IMEKO 23rd TC3, 13th TC5 and 4th TC22 International Conference
30 May to 1 June, 2017, Helsinki, Finland

# MEASUREMENT OF TIME DELAY CAUSED BY MIXER AND LOWPASS FILTER IN HETERODYNE INTERFEROMETER

*Ming Yang[1], Chenguang Cai[2], Ying Wang[1], Zhihua Liu[2], Haijiang Zhu[1]*

[1]Beijing University of Chemical Technology, Beijing, China
[2]National Institute of Metrology, Beijing, China, caichenguang@nim.ac.cn

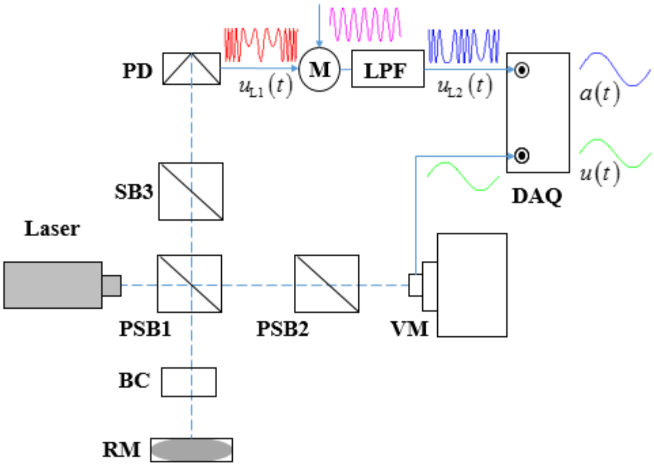
**Abstract:** Phase response is a key performance parameter of vibration transducers, which is usually measured by the primary calibration. The typical primary calibration method used analog mixer and lowpass filter to modulate heterodyne laser interferometer signal. There is some time delay caused by the analog devices, which will introduce some phase delay for the measurement of phase response of transducers. This paper proposed a novel time delay measurement method of the analog devices based on high definition oscilloscope (HDO) and phase unwrapping sine approximation method (PUSAM).

**Keywords:** phase response, primary calibration, phase delay, oscilloscope, sine approximation method.

## 1. INTRODUCTION

Phase response measurement of the transducers becomes more and more significant in primary calibration [1, 2]. The phase response is obtained from input acceleration signal to output electrical signal of transducers in which the acceleration signal is measured by laser interferometry. The heterodyne interferometer with 40 MHz carrier frequency is widely used in primary calibration, which has characteristics of high precision displacement measurement and low photoelectric signal fading. However, some phase delay was introduced to the measurement of acceleration signal, which results from the interferometer signal acquisition and optoelectronics of the interferometer. Since time delay of the optoelectronics is measured to be only a few nanoseconds [3], the phase delay usually is ignored. There are two methods for acquisition of the 40 MHz heterodyne laser interferometer signal: Nyquist sample method (NS) and the reduced sample method using the analog mixer and lowpass filter (MLPFS). The MLPFS has some advantages over the NS in sampling frequency and number of samples. While, the MLPFS method introduces phase delay due to using analog devices [4], which might have a strong effect on the measurement of phase response of the transducers.

The MLPFS method in the heterodyne interferometer calibration system is shown in Figure 1. $u_{L1}(t)$ is the output original interferometer signal, $u_{L2}(t)$ is the lower carrier frequency signal, $u(t)$ is the voltage or charge output signal of transducers, and $a(t)$ is the acceleration signal. The MLPFS uses the analog devices to reduce the 40 MHz interferometer signal to the lower carrier frequency signal. This procedure will introduce some time delay, which further leads to phase delay in the measured acceleration signal of the transducers.




| | |
|---|---|
| PSB polarizing beam splitter | BC Bragg cell |
| RM reference mirror | VM vibrating mirror |
| SB beam splitter | PD photo detector |
| M mixer | LPF lowpasss filter |

Fig. 1 The heterodyne interferometer calibration system.

In this paper, we propose a measurement method for the time delay in MLPFS method. The measured time delay is further useful for correction of the phase response.

## 2. THE TIME DELAY MEASUREMENT METHOD OF MIXER AND LOWPASS FILTER

Time delay of the analog devices measurement is shown in Figure 2. The functional signal generator (FSG) and HDO are used to measure the time delay of the above mentioned analog devices. The FSG is used to generate the 40 MHz carrier frequency FM signal that simulates the heterodyne interferometer signal in actual primary calibration system. The M and LPF are the analog devices and the HDO is applied to synchronously collect the original and lower carrier frequency FM signal. Since the HDO has a high passband and sample rate which is higher than the 40 MHz, the time delay introduced by the HDO acquisition channels for the two FM signals can be negligible. $u_{FM1}(t)$ and $u_{FM2}(t)$ are the original and lower carrier frequency FM signal respectively, $s_1(t)$ and $s_2(t)$ are the corresponding modulating signal of the FM signal.

