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ASSESSMENT OF THE MEMS ACCELEROMETER CALIBRATION BY USING THE VERY LOW FREQUENCY PRIMARY VIBRATION CALIBRATION SYSTEM WITH WIRELESS TRANSMISSION

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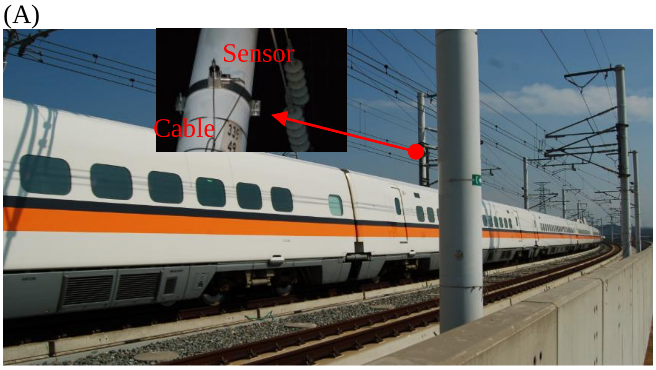
Abstract:
The very low frequency primary vibration calibration system in Taiwan has been improved. In order to provide local semiconductor foundry a more reliable way to calibrate the MEMS accelerometer, three kinds of accelerometers that are ADXL, PCB 356A15 and QA3000 were tested via such vibration calibration system. Unlike PCB 356A15 and QA3000, the MEMS type accelerometer, ADXL, was only performed well under 100 Hz. All the three kinds of accelerometers were connected to NI wireless modules in order to reduce the inconvenience of wires during vibration monitoring. The result suggests that we shall use MEMS accelerometer with the vibration under 100 Hz.

Keywords: primary vibration calibration, MEMS accelerometer, accelerometer wireless

1. INTRODUCTION

In order to detect human activities, MEMS accelerometers have been developed and embedded into mobile devices. The frequency and acceleration of the applied hand-shaking vibration have been experimentally found to be 4.6 Hz and 2g, respectively [1]. Due to the low frequency of the human hand-shaking, the low frequency calibration system becomes increasingly important. So far, the low frequency calibration system can be applied to calibrate not only the vibration measurements of earthquake and infrastructure monitoring but also the increasing amount of mobile devices and so on. Based on this, many national metrology institutes (NMIs) have spent dozens of years to develop primary calibration system for low-frequency accelerometers [2]. We, from National Measurement Laboratory (NML) in Taiwan, improved our accelerometer primary calibration in the very low frequency (VLF) range of 0.1 Hz to 160 Hz with uncertainty below 1.0% (confidence level = 95 %, coverage factor around 2)[3]. On the other hand, wireless calibration system has become popular for many NMIs lately. The National Institute of Standards and Technology (NIST), National Metrology Institute of Japan (NMIJ), and National Institute of Metrology (NIM) are working hard to overcome obstacles for enabling industrial wireless communication a more viable choice. Most of all, the inconvenience and complexity of wiring during measurement can be eliminated. In order to discuss with this, we introduced the PZT accelerometers and the MEMS accelerometers. Mounting them to the vibration calibrator separately helps us to understand their capability for measuring displacement from vibration signals. Wireless data transfer was achieved by using NI Wi-Fi modules in order to reduce the inconvenience of wires during vibration monitoring. In figure 1(A), wiring cables from the sensors to the analyzer was a nightmare to engineers, especially where was difficult during setting. As shown in figure 1(B) [4], through WSN (Wireless Sensor Network), the data was collected easily without wiring. Based on the test result, we do not recommend applying the MEMS accelerometers for monitoring the vibration in smart factory due to its larger inaccuracy compared with the PZT ones. However, the correct way to calibrate the sensitivities of the accelerometers is the key point to build the internet of things in the near future.

(A)



(B)

Figure 1. (A)Wiring cables is a big issue (B)Wireless transmission solves the problem and enables more applications.

