light with a wavelength of 632.8 nm which passes through the EOM twice by usage of a reflection mirror. Thus, the time delay of the measured acceleration is given as

\[ t_a = t_{PD} + t_{EOM} \]  

The digitizer records analogue-to-digital signal with a sampling frequency of 10 MHz and a vertical resolution of 18 bits. The EOM gives a modulation depth of 26 mrad/V at 532 nm. The signal generator supplies EOM with power voltage of 10 V to give the modulation depth around 260 mrad.

Figure 2 shows X-Y display of quadrature signal in analogue. The quadrature signal rotates with more than \(2\pi\) depending on a low-frequency vibration by ground noise. Therefore, it is sufficiently possible to calculate a phase shift between the reference AC voltage of a signal generator and the demodulated signal.
3. Measurement results

Figure 3 is a measurement results of phase shift in frequency range from 1 kHz to 2 MHz. As the result, the resolution to calculate the phase shift is insufficient below 100 kHz. But the phase shift is stably obtained in frequency range more than 100 kHz, and the time delay around 20 ns is calculated by dividing the phase shift with $2\pi f$. However, since the bandwidth of EOM is up to 250 MHz (its reciprocal is 4 ns), the time delay by EOM is estimated to be at least 4 ns. Accordingly, the time delay of the photo-detector is expected to be about 16 ns. Then, the standard uncertainty of the time delay in frequency range more than 100 kHz is 9.1 ns (phase shift of 0.12 degree at 20 kHz), which becomes the phase shift with 0.066 degree.
4. Summary
The time delay caused by the photo-electric conversion and amplification of a photo-detector with a preamplifier is estimated from same principle as sine approximation by transforming the optical length based on an EOM. The roughly estimated time delay becomes around 16 ns which corresponds to a phase shift of 0.12 degree at the vibration frequency of 20 kHz.

References
[1] Technical Protocol of the CIPM Key Comparison CCAUV.V-K5.
[2] ISO 16063-11:1999, Methods for the calibration of vibration and shock transducers – Part 11: Primary vibration calibration by laser interferometry, International Organization for Standardization, Geneva (1999).
[3] T Bruns, F Blume, K Baaske, M Bieler, H Volkers 2013 Measurement 46 1762-1765.