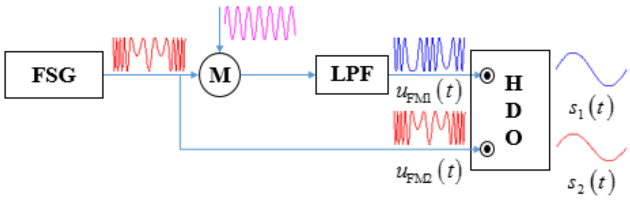



Fig. 2 Time delay of the analog devices measurement.

The two FM signals collected by the HDO are expressed as:

$$\begin{cases} u_{\text{FM1}}(t) = u_{\text{p}} \cos\left(\varphi_{\text{Mod}}(t)\right) \\ u_{\text{FM2}}(t) = u_{\text{p}}^{*} \cos\left(\varphi_{\text{Mod}}^{*}(t)\right) \end{cases} \tag{1}$$

where

$$\begin{cases} \varphi_{\text{Mod}}(t) = \varphi_0 + 2\pi f_{\text{c}} t + \dfrac{4\pi}{\lambda} s_{\text{p}} \sin\left(2\pi f_{\text{m}} t + \varphi_{\text{s}}\right) \\ \varphi_{\text{Mod}}^{*}(t) = \varphi_0^{*} + 2\pi f_{\text{c}}^{*} t + \dfrac{4\pi}{\lambda} s_{\text{p}} \sin\left(2\pi f_{\text{m}} t + \varphi_{\text{s}}^{*}\right) \end{cases} \tag{2}$$

are the phase of the original FM signal and the lower carrier frequency FM signal respectively. The differences between $\varphi_{\text{Mod}}^{*}(t)$ and $\varphi_{\text{Mod}}(t)$ are caused by the time delay of the analog devices. $\varphi_{\text{Mod}}(t)$ and $\varphi_{\text{Mod}}^{*}(t)$ are obtained from the collected signals $u_{\text{FM1}}(t)$ and $u_{\text{FM2}}(t)$ by phase unwrapping method [1]. $s_1(t)$ and $s_2(t)$ are calculated by sine approximation method.

$$\begin{cases} \varphi_{\text{Mod}}(t) = A\cos(\omega_{\text{m}} t) - B\sin(\omega_{\text{m}} t) + Ct + D \\ \varphi_{\text{Mod}}^{*}(t) = A^{*}\cos(\omega_{\text{m}} t) - B^{*}\sin(\omega_{\text{m}} t) + C^{*}t + D^{*} \end{cases} \tag{3}$$

From Eq. (3) we can calculate the coefficient A and B, where $\arctan(B/A)$ and $\arctan\left(B^{*}/A^{*}\right)$ are the initial phase of the $s_1(t)$ and $s_2(t)$.

And the time delay $t_{\text{mlp}}$ of the analog devices is given by:

$$t_{\text{mlp}} = \frac{\arctan\left(B^{*}/A^{*}\right) - \arctan\left(B/A\right)}{\omega_{\text{m}}} \tag{4}$$

Thus we can determine the time delay from Eq. (4). Furthermore, the phase delay is obtained by the time delay $t_{\text{mlp}}$ multiplying the frequency $f_{\text{m}}$.

## 3. RESULTS AND ANALYSIS

The experiment system to measure the time delay of the analog devices in MLPFS method is illustrated in Figure 3. The RIGOL DG5102 FSG with maximum frequency of 100 MHz is used to generate 40 MHz FM signal, the Mini-Circuits ZAD-1H+ mixer with 0.5 MHz - 500 MHz and Mini-Circuits BLP filter with 2.5 MHz cutoff frequency are used to convert the 40 MHz FM signal to lower carrier frequency signal, the American TELEDYNE HDO6104 with selective passband and 1 GHz sample rate is used to synchronously collect the 40 MHz FM signal and lower carrier frequency FM signal.