2. SENSORS AND EXPERIMENTAL ARCHITECTURE

The low frequency calibration system is mainly used to calibrate the low frequency target, where it is suitable for the slowly changing vibration amplitude and the rather long measuring period. Under this circumstance, noise treatment and voltage drift shall be well controled. Acording to ISO 16063-11 [5], we use the sine-approximation method (SAM), to calibrate the sensitivity of accelerometer. The system diagram is shown in figure 2. The laser interferometer was used to carry out measurement of the magnitude and the phase shift of the sensitivity of the accelerometer at the specified vibration frequencies and acceleration amplitudes. The lissajous curve is also shown in figure 2 where it is consist of the signals from the two quadrature components of the homodyne interferometer. Although the signal is not as circle as wished, we will make more effort to improve it in the near future. For conveniently installing the system, we used the ADXL 3-axies accelerometer that was bought easily from ordinary electrical retailers. The appearance is as referred to figure 3(A) and the specification in figure 3(B). According to the specification, the accelerometer value was to calculate by analyzing the acquired voltage of the accelerometer. At the same time, we compared it with the traditional one, PCB 356A15. The appearance and the specification is as shown in figure 4(A) and 4(B) separately [6] and further with the proposed architecture referred to figure 5 [7], the three kinds of accelerometers were compared to each other. All the signals of ADXL, PCB 356A15 and QA3000 are connected to the DAQ card, NI 9233, which is inserted into NI 9191, the WiFi access point. The NI PXI that equipped a WiFi wireless network card received the signals of NI 9233 via WiFi protocol. At the same time, the signal of laser interferometer is wired to NI PXI directly. The result is shown in the next paragraph.

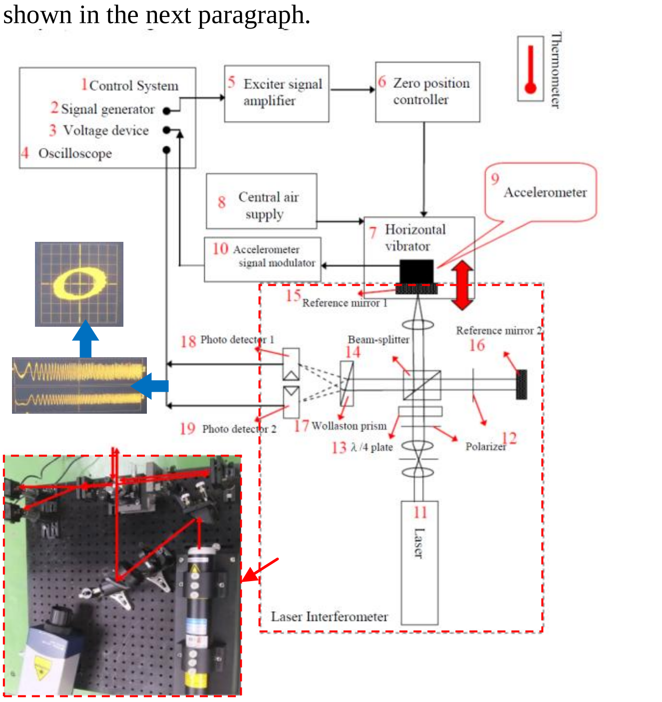


Figure 2 The very-low frequency calibration system at NML.

(A) (B)

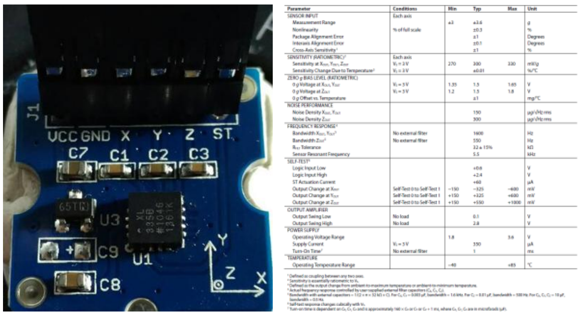


Figure 3 (A) The appearance of the ADXL (B) The Specification of the ADXL.

