Enhancing the capability of primary calibration system for shock acceleration in NML

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ABSTRACT

As the guardian of the national measurement standards, the Vibration laboratory of National Measurement Laboratory (NML) in Taiwan in compliance with the standard ISO 16063-13 had established primary shock calibration system in 2009, which was based on the rigid body collision method, with peak acceleration ranging from 200 m/s^2 to 5 000 m/s^2 and shock pulse duration less than 2.5 milliseconds. Hereafter, upgrading the capacity for measuring shock acceleration by increasing the maximum acceleration from 5 000 m/s^2 to 10 000 m/s^2 in 2011.The system had participated regional pilot comparison of the APMP Pilot Comparison (APMP.AUV.V-P1) in 2014. During the comparison, a weak point of capability was shown that the shock pulse was shorter than other NMIs. This research discusses the improvement of increasing the duration time of shock calibration system. Upgrade the electromagnetic shock source and reform the relative position of airborne hammer and anvil. Controlling different input DC voltage value and refining different hardness rubber will produce different acceleration and duration time. After enhancing the capability of system, the maximum shock pulse duration time is increasing from 2.5 milliseconds to 4 milliseconds. Finally, the system performance data is provided together with evaluation of measurement uncertainty.

Keywords: Shock calibration, Primary, I-INCE Classification of Subjects Number(s):72.2.2
(See . http://www.inceusa.org/links/Subj%20Class%20-%20Formatted.pdf .)

1. INTRODUCTION

The electronic and acoustical products, vehicle electronics, information goods and so on, must be executed with impact test during R&D process. In the meantime, it is also required that the shock accelerometer be applied to the vehicle hit-test to monitor acceleration. Therefore, shock calibration technology and the associated industrial development are obvious to be closely linked. As the guardian of the national measurement standards and echoing to industrial requirements, the Vibration laboratory of National Measurement Laboratory (NML) in Taiwan in compliance with the standard ISO 16063-13 (1) had established shock calibration system in 2010, which is based on the rigid body collision method, with peak acceleration ranging from 200 m/s^2 to 5 000 m/s^2 and shock pulse duration less than 2.5 milliseconds.(2) The system is different from other NMIs in the use of electromagnetic exciter, which shows the superiority of good reproducibility in the generation of peak shock acceleration.(3) Hereafter we had kept upgrading the capacity for measuring shock acceleration by increasing the maximum acceleration from 5 000 m/s^2 to 10 000 m/s^2 in 2011(4).

ISO 16063 mainly specifies two mechanical vibration modes to calibrate accelerometer. They are sinusoidal vibration and shock vibration, respectively. For the main difference between the two typical vibration modes, the sinusoidal vibration mode is for calibration at each discrete frequency point with small vibration amplitude, common acceleration amplitude does not over 1 000 m/s^2 ; while shock vibration mode is a transient shock pulse with short duration and large amplitude (acceleration amplitude up to 100 000 m/s^2) . Mechanical vibration measurement methods are divided into primary method and secondary method. Primary method adopts laser interferometry to determine the input mechanical vibration acceleration accelerometer, so it has very high calibration precision.

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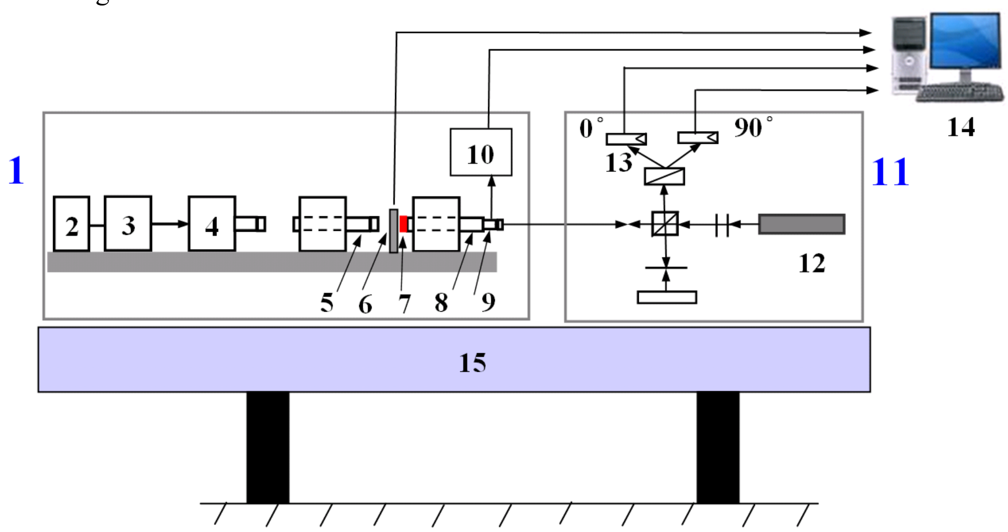
2. SYSTEM DESCRIPTION