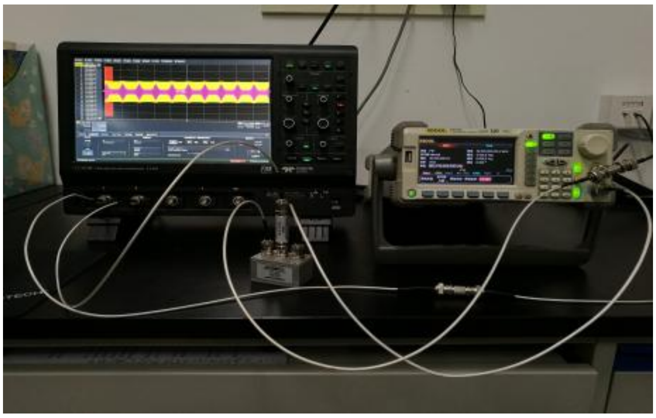
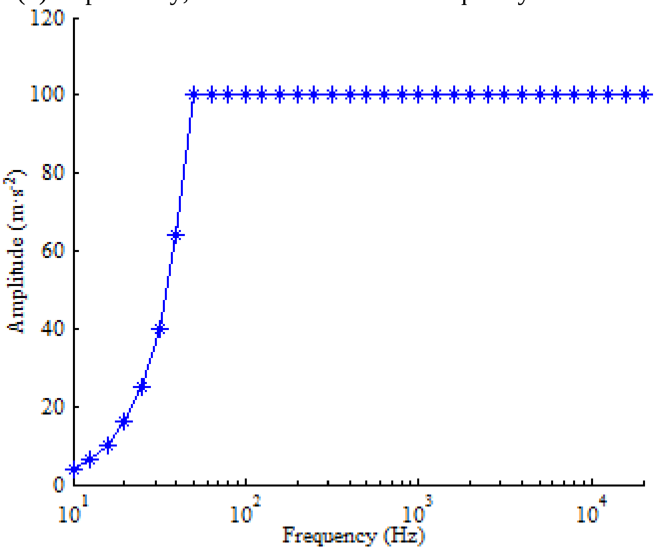
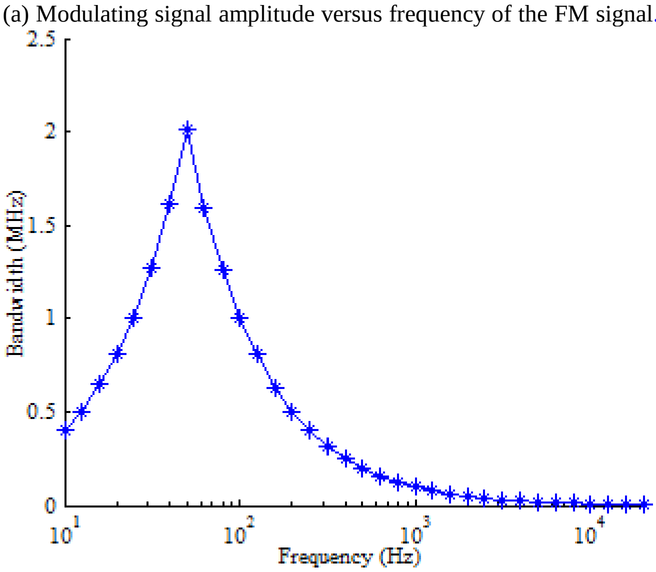


Fig. 3 Time delay of the analog devices measurement system.

The different amplitude of modulating signal and bandwidth of FM signal is generated by the FSG in different modulating frequency are shown in Figure 4(a) and Figure 4(b) respectively, and the lower carrier frequency is 1 MHz.



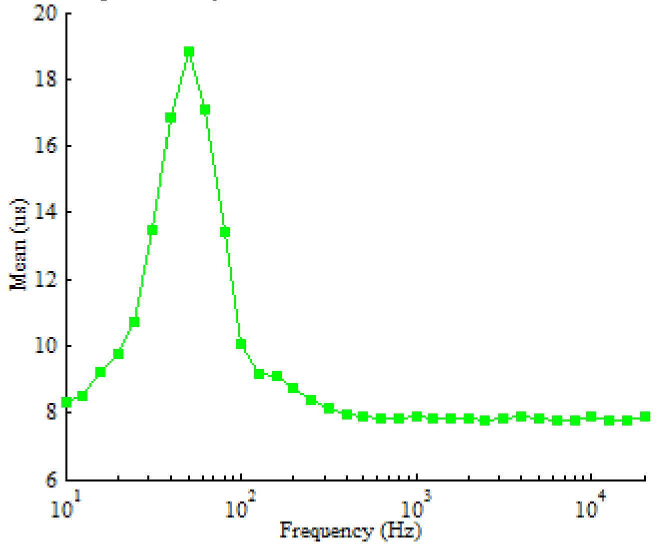

(a) Modulating signal amplitude versus frequency of the FM signal.