(A) (B)

Figure 4 (A) The appearance of PCB 356A15 (B) The specification of PCB 356A15.

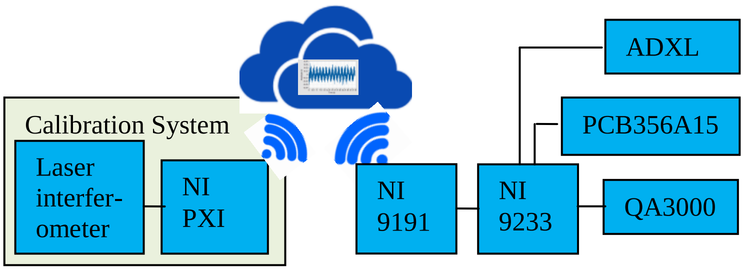


Figure 5 The architecture of the experiment.

3. EXPERIMENTAL RESULTS AND VALIDATION OF THE SYSTEM

To validate the very-low frequency primary calibration system, we conducted calibration of a reference accelerometer QA3000. The accelerometer has been tested annually for more than 10 years and it has sufficient stability to evaluate consistency of primary vibration calibration system. Its nominal sensitivity is 1.095 V/(m/s^2). We have changed our calibration method from Fringe Counting Method (FCM) to Sine Approximation Method (SAM). In figure 6, the SAM calibration result of the primary system shows excellent flatness, agreeing with that of the former primary system within its uncertainty. For the very low frequency 0.1 Hz, we used QA3000 to measure the signals and the RAW data and the filtered data were shown in figure 7. Wireless calibration must be finished by comparing the signals between wired signal of QA3000 in figure 8(A) and the wireless signal of QA3000 in figure 8(B). Refer to figure 8(A) and 8(B), the signals of wired and wireless are almost the same. Hence, the wireless transmission was validated as result. The primary calibration system was used to validate the three different kinds of accelerometers. All the three accelerometers performed well until we test the signals over 100 Hz. The signal of the ADXL was distorted apparently at 160 Hz that is shown in figure 9(A). Nevertheless, the signal of PCB 356A15 remained stable in figure 9(B). In order to figure out the frequency response of ADXL, we did another test range from 0.5 Hz to 160 Hz. Referring to the figure 10, the bandwidth of the ADXL accelerometer is between 0.5 Hz to 100 Hz (3dB). It agrees with the specification of the ADXL because we used a 0.05 μF external filter capacitor. That is the reason why the distortion phenomenon happened at 160 Hz. Consequently, we recommend that the MEMS accelerometer be applied in lower frequency. Nevertheless, the PCB 356A15 performed well in the frequency range of 0.5 Hz and 160 Hz and thus it shows the better performance in wider range and benefit in general purpose. Table 1 shows the difference between these three kinds of accelerometers. For MEMS types, the low-cost and good performance in lower frequency are the key point to be widely used in 3C electronic devices. On the other hand, the traditional accelerometer is more reliable in wider range of frequency. If the frequency of vibration is unknown, the traditional ones showed its capability to deal with wider range of applications. According to table 1, the nominal frequency was set to 2 Hz and 1.5 m/s^2. The acceleration were calculated by using the previously measured sensitivity values that are 1093.22 $mV/(m/s^2)$, 10.17 $mV/(m/s^2)$ and 32.26 $mV/(m/s^2)$ for QA3000, PCB 356A15 and ADXL individually. The best one was the QA3000 with error only 0.533 % in acceleration and without any difference in frequency. The worst one was the ADXL with error 0.3 % in frequency and 3.467 % in acceleration. However, the acceleration values were the average of ten experimental data, longer term stability compared to piezo-type accelerometers shall be concerned.