The primary calibration system for shock acceleration is established by referring to ISO 16063-13 rigid body motion method. The system mainly includes Shock level activating module, Laser interferometer module and Signal access device. The system connection diagram is showed in Figure-1. Shock level activating module refers to 1 in Figure-1, and Laser interferometer module is showed as 11 in Figure-1.



The symbols of element labeling are as followed:

1. Shock level activating module
2. EM activating controller
3. Programmable DC power supply
4. High speed EM hammer
5. Shock hammer
6. Trigger device
7. Rubber mat
8. Shock anvil
9. Shock accelerometer
10. Charge amplifier or power supply
11. Laser interferometer module
12. Single frequency stable frequency laser tube
13. Light detection module
14. Signal picks up device (Digital oscilloscope card)
15. Optics table

Figure-1 Diagram of system connection

The present primary calibration system for shock acceleration makes use of an accelerometer, ENDEVCO/2270, fixed on an airborne anvil after shock, and then through charge amplifier, ENDEVCO/133, to output voltage signal. Time-sequence signals are recorded by a digital waveform recorder, filtering and calculating maximum shock voltage signal V_{max}.

When an accelerometer is shocked, dual-channel interfering signals will be synchronously recorded via laser interferometer, and then time-sequence signals will be recorded via another digital waveform recorder. After dual-channel interfering signals are processed through low-pass filter and twice differential, maximum shock acceleration A_{max} can be calculated when an accelerometer is shocked. Through the ration between V_{max} and A_{max}, voltage sensitivity of an accelerometer, $S_{sh}=V_{max}/A_{max}$, can be determined.

2.1 Upgrade shock level activating module

The shock source of shock level activating module in Figure-2 is that one voltage input by electromagnetic excitation controller drives a high speed electromagnetic hammer through programmable DC supply to produce external shock force, which hits an airborne hammer supported with air bushing. After hit by a high speed electromagnetic anvil, an airborne hammer will continue to hit another airborne anvil supported by air bushing at an approximate uniform motion. In this study, we upgrade an electromagnetic excitation power supply and increase the rod’s radius of electromagnetic hammer from 25 mm to 30 mm.

The front end of airborne anvil is fixed by PU rubber with different Shore hardness. The back end fixes a shock accelerometer. When an airborne anvil is hit by an airborne hammer, it will conduct shock force by rigid motion to an accelerometer. At the meantime, an accelerometer will output one voltage with approximate half-sine shock waveform under external shock force. The maximum voltage will be V_{max} after low-pass filtering.

The radius of airbone hammer and airbone anvil increase from 25 mm to 30 mm. An airborne hammer and anvil in this module are supported by two radial porous air bushings and the corresponding air bushings also upgrade to right size. The radial gap between axis and air bushing is about 4 μm. The central line of both airborne hammer and anvil is aligned as ±0.2 mm. The axial linear and rotational motion can freely perform under low friction.

In the actual occurrence of shock, the lateral motion of non-axis motion will take place as well. In order to evaluate this characteristic, we make use of a triaxial high shock accelerometer to install on the back end of an airborne anvil and measure the lateral motion ratio. The ratio of maximum lateral motion for that system is less than 4 %.On the other hand, controlling different input DC voltage value and refining different hardness rubber will produce different acceleration and duration time.