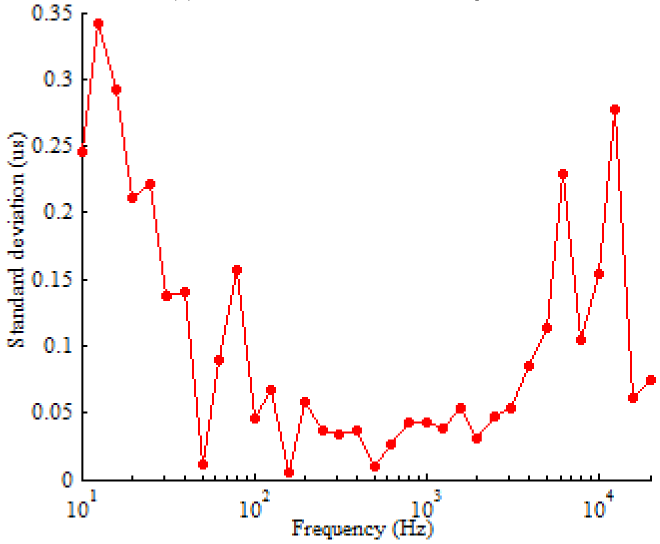

(b) Bandwidth of the FM signal.

Fig. 4 Amplitude versus frequency of modulating signal and bandwidth of the FM signal.

To eliminate the influence of the HDO acquisition channels for time delay measurement of the analog devices, 200 MHz passband is selected. The 5 times measurement mean and standard deviation of time delay of the analog devices for different modulating frequency are displayed in Figure 5(a) and Figure 5(b) respectively. The results show that the time delay of the analog devices are clearly different at different modulating frequencies, which are mainly caused by the bandwidth. Because the time delay is positively correlated with the bandwidth at the same carrier frequency, the time delay of the low frequency regions in Figure 5(a) is longer than the high frequency regions because of the bandwidth in the low are much wider than the high. Time delay of the analog devices is approximately about 7.9 us at the high frequency regions and introduces about 1° phase delay at 20 kHz.




(a) Mean of measured time delay.




(b) Standard deviation of measured time delay.

Fig. 5 The 5 times time delay measurement results of the analog devices for the modulating frequency from 10 Hz - 20 kHz.

In order to evaluate measurement errors of the time delay of the proposed method, each of the original FM signal, lower carrier frequency FM signal and the modulating signal of this FM signal is synchronous collected by two channels of the HDO. 20 times time delay errors of this method were measured at 1 kHz modulating frequency, and are shown in Figure 6. The time delay deviations of this method are less than 25 ns, which demonstrates that this measurement method is effective. Since the influence of bandwidth and carrier frequency on the time delay usually is coupled, which are considered separately in the future.

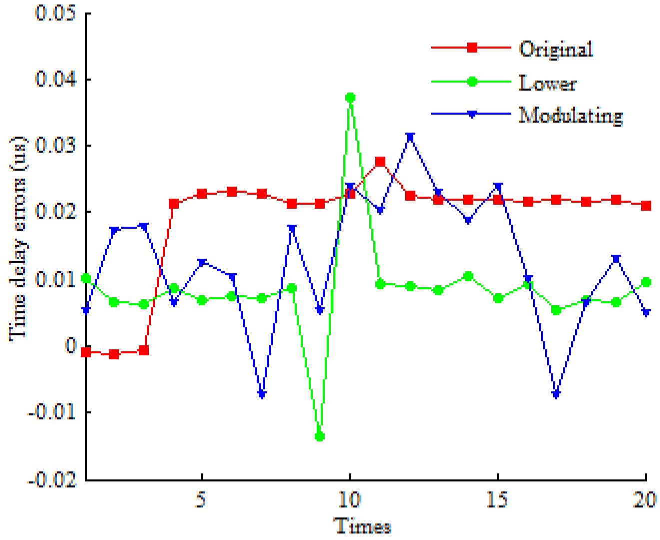



Fig. 6 Time delay errors to times.

## 4. CONCLUSION

The measurement method and devices of the time delay of analog devices in the heterodyne interferometer are discussed. The same carrier frequency FM signals with different bandwidths have been validly evaluated. Further work will concentrate on the measurement of the same bandwidth FM signals with different carrier frequencies.

## 5. ACKNOWLEDGE

This work has been supported by the Special Fund for Scientific Research in the Public Interest (201410009), National Natural Science Foundation of China (No. 51605461) and China Postdoctoral Science Foundation (No. 2016M591229).

## 6. REFERENCES

[1] ISO 16063-11: Methods for the calibration of vibration and shock transducers – Part 11: Primary vibration calibration by laser interferometry, International Organization for Standardization (1999).

[2] ISO 16063-41: Methods for the calibration of vibration and shock transducers – Part 41: Calibration of laser vibrometers, International Organization for Standardization (2011).

[3] B. Thomas, B. Frank, B. Kai, and B. Mark, “Optoelectronic phase delay measurement for a modified michelson interferometer”, IMKEO World Congress Metrology for Green Growth (2012).

[4] Q. Sun, T. Bruns, T. Angelika, L. Yang, A. Liu and A. Zuo, “Modifications of the sine-approximation method for primary vibration calibration by heterodyne interferometry”, Journal of Metrologia, vol. 46, no. 6, pp. 646-654, 2009.