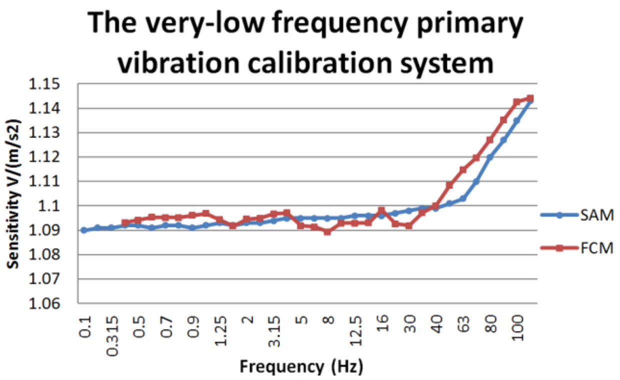


Figure 6 The calibration result of two methods.

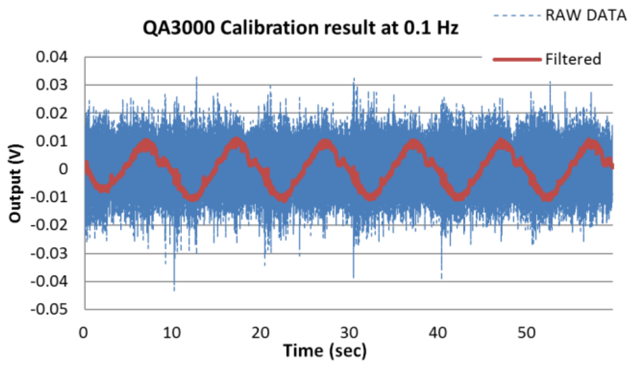
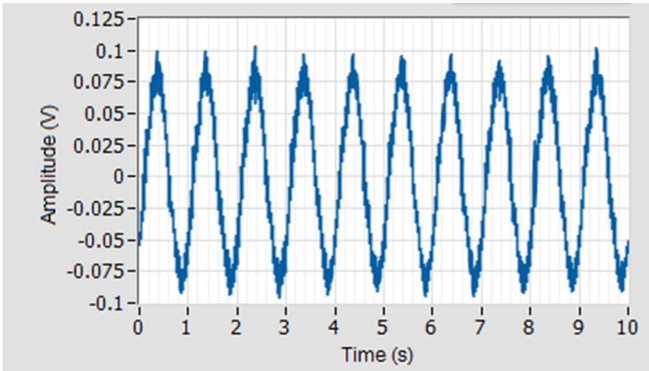


Figure 7. The test result of the QA3000 accelerometer at very-low frequency 0.1 Hz.

(A)



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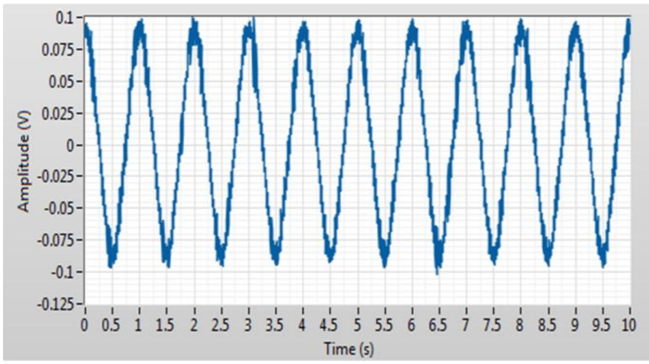
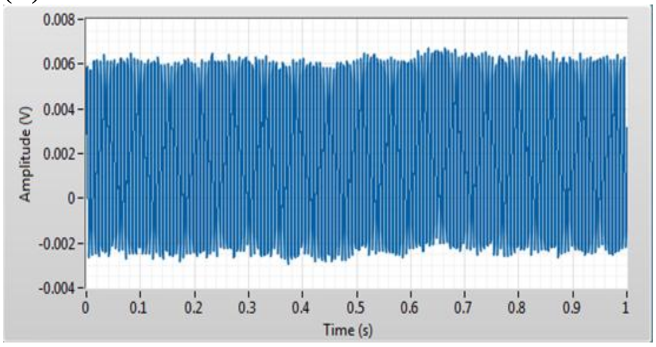


Figure 8 QA3000 at 1Hz (A) Accelerometer signal with wired cable; (B) Accelerometer signal with wireless transmission.