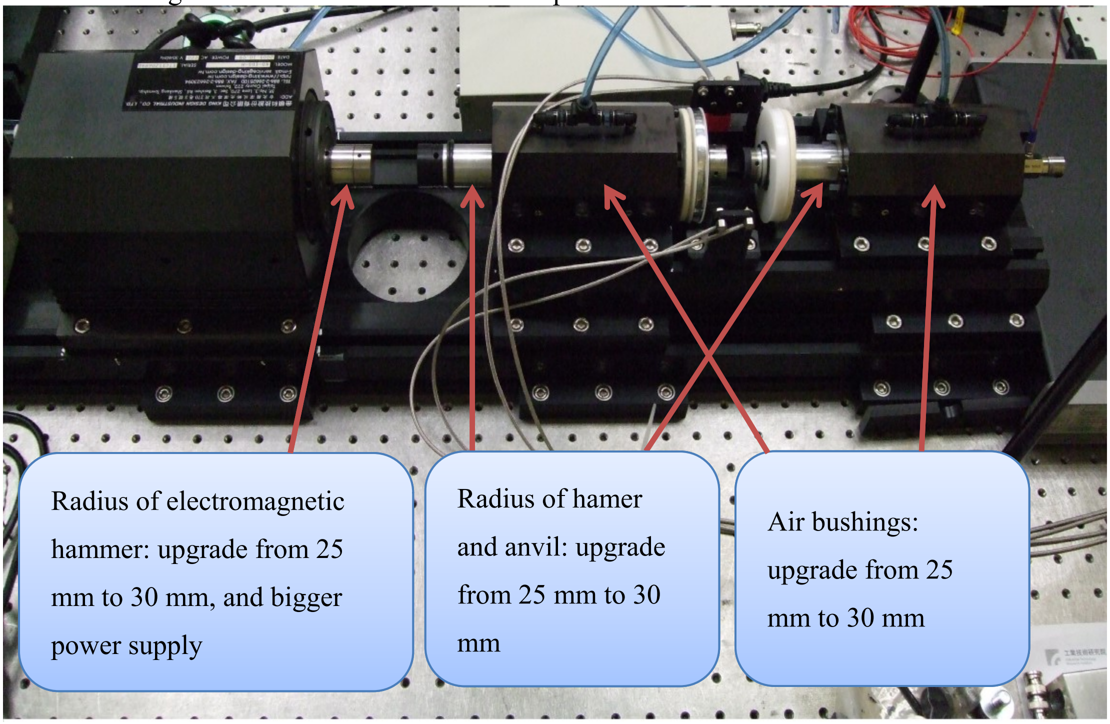


Figure 2 –Upgrade the shock level activating module

Shock accelerometers used for the primary calibration system for shock acceleration are accelerometer ENDEVCO/2270 and charge amplifier ENDEVCO/133, which that accelerometer provides the excellent vibration characteristics: such as maximum transverse sensitivity 0.3%, annual maximum change of charge stability ±0.2%, maximum shock acceleration 150,000 m/s^2 and a linear amplitude increment of 10,000 m/s^2 about 0.1%.

In order to simulate mass for an accelerometer under calibration, the back end of a shock accelerometer installs a dummy mass. This mass can be designed as 20–50 g. The dummy mass is made of stainless steel. Uniformity on the mirror end is less than 1/4 wavelength. Attention must be paid to parallelism for the both ends on-mirror and mirror. After dummy mass is installed, the relative motion between the vibration plane of an accelerometer and measurement plane of laser is less than 0.5%.

2.2 Interferometer

This laser interferometer is modified Michelson interferometer as prototype, which modifies the current structure. This structure is a combination of modified Michelson interferometer and Mach–Zehnder interferometer.(5) Interferometer and shock machine are put on optical table together, where frequency stabilized He–Ne laser is applied with a wavelength of 632.99 nm. In order to record high-speed shock data, bandwidth of two photo detectors output from interfering signals needs to meet $f_{max} = V_{max} \times 3.16 \times 106$. Therefore, the measuring bandwidth of photo detectors in this system is 150 MHz. Figure-3 shows an illustration of optical interferometer.