(A)



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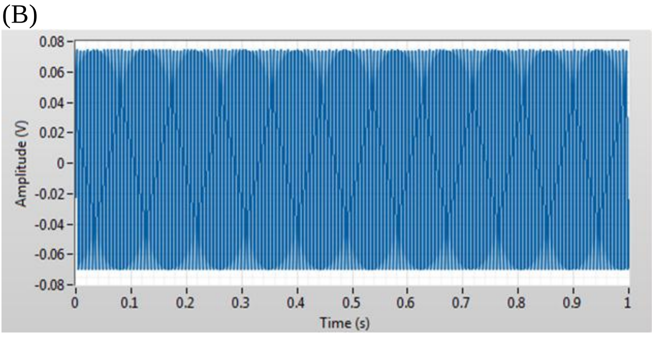

Figure 9 The signals at 160 Hz (A) the signal of ADXL was distorted (B) the signal of PCB 356A15 was stable.

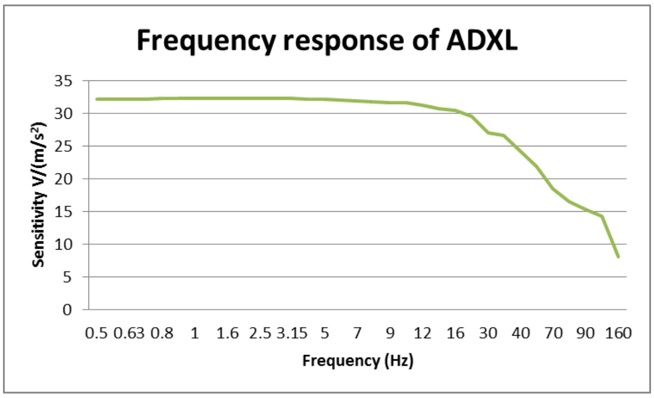

Figure 10 Frequency response of ADXL.

Table 1. Three types accelerometers calibration result

	Freq-uency (Hz)	Error in freque-ncy (%)	Accelera-tion (m/s^2)	Error in acceleration (%)
Nominal	2	-	1.5	-
QA 3000	2.000	0	1.508	0.533
PCB 356A15	2.003	0.15	1.514	0.933
ADXL	2.006	0.3	1.552	3.467

4. SUMMARY AND CONCLUSION

Taiwan is the largest semiconductor foundry manufacturing economy in the world [8]. In order to provide local foundries more reliable calibration opportunity to calibrate their MEMS accelerometers, NML had already improved the very-low frequency calibration system with the range of 0.1 Hz to 160 Hz under 1.0 % uncertainty (confidence level = 95%, coverage factor = 2). For the sake of our clients, we test three kinds of different accelerometers and compare their performance in Table 1. As result, MEMS accelerometer has good response in the low frequency under 100 Hz. For the frequency higher than 100 Hz, the error must be concerned carefully. However, due to its lower cost and smaller size than PZT accelerometers, MEMS accelerometer was the best solution for highly demanded in industry. Both QA3000 and PCB356A15 performed well at the very-low frequency and the low frequency. They can be used to deal with the cases in general purpose. In Taiwan, NML maintains the standard systems in order to serve our local clients. It is not easy to calibrate the consumer MEMS accelerometer via the primary vibration system in other country. Based on the good relationship between NML and Taiwan's companies, we were requested to test the three kinds of accelerometers via the primary vibration system. It can provide the MEMS accelerometers of our local clients the possibility to be traceable.

5. REFERENCES

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