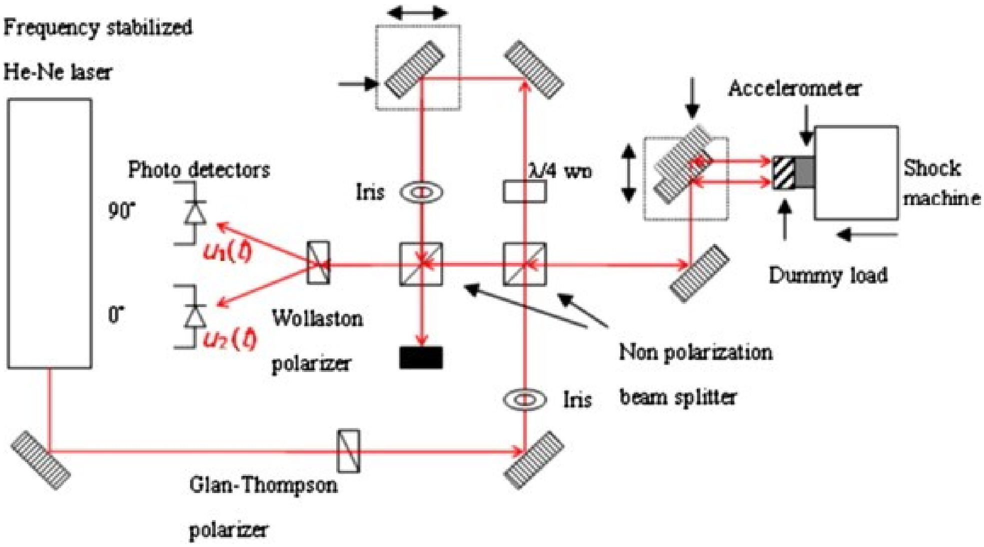


Figure-3 Illustration of optical interferometer

The interferometer mainly makes use of interfering signals $u_1(t)$ and $u_2(t)$ of dual-channel phase difference 90° to analyze the phase, where $u_1(t)$ and $u_2(t)$ are interfering signals detected by photo detectors. In order to reduce the uncertainty of accelerometer sensitivity, the relative amplitude variation of $u_1(t)$ and $u_2(t)$ should be adjusted and controller less than ±5 %. The phase difference should be 85–95°, $u_1(t)$ and $u_2(t)$ are as shown in Figure-4.

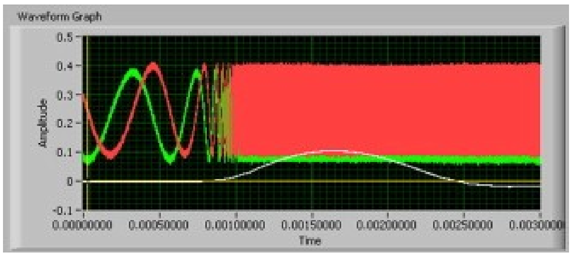


Figure-4 Interfering signal $u_1(t)$ and $u_2(t)$ of phase difference 90°.

2.3 Digital waveform recorder

Through Lab View programming, NI 5922 Digital Waveform Recorder will be synchronously triggered by proximity switch to record voltage output from an accelerometer. NI 5124 Digital Waveform Recorder is used to record dual-channel interfering signals, where sampling frequency of interfering signal is 200 MS/s with 12-bit resolution and that of accelerometer voltage is 15 MS/s with 24-bit resolution.

2.4 Digital signal process

In order analyze the phase of $u_1(t)$ and $u_2(t)$, the phase is defined as:

$$\phi(t) = \tan^{-1}\frac{u_1(t)}{u_2(t)} \tag{1}$$

This phase is time-sequence data. Upon the phase is determined, the shock displacement is defined as:

$$D(t) = \frac{\lambda}{4\pi}\phi(t) \tag{2}$$

As interfering signals are influenced by noise, this displacement signal will be filtered by low-pass Butterworth filter and differentiated once to obtain speed signal. After filtered by low-pass filter and differentiated once since speed signal is determined, shock acceleration signal can be obtained. The maximum value in this shock acceleration waveform is A_{max}.

This system is digitally filtered with 5 kHz cut-off frequency of four-order Butterworth low-pass filter. After the value is filtered by Butterworth low-pass filter, the value string will take place phase delay. Therefore, the front and rear value string will be overturned and filtered by two-order backward Butterworth low-pass filter after filtered by two-order forward Butterworth low-pass filter. This delay will be compensated.

3. SYSTEM EVALUATION

This system mainly evaluated the shock accelerometer set Endevco 2270/133 voltage sensitivity uncertainty. The voltage sensitivity of the accelerometer is calculated base on the following formula:

$$S_{sh} = \frac{V_{max}}{A_{max}} \tag{3}$$

Where S_{sh} is the accelerometer set voltage sensitivity (mV/(m/s^2)); V_{max} the voltage of maximum filtered accelerometer output (mV) and A_{max} is the maximum calculated acceleration from interferometer signal (m/s^2).

According to ISO 16063-13, the mathematical function relationship of uncertainty for accelerometer can be written as $y = f(x, e_1 \dots, e_n) = x + e_1 + e_2 + \dots + e_n$. Where the y is the accelerometer sensitivity, x means repeat measurements for accelerometer sensitivity and $e_1, e_2 \dots, e_n$ each factor means source of uncertainty respectively. From the result of measurement system validation procedure for shock accelerometer-phase operational method, Table 1 shows the example of uncertainty budget for shock level 200 m/s^2. The relative expanded uncertainty is less than 0.8 % within coverage factor k = 2 in the acceleration 200 m/s^2 and the duration time is bigger than 4 milliseconds.

Table 1 –Uncertainty budget for shock level 200 m/s^2

Source of uncertainty	Factor	Type A /B	Relative standard uncertainty component	DOF $\nu(x_i)$
Repeating evaluation of system	1	A	0.0122 %	9
Sensitivity influence of voltage measurement owing to digital oscilloscope card (NI 5922) resolution	$\sqrt{3}$	B	0.0176 %	200
Sensitivity influence of voltage measurement owing to digital oscilloscope card (NI 5922) accuracy	2	B	0.25 %	200
Sensitivity influence of voltage measurement owing to digital oscilloscope card (NI 5922)	$\sqrt{3}$	B	0.0011 %	200
Sensitivity influence of voltage measurement owing to digital filtering	$\sqrt{3}$	B	0.0483 %	200
Sensitivity influence of voltage measurement owing to hum and noise	1	A	0.0494 %	9
Influence of sensitivity measurement owing to charge stability for accelerometer	$\sqrt{3}$	B	0.1155 %	200
Sensitivity influence of voltage measurement owing to transverse swing	$\sqrt{2}$	B	0.0106 %	200
Influence of sensitivity measurement owing to accelerometer amplitude linearity	$\sqrt{3}$	B	0.0289 %	200
Sensitivity influence of voltage measurement owing to accelerometer amplitude and frequency variation	$\sqrt{3}$	B	0.1403 %	200
Sensitivity influence of voltage measurement owing to charge amplifier linearity	$\sqrt{3}$	B	0.0577 %	200
Sensitivity influence of voltage measurement owing to charge amplifier amplitude and frequency variation	$\sqrt{3}$	B	0.0073 %	200
Sensitivity influence of acceleration measurement owing to charge amplifier gain variation	$\sqrt{3}$	B	0.0069 %	200
Sensitivity influence of acceleration measurement owing to dual-channel interference phase signal to noise	$\sqrt{3}$	B	0.0231 %	200

Sensitivity influence of acceleration measurement owing to digital filtering	$\sqrt{3}$	B	0.0483 %	200
Sensitivity influence of acceleration measurement owing to relative motion	$\sqrt{3}$	B	0.231 %	200
Sensitivity influence of acceleration measurement owing to laser wavelength	$\sqrt{3}$	B	0.00053 %	200
Sensitivity influence of acceleration measurement owing to digital oscilloscope card (NI 5124) timing	$\sqrt{3}$	B	0.0075 %	200

4. CONCLUSIONS

This system utilizes electromagnetism excitation equipment to generate steady impulse force, and then guide the hammer and anvil with rigid body motion collision in an alignment by air bearing support. This research discusses the improvement of increasing the duration time of shock calibration system. Upgrade the electromagnetic shock source and reform the relative position of airborne hammer and anvil. Controlling different input DC voltage value and refining different hardness rubber produce different acceleration and duration time. After enhancing the capability of system, the maximum shock pulse duration time is increasing from 2.5 milliseconds to 4 milliseconds. We use the modified Michelson and Mach–Zehnder interferometer to collect the laser interferometer signal and then acceleration of the accelerometer is derived through two numerical differentiations and two low-pass digital filtering from the signal. At present the acceleration capability of primary shock calibration system is from 200 m/s^2 to 10 000 m/s^2, the shock pulse duration time is less than 4 milliseconds. The final evaluated relative expanded uncertainty is less than 0.8 % within coverage factor k = 2.

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